Biotic and Abiotic Factors Influencing Population Dynamics of Yellowstone Cutthroat Trout and Utah Chubs in Henrys Lake, Idaho

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Authorization to Submit Thesis

This thesis of Darcy K. McCarrick, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Biotic and Abiotic Factors Influencing Population Dynamics of Yellowstone Cutthroat Trout and Utah Chubs in Henrys Lake, Idaho" has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Negative interactions with nonnative species are a concern for many species including Yellowstone Cutthroat Trout (YCT) *Oncorhynchus clarkii bouvieri*. In many YCT fisheries, managers are tasked with balancing angler satisfaction and fish conservation. Trying to balance these needs is typified at Henrys Lake, Idaho. Recent surveys have revealed increase in the abundance of nonnative Utah Chubs (UTC) *Gila atraria* in Henrys Lake. The effect of nonnative UTC on native YCT in Henrys Lake is unknown, but UTC have negatively affected salmonids in other systems. A comprehensive analysis of historical data was conducted to assess long-term trends and identify factors influencing population dynamics of YCT in Henrys Lake. To better understand YCT and UTC interactions, YCT and UTC were radio-tagged in spring 2019 and 2020 to describe their movement and habitat use in Henrys Lake. This research provides insight into possible interactions between YCT and UTC, and provides a comprehensive understanding of factors influencing population dynamics of YCT that can be used to guide management actions.

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Dedication

This work is dedicated to my parents, Tom and Nancy McCarrick, and my late grandmother, Margaret Todd.

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Chapter 1: General Information

Freshwater systems are valued for recreation, consumption, and biodiversity (Warren and Burr 1994). Despite making up only 0.8% of the Earth's surface, freshwater ecosystems support approximately 40% of the world's fish diversity (Dudgeon et al. 2005). In the United States, 20% of fishes, 55% of freshwater mussels, and 36% of crayfishes are listed as extinct or imperiled compared to only 7% of birds and mammals (Warren and Burr 1994). The high levels of biodiversity, extinction, and imperilment of aquatic species makes freshwater habitats an important focus for conservation (Schlosser 1991). Threats to freshwater ecosystems are varied and include overexploitation, water pollution, flow modification, interactions with nonnative species, and climate change (Dudgeon et al. 2005).

The establishment of nonnative species continues to be a concern to the management and conservation of aquatic systems. Species have been introduced intentionally (e.g., food source, angling opportunity, ornamentation) and by accident (e.g., ballast waters; Copp et al. 2005; Rahel 2000). Historically, intentional introductions were considered beneficial and encouraged by acclimatization societies (Gozlan 2008). Since the 1970s, there has been increasing concern and opposition to the spread of nonnative species. Threats of nonnative species to native fishes include hybridization (Scribner et al. 2001; Campbell et al. 2002; Allendorf et al. 2004; Kovach et al. 2011; Al-Chokachy et al. 2018), spread of pathogens (Naylor et al. 2005; Gozlan et al. 2006), predation (Kaeding et al. 1996; Koel et al. 2011), and competitive interactions (Mills et al. 2004; Peterson et al. 2004; Gresswell 2011; Al-Chokhachy and Sepulveda 2018). As such, understanding interactions of native and nonnative species is a priority for conservation efforts.

Evaluating the influence of nonnative species has become a recent focus for management of Henrys Lake, Idaho. Henrys Lake is a shallow, eutrophic lake located in eastern Idaho. Henrys Lake is one of western North America's premier trout fisheries and is currently managed as a diverse fishery for trophy Rainbow Trout *Oncorhynchus mykiss* × Yellowstone Cutthroat Trout (YCT) *O. clarkii bouvieri* hybrids, YCT, and Brook Trout *Salvelinus fontinalis*. Based on a 2011 statewide angler economic survey, Henrys Lake supported over 34,000 angler trips, generating US$12.7 million in related angler spending (Idaho Department of Fish and Game, unpublished data). In addition to providing angling opportunities, conserving native YCT is also a high priority (Campbell et al. 2002). To help achieve these conservation efforts, Idaho Department of Fish and Game has completed extensive habitat restoration projects in tributaries (e.g., riparian fencing) and operates a hatchery supplementation program focused on maintaining genetic purity of YCT (Campbell et al. 2002). Unfortunately, nonnative Utah Chubs (UTC) *Gila atraria* were first detected in Henrys Lake in 1993 and have since increased in abundance (Gamblin et al. 2001; High et al. 2015; Flinders et al. 2016).

Little is known about the current or potential future influence of UTC on the YCT population in Henrys Lake, but introduced UTC have had a negative effect on salmonids in other systems (Hazzard 1935; Davis 1940; Schneidervin and Hubert 1987; Tuescher and Luecke 1996; Winters and Budy 2015). The purpose of this research was to provide insight on the population dynamics and interactions of YCT and UTC in Henrys Lake. The first objective was to evaluate population structure and dynamics of YCT in Henrys Lake using historical data. I sought to describe long-term trends in population characteristics and identify factors related to catch rates and growth. The second objective was to describe the movement and habitat use of YCT and UTC in Henrys Lake. My research investigated habitat relationships which provides much needed insight on the ecology of UTC. Habitat relationships and spatial overlap between the two species was also identified.

Thesis Organization

This thesis is divided into four chapters. Chapter two evaluates the population dynamics of Yellowstone Cutthroat Trout in Henrys Lake, Idaho, and will be submitted to *Journal of Fish and Wildlife Management.* Chapter three describes the movement and habitat use of Yellowstone Cutthroat Trout and Utah Chub in Henrys Lake, Idaho, and will be submitted to *North American Journal of Fisheries Management*. Chapter four discusses general conclusions and management recommendations.

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Chapter 2: Population dynamics of Yellowstone Cutthroat Trout in Henrys Lake, Idaho

Abstract

Yellowstone Cutthroat Trout (YCT) *Oncorhynchus clarkii bouvieri* is a species with high ecological and recreational value. In many YCT fisheries, managers are tasked with balancing angler expectations and fish conservation. Henrys Lake supports a popular trophy trout fishery, but the increase of nonnative Utah Chub (UTC) *Gila atraria* has caused concern for the YCT population. Long-term trends in abundance, length structure, body condition, and growth of YCT were summarized. Archived hard structures were examined to provide a comprehensive evaluation of changes in age and growth of YCT in the system. Scales were collected from fish sampled in 1977, 1984, 1987, 1988, 1991, and 1992 with a variety of sampling gears. Sagittal otoliths were collected from 2002 to 2020 during annual gill net surveys. Air temperature, snowpack, reservoir volume, discharge, stocking records, and catch rates of UTC and trout in Henrys Lake were used as covariates to explain changes in YCT catch rates and growth. Catch rates varied from 1.5 to 15.4 YCT per net night during the 2002 to 2020 sampling period, but no consistent patterns were identified. Length structure was consistently dominated by stock- to quality-length fish and few fish over 600 mm were captured. Relative weight of YCT has decreased from an average of 116 ($\pm$ SD; $\pm$ 16.5) in 2004 to 93 ($\pm$ 8.2) in 2020. In total, 3,025 YCT otoliths and 229 YCT scales were aged. Yellowstone Cutthroat Trout age varied between 1 and 11 years; YCT from 2010 to 2020 were the oldest. The majority of YCT sampled were age-4 and younger fish. Total annual mortality of age-2 and older YCT was higher than other Cutthroat Trout populations (i.e., 0.70 during 2002 to 2010 and 0.60 during 2011 to 2020). Regression modeling identified positive relationships between catch rates of YCT, Brook Trout *Salvelinus fontinalis,* and

hybrid trout. Negative relationships were observed between growth of YCT and abundance of UTC and Brook Trout. Although negative relationships were identified, YCT growth in recent decades is as fast or faster than earlier time periods. Results from this research suggest that major changes in YCT population dynamics are not evident over the last 20 years. Future efforts focused on monitoring YCT and UTC will be important for making conservation and management actions.

Introduction

The introduction of nonnative species is a primary threat to freshwater ecosystems (Dudgeon et al. 2005). Species have been introduced across the globe for a variety of purposes including aquaculture, aquaria, sport fishing opportunity, and what was perceived as "the national good" (Copp et al. 2005; Rahel 2000). Many of these introductions have been intentional, but accidental introductions through ballast water and illegal stockings have also occurred (Rahel 2000). Although society has benefited from some introductions, many populations of native fishes have suffered from negative interactions with nonnative species (Rahel 2002; Gozlan 2008).

In many systems, the effect of introduced species is poorly understood which presents concern for resource managers. Utah Chub (UTC) *Gila atraria* is one species that has spread outside its native distribution and become a detriment to native salmonid populations (Hazzard 1935; Davis 1940; Winters and Budy 2015). Utah Chub is native to Lake Bonneville basin in Utah, Idaho, and Nevada, and the Snake River drainage of Idaho upstream of Shoshone Falls and downstream of Mesa Falls (Sigler and Sigler 1996). Utah Chubs tolerate a wide variety of temperatures (i.e., 15.6 – 31.1°C) and are common in systems with dense vegetation. Utah Chubs are omnivorous and shift their diet in response to prey availability (Graham 1961; Sigler and Sigler 1996). A plastic life history has contributed to UTC establishment outside its native distribution.

Utah Chub is frequently considered a nuisance species and is not targeted by anglers (Graham 1961). In addition, UTC often compete with popular sport fishes (Davis 1940; Sigler and Sigler 1996; Tuescher and Luecke 1996). Utah Chubs have similar diets to salmonids and diet overlap has been documented in many systems (Hazzard 1935; Davis 1940; Schneidervin and Hubert 1987; Tuescher and Luecke 1996; Winters and Budy 2015). For example, diet overlap was observed between UTC and Rainbow Trout *Oncorhynchus mykiss,* kokanee *O. nerka,* and White Suckers *Catostomus commersonii* in Flaming Gorge Reservoir, Utah-Wyoming (Schneidervin and Hubert 1987). Tuescher and Luecke (1996) reported that as UTC densities increased in Flaming Gorge Reservoir, zooplankton biomass decreased and kokanee growth slowed. Small Bonneville Cutthroat Trout *O. clarkii utah* (< 350 mm) and UTC fed at virtually the same trophic position in Scofield Reservoir, Utah (Winters and Budy 2015). In Fish Lake, Utah, a decline in trout abundance was associated with competition with UTC for prey resources (Hazzard 1935; Davis 1940).

One system where nonnative UTC is a concern is Henrys Lake, Idaho. Utah Chub was first detected in Henrys Lake in 1993 and has since become abundant (Gamblin et al. 2001; Heckel et al. 2020). For example, catch-per-unit-of-effort was 1.6 UTC per net night in 2002 and 25.5 UTC per net night in 2018 (Heckel et al. 2020). Henrys Lake is a shallow lake located in eastern Idaho near the Idaho-Montana border that is managed for trophy Rainbow Trout × Yellowstone Cutthroat Trout (YCT) *O. c. bouvieri* hybrids, YCT, and Brook Trout *Salvelinus fontinalis* (Campbell et al. 2002). Yellowstone Cutthroat Trout is native to Henrys

Lake and conserving native YCT is a high priority for resource managers. Yellowstone Cutthroat Trout is considered particularly vulnerable to the negative effects of nonnative species (Young 1995; Kaeding et al. 1996; Peterson et al. 2004; Gresswell 2011; Koel et al. 2011; Al-Chokhachy and Sepulveda 2018). In 2011, genetically unaltered populations of YCT occupied only 28% of their historic distribution (Gresswell 2011). As a result, YCT is a species of high conservation concern by natural resource agencies. Yellowstone Cutthroat Trout maintain high ecological, cultural, and economic value, so minimizing the negative effects of nonnative species is a top priority for natural resource agencies.

Despite the popularity of Cutthroat Trout as a sport fish, numerous knowledge gaps remain. In particular, little is known about the population dynamics of adfluvial Cutthroat Trout which often complicates their conservation and management. Henrys Lake supports an adfluvial YCT population and provides a unique opportunity to learn more about adfluvial Cutthroat Trout. Historically robust, YCT face several threats including nonnative UTC. Little is known about the influence of UTC on the YCT population in Henrys Lake, but the Idaho Department of Fish and Game (IDFG) has reported increasing catch rates of UTC in their annual gill net surveys over the last two decades (2000 – 2020; High et al. 2015; Flinders et al. 2016a; Heckel et al. 2020). Patterns and potential response of the YCT population have not been thoroughly investigated. Understanding the population dynamics of both nonnative UTC and native YCT in Henrys Lake is important, particularly as the environment shifts to less favorable conditions for YCT (i.e., climate change, warming temperatures).

Fish populations have been monitored in Henrys Lake since 1970 and these historical data can provide valuable insight on long-term changes in population dynamics. A comprehensive evaluation of fish populations often includes information about abundance, length and age structure, body condition, and growth (Neumann et al. 2012; Quist et al. 2012). Catch rates and length structure are summarized annually for Henrys Lake (e.g., management reports), but YCT growth has only been investigated superficially (i.e., length at age at capture). Detailed analysis of growth provides insight into a population's ecology (Crecco and Savoy 1985; Allen and Hightower 2010; Ng et al. 2016). Understanding long-term trends in population structure and growth is critical for making informed management decisions and provides insight on how abiotic and biotic interactions (i.e., introduction of UTC) may influence YCT populations in Henrys Lake. Therefore, the specific objective of this chapter was to describe long-term trends in abundance, length structure, body condition, age structure, and growth of YCT. Additionally, I modeled relative abundance and growth to identify factors related to abundance and growth through time. I predicted that UTC abundance and warm temperatures would be negatively related to catch rates and growth of YCT. Additionally, I expected that growth of YCT would be influenced by density-dependent characteristics (e.g., abundance of trout, stocking rates).

Methods

Henrys Lake is a shallow eutrophic lake located in eastern Idaho (Figure 2.1). The maximum depth in the lake was just under 2 m in 1912 (Irving 1955). Despite the shallow depth, the lake supported a robust YCT population that provided recreational opportunity and a food resource for nearby mining communities. A dam was constructed on the lake in 1922 to increase water storage (Irving 1955; Griffin et al. 2017). Although Henrys Lake is still relatively shallow (mean depth = 4 m; Flinders et al. 2016a), it supports a renowned trophy trout fishery for YCT, Rainbow Trout × YCT hybrids, and Brook Trout (Campbell et al.

2002; Roth et al. 2020). Since the 1970s, the trout fishery has been primarily maintained by an extensive hatchery supplementation program (Rohrer and Thorgaard 1986; Campbell et al. 2002).

Historical fishery data were compiled from IDFG's annual population surveys (i.e., 1970-2020). Surveys provided information on the number of fish sampled, sampling effort, and total length (mm) of sampled fish. Beginning in 2004, weight measurements (g) were recorded to monitor body condition. Hard structures (i.e., scales, sagittal otoliths) were also collected during population surveys. Otoliths and scales were removed from all YCT sampled. The location of where scales were removed for the historic samples is unknown, but was likely from the area just posterior to the pectoral fin. During processing, YCT hard structures were subsampled from ten fish per centimeter length group for each year. Scales were pressed onto acetate slides and viewed with a dissecting scope (McInerny 2017). Sagittal otoliths were mounted in epoxy and a thin section was cut along the dorsoventral plane using an IsoMet Low Speed saw (Buehler Inc., Lake Bluff, Illinois; Koch et al. 2009; Long and Grabowski 2017). Ages were estimated by a single reader without knowledge of fish length. Incremental growth was measured with ImagePro software (Media Cybernetics, Inc., Rockville, Maryland).

