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ESCAPEMENT RATES OF TRANSLOCATED SMALLMOUTH BASS (*MICROPTERUS DOLOMIEU)* FROM ELKHEAD RESERVOIR TO THE YAMPA RIVER

Final Report Prepared by,

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Executive Summary

Tag-recapture data indicated that smallmouth bass (*Micropterus dolomieu*) translocated from the Yampa River to Elkhead Reservoir escaped into Elkhead Creek and then downstream to the Yampa River. The confluence of Elkhead Creek with the Yampa River is 8.5 river miles (13.7 river kilometers) downstream of Elkhead Reservoir. From 2003 to 2010, 261 of 4,934 smallmouth bass that had been tagged and translocated to Elkhead Reservoir from 2003 to 2009 were recaptured in the Yampa River (escapees). The 261 fish represent 5% of the tagged smallmouth bass that were translocated from 2003–2009 and is the minimum number that escaped from Elkhead Reservoir into the Yampa River. The count of recaptured escapees likely underestimates the number that escaped because sampling in open systems such as the Yampa River detects only a relatively small portion of the fish available. Thus, a better understanding of escapement rates required integration of recapture rates to estimate the actual number of translocated smallmouth bass that escaped.

After accounting for reach-specific recapture probabilities, we estimated that the average escapement rate (as a proportion) for cohorts translocated from 2003–2005 was 0.48 (0.33–0.64). Relatively high escapement rates were expected for those cohorts because in 2005, prior to the onset of dam reconstruction, the dam spillway was notched to allow reservoir drawdown and a temporary screen installed to prevent fish escapement failed. Escapement rates in the years following dam reconstruction were lower than pre-reconstruction cohort escapement rates but still substantial: estimates for 2006, 2007, 2008 and 2009 were 0.07, 0.23, 0.10 and 0.02, respectively. Pre-reconstruction and post-reconstruction escapement rates suggest that a total of 1,329 (27%) of the 4,934 smallmouth bass that were tagged and translocated to Elkhead Reservoir from 2003–2009 escaped back into the Yampa River by the end of 2010. Escapement

rates of the post-reconstruction cohorts (2006–2009) suggested that, by 2010, 281 (12%) of the 2,454 individuals from these cohorts had escaped. However, as more fish are recaptured after 2010, post-reconstruction escapement rates will increase. Continued relatively high post-reconstruction escapement was likely due to unscreened spillway releases; riprap placed adjacent to the dam may also have attracted smallmouth bass, potentially increasing escapement rates. We suggest that relatively high escapement rates combined with high smallmouth bass fecundity are sufficient to reestablish smallmouth bass in the Yampa River even in the unlikely event that control efforts were 100% effective.

In all scenarios, assumptions of the estimator we used to adjust counts of escapees were conservative. This *a priori* strategy ensured that escapement was likely an underestimate, but not an overestimate, of the true escapement rate for each cohort. Results of our analyses indicated that escapement of smallmouth bass from Elkhead Reservoir (as escapement is herein defined) exceeded the 10% maximum value recommended in the Lake Management Plan. The consequences of exceeding the 10% escapement rate included re-evaluation of translocation of smallmouth bass from the Yampa River to Elkhead Reservoir, a practice which was discontinued beginning in 2011. It's also noteworthy that we did not consider the potential escapement of unmarked, resident smallmouth bass in Elkhead Reservoir that were not part of our translocated cohorts. Assuming resident smallmouth bass also escaped, the number of smallmouth bass that escaped to the Yampa River from Elkhead Reservoir was higher than we estimated for just translocated smallmouth bass. We recommend that further translocation of smallmouth bass to Elkhead Reservoir remain suspended until it can be determined that the rate of escapement has fallen below a threshold at which escaped fish could establish a self-sustaining population.

Additionally, reducing escapement of all bass (and other taxa) from Elkhead Reservoir and other water bodies that support resident non-native fishes seems justified.

