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Survival, Abundance, and Relative Predation of Wild Rainbow Trout in the Deerfield Reservoir System, South Dakota

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SURVIVAL, ABUNDANCE, AND RELATIVE
PREDATION OF WILD RAINBOW TROUT IN THE DEERFIELD
RESERVOIR SYSTEM, SOUTH DAKOTA

BY

JEREMY L. KIENTZ

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SURVIVAL, ABUNDANCE, AND RELATIVE PREDATION

OF WILD RAINBOW TROUT IN THE DEERFIELD

RESERVOIR SYSTEM, SOUTH DAKOTA.

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Steven R. Chipps, Ph.D. Date
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This thesis is dedicated to Jamie, the love of my life.

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Author's Note: My use of pronouns such as we rather than I throughout this document reflect the collaborative nature of this project.

CONTENTS

ABSTRACT

SURVIVAL, ABUNDANCE, AND RELATIVE PREDATION OF WILD RAINBOW TROUT IN THE DEERFIELD RESERVOIR SYSTEM

JEREMY L. KIENTZ

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Rainbow Trout *Oncorhynchus mykiss* are routinely stocked in Black Hills streams and reservoirs to enhance angling opportunities for the public, however in most cases, hatchery-reared Rainbow Trout do not successfully recruit to establish natural populations. One exception is the Deerfield Reservoir system, where it is estimated that up to 25% of the Rainbow Trout population consists of naturally produced, wild Rainbow Trout. While recruitment of wild Rainbow Trout to the Deerfield Reservoir fishery does occur, annual stockings of 12,000 hatchery Rainbow Trout have continued. In recent years, adipose fin clips were used to identify hatchery Rainbow Trout stocked into Deerfield Reservoir, however the personnel and time requirements of fin clipping resulted in the termination of fin clips in May 2014. An elimination or reduction of hatchery stockings may be considered in the future management of the Deerfield Reservoir Rainbow Trout population, however a lack of knowledge regarding factors such as predation, movement and emigration patterns, relative abundance, and apparent survival of wild Rainbow Trout has generated a need for additional research in order to

help guide future management decisions. In addition, the termination of fin clipping requires the identification and evaluation of new techniques for the classification of wild and hatchery Rainbow Trout in Deerfield Reservoir. Thus the objectives of our research were to 1) investigate the predation on young Rainbow Trout and the diet composition of fishes in Deerfield Reservoir, 2) quantify the relative abundance, growth, and apparent survival of wild Rainbow Trout in the Deerfield Reservoir system, 3) describe the movement patterns and emigration rates of wild Rainbow Trout from tributary streams into Deerfield Reservoir, and 4) evaluate the use of stable isotope analysis and otolith microchemistry for the classification of wild and hatchery Rainbow Trout origins.

Juvenile Rainbow Trout were not found in the diets of Rock Bass *Ambloplites rupestris,* Yellow Perch *Perca flavescens,* and adult (>200 mm) Rainbow Trout in Deerfield Reservoir and indicated that the risk of predation upon Rainbow Trout is negligible. The diet composition of all species consisted primarily of aquatic invertebrates and dietary overlap did exist among Rainbow Trout, Yellow Perch, and Rock Bass. While diets were similar among species with regard to aquatic invertebrate prey, the degree of diet overlap with Rainbow Trout was generally low (range 0.2-0.57).

We found that the relative abundance of wild Rainbow Trout in tributary streams was greater in South Fork Castle Creek than in Castle Creek. Rainbow Trout movement and emigration from tributaries into

Deerfield Reservoir was monitored in both tributaries using 12 mm passive integrated transponder (PIT) tags which showed that within and among stream movement was minimal throughout our study. We tagged 380 Rainbow Trout and in subsequent sampling events recaptured 81 unique fish using backpack electrofishing. Of these 81 fish only 3 were recaptured outside of the 100 m site in which they were tagged, resulting in 96% fidelity to original tagging site. Out of the total 380 tagged Rainbow Trout, another 73 (19%) unique fish were detected by an in-stream passive PIT tag reader emigrating from tributary streams into Deerfield Reservoir.

We constructed a Von Bertalanffy growth model for wild Rainbow Trout in Deerfield Reservoir based on length frequency analysis and found that growth of fish up to age 4 was relatively slow in comparison to other populations, reaching only 210 mm by age 4. Using the growth parameters from the Von Bertalanffy growth model, we estimated survival of wild Rainbow Trout in the Deerfield Reservoir system to be as low as 3% during the first year of life. However, survival increased with each year of life, with relatively high survival (up to 66%) by age 4.

In the absence of fin clips, identifying future trends in the wild Rainbow Trout population in Deerfield Reservoir requires the accurate classification of both wild and hatchery origins. Using stable isotope analysis we found that wild Rainbow Trout can be classified with greater than 75% accuracy using pectoral fin tissue, and greater than 85%

accuracy using dorsal muscle tissue. We also used otolith microchemistry to identify the natal tributary stream origins of 9 wild Rainbow Trout collected in Deerfield Reservoir. Our results showed that 56% of wild Rainbow Trout in Deerfield Reservoir were classified to Castle Creek, while 44% were classified to South Fork Castle Creek. These results indicate that Castle Creek likely contributes a slightly greater number of wild Rainbow Trout recruits to the Deerfield Reservoir population than South Fork Castle Creek.

Overall our results indicate a healthy, sustainable population of wild Rainbow Trout in Deerfield Reservoir. Our analysis of survival, abundance, and emigration data, as well as low risks of predation suggest that management of Deerfield Reservoir for wild Rainbow Trout in the absence of stocking or at reduced stocking rates is likely sustainable. Managing Deerfield Reservoir primarily for wild Rainbow Trout may be viable, however fisheries managers should consider the impact of reduced stockings on angler catch rates. In addition, a reduction or elimination of hatchery stockings would likely have positive impacts on the wild Rainbow Trout population and monitoring changes in the population dynamics of wild Rainbow Trout would be beneficial to the assessment of any stocking changes.

CHAPTER 1: Introduction

Rainbow Trout *Oncorhynchus mykiss* are native to the United States in freshwater systems west of the Rocky Mountains (Ostberg and Rodriguez 2002), and are one of the most widely introduced fish species in North America (MacCrimmon 1971). Rainbow Trout thrive in lakes and streams with water temperatures generally below 25˚C. Coldwater stream habitat is abundant throughout the Black Hills of South Dakota, however species of the family Salmonidae are absent from native fish assemblages.

Although the Black Hills were historically void of salmonid species, introductions have been widespread since the late 1800s and fisheries dominated by Rainbow Trout, Brook Trout *Salvelinus fontinalis*, and Brown Trout *Salmo trutta* are now common throughout the Black Hills (Cordes 2007). In many Black Hills streams, Brown Trout and Brook Trout fisheries are sustained through natural reproduction and recruitment; however Rainbow Trout populations, with few exceptions, are primarily maintained through supplemental stocking of catchable-size (~ 275 mm) fish. While catchable-size Rainbow Trout are routinely stocked in the Black Hills to enhance angling opportunities for the public (Simpson 2010), it is rare for hatchery-reared Rainbow Trout to successfully reproduce and establish natural populations. Currently, Spearfish Creek near the confluence of Cleopatra Creek (James 2011), and the Deerfield

Reservoir system (Davis 2012) are the only populations in the Black Hills supported in part by naturalized Rainbow Trout.

Deerfield Reservoir was created by the impoundment of Castle Creek in 1947. Castle Creek, South Fork Castle Creek, and Ditch Creek are the primary tributaries into Deerfield Reservoir. Currently Deerfield Reservoir is managed primarily as a put-and-take Rainbow Trout fishery, but also supports populations of Rock Bass *Ambloplites rupestris*, Yellow Perch *Perca flavescens*, Brook Trout, and White Sucker *Catostomus commersonii*. In addition, Deerfield has also been stocked with Splake *Salvinus namaycush* X *Salvelinus fontinalis* every three years.

Annual stream surveys conducted by South Dakota Game, Fish and Parks revealed the presence of young-of-the-year Rainbow Trout in Castle Creek upstream of Deerfield Reservoir in the late 2000s (Miller et al. 2007; Bucholz and Wilhite 2010). This indicated that stocked Rainbow Trout had reproduced and wild progeny recruitment was successful. Observations of large individuals in the tributary system during spring (e.g., spawning season) indicated that the population may be characterized by an adfluvial life history strategy. In addition, it was hypothesized that naturally reproduced individuals were emigrating from tributaries to Deerfield Reservoir.

Recent genetic analysis of wild Rainbow Trout in Deerfield Reservoir found that two strains of stocked fish (Erwin and McConaughy) represent most of the naturalized production; a third strain (i.e., Shasta) contributes little to no natural reproduction (Davis 2012). Using scale growth patterns, Davis (2012) also found that up to 50% of the Rainbow Trout collected in Deerfield Reservoir were of unknown origin and as much as 25% of the reservoir population could be wild Rainbow Trout. These results confirmed that naturally reproduced Rainbow Trout were recruiting to the Deerfield Reservoir fishery; however questions remain regarding the survival, abundance, and predation mortality of this unique population.

The contribution of naturally-produced Rainbow Trout in Deerfield Reservoir has prompted questions regarding the continued management of this system as a 'put-and-take' fishery. Numerous studies have shown that stocking hatchery trout can negatively influence survival and growth of wild fish populations (Vincent 1975). In the Madison River, Montana, wild Rainbow Trout abundance and biomass increased by 8 to 10 fold, four years after the stocking of catchable-sized Rainbow Trout was discontinued (Vincent 1987). Similarly, Petrosky and Bjornn (1988) showed that high stocking densities of Rainbow Trout negatively influenced the survival of wild, Cutthroat Trout *Oncorhynchus clarkii*. Experimental manipulation of Rainbow Trout populations has shown that high abundance of larger trout causes changes in habitat use by age-0 trout, ultimately leading to reduced growth and survival of young fish (Biro et al. 2003). Stocking of mature hatchery-raised Rainbow Trout can also have deleterious effects on the genetic diversity of wild populations.

Studies on Rainbow Trout have shown that age-0 fish produced from wild x wild matings had significantly higher survival than those of hatchery x wild or hatchery x hatchery pairings (Reisenbichler and McIntyre 1977).

The presence of illegally introduced Rock Bass and Yellow Perch populations and their potential predation upon wild Rainbow Trout in Deerfield Reservoir also remains uninvestigated. Probst et al (1984) found that Rock Bass exhibit piscivory throughout the year; however fish were generally smaller than 100 mm and energetically less important than crayfish. Rock Bass also occupy a similar feeding niche to Smallmouth Bass *Micropterus dolomieu*, which have been shown to prey upon salmon smolts during out-migration (Fayram and Sibley 2000). Fraser (1978) showed that competition with Yellow Perch had negative impacts on the growth and survival of salmonids. Additionally, fish have been shown to account for significant portions of Yellow Perch diets (DePhilip and Berg, 1993), and predation on salmonids by Yellow Perch is often inferred (Johnson, 2009; Christensen and Trites 2011).

Beginning in 2009, hatchery-reared Rainbow Trout were given an adipose fin clip prior to stocking into Deerfield Reservoir. Complete removal of the adipose fin results in no regeneration (Thompson and Blankenship 1997) and therefore provides managers with a means to differentiate hatchery fish from wild Rainbow Trout. However, the costs associated with time and personnel requirements resulted in the termination of adipose fin clippings in August, 2014.

To adequately monitor fluctuations in the wild Rainbow Trout population, new techniques are needed to differentiate wild and hatchery fish. Davis (2012) used scale growth characteristics to identify wild and hatchery origin Rainbow Trout with 60% classification accuracy, however the model had reduced confidence due to appreciable overlap between the circuli measurements of wild and hatchery scales. Otolith microchemistry has been a successful method for classification of natal origins (Campana et al 2000; Carlson 2015), and stable isotope analysis (SIA) has been used to distinguish fish utilizing different sources of organic carbon and nitrogen using $\delta^{13}C$ and $\delta^{15}N$ signatures from various body tissues (Estep and Vigg 1985; Hobson 1999; Schroder and Garcia de Leaniz 2011).

While fisheries managers have gained considerable knowledge regarding the genetics and contribution of wild Rainbow Trout to Deerfield Reservoir, questions remain before future management decisions can be made. While it is desirable to remove stockings and manage the reservoir for wild Rainbow Trout, understanding sources of predation, movement patterns, and population dynamics is crucial. Thus, the objectives of this study were to 1) examine the relative predation and dietary habitats of Rainbow Trout and introduced species in Deerfield Reservoir, 2) estimate relative abundance and survival of wild Rainbow Trout in the Deerfield Reservoir system, 3) identify movement and emigration patterns of wild Rainbow Trout into the Deerfield Reservoir system, and 4) quantify classification of natal origins using stable isotope analysis and otolith microchemistry.

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CHAPTER 2: Relative Predation of Juvenile Rainbow Trout by Rock Bass, Yellow Perch, and Rainbow Trout

Introduction

Coldwater fisheries have been the main focus of fisheries management activities in the Black Hills of South Dakota since the introduction of salmonid species in the late 1800s (Cordes 2007). While coldwater species remain an important component of Black Hills fisheries, many cool and warmwater species have been introduced and now support recreational fisheries in Black Hills reservoirs. Species such as Largemouth Bass *Micropterus salmoides* and Yellow Perch *Perca flavescens,* have been intentionally introduced by South Dakota Game, Fish and Parks into Black Hills waters for recreational angling, however other species including Northern Pike *Esox Lucius*, Rock Bass *Ambloplites rupestris*, and Green Sunfish *Lepomis cyanellus* have been introduced through illegal stockings. Due to these introductions, management activities are now influenced by research (Scheibel 2015) and monitoring of several introduced species, however questions still remain regarding the interactions between introduced cool and warmwater species with stocked and wild salmonid populations.