Prior to 2002, a variety of gear types were used for population assessments on Henrys Lake including trap nets, a purse seine, and various gill nets (Table 2.1). In 2002, gill net surveys were standardized. Because of concerns with gear selectivity, long-term trends in catch rates and length structure were limited to 2002 to 2020. Catch rates for YCT were calculated as catch-per-net-night of all fish and by standard length category (i.e., stock [S; 200 to 349 mm], quality [Q; 350 to 449 mm], preferred [P; 450 to 559 mm], memorable [M; 600

to 749 mm], and trophy [T; ≥ 750 mm]). Total catch rates for Brook Trout, hybrid trout, and UTC were calculated for all fish by species. Length structure of YCT was summarized using proportional size distribution (PSD; Neumann et al. 2012). Relative weight (W_r) was calculated for all fish and by length category to evaluate body condition (Kruse and Hubert 1997; Neumann et al. 2012). Standard weight (W_s) was calculated as:

$$log_{10}(W_s) = a' + b * log_{10}(L)$$

where the intercept (a') is -5.192 and the slope (b) is 3.086 and L is total length (Neumann et al. 2012).

An age-length key was calculated and used to estimate age structure of YCT 2002 to 2020 from the subsampled YCT (*n* = 3,025; Quist et al. 2012). Age-2 and older fish were considered fully recruited to the gear based on age-specific catches. A weighted catch curve was used to calculate total annual mortality for age-2 to age-11 YCT (Smith et al. 2012). Total annual mortality estimates were summarized by decade (i.e., 2002 to 2010 and 2011 to 2020).

Back-calculated length at age was estimated by measuring the distance from the focus of the scale or nucleus of the otolith to each annulus (Quist et al. 2012). For scales, back-calculated lengths were estimated with the Fraser-Lee method:

$$L_i = \left(\frac{L_c - a}{S_c}\right) S_i + a$$

where L_i is the back-calculated length of the fish when the *i*th annulus was formed, L_c is the length of the fish at capture, S_c is the radius of the scale at capture, S_i is the radius of the scale at the *i*th annulus, and a is the intercept of the regression of fish length at capture on scale radius at capture. Back-calculated lengths were estimated for otoliths with the Dahl-Lea method:

$$L_i = L_c\left(\frac{S_i}{S_c}\right)$$

where L_i is the back-calculated length of the fish when the *i*th annulus was formed, L_c is the length of the fish at capture, S_c is the radius of the otolith at capture, S_i is the radius of the otolith at the *i*th annulus. Back-calculated lengths at ages 2 to 4 were summarized by decade. Growth comparisons were limited to ages 2 to 4 because of concerns with age estimates from scales. Ages are frequently underestimated from scales due to difficulty identifying the first annulus, crowding on the edge structure, and(or) resorption (Hoximeire et al. 2001; Kaeding and Koel 2011; McInerny 2017). Comparisons between Henrys Lake YCT scales and sectioned otoliths indicate back-calculated lengths of scales and otoliths were similar from age 2 to 5 (D. McCarrick, unpublished data). Summarizing back-calculated lengths by decade helped mitigate errors associated with age estimates from scales and allowed for broad comparison over a longer time period.

Historical stocking and environmental data were also compiled. Stocking records included species, date of stocking, number stocked, and average length at stocking. Long-term water temperature data do not exist; therefore, air temperature was used as a surrogate for water temperature during open water periods. Air temperature (°C) and snow-to-water equivalent (cm) data were obtained from Natural Resources Conservation Service SNOTEL Site 546 in Island Park, Idaho. A variety of temperature variables were calculated (e.g., average, minimum, maximum) annually, for the growing season (01 May – 31 October), and summer (20 June – 22 September). Lake volume (m^3) information was downloaded from the U.S. Geological Survey gage on the dam.

Catch rates and growth of YCT were further analyzed with regression analysis to evaluate relationships with environmental and biological characteristics. Although I evaluated PSD and relative weight (W_r), length and weight data are often biased by a variety of factors including gear type and time of year (e.g., spawning; Neumann et al. 2012). As such, regression models were not developed for PSD and W_r. Covariates in models for catch rates and growth of YCT included air temperature, snow-to-water equivalent, reservoir volume, catch rates for each species, and stocking rates for each species. Time lags were also included for stocking variables. Multicollinearity was evaluated with Spearman's correlation coefficient (Sokal and Rohlf 2001). If two covariates were significantly correlated (Spearman's $r \geq |0.70|$), the most ecologically relevant variable was retained for further analysis. For example, maximum air temperature during the growing season and annual maximum air temperature were highly correlated. Maximum air temperature during the growing season was deemed more ecologically relevant, so it was retained for candidate models.

Regression models for catch rates were created with a Poisson distribution using the glm function in R statistical program (R Development Core Team 2020). Total count was the response variable and an offset variable was used for effort. Growth was evaluated with mixed-effects models (Weisberg 1993; Weisberg et al. 2010; Watkins et al. 2017). Growth coefficients were estimated with a repeated-measures mixed-effects linear model that evaluated the effects of age and year on annual growth increments (Weisberg et al. 2010). Year and individual fish were treated as random effects and age was a fixed effect. Due to concerns with scales, growth coefficients were only calculated for years that otoliths were collected (i.e., 2002 to 2020). Simple linear models were created using the growth coefficients as the response variable.

Regression models for catch rates were evaluated for overdispersion. The dispersion parameter ($\hat{c}$) was calculated by dividing Pearson's residual deviance by the residual degrees of freedom (Burnham and Anderson 2002). If the dispersion parameter was greater than one, the model was considered overdispersed. Models that were not overdispersed were ranked with Akaike Information Criterion adjusted for small sample size (AIC_c). Quasi-AIC_c was used to evaluate models that were overdispersed and an additional parameter was added to K. Null models were included during model evaluation. The top model had the lowest AIC_c or $QAIC_c$ score and models within two AIC_c or $QAIC_c$ points were considered in the top models. Model fit was further evaluated with the coefficient of determination (R^2; Sokal and Rohlf 2001). For overdispersed models, McFadden's pseudo R^2 was used to evaluate model fit and was calculated as one minus the ratio of the log likelihood of a model with parameters and the intercept only model (McFadden 1974). Models with a McFadden's pseudo R^2 value of 0.20 – 0.40 are considered excellent models, but models with R^2 values as low as 0.10 have been shown to have good fit (McFadden 1974; Hosmer and Lemshow 1989; Klein et al. 2015).

Results

Catch-per-unit-of-effort from 2002 to 2020 was variable across years and averaged 7.4 YCT per net night ($\pm$ SD; $\pm$ 3.6) and 19.9 UTC per net night ($\pm$ 13.0; Figure 2.2). Catch rates peaked in 2008 at 15.4 YCT and 50.5 UTC per net night Yellowstone Cutthroat Trout catch rates declined steadily from 2011 to 2018. Catch was primarily comprised of S–Q and Q–P length fish. The relative abundance of P–M length YCT also varied through time and has generally declined since 2015. Length structure of YCT in Henrys Lake varied through time (Figure 2.3). No trophy-length YCT and few memorable-length YCT were sampled from 2002 to 2020. Relative weights varied across years and have decreased from an average of 116 (± 16.5) in 2004 to 93 (± 8.2) in 2020 (Figure 2.4). Relative weights were similar across length categories each year except for P–M length YCT which had slightly lower relative weights than the other length categories.

In total, 3,254 YCT scales and otoliths were aged (Table 2.1). Yellowstone Cutthroat Trout length varied from 105 to 650 mm (mean ± SD; 356.6 ± 91.1 mm) and in age from 1 to 11 years (2.7 ± 1.1 years). Age structure varied through time and was dominated by age-4 and younger fish (Figure 2.5; Appendix A). Growth of age-2 to age-4 fish was similar across decades with slightly higher mean back-calculated length in the two most recent decades (Figure 2.6). Using just otoliths from fish collected after 2002, age-1 to age-6 YCT grew fastest during 2002-2010 (Figure 2.7). Age-7 and older YCT grew faster from 2011 to 2020 than during the prior decade. Total annual mortality for age-2 and older YCT was estimated at 0.70 during 2002 to 2010 and 0.60 during 2011 to 2020.

Catch rates and growth were further analyzed with regression modeling. Catch rates were modeled by standard-length category, but top models did not provide additional insight beyond those for total YCT abundance. Regression modeling indicated positive relationships between abundance of YCT and the abundance of Brook Trout and hybrid trout (Table 2.2; Appendix B). However, the null model was also in the top set of models. Growth of YCT was negatively related to catch rates of Brook Trout, UTC, and all trout, and positively associated with YCT stocking rates and minimum air temperature during the growing season (Table 2.3; Appendix B). Brook Trout and Utah Chub catch rates were in three of the top four models for growth of YCT.

Discussion

Cutthroat Trout are declining across their distribution due to negative interactions with nonnative species and habitat degradation (Young 1995; Gresswell 2011). Despite the ecological and economic importance of Cutthroat Trout, limited information exists on the ecology of adfluvial Cutthroat Trout populations. The lack of information on adfluvial populations complicates comparisons between populations. My research provides important insight on the Henrys Lake YCT population—an important population of adfluvial YCT. Yellowstone Cutthroat Trout are abundant in rivers and streams, but are typically much smaller than lacustrine YCT. For example, YCT sampled from lotic populations rarely exceed 400 mm and few exceed 250 mm (Thurow et al. 1988; Meyer et al. 2003). In contrast, adfluvial populations of YCT often contain fish over 600 mm (Kaeding and Koel 2011; Heller 2021). Yellowstone Cutthroat Trout in Yellowstone Lake caught in gill nets had maximum lengths of 565 mm, but YCT over 630 mm have been reported (Kaeding and Koel 2011). Bonneville Cutthroat Trout reach lengths of 640 mm in Bear Lake, Idaho-Utah (Heller 2021), and Strawberry Reservoir, Utah, has produced YCT as long as 730 mm (Varley and Gresswell 1988). Maximum length of YCT collected from Henrys Lake from 2002 to 2020 was 644 mm and averaged about 350 mm.

Yellowstone Cutthroat Trout in Idaho typically live 8 to 9 years (Gresswell 2011). Maximum age of YCT in Yellowstone Lake was 10 years (Kaeding and Koel 2011) and Bonneville Cutthroat Trout in Bear Lake live up to age 12 (Heller 2021). Similar to other adfluvial populations, YCT in Henrys Lake had a maximum age of 11 years. Although YCT in Henrys Lake can live up to age 11, the majority of YCT were between ages 2 and 5. In 1955, YCT in Henrys Lake were reported to live 6 years (Irving 1955). Although fish may live longer in recent times, the change in apparent longevity is most likely a result of underestimation of age from scales (Kerns and Lombardi-Carson 2017). Yellowstone Cutthroat Trout scales often fail to form a first annulus (Kaeding and Koel 2011), and resorption, regeneration, and crowding make identifying annuli difficult on cycloid scales (Hoxmeier et al. 2001; McInerny 2017). Scales were less precise and underestimated ages compared to otoliths for kokanee, Dolly Varden Trout *Salvelinus malma*, and Rainbow Trout (Hining et al. 2000; Stolarski and Sutton 2013; Branigan et al. 2019). Hard structure comparisons between scales and otoliths of YCT in Henrys Lake suggest that scales underestimate ages relative to otoliths (D. McCarrick, unpublished data).

Vital rates provide important information on fish populations that are valuable for management decisions. Total annual mortality of age-2 to age-11 YCT in Henrys Lake was estimated between 60 and 70%. Mortality rates in Henrys Lake are higher than other lentic Cutthroat Trout populations (e.g., Heller 2020; Simmons 2020). For example, total annual mortality was 47% for Bonneville Cutthroat Trout in Bear Lake and 49% for Lahontan Cutthroat Trout in Summit Lake, Nevada. With regard to growth, YCT in Henrys Lake grow faster than YCT in Yellowstone Lake (Gresswell 2011). For example, YCT mean back-calculated length at age 2 in Henrys Lake was 259 mm, but only 140 mm in Yellowstone Lake. Similar patterns were observed for other ages. Yellowstone Cutthroat Trout in Henrys Lake grow at a rate similar to piscivorous Bonneville Cutthroat Trout in Bear Lake (Heller 2021). For instance, mean back-calculated length at age 3 was 332 mm for YCT in Henrys Lake and 291 mm for Bonneville Cutthroat Trout in Bear Lake. Adfluvial populations of Cutthroat Trout are typically piscivorous (e.g., Bonneville Cutthroat Trout and Lahontan Cutthroat Trout *O. c. henshawi;* Gresswell 1988). Relatively fast growth of YCT in Henrys

Lake could be due to high production of macroinvertebrates or because YCT in the system exhibit some level of piscivory. Although YCT are not typically considered piscivores, I did identify a positive relationship between YCT growth and YCT stocking rates of the same year.

Changes in growth may be associated with interactions with UTC. Unfortunately, regression modeling of YCT growth was limited to the period after UTC were first detected in Henrys Lake. Nevertheless, my analysis indicated a negative relationship between growth of YCT and UTC abundance. The specific mechanism is unknown, but diet overlap and competition between UTC and salmonids has been extensively documented in other systems (Schneidervin and Hubert 1987; Teuscher and Luecke 1996; Winters and Budy 2015). For instance, Schofield Reservoir, Utah, is dominated by UTC, but also contains several trout species such as Rainbow Trout, Tiger Trout (Brown Trout *Salmo trutta* × Brook Trout), and Bonneville Cutthroat Trout (Winters and Budy 2015). High diet overlap was demonstrated between all trout species and UTC, and smaller trout experienced reduced growth as a result of high UTC densities. Diet overlap in Henrys Lake has been evaluated to a limited extent, but results suggested diet overlap was minimal between UTC and YCT (Flinders et al. 2016b). If diet overlap is not occurring between UTC and YCT at a level that could explain changes in growth, UTC may have an indirect effect (e.g., changes to nutrient dynamics).

Climate change, and particularly warming temperatures, will likely compound the negative effects of habitat degradation and invasive species on native species (Williams et al. 2009). Rising temperature is a concern for aquatic systems, especially for salmonids. Some climate models predict trout habitat declines of 53% to 97% with warming temperatures (e.g., Flebbe et al. 2006). Environmental variables that may be related to climate change (e.g., air temperature, snowpack, reservoir volume) were included as covariates in my analysis. Interestingly, the only relationship detected with these environmental variables was a positive relationship between air temperature and YCT growth. I hypothesized that growth would slow as temperatures increased, but a negative relationship was not identified. One reason for this observation is that temperatures in Henrys Lake might not be warm enough to have a negative effect on YCT. Minimum air temperature during the growing season (i.e., 01 May to 31 October) has increased since the 1990s, but maximum air temperature has remained relatively constant. Alternatively, Henrys Lake may have enough thermal refuge that YCT are not yet affected by increasing temperatures (see Chapter 3). Similar patterns have been observed in other systems. Bonneville Cutthroat Trout were able to tolerate normally lethal water temperatures when cycled with cool-water periods (Johnstone and Rahel 2003; Schrank et al. 2003). As such, Bonneville Cutthroat Trout were able to "reset" when cold-water refugia were available. Yellowstone Cutthroat Trout survive in geothermally heated streams (≤ 27°C) in Yellowstone National Park by using thermal refugia (Varely and Gresswell 1988; Gresswell 2011). Yellowstone Cutthroat Trout in Henrys Lake have been documented congregating on springs and near tributaries during peak summer temperatures (see Chapter 3). Temperatures may rise above thermal tolerances for YCT, but there may be enough thermal refugia to mitigate any negative effects. Although temperature does not appear to be negatively affecting growth at this time, it might become a concern if temperatures rise.

