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Factors Influencing Mortality of Stocked Rainbow Trout In Black Hills Reservoirs

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FACTORS INFLUENCING MORTALITY OF STOCKED RAINBOW TROUT IN BLACK HILLS RESERVOIRS

BY

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

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ABSTRACT

FACTORS INFLUENCING MORTALITY OF STOCKED RAINBOW TROUT IN BLACK HILLS RESERVOIRS

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Because return to angler is an important outcome of put-and-take fisheries, understanding mortality of stocked Rainbow Trout is fundamental to managing these fisheries. Harvest rates of stocked Rainbow Trout *Oncorhynchus mykiss* in the Black Hills of South Dakota are believed to be below management objectives. Rainbow Trout not harvested by anglers are assumed to be lost to various sources of mortality, raising concerns about the cost of the Rainbow Trout stocking program relative to the benefit provided to anglers. (Simpson 2008). This study evaluated the factors influencing mortality of Rainbow Trout stocked into Black Hills reservoirs. We assessed the effects of angling, environmental conditions, stress, and diet on mortality of stocked Rainbow Trout.

We conducted this study on four small reservoirs (~1-10ha) in the Black Hills between 2018 and 2019. Using creel surveys, we determined harvest rate and expected angling mortality based on angling type. We measured environmental variables to determine how habitat suitability for Trout varied spatially and temporally within and among reservoirs. We assessed stress levels in Rainbow Trout using three common physiological indicators found in blood plasma that included cortisol concentration, glucose, and lactate. We evaluated stomach contents to assess the timing and use of natural prey sources by stocked Rainbow Trout. Using an information theoretic approach, we developed models that best explain how biological and environmental factors influence mortality of stocked Rainbow Trout.

Estimated angling-related mortality for Rainbow Trout during the study was relatively high at 78% (15,497) and ranged from 42% to 80% among reservoirs. Harvest by anglers was the greatest source of mortality, with an estimated 56% (11,071) of the 19,900 Rainbow Trout harvested by anglers. Catch-and-release angling was the second largest source of mortality with 22% (4,426) of stocked Rainbow Trout lost to catch-and-release mortality. Estimated catch-and-release mortality ranged from 11 to 30% among study reservoirs. Both harvest and catch-and-release mortality were reliably predicted by environmental and biological parameters. Based on AIC analysis, our top candidate models explained 80% of the variation in harvest mortality of Rainbow Trout and 85% of the variation in catch-and-release mortality.

CHAPTER 1

INTRODUCTION

Rainbow Trout *Onchorynchus mykiss* are a Salmonid species native to North America west of the Rocky Mountains from southern Alaska to northern Baja Mexico (Ostberg and Rodriguez 2002). Due to their popularity as a sportfish and ease of hatchery propagation, they have been introduced throughout North America (Miko et al. 1995; Nico and Fuller 1999) and on every continent but Antarctica. Hatchery production of Rainbow Trout began in the United States in 1870 and today nearly 100 million Rainbow Trout totaling about 25 million pounds are stocked annually by state and federal agencies throughout the US (Halverson 2010). The stocking of catchable-sized Rainbow Trout is an important part of many cold-water fisheries programs (Branigan et al. 2021) with Rainbow Trout stocking being the largest component of cold-water fisheries expenditures by many state agencies (Johnson et al. 1995).

Rainbow Trout were introduced in the Black Hills of South Dakota in the late 1890s (Cordes 2007) and today are one of the most abundant species in the region. The Black Hills region contains the majority of South Dakota’s cold-water fish habitat and is the focus of South Dakota Game, Fish and Parks’ Rainbow Trout stocking program, which stocks around 200 locations in the Black Hills. The endemic fishes of the Black Hills are comprised of cyprinids and catostomids (Cordes 2007), however several species of salmonids have been introduced, primarily, Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus fontinalis*, and Lake Trout *Salvelinus namaychush*. The region has no natural lakes, but small impoundments are common throughout the Black Hills. These reservoirs were primarily constructed between 1930 and 1950 for the purposes of flood control, water storage, and recreation, with most currently managed for all three purposes (Simpson et al. 2015). Black Hills reservoirs generally exhibit low levels of productivity (Holcomb 2002) and have no significant natural Rainbow Trout recruitment, except for in Deerfield Reservoir (Davis 2012; Kientz et al. 2020). Stocking Rainbow Trout in these unproductive reservoirs allows fisheries managers to create instant and consistent angling opportunities in the Black Hills.

Survey data indicate that Rainbow Trout are the most sought-after fish by anglers in small impoundments in the Black Hills (Simpson 2009). To meet this demand, South Dakota Game, Fish and Parks operates two hatcheries in the Black Hills, which produce around 200,000 lbs. of Rainbow Trout annually for stocking in public streams and reservoirs.

Put-and-take Fisheries

The term "'put-and-take' fisheries" refers to the practice of stocking catchable-sized fish with the expectation they will be harvested by anglers usually in a short time frame. Stocked fish are not expected to reproduce or fully recruit to the fisheries where they are stocked (Patterson and Sullivan 2013). Put-and-take Rainbow Trout programs are one of the most commonly used fisheries management strategies in the US (Hyman et al. 2016; Johnson et al. 1995). In 2004, for example, 45 states implemented put-and-take stocking as part of their trout management program (Halverson 2008). In many cases, put-and-take Rainbow Trout programs are used to enhance existing cold-water fisheries as well as to create seasonal fisheries in cool and warm water systems. Put-and-take programs allow managers to create instant angling opportunities in waters not suitable for long-term fish survival, or where harvest would deplete wild stocks of fish.

Economic Impact of Put-and-take Rainbow Trout

Understanding the economic impacts of put-and-take fisheries is extremely important, given the high cost of producing catchable trout and declining angler participation (Barnes and Palmer 2019). Trout anglers represent 26% of all freshwater recreational anglers in the US (Charbonneau and Caudill 2010). Nationally, spending by recreational trout anglers supported over 100,000 jobs and generated $\$13.6 \times 10^9$ in economic output during 2006 (Smallwood et al. 2010).

Put-and-take Rainbow Trout fisheries provide economic benefits to Black Hills communities. A comprehensive analysis of Black Hills hatcheries found that in 2019 the economic value of fish reared at Cleghorn Springs State Fish Hatchery was $5.1 MM and the total monetary impact of the hatchery on the local community was $89.4 MM (Martling et al. 2020) The economic value of the fish raised at McNenny State Fish Hatchery in 2017 was calculated to be $6.6 MM and the total local monetary impact on the local community was approximately $22 MM (Barnes and Palmer 2019). In the Black Hills, trout fisheries draw anglers from throughout South Dakota and surrounding states. This is due in large part to the lack of other opportunities to fish for Salmonids in surrounding areas. The mean distance traveled by anglers to fish Black Hills reservoirs is 175 miles (Simpson 2009).

Return to Creel of Stocked Rainbow Trout

Many state fisheries agencies report low numbers of stocked Rainbow Trout being returned to anglers. A Wyoming study found only 3 of the 24 streams evaluated had return-to-creel rates of stocked Rainbow Trout over 50 percent (Wiley et al. 1993). The average return-to-creel rate for catchable Rainbow Trout stocked in a Tennessee study was 19% (Bettinger and Bettoli 2002). In the Black Hills of South Dakota, return-to-creel of Rainbow Trout stocked into small reservoirs was estimated to be less than 40% on average (Simpson et al. 2015). Managers often assume the missing fish have been lost to natural mortality, although this is seldom verified. Although angler satisfaction is rated as 'good' for trout fishing in Black Hills reservoirs (Longmire, 2015), low rates of harvest by anglers have raised concerns about the costs (trout production) and benefits (angler use) of Rainbow Trout stocking programs (Simpson 2008).

Factors Influencing Mortality of Stocked Rainbow Trout

Harvest

Harvest by anglers would be the ideal outcome of put-and-take Rainbow Trout stocking, hence the "take". Angler harvest has been found to be highest immediately after stocking (Kientz et al. 2017; Thorpe et al. 1947). A recent study in the Black Hills found that 85% of harvest occurred within 3 weeks of stocking (Kientz et al. 2017). This may be because anglers expect higher catch rates closer to stocking events and target those times. It may also be related to weather, with more people angling during spring and summer months. Surveys conducted in the Black Hills found that around half of anglers at small impoundments were inclined to harvest the fish they caught and that anglers in larger reservoirs were more inclined to harvest. Stream anglers largely practiced catch-and-release (Simpson 2009).

Catch-and-release angling

The ideal outcome of catch-and-release angling is that a fish may be caught by an angler and released so that it may be caught again with minimal consequences to the fish. The practice of catch-and-release angling was initially intended as a regulation to be imposed to conserve fish populations and was implemented where recruitment overfishing occurred. Historically, anglers harvested fish as a source of food, but since the industrial revolution, angling, especially in inland waters, has become a leisure activity. Today, catch-and-release fishing is a practice often voluntarily adopted by anglers even when not regulated. The number of anglers practicing catch-and-release fishing is growing as a proportion of total fishing in the United States (Detar et al. 2014). Certain groups of anglers, such as fly fishers, may be much more likely to engage in catch-and-release due to negative social stigmas around harvesting trout, especially native species (Gigliotti and Peyton 1993). Creel surveys conducted in the Black Hills impoundments found that 50% of anglers elected to release their catch and that anglers fishing large reservoirs were more inclined to harvest (Simpson 2009).

Catch and release angling can contribute significantly to mortality of Rainbow Trout in put-and-take fisheries (Bartholomew and Bohnsack 2005; Schisler and Bergersen 1996). Fish may experience physical trauma from being angled that includes hook wounds, internal injuries, or damage to scales or slime coat (Wydoski et al. 1976). Catch-and-release angling can also cause negative, sublethal physiological effects, including elevation of stress hormones, decreased blood oxygen levels, and/or depletion of energetic reserves (Bouck and Ball 1966). The type and severity of trauma experienced when a fish is caught and released depends largely on angling method and how fish are handled by anglers (Meka 2004; Taylor and White 1992). In addition to hooking-related injuries, fish caught and released may be negatively affected by handling, temperature, and/or air exposure. After being released, fish may temporarily experience increased risk of predation or disease (Wedemeyer 1970). One study observed 85% delayed mortality of fish captured by hook and line, in the first 10 days after their release (Bouck and Ball 1966). Post release, fish may also exhibit behavioral changes such as prolonged fasting and lethargy (Wedemeyer and Wydoski 2008).

Stocking density

For many years, the success or failure of Rainbow Trout stocking programs was measured by angler catch rates. Today, many states use angler satisfaction as the metric for evaluating put-and-take programs. When lakes are easily accessible, the presumption is that angler effort will be positively related to stocking density. Managers may also determine stocking density based upon expected demand in a system. In the Black Hills, urban fisheries are stocked with very high densities of Rainbow Trout to provide increased angling opportunities (Simpson et al. 2015). Many agencies have begun stocking larger Rainbow Trout as recent research has determined that larger trout are caught by anglers at higher rates (Branigan et al. 2021; Losee and Phillips 2017; Yule et al. 2000).

