Management of a Cutthroat Trout Predator to Control Utah Chub in a High-Use Sport Fishery

ALAN WARD* AND JUSTIN ROBINSON
Strawberry Project Office, Utah Division of Wildlife Resources
777 SR 319, Box 5, Heber, Utah 84032, USA

ROGER B. WILSON
Utah Division of Wildlife Resources
1594 West North Temple, Suite 2110, Salt Lake City, Utah 84114, USA

Abstract.—Strawberry Reservoir is Utah’s most important coldwater fishery, sustaining as many as 1.5 million angler-hours annually. Persistent problems with the introduced Utah chub Gila atraria have necessitated two reservoir-wide rotenone treatments. The most recent treatment in 1990 was the largest complete chemical treatment ever attempted to date. In an effort to avoid future rotenone treatments, the current management plan at Strawberry Reservoir includes the use of Bear Lake cutthroat trout Oncorhynchus clarkii utah as a biological controller of Utah chub populations. Gill netting studies, cutthroat population modeling, a year-long diet study, and bioenergetics modeling were used to assess the effectiveness of cutthroat predation in controlling Utah chub populations. Various fishing regulation scenarios have been utilized since the 1990 treatment in an attempt to produce the needed cutthroat predator population for Utah chub control. Earlier (1990–2002), more liberal cutthroat fishing regulations were not effective at creating the necessary predatory cutthroat population. Diet information indicated that large (>508 mm total length) cutthroat were effective predators on the chubs, and a slot limit on cutthroat was enacted in 2003 to produce these larger predators. The current slot limit has created a large population of cutthroat that is larger on average than have previously been documented in the reservoir. Since 2003, overall chub populations have decreased by 61%, and age-1 chubs have decreased by 97%. Diet studies and resulting bioenergetics analyses indicated that cutthroat were responsible for considerable predation pressure on these chubs. The Bear Lake cutthroat have proven to be effective predators on Utah chubs in Strawberry Reservoir, and their predation is likely the major factor in the recent declines in chub numbers. However, adequate protection from overharvest needed to be provided so that a large population of large cutthroat predators could be produced.

Introduction
The literature contains relatively few examples of salmonid predators effectively controlling highly competitive introduced fish populations, particularly when the predator is a cutthroat trout Oncorhynchus clarkii (Yule and Luecke 1993; Perrin et al. 2006). Examples are even more scarce when the needed predator is a popular salmonid species whose population is maintained primarily by stocking efforts. However, biological control of introduced fish has long been a
desire of managers since the use of piscicides is not always possible or feasible due to factors such as cost, water-use issues, public perception, and water body size constraints (Cailteux et al. 2001; Finlayson et al. 2003). Biomanipulation of fish assemblages has proven to be successful for other species of predator and prey (Meijer et al. 1995; Dettmers et al. 1996; Irwin et al. 2003; Weston et al. 2006; Savenkoff et al. 2007), and it was hoped that similar results could be obtained with the use of a cutthroat predator.

Utah chub *Gila atraria* have long been used as a baitfish, and illegal introductions have been widespread (Sigler and Sigler 1987). Utah chub populations in the western United States have been shown to frequently overrun fisheries to the point where salmonid populations have declined (Hazzard 1935; John 1959; Olsen 1959; Jeppson 1966; Schneidervin and Hubert 1987; Sigler and Sigler 1987; Teuscher and Luecke 1996). Exceptions have been found where bass, perch, and/or walleye *Sander vitreus* populations have also been present (Ryals et al. 1998; Bouwes and Luecke 2001; Hepworth and Wiley 2007). However, the introduction of these nonnative percids is not always desirable from a sport fishery perspective, especially when native species concerns are an issue. Therefore, if Utah chub populations could be controlled with a predator that could provide a desired sport fishery, and also aid native species expansion, then all of these needs could be satisfied.