A negative relationship between YCT growth and Brook Trout catch rates was observed. Most research conducted on interactions between Brook Trout and YCT has focused on streams (Peterson et al. 2004; Young 1995). Results of that research consistently illustrate that Brook Trout are associated with reduced growth and recruitment failure of

Yellowstone Cutthroat Trout (Young 1995; Peterson et al. 2004; Gresswell 2011; Al-Chokachy et al. 2018). Limited information is available on the interactions of Brook Trout and YCT in lake systems; however, Donald (1987) documented displacement of Cutthroat Trout and Rainbow Trout by Brook Trout in 88% of lakes in the Canadian mountain national parks with small outlets. Cutthroat Trout and Rainbow Trout became established in only 5% of lakes where Brook Trout, Cutthroat Trout, and Rainbow Trout were stocked together. Although not well understood, aggressive interactions have been documented between Brook Trout and Cutthroat Trout (Dunham et al. 2002). Brook Trout are more sensitive to temperature than YCT (Cunjak and Green 1985; Young 1995) and may congregate near springs and other cold-water sources during periods of high temperature (i.e., summer), thereby limiting access for the other species like YCT.

The impetus of this project was to understand long-term trends in population dynamics of YCT in Henrys Lake. Although there have been concerns about YCT in Henrys Lake, my research suggests no major changes in the population characteristics of YCT. Management goals for Henrys Lake are to maintain 5.4 YCT per net night and for at least 10% of the YCT in annual gillnet surveys to be greater than or equal to 508 mm (Brett High, IDFG, personal communication). Catch rates in Henrys Lake averaged 7.4 YCT per net night from 2002 to 2020. The percentage of YCT greater than or equal to 508 mm has varied from 0% to 20% and averaged 3.4% ($\pm$ 4.5). In 2020, catch rates were 6.4 YCT per net night with 2% above 508 mm. Creel data further suggest that the population is stable. Angler catch rates have varied from year to year, but have generally remained constant (Heckel et al. 2020). Although UTC abundance was negatively related to YCT growth, YCT are still growing fast. A response from YCT may be observed if UTC abundance continues to increase. Like most systems, continued monitoring using standardized methods will be critical for evaluating YCT and UTC populations in Henrys Lake. Also, results from this research provide critical information on adfluvial YCT. Adfluvial Cutthroat Trout provide important fisheries and information on how adfluvial trout populations function is important to inform management and conservation decisions.

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Tables and Figures

Table 2.1. Sampling method, hard structures used for age and growth analysis, and number of Yellowstone Cutthroat Trout aged from Henrys Lake, Idaho.

Decade	Sampling method	Structure	Number aged
1971 – 1980	Creel	Scales	37
1981 – 1990	Creel, trap net, purse seine	Scales	154
1991 – 2000	Gill net	Scales	38
2001 – 2010	Gill net	Otoliths	1,193
2011 – 2020	Gill net	Otoliths	1,832

Table 2.2. Top multiple-regression models for catch-per-unit-of-effort (CPUE) for Yellowstone Cutthroat Trout in Henrys Lake, Idaho (2002–2020). Explanatory variables include CPUE for Brook Trout (BKT) and Rainbow Trout × Yellowstone Cutthroat Trout hybrids (HYB) in Henrys Lake. Models were ranked by Akaike's Information Criterion for overdispersed data and corrected for small sample sizes ($QAIC_c$). Delta $QAIC_c$, number of parameters (K), weight of the model (w_i), and coefficient of determination (McFadden's pseudo R^2) are reported. Direction of relationship between catch rates the covariates is indicated (positive [+], negative [-]).

Model parameters	$QAIC_c$	$\Delta QAIC_c$	K	w_i	R^2
+ BKT CPUE	21.1	0.00	2	0.24	0.18
+ BKT CPUE + HYB CPUE	21.8	0.75	3	0.16	0.25
Null	22.4	1.36	1	0.12	
+ HYB CPUE	22.6	1.53	2	0.11	0.10

Table 2.3. Top multiple-regression models for growth of Yellowstone Cutthroat Trout in Henrys Lake, Idaho (1994–2019). Explanatory variables include number of Yellowstone Cutthroat Trout (YCT) stocked annually, minimum air temperature (Temperature; °C) during the growing season (01 May – 31 October), and catch per unit of effort (CPUE) for Brook Trout (BKT), Utah Chub (UTC), and all trout in Henrys Lake. Models were ranked by Akaike's Information Criterion for overdispersed data and corrected for small sample sizes ($QAIC_c$). Delta $QAIC_c$, number of parameters (K), weight of the model (w_i), and coefficient of determination (McFadden's pseudo R^2) are reported. Direction of relationship between catch rates the covariates is indicated (positive [+], negative [-]).

Model parameters	AIC_c	ΔAIC_c	K	w_i	R^2
– BKT CPUE – UTC CPUE + YCT stocking	131.5	0.00	5	0.19	0.56
– UTC CPUE + Trout CPUE	131.7	0.17	4	0.17	0.45
– BKT CPUE	131.7	0.20	3	0.17	0.33
– BKT CPUE – UTC CPUE + Temperature	131.8	0.26	5	0.16	0.55

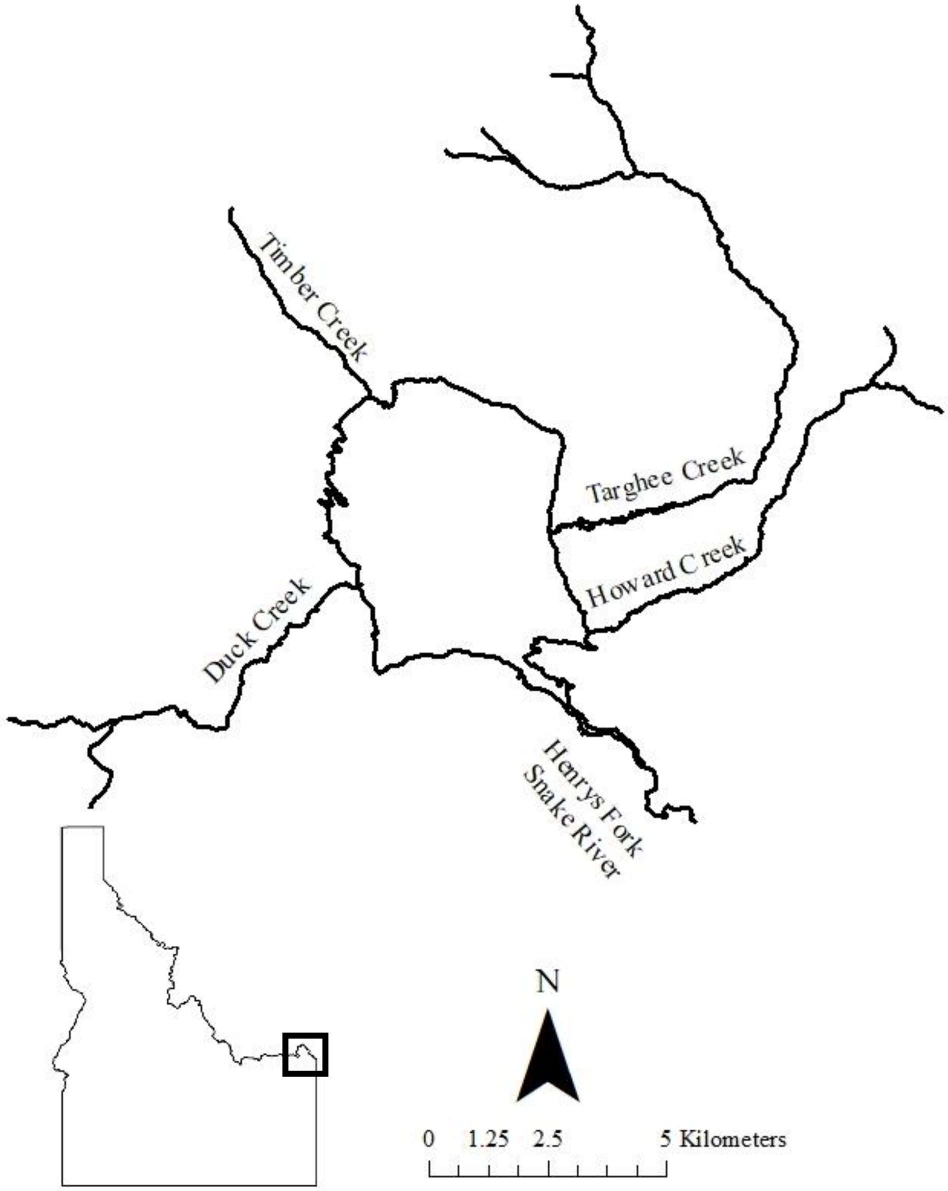

Figure 2.1. Map of Henrys Lake, Idaho, and major tributaries.

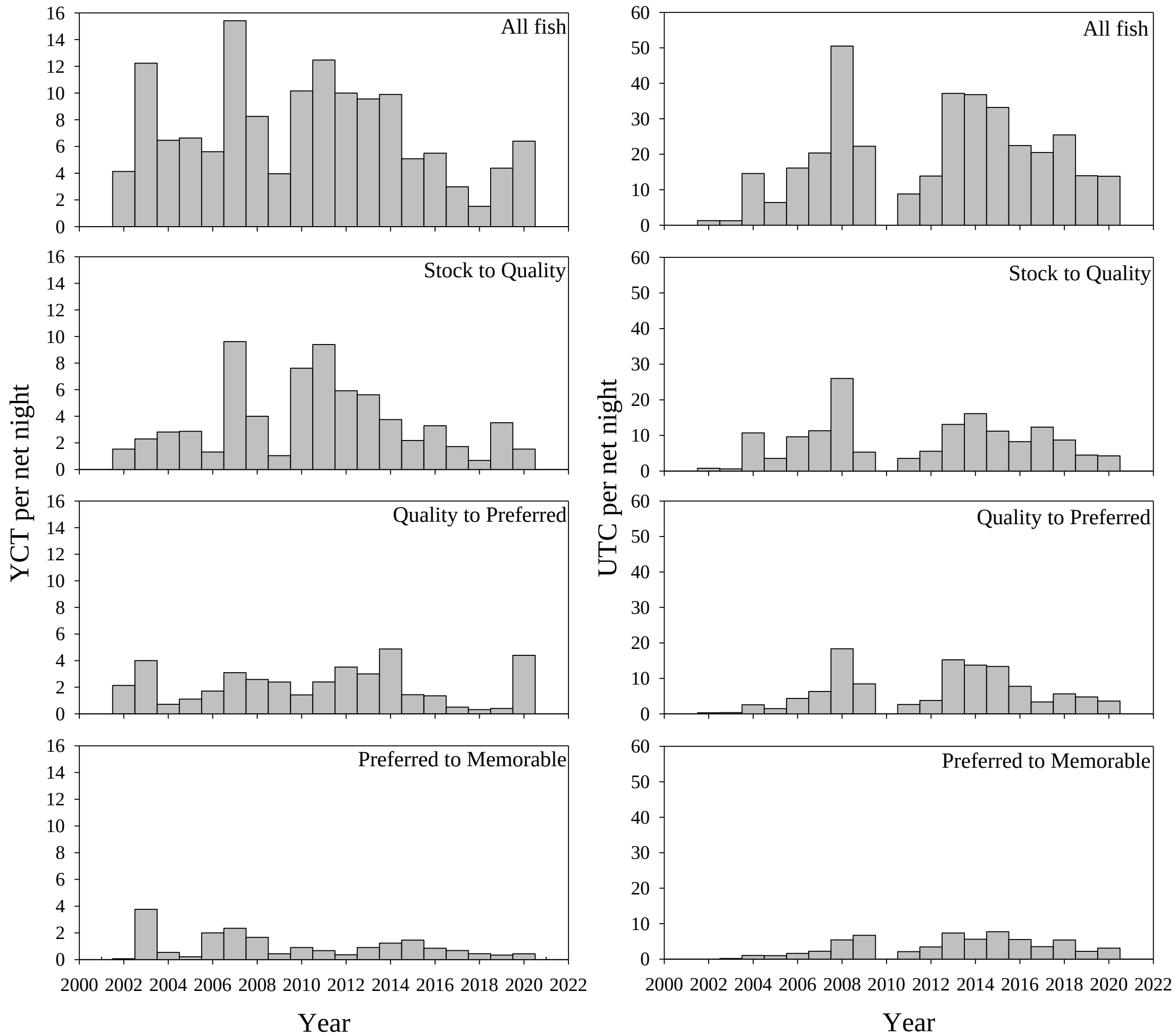

Figure 2.2. Catch-per-unit-of-effort for Yellowstone Cutthroat Trout (YCT) and Utah Chub (UTC) in Henrys Lake, Idaho from annual gill net surveys (2002–2020). Length categories for YCT include stock (S; 200 to 349 mm), quality (Q; 350 to 449 mm), preferred (P; 450 to 559 mm), and memorable (M; 600 to 749 mm). No trophy-length fish and few memorable- to trophy-length YCT (*n* = 5,524) were captured. Length categories for UTC include stock (S; 100 to 199 mm), quality (Q; 200 to 249 mm), preferred (P; 250 to 299 mm), and memorable (M; 300 to 379 mm). Few memorable- to trophy-length and trophy-length UTC (*n* = 14,834) were captured.