Foraging success

Several studies have shown that stocked trout can have difficulty transitioning from commercial hatchery food to natural prey sources. (Bachman 1984; Miller and Miller 1962). Additionally, stocked trout may not forage efficiently, swimming more and feeding less than wild trout, causing them to expend more energy than wild trout (Bachman 1984). The high energetic cost of this behavior may result in depletion of metabolites that can lead to death from acidosis or starvation (Miller and Miller 1962). Comparisons of lactic acid concentrations in blood between hatchery and resident trout have been found to be significantly different, suggesting that hatchery trout expend more energy searching for and capturing prey than wild fish (Miller 1958). Stocked Rainbow Trout have also been found to be less adept at locating and using energy efficient foraging locations than wild fish (Bachman 1984).

Environmental stressors

Rainbow Trout can be stocked into a wide range of cool-to-cold water habitats. The water quality attributes of the systems they are released into often vary appreciably. This variability affects mortality rates of newly stocked fish. The water quality attributes in a lake can vary spatially and temporally, resulting in changes to habitat suitability for Rainbow Trout. Localized hypoxia can reduce available habitat and restrict fish to areas with sufficient dissolved oxygen (Kramer 1987; Prince and Goodyear 2006). High temperatures (>25°C) and low dissolved oxygen concentrations (≤ 3mg/L) (Raleigh 1984), which come with summer months, present a substantial threat to survival of stocked trout. Factors such as water temperature, dissolved oxygen concentration, pH, alkalinity, and accumulation of toxic metabolites (Soderberg et al. 1983) all can cause mortality to fish or predispose them to disease. The combined effects of handling, confinement, and transportation can also result in Rainbow Trout being stressed at the time of stocking. Additional stress can be caused by fish being played, netted, and handled during the process of being caught and released by anglers. Reduced habitat may also restrict the ability of Rainbow Trout to access prey, as many aquatic invertebrates are more tolerant of low dissolved oxygen levels and find refuge from predators in these areas (Lucchesi 2021; Sih 1987).

Conclusion

The stocking of catchable Rainbow Trout is one of the most widely employed fisheries management strategies in the US. Stocking allows managers to create instant angling opportunities that are highly valued by anglers. Despite widespread use of put-and-take Rainbow Trout stocking, many agencies report low numbers of fish returned to anglers. (Bettinger and Bettoli 2002; Walters et al. 1997). As discussed previously, the reported reasons for this poor performance could include environmental factors, food acquisition, and/or angling-related mortality. In many cases, however, stocked Rainbow Trout simply go unaccounted for and are assumed mortalities. There remains a need for programmatic-level evaluations of put-and-take Rainbow Trout stocking programs in order to explain the prevalence of low return rates and to optimize the cost:benefit of put-and-take Rainbow Trout fisheries. (Goodman 1990).

Return-to-creel rates of Rainbow Trout stocked in Black Hills reservoirs has often been found to be below management objectives (Simpson 2009), raising concerns about the costs of trout production relative to the benefit provided to anglers. To improve the understanding of the cost: benefit of the Rainbow Trout stocking, I investigated factors affecting survival of Rainbow Trout stocked in Black Hills reservoirs. I examined factors including stocking density, food availability, environmental conditions, and catch-and-release angling on post-stocking survival. The diet and feeding habits of stocked trout have been widely researched, but typically in relation to competition with native salmonids. There remains a gap in our understanding of the role feeding habits and diets play on the success of put-and-take fisheries. Understanding the trophic relationships of put-and-take fisheries will inform stocking practices and maximize efficiency of these programs. The goals of this study are to evaluate factors affecting mortality of stocked Rainbow Trout in Black Hills reservoirs and make recommendations for improving the cost: benefit of the put-and-take stocking.

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Chapter 2.

FACTORS INFLUENCING MORTALITY OF STOCKED RAINBOW TROUT IN BLACK HILLS RESERVOIRS

Introduction

Rainbow Trout *Onchorynchus mykiss* are a Salmonid species native to North America west of the Rocky Mountains from southern Alaska to northern Baja Mexico (Ostberg and Rodriguez 2002). Due to their popularity as a sportfish and ease of hatchery propagation they have been introduced throughout North America (Miko et al. 1995; Nico and Fuller 1999) and on every continent but Antarctica. Hatchery production of Rainbow Trout in the United States began in 1870 and today nearly 100 million Rainbow Trout totaling nearly 25 million pounds are stocked annually by state and federal agencies throughout the US (Halverson 2010).

Rainbow Trout stocking is the largest component of fisheries expenditures by many state agencies (Johnson et al. 1995). The stocking of catchable (>152 mm) Rainbow Trout is an important part of many cold-water fisheries programs (Branigan et al. 2021). Of the 80 million non-anadromous Rainbow Trout stocked in North America in 2004, 60% were stocked as catchable (Halverson 2008). “Put-and-take” refers to the practice of stocking catchable fish with the expectation they will be harvested by anglers. Stocked fish are not expected to reproduce or fully recruit to the fisheries where they are stocked (Patterson and Sullivan 2013). In the United States, put-and-take is one of the most common fisheries management strategies used by state and federal agencies (Halverson 2008; Hyman et al. 2016; Johnson et al. 1995). In 2004, 45 US states were using put-and-take Rainbow Trout stocking as part of their trout management program

(Halverson 2008). Put-and-take Rainbow Trout programs are used to enhance existing cold-water fisheries as well as to create seasonal fisheries in cool and warm water systems. Put-and-take programs are attractive because they allow managers to create instant angling opportunities in waters not suitable for long-term fish survival, or where harvest would deplete natural stocks of fish. Despite its widespread use, there remains a lack of post-stocking research on specific causes of mortality to Rainbow Trout stocked in put-and-take programs. Calls for additional research on post-stocking survival and cause-specific mortality of stocked Rainbow Trout are prevalent in past and recent studies (Branigan et al. 2021; Hartzler 1988; Jackson et al. 2004).

Low return rates of stocked Rainbow Trout have been well documented in a variety of studies (Walters et al. 1997; Wiley et al. 1993) and have been attributed to poor post-stocking survival of hatchery fish (High and Meyer 2009; Walters et al. 1997). Work in central Canada showed that mortality of juvenile Rainbow Trout stocked into eight small, eutrophic lakes varied by season and was characterized by high mortality (60-90%) within the first 60 days of stocking (Ayles et al. 1976). Several factors have been associated with poor survival of stocked Rainbow including stocking size (Branigan et al. 2021; Walters et al. 1997) stocking density (Miko et al. 1995), food availability (Jodar et al. 2020), environmental conditions (Wagner et al. 1997), and stress (Francis-Floyd et al. 2009; Wydoski et al. 1976).

Catch-and-release angling

Catch and release angling can contribute significantly to mortality of Rainbow Trout in put-and-take fisheries (Bartholomew and Bohnsack 2005; Schisler and Bergersen 1996). Fish may experience physical trauma from being caught that includes hook wounds, internal injuries, or damage to scales or slime coat (Meka 2004). Catch-and-release angling can also cause negative sublethal physiological effects, including elevation in stress hormones, decreased blood oxygen levels, or depletion of energetic reserves (Wedemeyer and Wydoski 2008; Wydoski et al. 1976). The type and severity of trauma experienced when a fish is caught and released depends largely on angling method and how fish are handled by anglers (Meka 2004; Taylor and White 1992). In addition to hooking related injuries, fish caught and released may be negatively affected by handling, temperature, and(or) duration of air exposure (Meka and McCormick 2005). After being released, fish may also temporarily experience increased risk of predation (Barton 1997). One study observed 85% delayed mortality of fish captured by hook and line in the first 10 days after their release (Bouck and Ball 1966). Post release, fish may also exhibit behavioral changes such as prolonged fasting and lethargy (Bouck and Ball 1966).

Reported rates of Rainbow Trout mortality post catch-and-release are variable ranging from 6% to 85% (Taylor and White 1992). This variability is largely due to the differential levels of injury and/or stress incurred by different angling methods (Meka 2004). A meta-analysis of 18 Rainbow Trout hooking mortality studies which quantified the post release mortality of specific angling types found that mean hooking mortality for fish caught with bait was high (31.4%) compared to mortality of fish caught by artificial lures (4.9%) or by fly fishing (3.8%; Taylor and White 1992)). In addition to angling type, fish size can also influence catch-and-release mortality. Rainbow Trout mortality has been shown to be positively related to fish length (Branigan et al. 2021; Walters et al. 1997).

Hooking location and hook removal have also been found to affect mortality associated with catch-and-release angling. One study showed that hooking mortality of “deep-hooked” (Mason and Hunt 1967) Rainbow Trout averaged 74% when hooks were extracted, but was appreciably lower at 47% when anglers cut their line rather than extracting the hook (Schill 1996). Another study found that fish mortality was reduced from 55% to 21% by cutting the line rather than extracting the hook, when fish were deep-hooked (Schisler and Bergersen 1996).

Stocking density

For many years, the success or failure of Rainbow Trout stocking programs was measured by angler catch rates. Today, many states use angler satisfaction as a metric to evaluate put-and-take programs. Managers may also determine stocking density based upon expected demand in a system. Stocking density can play a role in the success of put-and-take Rainbow Trout fisheries. One study reported that catch rates of stocked Rainbow Trout were significantly higher at stocking rates of 2,100 trout/ha and 1,400 trout/ha than at 700 trout/ha (Miko et al. 1995). The timing of stocking has also been shown to play a role in Rainbow Trout mortality. Mortality is often greater shortly after stocking due to failure of trout to acclimate to environmental conditions (Threinen 1958).

Food Availability

The abundance and composition of available forage has long been thought to contribute to high mortality rates among stocked Rainbow Trout (Bachman 1984; Miller 1958). Even when food is available, hatchery-reared trout may not be able to take advantage of it (Fischer et al. 2019). Rainbow Trout have been shown to take time to transition from pelleted feed to natural prey items and often exhibit indiscriminate surface feeding behavior when first introduced into a natural environment (Jodar et al. 2020). This is the result of their inability to recognize natural prey items after being conditioned to hatchery food (Suboski and Templeton 1989). Stocked trout have been found to swim more and feed less than wild trout causing them to expend more energy than wild trout (Bachman 1984). The high energetic cost of this behavior (Bettinger and Bettoli 2002) may result in depletion of metabolites that can lead to death from acidosis or starvation (Miller 1958). Comparisons of lactic acid concentrations in blood between hatchery and resident trout have been found to be significantly different suggesting that hatchery trout expend more energy searching for and capturing prey than wild fish (Miller 1958). Stocked Rainbow Trout have also been found to be less adept at locating and using energy efficient foraging locations (Bachman 1984). The inability of stocked trout to efficiently feed may be related to competition with wild trout or the result of high stocking density. The diet and feeding habits of trout stocked have been widely researched but typically in relation to competition with native salmonids. There remains a gap in our understanding of the role feeding habits and diet play in affecting mortality of post-stocked Rainbow Trout. Understanding the trophic relationships of put-and-take fisheries will inform stocking practices and maximize efficiency of these programs.