Deerfield Reservoir is an impoundment on Castle Creek in the central Black Hills and is primarily managed as a put-and-take Rainbow Trout fishery, but also supports populations of Rock Bass, Yellow Perch, Splake *Salvinus namaycush X Salvelinus fontinalis,* Brook Trout *Salvelinus fontinalis*, and White Sucker *Catostomus commersonii.* In addition, the Deerfield Reservoir system is one of only two aquatic systems in the Black Hills, South Dakota where Rainbow Trout *Oncorhynchus mykiss* naturally reproduce and contribute to the adult population (Davis 2012). Recent research on this population has shown recruitment of wild Rainbow Trout into the Deerfield Reservoir population (Davis 2012), however in order to maintain desirable catch rates the reservoir is annually stocked with 12,000 catchable-size (~275 mm) hatchery Rainbow Trout.

A reduction or elimination of stocking catchable Rainbow Trout into the reservoir is desirable for fisheries managers due to the high cost associated with stocking, however little information exists regarding factors affecting survival of wild Rainbow Trout and potential interactions with introduced Rock Bass and Yellow Perch. While Rainbow Trout are known to recruit to the adult population in Deerfield Reservoir, survival and growth of naturally reproduced Rainbow Trout, as well as predation on wild trout has not been investigated. These questions are crucial to understanding this unique Rainbow Trout population and the ability to manage the reservoir primarily for wild Rainbow Trout.

Since their introduction into Deerfield Reservoir in the early 2000’s, Rock Bass and Yellow Perch have established relatively abundant populations. Predation on wild juvenile Rainbow Trout by Rock Bass and

Yellow Perch has not been investigated. Also of interest is the potential for dietary overlap between hatchery and wild Rainbow Trout, Yellow Perch, and Rock Bass which could result in reduced growth potential.

Mueller and Rockett (1962) found that Rainbow Trout under 100-mm may be susceptible to predation by Yellow Perch. Similarly, Probst et al. (1984) found that stream-dwelling Smallmouth Bass and Rock Bass consumed fish prey with mean lengths of 80 mm and 47 mm, respectively. Based on growth estimates from length frequency analysis, we estimated that wild Rainbow Trout in Deerfield Reservoir tributary streams will reach 80 mm within their first year of life (See Chapter 3), and therefore potentially be susceptible to predation at and below this size.

Due to questions regarding predation on wild Rainbow Trout in Deerfield Reservoir and their interactions with introduced Yellow Perch and Rock Bass our objectives were to 1) determine the relative predation of wild Rainbow Trout in Deerfield Reservoir, and 2) to quantify dietary overlap among Rainbow Trout, Yellow perch, and Rock Bass in Deerfield Reservoir.

Methods

We collected Yellow Perch (n=53), Rainbow Trout (n=84), and Rock Bass (n=104) using modified fyke nets and boat electrofishing from May-October in 2013 and 2014. Whole stomachs were excised for diet analysis, placed on ice, and frozen prior to analysis. In the laboratory, stomach contents were thawed, removed, and prey taxa were identified to family and weighed to the nearest mg wet weight. Diet items were then dried to a constant weight and measured to the nearest mg. We estimated the energy density (joules/g wet weight) of prey using the relationship between dry mass and energy density reported for invertebrates (James et al. 2012) or fish (Hartman and Brandt 1995). Energy density values were then multiplied by the prey's wet weight to estimate total energy (joules) for consumed prey taxa. We calculated the proportion of total energy (joules) obtained by individual fish for each prey taxon. The contribution of prey taxa to the total energy for a species was calculated using the prey importance index (Pii_i),

Prey importance index $$Pii_i = \frac{1}{P}\sum_{j=i}^{P}\left(\frac{W_{ij}X_i}{\sum_{i=1}^{Q}W_{ij}X_i}\right)$$

where Q = number of food types. P = number of fish with food in their stomachs. W_{ij} = weight of prey type i in fish j. X_i = energy density (J g^{-1} wet weight) of food type i.

We used Schoener's (1970) diet overlap index to identify areas of overlap on an energy basis. Wallace (1981) indicated that values exceeding 0.6 represent significant dietary overlap.

In order to identify feeding strategies and relative prey importance of Deerfield Reservoir fishes, we used a graphical technique first described by Costello (1990) and further developed by Amundsen et al. (1996). The Amundsen method plots frequency of occurrence (O_i) against prey specific abundance (P_i). The equation for frequency of occurrence is

$$O_i = J_i / P$$

where J_i is the number of fish containing prey *i* and P is the number of fish with food in their stomachs. The equation for prey-specific abundance is

$$P_i = (\Sigma\ S_i / \Sigma\ S_{ti}) * 100$$

where S_i is the total energy (joules) obtained from prey *i* in predator stomachs and S_{ti} is the total joules obtained by predators that consumed prey *i*. A high prey-specific abundance value indicates that predators have a specialized feeding strategy in contrast to a generalized feeding strategy identified by low P_i values. Dominant prey resources are identified by a high value for both frequency occurrence and prey-specific abundance.

Results

We observed a total of nine prey types consumed by fishes in Deerfield Reservoir. Crayfish and chironomid prey were the most energetically important resources for Rock Bass and Yellow Perch. Crayfish represented 26-62% of the total energy consumed by Rock Bass and Yellow Perch, while chironomid prey accounted for between 8% and 42% (Table 2-1). Chironomid and caddisfly spp. were important energetic components of Rainbow Trout diets, respectively representing 48% and 25% of total consumed energy.

Based on the Schoener (1970) diet overlap index, the greatest dietary overlap occurred between smaller Rock Bass (<130mm) and Yellow Perch where we observed 58% overlap (Table 2-2). Of primary importance to this study was identifying the dietary overlap of Rainbow Trout with Rock Bass and Yellow Perch. Overlap was greater between Rainbow Trout and small Rock Bass (57%) than with larger individuals (20%). We observed 48% overlap between the diets of Rainbow Trout and Yellow Perch, which was primarily driven by chironomid prey accounting for a high proportion (>40%) of energy in both species.

Rock Bass were the only fish species consumed by other fishes in Deerfield Reservoir. On average, however, consumption of Rock Bass accounted for less than 15% total energy consumed by Yellow Perch (4%) and both small (3%) and large Rock Bass (13%). No salmonid species were observed as prey in the diets of Deerfield Reservoir fishes.

Based on our graphical analysis Rainbow Trout, Yellow Perch, and Rock Bass all had highly specialized feeding strategies in Deerfield Reservoir as indicated by high prey-specific abundance values for prey resources. Yellow Perch did not appear to have a dominant prey (Figure 2-1), however chironomid prey contributed greatly to their energy intake.

Similarly, small (<130 mm) Rock Bass consumed numerous prey items with high prey-specific abundance but no specific prey appeared to be dominant in the diets. In contrast, large (>130 mm) Rock Bass acquired a large proportion of their energy from Crayfish which were a dominant prey item. Interestingly, Rainbow Trout consumed the fewest prey items among the fish species in Deerfield Reservoir. Chironomid species were dominant prey resources for Rainbow Trout, contributing nearly 50% of the overall energy consumed.

Discussion

Our results indicate that predation on young, wild Rainbow Trout in Deerfield Reservoir is likely not a significant source of mortality given the absence of trout in the diets of fishes. Mueller and Rockett (1962) suggested that Rainbow Trout under 100 mm total length could be subjected to predation by Yellow Perch. Probst et al. (1984) showed that the mean size of prey fish in Rock Bass diets was 47 mm. Wild Rainbow Trout in Deerfield Reservoir tributaries generally emigrate into the reservoir at lengths greater than 90 mm (see Chapter 3). In addition, recent fish surveys showed that the minimum size of Rainbow Trout in Deerfield Reservoir was 150 mm (Miller et al. 2013). This suggests that only the smallest emigrating Rainbow Trout would be subject to predation by Yellow Perch and Rock Bass and likely for a very short period of time.

Macroinvertebrates, especially chironomids, were the main dietary components for all three fish species. While diet overlap does exist for invertebrate prey in all species, overlap values less than 0.6 suggests that interspecific competition for prey resources is not supported by our data. Most prey taxa had prey-specific abundance values greater than 50, indicating that prey items within Deerfield Reservoir are likely not limited resources.

The largest overlap between Rainbow Trout and an introduced species was with small Rock Bass. Longmire (2015) reported that anglers fishing from shore at Deerfield Reservoir were concerned with the number of small Rock Bass that prohibited them from catching more desirable species. While the scope of our study did not allow us to draw conclusions about interspecific competition for resources, further investigation of this interaction would be helpful in understanding the relationship and potential competition between Rainbow Trout and Rock Bass in Deerfield Reservoir. In addition, we suggest future examination of the diets of White Suckers which could potentially overlap with Rainbow Trout for prey resources.

Crayfish represent important prey for centrachid fishes such as *Ambloplites spp*. and *Micropterus spp*. Fenner at al. (2004) showed that in May the percent occurrence of crayfish in the diets of Shadow Bass *Ambloplites ariommus* and Smallmouth Bass was 35 and 67, respectively. Probst et al. (1984) found that crayfish were the most important diet item for Rock Bass on a caloric basis. Crayfish were an important diet item for Rock Bass over 130 mm and Yellow Perch, accounting for 63% and 36% of their total energy, respectively. Our graphical analysis also indicated that crayfish were the dominant prey resource for large Rock Bass. In contrast, Rainbow Trout did not feed on crayfish and obtained most of their energy from other macroinvertebrate prey resources, and showed a preference for chironomid prey.

Fenner et al. (2004) found that Bray-Curtis dissimilarity between Rainbow Trout and Shadow Bass and Smallmouth Bass was greater than 85, where a value of zero indicates identical diets and 100 indicates no diet similarity. Furthermore, Fenner et al. (2004) observed that macroinverebrate prey (primarily snails and chironomids) dominated Rainbow Trout diets, while crayfish dominated the diets of both Shadow Bass (mean total length = 158mm) and Smallmouth Bass (mean total length = 243mm). These results are similar to the patterns we observed in the diets of Rainbow Trout and Rock Bass greater than 130 mm, however their results do not provide a direct comparison for smaller Rock Bass which had the greatest overlap with Rainbow Trout in Deerfield Reservoir.

Between 2010 and 2013 the relative weight (Wr) of Rainbow Trout in Deerfield Reservoir ranged from 70 to 80, indicating poor body condition (Miller et al. 2013). However, our results indicate that interspecific competition between Rainbow Trout and other fishes is minimal, suggesting that intra-specific competition (i.e., high trout density) may be related to low Wr values in Rainbow Trout and warrants further investigation.

Management Implications

The lack of a tertiary predator in the Deerfield Reservoir system reduces predation mortality on wild Rainbow Trout immigrating into Deerfield Reservoir, but also results in greater abundance of small Rock Bass and Yellow Perch. Introduction of a large piscivore into Deerfield Reservoir could potentially reduce the abundance of small Rock Bass and Yellow Perch where there was greater overlap with Rainbow Trout. Our results provided little evidence for competition between Rainbow Trout and introduced species, yet Rainbow Trout condition remains low. Future research activities should focus on investigating potential factors contributing to low Wr values.

Previous management of Rock Bass in Deerfield Reservoir has included mechanical removal with boat electrofishing and nettings with little success. While removals were effective, the efforts were minimal and likely not sufficient to reduce the population. Intense and effective mechanical removals could potentially reduce densities of Rock Bass and increase growth and size structure, thus resulting in fewer small Rock Bass where greater overlap with Rainbow Trout was observed. If overlap between small Rock Bass and Rainbow Trout is a concern for fisheries managers, mechanical removal could be an option for reducing these interactions. Furthermore, cove rotenone and boat electrofishing removal efforts may be effective methods for targeting Rock Bass in littoral areas during the warm summer months with little impact on Rainbow Trout due to their preference for deeper, cooler pelagic zones.

In addition to having moderate overlap with Rainbow Trout, small Rock Bass are one of the primary concerns for anglers fishing from shore at Deerfield Reservoir. Mechanical removals would likely reduce the abundance of small nuisance Rock Bass and increase the proportion of Rock Bass greater than 130mm which specialize heavily on crayfish resources. In addition, while observed at low levels, large Rock Bass were cannibalizing small Rock Bass, suggesting a relatively high abundance of smaller individuals and thus lending further support to management activities which reduce small Rock Bass and promote growth and increased size structure of Rock Bass in Deerfield Reservoir.

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Table 2-1. Mean, energetic contribution (proportion of total energy) of prey taxa to the diets of Rainbow Trout, small (<130 mm) and large (>130) Rock Bass, and Yellow Perch collected from Deerfield Reservoir, South Dakota, 2013-2014. Values in parentheses represent 1 SE.

Prey Taxa	Fish Taxa/Size			
	Rainbow Trout	Small Rock Bass	Large Rock Bass	Yellow Perch
Crayfish	--	0.26 (0.07)	0.63 (0.06)	0.36 (0.07)
Chironomids	0.48 (0.06)	0.21 (0.07)	0.08 (0.03)	0.42 (0.07)
Caddisflies	0.25 (0.05)	0.23 (0.07)	0.07 (0.03)	--
Rock Bass	--	0.03 (0.03)	0.13 (0.04)	0.05 (0.01)
Mayflies	0.14 (0.04)	0.13 (0.06)	0.03 (0.02)	0.06 (0.03)

Table 2-2. Values of Schoener's diet-overlap index between fishes of Deerfield Reservoir. Values range from 0.0 to 1.0, increasing with greater overlap between species.