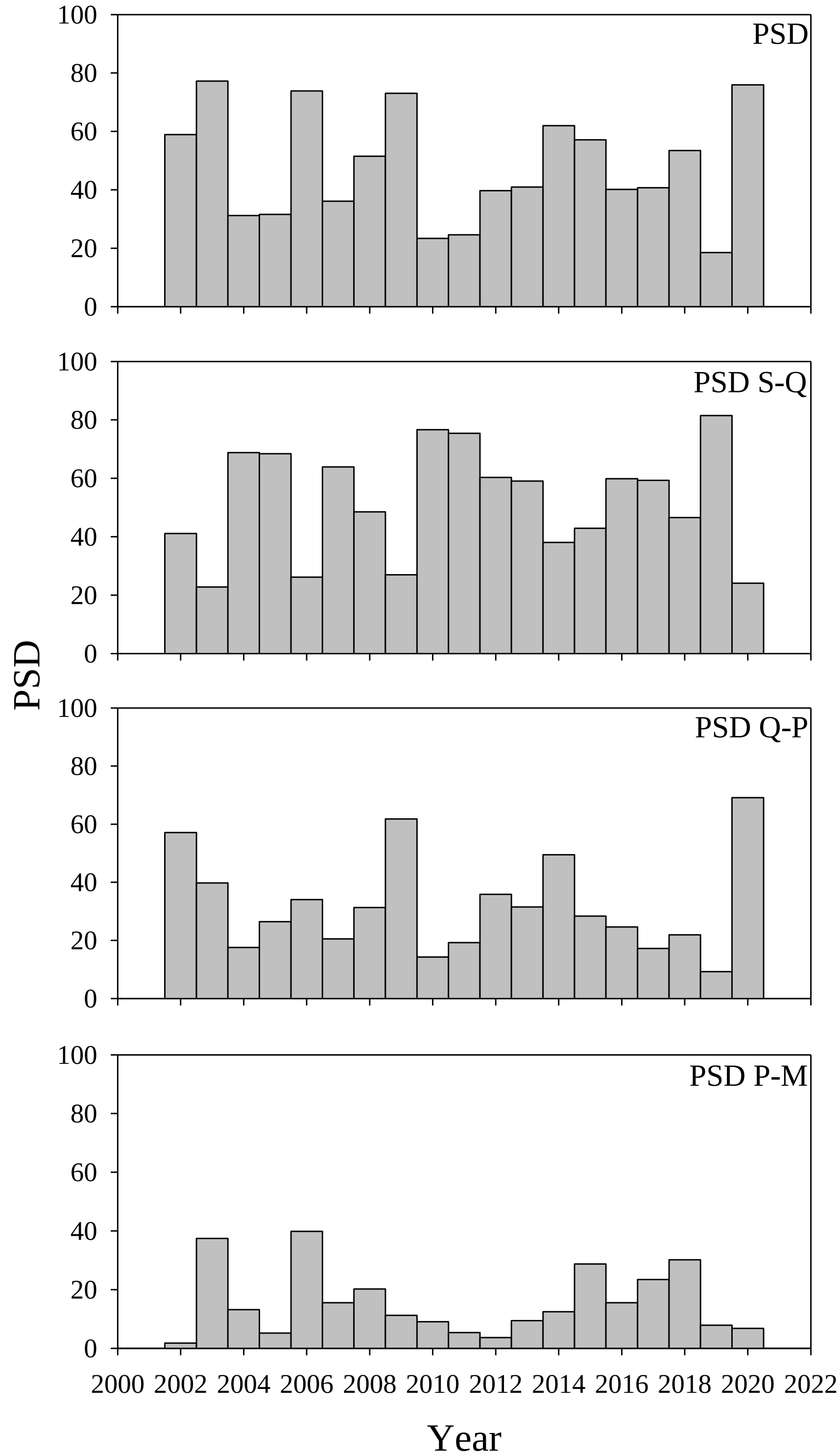

Figure 2.3. Proportional size distributions (PSD) for Yellowstone Cutthroat Trout in Henrys Lake, Idaho from annual gill net surveys (2002–2020). Length categories include stock (S; 200 to 349 mm), quality (Q; 350 to 449 mm), preferred (P; 450 to 559 mm), and memorable (M; 600 to 749 mm). No trophy-length fish and few memorable- to trophy-length YCT (*n* = 5,524) were captured.

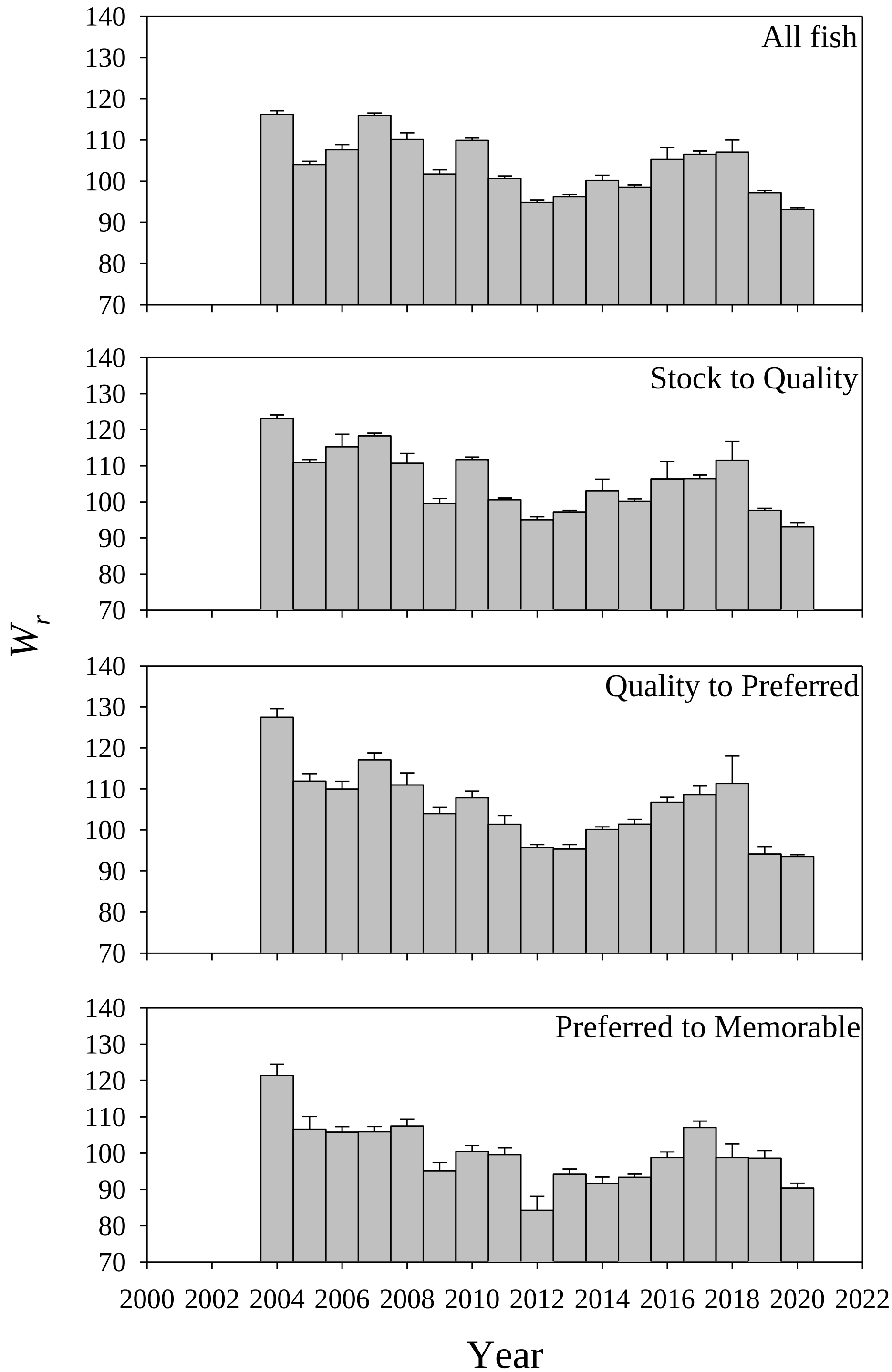

Figure 2.4. Relative weight (W_r) for Yellowstone Cutthroat Trout in Henrys Lake, Idaho from annual gill net surveys (2002–2020). Relative weight was calculated for each standard length category. Length categories include stock (S; 200 to 349 mm), quality (Q; 350 to 449 mm), preferred (P; 450 to 559 mm), and memorable (M; 600 to 749 mm). No trophy-length fish and few memorable- to trophy-length YCT (n = 5,484) were captured. Error bars represent standard error.

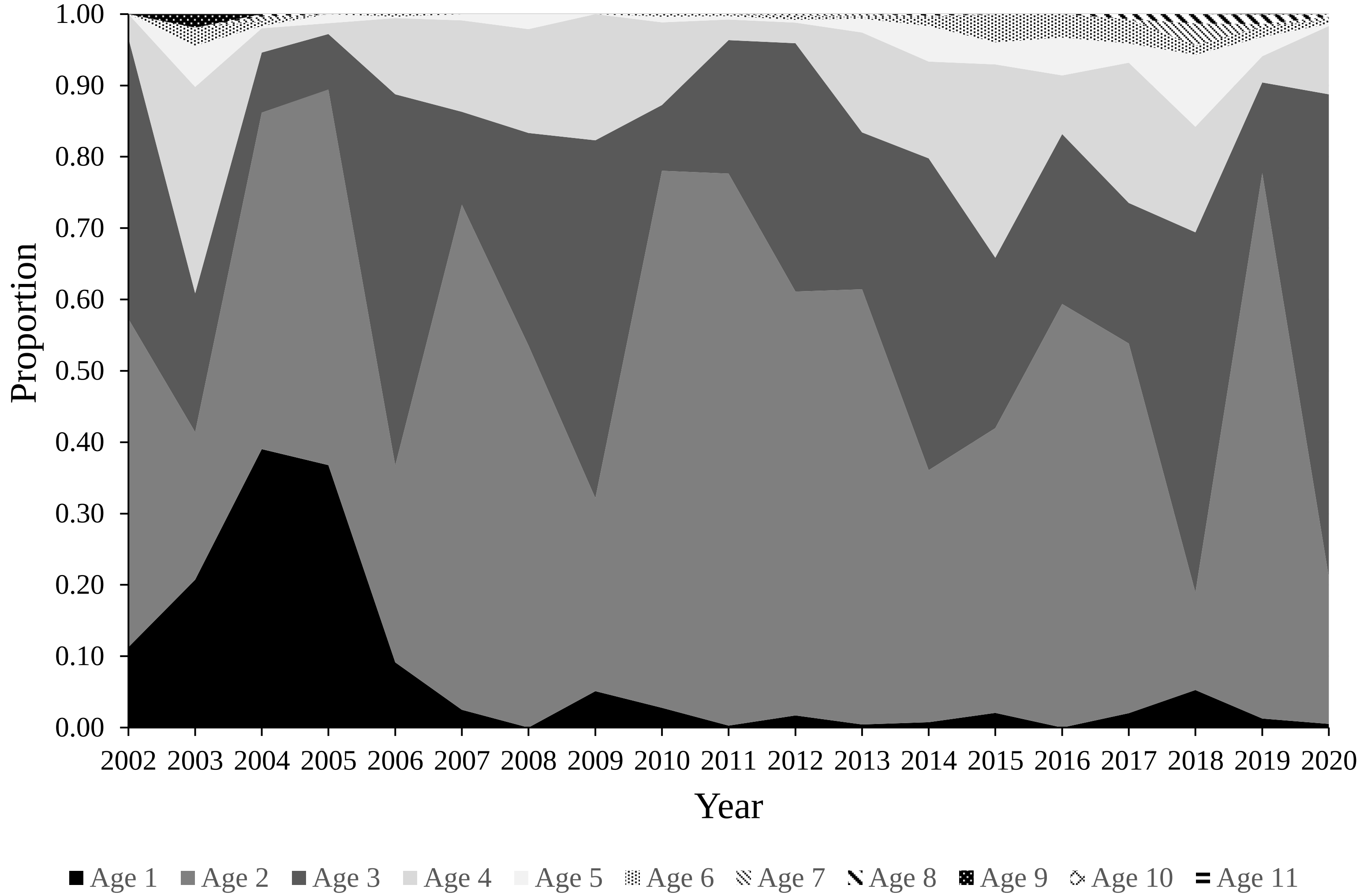

Figure 2.5. Proportion of Yellowstone Cutthroat Trout (YCT) at each age sampled from Henrys Lake, Idaho, 2002 to 2020.

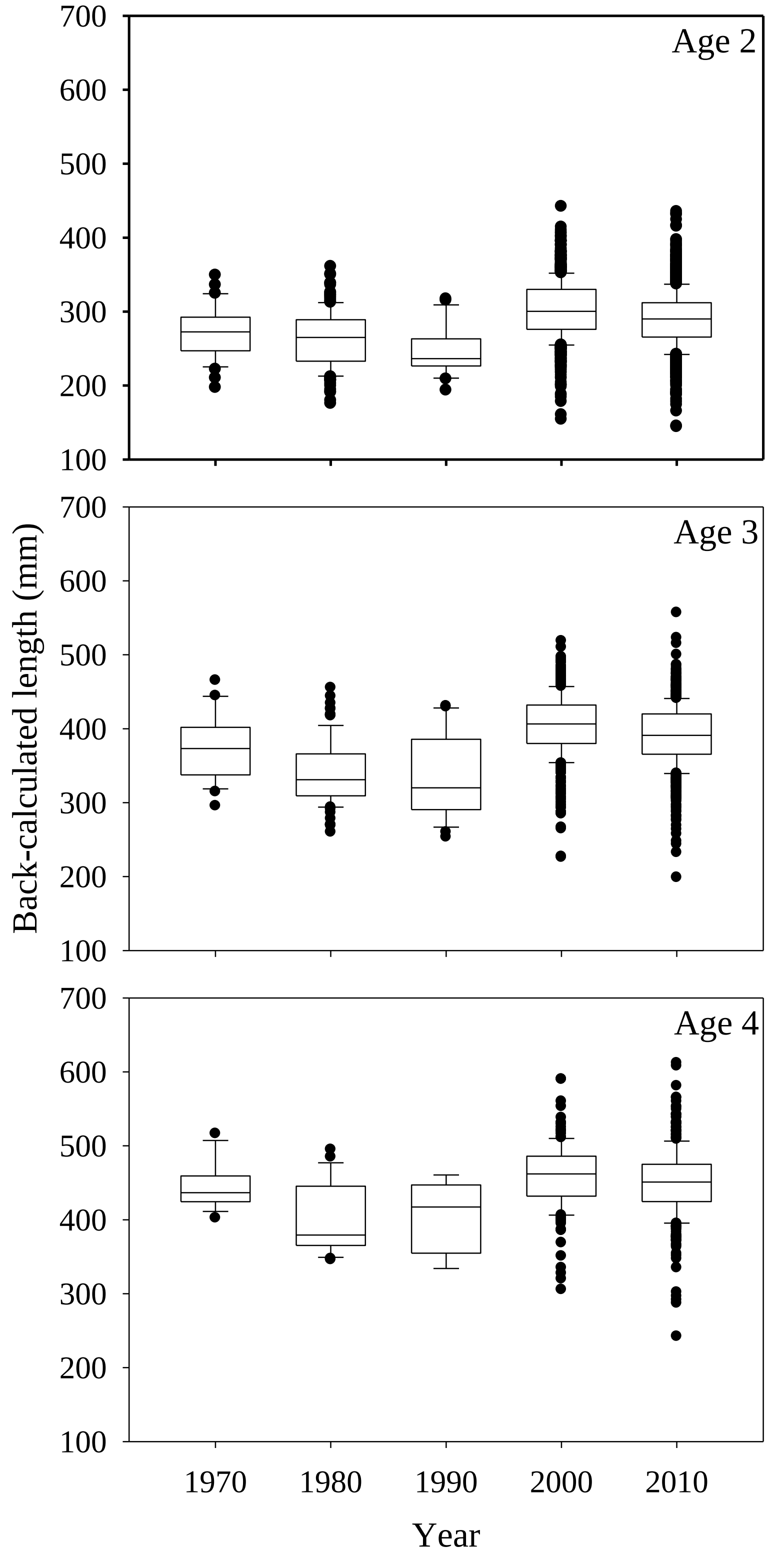

Figure 2.6. Back-calculated lengths for Yellowstone Cutthroat Trout in Henrys Lake, Idaho across five decades. Back-calculated lengths were calculated from scales (1970 – 1990) and otoliths (2000 – 2020).