Environmental stressors

Rainbow Trout can be stocked into a wide range of cool-to-cold water habitats. The water quality attributes of the systems they are released into often vary appreciably, affecting mortality rates of newly stocked fish. Water quality can vary spatially and temporally causing seasonal changes to the suitability of Rainbow Trout habitat. In many climates, the warm water temperatures (>25°C lethal) and low dissolved oxygen concentrations (≤ 3mg/L) which come with summer months can reduce survival of stocked trout (Raleigh 1984). Factors such as water temperature, dissolved oxygen concentration, pH, alkalinity, and accumulation of toxic metabolites can cause mortality to fish or predispose them to disease (Soderberg 1983; Flynn et al. 1983). Additionally, fish may be stressed at the time of stocking due to the combined effects of handling, confinement, and transportation during the stocking process. (Wagner et al. 1997). When suitable habitat in a lake is limited, Rainbow Trout may become stressed and deplete their energetic reserves as they are forced to spend time avoiding unfavorable conditions. A study of Rainbow Trout survival in 0.04 ha ponds showed that fish survival was inversely associated with ammonia exposure (Soderberg et al. 1983). At low exposure to un-ionized ammonia (<20 ug/L, NH3-N), survival of trout exceeded 85% after 120 days. Exposure to un-ionized ammonia at levels >40 ug/L, however, resulted in survival of less than 60% (Soderberg et al. 1983).

Angler Harvest

Harvest by anglers would be the ideal outcome of put-and-take Rainbow Trout stocking. Angler harvest has been found to be highest immediately after stocking (Kientz et al. 2017; Thorpe et al. 1947). A recent study in the Black Hills, found that 85% of harvest occurred within 3 weeks of stocking (Kientz et al. 2017). This may be attributed to anglers targeting stocking times with expectations of higher catch rates closer to stocking events. Weather may also play a role, with more people angling during spring and summer months and access to some lakes limited due to winter conditions. Research has concluded that harvest rates are positively related to size of Rainbow Trout stocked

(Branigan et al. 2021; Walters et al. 1997) leading to many agencies to stock fewer, but larger Rainbow Trout into put-and-take fisheries.

Black Hills Put-and-take Rainbow Trout

In the Black Hills of South Dakota, harvest of stocked Rainbow Trout is often found to be below management objectives (Simpson 2008). Creel surveys conducted on put-and-take Rainbow Trout fisheries in small Black Hills reservoirs found that less than 40% of stocked trout are harvested by anglers (Simpson 2008). Although management objectives such as catch rate and angler satisfaction are often met, low harvest in put-and-take fisheries has raised concerns among fisheries managers about the cost of Rainbow Trout production relative to the benefit (i.e., harvest) provided. In this study, we quantify post-stocking mortality of catchable Rainbow Trout in Black Hills reservoirs and evaluate relationships between reservoir attributes and post-stocking mortality of stocked Rainbow Trout.

Methods

Study area

Rainbow Trout were introduced in the Black Hills of South Dakota in the late 1890s (Cordes 2007) and today are one of the most abundant species in the region. The Black Hills contain the majority of South Dakota's cold-water fish habitat and is the focus of South Dakota Game Fish and Parks Rainbow Trout stocking program, which stocks them at around 200 locations. The endemic species to the Black Hills are comprised of two Cyprinids and two catostomids (Cordes 2007), however, several species of salmonids have been introduced including Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus fontinalis* and Lake Trout

Salvelinus namaychush. The region has no natural lakes but holds an abundance of small, man-made impoundments. In the Black Hills, urban fisheries in particular are stocked with high densities of Rainbow Trout to provide increased angling opportunities within communities (Simpson et al. 2015).

We selected four small impoundments in the Black Hills region of southwestern, South Dakota that included Horsethief Lake (6.9 hectares), Dalton Lake (.93 hectares), Bismarck Lake (9.7 hectares) and Iron Creek Lake (8.9 hectares; Figure 1). These reservoirs are distributed north to south along the Black Hills and were selected to be representative of small reservoirs (<10 ha) in the region. All are popular recreation areas and have amenities including campgrounds and vault toilet. All the reservoirs except Horsethief have a small boat launch but only allow electric motors. Our study reservoirs are populated by a variety of game and non-game species either by stocking or unauthorized or unintentional introductions. The four study reservoirs are managed as put-and-take Rainbow Trout fisheries by South Dakota Game, Fish and Parks, and receive regular stockings of catchable Rainbow Trout reared at two state Hatcheries. Rainbow Trout have a daily harvest limit of five fish, and a possession limit of ten fish. Study fish were raised at Cleghorn or McNenny State Fish Hatcheries located in the Black Hills.

Fish collection

Rainbow Trout were captured from Black Hills reservoirs using AFS standard modified fyke nets set overnight (Pope et al. 2009). Prior to stocking in 2018 and 2019, we conducted mark-recapture surveys to determine the number of Rainbow Trout present from stockings in previous years. Captured fish were marked before being released with a fin punch in the upper lobe of the caudal fin using a 6 mm hole punch, to identify them in subsequent captures. Fish that were recaptured were given sequential caudal punches for identification. The Schnabel method (Schnabel 1938) was used to estimate the number of carryover fish as,

$$\hat{N} = {\sum_{i=2}^{t} n_{,} M_i} \Big/ {\sum_{i=2}^{t} m_i + 1}$$

where t=number of sampling occasions; n_i = number of fish caught in i^{th} sample; m_i=number of fish with marks caught in i^{th} sample; and M_i = number of marked fish present in the population for i^{th} sample. Captured Rainbow Trout were measured for total length (mm) and weight (g).

Rainbow Trout stocked during the study period (total = 19,900) were all marked with an adipose fin clip prior to leaving the hatchery. Reservoirs were sampled bi-weekly from May through September, with Horsethief and Dalton reservoirs sampled from May through September of 2018 and Bismarck and Iron Creek Reservoirs sampled from May through September of 2019.

Creel survey

We conducted stratified, access point creel surveys (Meredith and Malvestuto 1996), surveying anglers upon completion of their fishing trips to obtain catch and harvest information. Surveys were conducted at Dalton and Horsethief lakes between May and September of 2018, and at Bismarck and Iron Creek lakes from May to September of 2019. Anglers were asked about the number of Rainbow Trout caught and how many of those fish were harvested or released. They were asked to categorize their angling method as either flyfishing, lure fishing, or bait fishing. Additionally, anglers were asked how many of the fish they caught and released were "deep-hooked" and if so, did they remove the hook or cut the line before releasing the fish (Appendix 1. Creel survey form).

Seasonal habitat availability

We sampled physiochemical attributes in each reservoir bi-weekly between May and September. To account for spatial variation, we established three sampling sites in each reservoir zone that included the riverine, transitional, and lacustrine zones (Lucceshi et al. 2021). Temperature and dissolved oxygen (DO) profiles were obtained by taking readings at 1-m depth intervals using a YSI PRO 1030 (Yellow Springs Instruments, Yellow Springs, Ohio).

We used relative available habitat (RAH) as an index to determine what portion of a lake was suitable to Rainbow Trout at a given time. We used water temperature and dissolved oxygen concentration to capture seasonal habitat variability that can induce stress and/or impact trout habitat during summer months (Davis 1975). Relative available habitat was modeled as,

$$RAH(\%) = (1 - \frac{O_i + T_i}{O + T}) \times 100,$$

where O is the number of vertical DO measurements, O_i represents the number of vertical measurements where DO < 5 mg/L, T is the number of vertical temperature measurements and T_i is the number of temperature measurements > 22 C° We used a dissolved oxygen threshold of < 5 mg/L because Rainbow Trout have been found to actively avoid areas of dissolved oxygen below this threshold (Matthews and Berg 1997).

We used the thermal threshold of <22 C° because the strain of Rainbow Trout used in our study exhibits ≥25% mortality at water temperatures >22 C° (Huysman et al. 2020).

Physiological indicators

We collected blood samples from Rainbow Trout between May and September 2018 and 2019. During each sampling event we attempted to capture and randomly select up to 10 stocked fish and 10 carryover fish (identified by the adipose fin) for blood collection. Fish were euthanized by cervical dislocation prior to blood collection (Julien et al. 2010). Blood was then immediately collected from the caudal vasculature (Steucke Jr and Schoettger 1967) using a 3 mL syringe with a 21 ga needle and placed into a vacuum-sealed, heparinized 5 ml vial. Blood samples were stored on ice and transported within 3 hours to the laboratory where they were centrifuged at 2000 g for 10 min at room temperature (Page et al. 2013). Plasma was then separated from blood cells and immediately frozen. Frozen plasma was stored in 3 ml vials at -20°C until processed.

We determined plasma glucose concentrations using an Accu-Chek Aviva Plus$^{\text{TM}}$ glucose meter (Roche Diagnostics, Indianapolis, IN: (Bartoňková et al. 2017). Tests were completed in the laboratory using the manufacturer’s single use test strips in accordance with their instructions. After a test strip was removed from its container it was inserted directly into the instrument and a 5μL sample of plasma was dropped onto the designated area of the test strip using a micropipetter. The instrument was calibrated at the manufacturer’s recommended interval.

Plasma lactate concentration was measured using an Arkray Lactate Pro2$^{\text{TM}}$ meter (Arkray Inc, Japan) (Stoot et al. 2014). Testing was conducted by calibrating the meter in accordance with the manufacturer’s guidelines and using single-use test strips according to instructions. For each test, a test strip was unsealed and immediately inserted into the meter where a 5 μL sample of plasma was dropped onto test strips using a micropipetter. After 60 seconds the reaction was complete and lactate concentration was recorded from the digital display.

Cortisol concentration in Rainbow Trout plasma was determined at the Animal Science Research Laboratory at South Dakota State University. Serum concentrations of cortisol were determined in duplicate by RIA using the ImmunChem Coated Tube Cortisol kit (MP Biomedicals, Solon, OH) according to the manufacturer’s directions. Sensitivity of the assay was 0.03 mg/dL and intra-assay CV was 2.9%. Inhibition curves of serum ranging from 10 to 25 mL were parallel to the standard curve. Recovery of 3, 10, and 30 mg of cortisol added to serum was 86.5%.

Stable isotope analysis

Tissue samples (~ 2g) were taken from dorsal muscle of euthanized Rainbow Trout using sterile surgical scissors and samples were placed into a Whirl Pak container and immediately frozen between blocks of dry ice. Samples were then frozen and stored at -20°C until processing. In the laboratory, tissue samples were thawed and then dried in a drying oven at 60°C until sample weight remained stable for two consecutive hours. Dried tissues were then homogenized in a coffee grinder before being ground into a fine powder with a mortar and pestle. Analysis of isotope samples was conducted by the Cornell University Stable Isotope Laboratory. Baseline δ^{15}N and δ^{13}C values for hatchery fish collected from Cleghorn and McNenny State Fish Hatcheries were established by the same procedure prior to fish stocking.

Trout foraging

We examined stomach contents from a total of 85 Rainbow Trout collected between May and September of 2018 and 2019 from the four study reservoirs. Rainbow Trout, from which blood and tissue samples were collected, were placed whole in a cooler of ice and frozen within four hours. They were later thawed in the laboratory, where whole stomachs were removed, dissected, and their contents fixed in a solution of formalin (10%) and then rinsed and stored in ethanol (70%) for later analysis. Rainbow Trout stomachs were dissected and examined under a dissecting microscope. When present, prey taxa were identified to family level, counted, and expressed as frequency of occurrence (Chipps and Garvey 2007). We also quantified the percentage of fish with an empty stomach for each sampling event.