Strawberry Reservoir is a 6,946-ha impoundment with a maximum depth of 61 m located in the central Utah mountains at an elevation of 2,320 m above sea level. It is considered a mesotrophic system based on a Carlson Trophic State Index between 40 and 50 (Adams and Judd 2006). The water level in Strawberry fluctuates about 2 m each year (Kuehn 2000). Strawberry Reservoir supports an intensively utilized sport fishery, sustaining as much as 1.5 million hours of angling pressure during the year, equating to 216 h/ha per year (Wilson and Ward 2003). From a year-long creel survey in 2001, it was estimated that 715,000 fish were caught (78% cutthroat trout, 22% rainbow trout *O. mykiss*, and <1% kokanee *O. nerka*) and 380,000 (75% cutthroat, 25% rainbow, and <1% kokanee) were harvested (Wilson and Ward 2003). The harvest totals from 2001 would have equated to 249 metric tons of fish being harvested, and for every kilogram stocked, 10 kg were harvested. Due to the intensive fishing effort and harvest, it has been necessary to supplement sport fish populations through regular stocking efforts. During 2006, 1.08 million Bear Lake cutthroat trout *O. c. utah*, 680,000 rainbow trout, and 750,000 totaling 39,000 kg, 22,000 kg, and 1,000 kg kokanee, respectively, were stocked into Strawberry Reservoir and its tributaries.

The management plan for Strawberry Reservoir, established in 1987, was designed to utilize the Bear Lake cutthroat to control the introduced nonnative Utah chub population (Johnson 1987). Strawberry Reservoir has been chemically treated with rotenone twice in the past to control introduced nongame fish populations, once in 1961 and again in 1990. The 1990 treatment was the largest rotenone treatment ever attempted to date, using more than 396 metric tons of rotenone to treat more than 4,856 surface hectares of the reservoir as well as all of the tributaries (Lentsch et al. 2001). The 1990 treatment, though not a 100% kill, was very effective at allowing managers to establish a new sport fish assemblage (Wilson and Spateholts 1998). Prior to the 1990 rotenone treatment, managers determined that they would reverse the management program for the reservoir from a rainbow trout focus with cutthroat trout as a species of minor importance, to one where cutthroat trout populations were the primary focus of man-
agagement (Johnson 1987). Establishment and maintenance of sterilized rainbow trout following the 1990 treatment was accomplished to appease a strong public desire to maintain rainbow trout as a sport fish in the reservoir (Johnson 1987). It had become apparent from the two previous rotenone treatments at Strawberry Reservoir, as well as from examples from other waters, that rainbow trout cannot adequately compete with Utah chub, and Utah chub populations will eventually sequester food resources and cause a collapse of rainbow trout populations (Hazzard 1935; Jeppson 1966). In addition to not being able to compete with the Utah chub for food resources, diet information from annual gill netting has indicated that rainbow trout have not proven to be an effective predator on Utah chub in Strawberry Reservoir. Public opinion surveys at Strawberry Reservoir indicated that there continued to be a strong desire among most anglers to maintain the reservoir as a salmonid fishery; therefore, centrarchid and percid fisheries were not considered as biological control options.

Following the 1990 treatment, the Bear Lake strain of cutthroat was selected as the predator/competitor of choice in Strawberry Reservoir due to the following factors: its evolutionary history in Bear Lake in which it has had to compete with, and prey upon, other effective plankton foragers; its ability to grow and survive in the presence of high chub densities as determined in a pre-1990 pilot study at Strawberry; its high return rate to the creel (easily caught); and because a brood source for eggs was readily available from Bear Lake, Utah (Lentsch and Spateholts 1988). The cutthroat strain that was present in Strawberry Reservoir prior to the 1990 treatment (a hybrid of numerous cutthroat strains) did not perform as well as the Bear Lake cutthroat in many of these categories during the pilot studies (Lentsch and Spateholts 1988). It was hypothesized that the Bear Lake cutthroat would not only be able to more effectively compete for food resources with the Utah chub, but that it would also be able to control chub populations through direct predation.

Our objective was to evaluate the effectiveness of utilizing Bear Lake cutthroat trout to control Utah chub populations in Strawberry Reservoir from 1990 to 2006. This study incorporated an evaluation of various fishing regulations intended to protect cutthroat predators, assessments of relative catches of Utah chubs from annual gill netting, population modeling of the cutthroat trout, and a cutthroat trout diet study conducted in 2005. This management approach was unique in that this highly harvested cutthroat trout was used in an intensely fished environment and was expected to control a highly competitive Utah Chub population.