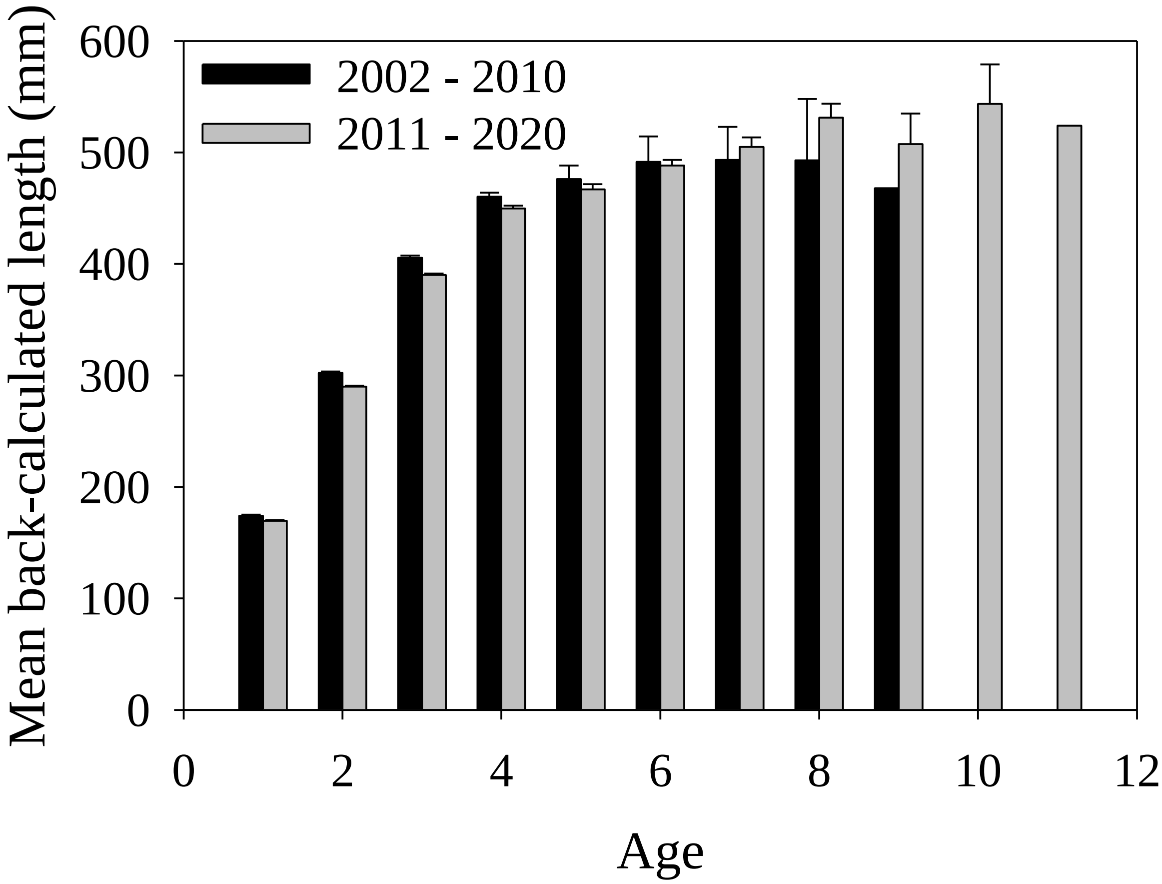

Figure 2.7. Mean back-calculated lengths and standard error for Yellowstone Cutthroat Trout in Henrys Lake, Idaho (2002–2020). Mean back-calculated lengths were calculated from otoliths.

Chapter 3: Spatial overlap and habitat selectivity of native Yellowstone Cutthroat Trout and nonnative Utah Chub

Abstract

Henrys Lake, Idaho, is a renowned trophy trout fishery that faces an uncertain future following the establishment of Utah Chub (UTC) *Gila atraria*. Utah Chubs were first documented in the lake in 1993 and have become abundant over the past two decades. The influence of UTC on Yellowstone Cutthroat Trout (YCT) *Oncorhynchus clarkii bouvieri* is largely unknown, but UTC typically have negative effects on salmonids in systems where they have been introduced. Ninety-four YCT and 95 UTC were radio-tagged in spring 2019 and 2020 to better understand potential interactions between YCT and UTC in Henrys Lake. Fish were located via mobile tracking and fixed receivers from June to December, 2019 and 2020. In June of both years, YCT and UTC were concentrated in nearshore habitats. As water temperatures increased from a minimum of 12.5°C in June to a maximum of 20.4°C in July, UTC were documented in deeper water (mean ± SD; 3.6 ± 1.4 m) and YCT became more concentrated in areas with cold water (e.g., mouth of Targhee Creek, Staley Springs). In July and August, large congregations of UTC were observed near the Idaho Department of Fish and Game hatchery, Henrys Lake State Park, and in the outlet near the dam. Yellowstone Cutthroat Trout were detected in Duck, Howard, Targhee, and Timber creeks from June to August. No UTC were detected in the tributaries. In September and October, both species were widely distributed throughout the lake. By late fall (November–December), YCT were located along the shoreline and UTC were detected in the middle of the lake. Both YCT and UTC were observed in areas with dense vegetation. Macrophytes likely provided a food source for UTC and cover from predators for both species.

Yellowstone Cutthroat Trout locations were negatively related to warm water temperatures, whereas, UTC were positively associated with warm water temperatures. Results from this research fill knowledge gaps in UTC and YCT interactions as well as provide valuable insight on the ecology of UTC and adfluvial Cutthroat Trout populations. Furthermore, movement patterns and habitat selectivity of YCT and UTC in Henrys Lake can be used to inform management decisions for fishery improvement and YCT conservation.

Introduction

Yellowstone Cutthroat Trout (YCT) *Oncorhynchus clarkii bouvieri* is a popular sport fish native to Idaho, Montana, Nevada, Utah, and Wyoming (Gresswell 2011). It inhabits a wide variety of habitats from large rivers and lakes to small streams and Beaver *Castor canadensis* ponds. Historically, YCT were distributed throughout the Snake River, Idaho, and the Yellowstone River system of Montana and Wyoming (Behnke 1992). As of 2011, YCT occupied only 42% of its historic distribution and genetically unaltered populations remained in only 28% of the historic distribution (Gresswell 2011). The current distribution of YCT is limited to the Snake River drainage upstream of Shoshone Falls on the Snake River, and the Yellowstone River drainage downstream of the Tongue River and including the Tongue River (Behnke 1992). This truncated distribution is caused by threats from nonnative species and anthropogenic activities that have reduced habitat quality and quantity (Behnke 1992; Campbell et al. 2002; Gresswell 2011).

Rainbow Trout *Oncorhynchus mykiss*, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus fontinalis*, and Lake Trout *Salvelinus namaycush* have all been introduced into waters where YCT are native (Young 1995; Kaeding et al. 1996; Gresswell 2011; Al-

Chokhachy et al. 2018). Approximately 70% of Yellowstone Cutthroat Trout populations have been hybridized with Rainbow Trout (Al-Chokachy et al. 2018). Hybridization is a growing challenge and concern in the Snake River basin (Young 1995; Campbell et al. 2002; Kovach et al. 2011). On the Henrys Fork Snake River, Idaho, hybridization with Rainbow Trout has caused the near complete disappearance of Yellowstone Cutthroat Trout (Young 1995). Other interactions with nonnative salmonids include competition and predation. In 1994, Lake Trout were discovered in Yellowstone Lake (Kaeding et al. 1996). Lake Trout are highly piscivorous and have caused a decline in the YCT population with consequent ecosystem-level effects (Koel et al. 2011). Brook Trout and Brown Trout have also been associated with reduced growth and recruitment failure of YCT in multiple systems (Young 1995; Peterson et al. 2004; Al-Chokhachy and Sepulveda 2018). As YCT maintain high ecological, cultural, and economic value, minimizing the negative effects of nonnative species is a top priority for fisheries managers.

The introduction of nonnative Utah Chub (UTC) *Gila atraria* into many YCT waters is a growing concern. Utah Chub is native to the Lake Bonneville basin in Utah, Idaho, and Nevada and the Snake River drainage upstream of Shoshone Falls in Idaho (Sigler and Sigler 1996). In the Snake River, its native distribution is limited to the area downstream of Mesa Falls. Utah Chubs tolerate a wide variety of temperatures (i.e., 15.6 – 31.1°C) and are common in systems with dense vegetation. Utah Chubs are omnivorous and shift their diet to available food resources (Graham 1961; Sigler and Sigler 1996). Utah Chub is generally considered a nuisance outside of its native distribution and often competes with popular sport fishes (Davis 1940; Graham 1961; Sigler and Sigler 1996; Tuescher and Luecke 1996). Utah Chub have similar diets to salmonids and diet overlap has been documented in many reservoirs and lakes (Hazzard 1935; Davis 1940; Schneidervin and Hubert 1987; Tuescher and Luecke 1996; Winters and Budy 2015). For example, a decline in trout abundance was associated with competition with UTC for prey resources in Fish Lake, Utah, (Hazzard 1935; Davis 1940). The majority of prior research has described changes following the establishment of nonnative UTC; few studies have directly focused on the ecology of UTC.

In 1993, nonnative UTC were first detected in Henrys Lake (Gamblin et al. 2001). Henrys Lake is a shallow lake located in eastern Idaho near the Idaho-Montana border. Although Henrys Lake is managed for trophy Rainbow Trout × YCT hybrids, YCT, and Brook Trout, the Idaho Department of Fish and Game (IDFG) has prioritized conservation of native YCT (Campbell et al. 2002). Idaho Department of Fish and Game has reported increasing catch rates of UTC in their annual gill net surveys over the last two decades (High et al. 2015; Flinders et al. 2016; Heckel et al. 2020). For example, catch-per-unit-of-effort was 1.6 UTC per net night in 2002 and 25.5 UTC per net night in 2018 (Heckel et al. 2020). The influence of UTC on YCT in the system is unknown, but resource managers are concerned about potential negative interactions.

Although YCT have been extensively studied, little is known about the ecology of adfluvial Cutthroat Trout populations. Understanding how YCT respond to warm water temperatures in lakes is particularly important. Some climate models predict that trout habitat in North America will decline by 53% to 97% with warming air temperatures (Flebbe et al. 2006). In 2017, water temperatures in Henrys Lake exceeded 25°C (B. High, IDFG, unpublished data), a temperature shown to result in elevated mortality of other Cutthroat Trout subspecies (e.g., Johnstone and Rahel 2003). Henrys Lake is shallow (mean depth is 4 m; Flinders et al. 2016) and does not stratify; therefore, thermal refuge is limited to springs and tributaries. Climate change, particularly warming temperatures, may compound the negative effects of invasive species (e.g., reduction in suitable habitat and negative interactions with nonnative species; Williams et al. 2009).

Understanding how YCT respond to warming water temperatures and nonnative UTC is useful for future management and conservation of YCT. Telemetry technology has been used to increase knowledge of fish movement and behavior. Telemetry can be used to collect information on fish migration (Baxter et al. 2003; Hightower and Harris 2017), mortality rates (Pollock et al. 2004; Friedl et al. 2013), movement (Eiler 1995; Pegg et al. 1997; Hilderbrand and Kershner 2000), behavior (McCauley et al. 2014), predation (Teuscher et al. 2015), and habitat use (Dare 2001). Radio telemetry is costly and time consuming, but it can provide insight into fish behavior and movement that is otherwise difficult or impossible to obtain. Although radio telemetry has been used to evaluate characteristics of YCT populations (Kaeding and Boltz 2001; Teuscher et al. 2015; Ertel et al. 2017), radio telemetry has not been used to evaluate movement and habitat use by UTC. The specific objective of this study was to describe spatial and temporal patterns in movement, habitat use, and habitat selection of YCT and UTC in Henrys Lake. I hypothesized that YCT and UTC movement patterns would be related to habitat characteristics, particularly temperature, depth, and macrophyte cover. I further predicted that YCT and UTC would congregate near cold-water sources during periods of elevated water temperatures (e.g., summer).

Methods

Henrys Lake is a shallow lake located 1,974 m above sea level in eastern Idaho (Figure 3.1). The lake is approximately 3.2 km wide, 6.4 km long, and relatively shallow (mean depth = 4 m; Flinders et al. 2016). Henrys Lake provides the headwaters for the Henrys Fork Snake River. Several springs are present in the lake (e.g., Staley Springs, Kelly Springs) and some of the largest tributaries are Targhee, Howard, and Duck creeks. In 1922, a dam was constructed on the outlet to increase water storage capacity for downstream irrigation and to maintain the lake and fishery (Irving 1955). Idaho Department of Fish Game began operating an egg-take station on Hatchery Creek to mitigate losses of natural YCT recruitment due to losses in habitat after the creation of the dam (Campbell et al. 2002). Many of the tributaries have also been subjected to water diversion for irrigation. For example, Targhee Creek was dewatered in 1966 and 1973, and the majority of flow from Howard Creek was diverted for irrigation in 1978. This resulted in substantial losses of juvenile YCT migrating into the lake (i.e., 71-95% lost in Howard Creek). In recent years, IDFG has conducted extensive habitat restoration efforts including the installation of fish screens on irrigation diversions, riparian fencing along tributaries and lake shorelines, and instream habitat improvement on tributaries.

Fish were captured for telemetry tagging via angling, electrofishing, and with trap nets 28 May to 5 June, 2019, and 24 May to 4 June, 2020. For electrofishing, a boat was outfitted with a variable voltage pulsator (Infinity control box; Midwest Lake Electrofishing Systems, Inc., Polo, Missouri) and a generator (American Honda Motor Co., Inc., Alpharetta, Georgia). Trap nets had two rectangular frames (0.9 × 1.9 m), five hoops (0.8 m diameter), and a single lead (0.9 × 21.9 m). The nets had a single slit at the mouth, a single throat (30.5-cm stretch measure), and 1.3-cm bar-measure mesh. Two trap nets were set perpendicular to shore each night and pulled after 12 hours. Fish were captured throughout the lake to ensure the radio tags were evenly distributed. After capture, fish were placed in an aerated holding tank.

Radio transmitters were one of four models: Model MST-820 T, Model MST-930 T, MCFT2-3BM, or MCFT2-3EM (Lotek Wireless Inc., Newmarket, Ontario, Canada). Transmitters included a temperature sensor that transmitted an instantaneous temperature reading. In an effort to increase tag detection, transmitters were programmed on two frequencies (i.e., 149.300 or 149.400 MHz in 2019 and 148.360 or 149.520 MHz in 2020) and grouped into one of three burst intervals (i.e., transmit a signal every 6, 6.5, or 7 seconds). Transmitter longevity was approximately 120 days (MST-820 T), 320 days (MST-930 T), 444 days (MCFT2-3BM), or 528 days (MCFT2-3EM).

Surgeries were conducted at or near the point of capture following Leidtke et al. (2012). Fish were held prior to surgery and pre-tagging condition was assessed. If a fish was injured during capture, it was not tagged. Proper operation of transmitters was confirmed prior to tagging (i.e., receiver detected transmitter and the sensor accurately measured temperature). Transmitters, forceps, hemostats, needles, scalpel blades, surgical scissors, and sutures were disinfected with chlorhexidine solution between fish. Fish selected for tagging were anesthetized and total length measured to the nearest millimeter. Utah Chubs had to be at least 205 mm long (total length) and YCT had to be at least 215 mm long to ensure tag weights did not exceed 2% of the fish’s body weight (Zale et al. 2005; Leidtke et al. 2012). The radio transmitter was implanted into the body cavity via an incision made with a stainless-steel surgical scalpel blade. The radio antenna was guided through the body cavity to the exit point using the shielded-needle technique (Ross and Kleiner 1982). The incision was closed with interrupted sutures. After completion of the surgery, fish were placed in an aerated holding tank to assess the immediate effects of surgery and allow for recovery. Fish were released at or near the point of capture after they recovered.