Angling-related mortality

Rainbow Trout abundance (T, no. fish) was calculated monthly from May to September in each reservoir as,

$$T = N + S - H_i + C_i$$

where N = estimated number of carry-over fish from mark-recapture estimate, S = initial number of stocked fish, H_i = number of fish harvested in month *i*, and C_i = number of fish lost to catch-and-release mortality in month *i* (see details below). Catch-and-release data from the creel survey were combined with information from a meta-analysis of angling-related mortality (Taylor and White 1992) to estimate catch-and-release mortality from May-September. Monthly catch-and-release mortality was estimated for each reservoir as,

$$C_i = \sum F_B + F_L + F_F,$$

where F_B = bait fishing mortality (estimated number of fish caught by bait * 0.314), F_L = lure fishing mortality (estimated number of fish caught by artificial lures * 0.049), and F_F = flyfishing mortality (estimated number of fish caught by flyfishing * 0.038; Taylor and White 1992).

Data analysis

We used Akaike's Information Criterion to evaluate factors influencing harvest mortality and catch-and-release mortality among Rainbow Trout in our study reservoirs. We calculated Akaike weights (Akaike 1973) and used evidence ratios to select the best supported model(s) for explaining variation in Rainbow Trout mortality (Burnham and Anderson 2002). Models were ranked by ΔAIC and a threshold of $\Delta AICc \leq 2$ was used to scale candidate model performance (Burnham and Anderson 2002). Individual predictor support was quantified by calculating the sum of AIC weights of all candidate models that included the predictor for each response variable.

Results

Creel evaluation

We conducted 840 angler creel surveys during 2018 and 2019 on our four study reservoirs. Anglers fished for a total of 39,750 hours, with effort in individual reservoirs ranging from 2,592 hours in Dalton Lake to 17,996 hours in Horsethief Lake (Table 1). Mean angler catch rates for Rainbow Trout ranged from 0.35 Rainbow Trout per hour in Dalton to 1.5 in Bismarck Lake. Harvest rates in study reservoirs ranged from 0.14 Rainbow Trout per hour in Dalton to 0.48 in Bismarck (Table 1).

Carryover estimate

Our mark-recapture estimates showed that 832 Rainbow Trout remained in reservoirs from stockings the years prior to our study. As a proportion of the fish stocked in each reservoir the number of fish which carried over was Bismarck 5% (273), Iron Creek 5% (314), Dalton 1% (15), Horsethief 3% (230) (Table 2).

Trout foraging and habitat availability

We collected diets from 85 Rainbow Trout during the study. The mean proportion of empty stomachs for all study reservoirs increased from June (18%) to a peak in August (60%; Figure 2). In contrast, habitat availability for Rainbow Trout generally decreased in each reservoir from May to August (Figure 3). Mean relative available habitat for all reservoirs combined ranged from 68% in May to a low of 35% in August, before beginning to rise again to 52% by September. Periods of low habitat availability appeared to influence foraging success by Rainbow Trout. The proportion of empty stomachs was negatively related to habitat availability ($r = -0.78$, $p=0.008$; Figure 4).

Stress hormone - cortisol

We measured cortisol in Rainbow Trout ($n=76$) between May and September in 2018 and 2019. Mean cortisol levels for all study reservoirs varied by month, ranging from 6.98 ug/dL in May to 23.65 ug/dL in June (Table 3). Analysis of variance showed that cortisol concentration varied significantly among reservoirs (ANOVA, $F_{3,72} =3.68$, $p=0.015$) and was greater in Iron Creek Lake than in Bismarck Lake (Table 4). Cortisol concentration was positively related to angling pressure ($r=0.65$, $p=0.02$) but was not correlated with catch-and-release rate.

Glucose metabolism – plasma glucose and lactate

Mean glucose concentration in Rainbow Trout (n=76) ranged from 84.4 mmol/L in July to 91.80 in August (Table 3). Analysis of variance showed that there was not a significant difference in mean glucose concentration among reservoirs ($F_{3,71}$=0.09, p=0.96; Table 4). Mean glucose levels of fish ranged from a low of 77.27 mg/dL in Bismarck Lake to a high of 94.38 mg/dL in Dalton Lake.

Mean lactate concentration for all reservoirs increased from May to July and decreased to initial levels by late August (Table 3). We found no significant difference in plasma lactate concentrations among reservoirs ($F_{3,72}$=1.92, p=0.13; Table 4). Plasma lactate concentration was positively related to the number of Rainbow Trout harvested by anglers (r=.58, p=0.007; Figure 5). Similarly, lactate concentration was also negatively correlated with relative available habitat, showing that as relative available habitat increased, lactate levels decreased (Figure 6).

Stable Isotopes

We found that $\delta^{13}C$ values in carryover Rainbow Trout changed little over the course of the study (n=36, mean=-20.742‰, SE=0.20) and were similar to those of hatchery Rainbow Trout (n=10, mean = -20.42‰, SE =0.12 ; Table 5). Similarly, we found no differences for all reservoirs combined, in $\delta^{15}N$ values of stocked or carryover fish.

Angling-related mortality

Angler harvest was the greatest source of mortality for Rainbow Trout in all four study reservoirs. Estimates show 56% (11,071) of the 19,900 Rainbow Trout stocked were harvested by anglers. Harvest was highest in June and July in all reservoirs except for Dalton Reservoir, where harvest was greatest August (Figure 7).

Catch-and-release mortality was the second largest contributor to mortality of stocked Rainbow Trout in study reservoirs. Of the 19,900 Rainbow Trout stocked, an estimated 4,484 (22%) experienced catch-and-release mortality (Table 7). Estimated rates of catch-and-release mortality varied among reservoirs, ranging from a low of 11% in Dalton to a high of 28% in Bismarck. Catch-and-release rates were highest during June and July. Our estimates of combined mortality from angler harvest and catch-and-release fishing were relatively high and ranged from 42% in Dalton to 86% in Iron Creek, with a mean among reservoirs of 77% (15,497) of all Rainbow Trout stocked (Table 5). Total angling related mortality was positively correlated with Rainbow Trout density in lakes ($r=0.86$, $p=0.00001$; Figure 8). Total estimated angling mortality was negatively correlated with relative available habitat (Figure 9).

Modeling Results

Of 15 candidate models, two models were supported for predicting angler harvest (Table 8). Our top model explained 80% of the variation in harvest mortality of Rainbow Trout and included angler catch rate (no/h), angling pressure (h/ha), Rainbow Trout size (mm), and blood lactate levels (mmol/L). Monthly harvest mortality (H_i), as a proportion of the initial number of Rainbow Trout stocked, can be estimated as,

$$H_i = \sin(-1.18842 + 0.2083(C_i) + 0.0003155(A_i) + 0.002674(TL_i) + 0.02976(L_i))^2,$$

where C_i equals catch rate during month i, A_i equals angler pressure, TL_i is mean total length of Rainbow Trout, and L_i is mean plasma lactate concentration of Rainbow Trout (Figure 10).

The top model for explaining Rainbow Trout catch-and-release mortality included angler catch rate (no/h) and angling pressure (h/ha) and explained 83% of the variation in catch-and-release mortality in study reservoirs (Table 8). Monthly catch-and-release mortality (CR_i), as a proportion of the initial number of Rainbow Trout stocked, can be estimated as

$$CR_i = \sin(-0.01284 + 0.1720(C_i) + 0.00017639(A_i))^2; \text{Figure 11)}$$

Discussion

Angling Related Mortality of Rainbow Trout

The primary source of mortality to Rainbow Trout stocked in our study reservoirs was recreational fishing. This is comprised of harvest by anglers and delayed hooking mortality caused by catch-and-release fishing. When combined, we can account for the fate of 78% of Rainbow Trout stocked in our study as angling related mortalities.

Angler harvest

Harvest by anglers was the greatest source of mortality in our four study reservoirs with 56% (11,071) of the 19,900 Rainbow Trout stocked being harvested by anglers. This is a higher level of harvest than had previously been documented in the Black Hills. Prior estimates found angler harvest only accounted for about 40% of Rainbow Trout stocked annually in Black Hills reservoirs (Simpson 2008). High rates of harvest are not unheard of in put-and-take Rainbow Trout fisheries, with some documented levels of harvest higher than we observed. In an Iowa lake, when a put-and-take Rainbow Trout fishery was established, managers documented harvest of 83% of fish stocked within the first two weeks after stocking (Schultz and Dodd 2008).

Our top AIC models showed that catch-rate, angling pressure, Rainbow Trout size and plasma lactate concentration can be used to reliably predict Rainbow Trout harvest in our study reservoirs. The contribution of higher catch rates to our model is not surprising as higher catch rates provide anglers greater opportunity to harvest Rainbow Trout. Fish size also is not surprising as research has shown larger stocked Rainbow Trout are more likely to be returned to anglers An Idaho study found that variation in return rates of stocked Rainbow Trout was best explained by fish length (Cassinelli and Meyer 2018). Interestingly plasma lactate concentration was also included in our both of our top models for explaining harvest. The inclusion of lactate in our models suggests that when Rainbow Trout are more actively foraging, they are more likely to be harvested by anglers.

Catch-and-release mortality

Catch-and-release angling was the second largest contributor to mortality in our study. By applying expected rates of post-release mortality based on angling type, we estimate that of the 19,900 Rainbow Trout stocked, 4,426 (22%) were potentially lost to catch-and-release mortality. AIC model selection distinguished the variables catch rate (no/hr) and angling pressure (hrs/ha) as the most important in predicting catch-and-release mortality. This model explains 85% of the variability in catch-and-release angling in study reservoirs and has a strong predictive power.

We estimate that large numbers of Rainbow Trout in small Black Hills reservoirs are being caught and released by anglers more than once. In our study, anglers caught 30,528 fish of 19,900 stocked (153%), implying that some fish were caught multiple times. Similar studies have found Rainbow Trout being caught and surviving to potentially be caught again. Rainbow Trout sampling in the Alagnak River revealed that 40% of fish had a distinct scar from a previous hooking injury (Meka 2004). Multiple catches of Rainbow Trout have been previously documented in small Black Hills reservoirs. Research conducted on Sylvan lake in 2007 documented that when 4,900 Rainbow Trout were stocked anglers reported catching 12,882 suggesting a trout were being caught 2.6 times (Simpson 2008).

The scope of our study did not include anglers' motivations to release Rainbow Trout or whether release was voluntary or compulsory (because an angler had harvested their daily limit of trout). Research has shown that when daily limits are decreased, anglers release more fish. Analysis of the Marine Recreational Fishery Statistic Survey indicates that increased releases and discards are primarily in response to mandatory regulations and to a lesser extent, voluntary releases (Bartholomew and Bohnsack 2005). This suggests that changing daily limit regulations on Rainbow Trout would change the proportion of catch-and-release relative to harvest rates and subsequently the number of fish lost to catch-and-release mortality. Should the harvest limit of Rainbow Trout be reduced, it is likely that it would result in an increase in catch-and-release mortality. To our knowledge, catch-and-release mortality has not previously been included in mortality estimates for stocked Rainbow Trout in the Black Hills. Without considering the effects of delayed catch-and-release mortality, managers do not know the fate of a large portion of the Rainbow Trout stocked, which could complicate management decisions.