Fish Taxa/Size	Rainbow Trout	Small Rock Bass	Large Rock Bass	Yellow Perch
Rainbow Trout	--	0.57	0.20	0.48
Small Rock Bass	--	--	0.52	0.58
Large Rock Bass	--	--	--	0.54

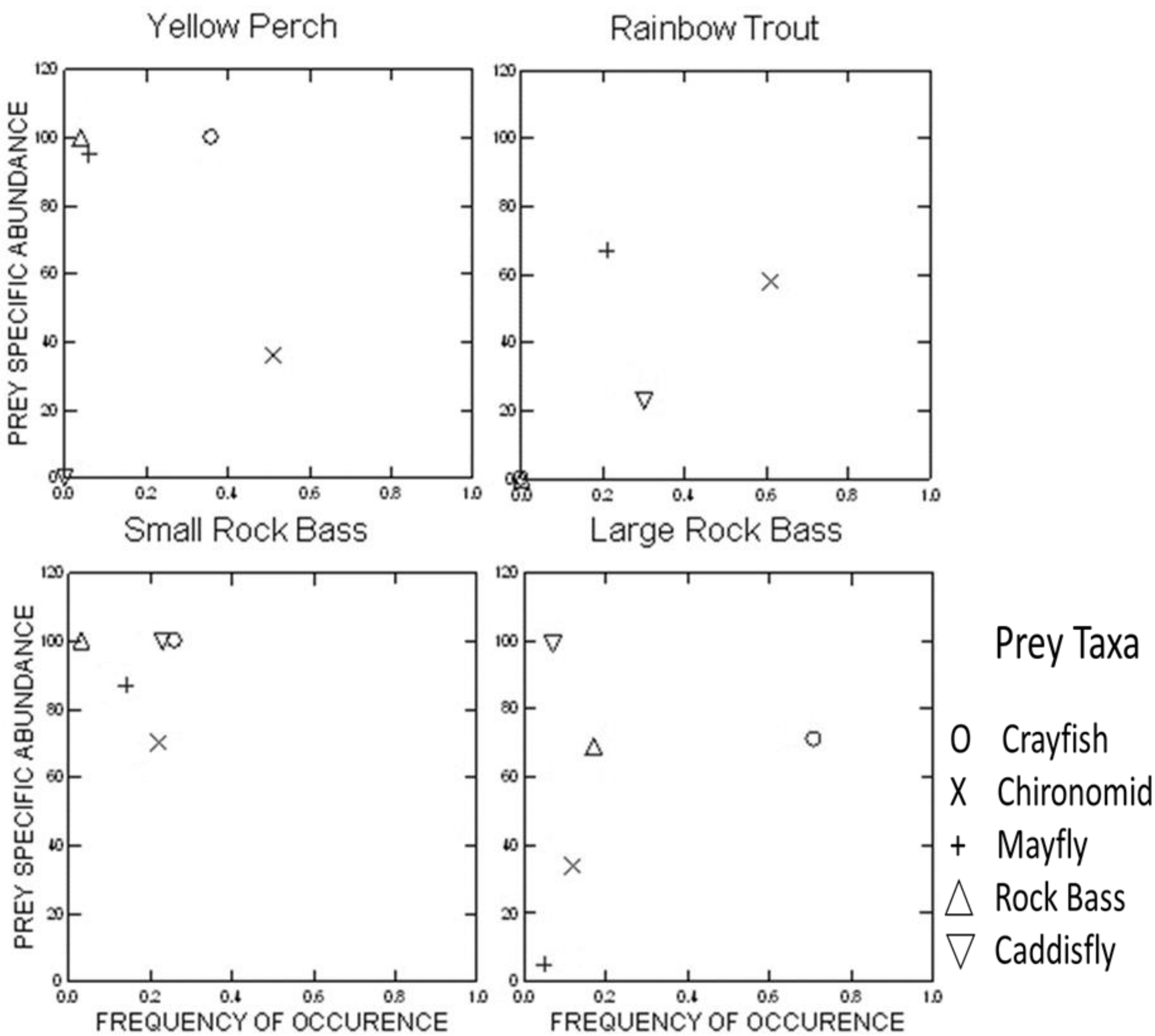

Figure 2-1. Amundsen plots of fishes in Deerfield Reservoir. Prey items included in the graphs collectively represent >80% of the energy consumed by each species.

CHAPTER 3: Survival, Abundance, Growth, and Movement of Wild Rainbow Trout in the Deerfield Reservoir System, South Dakota

Introduction

Deerfield Reservoir is an impoundment located on Castle Creek in the Black Hills of western South Dakota. Since 2004 Deerfield Reservoir has been principally managed as a put-and-take fishery through annual stockings of 12,000 catchable (~275 mm) Rainbow Trout *Oncorhynchus mykiss*. Since the discovery of wild Rainbow Trout in the reservoir and upstream tributaries the continued management of the reservoir using hatchery-reared trout has been questioned. Stocking hatchery reared salmonids into systems where natural reproduction occurs has often resulted in deleterious effects on wild populations (Vincent 1987; Petrosky and Bjornn 1988; Hindar et al. 1991, Reisenbichler and McIntyre 1977). Due to the costs of stocking catchable Rainbow Trout it is desirable to manage the reservoir through sustainable natural reproduction, however prior to 2012 information regarding this wild Rainbow Trout population was inadequate.

Catchable-size Rainbow Trout are often stocked in Black Hills reservoirs to enhance angling opportunities for the public (Simpson 2010), however establishment of naturalized populations is rare. James (2011) identified tributary use patterns of Rainbow Trout for spawning in Cleopatra Creek, the only other naturalized Rainbow Trout population in the Black Hills. The presence of wild young-of-year Rainbow Trout in the Deerfield Reservoir system was documented as early as 2006 (Shearer and James, 2007), indicating that natural reproduction was occurring in tributaries upstream of Deerfield Reservoir. These observations were supported by Bucholz and Wilhite (2009), who observed spawning aggregations of Rainbow Trout in South Fork Castle Creek. The use of tributaries by salmonids for spawning is well documented (Jones 1975; Johnston et al. 2000; Soulsby et al. 2001), and Rainbow Trout often use tributaries to lakes and rivers for spawning (Scott and Crossman 1973; Kwain 1983). Observations of trout spawning aggregations in South Fork Castle and Castle Creeks suggest this population exhibits an adfluvial life history strategy similar to that observed in Lake McConaughy, Nebraska (VanVelson, 1974). These surveys provided important information, however further research was required in order to determine the extent at which natural reproduction occurs above Deerfield Reservoir and the contribution of recruited wild Rainbow Trout to the reservoir fishery.

An initial investigation of the genetic structure, movement patterns, and recruitment of wild Rainbow Trout to the Deerfield Reservoir fishery was conducted from 2009-2011. Davis (2012) showed that up to 25% of the Deerfield Reservoir Rainbow Trout population was represented by naturally reproduced fish and that Erwin strain fish were the greatest genetic contributors to the wild population. Furthermore, this research identified adfluvial movements by adult Rainbow Trout using passive integrated transponder (PIT) tags to track movements between Deerfield Reservoir and the Castle Creek tributary system.

Key to understanding the population dynamics of wild Rainbow Trout in Deerfield Reservoir are three dynamic rate functions that include recruitment, growth, and mortality. Previous research by Davis (2012) contributed greatly to understanding wild Rainbow Trout recruitment to this population and raised further questions regarding the other dynamic rates of growth and mortality. In addition, questions remain regarding movement patterns and emigration rates of wild Rainbow Trout in Deerfield Reservoir tributary streams. Thus, the objectives of this study were to: 1) estimate abundance of wild Rainbow Trout in tributary streams, 2) estimate survival of wild Rainbow Trout in the Deerfield Reservoir system, 3) assess growth of Rainbow Trout in the Deerfield Reservoir system, and 4) identify movement patterns and emigration rates of wild Rainbow Trout from tributary streams into Deerfield Reservoir.

Methods

Study Area

Our study area encompassed Deerfield Reservoir and its upstream tributaries Castle, South Fork Castle, and ditch Creeks in the Black Hills, South Dakota (Figure 3-1). Castle Creek sampling locations were distributed from the mouth of Deerfield Reservoir upstream to a point where upstream reaches flow exclusively through private property. Stream sampling sites in South Fork Castle Creek were confined to public land between its confluence with Ditch Creek and its confluence with Castle Creek. Our sampling sites on Ditch Creek were confined to an approximately 1 km reach immediately upstream of its confluence with South Fork Castle Creek and above which a series of beaver dams appears to restrict the upstream movement of Rainbow Trout.

Abundance and Movement

Using a random number generator, we randomly selected 15, 100 m stream sites throughout the stream reaches previously described. To estimate the area of each site, stream widths were taken every 10 meters, averaged, converted, and expressed as hectares (ha). Rainbow Trout were collected using backpack electrofishing (Smith-Root LR-24; Smith Root, Inc., Vancouver, WA), and origin was discerned by presence (wild) or absence (hatchery) of an adipose fin and a total length less than 250 mm for wild fish. Wild Rainbow Trout were anesthetized using CO_2, measured for length (mm) and weight (g), and any fish over 90 mm (recommended minimum length) was implanted with a half-duplex, 12 mm Passive Integrated Transponder (PIT) tag using an injection needle (Oregon RFID, Portland, OR). Tags and injection needles were sanitized using iodine prior to injection into the body cavity. To investigate tag retention a subset of fish (n=101) were given a secondary mark by clipping the left pelvic fin.

Initial tagging of Rainbow Trout (n=162) was conducted at 15 sites during August and October 2013. Monthly recapture events were conducted from May-Aug. 2014, Oct.-Nov. 2014, and during April 2015. In order to increase sample size, all non-tagged Rainbow Trout collected in May 2014 (n=218) that were greater than 90 mm were tagged using the above methods. During recapture events fish were scanned for the presence of a tag using a handheld PIT tag reader (Biomark 601; Biomark Inc., Boise, ID). During all recapture events fish were checked for fin clips and tag number and total length to the nearest mm were recorded for analysis. In addition, an in-stream passive PIT tag reader (HDX Long Range Reader; Oregon RFID, Portland, OR) was installed near the mouth of Deerfield Reservoir in order to determine emigration of tagged Rainbow Trout from tributary streams into Deerfield Reservoir (Figure 3-2). The passive reader was used from initial tagging in August 2013 through October 2014.

Abundance data from each 100 m site was calculated and expressed as number of fish per hectare. To estimate abundance, we separated fish into two groups, total length $\leq$90 or >90 mm, based on the minimum size used during PIT tagging methods. Mean abundance (fish/ha) of wild Rainbow Trout less than or greater than 90 mm was compared between South Fork Castle Creek and Castle Creek using a oneway analysis of variance (ANOVA). Additionally, in order to test for differences in abundance of wild Rainbow Trout in South Fork Castle Creek and Castle Creek across our sampling intervals we conducted an analysis of covariance (ANCOVA) where sampling date was used as a covariate.

Growth and Survival

Based on data from length-frequency analysis (Quist et al. 2012) we estimated mean length-at-age for wild Rainbow Trout up to 4 years old. Using the mean length-at-age data we constructed a Von Bertalanffy growth model for fish ages 1 through 4 using the equation

$$L_t = L\infty \{1\text{-}e[-k(t\text{-} t_0)]\}$$

where L_t is the length (mm) at time t, L∞ is the mean asymptotic length, k is the growth coefficient, and t_0 is a time coefficient when length is equal to 0 mm (Isley and Grabowski 2007). Von Bertalanffy growth parameters were then used to derive age-specific estimates of survival based on the equation

$$M(t) = \begin{cases} \dfrac{\kappa}{1 - e^{-\kappa(t_0)}}, t \le t_m \\ \dfrac{\kappa}{\alpha_0 + \alpha_1(t - t_m) + \alpha_2(t - t_m)^2}, t \ge t_m \end{cases}$$

(Chen and Watanabe 1989)

where $M_{(t)}$ is estimated, natural mortality at time (age) t, and t_m is time (age) at maturity,

$$\begin{cases} a_0 = 1 - e^{-k(t_m - t_m)} \\ a_1 = ke^{-k(t_m - t_0)} \\ a_2 = -\frac{1}{2}k^2 e^{-k(t_m - t_0)} \end{cases}$$

$$t_M = -\frac{1}{k} 1n(1 - e^{kt_0}) + t_0$$

Results

Abundance

Mean abundance (fish/hectare) of wild Rainbow Trout less than 90 mm was significantly higher in South Fork Castle Creek when compared to Castle Creek ($p<0.001$, $F=20.395$, Table 4-1). Similarly, mean abundance of wild Rainbow Trout greater than 90 mm was also significantly higher in South Fork Castle Creek than Castle Creek ($p<0.001$, $F=15.721$). Temporal changes in Rainbow Trout abundance greater than 90 mm was not significant based on the stream*date interaction, indicating that temporal abundance trends were similar between streams (Figure 3-3). Conversely, our analysis of Rainbow Trout abundance less than 90 mm included a significant ($p < 0.05$) stream*day interaction, indicating that the magnitude of temporal changes in abundance was greater in South Fork Castle Creek than in Castle Creek (Figure 3-4).

Growth

Growth of wild Rainbow Trout up to age 4 in tributary streams of Deerfield Reservoir was described by the Von Bertalanffy growth equation

$$L_t = 312.91 \{1\text{-}e[-0.3(t- 0.29)]\}$$

and shows relatively slow growth in comparison to other populations (Figure 3-5).

