UNINTENDED CONSEQUENCES IN RESTORATION: INVESTIGATING INTERACTIONS BETWEEN TROUT HABITAT ENHANCEMENT AND ANGLERS IN WESTERN STREAMS

by

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ABSTRACT

Previous research spanning lotic, lentic, and marine environments suggests that habitat enhancement structures (HES) may attract and concentrate fish from adjacent habitats rather than increase fish populations. In addition to concentrating fish, we hypothesized that anglers may target HES, and therefore, that fish concentrated at HES may be more susceptible to angling. To test our hypotheses, we assessed spatial patterns of: 1) habitat structure; 2) fish holding locations; and 3) fishing pressure (i.e., casting patterns) in southwestern Montana stream reaches with HES. Findings suggest that HES aggregate fish and that anglers more successfully target fish holding near artificial HES than similar densities of fish holding further from artificial structures (e.g., near natural holding structures). We conclude that installation of HES may increase angling opportunities, but could also act as fish population sinks by focusing fishing pressure over likely fish holding areas.

CHAPTER ONE

INTRODUCTION

Problem Statement

Riverine restoration funding has increased markedly over the past 15 years (Bernhardt et al. 2005) enlarging the scope and influence of well-intentioned restoration manipulations across fluvial landscapes. One of the most commonly funded restoration techniques is the installation of fisheries habitat enhancement structures (HES). These structures have been shown to concentrate fish, yet stream and fisheries managers assume that unintended consequences associated with concentrating fish are benign. Looking at prior research in marine and lentic systems, we can infer that serious ramifications might arise from ignoring the relationship between anglers, fish, and HES. Therefore, the question to be asked is: *Does the placement of artificial habitat enhancement structures in streams increase the susceptibility of fish to angling?* If so, this has considerable management implications for one of the nation's most pervasive stream restoration techniques and may provide initial evidence that installation of HES might act as fish population sinks by focusing fishing pressure in probable holding areas.

Scientific Background

The importance of healthy, intact, resilient lotic systems and the goods and services they provide is well known. Simultaneously, evidence exists that global degradation of lotic systems is at an all-time high (Gleick 2003). Of further concern is that the ecological goods and services rivers provide are increasingly threatened by human activities in rivers and their catchments (Lake et al. 2007; Arthington, et al. 2010).

Natural resource managers have turned to restoration in an attempt to rectify current and past anthropogenic degradation (NRC 1992) as exemplified by marked increases in riverine restoration funding over the past 15 years, which now exceed one billion dollars annually (Bernhardt et al. 2005).

Society has become especially concerned with the plight of freshwater fish because of their role as a charismatic indicator species, as well as their economic, recreational, and cultural importance. According to the 2006 National River Restoration Science Synthesis project, 17% of all river restoration projects in the United States (Table 1) included the manipulation of instream physical structure to specifically improve fish habitat (Palmer 2006). In Montana, 'fish habitat enhancement' is the most common form of riverine restoration, representing 38% of all implemented projects.

Instream 'fish habitat enhancement' and true restoration are distinctly different. Much of what is considered to be fish habitat enhancement includes the installation of artificially constructed structures such as boulder clusters, designed log jams, and lunker structures (Figure 1). These are typically referred to as 'enhancements' rather than 'restorations' because they offer little more than symptomatic fixes. True restoration is the process of assisting streams in recovery of dynamic equilibrium and function at self-sustaining levels (FISRWG 1999; Roni et al. 2005). Nevertheless, HES remain one of the most pervasive techniques used to enhance fish habitat.

The intent of these structures is to alter the physical habitat of a stream, increasing complexity through creation of more frequent or deeper pools, sediment retention, or cover (White 1996). These structures have largely been successful at this over short-term monitoring durations (Hunt 1988; Whiteway et al. 2010; Roni et al. 2005). The emphasis on habitat-centric manipulation is predicated on the assumption that habitat is the primary limiting factor affecting fish in riverine systems (Hunt 1971; Rosi-Marshall et al. 2006), and that creation of more habitat will result in more fish (i.e., a population-level response). In stream reaches with HES, increased fish biomass and abundance have been well-documented (Hunt 1988; Riley and Fausch 1995; Binns 1994; Avery 2004; Roni et al. 2005; Whiteway 2010). These localized increases are often cited as support for a beneficial population response, and thus, HES are often presumed to benefit fish populations. However, metrics that describe localized physical response (e.g., change in pool frequency), or localized point-in-time fish use (e.g., presence/absence) may be misleading. The limited spatial and temporal scales of analysis prevent a holistic measure of biological effectiveness (Pretty et al. 2003; Roni et al. 2005; Roni et al. 2008). For example, mechanisms causing localized biomass and abundance increases are not well understood, such that increases may be caused by either a true population level increase OR simply redistribution at the watershed scale (i.e., localized immigration) (Gowan et al. 1994; Gowan and Fausch 1996; Frissell and Ralph 1998; Stewart 2009; Johnson et al. 2005).

In one of the few comprehensive studies on the topic, Gowan and Fausch (1996) showed that HES simply attracted and concentrated fish from adjacent habitats and did not increase population abundance. Similarly, artificial reefs and fish aggregating devices attract and aggregate fish in lake and marine environments (Clark 1945). Such clustering of fish in these lentic and marine systems has increased commercial and recreational catch rates (Polovina 1991; Grossman et al. 1997), and can result in overexploitation (Wege and Anderson 1979; Grossman et al. 1997). A similar relationship may exist in lotic environments, and stream and fisheries scientists have called for the quantification of angler effect upon fish assemblages in restored and enhanced riverine systems (Hunt 1988; Binns 2004; Thompson 2006). Despite this concern, many scientists, managers, and consultants maintain the assumption that restoration actions rarely leave streams in conditions worse than their pre-restoration states (Hilderbrand et al. 2005). This assumption has gone largely untested with respect to the installation of HES in streams.

Introduction to Study

In conducting this study, I intended to 1) elucidate relationships among HES, angler behavior, and fish; 2) determine if the installation of HES create habitats where fish are more susceptible to angling; and 3) provide one example of an unintended consequence associated with HES, thereby shedding light upon the common restoration myth that *well intentioned restoration actions are without negative consequences*.

Research Question

Might the placement of artificial habitat structures in streams increase the susceptibility of fish to angling?

Hypotheses and Predictions

I examined angler behavior in stream reaches containing artificial and natural habitat structure and quantified the extent to which anglers successfully targeted fish locations associated with each habitat structure type. Within experimental stream reaches, I examined general spatial patterns and degree of spatial correlation among artificial habitat enhancement structures, fish locations, and casting patterns and frequency. Anglers who more consistently and selectively casted to fish locations were deemed to be more "successful" at targeting fish. I tested three alternative hypotheses to determine if clusters of fish holding near HES were more susceptible to angling and, if so, whether the risk was elevated above that of fish clustered away from HES (e.g., near natural structures in the stream):

H1: Fish near HES are more susceptible to angling than fish far from HES because aggregations of fish near HES are targeted more effectively by anglers than other similarly sized natural aggregations of fish.

P1-1: HES attract both fish and angling effort (fish density and cast density near HES are higher than would be expected by chance).

P1-2: Anglers more effectively target clustered fish than isolated fish (fish density and cast density are positively correlated).

P1-3: Anglers more successfully target clusters of fish near HES than similar natural clusters of fish (a regression of cast density vs. fish density will generally under-predict cast density for fish near HES and over-predict cast density for fish far from HES).

H2: Fish near HES are more susceptible to angling than fish far from HES simply because HES aggregate fish and anglers target aggregations of fish (whether natural or artificial).

P2-1: Same as P1-1.

P2-2: Same as P1-2.

P2-3: P1-3 is incorrect.

H3: Fish near HES are no more susceptible to angling pressure because anglers do not successfully target aggregations of fish.

P3-1: Same as P1-1.

P3-2: P1-2 is incorrect.

H0: Fish near HES are no more susceptible to angling than other fish.

P0-1: Habitat enhancement structures do not aggregate fish *OR* anglers do not target HES.

If H1 holds, then installation of HES provides high quality holding habitat, but at the price of making fish more vulnerable to angling than natural high quality holding habitat. If H2 holds, then installation of HES provides high quality holding habitat without a greater increase in vulnerability to angling than would be expected from the formation of natural holding habitat (e.g., through passive restoration techniques). If H1 and H2 are rejected (and H0 is accepted) then HES are unlikely to cause problematic increases in susceptibility to angling.

Purpose and Broader Impacts

Installation of HES is on the rise (Cowx and Welcomme 1998). State, federal, and local governments, along with non-profits and private landowners are installing HES structures with increasing frequency. However, these structures are being installed under the assumption that unintended consequences are benign. This 'restoration myth' helps add context to why HES are so pervasive, and helps us identify the types of questions that need to be posed regarding HES, and more generally, about our current restoration paradigm. The research project described throughout the body of this chapter provides one example that debunks the myth that well-intentioned restoration actions are without negative consequences. Through example, it emphasizes the necessity for managers to align enhancement approaches with project goals. Furthermore, the project provides design recommendations for HES installation based on project-specific goals.

Organization of Thesis

This document consists of four chapters and seven appendices. This chapter functions as an introduction to the research project. The following chapters consist of a literature review (Chapter 2), a journal manuscript pending publication (Chapter 3), and a project summary (Chapter 4).

Project elements pertaining to the use of anglers in the study are discussed in Appendix A: Angler Behavior. This includes: 1) a brief description of the in-field angler surveys and follow-up questionnaires; 2) a summary of the questionnaire results; 3) the Institutional Review Board research exemption; 4) the initial angler interview questionnaire; 5) the consent form; 6) the post-field survey angler questionnaire; and 7) the debriefing form.

Project elements pertaining to salmonid mark-recapture studies are discussed in Appendix B: Electrofishing and PIT Tagging Surveys. This appendix consists of 1) a summary of the electrofishing surveys; 2) results; 3) electrofishing-specific literature referenced; and 4) protocol submitted to the Institutional Animal Care and Use Committee in partial fulfillment of an electrofishing permit.

Appendix C: Semivariograms, contains semivariograms and associated information quantifying spatial autocorrelation in the dataset and the distance at which spatial structure breaks down.

Specifics on the GIS component of this research project can be found in Appendices D-G. Information pertaining to the database schema designed to manage project-specific data are located in Appendix D: Database Schema. A data dictionary comprised of the technical parameters and properties of the GIS shapefiles created for this project is located in Appendix E: GIS Data Dictionary. Information on the process of how these shapefiles were created is located in Appendix F: GIS Shapefile Construction Methods. Finally, the hard copy of this thesis contains a CD of the GIS data files (and a linked Microsoft Access database with additional attribute data) that form the basis of all analyses in this study. This CD is located in Appendix G: Data File.

CHAPTER TWO

LITERATURE REVIEW

The State of River Restoration

Healthy, functioning lotic systems provide a plethora of ecological goods and services (FAO 1995). These include a source of drinking water and food, mitigation of floods, benefits to agriculture through irrigation and nutrients, aquatic plants and animals, and a riparian plant community to buffer and filter watershed activities. Although the importance of intact, resilient lotic systems is known, global degradation of these systems is at an all-time high (Gleick 2003) as a result of increasing human activities in rivers and their catchments (Richter et al. 1997; Lake et al. 2007; Arthington et al. 2010). Responding to this degradation, river restoration has become increasingly popular (NRC 1992; Kondolf and Micheli 1995; Cowx and Welcomme 1998; Bash and Ryan 2002) and highly profitable (NRC 1996; Lavendel 2002; Malakoff 2004) with U.S. national industry expenditures that exceed one billion dollars annually (Bernhardt et al. 2005). Moreover, restoration is assumed to play an increasing role in environmental management and policy decisions in the future (Palmer et al. 2004).

Instream Fish Habitat Enhancement

Society has become especially concerned with lotic fish because of their role as a charismatic indicator species of river health and the economic, recreational, and cultural importance placed upon them (FAO 1995; Roni et al. 2005). This importance is exemplified in the 2006 National River Restoration Science Synthesis report, in which fish habitat enhancement is identified as one of the most common types of riverine restoration (17% of total national projects) (Palmer 2006). The frequency of these types of restoration projects is higher in the Pacific Northwest (i.e., Washington, Oregon, Idaho, and Montana), where fish habitat enhancements comprise 41% of all river restorations implemented.

Much of what is considered to be instream ‘fish habitat enhancement’ includes the installation of artificially-constructed structures such as boulder clusters and designed log jams (Kauffman et al. 1997). These habitat enhancement structures (HES) are placed to generate a physical response (e.g., deep pools) under the assumption that an increase in physical diversity improves biological diversity (Palmer et al. 1997; Harper and Everard 1998; Newson and Newson 2000) or carrying capacity (Stewart et al. 2009). Because this type of intervention typically entails symptomatic fixes, it is referred to as an ‘enhancement’ (Kauffman et al. 1997) rather than ‘restoration’, with the latter defined as a project that assists a stream in recovery of dynamic equilibrium and function at self-sustaining levels (FISRWG 1999; SER 2004; Roni et al. 2005).

Within the context of traditional fisheries management, habitat enhancement structures have a long legacy of use in the U.S. (Reeves et al. 1991; Duff et al. 1995; White 1996) as important tools to create holding habitat (Hunt 1971, 1988; White 1975) and manipulate fish assemblage dynamics to meet management goals, including increasing angler CPU effort (Bolding et al. 2004) and fishing success (Thorn 1990; Binns 2004). This approach focuses on augmenting fish numbers through an increase in quality or quantity of habitat characteristics, rather than whole ecosystems (Nehlsen et al. 1991; Doppelt et al. 1993; Frissell et al. 1997) or landscape processes (Beechie and Bolton 1999), which are advocated in restoration projects. Although the traditional fisheries management approach is appropriate and effective in meeting intended goals, it may not be the most effective riverine restoration technique (Thompson 2006). Yet, as the demand for and practice of riverine restoration and enhancement increases, HES have become one of the most frequently used techniques (Palmer 2006). Although HES have proven themselves useful in traditional fisheries management aimed at enhancing angling opportunities and creating holding habitat (Binns 2004), within the context of ecological restoration and enhancement, the outcomes and population level effects upon fish are less certain (Pretty et al. 2003; Rosi-Marshall et al. 2006). Intuitively, if a stream is habitat deficient and this is the primary factor limiting a species or life cycle stage, then HES would certainly be an effective solution to support and restore fish populations. However, this technique is broadly applied, and frequently without a limiting factors analysis (Beechie and Bolton 1999). Thus, a large body of literature demonstrates that HES installation is not a panacea, and that the usefulness of these structures is context-specific (Reeves et al. 1990; Frissell and Nawa 1992; Roni et al. 2005) Therefore, the use of habitat structures for instream restoration does not ensure demonstrable benefits for fish assemblages, and their ability to increase fish populations should not be automatically presumed (Thompson 2006).

Habitat-Centric Approaches Can Ignore Limiting Factors

Traditional, habitat-centric fisheries management approaches are frequently used in attempts to compensate for anthropogenic simplification of stream habitats (Kauffman et al. 1997; Roni et al. 2005). This approach assumes that fish are simply habitat-limited, such that projects that increase suitable spawning habitat, deep pools, or cover will result in increased fish populations (Bond and Lake 2003; Rosi-Marshall et al. 2006). However, HES are frequently unsuccessful at meeting restoration goals because they have been constructed without consideration of the ecological and landscape contexts of habitat degradation (Beechie and Bolton 1999). Furthermore, they often neglect to address factors limiting production (Reeves et al 1991; Bjornn and Reiser 1991). Limiting factors can include trophic/energetic dynamics (Tilman et al. 1982), water quality and quantity (Roni et al. 2005), and long-term and large-scale processes (Bond and Lake, 2003). Habitat-specific limiting factors can be species or lifecycle stage dependent (Bjornn and Reiser 1991). Regardless of the limiting factor, bottlenecks to recruitment and survival must be identified before a successful restoration or conservation management strategy can be developed (Cowx and Collares-Pereira 2002).

With increased understanding of engendering healthy, sustainable lotic fish populations, scientists and practitioners now accept that there must be careful consideration of a watershed or ecosystem context in which individual restoration actions are set (Lichatowich et al. 1995; Beechie and Bolton 1999; Palmer et al. 2005). Furthermore, diagnoses and treatment of the causes of habitat degradation, rather than the effects of habitat degradation, are becoming increasingly popular (Beechie and Bolton 1999), especially when this approach can work within social and economic constraints.

Persistence of Habitat Enhancement Structures

Despite all of this, HES continue to be one of the most pervasive fisheries management and stream restoration techniques (Steward et al. 2009). This is probably attributable to:

(1) Policy: The fact that US policy (ESA, CWA) drives the continuing focus on a single species or water quality attributes instead of watersheds or ecosystems (Karr 1991; Beechie et al. 2003).

(2) Simplicity: HES have been deemed successful in the US since the 1930s, and are considered to be a simple, non-controversial ‘fix’ that can mitigate for more difficult and controversial solutions such as coordinated watershed-scale restoration efforts (Binns 2004).

(3) Economics: With important industries affecting riverine environments and fisheries (e.g., farming, timber, grazing, and development), working within existing constraints and addressing symptoms is the best that a manager can do (Roni et al. 2005).

(4) Assumptions: ‘Some action is better than no action’ assumes that restoration actions rarely leave streams in a condition worse than the pre-restoration state (Hilderbrand et al. 2005).

(5) Metrics of Success: HES are 'successful' according to the metrics we use to define success, regardless of how limited that definition of success is (Rosi-Marshall et al. 2006).