Return-to-creel

Although many studies have found that return-to-creel (i.e., the proportion of stocked fish caught by anglers) of put-and-take Rainbow Trout can be relatively low. Research conducted in Wyoming found only 3 of the 24 streams evaluated had return-to-creel rates of stocked Rainbow Trout over 50% (Wiley et al. 1993). In the Hoover Dam tailwater fishery, four stockings of Rainbow Trout of various sizes resulted in return rates ranging from 1% to 47% (Walters et al. 1997). Over the course of a four year study of 54 put-and-take Rainbow Trout fisheries in Idaho, 226 stockings resulted in an average first year return-to-creel rate of only 23.8%, and ranged from 0% to 76% for individual stockings. (Cassinelli and Meyer 2018). In our study reservoirs, we found return-to-creel to be 153%, much higher than had been documented in many previous studies. These numbers illustrate the intensity at which our study reservoirs are used by anglers.

Environmental Conditions and Food Availability

During summer months, available trout habitat was greatly reduced in study reservoirs (Figure 4). Rainbow Trout were often confined to small portions of reservoirs that were within their thermal and dissolved oxygen tolerance. When habitat availability was low, Rainbow Trout may have been forced to expend energy avoiding unsuitable conditions. Trout have been found to avoid hypoxic areas or warmer water, relocating to more favorable habitat based on seasonal or even daily fluctuations in habitat conditions (Brandt et al. 2011; Roberts et al. 2009; Suthers and Gee 1986). When the majority of habitat in a system is unsuitable, trout may be forced to make a trade-off, tolerating high temperatures with better dissolved oxygen concentration (e.g., near surface waters) or tolerating low dissolved oxygen to meet their thermal requirements (e.g., deeper water). A California study found that trout moved between nearly hypoxic cold-water thermal refuge and sub-lethal warmer water with higher dissolved oxygen over the course of a day (Matthews and Berg 1997). We found that relative available habitat was negatively correlated with total estimated angling mortality. This may be because fish that are confined to small areas of a lake are more easily exploited by anglers.

Reduction in available habitat may also be limiting production of prey resources or the ability of Rainbow Trout to access to them during summer months. Research conducted on Lake Alvin in South Dakota documented that invertebrate production was reduced in hypoxic conditions occurring during the summer months (Lucchesi 2021). Aquatic invertebrates may also be using hypoxic areas of lakes as refuge from Rainbow Trout. In Lake Ontario, areas of low dissolved oxygen provided *Daphnia* with refuge from predatory fish (Klumb et al. 2004). These occurrences could mean that Rainbow Trout in our study reservoirs had limited access to an already reduced prey base.

We found that as Rainbow Trout available habitat decreased foraging success declined This further supports the idea that lack of suitable-habitat is limiting access to prey or prey production. It may be that rather than failing to adapt to natural forage, Rainbow Trout in our study reservoirs simply didn’t have access to it. The proportion of empty stomachs we observed was also positively correlated to Rainbow Trout density in reservoirs, suggesting that high stocking densities could increase competition for available prey sources.

Stress

Of the physiological stress indicators we examined, lactate was the most important in predicting Rainbow Trout harvest mortality and was included in our top model. Because lactate is related to fish activity; as fish become more active (e.g., foraging) they may be more likely to be harvested by anglers.

Catch and release angling has been well documented to produce increased cortisol levels in Rainbow Trout (Meka and McCormick 2005; Pankhurst and Dedualj 1994). Research conducted in the Alagnack River in 2005 found that cortisol levels were increased when Rainbow Trout were caught and released, especially when landing time was greater than two minutes. (Meka and McCormick 2005). Interestingly we found that plasma cortisol levels were not correlated with the number of fish caught and released, indicating that the effects of catch-and-release angling are not driving cortisol levels of Rainbow Trout in our study reservoirs.

Environmental stressors did not appear to be driving cortisol levels. We found cortisol levels had no significant relationship to the amount of available trout habitat or Rainbow Trout density, indicating that high temperatures, hypoxic conditions, or the resulting increase in density of trout in available habitat are not producing a cortisol stress response. This finding is similar to those found in a 1977 study of cutthroat trout *Oncorhynchus clarki* where after being acclimated to diurnal temperature cycles (13–23 C) trout had no substantial changes in plasma cortisol concentration throughout the cycles (Strange et al. 1977).

The effects of stress on Rainbow Trout in our study reservoirs may not be consequential to management of these systems as fish were harvested before the accumulation of stress caused significant impact to fish condition. This is corroborated by the lack of a significant relationship between the plasma cortisol, lactate, or glucose to relative weight of stocked Rainbow Trout. If fish condition is maintained at a level that meets angler expectations, then stress may not need to be considered in day-to-day management decisions. If, however, stocking densities in reservoirs were increased to a level at which harvest was not sufficient to alleviate the effects of environmental stressors, then the physiological impacts of stress may become an important source of mortality affecting catch rate and angler satisfaction.

Stable Isotopes

Previous research in the Black Hills showed that stable isotope analysis can be used to reliably distinguish between stocked Rainbow Trout and naturally produced fish (Kientz 2016). In Deerfield Reservoir, it was observed that if stocked fish spent enough time at large in the reservoir, their isotopic signatures began to resemble those of wild fish (Kientz 2016). We did not observe this phenomenon in our study reservoirs. We found that δ^{13}C values in stocked Rainbow Trout changed little over the course of the study and remained similar to those of Rainbow Trout in the hatchery which were -20.7‰ and -20.42‰ respectively. This is likely due to the high rates of harvest we observed, resulting in stocked Rainbow Trout not spending enough time in the reservoirs to obtain more natural δ^{13}C signatures. Another explanation to explain the low variation in stable isotope composition of stocked Rainbow Trout is failure to obtain natural food. This could be the result of naivety to natural prey or inability to access prey due to environmental constraints as previously discussed. Research has shown that hatchery produced fish can be naïve to natural prey and engage in indiscriminate feeding behavior, consuming non-prey items (Jodar et al. 2020).

Conclusion

There are some preferred outcomes built into put-and-take fisheries: 1. Most stocked fish will be harvested by anglers. 2. Stocking more fish increases catch rate. 3. Catch rate affects angler satisfaction. 4. Angler satisfaction affects lake selection and subsequent angler effort for a given lake. Across the US, fisheries managers have long been operating under these assumptions without conducting the programmatic-level assessments needed to verify that they are true. The first assumption has met with limited success in many put-and-take Rainbow Trout fisheries across the US.

In the Black Hills, the fate of most stocked Rainbow Trout has been largely unknown, complicating management decisions and making it difficult to assess cost: benefit decisions related to Rainbow Trout stocking. By combining both harvest and catch-and-release mortality, we found that an appreciable proportion of Rainbow Trout stocked in small Black Hills reservoirs are experiencing angling related mortality. By accounting for carry-over fish and tracking changes in population size of stocked fish, we found greater than expected rates of harvest than had been previously documented. We also found that when determining the fate of stocked Rainbow Trout, it is critical to consider the effects of catch-and-release angling. Catch-and-release angling accounted for nearly a quarter of all Rainbow Trout mortality in our study, underscoring the value of quantifying angling-specific rates of catch-and-release mortality when determining the fate of stocked Rainbow Trout.

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Table 1. Summary of harvest, catch rate, angler hours and harvest rate for study reservoirs. Values in parenthesis represent 80% confidence interval. Catch-rate and harvest rate are measured in Rainbow Trout per hour.

May-September	Dalton 2018	Iron Creek 2019	Bismarck 2019	Horsethief 2018
No. interviewed	116	243	270	211
Angler hours	2592	10459	8703	17996
	(553)	(1009)	(1728)	(4133)
Catch-rate h^{-1}	0.35	0.69	1.50	0.53
	(0.23)	(0.20)	(0.45)	(0.19)
Harvest rate h^{-1}	0.14	0.38	0.48	0.19
	(0.12)	(0.10)	(0.10)	(0.07)
Total harvest	374	3986	3355	3357
	(191)	(458)	(868)	(952)

Table 2. Estimated number of Rainbow Trout remaining in lakes from stocking the year prior to study. Values in parentheses show percentage of the fish stocked which carried over based on schnanbel estimate

Lake	No. Rainbow Trout stocked	Estimated carryover
Bismarck	5985	273 (5%)
Dalton	1299	15 (1%)
Horsethief	7673	230 (3%)
Iron Creek	6200	314 (5%)

Table 3. Mean, monthly concentrations for Rainbow Trout glucose (micrograms per deciliter), lactate (millimoles per liter), and cortisol concentrations measured in Rainbow Trout for all study reservoirs.

Month	n	Glucose ug/dL	n	Lactate mmol/L	n	Cortisol ug/dL
May	10	90.20	10	10.17	10	6.98
June	26	88.91	26	14.57	26	23.65
July	30	84.43	30	16.19	30	15.08
August	10	91.80	10	10.58	10	18.14
Mean		88.84		12.88		16.03

Table 4. Mean glucose, lactate or cortisol concentrations for Rainbow Trout sampled in Black Hills, SD reservoirs. Values with the same letter(s) are not significantly different (P>0.05; Tukey multiple comparison test).

Lake	n	Glucose ug/dL	n	Lactate mmol/L	n	Cortisol ug/dL
Bismarck	22	84.14 a	22	16.22 a	22	14.15 a
Dalton	22	82.18 a	22	12.57 a	22	15.54 ab
Horsethief	11	77.27 a	11	14.17 a	11	12.98 ab
Iron creek	21	94.38 a	21	15.55 a	21	23.89 b

Table 5. Stable isotopes concentrations for δ13C and δ15N in stocked and carryover Rainbow Trout for all study reservoirs. Values in parentheses represent one standard error.

	Carryover trout			Stocked trout			Hatchery Trout	
Month	n	$\delta^{13}C$	$\delta^{15}N$	n	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
May	14	-21.3	9.1	7	-20.7	9.1	-20.0	9.1
		(.81)	(.13)		(.05)	(.05)		
June	11	-20.6	9.1	14	-20.4	9.1		
		(.32)	(.07)		(.10)	(.17)		
July	7	-20.3	8.9	10	-21.6	8.6		
		(.01)	(.10)		(.62)	(.20)		
August	5	-20.2	8.8	5	-20.1	9 (.10)		
		(.11)	(.07)		(.12)			
Mean		-20.60	8.94		-20.70	8.96		

Table 6. Estimated angling related mortality of stocked Rainbow Trout in four Black Hills reservoirs from May-September, 2018-2019. Values in parentheses represent percent mortality of the total number of fish stocked.

Year	Lake	No. of trout stocked	Estimated No. of trout harvested	Estimated No. of trout lost to catch and release angling	Total angling related mortality
2018	Dalton	1200	374 (31)	131 (11)	504 (42)
2018	Horsethief	6500	3356 (52)	1571 (24)	4927 (76)
2019	Bismarck	6700	3355 (50)	2001 (28)	5202 (78)
2019	Iron Creek	5500	3986 (72)	736 (13)	4722 (86)
Total		19900	11071 (56)	4426 (22)	15497(77)

Table 7. Estimated mean catch-and-release mortality (no. Rainbow Trout) by angling type in four Black Hills reservoirs, May-September 2018-2019. Values in parentheses indicate year.

Angling method	Reservoir			
	Bismarck (2019)	Dalton (2018)	Horsethief (2018)	Iron Creek (2019)
Artificial lure	139	6	58	35
Bait	1847	121	1511	689
Flyfishing	15	4	2	12
Combined	2001	131	1571	736

Table 8**.** Akaike's information criteria (AIC) Comparison of logistic regression models for factors influencing harvest mortality and catch-and-release mortality of Rainbow Trout. Number of parameters (K), Akaike's information criteria (AIC), change in AIC value (ΔIC), and AIC weights (w*i*) were used to select the top models from candidate models.