Methods

Fishing Regulations

Since the 1990 rotenone treatment of Strawberry Reservoir, there were four major changes to the fishing regulations. Most of these changes were attempts to protect cutthroat populations as needed for predator control of Utah chub populations, yet still allow for a highly desired harvest component to the fishery. Immediately following the 1990 treatment, the standard statewide bag limit of eight fish was retained. In 1993, the regulations were changed to allow only one of the fish in an anglers bag limit to be a cutthroat trout. Due to the immediate effectiveness of the one cutthroat regulation at increasing cutthroat numbers, the public requested an allowance for greater cutthroat harvest. During 1996, the regulations were changed to allow only one over 18” total length (TL; 457 mm)
allowed. Chub populations began to expand rapidly from 1996 to 2002, with gill-net catch rates increasing from 0.13 fish/h to 1.85 fish/h over that period. In response to the expanding chub populations, the regulations were changed again in 2003 to a four-fish bag limit, where only three fish could be cutthroat outside of a slot-size protection. The slot limit allowed only one of the cutthroat to be more than 22” TL (508 mm), and two less than 15” TL (381 mm). All cutthroat in the 15–22” slot range had to be immediately released.

Prior to the 2003 regulation change, an analysis of angler habits and hooking mortality indicated that bait restrictions were not necessary to obtain cutthroat population goals at Strawberry Reservoir (Wilson and Ward 2003). It was apparent from the regulation modeling that legal harvest had a far greater impact on cutthroat populations than hooking mortality.

The goal of the regulation changes since 1993 was to provide an adequate population of cutthroat to control Utah chub populations. The regulation changes were more or less a series of trial and error studies in this process. The effectiveness of each regulation was determined from population modeling that legal harvest had a far greater impact on cutthroat populations than hooking mortality.

Relative Fish Abundances
Relative abundance for each taxa of fish were determined from the annual fall gill netting conducted during the third week in October of each year from 1991 to 2006. Annual fall trend gill netting was accomplished with 38.1 × 1.8 m (125 × 6 ft) experimental gill nets ranging in mesh size from 12.7 to 50.8 mm in 12.7-mm increments (one-half inch to 2 inches in one-half-inch increments) set at 16 standardized sites. The catch rate for each species was calculated as number of fish per gill net hour. Nets were typically set overnight for an average of 16 h. This standardized approach has been utilized since 1990 at Strawberry, and similar methods were used prior to 1990 (varying only in numbers of nets and locations of sampling sites), making comparisons of catch rates possible. As a result, comparisons of relative chub densities and population expansion patterns can be made dating back to the first rotenone treatment in 1961. Determination of age-1 chubs was made by length–frequency distributions and was later verified by otolith and scale aging. All chubs from 90 to 129 mm TL were considered age-1 fish.

One-tailed paired t-tests were used to determine significance of mean difference in gill-net catch rates at a level of 95% confidence (p < 0.05). A one-way analysis of variance (ANOVA) was used to determine length differences in the cutthroat population from the gill netting during various time periods associated with regulation changes.

Cutthroat Population Modeling
Since the 1990 treatment of Strawberry Reservoir, cutthroat stocks have been marked so that survival estimates could be made and population modeling could be accomplished. Fall fingerling stocks were marked with oxytetracycline techniques administered through food intake similar to the methods described in Weber and Ridgway (1967). The spring-stocked advanced fingerlings and subcatchables (fish < 203 mm) were marked...
with external colored dye marks that were impregnated under the skin with forced air (Nielson 1990). Three colors were alternately applied to differentiate among cohorts. For instance, the 2001 year-class of spring cutthroat stocks were marked with green dye, red dye was used on the 2002 cohort, yellow dye for 2003 fish, and green dye for 2004. Samples from each lot of marked fish were taken to assess marking success, and marks were assumed to be permanent. After adjusting for fail-marked fish, the remainder of the unmarked fish in our catches were assumed to be from natural reproduction.