A combination of mobile and fixed receivers was used to monitor fish movement. Four Model SRX-DL3 stationary receivers (Lotek Wireless, Inc., Newmarket, Ontario, Canada) were placed near the mouth of Howard, Targhee, Timber, and Duck creeks to evaluate fish use of tributaries for thermal refuge. Three-element Yagi antennas were used on each stationary receiver. Stationary receiver locations were chosen based on flows and predicted fish use from historical data. Data were downloaded every two weeks. Temperature was monitored continuously in the tributaries with in-stream thermographs deployed at the mouth of each tributary. Mobile tracking was conducted with a SRX800-M2 mobile tracking receiver (Lotek Wireless, Inc., Newmarket, Ontario, Canada). A six-element Yagi antenna was used with the boat and a three-element Yagi antenna was used with the airplane. Starting locations were randomly selected for mobile tracking. Tracking was conducted along transects and the entire lake was covered approximately three times by boat each month from June to August. A transmitter was considered shed if maximum signal strength was achieved and the fish could not be disturbed. Only data from active fish were included in subsequent analyses. Aerial surveys were also conducted approximately twice a month from June to September and once a month from October to December. Aerial surveys included Island Park Reservoir and the Henrys Fork Snake River from Henrys Lake Dam to Ashton, Idaho. Tracking did not occur from January to May because ice cover made transmitters difficult to detect.

Detection distance was assessed by lowering a transmitter into the water column at 1 m, 3 m, and 6 m deep and maneuvering the boat around the transmitter location to determine the maximum distance the receiver could detect and decode the transmitter. The transmitter could be detected at distances up to 50 m at depth of 6 m. Location error was estimated by comparing the distance between a known location transmitter to the location identified during a typical tracking event of the same transmitter. The global positioning system (GPS) point recorded during tracking was approximately 10 m from the known locations when tracking by boat and within 400 m when tracking by airplane. Distribution maps were compared for boat and plane fish locations each month. Patterns in distribution were consistent between tracking methods.

When a transmitter was relocated, a GPS point was recorded with the tag identification number and the transmitted temperature. A habitat assessment was conducted for each fish located by boat. Visibility was estimated to the nearest decimeter with a Secchi disk (Reischel and Bjornn 2003). Depth (m) was estimated to the nearest decimeter. Water temperature (°C) and dissolved oxygen (mg/L) were measured every meter from the surface with a multiparameter water quality meter (Pro2030 Dissolved Oxygen, Conductivity, Salinity Instrument, YSI Incorporated, Yellow Springs, Ohio). Macrophyte cover was defined as any living submerged aquatic vegetation visible with the naked eye and assessed visually (Fisher et al. 2012). An underwater camera (760c series, Aqua-Vu, Crosslake, Minnesota) was lowered to the lake floor and percent macrophyte cover was estimated. The camera was oriented in two directions and the percentage of macrophyte coverage visible in the display monitor was recorded in each direction; the two values were averaged. Additional habitat assessments were conducted at 5 m and 20 m away from the fish’s location in two different randomly selected directions (e.g., north, south, east, or west) for a total of four additional habitat assessments. Habitat availability was evaluated with the same habitat assessment described above at 20 randomly selected sites every two weeks from June to August of each year. Because I was particularly interested in the response of fish to warm water temperatures, habitat assessments were only conducted from June to August, the warmest time of the year.

ArcMap GIS version 10.5.1 (Esri, Redlands, California) was used to map the spatial distribution of YCT and UTC (e.g., Penne and Pierce 2008). Probability of use was estimated using the kernel density tool in the spatial analyst toolbox. The density estimate was described by detections of radio-tagged fish in Henrys Lake. Because patterns were similar between sampling years, 2019 and 2020 data were combined. Fish locations were randomly subsampled for individual fish detected more than four times per month to prevent autocorrelation (Hansteen et al. 1997). The multivariate kernel density estimator was defined as:

$$\hat{f}(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left\{\frac{1}{h}(x - X_i)\right\}$$

where K was the gaussian kernel, $K(x)$ was the kernel function defined for d-dimensional x, h was the bandwidth, and X_i was a random sample of sample size n (Silverman 1986). The kernel was defined as:

$$K_2(x) = \begin{cases} 3\pi^{-1}(1 - x^T x)^2 & if\ x^T x < 1 \\ 0 & otherwise \end{cases}.$$

The default bandwidth was calculated in ArcMap as:

$$f(x) = 0.9 * \min\left(SD, \sqrt{\frac{1}{\ln(2)}} * D_m\right) * n^{-0.2}$$

where SD is the standard distance, D_m is the median distance, and n is the sample size. Kernel density function was estimated for UTC and YCT in Henrys Lake for each month (i.e., June to December; Rogers and White 2007; Penne and Pierce 2008).

Resource selection functions were used to assess habitat selection (e.g., Long et al. 2014; Merems et al. 2020). Similar to probability of use, data were combined for 2019 and 2020 because no notable differences were observed between years. Covariates for models were depth, visibility, percent macrophyte cover, average dissolved oxygen, and water temperature. Habitat values at the fish's location reflected use and biweekly lake-wide habitat assessments were used to reflect available habitat. Water temperature values from the temperature sensor on the radio transmitter represented fish use. Water temperature was averaged across the depth profile at each site to estimate availability. Dissolved oxygen was also averaged across the depth profile at each site. Probability of YCT or UTC use at a location was extracted from the kernel density estimates. Probability of YCT use was included in regression models for UTC and probability of UTC use was included in YCT models. Spearman's correlation coefficient was used to evaluate multicollinearity among variables (Sokal and Rohlf 2001). If two covariates were significantly correlated (Spearman's $r \geq |0.70|$), the most ecologically relevant variable was retained for further analysis. For example, visibility and macrophyte cover were highly correlated. Macrophyte cover was deemed ecologically relevant and retained for regression analysis.

Habitat selectivity was analyzed at the lake-wide scale with a use-availability design (Manly et al. 2002). Locations where individual fish (2019: n = 50 YCT, 50 UTC; 2020: n = 44 YCT, 45 UTC) were found represented use and random habitat sites represented availability (up to 80 total random locations per month). Generalized linear models with a logit link function and binomial response variable distribution were used to model habitat selectivity. Separate resource selection functions were fit for each month (i.e., June–August) and species. Models were ranked with Akaike information criterion adjusted for small sample size (AIC_c). The top model had the lowest AIC_c score and models within two AIC_c values were considered top models. McFadden's pseudo R^2 was used to evaluate model fit and was calculated one minus the ratio of the log likelihood of a model with parameters and the intercept-only model (McFadden 1974). Models with a McFadden's pseudo R^2 value of 0.20 – 0.40 are considered excellent models, but models with R^2 values as low as 0.10 have been shown to have good fit (McFadden 1974; Hosmer and Lemshow 1989; Klein et al. 2015).

Results

In total, 95 UTC (2019: n = 50; 2020: n = 45) and 94 YCT (2019: n = 50; 2020: n = 44) were implanted with radio transmitters. Utah Chub varied in length from 222 to 343 mm (mean $\pm$ SD; 279.4 $\pm$ 34.3 mm) in 2019, and from 245 to 369 mm (294.0 $\pm$ 3.3 mm) in 2020. Yellowstone Cutthroat Trout varied in length from 275 to 595 mm (414.4 $\pm$ 88.1 mm) in 2019, and from 315 to 562 mm (418.0 $\pm$ 49.4 mm) in 2020. Seventy-six UTC (33 in 2019 and 43 in 2020) and 82 YCT (40 in 2019 and 42 in 2020) were located at least once during the study period. The number of relocations per individual fish varied from one to six relocations. Nineteen UTC (6 in 2019; 13 in 2020) and 25 YCT (9 in 2019; 16 in 2020) died or shed their transmitters during the study period. One UTC and five YCT transmitters were located on land, but could not be recovered because they were located on private property. Two transmitters were recovered during the study period. One recovered transmitter was from a YCT found dead near Hope Creek. The other was from a UTC under a Double-crested Cormorant *Phalacrocorax auritus* nest. The remaining 36 transmitters were not recovered because they were located on the lake bottom. No fish were detected outside the system (e.g., downstream of the dam).

Movement patterns varied seasonally and between species (Figure 3.2). In June, when water temperatures averaged 14.0°C ($\pm$ SD; $\pm$ 0.9°C), YCT and UTC were located primarily in nearshore habitats (i.e., within 1 km of shore). Utah Chubs were congregated in the outlet and the northwest region of Henrys Lake. As water temperatures increased in July (mean $\pm$ SD; 17.9°C $\pm$ 1.1°C) and August (19.9°C $\pm$ 0.9°C), YCT became more closely associated with cold-water sources (i.e., Staley Springs, Targhee Creek, Gillan Creek). Utah Chub moved into deeper water and became densely congregated at the outlet during July and August. During mobile tracking, large congregations of UTC were frequently observed throughout the lake in July and August. In September and October, both species were distributed throughout the lake, but were most common in the northwest region of the lake. Ice formed on the lake in November and UTC were rarely found nearshore in late fall and winter. In contrast, YCT were located throughout the lake in November. In December, YCT were located primarily in nearshore habitats, particularly in the southern half of the lake. Yellowstone Cutthroat Trout were consistently located near Targhee Creek regardless of season. Sixteen YCT were detected at tributary mouths on fixed receivers during June to August in both years (Table 3.1). No UTC were detected on the fixed receivers. Average June to August water temperatures in the tributaries were cooler than lake-wide water temperatures. For example, water temperatures averaged 10.5°C ($\pm$ SD; $\pm$ 3.1°C) for Duck Creek, 9.0°C ($\pm$ 3.2°C) for Howard Creek, 9.5°C ($\pm$ 3.1°C) for Targhee Creek, and 13.7°C ($\pm$ 2.9°C) for Timber Creek; whereas, water temperatures for Henrys Lake were 17.7°C $\pm$ 6.0°C.

Fish locations appeared to be related to habitat characteristics (Figure 3.3). Visibility averaged 3.9 m ($\pm$ SD; $\pm$ 0.9 m) in June and decreased to 3.2 m ($\pm$ 0.8 m) by August. Both species were typically located in areas with low visibility (e.g., ≤ 2.5 m). Similarly, YCT and UTC were consistently located in association with macrophytes during the study period. Percent macrophyte cover varied greatly across sites throughout the lake. In June, little vegetation was observed in the lake and averaged 22.6% (± 39.9%) cover across habitat availability sites. Average macrophyte cover peaked at 51.6% (± 46.3%) in July at habitat availability sites. Yellowstone Cutthroat Trout were frequently located in water averaging 3.2 m (± 1.4 m) depth. In contrast, UTC were in shallow water in June (2.8 ± 1.3 m), but moved to deeper water in July and August (3.7 ± 1.4 m). Water temperature in 2019 and 2020 increased from an average of 14.0°C (± 0.9°C) in June to an average of 19.9°C (± 0.9°C) in August. On average, YCT and UTC used habitat with water temperatures similar to lake-wide water temperatures; however, some YCT were located near cold-water sources that were several degrees cooler than surrounding water temperatures. For example, YCT located near Targhee Creek and Gillan Creek in July were in water that averaged 13.6°C (± 1.5°C) when lake-wide water temperatures averaged 17.9°C (± 1.1°C). Dissolved oxygen decreased from June to August. No distinct pattern was identified between UTC and dissolved oxygen levels, but YCT were typically located in areas with higher dissolved oxygen levels than the lake-wide averages.

Habitat selection varied by month and between species (Table 3.2; Appendix B). In June, regression modeling indicated a negative relationship between YCT habitat use and depth and dissolved oxygen, and a positive relationship with water temperature and probability of UTC. Utah Chub were positively associated with macrophyte cover, water temperature, and probability of YCT. Regression models for July revealed similar habitat selection between the two species. In July, YCT habitat use was negatively related to depth and positively related to dissolved oxygen and probability of UTC. Specifically, YCT were common in areas with shallow depths, high dissolved oxygen, and UTC. Utah Chub habitat use was positively associated with water temperature and probability of YCT. Lastly, regression models for habitat use of YCT in August identified a positive relationship with macrophyte cover and negative relationships with water temperature, dissolved oxygen, and depth. In August, UTC were negatively associated with dissolved oxygen and depth, and positively associated with macrophyte cover.

Discussion

Management and conservation decisions benefit from understanding movement, distribution, and habitat selection of fishes. Identifying potential overlap in resource use between native and nonnative species is particularly helpful to resource managers as they evaluate threats to species of conservation concern. In Henrys Lake, YCT and UTC used similar habitat characteristics (e.g., macrophyte cover) during some portions of the year and dissimilar habitat (e.g., water temperature) during other time periods. Nevertheless, UTC and YCT displayed limited overlap over the course of this study.

Fish locations in June were likely associated with spawning and water temperature. Yellowstone Cutthroat Trout and UTC were both located in nearshore habitats in June. Adfluvial YCT typically move into tributaries to spawn in May or early June (Gresswell 2011). Several YCT were detected in the tributaries in June, likely due to spawning. Utah Chubs have been documented moving from deep to shallow water for spawning purposes in early summer (Sigler and Sigler 1996). Spawning UTC have been observed from mid-May to mid-August in other systems when water temperatures are between 11.1°C and 20.0°C

(Graham 1961; Sigler and Sigler 1996). In June, water temperatures (14.0°C) were within the thermal requirements for spawning and UTC were observed in shallow areas of the lake along the shoreline. Although spawning was not documented during this study, movement and habitat relationships suggest spawning of both species likely occurred in June.

Consistent with my hypothesis, YCT moved to areas of cold water during peak summer temperatures. Yellowstone Cutthroat Trout are thermally sensitive and typically found in systems with water temperatures between 4.5 and 15.5°C (Gresswell 2011). During peak summer water temperatures (~22.0°C), YCT were documented in tributaries, near the mouths of tributaries, and near springs. Summer water temperatures in the lake averaged 18.9°C (± SD; ± 1.4°C) in July and August, but some YCT were located in water as cool as 11.6°C during the same time period. Water temperatures at springs and tributaries were about 5°C cooler than the rest of the lake, which suggests at least some YCT were seeking thermal refuge. Although few studies have investigated YCT movement in lakes, YCT have been documented using thermal refugia in rivers and streams (Varley and Gresswell 1988; Harper and Farag 2004; Gresswell 2011). In Yellowstone National Park, YCT exist in geothermally heated streams with water temperatures up to 27°C (Varely and Gresswell 1988). Yellowstone Cutthroat Trout are able to survive high water temperatures by using thermal refugia (Gresswell 2011). In Henrys Lake, some YCT did not selectively use colder habitats and were located throughout the lake in water temperatures that reflected lake-wide water temperatures. The warmest water temperatures used by YCT was 19.6°C in 2019 and 20.4°C in 2020. The diversity of movement patterns may indicate a lack of sufficient thermal refuge or that factors other than temperature are influencing YCT movement. Whatever the mechanism, diversity in phenotypic characteristics is vital to a population’s persistence in a system (Watters et al. 2003; Fox 2005) and maintaining variation in behavior could be important for YCT conservation.