Model (harvest mortality, proportion)	K	AIC_C	Δ_i	W_i	Evidence ratio
catch rate + angler pressure + rainbow trout length + lactate	6	-62.31	0	0.74	1.0
catch rate + angler pressure + lactate	5	-60.22	2.1	0.26	2.8
Model (catch-and-release mortality, proportion)					
catch rate + angler pressure	4	-89.34	1.00	0.70	1.0
catch rate + angler pressure + glucose	5	-87.75	0.45	0.31	2.2

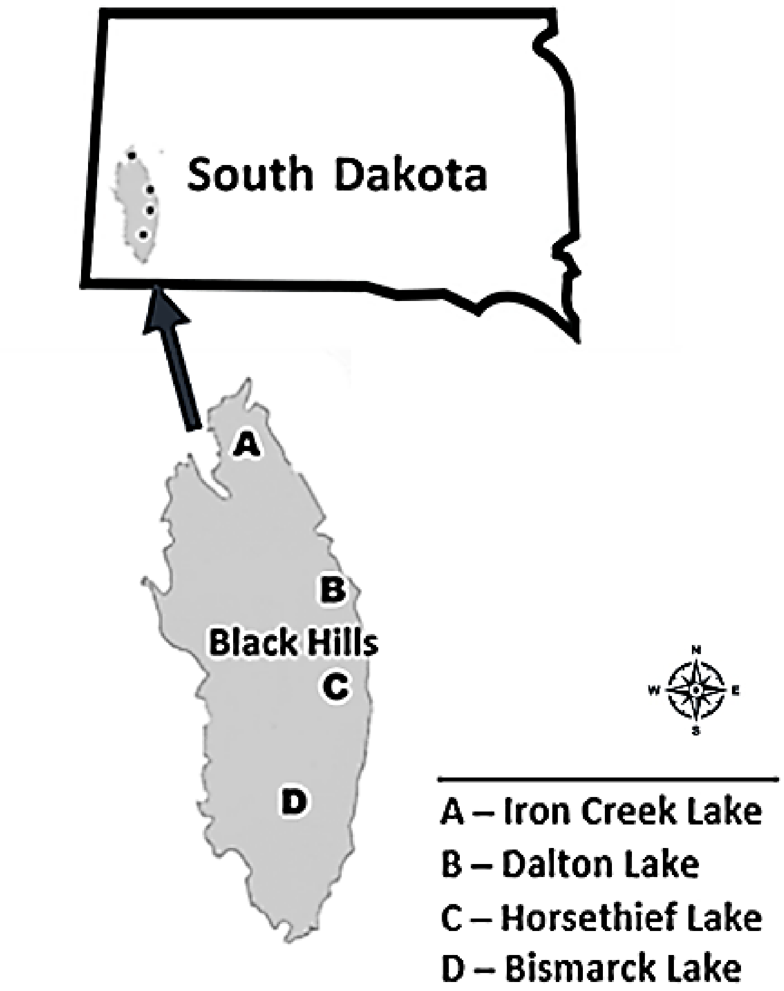


Figure 1. Schematic of the Black Hills Region of South Dakota showing the location of the four study reservoirs. Each letter on the map shows the location of a study reservoir and corresponds to a lake name in the map legend.

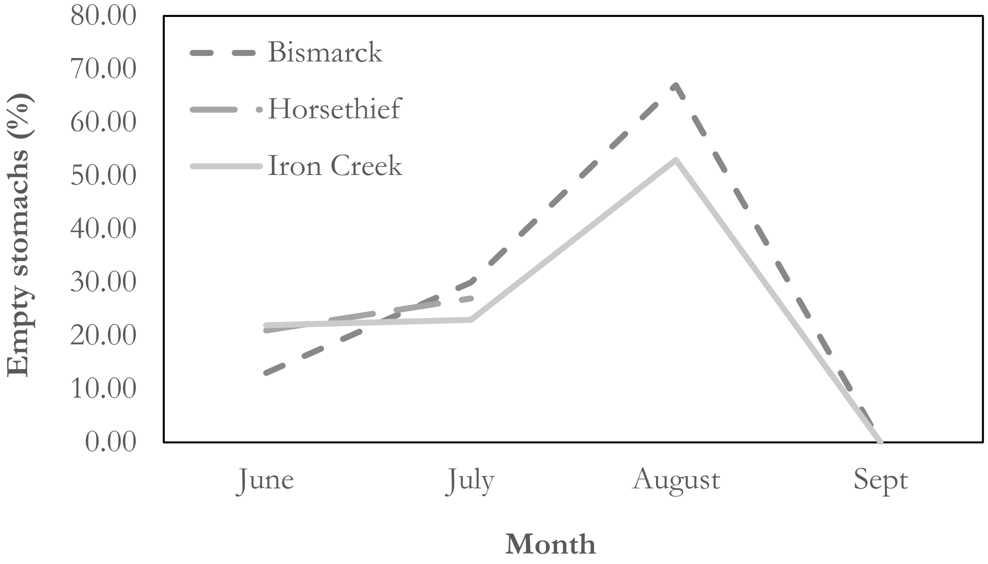


Figure 2. Mean percent of empty Rainbow Trout stomachs in four study reservoirs from May to September. 2018 (Horsethief) or 2019 (Bismarck and Iron Creek).

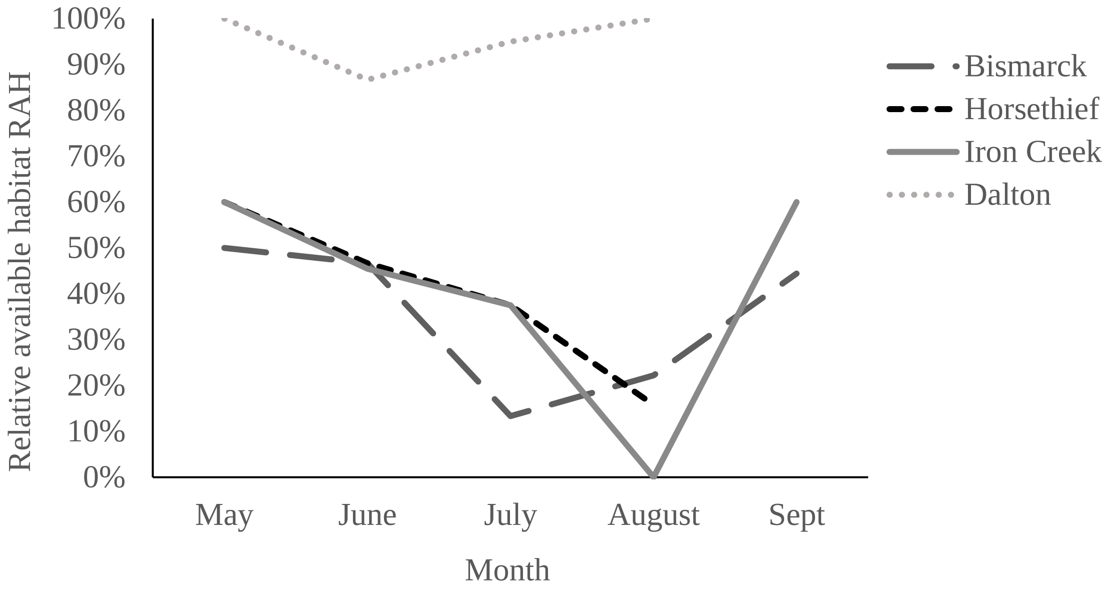


Figure 3. Relationship between the amount of Rainbow Trout available habitat (see text) and month from May through September (Horsethief and Dalton 2018 and Bismarck and Iron Creek 2019).

Figure 4. Proportion of empty Rainbow Trout stomachs as a function of relative available habitat in Black Hills reservoirs (linear regression analysis, $r^2=0.62$; $p=0.006$; $Y = 0.579-0.913(X)$.

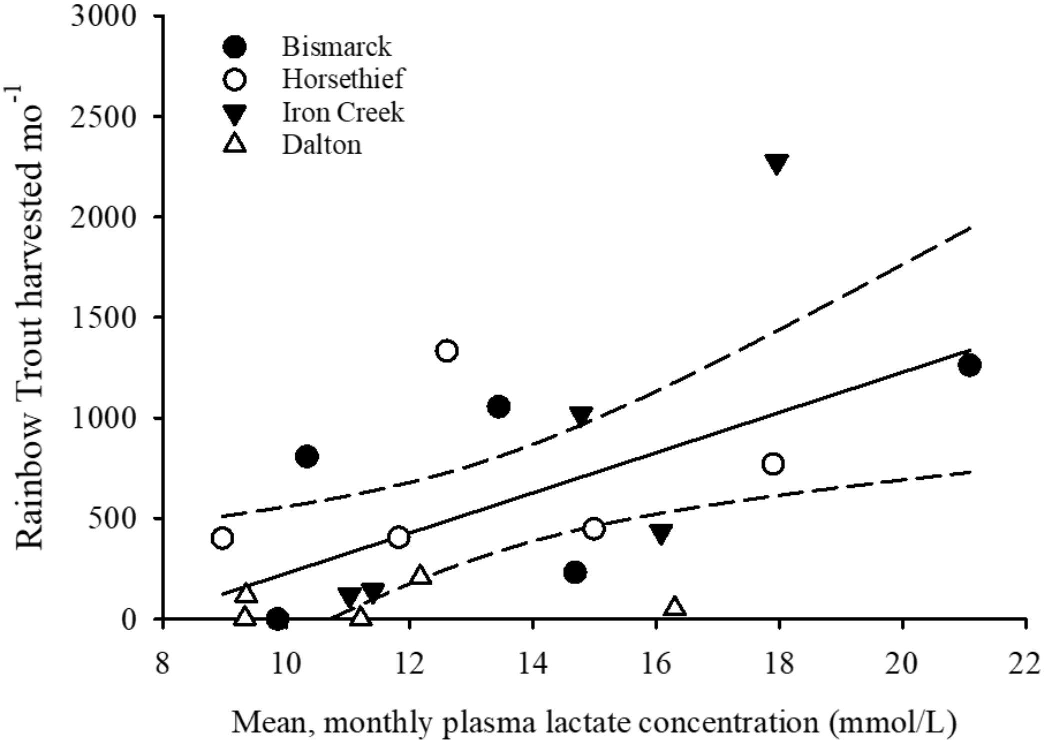


Figure 5. Rainbow Trout harvest (no. mo^{-1}) as a function of mean, monthly plasma lactate concentration from fish collected in four Black Hills reservoirs, May-September, 2018-2019. Dashed lines represent 95% confidence intervals around the regression line (linear regression analysis, Y=-773.5+100.07X; r^2=0.32, p=0.002).