In order to estimate population size, survival estimates for each cohort of cutthroat had to be derived from relative catches in our gill nets from one year to the next. For instance, if catches decreased by 50%, then survival was assumed to be 50% for that cohort. Though estimating survival from these dye-marked fish was relatively simple, estimating the first-year survival of the smaller fall stocks and natural reproduced fish was more problematic, as these fish were vulnerable to substantial predation for an entire year before they are sampled in our gill nets the year following being stocked. Therefore, survival estimates for the first year of life on the fall stocks were derived from catch rates in the gill nets compared to a survival relationship developed for Strawberry Reservoir from prior studies at Strawberry Reservoir and Minersville Reservoir, Utah (Hepworth and Duffield 1991; Wilson and Spateholts 1998; Orme 1999). Hepworth and Duffield (1991) and Orme (1999) used mark–recapture studies to assess first-year survival of stocked and naturally recruited salmonids; gill-net catch rates were associated with these survival estimates (Orme 1999), which allowed for an estimate of survival based on gill-net catch rates. Our estimate of first-year survival assumes that survival relates directly to stocking rates and area adjusted gill-net catch rates as an age-1 fish.

Based on the estimates of survival, population sizes could be tracked from one year to the next for each cohort of cutthroat. This detailed analysis allowed us to track responses of the cutthroat population to fishing regulation changes in this study. Other environmental impacts to the cutthroat population were assumed to be negligible and consistent, as there were strong correlations between angler harvest and population fluctuations.

**Cutthroat Diet Study**

During the 2005 calendar year, a diet study was conducted to determine cutthroat feeding patterns. The diet study was used to validate whether or not cutthroat were preying upon the Utah chubs to the point where they could be impacting their abundance in Strawberry Reservoir.

Sampling was stratified into five seasonal categories: winter (January 1 to April 16), early spring (April 17 to May 14), late spring (May 15 to June 18), summer (June 19 to August 27), and fall (August 28 to December 31). This seasonal stratification was based upon previous information derived from gill netting, indicating different feeding habits and/or food availability in each of these strata. Three to four (four during the fall period and three in all others) sampling dates were randomly selected in each of the strata. Two horizontal experimental nets (described above) and one vertical array (five 15.2 × 1.8 m nets also varying in mesh size from 12.7 to 50.8 mm in 12.7-mm increments) were set overnight on each sampling date at randomly selected sites.

Stomach contents of the cutthroat caught were identified to the following groups: zooplankton, invertebrate, Utah chub, redside shiner *Richardsonius balteatus*, salmonid, mammal, and debris. The percent-
age of each category in a stomach was visually estimated by volume. Prey energy densities were then applied to each prey category (Baldwin 1998). Fish growth throughout the year was estimated based on the fall to fall gill netting of each marked cohort. These parameters allowed us to use the Fish Bioenergetics 3.0 program from the Center for Limnology, University of Wisconsin-Madison to estimate consumption of each food category by cutthroat (Hanson et al. 1997). Since cutthroat physiological parameters have not been incorporated into the bioenergetics program, coho salmon *Oncorhynchus kisutch* models were used with slight modifications, as described in earlier cutthroat bioenergetics modeling at Strawberry and elsewhere (Beauchamp et al. 1995; Baldwin 1998; Cartwright et al. 1998; Orme 1999; Mazur and Beauchamp 2006). Thermal experience for the cutthroat was derived from estimates obtained from previous bioenergetics studies at Strawberry Reservoir (Baldwin 1998; Orme 1999).

The cutthroat bioenergetics modeling allowed for a reservoir-wide estimate of overall consumption. Estimates of average fish size in the diets allowed for an estimate of numbers of prey fish consumed by the cutthroat population by season and for the entire year.