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Elkhead Dam, Elkhead Creek, upper Colorado River basin, escapement rate, invasive, endangered species, recovery, stocking

Introduction

Elkhead Dam and Elkhead Reservoir were completed in 1974 and the reservoir was stocked with smallmouth bass (*Micropterus dolomieu*) in 1978 by Colorado Parks and Wildlife (Hawkins *et al.* 2009). Establishment of smallmouth bass in the reservoir and subsequent escapement downstream into the Yampa River created potential conflicts with native fish management in that area, and prompted bass removal and translocation back to Elkhead Reservoir. Although recommendations for escapement rates existed, estimates of escapement rates of translocated bass from the reservoir were unknown (Colorado Division of Wildlife [now Colorado Parks and Wildlife] 2007). Therefore, our main objective was to estimate escapement rates of translocated smallmouth bass from Elkhead Reservoir for each of seven annual translocation cohorts, from 2003–2009. We also provide additional information just below to aid understanding of the historical context of this issue.

Prior to the initial stocking in Elkhead Reservoir, smallmouth bass were not detected in the Yampa River, as evidenced by the absence of smallmouth bass during extensive Yampa River sampling in 1951, 1967–1971 and 1976–1977 (Bailey and Alberti 1952; Holden and Stalnaker 1975; Carlson *et al.* 1979). Additionally, extensive electrofishing, seining, and dip-netting efforts from 1981–1982, encompassing 121 river miles (rmi; 194 river kilometers, rkm) of the Yampa River mostly downstream of Elkhead Reservoir, produced just one smallmouth bass, the first one detected in the Yampa River, out of a sample of nearly 4,000 adult and sub-adult fish and approximately 35,000 small-bodied fish (Hawkins *et al.* 2009). Similar efforts from 1986 through 1988 did not detect any smallmouth bass (Wick *et al.* 1985; McAda *et al.* 1994). Relatively large numbers of smallmouth bass were first introduced into the Yampa River in 1992, when Elkhead Reservoir was drained for dam repairs and resident smallmouth bass escaped downstream through the unscreened outlet structure. Since that time, smallmouth bass numbers have increased in the Yampa River. For example, smallmouth bass comprised a measurable but small portion of the fish community in 1992 (only 49 were captured), but by 2003 were 18%, and by 2007, 51% of the adult fish captured within Little Yampa Canyon (McAda *et al.* 1994, Anderson 2004; Hawkins *et al.* 2009).

The Upper Colorado River Endangered Fish Recovery Program (Recovery Program) initiated a formal removal program for smallmouth bass in 2003. One element of the removal program involved translocation of smallmouth bass captured in the Yampa River to Elkhead Reservoir, which is located on the Yampa-River-tributary Elkhead Creek 8.5 river miles (rmi; 13.7 rkm) upstream of the Yampa River and 17.5 rmi (28 rkm) upstream of Craig, Colorado (Roehm 2004). Smallmouth bass were translocated to Elkhead Reservoir (mandated by the State of Colorado) as a condition of their removal from the Yampa River to provide fishing opportunities for recreational anglers. Despite escapement of smallmouth bass when the reservoir was rapidly drained in 1992, it was assumed that escapement would be minimal during normal dam operations. The majority of the smallmouth bass translocated to Elkhead Reservoir were tagged prior to release to document success of reservoir anglers at recapturing translocated smallmouth bass and to track potential movements of those fish out of the reservoir. Another drawdown of Elkhead Reservoir through a notched spillway just prior to 2005 dam reconstruction was initiated to accommodate reservoir reconstruction and also allowed smallmouth bass to escape including those tagged and translocated from the Yampa River to Elkhead Reservoir in 2003, 2004 and 2005.

Elkhead Dam reconstruction in 2005 increased the height of the earthen dam, changed spillway design, and screened and increased the capacity of the outlet structure. The original spillway was an unscreened, U-shaped, ogee crest structure and the primary outlet structure had an unscreened, controlled, inlet near the bottom of the reservoir with a maximum capacity of 180 cfs (URS 2001; Miller *et al.* 2005). In 2005, the spillway was rebuilt into an unscreened, W-shaped, labyrinth design and the outlet structure was screened with ¼ inch (6.4 mm) mesh and enlarged to allow controlled releases of up to 550 cfs. When flows exceed 550 cfs they are released over the unscreened spillway. Water released from Elkhead Reservoir spills into Elkhead Creek downstream of the dam after passing through a small stilling basin at the foot of the spillway (Appendix I). In all years since reconstruction, spring snowmelt runoff has been high enough to spill over the unscreened reservoir spillway.