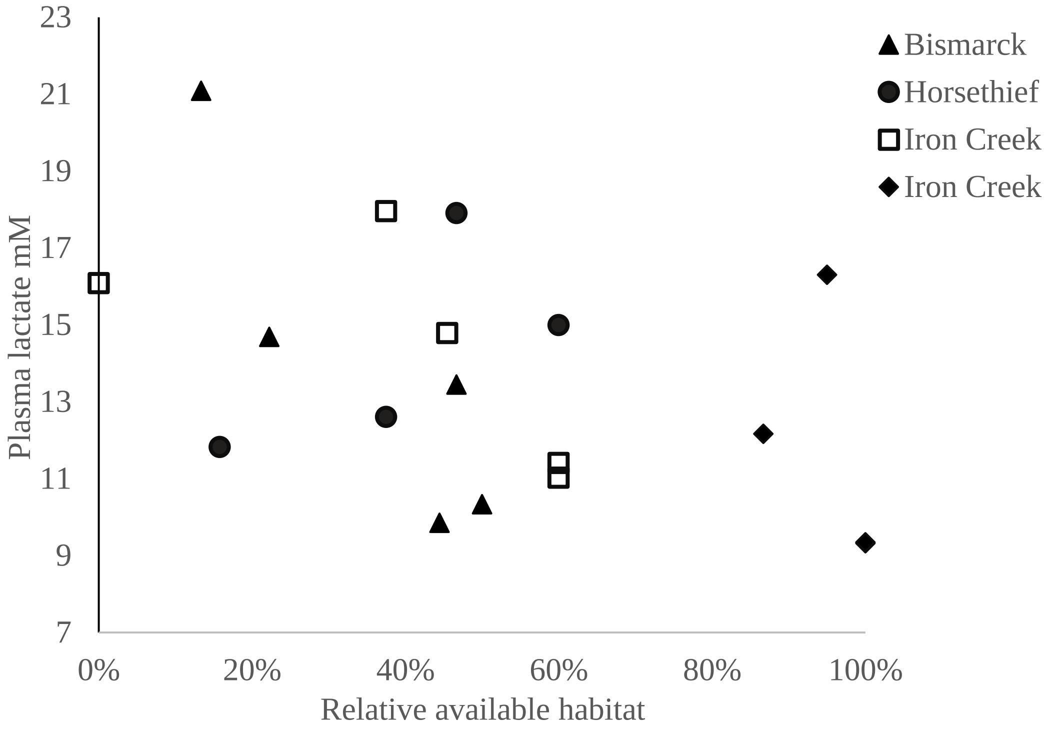


Figure 6. Relationship between relative available habitat and Rainbow Trout plasma lactate concentration in four, Black Hills reservoirs stocked with put-and-take Rainbow Trout.

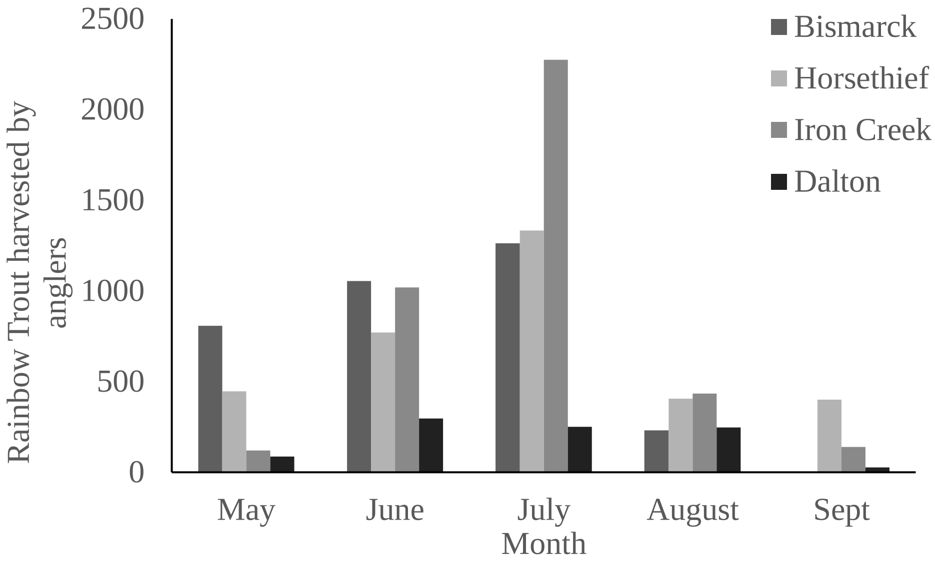


Figure 7. Angler harvest of Rainbow Trout in study reservoirs by month

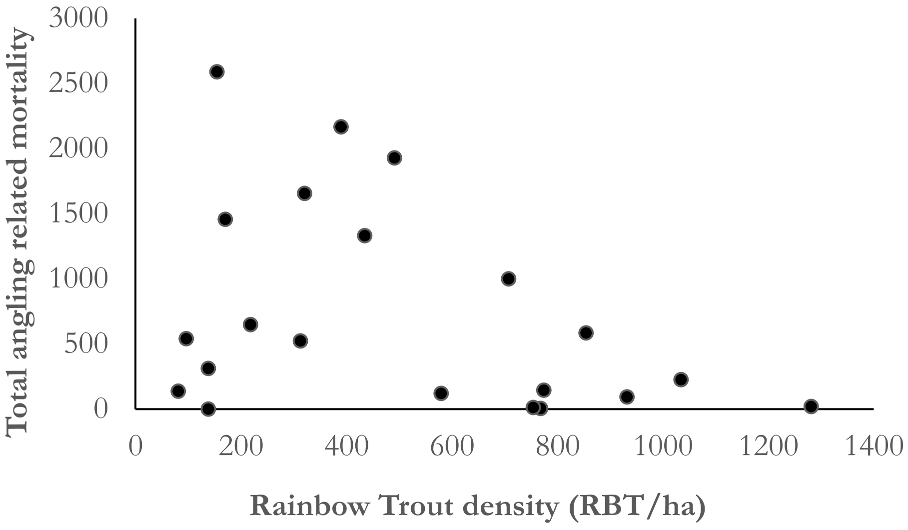


Figure 8. Total angling related mortality of Rainbow Trout as a function of Rainbow Trout density

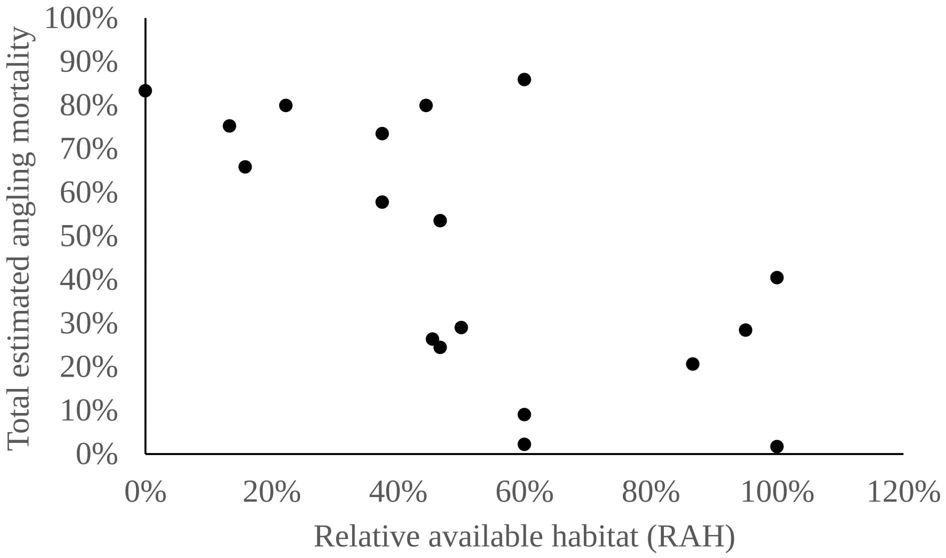


Figure 9. Total estimated angling mortality as a function of Relative available habitat (RAH) for Rainbow Trout

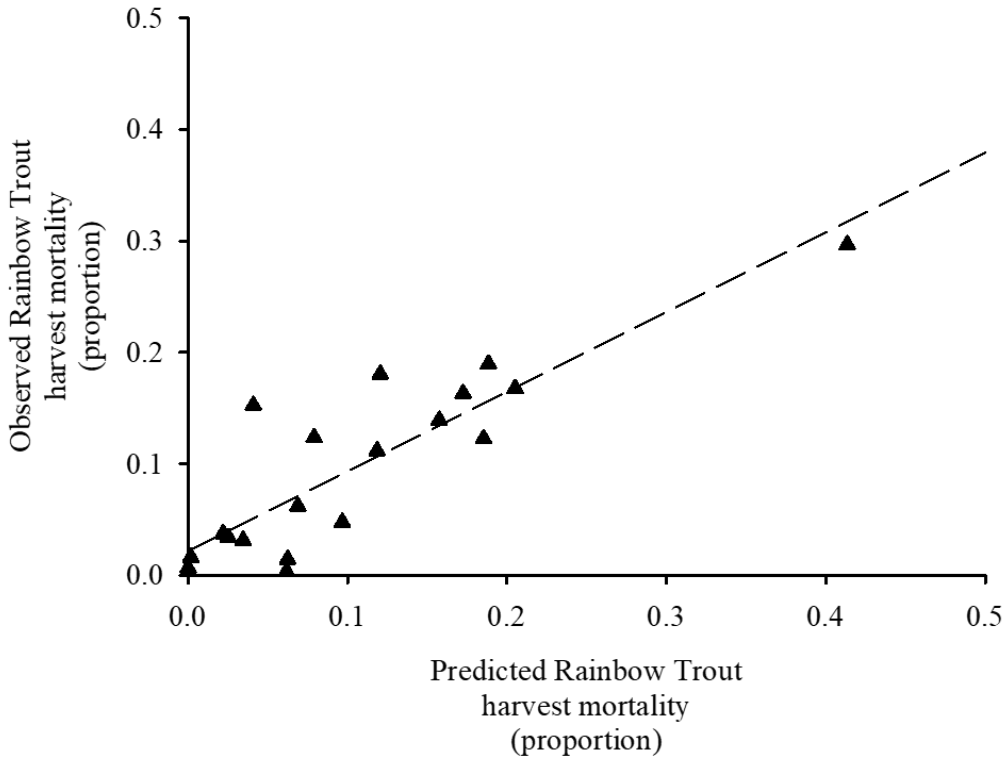


Figure 10. Relationship between observed and predicted harvest mortality of Rainbow Trout in four Black Hills reservoir based on best-supported AIC model (see text for model parameter coefficients).