Metrics of Success Contribute to Uncertainty

Until recently, monitoring HES projects in the US focused primarily on whether enhancement structures were durable (Roni et al. 2002), or more notably, produced a localized physical response (Rosenfeld and Huato 2003). Large and significant increases in pool frequency, pool depth, woody debris, complexity, and sediment retention following placement of HES have been well documented (Hunt 1988; Crispin et al. 1993, Cederholm et al. 1997; Reeves et al. 1997; Roni and Quinn 2001; Whiteway et al. 2010), and deemed successful. It is now generally accepted, however, that physical response to enhancement is not an appropriate surrogate or reliable predictor of biological or ecological response (Pretty et al. 2003; Thompson 2006). Therefore, biomass and abundance estimates became the new standard, and described localized point-in-time fish use (e.g. presence/absence). According to these metrics, HES are deemed biologically successful by many studies (Hunt 1988; Riley and Fausch 1995; Shields et al. 1995; House et al. 1996; Gortz 1998; Binns 1999; Avery 2004; Whiteway et al. 2010). However, this too, may be misleading because the limited spatial and temporal scales of analysis prevent a holistic measure of biological effectiveness (Pretty et al. 2003; Roni et al. 2005; Roni et al. 2008). For example, mechanisms causing localized biomass and abundance increases are not well understood and may be caused by *either: 1)* a true population level increase; or 2) movement at the watershed scale (i.e., immigration) (Gowan et al. 1994; Gowan and Fausch 1996; Frissell and Ralph 1998; Stewart 2009; Johnson et al. 2005).

Fish Aggregation

Most of the abundance increase of trout in high-elevation Colorado streams enhanced with log structures was caused by immigration (Gowan and Fausch 1996). In showing that movement was important in the response of trout populations to habitat enhancement, a corollary finding of this study was the rejection of Gerking's 1959 "restricted movement paradigm" (Gowan et al. 1994). This theory proposed that resident salmonids are sedentary (i.e., adult salmonids establish restricted territories for feeding and remain there), and guided much of the research into the dynamics of fish populations for the next 30 years (Gowan et al. 1994). Rejection of this paradigm has important implications for management, and corroborates the theory that HES can attract and concentrate fish from adjacent riverine habitats rather than increasing population abundance.

Despite the pervasiveness of enhancement structures, little attention has been paid to their unintended effects, such as artificial fish aggregation, on other aspects of stream ecosystems (Cowx and Gerdeaux 2004; Rosi-Marshall et. al 2006). In narrowly defining success, we preclude assessment or consideration of whole-systems effects. Therefore, HES are being installed under the assumption that if any consequences exist, they are benign. Because studies have shown that HES can attract and concentrate fish, it makes sense to examine system-wide consequences resulting from species redistribution at a watershed scale.

Marine and Lentic Aggregation

Installation of artificial habitat structures in marine and lentic environments (e.g., artificial reefs, fish aggregation devices) has been shown to concentrate fish, increase commercial and recreational catch rates, and contribute to overexploitation of stocks (Polovina 1991; Polovina 1989; Walters et al. 1991; Grossman et al. 1997; Wege and Anderson 1979; Moring et al. 1989; Moring and Nicholson 1994; Wilbur 1978; Prince and Maughan 1978; Wege 1981; Bolding et al. 2004). Because it is reasonable to assume a similar relationship exists in lotic environments, stream ecologists have called for the quantification of angler effect upon fish assemblages within restored and enhanced riverine (Hunt 1988; Binns 2004; Thompson 2006). Despite this, no investigation explicitly elucidating this relationship yet exists.

Effect of Recreational Anglers

Fisheries managers have long recognized that recreational angling affects fisheries (Coleman et al. 2004) and therefore have harnessed recreational angling as a powerful technique to manage and manipulate fish populations (Nielsen 1999). However, this has not transferred to the theory and practice of habitat-enhancement and restoration. River restoration-related literature has given little attention to the human aspects of restoration and enhancement, other than habitat management or anthropogenic degradation (White 1996). According to White (1996), in a meta-analysis of 1367 papers, less than 1% (n=12) mentioned recreational implications (including angling), as it relates to riverine restoration.

Within the context of riverine and fisheries restoration, potential for negative population effects from anglers has been dismissed by assuming that recreational fishing does not affect fisheries. Yet, failure to recognize the role of recreational anglers in fisheries decline jeopardizes the sustainability of the resource (Cooke and Cowx 2004; Cooke and Cowx 2006). Although national recreational harvest data do not exist (Cooke and Cowx 2004), about 25.4 million freshwater anglers in the U.S. amass 433 million fishing days annually (USFWS 2006). Accordingly, recreational angling has considerable direct effects on aquatic ecosystems (Magnuson 1991) and can result in fish stock declines (Post et al. 2002; Coleman et al. 2004).

Specific to HES installation, Binns (2004) reported post-treatment decreases in fish abundance (14% and 71%) at two sites that were probably the result of increased angler access to enhanced study reaches and harvest beyond a level supported by the wild trout populations. Furthermore, Thompson (2006) recommended that any test of the effect of instream structures must also consider the influences of changes in recreational fishing pressure. Although catch-and-release practices lessen this threat, the potential remains for anglers to directly affect fisheries where harvest is standard practice, with highly sensitive species, or in the face of increasing environmental stressors (e.g., climate change, decreased instream flows, water quality issues). Failure to recognize this will hinder efforts to conserve aquatic resources (Cooke and Cowx 2004, Cooke and Cowx

2006), and without changes to managing and monitoring recreational fisheries, they may not be sustainable in the long term (McPhee et al. 2002).

Other Potential Consequences of Fish Aggregation

Other consequences of fish assemblage aggregation include competition, hybridization, disease, and forms of predation other than angling. The following examples are given irrespective of the root cause of fish aggregation.

(1) Predation: The northern squawfish (*Ptychocheilus oregonensis*) has demonstrated the ability to feed on anadramous juvenile salmonids spatially concentrated in the tailraces immediately below dams (Beamesderfer et al. 1995).

(2) Competition: Aggregated fish in lentic systems have resulted in overpopulation, decreased biomass, and slowed growth (Crowder and Cooper, 1979; Savino and Stein 1982; Bettoli et al. 1992).

(3) Disease: Human intervention, deterioration of habitat, competition, and increased host population density have all been shown to contribute to disease spread (Moyle and Cech 2003). In artificial marine reefs, increased rates of disease spread has been linked to highly mobile hosts, higher densities of fish relative to surrounding natural reefs, and increased contact time with invasive stages of parasites (Gaevskaja and Machkevsky 1995).

(4) Hybridization: If structures are installed at or near sites where hybridization is occurring, the potential exists to increase pathways of hybridization or break down genetic isolation in metapopulations by aggregating fish (Moyle 2002).

Future Use of HES

When the goal of a project is simply to increase fish holding habitat, recreational angling opportunities, angler success, or combination thereof, the role and effects associated with habitat structure installation seems fairly straightforward. However, when the goal of a project is to facilitate a healthy, sustainable fishery (i.e., population level response), the role and effects of HES are more uncertain (Hicks and Reeves 1994; Roni et al. 2005).

Although the science of stream restoration has moved toward a general acceptance of process-based (Beechie and Bolton 1999), watershed-scale restoration (Lichatowich 1995), the practice of stream restoration overwhelmingly continues to emphasize treating the symptoms of degradation (Roni et al. 2005) with site-scale design and implementation. These inconsistencies have begun to be resolved in projects where instream structures are considered as part of a more comprehensive plan designed to restore not only habitat but also ecological functions and processes (Sedell and Beschta 1991; Hicks and Reeves 1994; Beechie and Bolton 1999). In such restoration projects, structures are viewed as a catalyst that may facilitate the recovery of habitat in the short term while other components of a restoration are being carried out that will initiate longer-term recovery (Hicks and Reeves 1994; House 1996; Pretty et al.2003). Other successful HES integrations result from placement of artificial structures (namely LWD) that mimic natural process by using and placing materials consistent in size, type, location, and orientation to that found in natural channels (Kauffman et al. 1997; Roni et al. 2002).

Perhaps the most apparent lesson gained from HES installation in North America is that watershed protection is the most successful method of habitat enhancement, given the high costs associated with repairing damage once it has occurred, and the fact that some damage may not be reversible (Reeves et al. 1991). Therefore, the far-sighted policy, both ecologically and economically, is to prevent damage to streams and the aquatic system, rather than attempting to repair or mitigate it afterwards (Hicks and Reeves 1994). Regardless of interventions, restoration in conjunction with conservation will become increasingly crucial especially given the rate at which humans are altering watersheds and specifically streams (Palmer et al. 2004).

CHAPTER THREE

FISH AND ANGLER USE OF INSTREAM HABITAT ENHANCEMENT STRUCTURES IN 'RESTORED' STREAM REACHES

Contribution of Authors and Co-Authors

Manuscript in Chapter 3

Author: E. Jordanna Black

Contributions: Conceived the study, collected and analyzed output data, and wrote the manuscript.

Co-Author: Geoffrey C. Poole

Contributions: Assisted with study design, discussed the results and implications, and edited the manuscript at all stages.

Co-Author: Alexander Zale

Contributions: Assisted with methods, discussed the results and implications, and edited the manuscript.

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Abstract

Habitat enhancement structures (HES) are commonly installed in streams to provide holding habitat for fish. Given that HES may attract both fish and anglers, we hypothesized that fish holding near HES may be more susceptible to angling than fish occupying natural holding habitats. We assessed spatial patterns of habitat structure, fish holding locations, and fishing pressure (i.e., casting patterns) in southwestern Montana stream reaches with HES. Structures aggregated fish, and anglers more successfully targeted fish holding near HES than similar densities of fish holding near natural structures. HES may be useful for increasing angling opportunities. However, by attracting fish to locations where they are more vulnerable to angling, HES work in opposition to fish conservation goals for species of concern. We recommend a more critical consideration of the potential consequences (both negative and positive) of attracting and aggregating of fish via the installation of HES.

Introduction

Riverine restoration funding has increased markedly over the past 15 years such that national industry expenditures exceed one billion US$ annually (Bernhardt et al. 2005). According to the 2006 National River Restoration Science Synthesis project, 17% of all river restoration projects in the United States (Table 1) include the manipulation of instream physical structure to improve fish habitat (Palmer 2006). This percentage is even higher in the Pacific Northwest (i.e., Washington, Oregon, Idaho, and Montana) where fish habitat enhancement projects make up 41% of river restoration projects.

Instream fish habitat enhancement commonly includes the installation of artificial habitat enhancement structures (HES) such as boulder clusters, log jams, and lunker structures (Figure 1). Because HES increase habitat complexity, these installations are often presumed to benefit fish populations. Reports of localized increases in fish biomass in reaches with HES (Hunt 1998; Avery 2004; Whiteway 2010) are often cited as support for a beneficial population response. However, metrics that describe localized physical response (e.g., change in pool frequency), or localized point-in-time fish use (e.g., presence/absence) may be misleading because the limited spatial and temporal scales of analysis prevent a holistic measure of biological effectiveness (Pretty et al. 2003; Roni et al. 2008). In fact, in one of the few comprehensive studies on the topic, Gowan and Fausch (1996) showed that HES simply attracted and concentrated fish from adjacent habitats and did not increase population abundance. Similarly, artificial reefs and fish aggregating devices attract and aggregate fish in lake and marine environments (Clark 1945). Such clustering increases commercial and recreational catch rates (Polovina 1991; Grossman et al. 1997) and can result in overexploitation (Wege and Anderson 1979; Grossman et al. 1997). A similar relationship may exist in lotic environments, and stream ecologists have called for the quantification of angler effect upon fish assemblages in restored and enhanced riverine systems (Hunt 1988; Binns 2004; Thompson 2006). Despite this, many scientists, managers, and consultants maintain the assumption that restoration actions rarely leave streams in a condition worse than their pre-restoration state (Hilderbrand et al. 2005) and this assumption has gone largely unchecked with respect to the installation of HES in streams.

In this study, we asked the question: *Do artificial habitat structures in streams increase the susceptibility of fish to angling?* Specifically, we hypothesized that anglers target fish associated with HES more successfully than natural aggregations of fish (i.e., fish holding near natural structures). This hypothesis yielded the following predictions: (1) fish density will be higher near HES than near natural structures; (2) angler effort will focus on HES; and (3) anglers are more effective at targeting fish clustered near HES than fish clustered far from HES (e.g., at natural holding structures). For our hypothesis to be supported, all three predictions must be true. Without support for prediction one, we have no evidence that HES affect fish location. Without support for prediction two, we have no evidence that angler behavior is influenced by the presence of HES. Finally, and perhaps most importantly, without support for prediction three, we have no evidence that fish associated with HES are more vulnerable than fish associated with natural habitat structures.

To test this hypothesis, we assessed spatial patterns of habitat structure, fish holding locations, and angling effort (i.e., casting patterns) in four southwestern Montana stream reaches where HES have been installed.

Methods

Study Sites

Study sites included four sinuous, single-threaded, low-order streams with trout fisheries (Table 2) in the Yellowstone and Missouri river headwaters in southwestern Montana (Figure 2). Specific stream study reaches were selected based on HES presence, density, and diversity (Table 3).

Field Methods

To create GIS base images of our study sites, we obtained aerial photographs during baseflow conditions (July 2010) and spatially referenced imagery by rubbersheeting (i.e., non-uniform adjustment of cover features to enable alignment) each image to ground-truthed GPS points post-processed to less than 0.3 m horizontal accuracy. We conducted GPS surveys to determine the horizontal position of each enhancement structure to within 0.3 m and measured the size and recorded the type (e.g., boulder, boulder cluster, log, log jam, root-wad, pool) of each HES. Base images were printed with Capturx™ for ArcGIS® Desktop on 8.5 × 11 in paper at 1:150 scale and taken into the field. We annotated fish holding locations during snorkel surveys (as described below) and locations targeted by fly fishing anglers (also described below) directly on the printed base images using an Adaptx™ digital pen. The pen marks each annotation on the printed base image (as does a conventional pen) and simultaneously stores the spatially referenced annotation digitally on a memory chip in the pen. When connected to a computer, the pen generates a GIS shape file of the annotations. We used the digital pen to produce four GIS shape files describing: 1) fish holding locations; 2) cast locations (the points where anglers' flies first contacted the water); 3) drift paths (the paths traveled by anglers' flies when carried downstream in the current); and 4) HES locations at each site

Snorkel Surveys: Snorkel crews followed USFS salmonid snorkeling protocols (Thurow 1994) to conduct two fish surveys (July and September 2010) at each study site. A snorkeler identified fish locations to within about 1 m horizontally and called out the species and size class (< 13 cm; 13 to 30 cm; ≥ 30 cm) while a technician on shore 3 m behind the snorkeler recorded the location and attributes of each fish on printed base imagery using the Adaptx™ digital pen. Location data were downloaded from the pen into a GIS and attribute data (e.g., site, species, size, date) were added to the GIS shapefile manually. Fish locations from both surveys were combined into a single GIS layer.

Angling Surveys: Volunteer anglers were selected through preliminary interviews designed with the aid of a behavioral psychologist to incorporate a range of potentially confounding variables (e.g., experience, age, sex, preferred access). The primary researcher (Black) individually escorted anglers to each stream (with site order randomized for each angler) during summer 2010 where they were directed simply to fly fish between two markers along the stream that denoted the upstream and downstream ends of the study site (single blind study). Anglers fished only with dry (floating) flies. The researcher recorded the location of each cast and drift using the Adaptx™ pen.

Spatial Analysis Methods

Fish location data were thinned so that only "catchable-sized" fish (i.e., fish > 13 cm) were included in the data analysis. For each fish, we used a GIS to calculate a neighboring fish density (a measure of fish density surrounding each fish). Cluster analysis using Ripley's K-function (Ripley 1976), yielded an estimate of the spatial scale (i.e., the average diameter of a cluster) at which the clustering of fish was most pronounced. Using this cluster diameter as the size of a circular neighborhood, a kernel density function (Silverman 1986) generated a continuous map of fish density across the study site. Each fish was then assigned a density value equal to the mapped fish density at its location. To determine an index of fishing pressure experienced by each fish, we used a GIS to generate a 1.0 m circular buffer around each fish to represent the fish's "reactive distance" (i.e., the distance a fish is likely to move from its holding location to intercept prey) and anglers' drifts intersecting each fish's buffer were summed. We termed this sum the "drift density" for each fish.

To determine the shortest instream distance of each fish and each cast to the nearest HES, we used 'least cost path' on a uniform cost grid (Dijkstra 1959), with terrestrial areas masked (i.e., the calculated distance could not cross over terrestrial areas). These distances were used in subsequent statistical analyses (described below) to characterize the distribution of casts and fish relative to HES.

Statistical Analysis Methods

To assess predictions 1 and 2, histograms showing the observed distribution of distance to HES were generated for both fish and casts. A bootstrapping approach determined whether observed patterns were random. R open-source statistical software (version 2.8.1) generated a per-site distribution of mean distance-to-HES values for 10,000 sets of randomly drawn locations in each study reach with the number of random points equal to the number of observed fish at a given site. The observed mean cast or fish distance to HES for each site was assessed relative to the distribution of 10,000 random means. Using this technique, we can conclude that fish and cast locations are significantly (α =0.95) clustered near HES if the observed mean distance is less than the lower 5th percentile of the distribution of means from randomly drawn locations in the study reach.