**Results**

Since the rotenone treatment in 1990, the various cutthroat trout regulations at Strawberry Reservoir have produced mixed results. Based on relative gill-net catches and the resulting population estimates, adult (age-3 and older) cutthroat numbers increased sharply from 1993 to 1996 during the implementation of the one-cutthroat daily bag limit (1993 to 1995) (Figure 1). By 1996, the adult cutthroat population had reached a relatively high level (415,000 fish); however, the regulation was subsequently liberalized in 1996 to a four-fish bag limit with only one fish allowed over 18”, and the population immediately declined from 1997 to the lowest estimated population since the treatment in

![Figure 1. Estimated number of adult (age-3 and older) cutthroat in Strawberry Reservoir by age-class from 1992 to 2006.](image-url)
1999 (58,000 fish) (Figure 1). The population rebounded in 2000, which was largely the result of considerable natural reproduction occurring in the spring of 1997. The model’s predictions of abundant adult cutthroat populations during the fall of 1996 correspond well with the 1997 spike in natural reproduction. The natural reproduction from 1997 accounted for nearly 65% of the adult population in 2000. However, the large adult cutthroat population observed in 2000 again declined by 2002. After implementation of the slot limit during 2003, adult cutthroat populations increased dramatically and have remained relatively stable when compared to years prior to this regulatory change (Figure 1).

Not only has the population of adult cutthroat increased since the slot limit was enacted in 2003, but the population structure is much different as well. More larger/older cutthroat were sampled in Strawberry since 2003 than have been seen previously in Strawberry’s history (Figure 1). Since 2003, about 20% of the cutthroat catches in the fall gill nets have been composed of fish 508 mm TL (20 in) and larger. Catch rates of cutthroat greater than 508 mm TL increased from an average of 0.02 fish per net hour (number/h) over the period 1993 to 2002 to 0.10/h on average during the period of 2003 to 2006, a 500% increase. From 1993 to 1995 (the period of the fishing regulation that only allowed one cutthroat to be harvested), the cutthroat averaged 361 mm TL in the gill-net surveys. From 1996 to 2002, during the more liberal four-fish bag limit (which allowed only one cutthroat trout over 18”), the cutthroat averaged 364 mm TL. However, during the period of the current slot limit on cutthroat (2003 to 2006), the cutthroat have averaged 443 mm TL. A one-way ANOVA of these regulatory treatments indicated a significant difference in cutthroat size between these time periods ($F = 8.557; df = 2, 31; P = 0.006$). A Tukey-HSD (Tukey honestly significant difference) analysis indicated that there was a significant difference between the cutthroat lengths from the 1993 to 1995 regulatory period and the 2003 to 2006 regulatory period ($P = 0.018$), as well as a significant difference in cutthroat lengths between the 1996 to 2002 period and the 2003 to 2006 period ($P = 0.007$). No significant difference existed between the two earlier (1993 to 1995 and 1996 to 2002) regulation periods.

Utah chub were a rather insignificant portion of the gill-net catches (less than 0.13 fish/h) prior to 1997 (Figure 2). Chub numbers increased sharply from 1997 to 2002 and provided the impetus for the 2003 regulation change on cutthroat. Immediately following the regulation change in 2003, and the subsequent increase in large cutthroat in Strawberry Reservoir, chub catches ceased the pattern of exponential increase and even exhibited a significant ($t$-test; $T = 2.46; df = 2, 15; P = 0.01$) decrease of 61% by 2005 (Figure 2). Catch rates leveled off with only a slight increase from 2005 to 2006 (Figure 2). Catch rates of age-1 chubs have decreased dramatically since 2003, with an overall decrease of 97% from the fall of 2002 to the fall of 2006 (Figure 3).

Bioenergetics modeling based on the year-long diet study in 2005 indicated that nearly 776 metric tons of Utah chub were consumed by cutthroat during 2005 (Table 1). By estimating the average size of chubs from the diet information, this consumption would have equated to a consumption of nearly 64 million chubs (Table 1). Zooplankton and other invertebrates were the most abundant food items for cutthroat during the diet study, and combined consumption totaled nearly 5,500 metric tons for the year (Table 1).

Cutthroat more than 508 mm TL were more likely to include fish in their diet than
Figure 2. Catch rate, expressed as number of fish caught per gill-net hour, of all chubs caught in the fall gill nets from 1991 to 2006.