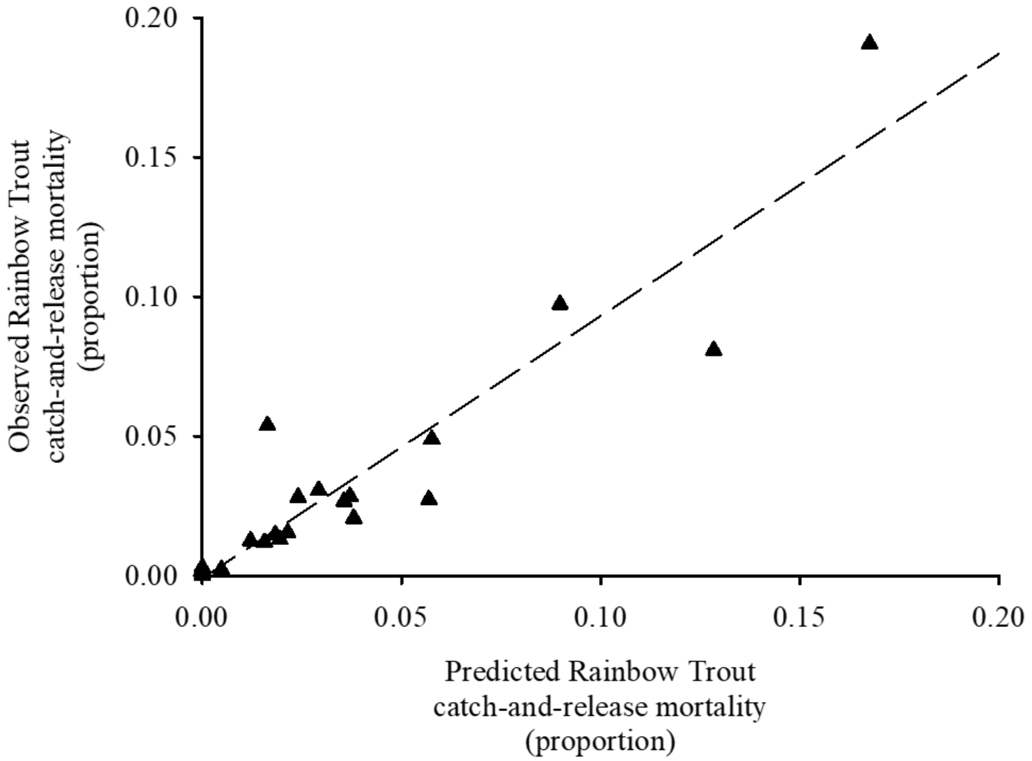


Figure 11. Relationship between observed and predicted catch-and-release mortality of Rainbow Trout in four Black Hills reservoir based on best-supported AIC model (see text for model parameter coefficients).

Chapter 3

Management Implications

The research conducted in this study provides improved clarity as to the fate of Rainbow Trout stocked into small Black Hills reservoirs. This information should prove useful in evaluating the cost vs. benefit of the Rainbow Trout stocking program. This work also provides managers information related to stocking density, catch and release mortality, and seasonal habitat availability which should be useful in making management decisions regarding put-and-take Rainbow Trout fisheries in the Black Hills.

My research demonstrates that fates of most of the Rainbow Trout stocked into our study reservoirs can be accounted for as mortalities through either angler harvest or catch and release mortality. When estimates of harvest and catch-and-release mortality are combined, relatively few stocked Rainbow Trout remain unaccounted for. Furthermore, our carryover estimates corroborate our estimates of mortality and show that some fish are in fact surviving from stocking into subsequent years. This research also presents models which can be used to reliably predict harvest and catch-and-release angling mortality in other Black Hills reservoirs.Angler Harvest

Our estimates of harvest mortality are higher than had previously been observed in many small Black Hills Reservoirs. The difference between the levels of mortality we observed and those that have been previously documented could be due to the intensity of the creel surveys we conducted. Our study reservoirs had only a single access point making them ideal for access point surveys as opposed to roving surveys. In larger Black Hills reservoirs, conducting more thorough creel surveys at multiple access points would provide a clearer picture of harvest and catch-and-release mortality. While these surveys would be more expensive to conduct, the survey cost would likely be less than the value of the Rainbow Trout unaccounted for annually in these reservoirs. Misidentification of fish species during surveys was mitigated in our study by providing pictures to anglers to aid in identification. This is recommended for future creel surveys to improve the accuracy of survey results.

Catch-and-release mortality

Our estimates of catch-and-release mortality illustrate that catch-and-release angling contributes significantly to mortality of stocked Rainbow Trout in Black Hills reservoirs. We estimated that a mean of 22% of Rainbow Trout stocked into the four study reservoirs were lost to catch-and-release mortality. If fisheries managers wish to accurately determine the fate of Rainbow Trout stocked into Black Hills reservoirs, then catch-and-release mortality must be considered.

Changes in regulations on Rainbow Trout harvest would likely influence rates of catch-and-release mortality. For example, lowering the daily limit for Rainbow would likely increase compulsory releases which would result in higher catch-and-release mortality. Changes in angler behavior could also influence catch-and-release mortality rates. As the popularity of catch-and-release angling continues to increase, it is likely that harvest mortality will decline, and catch-and-release mortality will increase.

I would recommend that future creel surveys should collect the data required to estimate catch-and-release mortality as was done here. This data can then be combined with harvest survey data and used to estimate total angling mortality as was done in this study. Managers should consider the angling methods most used in specific reservoirs when attempting to quantify mortality or decide how many fish to stock. Mortality will be markedly higher where more bait fishing occurs and lower where flyfishing is predominant.

Habitat and Rainbow Trout Density

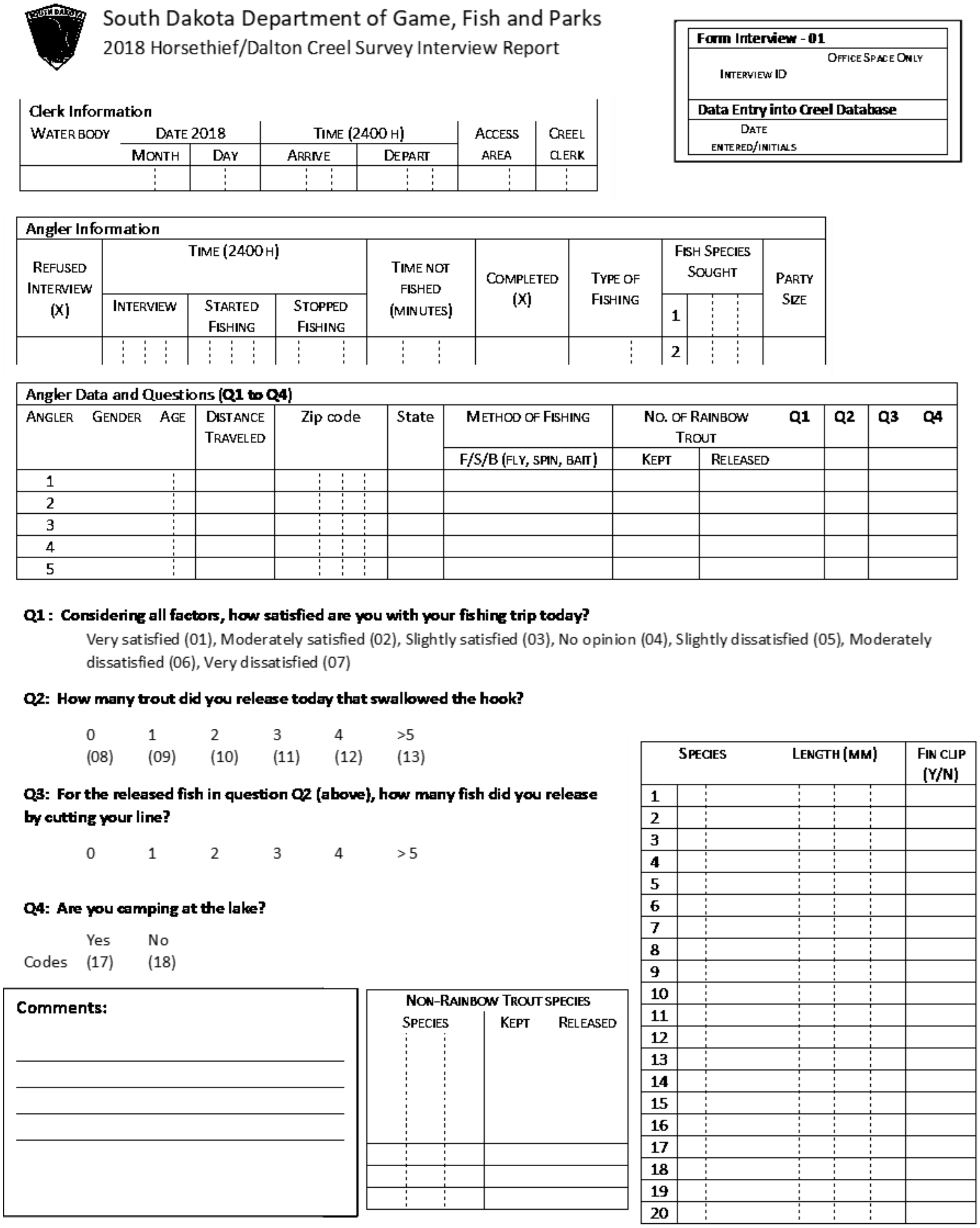
Our findings demonstrate that habitat conditions should be taken into consideration when stocking Rainbow Trout in small Black Hills reservoirs. We observed that relative available habitat for Rainbow Trout varied appreciably in study reservoirs seasonally. When relative available habitat is low, the actual stocking density of Rainbow Trout in a reservoir may be much higher than initial stocking density (no/ha). Lakes with low relative available habitat during summer months appear to be inducing stress as competition is increased and access to food sources is limited, creating a need for increased activity to acquire food. We showed that when available trout habitat was low, plasma lactate levels increased. While we did not observe negative impacts to Rainbow Trout relative weight in our study reservoirs, stressed fish may be more susceptible to disease, have reduced slime coats, and/or have an unappealing appearance. While it was outside the scope of this study to explore, fish caught in this condition may have a negative impact on angler satisfaction.

During our study, high rates of harvest corresponded with periods of low available habitat and may have mitigated negative impacts to relative weight. However, in reservoirs with lower levels of harvest or during years with higher summer temperatures this may not be the case and fish condition may suffer. Multiple stockings of Rainbow Trout throughout the season could be used where appropriate to keep density lower and preserve fish condition during times of low available habitat. This could likely be done with minimal impacts to angler usage as angling pressure has been found to asymptote with stocking density.

Future Research

Further research on Black Hills put-and-take Rainbow Trout fisheries should focus on the fate of fish stocked in larger reservoirs. The methods used in this study could be used to estimate harvest and cat-and-release mortality in those systems and the models we present used to predict angling related mortality under different conditions. The information required to make these estimates and employ these models could be easily through obtained through additional creel surveys and use of a portable point of care lactate testing meter.

Appendix 1



South Dakota Department of Game, Fish and Parks
2018 Horsethief/Dalton Creel Survey Interview Report

Form Interview - 01
Office Space Only
Interview ID

Data Entry into Creel Database
Date entered/initials

Clerk Information

Water body	Date 2018		Time (2400 h)		Access area	Creel clerk
	Month	Day	Arrive	Depart		

Angler Information

Refused Interview (X)	Time (2400 h)			Time not fished (minutes)	Completed (X)	Type of Fishing	Fish Species Sought	Party Size
	Interview	Started Fishing	Stopped Fishing					
							1	
							2	

Angler Data and Questions (Q1 to Q4)

Angler	Gender	Age	Distance Traveled	Zip code	State	Method of Fishing	No. of Rainbow Trout		Q1	Q2	Q3	Q4
						F/S/B (fly, spin, bait)	Kept	Released				
1												
2												
3												
4												
5												

Q1 : Considering all factors, how satisfied are you with your fishing trip today?

Very satisfied (01), Moderately satisfied (02), Slightly satisfied (03), No opinion (04), Slightly dissatisfied (05), Moderately dissatisfied (06), Very dissatisfied (07)

Q2: How many trout did you release today that swallowed the hook?

0	1	2	3	4	>5
(08)	(09)	(10)	(11)	(12)	(13)

Q3: For the released fish in question Q2 (above), how many fish did you release by cutting your line?

0 1 2 3 4 > 5

Q4: Are you camping at the lake?

	Yes	No
Codes	(17)	(18)

	Species	Length (mm)	Fin clip (Y/N)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Comments:

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Non-Rainbow Trout species

Species	Kept	Released