We used regression analysis to assess prediction 3. Low fish densities at Mill Creek (Table 4) precluded quantifying clusters of fish, and thus fish density, so the site was excluded from the regression analysis. In Bridger Creek all fish were associated with HES, suggesting a complete lack of natural holding habitat. The resulting colinearity between fish density and distance to HES ($p << 0.001$) violated the assumptions of the regression necessary to test prediction 3, so this site was also precluded. At the two remaining sites, linear regression using an Ordinary Least Squares (OLS) model assessed the relationship between cast density and fish density using the equation

$$CD = m_{FD1}FD + b \quad (1)$$

where CD = angler effort measured by cast density, m_{FD1} = the model coefficient for fish density equation 1, FD = fish density, and b = the y-axis intercept. A significant positive relationship between CD and FD in this regression would suggest that anglers are able to identify and target areas where fish are clustered. Regression residuals were spatially autocorrelated (assessed by calculation of Moran's I on the regression residuals using GeoDa version 0.9.5-i), violating the underlying assumption of OLS regression. To account for spatial autocorrelation in the regression residuals, we reran the regression using a spatial lag model that assessed the relationship between cast density and fish density using the equation

$$\mathrm{CD} = m_{FD2}\mathrm{FD} + m_{SL}\mathrm{SL} + b \quad (2)$$

where SL = a spatially lagged dependent variable representing the averaged cast density value for neighboring fish, m_{FD2} = the model coefficient for FD in equation 2, and m_{SL} = the model coefficient for SL in equation 2. Results from running several different neighborhood sizes yielded nearly identical regression results, so neighborhood radius was arbitrarily set equal to the smallest distance that ensured each observed fish had at least one neighbor. This choice of neighborhood radius ensured that SL could be calculated for every fish and therefore allowed all fish to be included in the regression. Output included Akaike information criterion (AIC) to compare model fits (Table 6) and basic diagnostics for heteroskedasticity (Breusch-Pagan test) and nonnormality of errors (Jarque-Bera test). Moran's I revealed that the addition of a spatial lag term resolved the spatial autocorrelation in the model residuals.

The regression residuals resulting from linear regression using equation (2) represent estimates of cast density for each fish after removing any effect of local fish density. Thus, if the residuals are significantly and negatively correlated with distance to HES, we can conclude that clusters of fish close to HES are more effectively targeted than clusters of fish farther from HES (e.g., near natural structures). Ordinary Least Squares regression assessed the relationship between equation (2) regression residuals and distance to HES

$$\mathrm{R}_2 = m_{DHES}\mathrm{DHES} + b \quad (3)$$

where R_2 = the residuals of regression results using equation (2), m_{DHES} = the model coefficient in equation (3), and DHES = the distance to the nearest habitat enhancement structure. Analysis using GeoDa yielded Moran's I, Jarque-Bera, and Breusch-Pagan tests for the residuals of the regression from equation (3).

Results

Snorkeling and angling surveys returned a total of 859 catchable fish and 6,941 casts with associated drifts (Table 2). At all four sites, fish distributions were skewed in proximity to HES (Figure 3). Mean distances to nearest HES were significantly lower than would be expected if fish were distributed randomly (Figure 4), revealing that fish were clustered near HES. Similarly, angling effort was skewed toward HES (Figure 5) and was significantly clustered (Figure 6).

Fish density was a significant predictor of cast density at the Hyalite and Fish creek sites (Table 5). Applying a spatial lag model resolved the issue of spatial autocorrelation within model residuals at both sites and out-performed the OLS model based on AIC (Table 6). Model residuals were normally distributed. Both spatial lag (a variable reflecting the cast density experienced by neighboring fish) and fish density were significant predictors of cast density (Table 7).

Distance to HES was a significant, negatively correlated predictor of the residuals from the spatial lag model (Figure 7) revealing that fish closer to artificial habitat structures were subjected to higher angling pressure than fish holding in similarly dense clusters, but farther from artificial habitat structures. We can therefore conclude that clusters of fish associated with artificial HES were targeted by anglers more successfully than clusters of fish holding near natural habitat structures.

Discussion

Our findings - that both fish and anglers were attracted to HES in streams - were consistent with previous findings in lotic (Gowan and Fausch 1996; Binns 2004), lentic (Bolding et al. 2004), and marine environments (Polovina 1991). Our results, however, also demonstrate that artificial structures in streams were more heavily targeted by anglers than natural holding locations of similar quality (as defined by the size of associated clusters of fish). Assuming that cast density accurately reflects vulnerability to angling, data suggest that installation of HES may therefore systematically improve the efficacy of anglers, amplifying any effect of recreational angling on fish populations, including contributing to fish stock declines (Post et al. 2002; Cooke and Cowx 2004, 2006). Although our data fell short of documenting population-level effects from installation of HES, our results add weight to appeals to investigate the potential for negative effects of HES on fish populations in riverine systems (Hunt 1988; Binns 2004; Thompson 2006). For instance, increased angling efficacy suggests a potential for reaches with HES to serve as population sinks by attracting fish to locations where they are more vulnerable to angling. Such population-level risks could be amplified or mitigated by a number of factors. A population sink effect might be amplified where target fish populations are declining or depleted, natural holding habitat in the augmented reach or in adjacent reaches is limited, the level of fishing access and pressure are high, fishing regulations are lax, or environmental stressors (e.g., climate change, decreased instream flows, or water quality issues) are prevalent. Alternatively, where the opposites are true, any population sink affect is likely to be mitigated.

Our findings lead us to formulate a number of recommendations regarding the installation of HES in streams. HES tend to be installed with the intent of either enhancing fishing opportunities or facilitating conservation of game fish species. Our results suggest that HES are useful for attracting fish, and enhancing fishing opportunities and success rates. Therefore, HES would be appropriate management tools to enhance fishing opportunities in systems with healthy fish populations. Installation of HES may be especially appropriate, for instance, at handicapped-accessible fishing sites, in conjunction with stocking regimes, or to concentrate angler use away from ecologically sensitive parts of a stream or riparian zone.

In cases where population-level conservation goals predominate, especially with threatened and endangered species, we recommend more caution. Installation of HES should facilitate population-level conservation if lack of secure holding habitat has been demonstrated (rather than simply presumed) to be a limiting factor in the life-cycle of a species of interest. However, in this context, HES might be more effective if designed to be as inconspicuous to anglers as possible in order to yield more secure holding habitat. Further, "catch-and-release only" regulations in reaches with HES might also help compensate for increased angling efficacy.

From a broader perspective, we recommend careful consideration of assumptions that can underpin restoration or enhancement efforts (s.s., Hilderbrand et al. 2005: *The*

Myths of Restoration Ecology) before implementing a project. In the case of HES, the name "Habitat Enhancement Structure" connotes that these structures unilaterally enhance fish habitat, even though an array of potential negative effects has gone largely unstudied. Such consequences include: increases in disease transmission, introgressive hybridization, intra- and inter-specific competition, and predation rates (Gaevskaja and Machkevsky 1995; Beamesderfer et al. 1995). Perhaps adopting the term 'fish aggregation structures', as similar devices are termed in marine and lentic environments., would focus stream restoration practitioners on fish aggregation as the primary proven effect of these structures, and encourage more critical evaluation of whether fish aggregation is desirable in light of specific management goals.

Second, because restorative actions (including rehabilitation, remediation, reclamation, replacement, or mitigation; Bradshaw 1996), are intended to improve a natural resource, it is easy to assume such actions will yield, at worst, benign consequences. Yet, management experience and scientific literature are replete with examples to the contrary in aquatic systems. Historically, fisheries management has operated within the context of the assumption of benign consequences. For instance: fish introductions and stocking have resulted in transitions from native to nonnative fisheries (Allendorf and Leary 1988); food web manipulations have yielded serious, system-wide trophic cascades (Spencer et. al. 1991; Ellis et al. 2011); and removal of large woody debris from streams in the Pacific Northwest to encourage upstream adult salmonid passage destroyed juvenile rearing habitat, causing further declines in salmonid fisheries (Bryant 1983). In all cases, well-intentioned manipulation of ecosystems occurred presuming benign consequences, without fully assessing or considering whole-system effects.

Similarly, habitat enhancement structures are frequently installed assuming that their effects are beneficial and any unintended consequences are benign. Yet, restoration/enhancement actions represent manipulations of complex ecosystems. Therefore, just as with extractive or consumptive manipulations of stream ecosystem services (e.g., dam construction, channelization of streams, levees, etc.), restorative manipulations should be approached with critical analysis and application of the precautionary principle, which states that precautionary measures should be taken in the face of uncertainty to avoid harm to human health and the environment (Tickner et al. 2000).

Conclusions

Installation of artificial HES in streams can systematically attract fish to locations where the efficacy of anglers is enhanced relative to natural holding habitats. This effect can be beneficial for augmenting angling opportunities, but also leaves open the potential for populations-level impacts on recreational fisheries, especially where target fish populations are already under stress. We recommend more critical evaluation and more selective use of HES, after careful consideration of the potential benefits and consequences of aggregating fish in streams. Such benefits and consequences should be identified and assessed relative to well-defined project goals and in consideration of the resiliency of the fishery being managed.

Tables and Figures

Table 1. Top five goals of riverine restoration projects in the Pacific Northwest and nationally. Data were compiled from the 2006 National River Restoration Science Synthesis (NRRSS) database (Palmer 2006; http://nrrss.nbii.gov/). The category "in-stream fish habitat enhancement" is an estimate created by combining the NRRSS categories of "in-stream habitat enhancement," "in-stream species management," and "fish passage."

	Pacific Northwest Projects	National Projects
Instream Fish Habitat Enhancement	**1: 41%**	**3: 17%**
Riparian Management	2: 24%	1: 25%
Water Quality	3: 17%	2: 23%
Bank Stabilization	4: 11%	4: 12%
Aesthetics	5: 3%	5: 6%

Figure 1. Examples of habitat enhancement structures. From left to right: Artificially constructed log jam (USFS), check dam structure (Oklahoma Department of Wildlife Conservation), and log cross vanes (National Center for Earth-Surface Dynamics).

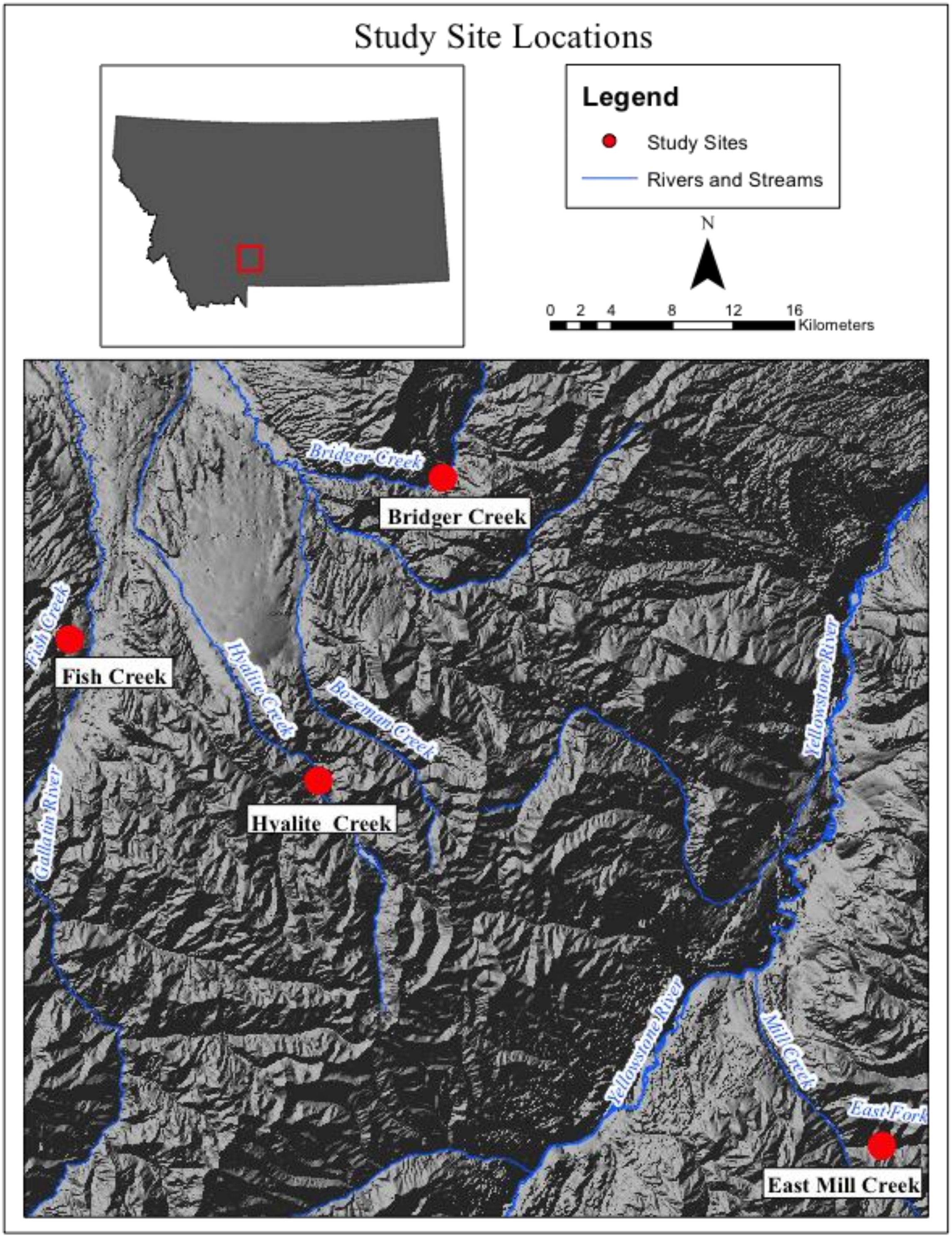

Figure 2: Site locations in the upper Yellowstone and Gallatin subbasins (the Upper Missouri headwaters).

Table 2. General study site characteristics.

	Type	Form	Substrate (Dominate/ Sub-dominate)	Surrounding Land use	Length/ Width (m)
Bridger Creek	Floodplain creek	Riffle-pool	Cobble-pebble	Irrigated hay, cattle grazing	315/ 6
Hyalite Creek	Alpine stream	Riffle dominated	Cobble-boulder	National forest lands, open to recreation	215/ 10
Mill Creek	Alpine stream	Riffle dominated	Cobble-boulder	National forest lands, open to recreation	275/ 9
Fish Creek	Spring creek	Riffle-pool	Cobble-pebble	Irrigated hay	500/ 3.5

Table 3. Restoration/enhancement attributes of study sites. For boulder clusters and log jams, the number of structures is followed by the total number of boulders/logs comprising the structures.

	Reason for Restoration	Structure Type	No. (Total Parts)	Relative Abundance of Natural Habitat Structures	Ownership
Bridger Creek	Angling opportunities, fish carrying capacity	Boulder weir Pool	4 (39) 1	Low	Private
Hyalite Creek	Increase population	Boulder Boulder cluster Log	2 7 (23) 1	High	Public
Mill Creek	Increase population	Boulder Boulder cluster Log	1 7 (67) 1	Low	Public
Fish Creek	Angling opportunities, fish carrying capacity	Boulder Boulder cluster Log Log jam Pool Root-wad	10 16 (51) 6 2 (5) 2 1	Low-Mid	Private

Table 4. Summary of fish observation and angler surveys conducted June-September 2010.

Site	Total Fish	Catchable Fish ≥ 13cm	Casts/Drifts
Bridger Creek	185	142	1424
Hyalite Creek	303	238	2123
Mill Creek	25	23	1324
Fish Creek	633	456	2070

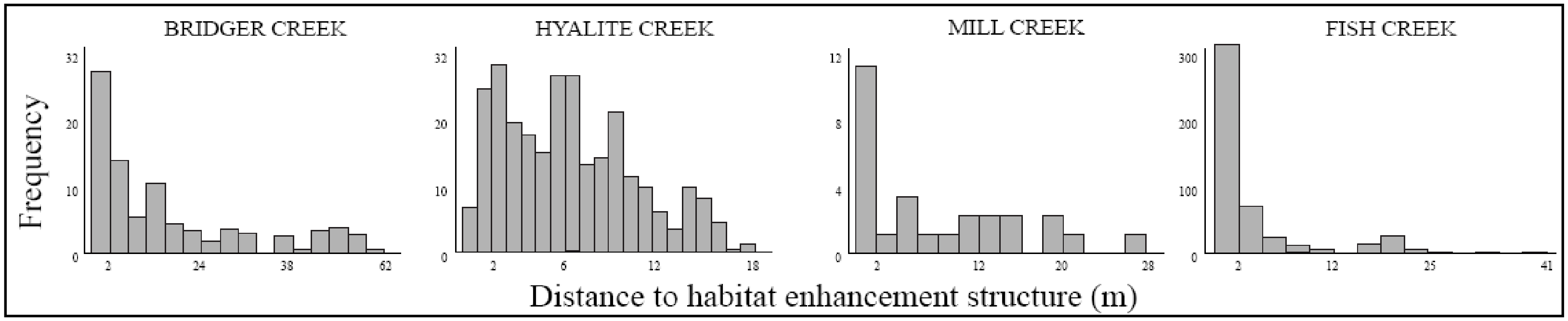

Figure 3. Observed frequency of individual fish as a function of distance to habitat enhancement structure.