Movement patterns of UTC also appeared partially related to water temperatures. Utah Chub were positively associated with warm water temperatures in Henrys Lake and were not typically located near cold-water sources such as springs and tributaries during the summer. Unlike YCT, UTC tolerate a wide variety of water temperatures (i.e., 15.6 – 31.1°C; Sigler and Sigler 1996) and movements of UTC may not be motivated solely by temperature. In July and August, a shift in UTC locations from nearshore habitat to deeper habitats was observed. The shift in UTC locations could be explained by the completion of spawning, response to temperature, or protection from predation (Graham 1961; Sigler and Sigler 1996). Furthermore, UTC were frequently observed in large congregations from July to August. Large schools of UTC have also been observed in Hebgen Lake, Montana, during summer (Graham 1961). Shoaling behavior has been documented to reduce predation risk in several species of fish (Moyle and Cech 2004).

Many species are often found in association with some form of cover, including Cutthroat Trout (Harper and Farag 2004; Heckel et al. 2020). For instance, Heckel et al. (2020) found that the abundance of Westslope Cutthroat Trout *Oncohynchus clarkii lewisi* in the Saint Maries River, Idaho, was positively related to the amount of instream cover, especially large wood. Similar results have been reported by Harper and Farag (2004) and Berger and Gresswell (2009) for Cutthroat Trout subspecies in streams. In Henrys Lake, YCT regularly used areas with high densities of macrophytes. Given the shallow depth of Henrys Lake, YCT were likely using macrophytes as a form of cover from predators (e.g., American White Pelicans *Pelecanus erythrorhynchos*, Bald Eagles *Haliaeetus* *leucocephalus*). Utah Chub also used macrophytes in Henrys Lake. Similar to YCT, UTC likely used vegetation as protection from predators. In addition, plant material is a common food resource for UTC and has been found to compose up to 70% of the food volume in UTC stomachs (Graham 1961; Sigler and Sigler 1996).

Winter distribution patterns differed between YCT and UTC. The majority of YCT were documented nearshore and particularly near the mouths of Targhee and Howard creeks. Garren et al. (2007) conducted a small-scale telemetry study with YCT, Brook Trout, and hybrid trout in Henrys Lake and found that 73% of radio-tagged fish (n = 40) were in shoreline habitats during the winter. In river systems, YCT have been documented moving into areas with groundwater influence when water temperatures drop below 1.0°C (Harper and Farag 2004). Unlike YCT, UTC were located in deeper waters away from the shoreline. Likewise, UTC in Hebgen Lake were documented moving into deeper water during periods with ice cover (Graham 1961).

The current study provides much needed insight into UTC and YCT movement and habitat relationships. Utah Chub have been associated with declines in salmonid populations in other systems (Hazzard 1935; Davis 1940; Schneidervin and Hubert 1987; Tuescher and Luecke 1996; Winters and Budy 2015). Understanding UTC ecology will help inform management decisions of potentially negative effects on salmonids where UTC have been introduced. In Henrys Lake, minimal spatial overlap was observed between YCT and UTC. Water temperature, macrophyte cover, and depth appeared to influence fish movement patterns. Although water temperatures in Henrys Lake have exceeded 25.0°C in other years, water temperatures peaked at 21.7°C during the course of this research. Patterns in YCT and UTC spatial overlap during a year with higher water temperatures may differ than what I observed during my study. Continued monitoring is important as the UTC population continues to increase. Prior to this study, little was known about the ecology of UTC and adfluvial trout. Adfluvial trout provide economically and socially important fisheries that function differently than other life histories, so understanding their ecology is critical for management and conservation. Insight into movement and habitat relationships provide valuable information that is useful for maintaining important adfluvial trout populations and mitigating potentially negative effects of introduced fishes.

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Tables and Figures

Table 3.1. Radio-tagged Yellowstone Cutthroat Trout (YCT) detected in four tributaries of Henrys Lake, Idaho, during June to August (2019–2020).

Stream	June	July	August
2019			
Duck Creek	1 YCT	1 YCT	
Howard Creek	1 YCT	1 YCT	
Targhee Creek			1 YCT
Timber Creek			
2020			
Duck Creek	1 YCT		
Howard Creek	1 YCT		
Targhee Creek	4 YCT	3 YCT	1 YCT
Timber Creek	1 YCT		

Table 3.2. Top multiple-regression models for resource selection of Yellowstone Cutthroat Trout (YCT) and Utah Chub (UTC) in Henrys Lake, Idaho (2019–2020). Explanatory variables include depth, percent macrophyte cover, water temperature, and dissolved oxygen. The probability of UTC was included as a covariate in the YCT models and probability of YCT was included as a covariate in UTC models. Models were ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c). Delta AIC_c, number of parameters (K), weight of the model (w_i), and coefficient of determination (McFadden's pseudo R^2) are reported. Direction of relationship between catch rates the covariates is indicated (positive [+], negative [-]). Table on next page.

Response variable	Model parameters	AIC_c	ΔAIC	K	w_i	R^2
Yellowstone Cutthroat Trout						
	June					
	− Depth − Dissolved oxygen	92.7	0.00	3	0.28	0.23
	− Depth + Temperature	92.9	0.15	3	0.26	0.23
	− Depth	93.7	0.96	2	0.17	0.20
	− Depth − Dissolved oxygen + Probability of UTC	94.5	1.75	4	0.12	0.23
	July					
	− Depth + Probability of UTC	115.5	0.00	3	0.31	0.20
	− Depth	116.3	0.83	2	0.21	0.18
	− Depth + Dissolved oxygen + Probability of UTC	117.4	1.91	4	0.12	0.20
	August					
	– Temperature – Dissolved oxygen + Macrophyte cover	48.6	0.00	4	0.52	0.46
	– Temperature – Dissolved oxygen − Depth	48.9	0.37	4	0.43	0.46
Utah Chub						
	June					
	+ Temperature + Macrophyte cover	69.1	0.00	3	0.26	0.40
	+ Macrophyte cover	69.7	1.31	2	0.20	0.38
	+ Macrophyte cover + Probability of YCT	70.2	1.43	3	0.15	0.39
	July					
	+ Temperature + Probability of YCT	97.8	0.00	3	0.43	0.22
	August					
	− Dissolved oxygen + Macrophyte cover	39.5	0.00	3	0.45	0.43
	− Dissolved oxygen − Depth	40.6	1.06	3	0.27	0.41

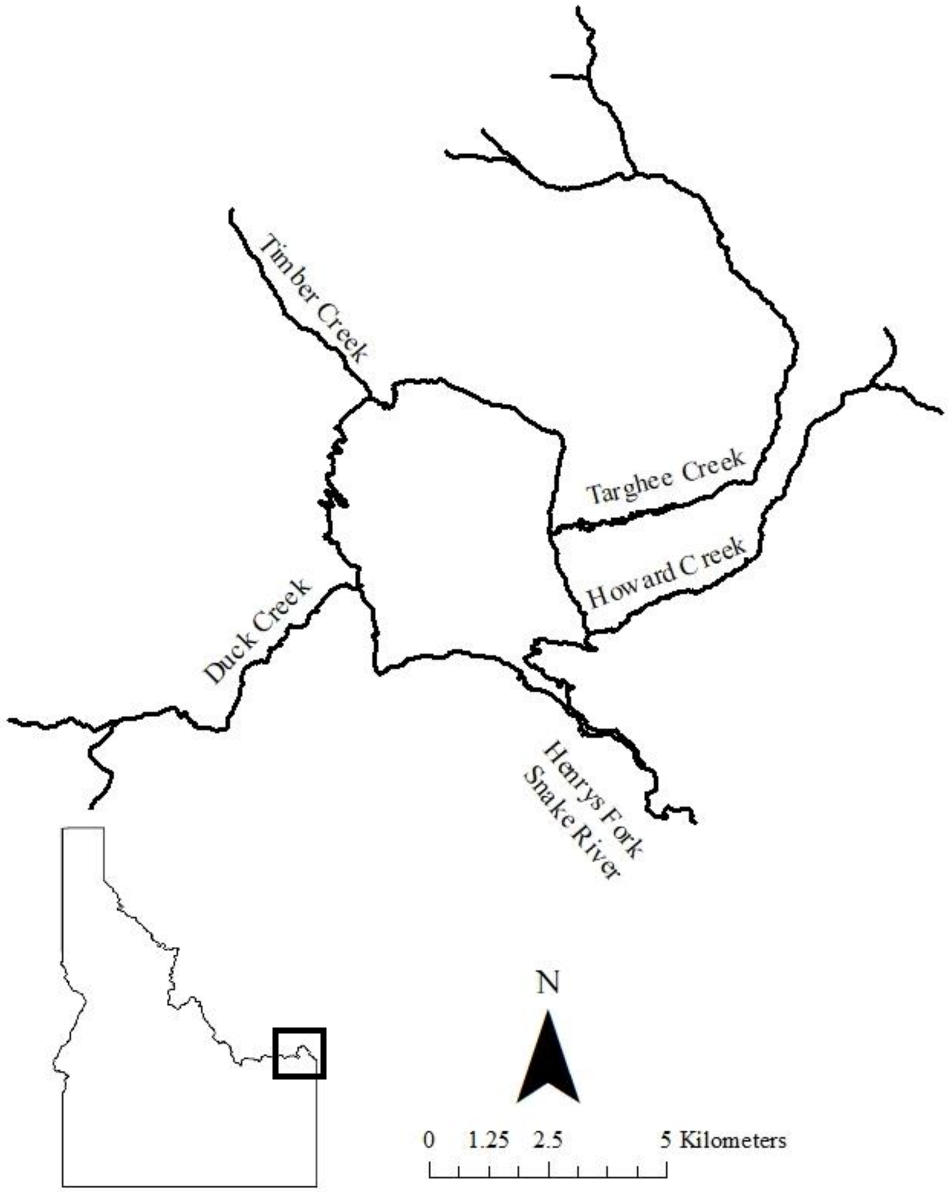
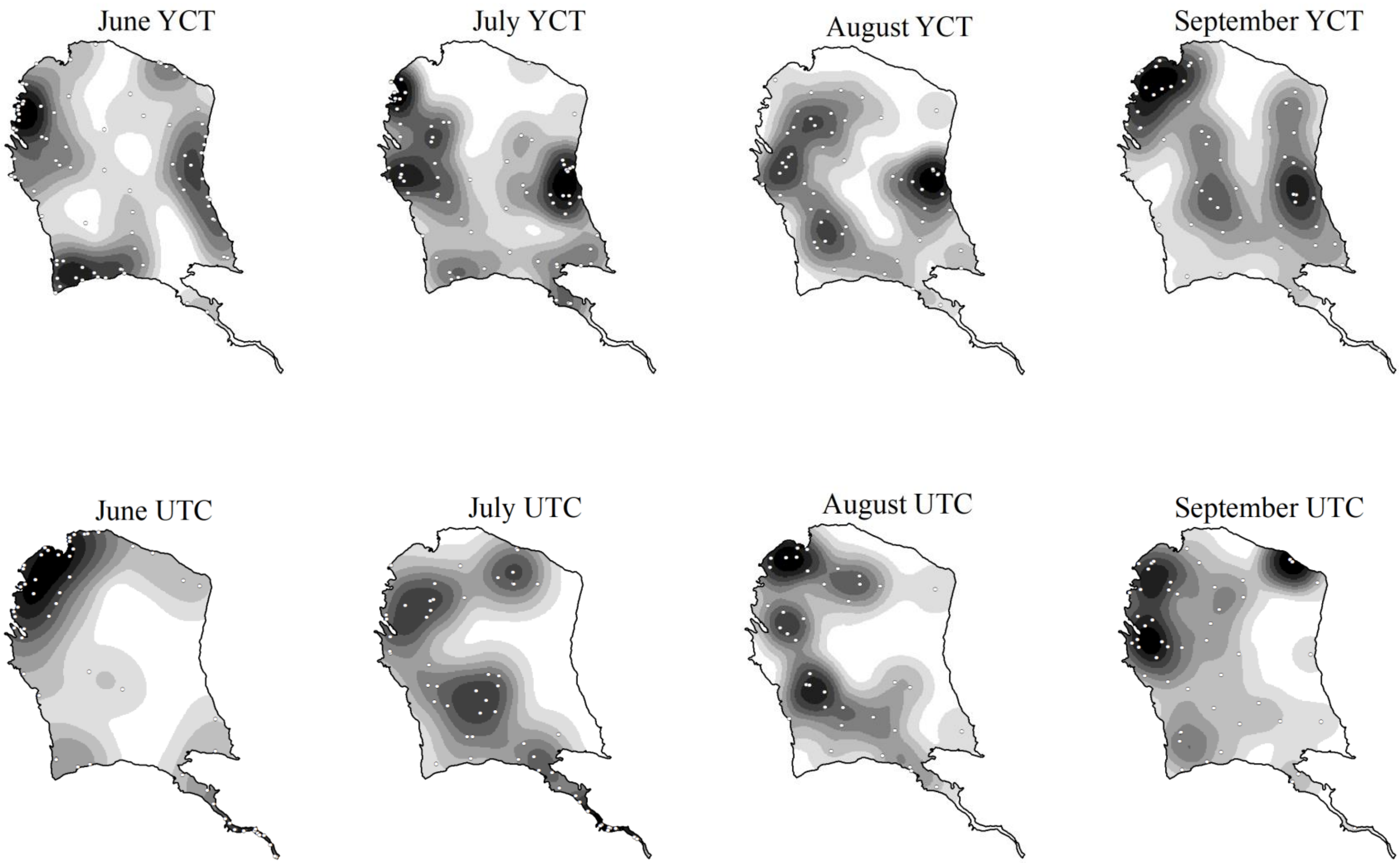


Figure 3.1. Henrys Lake, Idaho, and major tributaries.