Movement

To our knowledge, no loss of PIT tags occurred throughout the study based on 100% retention of tags in wild Rainbow Trout that were given a secondary mark. Of the 380 fish implanted with PIT tags we passively detected or recaptured a total of 154 (41%) unique Rainbow Trout during subsequent sampling events. Within and among stream movement of PIT tagged Rainbow Trout was minimal over the course of our study. Of the 81 unique fish recaptured (backpack electrofishing) during post-tagging sampling events, only 3 were captured outside their 100 meter
site of origin. Additionally, another 73 unique fish were passively detected by our stationary reader, indicating emigration from the tributary system into the reservoir (Figure 3-6). Most emigration occurred during the spring and early summer of 2014, with most Rainbow Trout emigrating during May and June 2014 respectively (Figure 3-7). A total of

10 fish emigrated during other months suggesting that small numbers of wild Rainbow Trout may emigrate during other times of the year.

Survival

Annual, age-specific mortality (A_i) of wild Rainbow Trout in Deerfield Reservoir was described by the equation

$$A_i = 0.194 + 0.775e^{(-0.445 * age)},$$

where age is in years. Age-specific mortality estimates for wild Rainbow Trout in the Deerfield Reservoir system ranged from 97% for age 0 fish to 34% for age 4 fish (Table 3-2). Estimates of annual mortality were noticably high during the first year of life, but decreased appreciably by age 4 (Figure 3-7).

Discussion

Mortality of Rainbow Trout in Deerfield Reservoir was greater than 95% during the first year of life. This estimate is similar to values reported by Mitro & Zale (2002) where age 0 Rainbow Trout mortality ranged between 77% and 100%, which they attributed to lack of suitable overwinter habitat. Biro et al. (2003) found that smaller individuals experienced overwinter mortality rates in excess of 90% due to depleted lipid reserves. Additionally, Simpkins et al. (2003) showed that mortality of juvenile Rainbow Trout could be predicted by lipid reserves. Our survival estimates also produced values similar to those produced by other indirect methods of survival/mortality estimation proposed by Peterson and Wroblewski (1984), Jensen (1996), and Pauly (1980).

Due to the deleterious effects of stocking on wild Rainbow Trout such as reduced genetic fitness and competition for prey resources, eliminating hatchery stockings could potentially increase the growth, survival, and abundance of wild Rainbow Trout in Deerfield Reservoir. Davis (2012) showed that hatchery fish stocked into Deerfield Reservoir moved upstream into both South Fork Castle Creek and Castle Creek during traditional spring spawning timeframes. Studies on Rainbow Trout have shown that age-0 fish produced from the matings of two wild fish had significantly higher survival when compared to crossings of a hatchery and wild fish or two hatchery fish (Reisenbichler and McIntyre 1977). Hatchery fish spawning in tributary streams could mate with wild fish and thus negatively influence survival of naturally reproduced progeny. Additionally, Petrosky and Bjornn (1988) showed that high stocking densities of Rainbow Trout negatively influenced the survival of wild, Cutthroat Trout *Oncorhynchus clarkii*. Wild Rainbow Trout abundance and biomass increased up to 10 fold four years after the elimination of catchable Rainbow Trout stockings (Vincent 1987).

Our growth model shows that wild Rainbow Trout in the Deerfield Reservoir system could reach approximately 60 mm by the end of their first year of life. Fish at this size could be vulnerable to depleted lipid levels during overwintering periods which may explain the high rates of mortality observed in age 0 Rainbow Trout. While high rates of mortality in age 0 cohorts may be observed in some years, the presence and relative abundance of wild Rainbow Trout of all sizes throughout the year suggests that recruitment is consistent from year to year.

Abundance of wild Rainbow Trout in tributary streams was variable throughout the year. We observed that abundance in fall months can become inflated due to the recruitment of age-0 fish to the electrofishing gear. Abundance estimates are also likely to be inflated in spring months when lake dwelling Rainbow Trout return to the streams during spawning in April and May. Based on emigration of tagged fish, most spawning Rainbow Trout return to the reservoir by mid-June. Due to these phenomena, abundance estimates are more likely to be stable across years in the month of July and therefore a better indicator of year to year abundance patterns.

Wild Rainbow Trout abundance was greater in South Fork Castle Creek than in Castle Creek. Observations made in the field, while not quantified, indicate that these differences could be driven by habitat. We observed that there may be marked differences in large woody debris (LWD) inputs between South Fork Castle Creek and Castle Creek. Large woody debris is known to have positive impacts on salmonid fisheries. Benke and Wallace (2003) found that LWD was positively correlated with greater invertebrate abundance which could result in increased growth for trout species. Additionally, Dolloff and Warren (2003) suggested that

LWD provides fish with cover habitat that decreased predation. South Fork Castle Creek meanders through mature Ponderosa Pine forest and the proximity of these trees to the stream often results in the recruitment of wood via fallen trees. In contrast, Castle Creek meanders through open meadow and the distance to large trees greatly restricts the potential recruitment of LWD into the stream which causes a general lack of overwintering habitat such as deep pools and runs.

Management Implications

South Fork Castle Creek appears to be the most important tributary stream for spawning and production of wild Rainbow Trout based on greater abundance of fish under 90 mm. South Fork Castle Creek also supports a greater abundance of Rainbow Trout greater than 90 mm. Further investigation into the drivers of these abundance differences could be useful in guiding future research and management activities.

Habitat in Castle Creek, specifically in relation to LWD recruitment and retention, could be a potential area for future research. Based on my research, personal observations, and review of relevant literature an increase in LWD in Castle Creek could potentially increase wild Rainbow Trout production and growth, decrease predation by both fish and avian predators, and increase abundance through the creation of pool habitats.

Abundance patterns, coupled with estimates of survival and emigration of wild Rainbow Trout, indicate that future management activities could include an elimination or reduction of hatchery Rainbow Trout stockings in Deerfield Reservoir. A decision to eliminate or reduce stocking of Rainbow Trout into Deerfield Reservoir may result in lower angler catch rates, especially in the initial years, however monitoring of catch rates through a creel survey could help identify increases in the abundance of wild Rainbow Trout in the reservoir.

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Table 3-1. Mean abundance of wild Rainbow Trout (RBT) in Castle Creek and South Fork Castle Creek, South Dakota. Values within the same column with different letters were significantly different ($p<0.05$).

Stream	Mean Stream Width (m)	Mean Abundance ± SE (fish/ha) of RBT ≤ 90 mm	Mean Abundance ± SE (fish/ha) of RBT > 90 mm
Castle Creek	2.15	35 ± 9 a	312 ± 43 a
South Fork Castle Creek	3.66	195 ± 32 b	610 ± 60 b

Table 3-2. Indirect mortality estimates of Wild Rainbow Trout in the Deerfield Reservoir system, South Dakota.

Age	Mean length (mm)	Total Annual Mortality
0	40	0.97
1	60	0.70
2	125	0.53
3	175	0.41
4	210	0.34

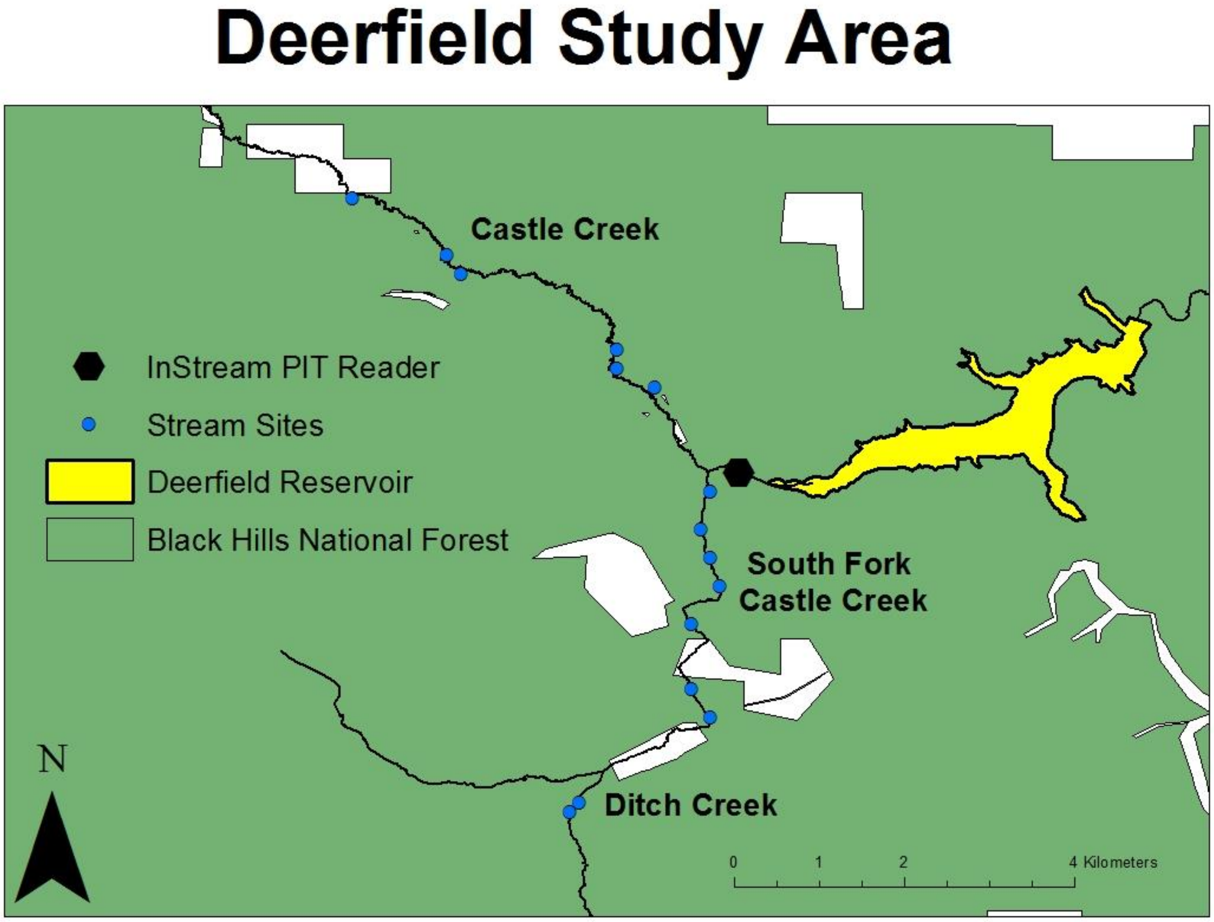

Figure 3-1. Map of Rainbow Trout sampling sites and the location of a stationary passive integrated transponder (PIT) tag reader in the Deerfield Reservoir System, South Dakota.

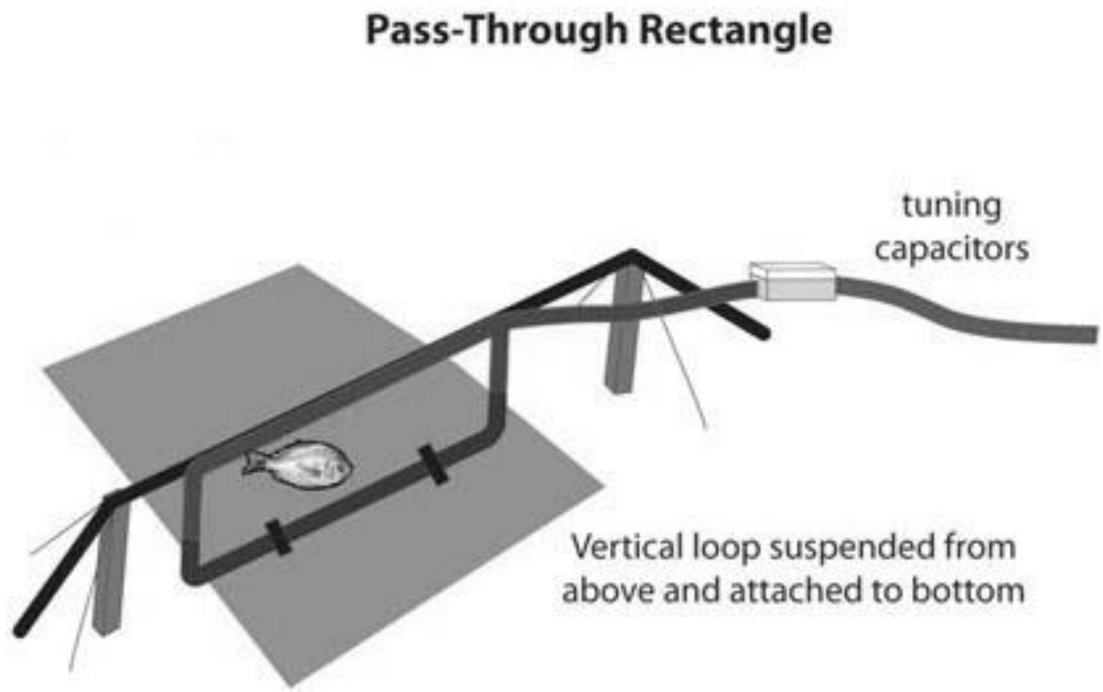

Figure 3-2. Antenna design configuration of the stationary passive integrated transponder (PIT) tag reader located above Deerfield Reservoir in Castle Creek, South Dakota. Image created by Oregon RFID, Portland, Oregon.