Documented smallmouth bass escapement initiated efforts to better understand pre-reconstruction and post-reconstruction escapement rates from Elkhead Reservoir (Hawkins *et al.* 2009). This was important because the 2007 Lake Management Plan for Elkhead Reservoir established a maximum allowable escapement rate for translocated smallmouth bass of 10% in the post-reconstruction period (Colorado Division of Wildlife 2007). Exceeding that value would prompt re-evaluation of the practice of translocating smallmouth bass captured in the Yampa River to Elkhead reservoir. Escapement of smallmouth bass into the downstream Yampa River was problematic because of the presence of endangered fishes, which smallmouth bass may compete with or prey upon. Federally listed endangered species include humpback chub (*Gila cypha*), bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). Results of a bioenergetics analysis implicated smallmouth bass, due to their abundance relative to larger predators such as northern pike (*Esox lucius*), as the greatest threat to the survival of small-bodied fishes including the four endangered species (Johnson *et al.* 2008), so a large-scale removal program was instituted. Based on preliminary population projections (Haines and Modde 2007), the Recovery Program established an interim goal of removing (exploiting) 60% of the adult smallmouth bass population annually to achieve population levels of 30 adults/rmi (18 adults/rkm) in many reaches in the upper Colorado River basin in 10–20 years.

Estimates of escapement rates of smallmouth bass from Elkhead Reservoir for each of seven annual translocation cohorts, 2003–2009, are presented below. Those analyses may guide on-going management of smallmouth bass in the upper Colorado River basin and specifically, decisions regarding future translocation of smallmouth bass from the Yampa River to Elkhead Reservoir (Colorado Division of Wildlife 2007; Martinez and Crockett 2011).

Study Area

The study area (Figure 1) included the Yampa River from the confluence with the Green River at Echo Park in Dinosaur National Monument to State Highway 40 Bridge near Hayden, Colorado, and encompassed 171.5 rmi (276 rkm). This reach was partitioned into 11 management units or reaches based on discrete fish sampling in each (see Breton *et al.* 2013 for more details). The Elkhead Reservoir dam is on Elkhead Creek and located 8.5 rmi (13.7 rkm) upstream of the Yampa River confluence (rmi 148 [237 rkm]); Elkhead Creek enters the Yampa River in the middle of the most upstream management unit (Hayden-Craig).

Methods

Data Collection. Smallmouth bass were captured using boat electrofishing by personnel from the U.S. Fish and Wildlife Service, Larval Fish Laboratory at Colorado State University, and Colorado Parks and Wildlife. A typical sampling effort used a pair of concurrently operating electrofishing boats moving downstream close to shore on opposite banks. The center of the river channel was not typically sampled because smallmouth bass density was assumed low in that high velocity portion of the channel (Coble 1975) and deeper water limited electrofishing efficiency. Sampling completed through the entire reach one time constituted an electrofishing pass, and multiple electrofishing passes were completed in all years and reaches. For more details see Breton *et al.* (2013).

Captured smallmouth bass were transferred to a live well and processed every 0.5–1 rmi (0.8–1.6 rkm). Fish were measured to the nearest millimeter total length (TL). Minimum lengths for tagging and translocation varied through time (Hawkins *et al.* 2009); bass of all sizes were translocated in 2003 and 2004 but only fish ≥100 mm and ≥150 mm TL, respectively, were tagged prior to translocation. From 2005–2010, only bass ≥250 mm TL were tagged and translocated. Untagged smallmouth bass captured during sampling that met length criteria were tagged with an anchor tag (model FD-94, Floy Tag and Manufacturing, Inc., Seattle, WA, U.S.A) using standard methods (Guy *et al.* 1996). Bass were translocated to Elkhead Reservoir in a live well, typically on the same day they were removed from the river.