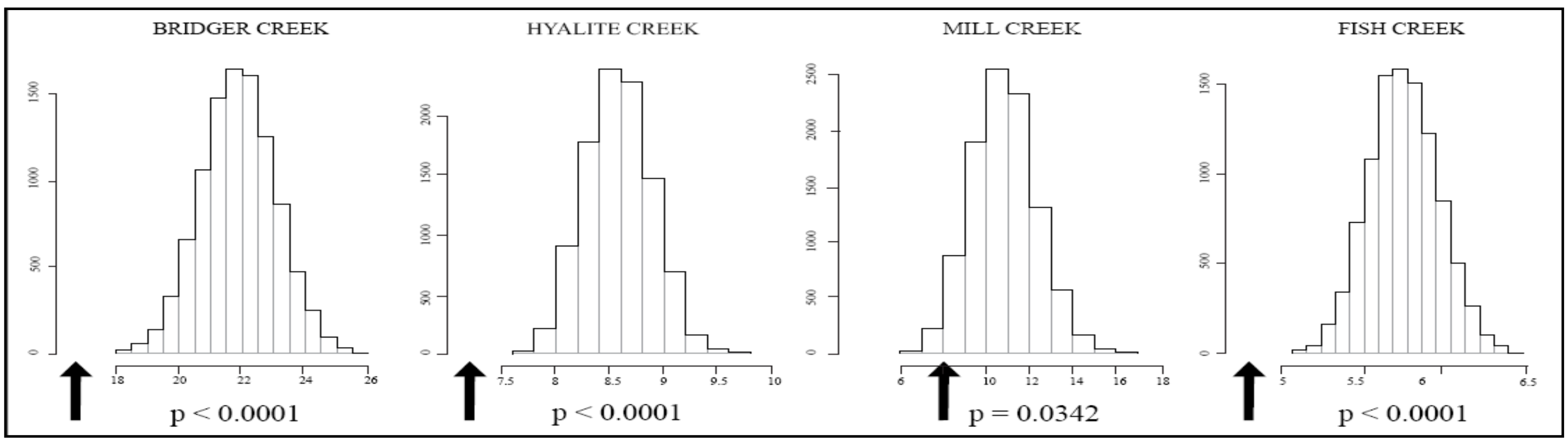

Figure 4. Distributions of mean distance to habitat enhancement structure values for 10,000 sets of randomly drawn (bootstrapped) locations in each study site. For each random data set, n= observed number of fish at each site. Arrows represent observed means distance from fish to HES.

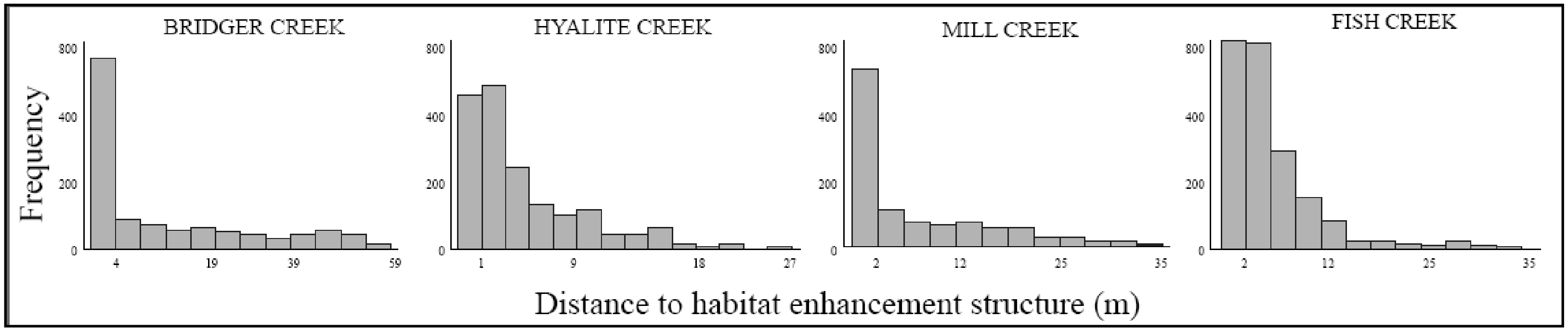

Figure 5. Observed frequency of individual casts as a function of distance to habitat enhancement structure.

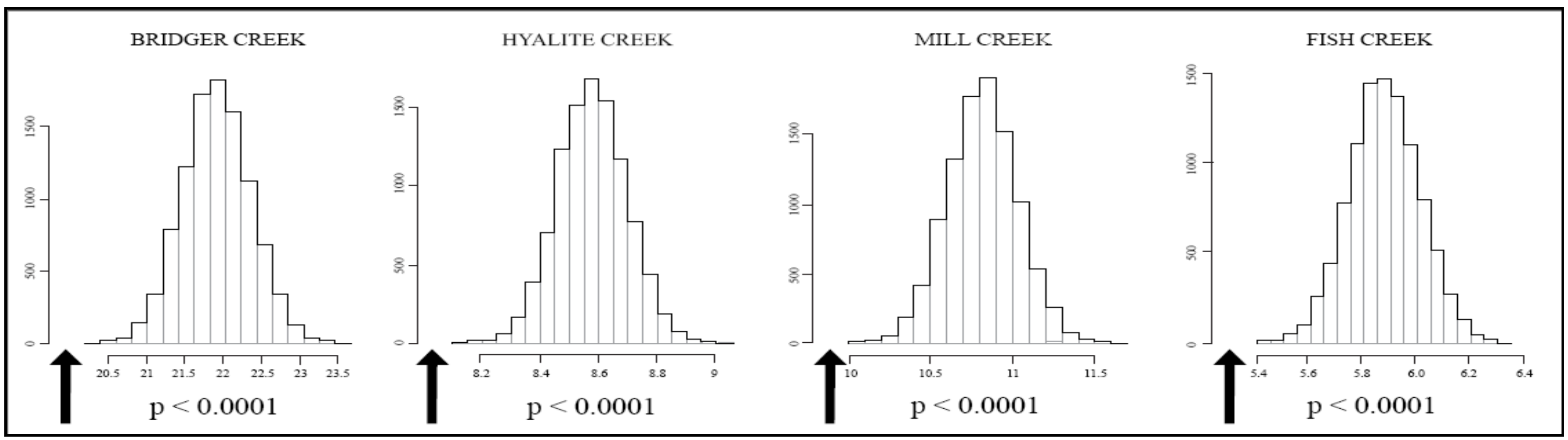

Figure 6. Distributions of mean distance to habitat enhancement structure values for 10,000 sets of randomly drawn (bootstrapped) locations in each study site. For each random data set, n= observed number of casts at each site. Arrows show observed mean distance from casts to HES.

Table 5. Results from Ordinary Least Squares regression of cast density (within reactive distance of a fish) as a function of fish density surrounding the fish. Bolded values are statistically significant at $\alpha = 0.95$.

Results Summary

Factor	Coefficient/Value	
	Hyalite Creek	Fish Creek
Fish Density	**3.9113 (p=0.0037)**	**1.9178 (p<0.0001)**
Intercept	**4.3395 (p=0.0013)**	**6.0773 (p<0.0001)**

Residual Tests

Test	Purpose	Value	
		Hyalite Creek	Fish Creek
Jarque-Bera	Normality	**157.3569 (p<0.0001)**	**272.1435 (p<0.0001)**
Breusch-Pagan	Heteroskedasticity	0.1357 (p=0.7126)	**5.1315 (p=0.0235)**
Moran's I	Spatial Autocorrelation	**0.3989 (p<0.0001)**	**0.3456** (**p<0.0001**)

Table 6. Akaike info criterion (AIC) for regressions

Equation	Form	Hyalite Creek	Fish Creek
E_1	OLS	1715.24	3126.98
E_2	Spatial Lag	1639.04	2977.38
E_3	OLS	1600.38	2941.12

Table 7: Results from Spatial Lag regression of cast density (within reactive distance of a fish) as a function of fish density surrounding the fish. Bolded values are statistically significant at α=0.95.

Results Summary

Factor	Coefficient/Value	
	Hyalite Creek	Fish Creek
Fish Density	**2.1846 (p=0.0448)**	**1.1567 (p=0.0002)**
Lag Variable	**0.6387 (p<0.0001)**	**0.7308 (p<0.0001)**
Intercept	0.5604 (p=0.6204)	0.5035 (p=0.4774)

Residual Tests

Test	Purpose	Value	
		Hyalite Creek	Fish Creek
Breusch-Pagan	Heteroskedasticity	0.0396 (p=0.8423)	**9.1232 (p=0.0025)**
Moran's I	Spatial Autocorrelation	-0.0095(p=0.4633)	0.0097 (p=0.2206)

*GeoDa does not test for nonnormality in Spatial Lag Model residuals (Jarque-Bera)

Table 8: Results from Ordinary Least Squares regression of spatial lag model residuals as a function of distance to habitat enhancement structures. Bolded values are statistically significant at α=0.95.

Results Summary

Factor	Coefficient/Value	
	Hyalite Creek	Fish Creek
Distance to HES	**-0.4628 (p<0.0001)**	**-0.1407 (p=0.005)**
Intercept	**2.8041 (p=0.0005)**	0.5312 (p=0.1379)

Residual Tests

Test	Purpose	Value	
		Hyalite Creek	Fish Creek
Jarque-Bera	Normality	**62.8214 (p<0.0001)**	**131.7133 (p<0.0001)**
Breusch-Pagan	Heteroskedasticity	**27.5077 (p<0.0001)**	**14.3541(p=0.0002)**
Moran's I	Spatial Autocorrelation	-0.0426 (p=0.1160)	0.0070 (p=0.2664)

*HES=Habitat Enhancement Structure

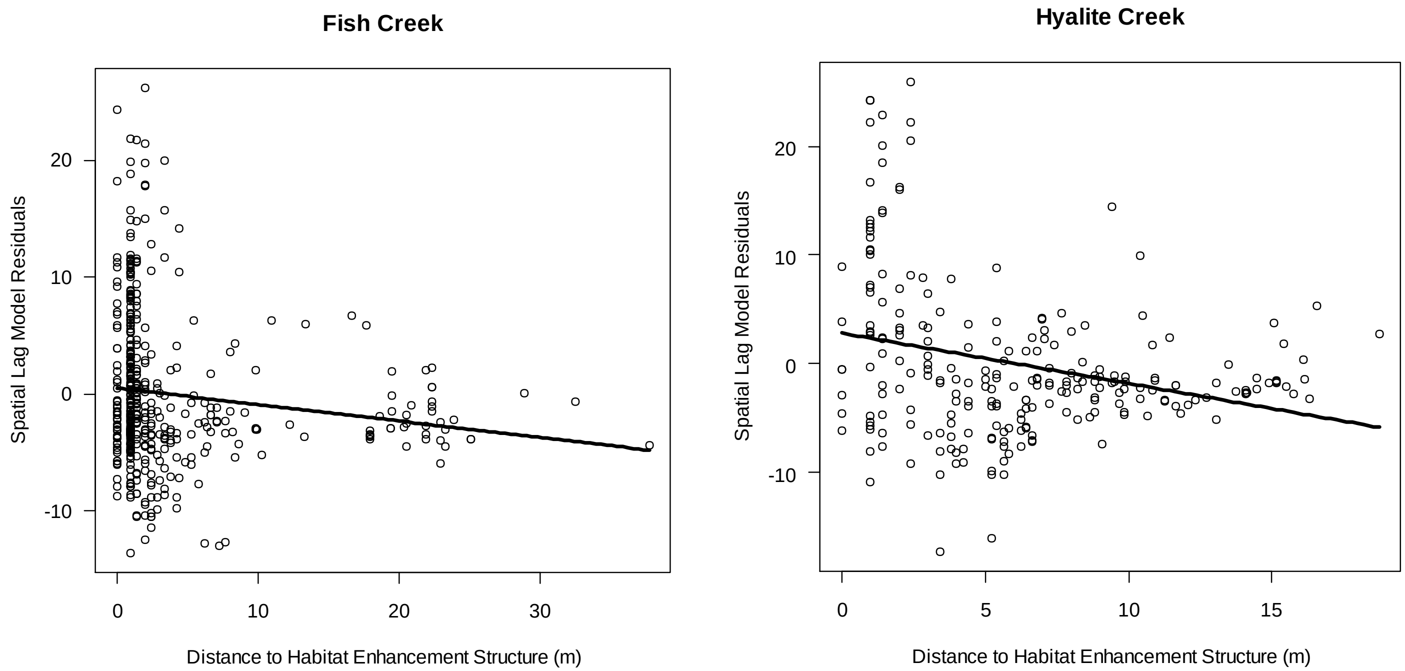

Figure 7: Ordinary least squares model regression of spatial lag model residuals (y) as a function of distance to habitat enhancement structures (x).

CHAPTER FOUR

CONCLUSIONS

Summary

Global stream and river degradation is occurring at unprecedented levels (Gleick 2003). This has resulted in a management trend emphasizing river restoration (Bernhardt 2005), which will continue to play an increasing role in environmental management and policy decisions (Palmer et al. 2004). Therefore, it is important to align project-specific goals with restoration actions. This study emphasizes these points by highlighting a potential consequence associated with one of the nation's most pervasive stream restoration techniques, the installation of habitat enhancement structures.

In conducting this study, I attempted to determine if placement of artificial habitat structures in streams increases the susceptibility of fish to angling. I found that HES aggregated both fish and anglers. In accounting for the higher densities of fish typically associated with HES, I also found that anglers were more successful at targeting fish clustered around artificial structures than those clustered away from artificial structures (e.g., at natural structures).

Assuming that cast density accurately reflects vulnerability to angling, my data suggest that installation of HES may systematically improve the efficacy of anglers, perhaps multiplying any effect of recreational angling on fish populations. Such effects may be especially problematic within the context of degraded stream habitats, where fish assemblages can be more vulnerable than fish in otherwise healthy streams due to the conditions necessitating the enhancement action. Therefore, placement of artificial habitat enhancement structures in streams may increase the susceptibility of fish to angling. This poses critical management concerns regarding fish security, and could provide initial evidence that artificial habitat structures obvious to anglers act as fish population sinks by focusing fishing pressure over likely fish holding areas.

Although I attempted to quantify the response of fish to angling pressure in my study reaches (Appendix B), I was unable to do so in the timeframe of this study with the available resources. Although this study falls short of documenting population-level effects from installation of HES, it provides empirical evidence to support prior appeals to investigate the potential for negative effects by HES on fish populations in riverine systems (Hunt 1988; Binns 2004; Thompson 2006).

Recommendations

Based on the tenets of the precautionary principle (which states that precautionary measures should be taken to avoid harms to human health and the environment, even in the face of scientific uncertainly; Tickner et al. 2000), recommendations can be made for installation of habitat enhancement structures.

1) Match the project goal: Fisheries enhancement/restoration goals tend to fall into one of two broad categories, enhancing fishing opportunities or population-level conservation. Results show that HES are probably useful for providing enhanced fishing opportunities and success, and therefore may be suitable management tools in certain projects. For example, installation of HES might be especially appropriate to attract fish

to handicapped-accessible fishing sites, in conjunction with stocking, or to concentrate anglers in otherwise ecologically sensitive riparian areas.

2) Consider HES context and design: Installation of HES may be consistent with population level conservation *where lack of secure holding habitat has been demonstrated to be a fish population bottleneck.* However, in this context, we recommend that structures be designed to be as inconspicuous to anglers as possible, or inaccessible due to riparian vegetation, etc. Further, “catch-and-release only” regulations in reaches with HES might compensate for increased angling opportunities while avoiding population effects from expected increases in angler success.

Whereas these recommendations may help reduce population effects from increased angler efficacy, they are not intended to address other potential negative effects of concentrating fish near HES such as increased potential for disease transmission, hybridization, intra- and inter-specific competition, or predation (Gaevskaja and Machkevsky 1995; Beamesderfer et al. 1995).

My research helps elucidate relationships among instream structures, fish use, and angler behavior. The unintended consequences of these relationships can then be considered in relation to project-specific goals and objectives in future restoration design efforts. Perhaps more importantly, this research aims to highlight the need for a more holistic framework for assessing the role of habitat enhancement structures in the context of the larger stream network and challenges resource managers to reevaluate the current metrics of restoration project success.

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APPENDICES

APPENDIX A

ANGLER BEHAVIOR

Angler Behavior

This appendix consists of 1) a brief description of the in-field angler surveys, and follow-up questionnaires; 2) a summary of the questionnaire results; 3) the IRB research exemption; 4) the initial angler interview questionnaire; 5) IRB suggested consent form; 6) post-field survey angler questionnaire; and 6) IRB suggested debriefing form.

Quantification of angling patterns consisted of two parts, an in-field component and a questionnaire. Participants for the in-field component were selected through a preliminary interview process designed to incorporate a range of potentially confounding variables (e.g., age, experience level) (see angler subsample below). In-field surveys consisted of recording each cast and associated drift (as reported in Chapter 3). After field data collection, anglers participated in a questionnaire designed to identify potentially confounding variables and clarify inherent assumptions (e.g., all anglers preferentially target obvious habitat). The majority of questions focused on whether anglers were aware of artificial structure placement during the casting portion of the survey, how they felt about artificial instream habitat structures, and how their behavior might change with the knowledge a stream had been enhanced. Another component of the questionnaire was a paper 'casting exercise' to simulate in-field casting patterns. A picture of the site each angler most recently fished was presented, and they were asked to place 5 casts then explain why they chose each location. I assumed this would function to 1) elucidate the variance between in-field behavior and true intent, 2) provide a more accurate record of drift pattern, which is difficult to capture in the field, and 3) force the angler to identify their most preferential casts, and thus, their preferred locations to target.

Finally, a series of stream habitat pictures were presented so that the angler could distinguish between natural and artificial habitat and rate the obviousness of various types of enhancement structures.