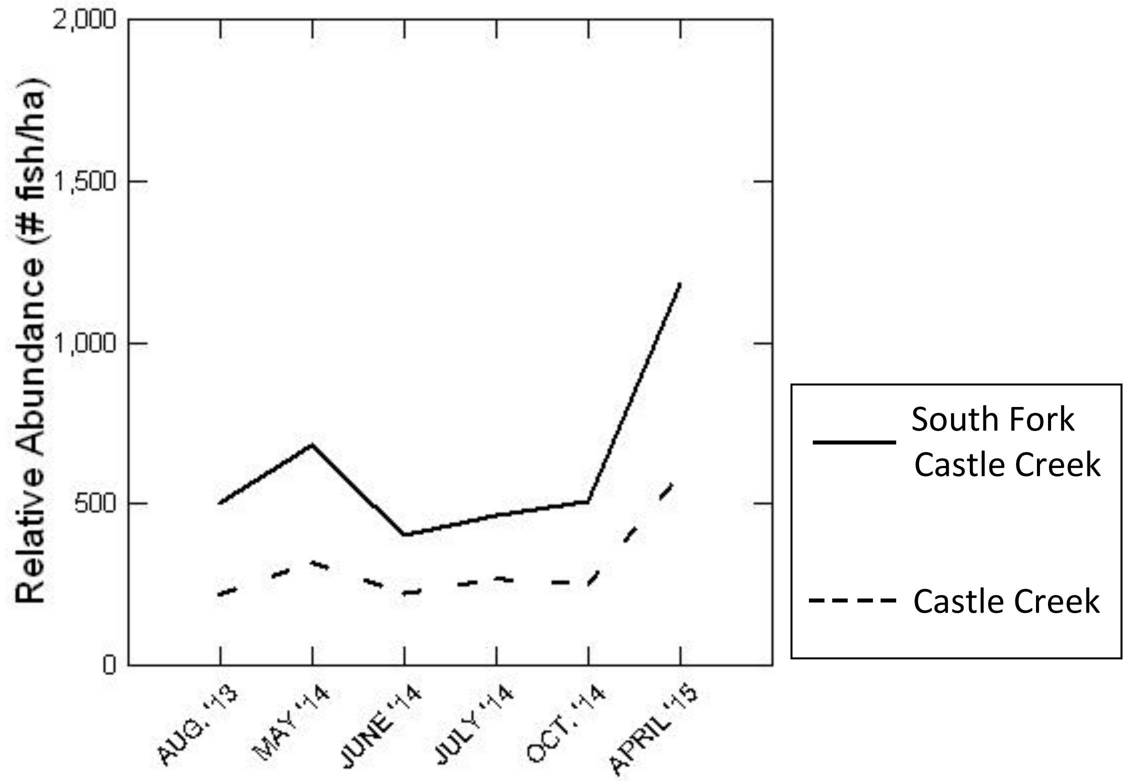

Figure 3-3. Abundance of wild Rainbow Trout greater than 90 mm in Deerfield Reservoir tributary streams from August, 2013 through April, 2015.

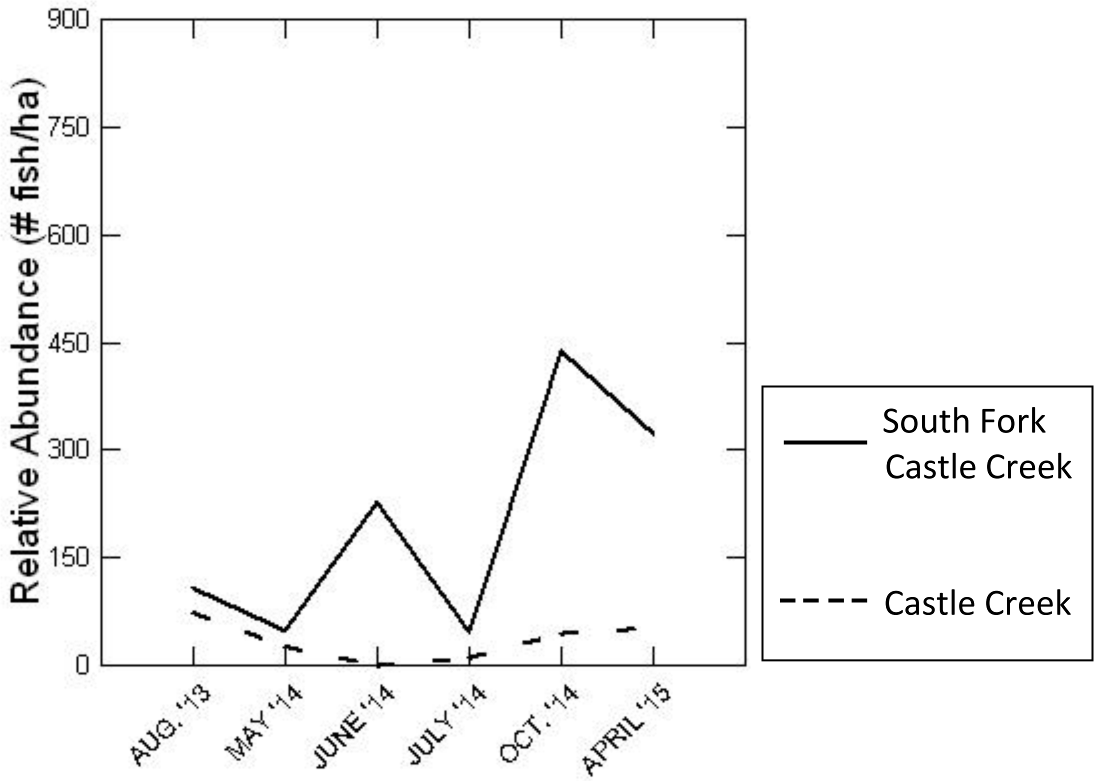

Figure 3-4. Abundance of wild Rainbow Trout less than 90 mm in Deerfield Reservoir tributary streams from August, 2013 through April, 2015.

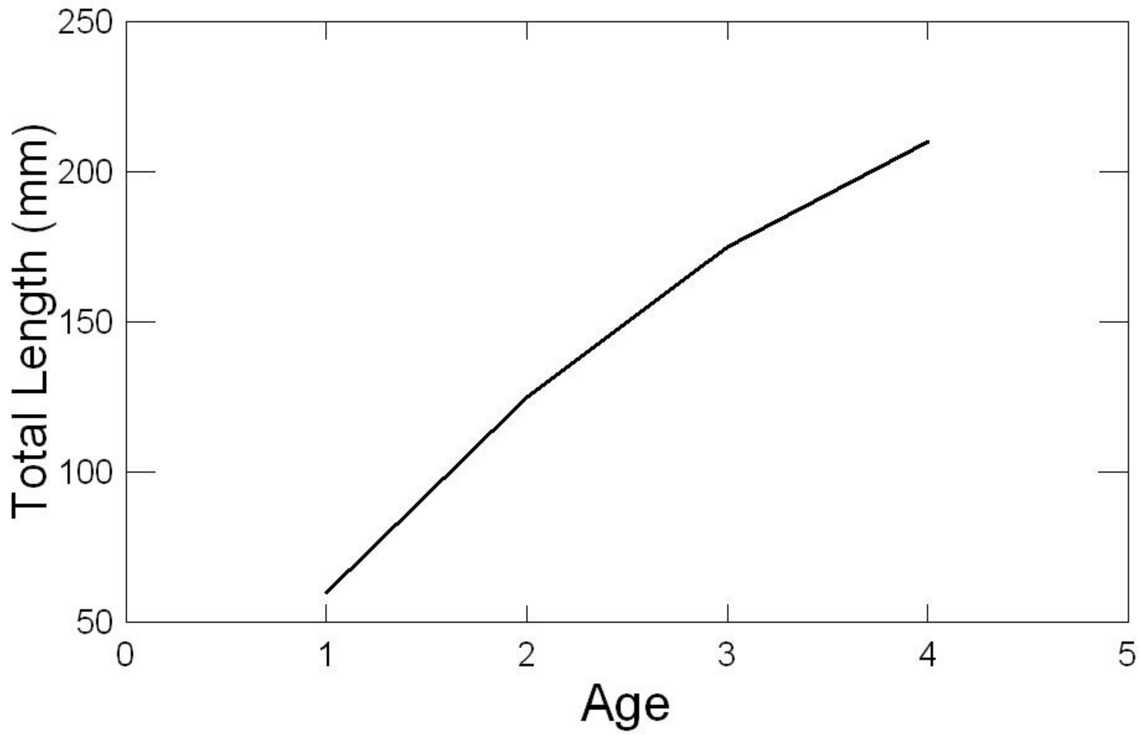

Figure 3-5. Von Bertalanffy growth curve of wild Rainbow Trout (ages 1-4) in the Deerfield Reservoir system, South Dakota.

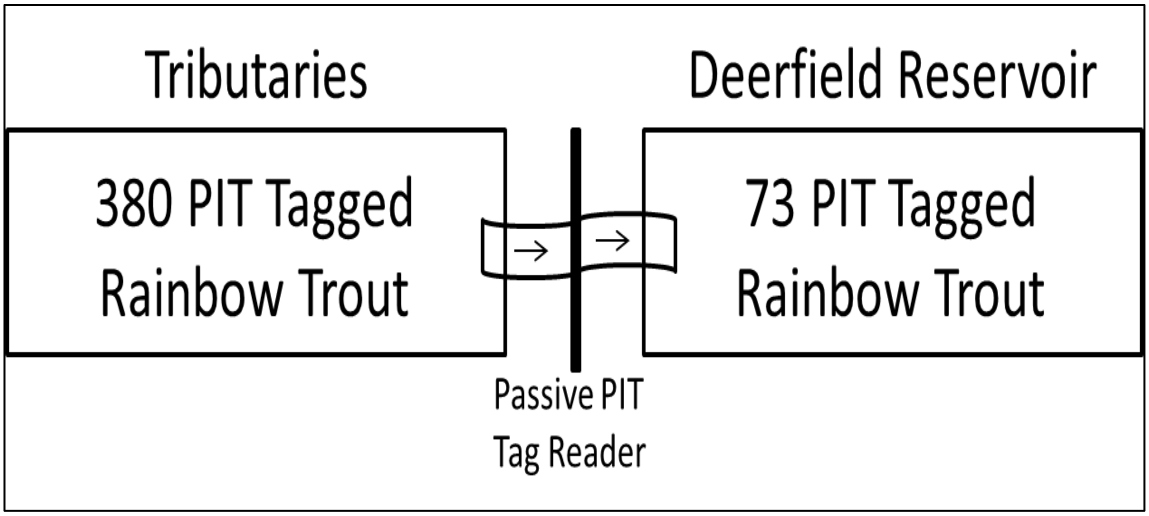

Figure 3-6. Schematic of passive integrated transponder (PIT) tagged wild Rainbow Trout emigration from Castle Creek and South Fork Castle Creek tributary streams into Deerfield Reservoir, South Dakota detected by the use of a passive PIT tag reader.

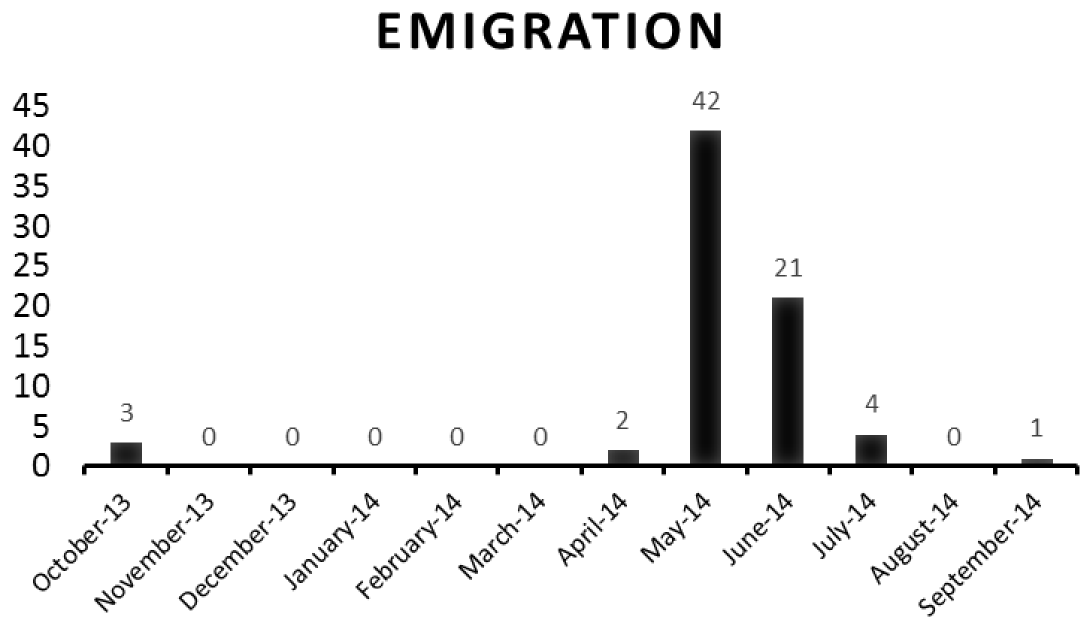

Figure 3-7. Monthly number of fish emigrating from tributary streams into Deerfield Reservoir, South Dakota from October 2013 through September 2014.