Data Analysis. A cohort was defined as all smallmouth bass that were tagged and translocated to Elkhead Reservoir in one year. We estimated the number of tagged and translocated smallmouth bass from each cohort that escaped (escapees) from Elkhead Reservoir and were available for recapture in seven management units or reaches in the Yampa River (Table 1) during electrofishing removal efforts. We then divided the estimated number of bass that escaped by the number translocated to Elkhead Reservoir for each cohort to arrive at cohort-specific escapement rates. Four reaches did not produce recaptured escapees. Therefore, these were not included in our analysis because our abundance estimator integrated only recaptured fish. The majority of smallmouth bass translocated in 2010 were transported and released into

Elkhead Reservoir after the spillway stopped spilling. Thus, given that few of these fish had an opportunity to escape over the spillway and be recaptured, they are not included in this analysis.

To estimate the number of smallmouth bass that escaped from Elkhead Reservoir for each translocation cohort (2003–2009), we modified the canonical estimator of abundance (Huggins 1989; Williams *et al*. 2002, pg. 243),

$$\hat{N} = \frac{C}{\hat{p}}$$

to account for individual heterogeneity in detection probability ($\hat{p}^*_{i,all}$), annual rates of tag retention ($(\hat{R})^{yal}$), and survival ($(\hat{S})^{yal}$),

$$\hat{N}_J = \sum_{i=1}^{C_j} \frac{1}{\hat{p}^*_{ij,all}} / (\hat{R})^{yal} / (\hat{S})^{yal}$$

where *C* is the number of smallmouth bass from the *j*th cohort recaptured in the Yampa River. The term $\hat{p}^*_{ij,all}$ is the probability of detecting the *i*th smallmouth bass from the *j*th translocation cohort over *all* passes and years when it was susceptible to recapture. For example, if the *i*th fish from the *j*th translocation cohort was susceptible to recapture probability on four passes in year one and three passes in year two, then the probability of being detected over these seven passes would be,

$$\hat{p}^*_{ij,all} = 1 - [(1 - p^{ij}_{1,1}) * (1 - p^{ij}_{2,1}) * (1 - p^{ij}_{3,1}) * (1 - p^{ij}_{4,1}) * (1 - p^{ij}_{1,2}) * (1 - p^{ij}_{2,2}) * (1 - p^{ij}_{3,2})].$$

$1/\hat{p}^*_{ij,all}$ is the contribution made by each individual to the adjusted count of escapees, these are always ≥1. $\hat{R}$ and $\hat{S}$ are annual rates of tag retention and survival, respectively, and *yal* (years-at-large) is the number of years between translocation and recapture. The true tag retention and survival probabilities for each cohort of translocated fish that escaped to the Yampa River are not known. To accommodate this uncertainty, we considered nine plausible combinations of tag retention and survival rates, based on literature values and other analyses (below), and solved our estimator under each of these scenarios for each translocation cohort (*j*). Subsequently, we took the average of these nine estimates to arrive at an average escapement rate ($\hat{E}_j$), based on all scenarios, for each cohort. Averaging across scenarios was motivated by the concept of model averaging discussed by Burnham and Anderson (2002). In our calculation of an average escapement rate ($\hat{E}_j$), each tag-retention-survival scenario was given an equal weight, 1/9 = 0.11.

Estimates of detection probabilities ($\hat{p}_i$) were provided by closed-population abundance analyses (Breton *et al.* 2013). Data were from capture-mark-recapture-removal experiments from the seven management units where escapees were recaptured: Lily Park; Sunbeam; Upper Maybell; Juniper; Little Yampa Canyon; South Beach; and Hayden-Craig (Table 1). Estimates of detection probability as a function of fish length, pass, year, reach, and an effect of behavior were available from Lily Park and Little Yampa Canyon analyses. In addition to main effects, pass× year, and behavior× year interactions were also available. For all other reaches except Hayden to Craig, sparse recapture data allowed detection probability to be modeled only as a function of pass, behavior, and fish length; for Hayden to Craig only effects of pass and fish length could be estimated. All analyses were performed in program MARK using the Huggins form of the closed-population abundance estimators (Huggins 1989, 1991; White and Burnham 1999; Borchers *et al.* 2002; Bestgen *et al.* 2007).