June YCT
July YCT
August YCT
September YCT
June UTC
July UTC
August UTC
September UTC

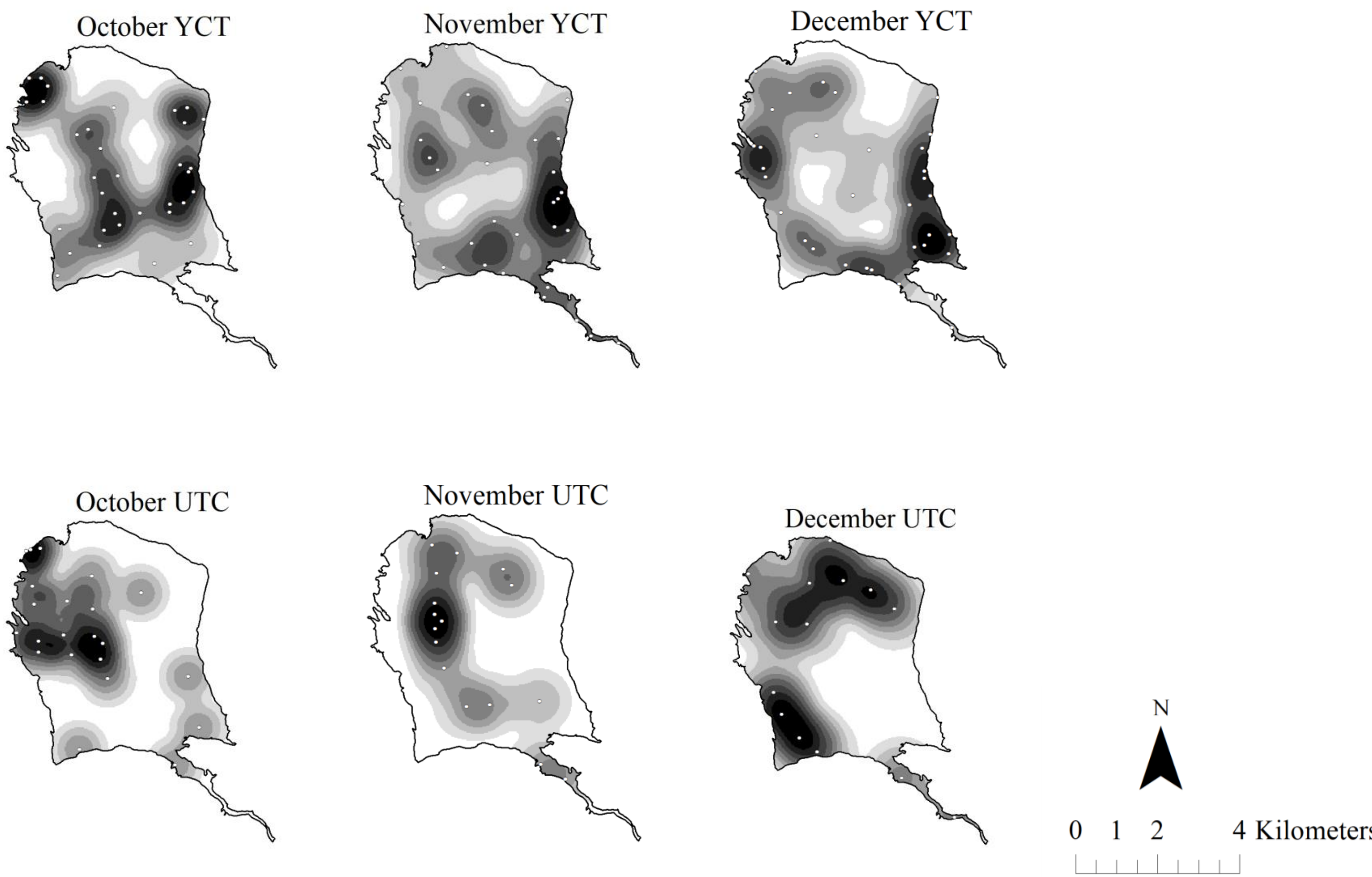

October YCT
November YCT
December YCT
October UTC
November UTC
December UTC
N
0 1 2 4 Kilometers

Figure 3.2. Monthly distribution maps of Yellowstone Cutthroat Trout (YCT) and Utah Chub (UTC) in Henrys Lake, Idaho (2019–2020). Fish locations are indicated by white circles and Maps on the left are YCT and UTC are on the right. Shaded contours represent density of use from kernel density estimates. The darker shading indicates higher probability and lighter shade indicates low density of use. Figure on previous page.

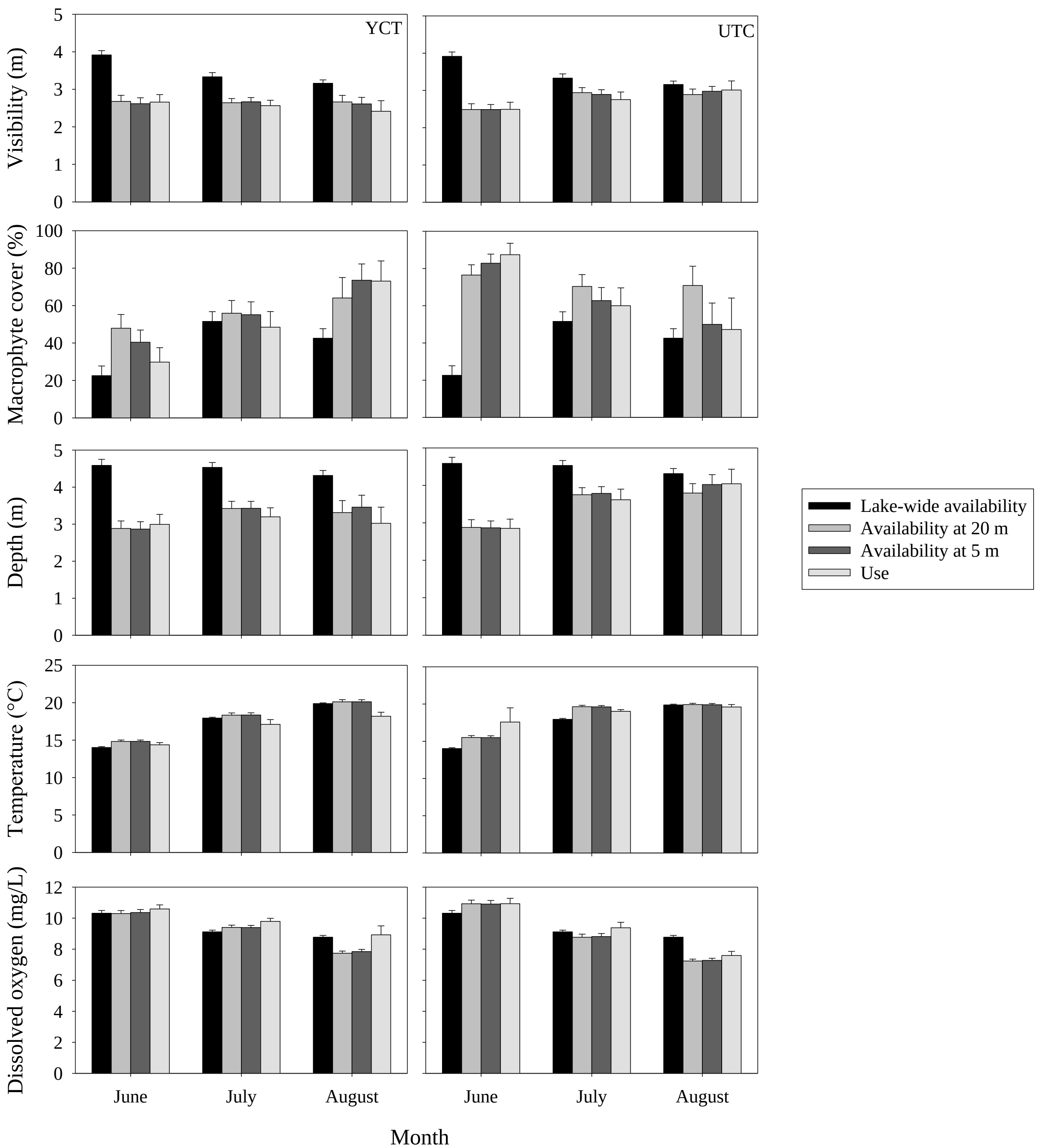


Figure 3.3. Average habitat characteristics and standard error for Henrys Lake, Idaho (2019–2020). Habitat characteristics are reported lake wide, 5 m from a fish's location, 20 m from a fish's location, and at a fish's location (use). Yellowstone Cutthroat Trout (YCT) are displayed on the left and Utah Chub (UTC) on the right.

Chapter 4: General Conclusions

Yellowstone Cutthroat Trout (YCT) *Oncorhynchus clarkii bouvieri* hold cultural, recreational, and ecological value. Nonnative species have threatened the persistence of YCT across much of its distribution. Utah Chub (UTC) *Gila atraria* has spread outside its native distribution and has negatively affected salmonids. The impetus of this research was to understand how nonnative UTC may have influenced native YCT in Henrys Lake, Idaho. This thesis contributes valuable information about population dynamics of YCT. Specifically, the population dynamics of YCT in Henrys Lake, Idaho, were evaluated using long-term historical data, and the movement and habitat relationships were described for YCT and UTC in Henrys Lake. I sought to provide insight into potential interactions between YCT and UTC. Additionally, information about the ecology of adfluvial YCT and UTC was also provided.

Trends in population dynamics of YCT in Henrys Lake are encouraging. Catch rates have improved in the most recent surveys and were above management goals for Henrys Lake in 2020. Although I identified negative relationships between YCT growth and the abundances of Brook Trout *Salveninus fontinalis* and UTC, YCT are currently growing as fast or faster than in the past. Growth of YCT in Henrys Lake is faster than other YCT populations and is most similar to adfluvial Bonneville Cutthroat Trout *Oncorhynchus clarkii utah* in Bear Lake, Utah. Similar to Bonneville Cutthroat Trout in Bear Lake, YCT in Henrys Lake might be somewhat piscivorous. Growth of YCT was positively related to stocking rates of YCT, suggesting some level of piscivory. My results suggest that UTC are not likely affecting YCT at a population level, but continued monitoring is important. A change in YCT population dynamics may be observed as the UTC population increases.

Telemetry data further support the assertion that UTC are not having a direct effect on the YCT population. Species distribution patterns and resource selection modeling indicate minimal overlap between YCT and UTC. Species distribution patterns were related to habitat characteristics and appeared to be influenced by temperature and macrophyte cover. Yellowstone Cutthroat Trout congregated near cold-water sources during periods of warm temperatures, suggesting that maintenance of cold-water refugia may be important for adfluvial trout populations. Utah Chubs are not as thermally sensitive as YCT and were associated with warm water temperatures. Both YCT and UTC were associated with macrophytes and were likely using vegetation as a source of protection from predators.

Collectively, my research provides valuable insight into factors influencing the population dynamics of YCT in Henrys Lake. Although the results do not indicate a population-level response of YCT to UTC, continued monitoring is critical because a response may emerge as UTC become more abundant. Additionally, water temperature appears to be an important factor in YCT behavior, but does not seem to be adversely affecting YCT growth or abundance. Changes in management at Henrys Lake do not seem necessary at this time. Importantly, my research fills important knowledge gaps in the ecology of YCT and UTC. The information I provided on YCT will inform management decisions for conservation of an important native species and other adfluvial trout populations. Prior to this thesis, little was known about UTC and understanding UTC ecology has become more important as it has spread outside its native distribution.

APPENDICES

Appendix A. Proportion of Yellowstone Cutthroat Trout at each age sampled from Henrys Lake, Idaho, 2002 to 2020.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11
2002	0.113	0.460	0.394	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.207	0.207	0.194	0.289	0.058	0.025	0.000	0.000	0.019	0.000	0.000
2004	0.390	0.472	0.084	0.034	0.003	0.007	0.007	0.003	0.000	0.000	0.000
2005	0.368	0.527	0.078	0.015	0.013	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.091	0.276	0.520	0.107	0.002	0.004	0.000	0.000	0.000	0.000	0.000
2007	0.025	0.708	0.130	0.128	0.009	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.536	0.298	0.146	0.021	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.051	0.270	0.502	0.177	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.028	0.753	0.092	0.116	0.008	0.003	0.000	0.000	0.000	0.000	0.000
2011	0.003	0.774	0.187	0.029	0.005	0.003	0.000	0.000	0.000	0.000	0.000
2012	0.017	0.594	0.348	0.029	0.004	0.006	0.000	0.000	0.000	0.002	0.000
2013	0.004	0.610	0.220	0.140	0.020	0.002	0.004	0.000	0.000	0.000	0.000
2014	0.007	0.353	0.437	0.136	0.050	0.013	0.002	0.002	0.000	0.000	0.000
2015	0.021	0.399	0.239	0.271	0.031	0.040	0.000	0.000	0.000	0.000	0.000
2016	0.000	0.594	0.238	0.082	0.053	0.033	0.000	0.000	0.000	0.000	0.000
2017	0.020	0.518	0.197	0.197	0.027	0.035	0.000	0.007	0.000	0.000	0.000
2018	0.053	0.137	0.505	0.148	0.101	0.013	0.031	0.013	0.000	0.000	0.000
2019	0.013	0.765	0.127	0.037	0.027	0.014	0.004	0.013	0.000	0.001	0.001
2020	0.005	0.206	0.677	0.096	0.003	0.005	0.005	0.002	0.000	0.001	0.000

Appendix B. Parameter estimates and confidence intervals for top regression models. Top multiple-regression models for catch-per-unit-of-effort (CPUE = number per net night) for Yellowstone Cutthroat Trout (YCT) in Henrys Lake, Idaho (2002–2020). Explanatory variables include CPUE for Brook Trout (BKT) and Rainbow Trout × YCT hybrids (HYB) in Henrys Lake. Top multiple-regression models for growth of Yellowstone Cutthroat Trout in Henrys Lake, Idaho (1994–2019). Explanatory variables include number of YCT stocked annually, minimum air temperature (Temperature; °C) during the growing season (01 May – 31 October), and CPUE BKT, Utah Chub (UTC), and all trout in Henrys Lake. Top multiple-regression models for resource selection of YCT and UTC in Henrys Lake, Idaho (2019–2020). Explanatory variables include depth, percent macrophyte cover, water temperature, and dissolved oxygen. The probability of UTC was included as a covariate in the YCT models and probability of YCT was included as a covariate in UTC models.

Model set	Model	Parameter	Parameter estimate	Standard error
CPUE	Model 1	BKT CPUE	1.1409	0.0660
	Model 2	BKT CPUE	1.0464	0.0668
		HYB CPUE	1.4060	0.1379
	Model 4	HYB CPUE	1.6058	0.1303
Growth	Model 1	BKT CPUE	-28.2900	10.5900
		UTC CPUE	-4.0700	1.7200
		YCT stocking	0.0000	0.0000
	Model 2	UTC CPUE	-4.1870	1.7930
		Trout CPUE	-9.0670	4.0390
	Model 3	BKT CPUE	-32.2510	11.4340
	Model 4	BKT CPUE	-4.4618	1.7172
		UTC CPUE	-30.5537	10.1080
		Temperature	0.1180	0.4146
YCT habitat June	Model 1	Depth	-0.9847	0.2360
		Dissolved oxygen	-0.3948	0.2511
	Model 2	Depth	-0.8175	0.1925
		Temperature	0.3624	0.2250
	Model 3	Depth	-0.7838	0.1853
	Model 4	Depth	-0.9581	0.2419
		Dissolved oxygen	-0.3959	0.2536
		Probability of UTC	0.0907	0.1816

Appendix B. Continued from previous page.

YCT habitat July	Model 1	Depth	-0.8780	0.1947
		Probability of UTC	0.4062	0.2442
	Model 2	Depth	-0.7902	0.1787
	Model 3	Depth	-0.8436	0.2261
		Dissolved oxygen	0.0715	0.2444
		Probability of UTC	0.3854	0.2540
YCT habitat August	Model 1	Temperature	-1.8781	0.5094
		Dissolved oxygen	-1.3633	0.5056
		Macrophyte cover	0.0369	0.0124
	Model 2	Temperature	-1.4956	0.5155
		Dissolved oxygen	-1.7108	0.6655
		Depth	-1.5724	0.5050
UTC habitat June	Model 1	Temperature	0.3042	0.2360
		Macrophyte cover	0.0344	0.0080
	Model 2	Macrophyte cover	0.0376	0.0078
	Model 3	Macrophyte cover	0.0362	0.0080
		Probability of YCT	0.1850	0.1542
UTC habitat July	Model 1	Temperature	1.1925	0.3008
		Probability of YCT	0.1794	0.1385
UTC habitat August	Model 1	Dissolved oxygen	-4.0097	1.2333
		Macrophyte cover	0.0301	0.0130
	Model 2	Dissolved oxygen	-3.2468	0.9848
		Depth	-0.9471	0.4142