Angler Subsample

Anglers were male (n=6) and female (n=2) with ages ranging from 21-66 years old. They all currently reside in Gallatin County, Montana, but spent at least half their life residing in other U.S. regions (East Coast, Midwest, South East, and Intermountain West). Fly fishing experience level ranged from “novice” to “very experienced”, and participants considered themselves “anglers” for 3 to 50 years, and “fly anglers” for 1 to 30 years. Typical fly fishing days per year ranged from 1 to 100+. Based on total reported fishing days, anglers spent most of their time on rivers (47% of the time), followed by (in order), reservoirs (19%), small streams (16%), lakes (16%), and spring creeks (<1%). Anglers did not spend any time (in an average year) fishing in salt water environments. They typically accessed fishing by wading, although they also fished from the shore, by boat, or by float tube. In addition to fly fishing, anglers also practiced spin casting and ice fishing. All anglers tended to practiced catch-and-release fishing.

Summary of Results

The study sites were new to all anglers, so previous knowledge of a site was not a confounding factor. When anglers walked past an area during the in-field casting, this was typically because “fishing did not look good”, but also resulted from “potentially dangerous instream conditions (high-current, slippery substrate, etc.)”, “thick vegetation", and or they simply "didn't feel like it". In-field angler casting patterns paralleled the paper casting exercise.

When anglers were asked if they were aware that artificially constructed habitat structures had been installed in at least one of the four stream reaches, 75% of anglers (n=8) said yes, they were aware. However, they underestimated the amount of structure placed by approximately 50%. This suggests that artificial habitat is obvious and anglers tend to target this habitat, but not necessarily because they are cognizant it is artificial, but because it is simply very obvious. Boulder weirs (boulders placed in a row across the wetted width perpendicular to stream flow) and log drop structures (logs placed perpendicular to flow) were most easily identified by anglers.

If given the knowledge that a stream reach was artificially enhanced, 50% (n=8) responded they were "more" likely to target enhanced habitat, while one angler mentioned she was "less" likely to target this habitat, and three said they were "as" likely to target artificial habitat as they were natural habitat. When asked the follow-up question: *If you determined that you were more likely to target artificial habitat as opposed to natural habitat, why*? Anglers responded: (in order of frequency) "because I believe more fish hold in these locations" (n=3), "because it was available" (n=3), "because it was obvious" (n=2), and/or "because it was easy" (n=1) (anglers were not limited to one answer).

Although only 50% said they were "more" likely to target enhanced habitats, when asked: *If you were to fish these sites again, would you attempt to target artificial habitats?"* 75% of anglers said they would attempt to target enhanced habitats. The reason being: “because I believe more fish hold in these areas” (n=3), “because it is easy” (n=1), “because it is obvious” (n=2), “because it’s there” (n=2) (anglers were not limited to one answer). Only one angler believed that targeting artificial habitat enhancement structures was “less sporting”.

When asked to rate the obviousness of 12 pictures of instream habitats:

- Logs placed parallel to flows were rated as “completely artificial” when exposed cut ends were visible.
- Logs placed parallel to flows were rated “somewhat artificial” when cut ends were not exposed, or when they were rough.
- Designed log jams were rated “somewhat artificial” or “natural”.
- Boulder weirs that had accumulated organic debris were rated “somewhat artificial” or “natural”.
- Boulder weirs without organic debris ranged from “completely artificial” to “natural”.
- Boulder clusters ranged from “completely artificial” to “natural”.

Institutional Review Board Waiver

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
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MEMORANDUM

TO: Eva Black and GeoffreyPoole

FROM: Mark Quinn, Ph.D. Chair *Mark Quinn CJ*
Institutional Review Board for the Protection of Human Subjects

DATE: August 19, 2009

SUBJECT: *Assessing Fish and Angler Utilization of Artificial In-stream Habitat Enhancement Structures [EB081909-EX]*

The above research, described in your submission of August 13, 2009, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal Regulations, Part 46, section 101. The specific paragraph which applies to your research is:

___ (b)(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b)(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

___ (b)(3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

___ (b)(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

___ (b)(5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

___ (b)(6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

Participant Recruitment Questionnaire

Thank you for your interest in helping with this very important study. It is our aim to obtain a diverse range of experience levels so that this study adequately describes the general fishing patterns of fly anglers. In order to do this, it is necessary for potential research participants to fill out the following questionnaire. There is no right or wrong answers; we are simply interested in your experience and ability levels relative to certain types of fishing.

(1) What is your age? ______________

(2) What is your sex? ______________

(3) What city do you live in? ___________________________

(4) How many years have you considered yourself an angler (any type of fishing)?
(a) 0-1
(b) 2-3
(c) 3-5
(d) 5-10
(e) 10+

(5) How many years have you considered yourself a FLY angler?
(a) 0-1
(b) 2-3
(c) 3-5
(d) 5-10
(e) 10+

(6) How many days do you FLY fish in a typical year? ______________________

(7) How would you rate your FLY angling level of experience?
(a) novice
(b) somewhat of a novice
(c) somewhere in the middle
(d) somewhat experienced
(e) very experienced

(8) In terms of rating your fly fishing ability level, how often does your fly land where you intend it to?
(a) never
(b) ¼ of the time
(c) ½ of the time
(d) ¾ of the time
(e) always

(9) What environments do you typically fish, and how many days per year (on average) do you frequent each?
Small streams
☐____
Spring Creeks
☐____
Rivers
☐____
Reservoirs
☐____
Lakes
☐____
Salt water
☐____
Other
☐____

(10) What is your typical method for accessing fishing opportunities, and how many days per year (on average) do you frequent each?
Wading
☐ ____
Shore
☐____
Float tube
☐____
Boat
☐____
Other
☐____

(11) What other types of fishing do you practice, and how many days per year (on average)do you use each technique?
Spin casting
☐____
Hook and line setting
☐____
Other
☐____

(12) Do you practice catch-and release fishing techniques?
____
____

(13) Are you comfortable with spending approximately 6 hours a day walking in waders up cobble and boulder dominated streams?_________________________________
____

Thank you very much for your time and interest in participating with this study. Once we receive your responses, we can determine if your participation is beneficial, and then we will schedule a convenient time for you to fish the four study sites. Thanks again.

Subject Consent Form

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH AT MONTANA STATE UNIVERSITY

Assessing the Efficacy of Fisheries Management Actions Across a Variety of Stream Characteristics in Southwest Montana

You are being asked to participate in a study testing the efficacy of fisheries management actions in Southwest Montana. We believe that this may help to quantify relationships potentially existing between angler use patterns and a variety of physical and biological stream characteristics, thus informing a range of future fisheries management strategies. Because of your interest in recreational angling and your experience level, you have been identified as an appropriate participant in this study.

If you agree to participate, we ask that you are available for two days within a 14 day period during July-August, 2010. Accompanied by a field technician, you will be brought to four locations in the greater Bozeman/Livingston area, and asked to fish in your typical style. The only restraints given will be the requirement to use only dry flies, and to fish two streams each of the two days. During this time, the field technician will record your general angling use patterns, including stream access points and cast placement. In order to respect individual's confidentiality, all participants will be given a code so that field data collection and the follow-up questionnaire can be correlated, but no paper record of identifying information linking responses to individuals will exist. This experiment has been designed to take two days, which includes field data collection and time to complete a brief questionnaire. If the experiment cannot continue on the scheduled day, because of weather or any other unforeseen obstructions, you will be asked to return so that all of the necessary data can be collected.

While your participation in this experiment is extremely useful and very much appreciated, it is voluntary and you may discontinue your participation at any point without being penalized in anyway.

It is important to note that this study is of no direct benefit to you and you will receive no compensation for your time, however there is little to no risk inherent in the research design. Funding for this study has been provided by Montana State University's Land Resources and Environmental Sciences Department.

Any questions or concerns you may have about the study are welcome and can be answered by Jordanna Black, Principle Investigator, at (406) 994-4473, or Eva.Black@MSU.Montana.edu. Additional questions about the rights of human subjects can be answered by the Chairman of the Institutional Review Board, Mark Quinn, at (406) 994-4707.

Authorization: I have read the above and understand the potential inconvenience and risk (or lack thereof) of this study. I, ____, agree to participate in this research. I understand that I may later refuse to participate and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: ________________________________Date: ___________________________

In-field Angler Questionnaire

Name:
Current Site:
Order of sites visited:
Date:
Time:
Weather:

In-field Angler Questionnaire

(1) How often did your fly land where you intended it to?
 (a) never
 (b) ¼ of the time
 (c) ½ the time
 (d) ¾ of the time
 (e) always

(2) Have you fished any of these streams before? If so, which ones?

____

____

____

(3) What clues you into fish locations/where you decide to present your fly? What elements make fish locations most easy to identify?

____

____

____

____

____

____

____

____

____

____

(4) Below you will find an aerial photograph of a portion of the stream you just fished. On this image, please fish this site again, limiting yourself to only 5 casts. Please indicate (with an "x") the locations you would target.

[Picture of last site visited; varies per angler]

(5) Does this directly relate to where you think fish are located? If not, please indicate (with an "o") the locations you believe fish to be. (is this important to differentiate? where fish are/where you would fish)

For the following questions please consider ALL FOUR fishing sites, not simply those fished today:

(6) Was the artificially constructed habitat in these stream reaches obvious to you?

____

____

____

____

(7) If so, can you recall what material(s) it/they were comprised of?

____

____

____

____

____

(8) If you believed there to be artificially constructed habitats, can you please show me an example of this at THIS stream.

(9) All four of the streams that you visited have had some amount of artificially constructed habitat. At times it can be hard to tell, given the construction materials and design. Now, could you please rate how artificial the following habitats look, using a 10-point scale. For each of the following 12 pictures, please rate the "level of artificiality", with 1=looking completely natural, and 10=looking completely artificial. These do not need to be sequentially ordered, and you may assign the same value for as many pictures as you would like.

(10) Do you preferentially cast to artificial habitat because its obvious?

(11) Do you find that casting to artificial habitat to be less ‘sporting’?

(12) Does the knowledge that a stream has been “restored or enhanced” with artificial means make you more likely or unlikely to fish an area? Why?

Thank you for sharing your feedback. Once you have completed this survey, you will be given the disclosure/debriefing form and allowed to ask any questions.

Subject Debriefing Form

Debriefing: Identification of Fish Holding Habitat in Artificially Enhanced Streams

Additional collected data:

You were made aware that in the field we collected data on the number of rises you received, the specific locations you casted to, and your drift pattern. We did this in attempt to quantify a relationship that potentially exists between (1) the spatial distribution of fish holding locations, and (2) stream reaches that have been restored/enhanced to augment fish habitat. Details pertaining to the study were withheld with the aim of not altering your typical angling pattern, thus reducing the chance of introducing bias into the data set.

Why is this research important to scientists or the general public?

Nationally, we spend over a billion dollars a year on stream restoration and enhancement work. One of the most frequently implemented techniques involves the installation of artificial habitat enhancement structures placed with the intent of increasing the quality and quantity of fish habitat. Despite the frequency of these projects and the amount of money we spend on them, less than 10% of projects are monitored. Because of this, it is imperative we have a better understanding of the effectiveness of these structures. Clarifying the relationship between angler utilization of artificial instream habitat structures and the potential consequences for fish assemblages will help natural resource managers determine if artificial habitat enhancement structures are really an effective strategy.

What are we trying to learn in this research?

The purpose of this study is to examine the long term effectiveness of artificial instream habitat enhancement structures. Specifically, there may be unacknowledged relationships between anglers, fish assemblages, and artificial in-stream structures. For example, when natural resource managers install artificial enhancement structures, they may be creating environments were anglers can be more efficient predators. In certain circumstances this may be appropriate, while in others this is not the intended goal.

What are our hypotheses and predictions?

We believe that when streams are ‘restored’ with the widespread technique of installing artificial structure to enhance habitat, anglers can more readily read the water in these reaches. Thus, restored stream reaches have fish holding habitats that are more obvious to anglers. We think the data we are collecting will show fish holding locations in restored reaches are more obvious than fish holding locations in unaltered reaches for all anglers regardless of experience level. However, we believe that the obviousness of fish holding locations in artificial reaches will be more pronounced to novice anglers who may not be as effective at identification of the more subtle fish holding locations that tend to occur in unaltered stream reaches.

What if I have questions later?

Thank you for your participation and if you have questions at anytime please feel free to contact Jordanna Black at 994-4473 or Eva.Black@MSU.Montana.edu

APPENDIX B

ELECTROFISHING AND PIT TAGGING SURVEYS

Electrofishing and Pit Tagging Surveys

This appendix consists of 1) a summary of the electrofishing surveys; 2) results; 3) electrofishing-specific literature referenced; and 4) protocol submitted to IACUC in partial fulfillment of an electrofishing permit.

Angler casting surveys were designed to describe a mechanism that might suggest increased susceptibility of fish with proximity to habitat enhancement structures. A corresponding survey in the same research sites, using electrofishing to uniquely identify fish with PIT tags, was designed to quantify the actual response of fish assemblages to angling pressure.

Electrofishing Surveys

During July 2010 (Hyalite Creek: 7/13/2010, Mill Creek: 7/20/2010), two of the four research sites were electrofished so that PIT tags could be inserted into fish. "Crawdad style" (i.e., dragable) boats carrying a generator and recovery wells moved in a downstream direction emitting an electrical charge. This temporarily shocked fish long enough so that they could be netted and placed in a recovery well. Instead of emitting a constant charge, the crawdad operator targeted zones. These were delineated to be 10-25 meters in length containing only natural habitat OR artificial enhancement structure, with at least 15 meters of "buffer" between zones. Technicians placed block nets at the upstream and downstream reach boundaries, and conducted a triple pass electrofishing survey. Given the width and volume of the stream, depletion was not realized at either site. Technicians used clove oil to sedate salmonids greater than 5", injected them with

12 mm glass implant PIT tags, and allowed them to recover before releasing them back into the stream after completion of the third electrofishing pass. Hyalite Creek's observed fish assemblage consisted primarily of rainbow trout, with some brook trout, brown trout, and sculpin. Mill Creek's observed fish assemblage consisted only of Yellowstone cutthroat trout.

During angling casting surveys, a PIT tag reader checked each caught fish for a PIT tag. Once casting surveys were completed, a second round of electrofishing attempted to quantify the existence of and spatial distribution of tagged fish (Hyalite Creek: 10/24/2010, Mill Creek: 10/1/2010). The same crawdad unit setup conducted the recapture component of the survey on Hyalite Creek, while low flows in Mill Creek dictated the use of two backpack shockers.

Unfortunately, no discernable patterns emerged from data analysis. This can be attributed to multiple factors; (1) Mill Creek's fish population was too low (snorkel surveys observed 25 fish over a 275m reach); 2) Targeting 'zones' instead of continuous shocking, could have easily scared fish, drove fish from holding locations, and allowed them to take refuge in the "buffer" areas OR netted and identified to zones not representative of their original holding locations; 3) Furthermore, continuous shocking would have resulted in a greater number of tagged fish; 4) Available resources which included a volunteer field crew, USFS personnel, and electroshocking gear, limited potential field days to 1 day per survey (mark or recapture), and thus, resulted in too few fish being tagged; 5) Spawning and movement of rainbow trout (and to a lesser degree brown trout) could have contributed to a low recapture rate.

Electrofishing Survey Results

Results of summer 2010 electrofishing

Site	Total Fish Marked	Recaptured via electrofishing	Recaptured via hook and line during casting surveys
Hyalite Creek	82	5	7
Mill Creek	15	2	0

Electrofishing Literature Referenced

Montana Fish Wildlife and Parks. Electrofishing Safety Policy and Guidelines. Montana Fish Wildlife and Parks. Helena.

Peterson, J.T., Thurow, R.F., Guzevich, J.W. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society. 133(2): 462-475

Snyder, D.E. 2003. Electrofishing and its harmful effects on fish, Information and Technology Report USGS/BRD/ITR--2003-0002: U.S. Government Printing Office, Denver, CO, 149 p.

Snyder, D.E.. 2004. “Invited overview: conclusions from a review of electrofishing and its harmful effects on fish.” *Reviews in Fish Biology and Fisheries* 13: 445–453.

Institutional Animal Care and Use Committee (IACUC) Permit:

Project Information

1. Project Title: Investigating relationships between angler and fish use of artificially enhanced stream reaches [Investigating relat]

2. Project Type: new [new]

a) If a renewal or revision, please provide previous protocol number: [ ]

3. Principal Investigator/Faculty Advisor:

Principal Investigator Assurance and Statement of Accuracy

- I certify that the information provided in this application is complete and accurate and consistent with any proposal(s) submitted to external funding agencies.
- I accept full responsibility for abiding by all applicable federal, state, local and Montana State University animal care and use policies.
- I will provide proper surveillance of this project to ensure that the health and welfare of animal subjects are protected. As such, I will report any problems to the appropriate review committee(s).
- I agree that modifications to the originally approved project will not take place until reviewed and approved by the animal care and use committee.
- I will ensure that all personnel listed on this application have been trained in proper and humane procedures of animal handling and, where applicable, appropriate procedures for the administration of anesthetics, analgesics or euthanatizing agents.
- I certify that I have reviewed the pertinent scientific literature and have found no valid alternative to any procedures described herein, especially those which may cause more than momentary pain or distress, whether it is relieved or not. Animal usage in this protocol does not unnecessarily duplicate previous experiments.
- Note: I am aware that electronic submission of this form constitutes my signature.