Figure 3. Catch rate, expressed as number of fish caught per gill net hour, of age-1 Utah chub in the fall gill nets from 1997 to 2006.

smaller cutthroat, with 51% of the larger cutthroat having fish in their diet during 2005 (Figure 4). Predator lengths compared to prey lengths from the diet study indicate that larger cutthroat are able to eat larger chubs; however, the larger cutthroat were also able to utilize the smaller fish prey as well (Figure 5). The diagonal line
Table 1. Bioenergetics modeling of total cutthroat consumption (expressed as metric tons) by size category in Strawberry during 2005. Cutthroat are categorized into three size-classes: cutthroat less than 381 mm TL (<381), cutthroat from 381 to 508 mm TL (381–508), and cutthroat larger than 508 mm TL (>508). Cutthroat population estimates allowed for estimates of total biomass consumed for each prey item. Size estimates of fish prey also allowed for an estimate of total numbers of fish prey eaten.

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Figure 4. Proportion of cutthroat from the 2005 diet study that had fish as a component of their diet. Cutthroat are categorized into three size-classes: cutthroat less than 381 mm TL (<381, n = 176), cutthroat from 381 to 508 mm TL (381–508, n = 401), and cutthroat larger than 508 mm TL (>508, n = 104).
on Figure 5 represents a possible upper prey size limitation for Bear Lake cutthroat when preying on Utah chub.

Discussion

Biomanipulation of aquatic systems can be a very desirable management strategy due to recurring problems with invasive species and the high cost and feasibility issues of complete eradication. Many studies have demonstrated the ability of other species of predators (largemouth bass *Micropterus salmoides*, hybrid striped bass [*Morone saxatilis × M. chrysops*], northern pike *Esox lucius*, and cod *Gadus* sp.) to effectively control undesirable fish species (Meijer et al. 1995; Dettmers et al. 1996; Irwin et al. 2003; Weston et al. 2006; Savenkoff et al. 2007). However, the use of a cutthroat predator in a highly utilized fishery has not been documented (Perrin et al. 2006).

Cutthroat trout predators demonstrated an ability to control invasive Utah chub populations in Strawberry Reservoir, Utah. However, close monitoring and implementation of special fishing regulations were necessary in order to obtain these results. Not only was a large population of cutthroat needed for this type of control, but a large population of large individuals was needed. Although our data are not conclusive in determining that cutthroat predation was the only factor in the recent declines of chubs, it is substantiated by the results of the bioenergetics modeling and the immediate decline in chub populations.

Heavy angling pressure necessitated relatively severe restrictions on the number and size of cutthroat that could be harvested in order to create and maintain an effective cutthroat predator population. Diet information indicated that the larger cutthroat were far more likely to prey on chubs than the smaller cutthroat, and the larger cutthroat were also able to consume...
larger individuals. Therefore, at Strawberry Reservoir, the size of the predators must be managed in conjunction with numbers of predators to maximize their ability to effectively control a prey population. The bag limit that allowed only one cutthroat to be harvested was effective at building a large population of cutthroat in Strawberry, but without the protection being offered to the larger cutthroat (up to 558 mm TL), it would likely not have worked as well at controlling chub populations as the current slot limit. The average size of the cutthroat generated from the bag limit allowing only one cutthroat was not different than the average size created with the more liberal four-fish limit. Harvest with the one-cutthroat bag limit was still high enough that anglers were removing larger individuals, thus keeping the average size low. In contrast, within the first year of its implementation, the slot limit enacted in 2003 was able to create a population of cutthroat that was larger on average than had been previously documented in Strawberry Reservoir.

It was evident from the highly fluctuating cutthroat population, the relatively small average size of the cutthroat, and the increasing chub population from 1996 to 2002 that the four-fish bag limit with only one over 18” did not create a cutthroat predator population that could impact the Utah chub population. During this period, cutthroat trout averaged only 364 mm TL, with very few surpassing 508 mm TL. Again, with the heavy angling pressure that Strawberry receives, the cutthroat were typically not able to get beyond the 18-in (457-mm) mark where they would receive limited protection.