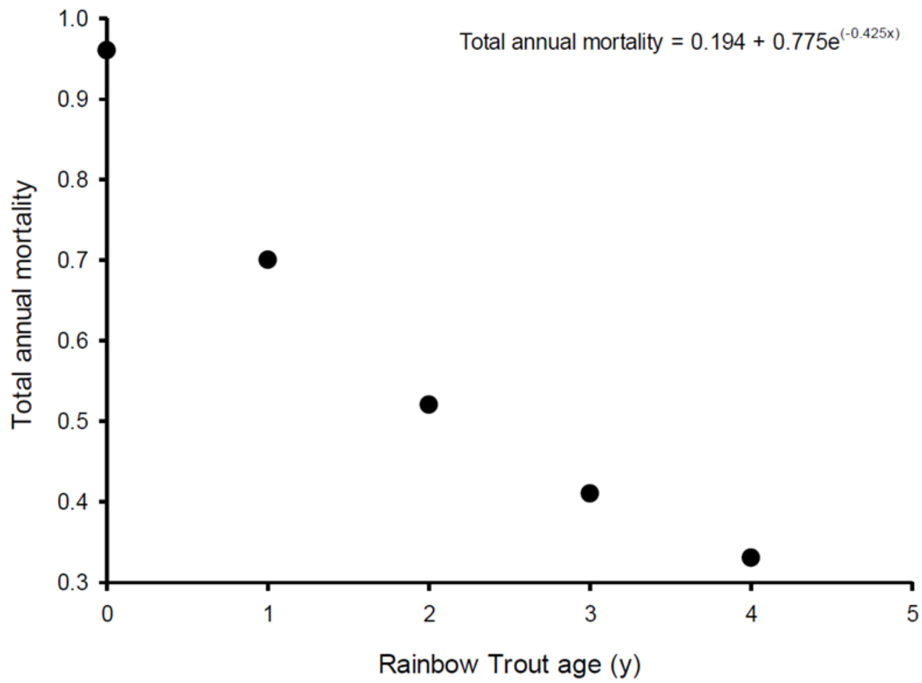

Figure 3-8. Indirect estimates of total annual mortality of wild Rainbow Trout in the Deerfield Reservoir system based on the equation given by Chen and Watanabe (1989).

CHAPTER 4: Classification of Wild and Hatchery Rainbow Trout with Reference to Natal Stream Origins of Wild Fish in the Deerfield Reservoir System, South Dakota

Introduction

Deerfield Reservoir is one of only two aquatic systems in the Black Hills of South Dakota that supports a Rainbow Trout *Oncorhynchus mykiss* population through natural reproduction. While naturally reproduced Rainbow Trout are believed to contribute to the overall fishery in Deerfield Reservoir (Davis 2012), the population is annually stocked by McNenny State Fish Hatchery with about 12,000 catchable-sized (~275 mm) Rainbow Trout in order to maintain desirable catch rates. Thus, to better understand the contribution of wild Rainbow Trout to a population, it is essential that fisheries managers have the ability to distinguish between wild and hatchery fish.

Wild Rainbow Trout from Deerfield Reservoir reproduce in upstream tributaries that include Castle and South Fork Castle Creeks. We found that young-of-the-year Rainbow Trout produced in tributary streams recruit to adulthood and eventually emigrate downstream into Deerfield Reservoir (See Chapter 3). Davis (2012) identified that Rainbow Trout were using both streams during the spring spawning season, however it remains unknown the extent to which these streams contribute recruits to the overall reservoir fishery.

Beginning in 2009, hatchery-reared Rainbow Trout stocked into Deerfield Reservoir received an adipose fin clip to distinguish them from wild produced Rainbow Trout. Thompson and Blankenship (1997) found that complete removal of the adipose fin resulted in no regeneration, thus providing a reliable, long-term mark. However, due to time and cost constraints, adipose fin clipping was discontinued in August 2014, although South Dakota Game, Fish and Parks continues to assess fluctuations in the wild Rainbow Trout population through annual surveys. The absence of adipose fin clips to identify hatchery reared Rainbow Trout in future monitoring efforts necessitates research into alternative methods for classification of natal origins.

In a recent study to evaluate the contribution of wild Rainbow Trout to the fishery, Davis (2012) used scale growth characteristics to classify the origin of fish as either hatchery or wild. However, Davis (2012) found a moderate degree of overlap in circuli measurements between wild and hatchery fish that introduced uncertainty in classifying trout as either hatchery or wild fish, in lieu of other characteristics (i.e., fin clips).

Stable isotope analysis (SIA) has been widely used to distinguish fish that rely on different sources of organic carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) (Hobson 1999; Schroder and Garcia de Leaniz 2011; Quinn et al. 2012). Similarly, otolith microchemistry has been used for determining natal origins in a variety of freshwater fishes (Campana et al 2000; Gibson-Reinemer et al. 2009; Zitek et al. 2010; Carlson 2015).

Using $\delta^{13}C$ and $\delta^{15}N$ isotopes, Estep and Vigg (1985) found distinct differences in wild and hatchery Lahontan Cutthroat Trout *Oncorhynchus clarkii henshawi*. Similarly, Quinn et al. (2012) detected significant differences in $\delta^{13}C$ and $\delta^{15}N$ isotope values of wild and hatchery Steelhead *Oncorhynchus mykiss*. Gibson-Reinemer et al. (2009) demonstrated the effectiveness of otolith microchemistry where hatchery Rainbow Trout moved between distinct hatcheries could be classified to their hatchery of origin with 96% accuracy using Sr and Ba trace element concentrations together with $^{87}Sr/^{86}Sr$ isotopes.

In the absence of adipose fin clips, stable isotope analysis and otolith microchemistry may be useful techniques for the classification and natal origin determination of wild and hatchery Rainbow Trout in the Deerfield Reservoir system. Thus our objectives were to 1) investigate the use of stable isotope analysis for classification of hatchery-reared and wild Rainbow Trout, and 2) evaluate the use of otolith microchemistry as a method for distinguishing natal stream origins of wild Rainbow Trout in Deerfield Reservoir.

Methods

Study Area

Deerfield Reservoir is located 42 km west of Rapid City, South Dakota on Castle Creek with a pool elevation of 1,792 m. Storage of Deerfield Reservoir is 1,781 ha-m when at full pool, with a regulated out-flow of ~0.25 m^3/sec and is operated in tandem with Pactola Reservoir, located downstream on Rapid Creek, by the U. S. Bureau of Reclamation. McNenny State Fish Hatchery is located 10 miles west of Spearfish, South Dakota.

Stable Isotopes

We collected fish in June 2014 from raceways at McNenny State Fish Hatchery, which stocks Deerfield Reservoir, one week prior to stocking in order to identify baseline isotope signatures for $\delta^{13}C$ and $\delta^{15}N$ in fin and muscle tissue of hatchery origin Rainbow Trout. All fish were given a pelvic fin clip (PFC) prior to stocking in order to distinguish them from prior stockings marked with an adipose fin clip (AFC). In August 2014, we collected fish from Deerfield Reservoir and characterized hatchery fish as those with a PFC (2 months at-large) or those with an AFC (> 1 year at-large). Rainbow Trout with no fin clip were presumed to be wild fish. Fish were immediately euthanized and frozen for transport back to the laboratory for further preparation of samples at South Dakota State University, Brookings, SD.

We clipped both pectoral fins and collected a 1-2 g sample of dorsal muscle tissue from all fish. Fin and muscle samples were dried at 60˚C to a constant weight, ground to a fine powder with a mortar and pestle and sealed in sterile glass scintillation vials. Analysis of isotope samples was conducted by the Cornell University Stable Isotope Laboratory (COIL; http://www.cobsil.com).

Otolith Microchemistry

Duplicate water samples from the Deerfield Reservoir system and McNenny State Fish Hatchery were collected in April 2015 to identify trace element concentrations. Water sample collection and measurement of trace elements were accomplished using the methods described by Carlson (2015). Calcium was used as a pseudointernal standard (Bickford and Hannigan 2005; Ludsin et al. 2006; Whitledge et al. 2007).

Wild Rainbow Trout were collected from stream sites in Castle Creek and South Fork Castle Creek using backpack electrofishing and from Deerfield Reservoir using boat nighttime electrofishing. In order to prevent otolith contamination, Rainbow Trout were sacrificed immediately after collection and placed on ice. Sagittal otolith removal and storage was completed using sterile procedures (Campana et al. 2000; Brazner et al. 2004; Zeigler and Whitledge 2010). Adult otoliths were sectioned in the transverse plane using a low-speed Isomet diamond saw, whereas age-0 otoliths were sanded and polished using 600 grit sandpaper.

We used an Agilent Technologies 7500a quadrupole inductively coupled plasma mass spectrometer (ICPMS) at the University of California–Davis Interdisciplinary Center for ICPMS to measure a suite of trace elements (i.e., ^{88}Sr, ^{86}Sr, ^{138}Ba, ^{137}Ba, ^{24}Mg, ^{55}Mn, and ^{23}Na). Laser settings, calibration, and quality control standards followed the methods outlined by Carlson (2015). Rainbow Trout otoliths were ablated at the core, edge, and at each annuli. Core ablations were used for analysis of natal origins. For each spot, a 15-s laser warm-up time was followed by a 20-s dwell time during which the sample was ablated. The integration time for all elements (0.01 s for ^{43}Ca, 0.05 s for ^{88}Sr and ^{137}Ba) was repeated throughout the 20-s dwell time. Following ablation, there was a 95-sec washout time.

Statistical Analysis

Using PROC DISCRIM in SAS, data were analyzed using the K-nearest neighbor (KNN) classification approach to evaluate classification accuracy of $\delta^{13}C$ and $\delta^{15}N$ signatures in fin and muscle tissues and trace element concentrations in sagittal otoliths for discrimination of wild and hatchery origin Rainbow Trout and natal stream origins. This non-parametric method has been used in previous studies to analyze otolith data which do not meet parametric assumptions (Carlson 2015; Bickford and Hannigan 2005). Furthermore, KNN has been shown to be a powerful statistical approach for analysis of stable isotope data, even with small sample sizes (Rosing et al. 1998). Cross-validation was used to better assess classification accuracy and associated error.

We used KNN (k=4) analysis to classify wild Rainbow Trout (n=12), baseline hatchery (n=50) fish collected prior to stocking, and known hatchery origin trout at large in Deerfield Reservoir for 2 months (n=19) and greater than 12 months (n=10). Analysis of sagittal otoliths was conducted using known origin wild Rainbow Trout collected from Castle Creek (n=14) and South Fork Castle Creek (n=11) to create a test data set for KNN (k=9) classification of natal stream origin based on ^{88}Sr and ^{137}Ba trace element concentrations. We then used otolith trace element signatures from wild Rainbow Trout collected in Deerfield Reservoir (n=9) in order to evaluate classification to natal tributary streams and the relative contribution of Castle and South Fork Castle Creeks to the overall reservoir fishery.

Results

Stable Isotopes

While $\delta^{15}N$ values were generally similar between hatchery and wild origin Rainbow Trout, $\delta^{13}C$ values were depleted in wild and hatchery fish at-large in Deerfield Reservoir. Hatchery Rainbow Trout at-large for 2 months showed isotope values similar to baseline hatchery values, while fish at-large for over 1 year had depleted $\delta^{13}C$ values that were intermediate to wild and baseline hatchery values (Figs 4-1 and 4-2). Mean baseline $\delta^{15}N$ and $\delta^{13}C$ values for hatchery fish collected from raceways at McNenny State Fish Hatchery were 10.5 ‰ and -21.0 ‰ in muscle tissue, and 9.3 ‰ and -19.3 ‰ in fin tissue (Table 4-1). Wild Rainbow Trout collected from Deerfield Reservoir had similar $\delta^{15}N$ values to hatchery fish with mean values of 10.2 ‰ in muscle tissues and 9.7 ‰ in fin tissues, however values for $\delta^{13}C$ were depleted in wild fish where we observed mean $\delta^{13}C$ values of -31.4 ‰ and -29.8 ‰ in muscle and fin tissues, respectively.

KNN results for the calibration data using both fin and muscle tissues provided cross-validated classification accuracy greater than or equal to 75% for wild and hatchery Rainbow Trout collected from Deerfield Reservoir (Figure 4-3). Fin tissue accuracy was lower than muscle for both wild and hatchery fish, however fin tissues provide the added benefit of non-lethal sample collection. Randomly selected fin (n=3) and muscle (n=3) samples were tested and classified to natal origin with 100% accuracy (Table 4-2).

Otolith Microchemistry

Based on trace element concentrations of ^{88}Sr and ^{137}Ba, cross-validated classification accuracy of calibration data using known wild Rainbow Trout collected in Castle Creek and South Fork Castle Creek was 64% and 82%, respectively (Figure 4-4). Using wild Rainbow Trout collected from Deerfield Reservoir (unknown stream origin) as test data, 56% and 44% were classified to Castle and South Fork Castle Creeks, respectively (Figure 4-5).

Discussion

We found that stable isotope analysis can be used to reliably classify wild or hatchery Rainbow Trout in Deerfield Reservoir with accuracy greater than 75%. Both fin and muscle tissues had high classification accuracy and provide fisheries managers with options for non-lethal sampling. In addition, otolith microchemistry can identify natal stream contributions using trace element concentrations in the sagittal otoliths of wild fish.

Samples from Deerfield Reservoir Rainbow Trout had mean muscle $\delta^{13}C$ values of -31.4 ‰ in wild fish compared with -26.2 ‰ in the muscle tissues of hatchery origin Rainbow Trout. Cucherousset (2007) found that $\delta^{13}C$ values became depleted in Brown Trout *Salmo trutta* as their diet shifted with increased consumption of terrestrial invertebrates. We found that aquatic and terrestrial invertebrates were the primary diet components of Rainbow Trout collected from Deerfield Reservoir (See chapter 2). Baseline $\delta^{13}C$ values in muscle and fin tissues from our study were -21.0 ‰ and -19.3 ‰, respectively. These results were similar to those found by Estep and Vigg (1985) where hatchery Lahontan Cutthroat Trout $\delta^{13}C$ values closely resembled that of hatchery feeds and ranged from -18.3 ‰ to -20.0 ‰ in comparison to a $\delta^{13}C$ values of -31.4 ‰ and -29.8 ‰ in fin and muscle samples collected from wild fish. Based on the literature and our results we expect that as hatchery-reared Rainbow Trout consume invertebrate prey their $\delta^{13}C$ values will change.