To estimate detection probability for each fish ($\hat{p}^*_{ij,all}$) over all passes and years when it was susceptible to recapture, we made three assumptions. First, we assumed that if a fish escaped the reservoir, it did so on the first day a spill occurred after translocation. For the majority of fish, this was the first day of the spill in the year after translocation. This assumption was needed to determine the number of passes an individual escapee was subjected to after escapement. Some of the smallmouth bass translocated in 2004 (*n* = 1215), 2005 (428), 2009 (566) and 2010 (174) were translocated when Elkhead Reservoir was actively spilling; we assumed that these fish escaped on the day that they were translocated. One fish from the 2007 cohort escaped the same year it was translocated during a non-spill period, and we assumed that this fish escaped by unknown means on the day it was translocated. Second, we also assumed that once fish escaped, they immediately moved to the reach where they were eventually recaptured. Third, we assumed that detection probability on passes within the translocation year were a function of behavior (higher initial capture probability than recapture probability) and those after the translocation year were not, i.e., we assumed that the aversion to capture noted in Breton *et al.* (2013) dissipated after a year. Those assumptions effectively maximized the number of electrofishing passes that escapees were susceptible to, which in our model, maximizes their detection probability, and therefore, minimizes (conservative) their contribution to the adjusted number of escapees that we attempted to estimate.

Recovery Program tag retention studies in 2007 and 2008 suggested high retention rates, 0.96–1.0 over 19–186 days (P. Badame unpubl. data, T. Jones unpubl. data, JAH unpubl. data, T. Hendrick unpubl. data). However, Walsh and Winkelman (2004) reported much lower retention rates for anchor-tagged smallmouth bass, 0.76 over 1.5 months and 0.48 over 4 months. To accommodate uncertainty in retention rates, we assessed three scenarios with high (0.9), medium (0.75), or low (0.6) tag retention where 10%, 25% or 40% of smallmouth bass would be expected to lose their tags annually.

Beamesderfer and North (1995) reported an average, natural, annual adult mortality rate of 35% based on a literature review encompassing 409 smallmouth bass populations. In our system, sources of mortality included an active smallmouth bass fishery in Elkhead Reservoir and a lower impact fishery in the Yampa River, and natural mortality that included potential effects from escapement over the spillway and mortality associated with migration into the Yampa River. We assessed three scenarios of high (0.85), medium (0. 75) and low (0.65) annual survival (e.g., 15%, 25% or 35% of adult smallmouth bass die annually) in all possible combinations with the three tag retention rate scenarios described above (nine total), noting that survival rates we used were conservative relative to the average rates found by Beamesderfer and North (1995). We assumed that tag retention and survival did not vary by year or any other effects (but see Discussion for year 2006).

We identified periods of flow over the spillway (Table 2) as the date of the first spill to end date of the last spill in a year. Spill dates were calculated from an unpublished flow and spill model (R. Tenney, Colorado River Water Conservation District). The reservoir was maintained at near maximum capacity and the outflow during spill periods was similar to the gauged inflow, after the reservoir was filled. Since 2006, reservoir releases up to 550 cfs were released through the screened outlet structure, and flows greater than 550 cfs go over the spillway. (R. Tenney pers. comm.; Ruddy 2010). We assumed that fish did not escape through the outlet structure in any year and that escapement only occurred when water was released over the spillway.

Results

From 2003 to 2010, 261 of 4,934 smallmouth bass that had been tagged and translocated to Elkhead Reservoir over the period 2003 to 2009 were recaptured in the Yampa River (escapees) in one of seven reaches (Table 3); three others were recaptured in the pool below the Elkhead Dam spillway. The 261 escapees represented 5% (261/4,934) of the smallmouth bass that were tagged and translocated from 2003–2009.

Based on our analyses using tag-recaptures and recapture probabilities, escapement rates of smallmouth bass from Elkhead Reservoir to the Yampa River were much higher than 5% (*n* = 261 bass). Conservatively, we estimated that 1,329 translocated smallmouth bass escaped when averaged over all survival and tag loss rate scenarios (709–2,311, Table 4). That translates to an average escapement rate over all survival and tag loss rate combinations of 27% (2–47%) for cohorts from 2003–2009.