[x] [1] I Agree

a) Name:

First:

Geoffrey [Geoffrey]

Last:

Poole [Poole]

b) Department:

Land Resources and Environmental Sciences [Land Resources]

c) Title:

Assistant Professor Assistant Profes

b) Phone #:

(406) 994-5564 (406) 994-5564

e) Email address:

gpoole@montana.edu gpoole@montana

4. Indicate funding information - check any that apply:

a) Extramural grant application (NIH, USDA, etc.)

[ ]

i. Provide funding agency name:

ii. Assigned grant number (if available):

iii. Submission date:[mm/dd/yyyy]

11 11 /30 30 /

iv. In whose name is the grant submitted:

b) Intramural funding application (Dept/College):

[x] 1

c) Commercial/Industry funding (Private Sector):

[ ]

i. Provide complete company name:

d) Other :

Personnel

Name:

Eva Jordanna Black Eva Jordanna Bla

Title:

Graduate Research Assistant Graduate Resear

Email address:

eva.black@msu.montana.edu eva.black@msu.r

Training or Experience:

In-field electro-fishing, PIT tagging, and snorkeling field experience:

-United States Forest Service; Sawtooth National Forest (summer 2005)
-Oregon Department of Fish and Wildlife; Corvallis Research Station (summer 2006)
-Idaho Department of Fish and Game; Salmon District (summer 2007)
- Utah Department of Natural Resources; Washington County Field Office (spring 2007)
Formal training:
-MT Fish Wildlife and Parks 2-day electro-fishing safety course (June 2-3, 2010)
-ODFW 1-day snorkel training course (summer 2006) In-field electro-fis

General

1. Provide an abstract that summarizes the overall scientific goals and specific objectives of the proposed work.(Use language that community members or those not in your field of scientific discipline can understand. Define all abbreviations.)

The placement of in-stream habitat structures for fisheries enhancement is a commonly implemented stream restoration technique, one which Americans spend approximately one billion dollars on annually. Managers typically evaluate the success of these projects by assessing either associated changes in habitat structure (e.g., pool formation) or using point-in-time observations of fish use (e.g., holding patterns) as a surrogate for biological response. Because of the visually obvious nature of artificial in-stream habitat structures, I hypothesize that anglers can easily identify fish holding locations, resulting in greater fish vulnerability. To test my hypothesis, I will survey enhanced and natural (i.e. unaltered) stream reaches in southwest Montana to assess spatial patterns of: 1) habitat structure; 2) fish holding locations; and 3) angling patterns. Infield data collection includes documenting the mechanism of increased angler identification of artificial in-stream habitat by observing casting patterns of anglers and relating these patterns to fish distributions which will be quantified by non-invasive repeat snorkel surveys. Field methods also include documenting responses in the fish community to this hypothesized mechanism with a mark-recapture fish survey utilizing PIT tags and electro-fishing techniques. An increase in spatial correlation among habitat structures, fish holding locations, and angling patterns in enhanced stream reaches will provide initial evidence that artificial habitat structures obvious to anglers might act as fish population sinks due to concentrated fishing pressure. A response in the local fish community will corroborate this. Results from this research will elucidate relationships between habitat structure, fish use, and angler behavior, directly informing future design of one of the Northwest's most pervasive stream enhancement techniques. Perhaps most importantly, this research aims to highlight a more holistic framework for assessing the role of fisheries enhancement structures in the context of the larger stream network and challenge resource managers to reevaluate the current metrics of restoration project success. The placement of

2. Describe in non-scientific language (high-school level of understanding) how the proposed animal project will benefit human or animal health, the advancement of knowledge, or

the good of society.

This work calls into question some of our most pervasive in-stream fisheries enhancement techniques. Results have the potential to identify more effective fisheries enhancement and restoration techniques, thus allowing for limited human and financial resources to be more appropriately distributed for the overall health of stream systems and for sustaining fish populations. [This w ork calls ir]

3. As primary investigator, I have determined, by means of the following sources, searches, or methods, that alternatives to procedures which may cause pain or distress are not available, and that this protocol does not unnecessarily duplicate previous experiments. USDA regulations require documentation (to be maintained by the PI) of the following sources searched.

a) Databases searched:

American Fisheries Society, Google scholar, Web of Science [American Fisheri]

b) Specify all key words that were used in the search (e.g. MESH headings):

Habitat, restoration, enhancement, fish, fisheries, stream, artificial, structures, predation, human, angler, electro-fishing, electro-shock, snorkeling, anesthesia, MS-222, clove oil, cortisol response, fish stress, safe fish handling, PIT tag injection, syringe [Habitat, restoratic]

c) What years were covered by the search?

1937-2010 [1937-2010]

d) Provide the most recent date on which the search was performed. (must be within six months):[mm/dd/yyyy]

01 [01] /10 [10] /2010 [2010]

e) Did your search find any alternatives to your proposed animal related procedures that would allow...

i. Reduction?

( ) yes (x) [0] no

Explain:

We intend to conduct mark-recapture electro-fishing surveys in order to quantify the change in abundance and spatial distribution of individual fish in manipulated/enhanced stream reaches. In order to see meaningful patterns, we must delineate study sites so that a range of distances between artificial habitat enhancement structures is realized. Thus, stream sites must be long enough to effectively capture this range of distances. This has been determined to be 250-500 meters, and will vary depending on the stream reach. [We intend to con]

ii. Replacement?

( ) yes (x) [0] no

Explain:

See 3e i. above See 3e i. above
iii. Refinement?
( ) yes (x) 0 no
Explain:
No, because this is a behavioral study. No, because this

4. Why must animals be used in this study? (Check the appropriate boxes)
[x] 1 a) No in vitro options are available.
[x] 1 b) Systemic interactions are needed.
[x] 1 c) Studies cannot or should not be undertaken in humans
[x] 1 d) studies involve analysis of behaviors or biologic processes
[ ] e) Other:
*If you selected "Other", Explain:

5. Will any portion of the live work performed under this protocol be conducted at facilities or institutions outside Montana State University?
( ) yes (x) 0 no
i. What procedures will be done?
ii. What species will be involved?
iii. At what institution will this activity take place?
iv. Provide the Office of Laboratory Animal Welfare (OLAW) Assurance Number of the institution.
v. Provide the IACUC approval number (a copy of the approval letter must be submitted to the IACUC office):

6. Will any live animals be housed outside the Animal Resources Center for continuous periods of longer than 12 hours?

( ) yes (x) 0 no
i. Building:
ii. Room number:
iii. Provide justification:

Field Studies (including Fish and Amphibians)

1. Species to be studied:
The study is not species-specific, rather it intends to observe the behavior of local salmonid assemblages as they interact with artificial in-stream enhancement structures.

This potentially includes Westslope Cutthroat Trout, Yellowstone Cutthroat Trout, Rainbow Trout, Brook Trout, Brown Trout, and Mountain White Fish.

Other observed/effected species may include Mottled Sculpin, Long Nose Dace, Long Nose Sucker, Mountain Sucker, and White Sucker. The study is not s

2. General Procedures - Describe, in chronological order, all procedures that will include the use of animals:

This study includes (1) snorkel surveys, (2) angler use surveys, and (3) electro-fishing mark-recapture surveys to be preformed at four different stream reaches in SW Montana.

At all four stream reaches, non-invasive snorkel surveys will be conducted. As soon the threat of fish movement associated with spawning passes and sites approach base flow conditions, surveys will commence. First, block nets will be installed at the upper and lower boundaries of the reach to prevent fish movement out of the study sites (Peterson et al., 2005). Then, a team of 1-4 snorkelers will progress upstream slowly, in accordance with underwater survey protocols developed by Thurow (1994) specific to the Rocky Mountain region. Upon spotting a “catchable” salmonids (> 150 mm Total Length (TL)), a snorkeler will drop a brightly colored, weighted marker at the location of each fish. This location will be benchmarked with a mapping-grade GPS unit. Fish will be described according to size and species. Snorkel surveys will be repeated at each site two times, as soon as sites approach base flow conditions, and again at the end of the field season after the angler casting surveys have been completed.

At each of the four sites 8-10 anglers will fish with barbless hooks using catch and release techniques while a field technician records the spatial distribution of an angler's cast and drift patterns.

At two of the four sites, electro-fishing surveys will be conducted as part of a mark-recapture study to try and ascertain the spatial and temporal response of fish assemblages over a single field season to concentrated angling effort hypothesized to be associated with artificial habitat structures.

In order to initially capture and tag fish, a single-pass electro-fishing survey will be conducted after the threat movement related to spawning passes and conditions are at or near base flow. First, block nets will be installed at the upper and lower boundaries of the reach to prevent fish movement from the site (Peterson et al., 2005). Starting at the bottom of the reach, one crew leader operating the backpack shocker and 2-4 assistants with dip nets will progress upstream in accordance with standardized electro-fishing protocols. Electro-shocking surveys will be conducted in a downstream to upstream orientation with a Smith-Root backpack electro-fishing unit that discharges direct pulsed current. Fish that are on the periphery of a weak electrical current experience mild nerve excitation but still retain control of swimming ability and will escape from the field. Those under a strong electrical field experience a progressive series of reactions that culminate in immobilization. During this immobilization, crew members will use a dip net to catch each fish.

Upon capturing a 'tag-able' salmonid > 150mm TL, personnel will use clove oil at a concentration of 30mg/L to anesthetize and then tag each fish with a 12mm full-duplex passive integrated transponder (PIT) tag inserted with a syringe into the abdominal cavity (Prentice et al. 1990b). During recovery, personnel will record the spatial location of each fish with a mapping-grade GPS unit and record pertinent biological data (e.g., species, length). Once data has been collected, fish will be placed in a recovery tank and then moved to a secured in-stream live well positioned in slow moving water, outside of the electrical field for the remainder of the study. Electro-shocked fish that are not to be tagged will be placed into recovery tanks and upon signs of recuperation will be transferred into live wells. No anesthesia will be administered as they will not be handled nor will any data be collected from these fish.

Crews will continue to move upstream shocking, capturing, tagging, and placing fish first into a recovery tank followed by a live well for the remainder of the survey. The least amount of voltage and lowest frequency pulse that effectively immobilizes fish will be used in order to decrease stress and chance of injury to fish. At the end of the day's surveying, detained fish will be released at/near the site of initial capture.

In mid-August to early September, the recapture component of the survey will be conducted as a triple-pass depletion electro-fishing survey with the aim of recapturing all of the fish previously tagged. First, block nets will be installed at the upper and lower boundaries of the reach to prevent fish movement from the site (Peterson et al., 2005). Starting at the bottom of the reach, one crew leader operating the backpack shocker and 2-3 assistants with dip nets will progress upstream in accordance with standardized triple-pass electro-fishing protocols (Peterson et al., 2004). A Smith-Root backpack electro-shocking unit will be used with appropriate settings given the water temperature and physical habitat features. Upon capture, personnel will use a hand-held PIT tag identification reader to determine whether a fish had been previously tagged, and then record the spatial location of each fish using a GPS unit. Fish will be placed into in-stream live wells positioned downstream, outside of the electrical field for the remainder of the study. Fish will be released at/near the site of initial capture at the conclusion of the triple-pass survey. The data generated will be used to quantify the change in individual fish, localized fish assemblages proximal to enhancement structure, and fish assemblages in each enhanced reach. This study includ

3. Location - Describe the anticipated off campus location(s) where the field study will be performed:

-East Fork of Mill Creek, tributary of the Yellowstone River on USFS property

-Hyalite Creek, below Hyalite Reservoir and adjacent to Langhor Campground on USFS property

4. Permits - If permit(s) are required for the proposed studies, list or describe the appropriate permit(s), the date(s) they were obtained, and their expiration date(s):

(1) Fish Wildlife and Parks requires a Scientific Collectors Permit that was applied for on 4/1/2010 and will expire after one year. This permit requires a two-day electro-fishing safety course, agreement to follow accepted survey protocol, and a follow-up report detailing any take resulting from the surveys.

(2) The USFS Bozeman and Livingston Ranger Districts on the Gallatin National Forest require a Temporary Special Use Permit. The Bozeman District granted the permit on 8/20/09 and expires on 9/30/10. The Livingston permit still pends approval.

(3) The Montana State University's Institutional Review Board requires clearance for those conducting research entailing experiments with human participation. Given the human behavior component to this study, the proposal was presented to the IRB in July, 2009 and this study was granted an exemption on 8/19/09. This does not expire.

(1) Fish Wildlife a

5. Are any of the animals under study considered endangered or threatened?

( ) Yes (x) 0 No

a. List applicable permits and measures that will be taken to avoid mortalities or deleterious effects.

Although no fish are considered federally threatened or endangered, both the Westslope Cutthroat Trout and the Yellowstone Cutthroat Trout are considered Montana "Species of Concern" by MT Fish Wildlife and Parks.

In-stream electro-fishing surveys will only be conducted in appropriate water temperatures and outside of spawning season windows to avoid any deleterious effects. Appropriate conditions will be confirmed by the requirement (as stipulated by FWP's Scientific Collector's Permit) to contact the FWP regional fish manager 7-10 days prior to electro-fishing. This is to ensure that conditions are suitable for collection (e.g., appropriate water temperatures). Spot checks of gear and environmental conditions may be further be required by the regional fisheries manager.

By following this protocol, the chance of stressing fish (even to the point of mortality) will be reduced. Given the intent of this study, there can be no way to effectively sample while reducing the chance of mortality to 0%. Although no fish

6. Animal Numbers - Procedure Categories (should be listed for the 3-year duration of the protocol).

a) Total number of animals:

1264 1264

b) Category C: minimal, transient, or no pain/distress

N/A N/A

c) Category D: with anesthesia/analgesia

500 500

d) Category E: with pain (non-relieved)

1264 1264

7. Justification of animal numbers - briefly explain the rationale, prior experience, statistical analysis, or other methods used to determine the anticipated total number of animals (listed in question #6) that will be encountered or involved during the 3-year approval period for this protocol. (The IACUC recognizes that it is not always possible to accurately predict at the initiation of field studies the number of animals to be encountered. The minimum number of animals necessary for accomplishing the goals of the study should be used.)

In order to see meaningful patterns in the relationship between anglers, fish, and the spatial distribution of artificial habitat enhancement structures, study sites have been delineated at lengths varying between 200-400m. This reach length allows for sites to envelop a range of distances between artificial structures, which is imperative to the study. Fish population data is therefore based on average reach lengths (305m) for this study.

Fish assemblages in these 200-400m reaches will be subjected to (1) non-relieved pain associated with angling, (2) non-relieved pain associated with electrofishing, and (3) pain relieved with anesthesia as a result of electrofishing and then PIT tagging fish.

Total number of fish: From the best available data, the cumulative fish population in the four reaches is estimated at 1264 (FWP and USFS for years spanning 1993-1998; MFISH Database). [East Fork Mill Creek: 57 fish; Hyalite Creek: 1066 fish; Bridger Creek: 54 fish; Fish Creek: 87 fish].

[Category D] Mark- recapture surveys will consist of administering a clove oil anesthetic and insertion of PIT tags affecting up to 500 adult salmonids > 150mm TL.

We expect to tag approximately 50% of the adult salmonids in these reaches (Reid 2008; Gresswell et al., 2005) which results in a maximum of 500 fish across the two reaches where mark-recapture surveys are to be conducted[Mill and Hyalite Creeks].

Because of the threat of harvest associated with intense fishing pressure, potential for spawning related migration, fish movement out of reaches, and mortality, we believe that tagging and monitoring approximately 50% of the fish assemblages in the two reaches is necessary to generate a representative sample of adult salmonids at recapture. It is assumed that tagging a larger percentage of the population would not necessarily result in a more robust dataset. Likewise, we believe that tagging fewer fish would run the risk of not having enough data to demonstrate patterns or statistical validity.

[Category E] Of the 1264 fish in the four study reaches, potentially all of them are expected to experience non-relieved pain associated with electro-shocking. Of these fish, approximately 500 will be anesthesized for the tag insertion procedure, while the remaining 764 will not be anesthesized post-electro-fishing as no biological data will be collected from these fish and they will not be handled (other than a transfer between the recovery tank and live well).

[Category E] Non-relieved pain and/or stress will occur also occur associated with angling surveys. Based on the best available catch-per-unit effort data, approximately 412 of the total 1264 fish in the four study reaches (salmonids and non-salmonids) could potentially be caught during this study (FWP from 1996-2008; MFISH Database). This figure is based on eight anglers fishing each site for three hours. [Catch-per-unit effort varies based on site conditions: 3.3 Mill Creek; 4.47 Hyalite Creek; 7.8 Bridger Creek; 1.6 Fish Creek (MFISH Database).]

Since the angling, marking surveys(electro-fishing and PIT tagging), and recapture surveys(electro-fishing) occur at different times throughout the course of the summer, an individual fish may experience category D and E over the course of the surveys. For example, it is feasible for an individual fish to be shocked twice, tagged once, and caught as a result of angling up to eight times (unless the same angler catches the same fish multiple times within a three hour period on a given day). In order to see m

8. Will animals be captured or restrained as part of this study?

(x) 1 Yes ( ) No

a) Briefly describe the technique(s) of wild animal capture and the method(s) and duration of animal restraint.