As Rainbow Trout in Deerfield Reservoir continue to feed on natural prey such as aquatic invertebrates their isotope signatures will eventually equilibrate to values similar to wild fish. The rate at which this process occurs is dependent on many factors including acquisition of natural prey and subsequent growth and turnover rates of body tissues. Our sample of 1+ years post-stocking hatchery fish from Deerfield Reservoir was assumed to be representative of individuals remaining from all previous stockings. Based on this assumption and baseline isotope signatures, we found that mortality of stocked Rainbow Trout likely occurs prior to a full equilibration of their isotopic signatures to that of wild fish. The mechanism for our observation of slow equilibration is likely due to poor assimilation of hatchery-reared trout to natural prey resources which is reflected in a low, 5-year mean relative weight (Wr) value of 74.1 (Miller et al. 2013) compared to pre-stocking Wr values likely to be equal to or greater than 100 (M. Barnes; Hatchery Manager, McNenny State Fish Hatchery, Spearfish, SD, personal communication).

Our results indicate that the contribution of Rainbow Trout from Castle Creek and South Fork Castle Creek to the overall reservoir population is similar, with Castle Creek providing a slightly greater contribution. This contrasts with our results showing a greater abundance of wild produced Rainbow Trout in South Fork Castle Creek when compared to lower abundance levels in Castle Creek (See Chapter 3). Unequal representation in our sample, unexplained variation in trace element concentrations, or differential survival of recruits could be contributing to the incongruity of these results.

Management Implications

While our study was confined to Deerfield Reservoir, our results demonstrate that these classification techniques may be viable options for fisheries managers seeking to identify wild or hatchery origins and natal stream origins of salmonid species in the Black Hills. Due to the widespread use of feeds containing marine-derived fish meal in hatchery rearing of salmonid species, our stable isotope results are likely to be transferable for hatchery-reared salmonids in freshwater systems; however we suggest caution and consideration of tissue turnover rates for stocked salmonids in systems where growth resulting from consumption of natural prey is assumed or expected.

As fisheries managers continue to monitor the Rainbow Trout population in Deerfield Reservoir our results will provide a means to identify wild individuals and subsequently identify the contribution of tributary streams to the overall fishery. We have also provided a means to identify wild individuals using non-lethal (fin) methods, which will help minimize sampling-related mortality in this unique population.

For state agencies operating under budget constraints stable isotope analysis provides a low cost option for natal origin analysis when compared to otolith microchemistry. When possible, SIA costs can be reduced by drying and grinding isotope samples prior to analysis. While some cost saving can be accomplished for otolith microchemistry samples, the cost for sample processing and lab fees are often 5-10 times greater than the cost of stable isotope analysis.

Overall our results provide tools for the long-term monitoring of wild Rainbow Trout in Deerfield Reservoir. When budgets allow our methods can be used with great accuracy to assess both the proportion of wild fish in the overall reservoir population and identify the contribution of distinct tributaries to the recruitment of wild Rainbow Trout. These tools will also provide a useful method for identifying trends in the wild Rainbow Trout population when annual sampling cannot be achieved.

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Table 4-1. Summary of mean $\delta^{13}C$ and $\delta^{15}N$ values in fin and muscle tissue samples of hatchery and wild Rainbow Trout collected from McNenny State Fish Hatchery (baseline) and Deerfield Reservoir, South Dakota. Mean values for 2 Months represent signatures of hatchery fish collected 2 months post-stocking and >12 Months represent fish collected greater than 12 months post-stocking.

Origin	N	Fin		Muscle	
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Baseline	50	-19.3 (0.07)	9.3 (0.04)	-21.0 (0.05)	10.5 (0.03)
2 Months	19	-20.0 (0.21)	10.5 (0.20)	-21.0 (0.09)	10.3 (0.06)
>12 Months	10	-25.3 (0.72)	9.6 (0.13)	-26.2 (0.69)	9.9 (0.10)
Wild	12	-29.8 (0.30)	9.7 (0.14)	-31.4 (0.24)	10.2 (0.12)

Table 4-2. Percent correct classification of randomly selected baseline hatchery and wild individuals based on $\delta^{13}C$ and $\delta^{15}N$ signatures of fin and muscle tissues. Hatchery origin trout were collected from McNenny State Fish Hatchery and wild fish were collected in Deerfield Reservoir, South Dakota.

Sample	Origin	$\delta^{13}C$	$\delta^{15}N$	Classification Accuracy (%)
Fin	Hatchery 2 Mos	-19.8	9.2	100
	Hatchery >12 Mos	-25.7	9.5	100
	Wild	-32.1	10.3	100
Muscle	Hatchery 2 Mos	-20.8	10.3	100
	Hatchery >12 Mos	-26.9	10.3	100
	Wild	-29.9	9.8	100

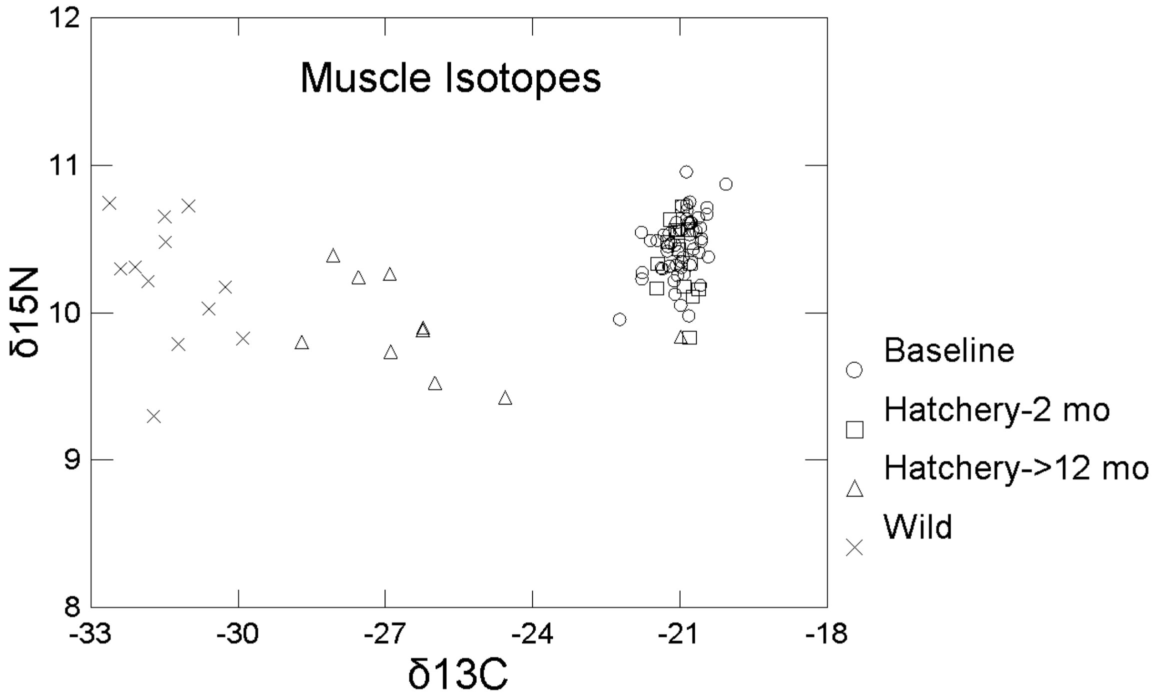

Figure 4-1. Muscle isotope signatures of $\delta^{13}C$ and $\delta^{15}N$ in wild and hatchery Rainbow Trout collected from McNenny State Fish Hatchery (Baseline) and Deerfield Reservoir. Hatchery 2 mo. indicates fish collected 2 months post-stocking and Hatchery >12 mo. indicates fish collected after greater than 12 months post-stocking.

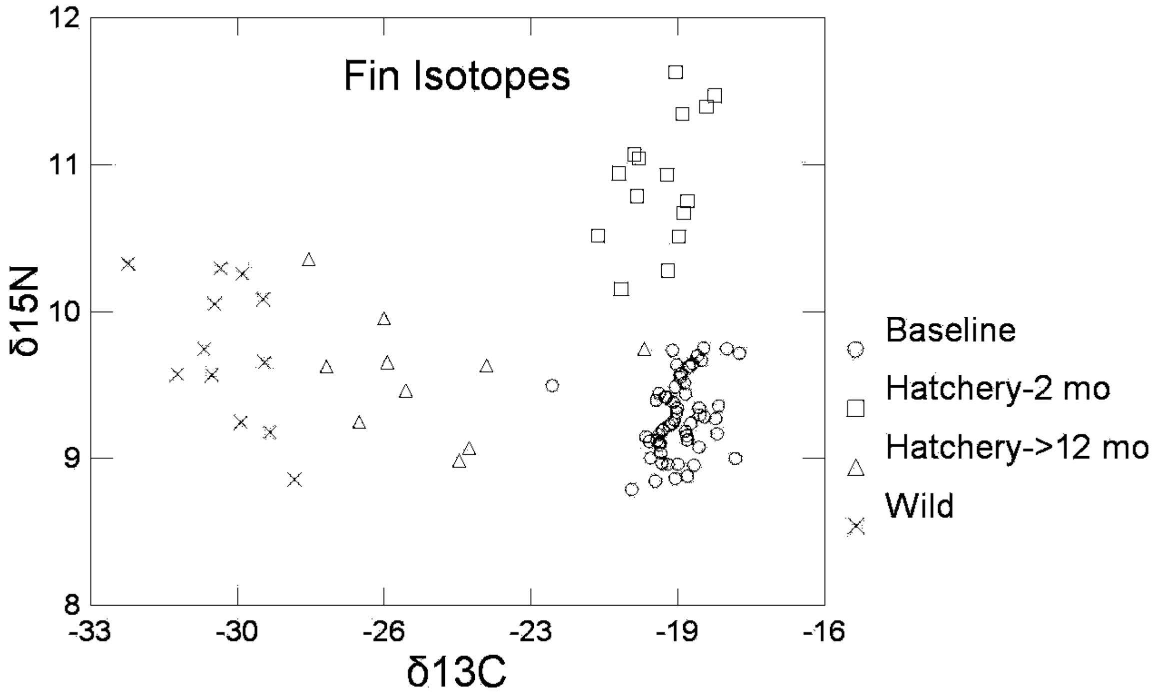

Figure 4-2. Fin isotope signatures of $\delta^{13}C$ and $\delta^{15}N$ in wild and hatchery Rainbow Trout collected from McNenny State Fish Hatchery (Baseline) and Deerfield Reservoir. Hatchery 2 mo. indicates fish collected 2 months post-stocking and Hatchery >12 mo. indicates fish collected after greater than 12 months post-stocking.

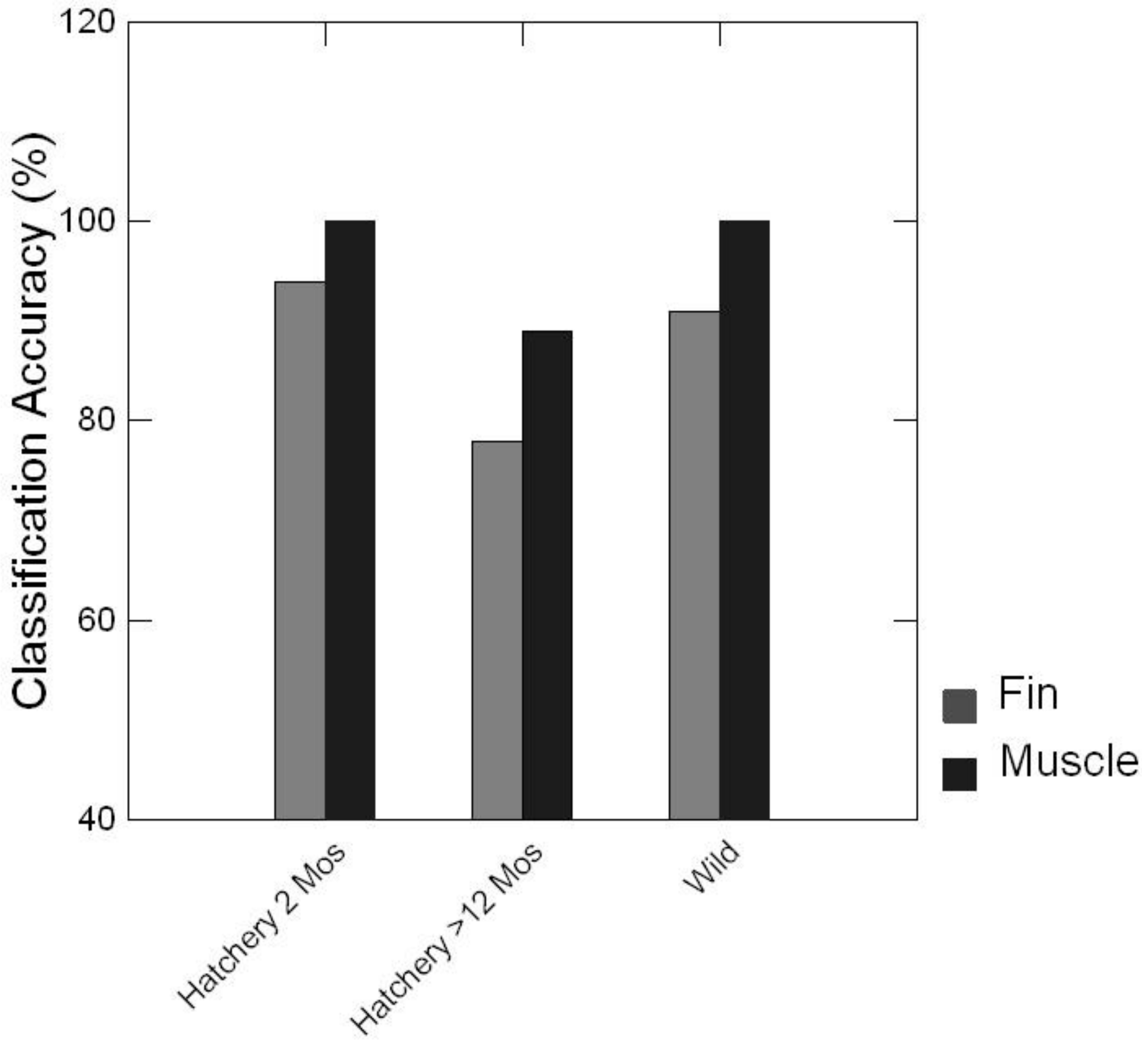

Figure 4-3. Percentage of correctly classified hatchery and wild Rainbow Trout collected from Deerfield Reservoir based on $\delta^{13}C$ and $\delta^{15}N$ isotope signatures of fin and muscle tissue samples. Hatchery 2 mo. indicates fish collected 2 months post-stocking and Hatchery >12 mo. indicates fish collected after greater than 12 months post-stocking.