Averaged across all scenarios, escapement rates for 2003–2005 cohorts, for which few additional recaptures are expected, were 0.47, 0.33, and 0.64, respectively (Table 4). Escapement rates for 2006–2009 cohorts, which will likely increase due to additional future recaptures, were 0.07, 0.23, 0.10 and 0.02, respectively, after year 2010. Escapement by the relatively small 2006 translocation cohort appears to be an outlier with only four fish recaptured in the Yampa River as of 2010 (Table 3).

Probabilities of detection, $\hat{p}^*_{ij,all}$, were, on average, relatively low in the Hayden-Craig (0.30), South Beach (0.54) and Juniper (0.73) reaches compared to Lily Park (>0.99), Little Yampa Canyon (0.97), Sunbeam (0.99) and Upper Maybell (0.97; Table 5). As a result, contributions to the estimated number of fish that escaped ($1/\hat{p}^*_{ij,all}$) were much higher for escapees recaptured in the reaches with low detection probabilities (9.18–11.36 fish) compared to reaches with higher detection probabilities (1–1.53 fish; Table 5).

Most smallmouth bass that escaped Elkhead Reservoir were found in the three most upstream reaches of Hayden to Craig, South Beach, and Little Yampa Canyon. We estimated that 281 (12%) of the 2,454 individuals from the post-reconstruction cohorts (2006–2009) had escaped by 2010 and 95% of these immigrated to the uppermost three reaches closest to the Elkhead Creek confluence (Figure 2). Combined post-reconstruction (2006–2009) cohort densities in Hayden-Craig, South Beach, and Little Yampa Canyon reaches were 1.45, 6.68, and 5.99 fish/river mile, respectively. High immigration to these reaches was also apparent with the pre-reconstruction cohorts (2003–2005; Figure 2). Escapee densities ranged from 0–19 fish/rmi for the combined periods of pre-reconstruction and post-reconstruction for those three most upstream reaches. In contrast, escapee densities were much lower in the lowermost reaches downstream of Little Yampa Canyon and ranged from 0–1.5 fish/rmi for the combined pre-reconstruction and post-reconstruction periods.

The majority of smallmouth bass that escaped were over 200 mm TL when translocated to Elkhead Reservoir. The length distribution of those fish shifted upwards approximately 50 mm by the time these fish were recaptured in the Yampa River (Figure 3).

Discussion

We conservatively estimated that 1,329 (27%) of the 4,934 smallmouth bass that were tagged and translocated to Elkhead Reservoir from 2003–2009 escaped back into the Yampa River and downstream by the end of 2010. Smallmouth bass escapement from Elkhead Reservoir was variable over time but remained relatively high even in the post-reconstruction period when up to 550 cfs of discharge was screened during the runoff period. Escapement rates for post-reconstruction cohorts (2006–2009) suggested that, by 2010, 281 (12%) of the 2,454 individuals from these cohorts had escaped. However, post-reconstruction escapement rates are likely to increase, because additional tagged escapees will be captured in the Yampa River. For example in 2011, 55 additional escapees (more than the total escapees recaptured in 2009 and 2010, n = 54) were recaptured in the Yampa River, all of which were from post-reconstruction cohorts.

Despite the possibility of additional recaptures in future years, the 2006 cohort appears to have escaped at a relatively low rate. Our estimates assumed that the level of mortality experienced by each cohort in the reservoir was similar. However, smallmouth bass translocated in 2006 may have been subjected to high mortality due to extremely low water levels in Elkhead Reservoir during the final phase of dam reconstruction. Thus, fewer bass from the relatively small 2006 cohort would have survived to escape in 2007 and after. Factors that may have reduced their survival more than in other years included a reduction in food availability, high summer water temperatures, poor water quality, and predation by northern pike. Assuming the 2006 cohort survived in the reservoir at an anomalously low rate, then our three survival rate scenarios (0.85, 0.75 and 0.65) were likely high for this cohort, and as a result our 2006 escapement rate estimate, 0.07, is likely low.