At two of the four sites, a single pass electro-fishing survey will be used to capture fish. During these surveys, fish will temporarily be paralyzed by the electric charge in the water. At this moment, the fish will be scooped out of the water by an assistant with a dip net, and the electric charge will cease. Upon capture, fish that will not be tagged will be placed into a recovery tank and then transferred into a live well. Fish to be tagged will be anesthetized, have a PIT tag inserted, and field personnel will then collect biological data for each fish, which should take approximately five minutes. Fish will then be placed into a recovery tank in order to recuperate from the effects of the anesthetic, typically taking approximately five minutes (Prince and Powell 2000) and then placed into an in-stream live well. This live well will be positioned downstream, outside of the electrical field. Fish will remain detained here for the remainder of the study in order to prevent upstream fish movement which could potentially subject fish to additional electricity. The duration of restraint will be approximately 8 hours (not to exceed 12 hours).

The recapture (triple-pass electro-fishing) survey conducted at two of the four sites will capture fish in the same manner described above. Since no anesthetic will be used in the triple-pass survey, fish will be placed directly into the live well and will remain here for the duration of fish restraint is also estimated at 8 hours (not to exceed 12 hours).

At two of the fou

b) If drug-induced immobilization will be used, indicate the drug name(s), dose(s) and route(s) of administration.

Before inserting tags, fish will be submerged into a solution of clove oil (eugenol) so that anesthetic may be absorbed through their gills. Fish will remain in the anesthetic bath until a level four anesthesia is achieved. This is categorized by very weak opercular movement, total loss of swimming motion, and a total loss of equilibrium (Yoshikawa et al. 1988). Previous studies suggest that a typical induction time for an adult salmonid is approximately 3.5 minutes, but a wide range of induction times may occur (Prince and Powell 2000, Keene et al. 1988). Because of the potential range in induction times, (0.9-17.6 minutes is described by Prince and Powell in their 2000 study), close monitoring of fish while in the anesthetic bath is imperative.

The recommended dosage of clove oil is 30mg/L. However, it is suggested that concentrations may vary slightly given specific stream conditions. Because of this, the precise ratio of clove oil to stream water will be determined in the field.

Clove oil will be used instead of other, common anesthetics such as tricaine methanesulfonate (MS-222) or carbon dioxide at the request of the land owner, the United States Forest Service. Their justification includes concern about human consumption of fish given the intensity of recreational angling in the vicinity of the study sites. Before inserting t

c) If substances controlled by the Drug Enforcement Administration will be used in this protocol, please list the controlled substances and who holds the DEA license for the controlled substances.

N/A N/A

d) If live-animal traps, nets, or other passive gears will be used, how often will they be checked and how will animals be appropriately sheltered and protected from predators? Are the gears designed to prevent capture of non-targeted animals?

N/A; but see 9a for clarification on the use of block nets. N/A; but see 9a f

e) What are the most likely capture-related health risks (i.e., capture myopathy, physical injury, mortality, etc.) and what will be done to minimize such risks?

Pulsed direct electrical current applied to fish can cause physiological stress for several days following shocking. More serious injury includes damage to swim bladders, muscles and skin; fractured vertebrae; internal bleeding; and mortality.

To minimize risks, surveys will be conducted in cooler water temperatures with the correct voltage settings (continuously adjusted for environmental conditions using the least amount of voltage and lowest frequency pulse that effectively immobilizes fish), and by a trained survey crew. Pulsed direct elec

f) What will be done (e.g., treatment, euthanization) if an animal is injured in the course of handling or restraint?

Should a fish display visible signs of injury that suggest inevitable mortality, it will be euthanized with a lethal dose of clove oil (150mg/L). Then, the gut of the fish will be slit in order to puncture the air bladder. The fish will then be left in the creek to be scavenged for.

If mortality should occur, required information will be reported to Fish Wildlife and Parks, as stipulated in the research permit. Should a fish disp

g) List the individual(s) performing capture of animals and the training or experience or both the individual(s) have with these techniques.

Eva Jordanna Black, graduate student in the Land Resources and Environmental Sciences program, will directly supervise fish capture, anesthesia administration, and PIT tagging. Her in-field electro-fishing, PIT tagging, and snorkeling training/experience is as follows:
- United States Forest Service; Sawtooth Ranger District (summer 2005)
-Oregon Department of Fish and Wildlife; Corvallis Research Station (summer 2006)
-Idaho Department of Fish and Game; Salmon District (summer 2007)
- Utah Department of Natural Resources; Washington County Field Office (spring 2007)
Formal training:
-MT Fish Wildlife and Parks 2-day electro-fishing safety course (June 2-3, 2010)
-ODFW 1-day snorkeling training course (summer 2006)
Black will be supervised by major advisor Geoffrey Poole, and advisor Al Zale.
1-4 additional field crew members will aid in the dip-netting of shocked fish, data recording, and placement/monitoring of fish in live wells. As stipulated by the Fish Wildlife and Park's permit, field crew will be given a overview of electro-fishing safety concerns and fish handling techniques. Eva Jordanna Bla

9. Will animals be confined or restricted to an enclosure in their natural setting?

(x) 1 Yes ( ) No

a) Indicate the period of time the animals will be confined in the field.

During electro-fishing and snorkel surveys, block nets will be deployed upstream and downstream of the delineated reaches (250-400 meters in length) to prevent fish movement into/out of the study reach. Block nets will be installed immediately prior to the survey and removed immediately after conclusion of the survey. Block nets will be in place for approximately 8 hours (not to exceed 12 hours), twice at each site corresponding to the four snorkel surveys, and two additional times at the two sites where mark-recapture electro-fishing surveys will be conducted.

In conjunction with electro-fishing surveys, fish will be confined to a recovery tank for approximately five minutes, and then confined in a secured in-stream live wells for approximately 8 hours (not to exceed 12 hours). During electro-fis

b) Describe the enclosure(s) used and the methods for maintaining species-appropriate living conditions.

Block nets will consist of large mesh nets spanning the width of the stream at upstream and downstream boundaries of each site. The mesh is large enough to pass small organic debris and not restrain stream flow. The mesh will be small enough, however, to prevent the migration of salmonids > 150 mm TL.

Recovery tanks and live wells will be made of large, dark colored plastic tubs (approximate dimensions 2'x 2'x 3') which have been shown to result in less stress/ skittishness (relative to white or light colored tubs). Recovery tanks will be refilled with fresh stream water before a fish is placed in it. The live wells will have numerous small holes on the sides of the tubs which will deliver fresh, oxygenated water to fish and prevent an elevated water temperature inside the tub. Block nets w ill cc

c) Describe factors that will be monitored to ensure adequate health and well-being of the animals (i.e., appearance, behavior, activity, etc.) and state the frequency of monitoring.

The recovery tanks will be consistently monitored by field crew. The live wells will be monitored at a minimum of every 30 minutes. During monitoring fish will be assessed for signs of recovery from anesthesia and electro-shocking as well as symptoms of overcrowding or stress from live well containment. Signs and symptoms include: breathing rates (opercular movement), equilibrium, and response to stimulus.

The recovery tan

10. Will this protocol require that animals be transported from the location of capture?

( ) Yes (x) 0 No

a) Describe why it is necessary to transport the animals.

b) Describe the method of transport. Include how animals will be housed during the transport to maintain species-appropriate living conditions and if sedation or anesthesia will be required.

c) How will food and water be provided during transport?

d) How often will the animals be checked during transport?

e) Will live animals be transported back to Montana State University? If so, where will they be housed?

11. Will animals need to be identified, marked, or radio-collared in some manner?

(x) 1 Yes ( ) No

a) Briefly describe the technique that will be used.

Adult fish > 150 mm TL will be tagged with 12mm full-duplex passive integrated transponder (PIT) tags. Fish will be anesthetized with clove oil (30mg/L) and PIT tags will be inserted with a syringe into the abdominal cavity (Prentice et al. 1990b).

Post-injection, fish will be placed in recovery tanks and monitored for recuperation. Signs of recovery include: proper orientation, response to stimulus, and normal gilling behavior. Adult fish > 150 r

b) After marking, is it anticipated that animals will be at greater than normal risk of infection, predation, or have a decrease in survivability? Please explain and describe procedures to minimize such risks:

Fish should not be at an increased risk of predation as a result of internal PIT tag insertion. Although it has been determined that clove oil does not affect the swimming performance of adult salmonids (Anderson et al. 1997) and that it is generally accepted as "safe", the physiological effects of this anesthetic are still largely unknown (Prince and Powell 2000). Furthermore, the handling of fish generally evokes a physiological stress response including immunosuppression (Bonga 1997).

To minimize stress risks, the field crew will attempt to handle and stress fish as little as possible. This includes placement of fish into live wells after electro-shocking induced capture, thus ensuring that fish will stay out of the direct electric field during the remainder of the electro-fishing survey. Fish should not b

12. Will samples (i.e., blood, tissues, body fluids, scales, fin clips, etc.) be collected from captured animals prior to their release?

( ) Yes (x) 0 No

a) List the samples that will be collected and indicate the amount/volume to be collected, frequency of collection, and the method used to collect the samples.

13. Will a surgical procedure, either recovery or terminal, be performed on the animals?

(x) 1 Yes ( ) No

a) Describe any pre-operative procedures (e.g., fasting):

There no are required pre-operative procedures. There no are requ

b) Will the animals be anesthetized for the procedure? If so please provide the drug name, dose and route used for induction and maintenance of anesthesia:

Before inserting PIT tags, fish will be submerged into a solution of clove oil (eugenol) so that anesthetic may be absorbed through their gills. Fish will remain in the anesthetic bath until a level four anesthesia is achieved. This is categorized by very weak opercular movement, total loss of swimming motion, and a total loss of equilibrium (Yoshikawa et al. 1988). Previous studies suggest that a typical induction time for an adult salmonid is approximately 3.5 minutes, but a wide range of induction times may occur (Prince and Powell 2000, Keene et al. 1988). Because of the potential range in induction times, (0.9-17.6 minutes is described by Prince and Powell in their 2000 study), close monitoring of fish while in the anesthetic bath is imperative.

The recommended dosage of clove oil is 30mg/L. However, it is has been suggested that concentrations may vary slightly given specific stream conditions. Because of this, the recommended 30mg/L concentration will be used as a starting point and will be increased/diluted given fish response. Thus, the precise ratio of clove oil to stream water will be determined in the field. Before inserting I

c) Describe the method for monitoring anesthetic depth (parameters, frequency):

A level four anesthesia depth (Yoshikawa et al. 1988) will be maintained during the few minutes it takes to insert a PIT tag and collect biological data. Level four anesthesia is categorized by very weak opercular movement, total loss of swimming motion, and a total loss of equilibrium. Fish will constantly be monitored for these signs while in the anesthetic bath, namely opercular motion, which allows us to assess whether the fish is emerging from anesthesia or is becoming more deeply anesthetized. Since the injection procedure and collection of biological data is a quick process lasting about a minute, initial induction should be the only dose of anesthetic necessary. A level four anes

d) Who will be responsible for monitoring anesthesia?

Graduate student Eva Jordanna Black and a field technician will monitor anesthesia.

Graduate student

e) Describe the surgical procedures performed on living animals in detail, including name of procedure, anatomic approach, tissue manipulation, and closure techniques.

Salmonids larger than 150 mm TL will be implanted with a 12mm PIT tag. This procedure begins with an individual fish being captured with the use of electrical current and then placed into a tank of prepared anesthetic (clove oil concentration = 30 mg/L), until stage 4 anesthesia is reached (total loss of swimming motion with weak opercular movement as described by Yoshikawa et al. 1988).

Personnel will then implant a 12mm full-duplex passive integrated transponder (PIT) tag with a syringe into the abdominal cavity (Prentice et al. 1990b). Reusable needles will be used, and thus disinfected with ethanol between fish. Needles will be replaced once they are no longer sharp. No suture is necessary.

Post-injection, the fish will be put into a recovery tank and monitored for signs of recuperation. Signs of recovery include proper orientation, response to stimulus, and normal gilling behavior.

When the fish has completely recovered, it will be moved to a secured live well situated outside of potential electrical current, and fish will remain here until the survey concludes.

Anesthetic will be periodically changed once level 4 anesthesia is no longer routinely being achieved in the same amount of time (as indicated by monitoring opercular motion) and all surgical equipment will be disinfected between each fish.

Salmonids larger

f) Who will perform the surgical procedure?

Graduate student, Eva Jordanna Black. Graduate student

g) Where will the surgical procedure be performed?

In the field. In the field.

h) Will animals be allowed to recover from the anesthetic?

(x) 1 Yes ( ) No

i. What will be done to minimize the risk of sepsis?

Surgical gloves will be worn during PIT tag implantation and instruments will be disenfected with ethanol. Live wells will be cleaned and disenfected prior to relocation in a new stream. Multiple live wells will be used in the field, so that a stress response, related to lowered immune function, is less likley to ocur as a result of overcrowing.

Surgical gloves w

ii. Describe the post-operative procedures and monitoring of the animals:

Post tag implantation, fish will be allowed to recuperate in a recovery tank filled with stream water. They will be monitored by in field technicians for the duration of the recovery time which is estimated at about five minutes. Then, fish will be placed into in-stream live wells for the remainder of the study. Live wells will be monitored every 30 minutes by field crew members, and then released at the end of the field day. Post tag implantat

iii. Will the surgery result in increased risk of predation or decreased survivability?

No, the PIT tag should not. However, the physiological effects of clove oil, particularly acute stress responses, are largely unknown (Prince and Powell 2000). No, the PIT tag sh

i) Will more than one major survival surgery be performed on an animal?

( ) Yes (x) 0 No

i. Provide justification:

j) Will a single animal experience more than one major survival surgical procedure (penetrates and exposes a body cavity or produces substantial impairment of physiologic function; and the animal recovers from anesthesia)? If Yes, answer all sub-questions.

( ) Yes (x) 0 No

i. How many surgeries will the animal experience?

ii. What will be the time period between surgeries?

iii. Provide a scientific rationale for the necessity of multiple major survival surgical procedures on the same animal.

14. Will muscle relaxants (paralytics, neuromuscular blocking agents) be used?

( ) Yes (x) 0 No

a) List the agent/dose (mg/kg)/route of administration/frequency of administration.

b) How will it be determined that the paralyzed animal is adequately anesthetized?

c) Provide the rationale for the use of a muscle relaxant.

15. Will analgesics (pain relievers) be used?

( ) Yes (x) 0 No

a) List behavioral or clinical signs or both that will be used to evaluate pain:

b) Agent/dose (mg/kg)/route of administration/frequency of administration.

16. Will a toxic substance, carcinogen, or mutagen be administered to the animals?

( ) Yes (x) 0 No

a) List the agent/route of exposure

b) Is this substance excreted by the animals? What is the length of excretion?

17. Will any of the procedures performed as part of this project result in more than momentary pain or distress (more than would occur with an injection or blood draw?

(x) 1 Yes ( ) No

a) What procedures will be performed to minimize pain/distress (i.e., sedation, anesthetics, analgesics, handling techniques)?

Since the handling of fish generally evokes a physiological stress response, including immunosuppression (Bonga 1997), the amount of time that fish are handled by field personnel will be minimized. This includes anesthetizing and handling only a few fish at a time, stipulating that anglers may use only barbless hooks, and placing fish into live wells after electro-shocking induced capture to ensure they remain out of direct electric current for the remainder of the survey. Since the handlin

18. Following completion of capture or confinement, what will be the disposition of the animals?

Released at the site of original capture Released at the s

19. Is euthanasia part of this protocol?

( ) Yes (x) 0 No

a) Provide the method of euthanasia that will be used.

b) Will the animal be sedated or anesthetized at the time of euthanasia?

c) How will carcasses be disposed of? Does carcass disposal have the potential to negatively affect other wildlife (e.g., carcass tainted with chemicals)?

20) Occupational Health - do the animals to be captured or handled pose any risk to human health?

( ) Yes (x) 0 No

a) What are the potential zoonotic risks?

b) What handling precautions will be taken to decrease zoonotic risks?

c) What other human health hazards could be anticipated as part of this project (e.g., immobilizing agents, animal handling injury, needle sticks)?

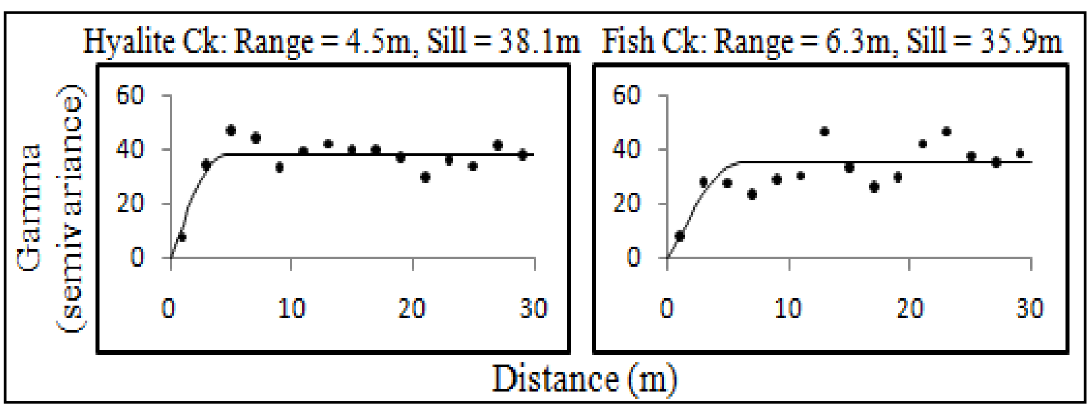
d) Does someone involved with this protocol have basic training in first aid techniques?

Yes. Eva Jordanna Black has a valid Wilderness First Responder certification as well as Red Cross certifications in Basic First Aid and Safety, and Adult CPR.