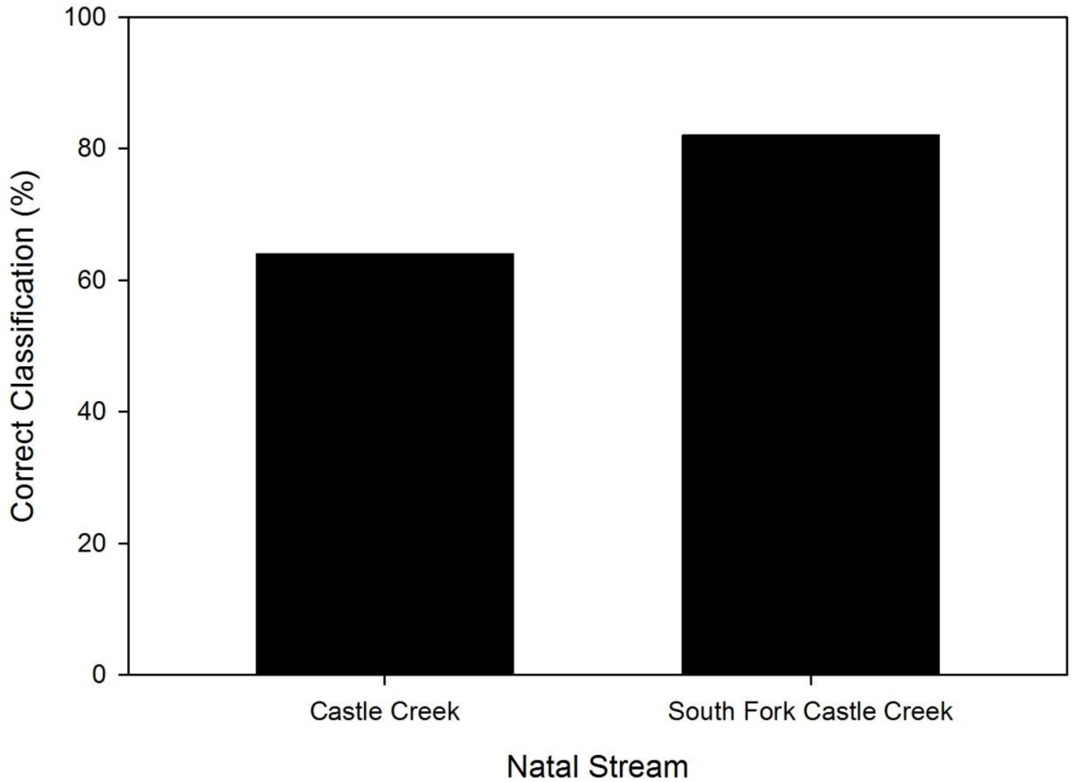

Figure 4-4. Percentage of known origin wild Rainbow Trout correctly classified to Castle Creek and South Fork Castle Creek natal tributary streams based on trace element concentrations from sagittal otoliths

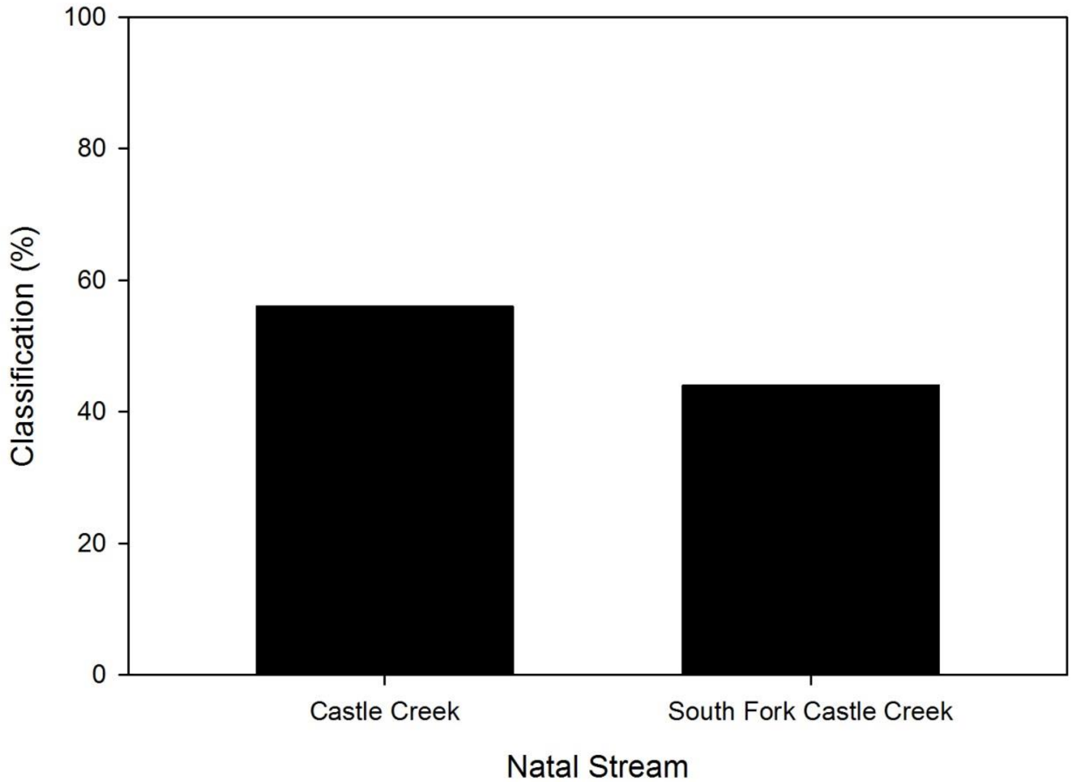

Figure 4-5. Percent classification of Rainbow Trout collected from Deerfield Reservoir to natal tributary streams based on trace element concentrations of sagittal otoliths.

CHAPTER 5: Summary and Research Needs

Summary

Our work has provided a greater understanding of the factors influencing wild Rainbow Trout in the Deerfield Reservoir System and their potential to sustain a viable population in the absence of hatchery stockings. Our research has provided fisheries managers with a foundation of knowledge regarding wild Rainbow Trout in Deerfield Reservoir and their interactions with introduced species, abundance, survival, and movement patterns, as well as provided methods for the classification of wild Rainbow Trout origins following the termination of hatchery fin clipping. Furthermore, our results will help guide management research and decisions regarding hatchery stockings or the potential reduction or elimination of these stockings in the future.

We showed that wild Rainbow Trout in Deerfield Reservoir have limited risk of predation by Rock Bass and Yellow Perch. The greatest risk of predation exists for wild Rainbow Trout less than 80 mm. We found that while it may be possible for Rainbow Trout to emigrate from tributaries into Deerfield Reservoir at these sizes, most fish migrating into Deerfield Reservoir have already attained sizes greater than 100 mm. In addition, our research quantified the diets of Rainbow Trout, Rock Bass, and Yellow Perch and upon subsequent analysis concluded that while diet overlap does exist between these species for invertebrate prey, there is little evidence to suggest these interactions would limit the wild Rainbow Trout population.

We quantified the abundance, movement patterns, growth, and apparent survival of wild Rainbow Trout in the Deerfield Reservoir System. We found that South Fork Castle Creek has much greater abundance of both juvenile and adult wild Rainbow Trout than Castle Creek. Based on these results we concluded that South Fork Castle Creek likely contributes a greater number of fish to the overall reservoir population than Castle Creek, however this conclusion contrasts with our analysis of the natal origins of wild Rainbow Trout using otolith microchemistry.

We tagged wild Rainbow Trout with Passive Integrated Transponder (PIT) tags in order to assess their movements in South Fork Castle Creek and Castle Creek and quantify the number of fish emigrating from tributary streams into Deerfield Reservoir. Movement of PIT tagged Rainbow Trout was minimal while in the stream reaches of both South Fork Castle and Castle Creeks. Out of a total of 380 tagged fish, we recaptured 81 unique PIT tagged Rainbow Trout in stream reaches and passively detected another 73 unique fish emigrating into Deerfield Reservoir. Throughout the course of our study only 3 of the 81 fish recaptured in tributary streams were recaptured outside of their 100 m site of origin. We hypothesized that emigration of wild Rainbow Trout would occur during periods of increased discharge during spring and early summer. Of the 73 fish that emigrated during our study, 86% (n=63) of wild Rainbow Trout emigrated in the months of May and June.

Growth of wild Rainbow Trout in the Deerfield Reservoir system appears to be slow in comparison to other populations. Based on length-frequency analysis and the fit of a Von Bertalanffy growth model to our data, we found that wild Rainbow Trout only reach a length of 60 mm by the end of their first year of life. We calculated growth for fish up to age 4 where wild Rainbow Trout had achieved a length of 210 mm.

Apparent survival of wild Rainbow Trout during their first year of life in Deerfield Reservoir was poor at just 3%, however survival steadily increases to over 45% at age 2, and greater than 65% at age 4. Based on the small size of age-0 fish (~ 60 mm) over-winter survival may be low in the first year. In spite of high mortality during the early life stage, abundance of multiple year classes and recruitment of wild Rainbow Trout appears to be consistent in Deerfield Reservoir and its tributaries.

Due to the termination of fin clips for hatchery Rainbow Trout stocked into Deerfield Reservoir we evaluated two techniques for the classification of Rainbow Trout origins. We found that fin and muscle tissues collected from wild Rainbow Trout can be used to classify wild and hatchery origin Rainbow Trout with over 75% accuracy. While muscle tissues provided accuracy greater than 85%, fin tissues may be desirable when non-lethal sampling is desired. In addition, we used otolith microchemistry to quantify the natal stream origins (Castle Creek or

South Fork Castle Creek) of Wild Rainbow Trout collected from Deerfield Reservoir. We found that Castle Creek (56%) contributed slightly more than South Fork Castle Creek (44%) to the overall Deerfield Reservoir population. This contrasts with our analysis of abundance and emigration of wild Rainbow Trout and may indicate that there is differential survival of wild Rainbow Trout produced in these two streams after emigration into Deerfield Reservoir.

Overall, our research has furthered our understanding of wild Rainbow Trout in Deerfield Reservoir. While a reduction or elimination of hatchery Rainbow Trout would likely result in lower catch rates for reservoir anglers, these management actions would likely benefit the wild Rainbow Trout population as shown in previous studies (i.e. increased fitness, abundance, and biomass). Following a reduction or elimination of stocking it would be wise for fisheries managers to maintain annual surveys in order to track changes in the dynamics of the wild Rainbow Trout population.

Research Needs

Continued assessment of fluctuations in the wild Rainbow trout population will be aided by the use stable isotope analysis and otolith microchemistry methods to determine the proportion of wild produced fish in future surveys as well as contribute an understanding of tributary stream contributions. Both techniques could be improved by continued research and application. Otolith microchemistry can be especially sensitive to temporal changes in trace element concentrations in various aquatic systems and may require periodic monitoring in order to validate future applications.

Data collection and analysis for this study ended prior to the stocking of adult Lake Trout *Salvelinus namaycush* into Deerfield Reservoir in 2015. Our diet analysis of potential fish predators indicated a low risk of predation upon wild Rainbow Trout. Analysis of adult Lake Trout diets will help to determine if predation on wild Rainbow Trout has any negative impacts. In addition, although competition for prey resources appeared negligible between Rainbow Trout, Yellow Perch, and Rock Bass, predation on these introduced species by adult Lake Trout may result in changes to other food web dynamics which may indirectly affect wild Rainbow Trout and should be considered during the assessment of this introduction.

Abundance of wild Rainbow Trout of all sizes was greater in South Fork Castle Creek than in Castle Creek. These results coupled with observations of greater runs of spawning adults in South Fork Castle Creek led to a hypothesis that the contribution of South Fork Castle Creek to recruitment of wild Rainbow Trout into the Deerfield Reservoir population was likely greater than the contribution of Castle Creek. Contrary to this hypothesis were results showing a greater contribution from Castle Creek in comparison to South Fork Castle Creek based on the natal stream origins of wild Rainbow Trout collected in Deerfield Reservoir. Future research should continue to evaluate these techniques and explore alternative ways to evaluate the importance of these tributary streams to recruitment of wild Rainbow Trout into the reservoir population.

During our study we observed vast contrasts in the stream habitats of South Fork Castle and Castle Creek that we were unable to evaluate within the scope of our research. We observed noticeable differences in large woody debris (LWD) inputs between South Fork Castle Creek which runs primarily through mature pine forest and Castle Creek which meanders primarily through open meadowland. Potentially due to the lack of LWD in Castle Creek there is also a lack of pool habitats which are important for overwinter survival. In addition, Beaver *Castor canadensis* activity was present in both streams but appeared to be the source of a large proportion of LWD inputs to Castle Creek. Given the positive influences of LWD to stream salmonid populations, a greater understanding of these habitat differences could provide key information for the management of the wild Rainbow Trout population.