Based on our estimates and preliminary data, escapement by the 2009 and 2010 cohorts appears to be on-track with, or possibly even greater than, relatively high escapement detected from the 2007 post-reconstruction cohort. For example, in 2011 an additional 31 escapees not included in our analysis were recaptured from the 2009 cohort in the Yampa River (JAH unpubl. data, B. Wright unpubl. data, A. Webber unpubl. data); another escapee from this cohort was recaptured in Lodore Canyon on the Green River (KRB, unpubl. data.). That number (n = 32) of escaped bass would elevate the 2009 cohort escapement rate to nearly 10% in just two years post-translocation. Additionally, from the 2010 translocation cohort which we excluded from our analysis for reasons given in our introduction, 21 escapees were recaptured in the Yampa River in 2011 (JAH unpubl. data, B. Wright unpubl. data, A. Webber unpubl. data). Those 21 fish, recaptured in the year following translocation, represent 3% (21/685) of the 2010 cohort. In contrast, only 1.8% of the 2007 cohort of bass was recaptured a year later in 2008 but a minimum cohort escapement rate of 23% was documented based on recaptures through 2010. Those results suggested that initial escapement by the 2010 cohort may have been higher than any other post-reconstruction cohort to date and may be related to the relatively high and long-duration runoff experienced in 2011.

Our analyses suggested that post-reconstruction escapement rates have declined relative to those documented for the pre-construction period, but substantial numbers of smallmouth bass continued to leave Elkhead Reservoir. Even though up to 550 cfs of reservoir releases have been screened since modifications to the outlet structure in 2005, in most years, spring snowmelt runoff is high enough to require release of water over the unscreened reservoir spillway. For example, in 2011, flow over the spillway during spring runoff was sufficient to fill Elkhead Reservoir more than three times. Thus, spillway releases likely explain the continued escapement of translocated smallmouth bass since dam outlet and spillway modifications were completed in 2006. Escapement over the new spillway may be exacerbated by the new spillway design or by riprap placed near the dam and spillway, where catch rates of smallmouth bass were among the highest in the reservoir (pers. comm., B. Wright, CPW).

Our estimated escapement rates of smallmouth bass exceed the maximum rates recommended in the Elkhead Reservoir Lake Management Plan (Colorado Division of Wildlife 2007), even though we were not able to implement the sampling protocol required to directly assess the Plan guidelines. Specifically, the Plan states, “If the estimated number of tagged, reservoir smallmouth bass recaptured in the Hayden - Craig reach of the Yampa River in a given year exceeds 10% of the number of fish translocated to the reservoir in the previous year, transplanting of smallmouth bass to the reservoir would be reevaluated.” When the 2007 Elkhead Reservoir escapement criterion was developed, interested parties were assessing preliminary escapement numbers from the pre-reconstruction period and likely thought escapement would be diminished post-reconstruction because of the fish screen installed in the outlet works. Further, the assumptions at that time likely were that: 1) the majority of escapees would be found close to the reservoir, i.e. between Hayden and Craig; and 2) with considerations for assumed tag loss and mortality that the majority of escapees from any annual translocation effort would be most readily detected during the subsequent year. Our new information informs us otherwise and invalidates assumptions made in the Lake Management Plan regarding timing and dispersal of bass escapement. This is because bass escapement rates generally remained high post-reconstruction and because most escapees occupied the Hayden to Craig reach, but only briefly and while in transit to areas well downstream (e.g., downstream of Craig, Colorado) where water temperatures and habitat are more optimal for smallmouth bass. Further, more escapees from annual translocation efforts were recaptured two or even three years post-translocation and not in the first year after translocation, and importantly, escapees from any given annual cohort have been detected in the Yampa River as many as four years after translocation. For those reasons, we suggest that the 2007 Lake Management Plan escapement criteria, which were crafted with the best available but substantially incomplete information, are obsolete.