APPENDIX C

SEMIVARIOGRAMS

Preliminary analyses suggested the presence of spatial autocorrelation in the variable cast density, which threatened to violate assumptions of the intended linear regressions. To characterize spatial structure in the dataset, R constructed semivariograms based on best fit correlation structures as determined by Akaike Info Criterion values. Best fit semivariograms calculated a range, or distance at which spatial structure breaks down. Casts density values beyond this distance were assumed to be independent observations lacking spatial autocorrelation. Isotropic semivariance was assumed given the scale (1m) of our question of interest (as determined by reactive distance). Semivariograms suggested that measures of angler effort were spatially autocorrelated in a range of about 5 m (figure below). This information provided an explicit reason for why Ordinary Least Squares regression residuals were spatially autocorrelated (Chapter 3, Table 5) violating regression assumptions.

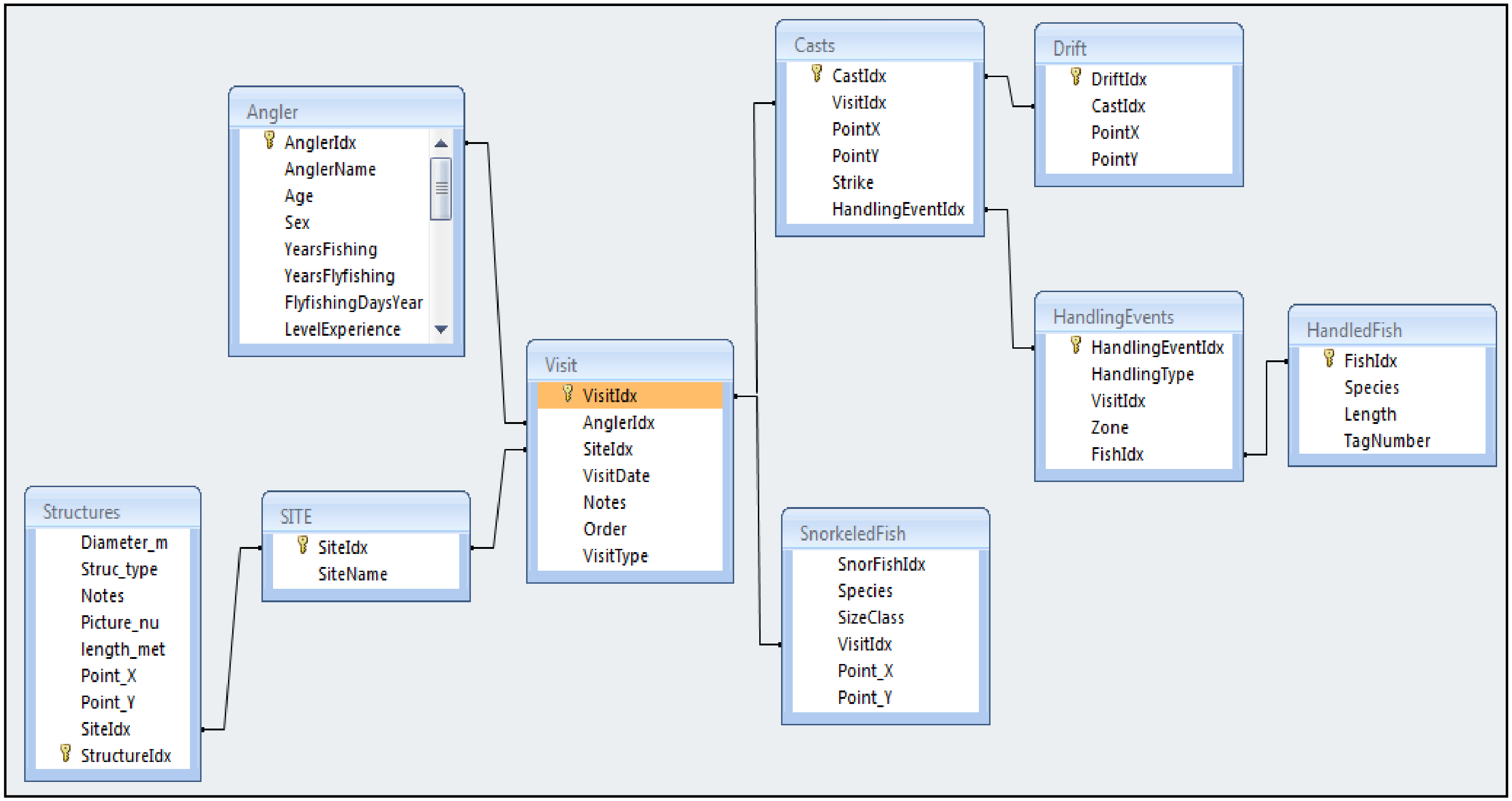


Semivariograms for cast density. Range indicates the distance at which cast density no longer exhibits spatial autocorrelation.

APPENDIX D

DATABASE SCHEMA

The database was created and managed in Microsoft Access 2007 because of the ease of its graphic user interface and ability to directly join and relate ArcMap GIS data tables. This database schema contains five main sets of field data: (1) in-field angler casting surveys: [CAST]; (2) each cast's corresponding drift from in-field angler casting surveys [DRIFT]; (3) in-field angler fish distributions gathered from snorkeling surveys [SNORKELED_FISH], (4) electromagnetically PIT-tagged and recaptured fish [HANDLED_FISH], and (5) information pertaining to artificial habitat enhancement structures [STRUCTURES]. The most logical way to organize this dataset was through a 'visit index'. This index associated multiple tables with necessary information (e.g., angler, site, date, etc.).



Database Schema

Example:
TABLE NAME
Field Name [Data Type] (Pertinent information about field)

STRUCTURE
Structure Index [AutoNumber]
Site Index [Number]
Structure Type [Text]
Diameter [Number] (m)
Length [Number] (m)
Picture [Number]
Notes [Text]
X Coordinate [Number]
Y Coordinate [Number]

ANGLER
Angler Index [AutoNumber]
Name [Text]
Sex [Text]
Age [Text]
Years Fishing [Text]
Years Fly Fishing [Text]
Relative Experience Level [Text]

VISIT
Visit Index [AutoNumber]
Site Index [Number]
Angler Index [Number]
Visit Date [Date/Time]
Visit Type [Text](Angler Survey, Electrofishing Mark, Electrofishing Recapture)
Order Visited [Number]
Notes [Memo]

SITE
Site Index [AutoNumber]
Site Name [Text]

CAST
Cast Index [AutoNumber]
Visit Index [Number]
X Coordinate [Number]
Y Coordinate [Number]
Strike [Yes/No]
Handling Event [Number]

<u>SNORKELED FISH</u>
Snorkeled Fish Index [AutoNumber]
Species [Text]
Size Class [Number]
Visit Index [Number]
X Coordinate [Number]
Y Coordinate [Number]

<u>DRIFT</u>
Drift Index [AutoNumber]
Cast Index [Number]
End Location x Coordinate [Number]
End Location y Coordinate [Number]

<u>HANDLING EVENT</u>
Fish Handling Event Index [AutoNumber]
Fish Index [Number]
Visit Index [Number]
Handling Type [Text] (Angler catch, Electrofishing Mark, Electrofishing Recapture)
Zone [Text]

<u>HANDLED FISH</u>
Fish Index [AutoNumber]
Species [Text]
Length [Number]
PIT Tag [Number]

APPENDIX E

DATA DICTIONARY

Dataset: *Aerial Imagery*

Source: Solicited by Jordanna Black and MSU's Fluvial Landscape Ecology Lab

Description: Raster dataset of aerial photographs taken July 15th, 2010 by Kestrel Aerial and georeferenced by Global Positions, Inc., both of Bozeman, MT; Four layer, one for each site; Used as a background layer to collect field data upon (casting patterns, fish locations); Cell size ranges from 0.066m to 0.17m (see table below); Montana State Plane, Lambert Conformal Conic Projection; scale is unknown as images were not ortho-photo rectified.

Cell size for each site
Mill Creek: 0.066 x 0.066m
Hyalite Creek: 0.1 x 0.1m
Fish Creek: 0.1 x 0.1m
Bridger Creek: 0.17 x 0.17m

Dataset: *Casting Patterns*

Source: Collected by Jordanna Black July-September 2010 using *Penx,* a digitally enabled pen, in conjunction with aerial photos printed with *Capturx* for *ArcGIS* software.

Description: Point dataset identifying discrete locations anglers target via casts and drifts in each of four study sites; Originally 32 layers (eight anglers per each of four sites) appended into one layer per site; Used in spatial analysis relating the areas anglers target with both fish locations and artificial structures; Montana State Plane, Lambert Conformal Conic Projection.

Attributes of Casting Patterns:

FIELD	TYPE	DECRIPTION
Cast Index	Integer	Unique identifier
Rastervalu	Decimal	Distance to nearest artificial habitat enhancement structure, generated in the GIS
Angler	Text	Angler name
Cast Type	Text	'Bite', 'Catch', or 'Null'
Site	Integer	Value: 1-4, each number corresponds to a site, defined in the Access database
Species	Text	If a fish is caught: Species
Size_Inch	Decimal	If a fish is caught: Size in inches
Tag	Integer	If a fish is caught: Does it have a PIT tag number?
Point_X	Decimal	Easting
Point_Y	Decimal	Northing

Dataset: *Fish Locations*

Source: Collected by Jordanna Black and lab assistants (A. Hyman, E. Zinego, H. Warneck, M. Spendel) June-September 2010 using *Penx*, a digitally enabled pen in conjunction with aerial photos printed with *Capturx* for ArcGIS software.

Description: Point dataset identifying the discrete locations of fish in study sites encompassing both spatial and temporal components; Data was collected through repeat snorkel surveys capable of identifying fine-scale habitats utilized by fish in study reaches; Repeat surveys resulted in 8 layers (two per site) which were appended and resulted in four site-specific layers; Used in spatial analysis relating fish locations to both artificial structures and the locations anglers tend to target; Montana State Plane, Lambert Conformal Conic Projection.

Attributes of Fish Locations:

FIELD	TYPE	DESCRIPTION
SiteName	Text	Hyalite, Bridger, Spur or Mill
SizeClass	Integer	Value 1-3, corresponds to <5”; ≥5”-<12”; ≥12”
Species	Text	3-letter code: cutthroat, rainbow, brown, brook, hybrid, misc.
FishId	Float	Length of fish measured in inches.
Rasterva_1	Decimal	Relative fish density; generated in the GIS
Join_Count	Integer	Number of Drifts intersecting each individual fish’s reactive zone (used to determine “drift density”); generated in the GIS
Rastervalu	Decimal	Distance to nearest artificial habitat enhancement structure; generated in the GIS
Point_X	Decimal	Easting
Point_Y	Decimal	Northing

Dataset: *Artificial Habitat Enhancement Structures*

Source: Collected by Jordanna Black June-September 2010 using a Trimble™ XT handheld GPS receiver used in conjunction with a Trimble™ Tempest antenna and range pole. GPS Pathfinder® Office (version 4.20) software post-processed ground points providing sub 0.3m horizontal accuracy.

Description: Site-specific point dataset identifying the discrete locations of artificial habitat enhancement structures in study sites; Used in spatial analysis relating artificial structures to both fish holding locations and areas anglers target; Montana State Plane, Lambert Conformal Conic Projection; Data points were manually manipulated to align with aerial images at a coarser spatial resolution given that only relative accuracy, NOT geographic accuracy is pertinent to this study. Therefore, estimates of accuracy are not available, nor are they relevant.

Attributes of Artificial Habitat Enhancement Structures:

FIELD	TYPE	DESCRIPTION
Struc_type	Text	Type of structure: Log, rootwad, boulder, or underwater boulder [varies from Access database, which excludes “underwater boulder” and includes pool; the Access database is the default, NOT the GIS shapefiles]
Diameter_m	Decimal	Diameter of boulders or logs in meters
Length_met	Decimal	Length of logs in meters
Notes	Text	General Notes describing structures
Point_X	Decimal	Easting
Point_Y	Decimal	Northing

APPENDIX F

CREATING GIS LAYERS FOR SPATIAL ANALYSIS

Five data layers were created for each of the four research sites to display and analyze within a GIS (ArcGIS 9.3). Analysis was conducted upon four of the data layers including: (1) spatial distribution of fish, (2) angling patterns: casts, (3) angling patterns: drifts, and (4) spatial distribution of artificial habitat enhancement structures. A fifth data layer, aerial photographs, was used as a reference layer but not for analysis.

Aerial Imagery

Fine resolution aerial images were taken on July 15th, 2010, by Kestrel Aerial (cell size ranged from 0.066m to 0.17m). Global Positions, Inc., georeferenced images with a "rubber-sheeting" technique, rectified with control points (e.g., adjacent roads, bridges) collected with a *Trimble XH* receiver and *Tempes* external antenna with sub-0.3 meter accuracy. Images were not ortho-rectified, as geospatial data was not available publically (or does not exist) at a fine enough resolution to allow for ortho-rectification at a large-enough scale appropriate for this study. Because of this, inherent distortions and uncertainties exist regarding the precision of this dataset at fine scales. Images arrived from Global Positions, Inc. in multiple coordinate systems, so they were reprojected with *ArcToolbox's* 'project' tool to an appropriate geographic coordinate system (Montana State Plane). Although no analysis was conducted upon this layer, it was used as a background layer to collect casting pattern and fish location data upon.

Artificial Habitat Enhancement Structures

The spatial distribution of artificial habitat enhancement structures was recorded June-September, 2010 with a *Trimble XH* receiver and *Tempest* external antenna with sub-0.3 meter accuracy. *GPS Pathfinder Office* software (Version 4.20) was used to create a data dictionary specifically for this need, and was exported to *Terrasync*, the receiver's internal software. The center of each rock or log was recorded in the field along with a host of other attribute data. This data was then exported back into *GPS Pathfinder Office* software, differentially corrected to the Montana CORS station, and then exported into GIS. During the exportation process, the preferred Montana State Plane geographic coordinate system was specified. The resulting product was 16 shapefiles, one shapefile for each site per type of artificial structure (i.e., rock, log, underwater rock, rootwad). Using a "structure type" field, layers were appended to create four site-specific layers. Unfortunately, this highly precise dataset did not align with the aerial images (which the rest of the data was referenced upon). Reducing the resolution until all datasets aligned would have resulted in an inappropriate scale for analysis. It was determined that relative accuracy, NOT geographic accuracy was pertinent to this study. Therefore, all of the points representing artificial structures (n=210) were manually moved in an *ArcMap* editing session using the "modify feature" tool. Non-relevant fields in the attribute table were removed, such as point-precision data. The new, manual placement of each structure was then field-checked for correctness.

Fish Distributions

Repeat snorkel surveys collected June-September 2010 identified micro-habitats utilized by fish, with the goal of describing the entire fish population within a study reach. A technician on land used *Penx*, a digitally enabled pen which recorded the spatial distribution of fish data, in conjunction with the aerial photos printed with *Capturx* for

ArcGIS software. Spatial data collected and stored in the pen was uploaded to *ArcMap* daily. It was then checked against the paper copies for accuracy. Once uploaded to *ArcMAP*, shapefiles were created consisting of all of the data collected for a given day. Repeat surveys at a given site were appended to each other, resulting in four distinct shapefiles. Since the original geographic coordinate system of each shapefile was based upon the original coordinate system of the aerial images, each of the four resulting shapefiles were also reprojected in *ArcToolbox* to Montana State Plane. Attribute data, collected in the field (e.g., species, size class), was manually entered for each individual fish location (n= 1158 across all sites) into a database specifically designed for this dataset (*Microsoft Access 2007*, see Appendix C. Database Schema). This database was joined to the *ArcMAP* attribute table by creating a common index field, this allowed spatial and attribute data to be queried in an efficient and powerful way.

Angling Patterns

Volunteer anglers were recruited to fish study reaches, resulting in a dataset qualifying angler use patterns within the study reaches. The goal of these surveys was to quantify every single cast made by each angler during the duration they fished each study reach. Although there was some subjectivity pertaining to the location that the observer recorded each cast, this most likely occurred at a scale smaller than analysis occurred on. Use of a single observer minimized bias. The observer used *Penx,* a digitally enabled pen which recorded the spatial distribution of each cast, in conjunction with the aerial photos printed with *Capturx* for *ArcGIS* software. Spatial data collected and stored in the pen was uploaded to *ArcMap* daily. It was then checked against the paper copies for accuracy.

Once data was uploaded to *ArcMAP*, shapefiles were created consisting of all of the casts collected for a given day, resulting in 32 shapefiles (8 anglers x 4 sites). Shapefiles from the same sites were appended to each other, resulting in four distinct shapefiles. Since the original geographic coordinate system of each shapefile was based upon the original coordinate system of the aerial images, the four final shapefiles were also reprojected in *ArcToolbox* to Montana State Plane. Attribute data collected in the field (e.g., type of cast (strike, catch, null), angler, date) was manually entered for each individual cast location (n= 6990 across all sites) into an database specifically designed for this dataset (*Microsoft Access 2007*, see Appendix C. Database Schema). This database was joined to the *ArcMAP* attribute table by creating a common index field.

APPENDIX G

DATA FILE

This CD includes five files:

(1) Access 2007 Database

(2) GIS Shapefiles: Hyalite Creek

(3) GIS Shapefiles: Bridger Creek

(4) GIS Shapefiles: Fish Creek

(5) GIS Shapefiles: Bridger Creek

To request an electronic copy of the GIS data, contact your local public or university library to place an interlibrary loan request to Montana State University. For questions call (406) 994-3161