Of particular interest to managers is the fact that bait and/or gear restrictions were not needed in conjunction with the current slot limit to build up the necessary cutthroat predator population. As was hypothesized from pre-2003 regulation modeling efforts (Wilson and Ward 2003), the needed cutthroat population increase was obtained from the slot limit without restricting the use of bait at Strawberry Reservoir. According to regulation modeling accomplished prior to the 2003 slot-limit regulation change, bait restrictions would have reduced overall angler exploitation (harvest + hooking mortality) by about 13% under a similar slot limit scenario (16–20” rather than 15–22”) (Wilson and Ward 2003). However, with nearly 81% of the anglers at Strawberry using some type of bait (A. Ward and R. B. Wilson, unpublished Strawberry Reservoir creel data), such restrictions on the use of bait would have been unpopular among many of these anglers and would likely have driven away some anglers. It is clear that the desired cutthroat population response was obtained without the imposition of bait or gear restrictions. If bait and/or gear restrictions are not needed on such an intensively utilized fishery as Strawberry Reservoir, where anglers are currently releasing roughly 90% of their cutthroat catch, then such restrictions may not be needed on many waters with special regulations.

Recent declines in Utah chub populations in our gill-net monitoring at Strawberry Reservoir were largely the result of considerable decreases in age-1 and age-2 chubs. Larger adult chubs continued to occur in relatively large numbers due to most of these having grown beyond the size of vulnerability to cutthroat. However, during 2006, the adult chub population has also started to experience declines due to the heavy cutthroat predation and the resultant reduction in recruitment from the younger age-classes. The declining trend in overall chub numbers (adults and subadults) is likely to continue based on recent and substantial reductions in chub production.
The cutthroat diet contents and resulting bioenergetics modeling provided compelling evidence that recent declines in chub catches are primarily the result of heavy predation by the cutthroat. Within the first year of the enactment of the current slot limit and the resulting increase in the large cutthroat predators, age-1 chub numbers decreased substantially. Though we will likely never be able to design and implement a study to actually quantify the chub population in this large and complex system, the consumption of an estimated 64 million chubs (9,303 individuals or 549 kg/ha) by cutthroat throughout the year is considerable. Although some other factors may have confounded our conclusion of predation being the primary factor for the decreases in chubs, there were no other factors that stood out as having the potential to elicit such dramatic results. For instance, water level does not fluctuate dramatically in Strawberry Reservoir (typically less than 2 m overall each year in a 61-m-deep reservoir). In addition, studies conducted at Strawberry Reservoir that looked at potential effects of reservoir fluctuations on chub production indicated that even more dramatic fluctuations would have little if any impact on chub production (Kuehn 2000).

The ongoing 16-year study at Strawberry Reservoir, Utah has demonstrated that a salmonid species such as the Bear Lake cutthroat trout can be utilized as an effective controller of an invasive fish population. Utah chub populations that previously overran the system on two occasions have been controlled over the past 4 years through manipulation of the predatory cutthroat population, and this has occurred in spite of relatively intense angling pressure. Similar results have been found with other predator-prey systems where an undesirable species was controlled by management of a predator (Meijer et al. 1995; Dettmers et al. 1996; Irwin et al. 2003; Weston et al. 2006; Savenkoff et al. 2007). However, use of a cutthroat predator for such purposes has been limited.

We would propose that similar efforts need to be implemented in various other systems with similar invasive fish problems to test the utility of manipulating the size and structure of salmonid predator populations as a means of biologically controlling unwanted fish populations. However, managers need to be willing to change the management of the fishery to respond to the biological needs of the system. For instance, the predatory species needs to be the main focus of the management (stocking, regulation development, etc.) and cannot be a secondary part of the fishery, and harvest and size restrictions need to be carefully considered in order to build an effective predatory population with numerous large individuals. All of this can be problematic when public opinions and desires are thrown into the mix; however, these issues need to be considered and dealt with prior to implementation.

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References


Jeppson, P. J. 1966. Tests for increasing returns of hatchery trout. Idaho Department of Fish and Game, Boise.


Trends in Fisheries Science and Management 1, Bethesda, Maryland.