Prior to carrying-out the analysis presented in this report, Drs. Gary White (Colorado State University) and Paul Lukacs (formerly Colorado Parks and Wildlife) fit a multi-state model to 2003–2010 escapement data that estimated annual transition (escapement) rates of tagged smallmouth bass from Elkhead Reservoir to the Yampa River for both the pre-reconstruction and post-reconstruction periods and an overall survival rate. Models with up to 23 parameters were fit but most did not produce useful parameter estimates; only the simplest models provided useful estimates. One of the simpler models that gave reasonable estimates had four parameters, constant annual survival for smallmouth bass in both Elkhead Reservoir and the Yampa River ($\hat{S}$ = 0.65, 95% CI: 0.60 to 0.69), constant capture probability in the Yampa River across years ($\hat{p}$ = 0.10, 95% CI: 0.03 to 0.29), and two annual transition (escapement) rate estimates from the reservoir to the Yampa River (pre-reconstruction cohorts, $\hat{\varphi}$ = 0.156, 95% CI: 0.04 to 0.43; post-reconstruction cohorts, $\hat{\varphi}$ = 0.103 (10.3%), 95% CI: 0.03 to 0.28).

We compared estimates of escapement from the analysis presented in our Results with the multi-state model and found predictions were consistent. For example, using the estimates from the White and Lukacs four parameter model, annual escapement of the 2007 cohort would produce 87, 78 and 71 escapees in 2008, 2009 and 2010, respectively (10% annually [rounded down from 10.3%] without replacement), a cohort-level escapement rate of 87+78+71/871=0.27 or 27% which was similar to our estimate of 23%. The consistent predictions of escapement rates from Elkhead Reservoir using the two techniques offered support that the results were robust, regardless of the analysis technique and the available data. Those results also suggest that the 10% maximum escapement rate for cohorts of smallmouth bass recommended in the Lake Management Plan for Elkhead Reservoir (Colorado Division of Wildlife 2007) was exceeded not just in the year following translocation but every year that translocated bass were alive. This was viewed as particularly problematic given the relatively long escapement horizon and the extended recapture period for smallmouth bass in the Yampa River (four or more years).

Where possible we attempted to use conservative assumptions when conducting analyses so that our results can be viewed as minimum estimates of escapement of smallmouth bass from Elkhead Reservoir. We applied several constraints to this *a priori* strategy: (1) we excluded escapees recaptured in the spillway (n = 3 escapees) which reduced the number of known escapees in our analysis; (2) we assumed that fish escaped from the reservoir on their first opportunity which effectively maximized their over-all detection probabilities ($\hat{p}^*_{ij,all}$) and minimized their contribution ($1/\hat{p}^*_{ij,all}$) to $\widehat{N}$ (which reduces escapement rate estimates); (3) we assumed that fish were immediately susceptible to electrofishing removal in the reach where they would eventually be recaptured thus allowing no transit or residence time in reaches where lower effort was applied; (4) we applied the effect(s) responsible for lower recapture rate relative to initial capture only to pass-specific detection probabilities in the translocation year and this maximized over-all detection probabilities and minimized contributions made to $\widehat{N}$ by each fish; (5) we used *annual* tag loss rates of less than 40% despite tag loss rates reported in the literature of up to 24% after only 1.5 months (Walsh and Winkelman 2004), thus reducing the adjusted number of escapees in our analysis; (6) we used relatively high survival rates in scenarios relative to that reported in the literature (Beamesderfer and North 1995) and relative to that which was estimated for smallmouth bass in the Yampa River in the multi-state model, which reduced subsequent escapement rate estimates; and (7) we assumed that escapees were not present in reaches where none were detected even though sampling effort was low and as a result detection probabilities were also low, which eliminated potential contributions of escapees in those reaches to the escapement rate estimates. Of significance for this last assumption was the recapture of an escapee from the 2009 cohort in Lodore Canyon on 11 August 2011 which demonstrated that escapees may reside in reaches where they have not yet been detected, including reaches far from Elkhead Reservoir.

Our estimates of escapement, using only translocated and tagged fish from the Yampa River, also do not account for escapement of resident, unmarked smallmouth bass from Elkhead Reservoir. It seems reasonable to assume that resident smallmouth bass also escape from Elkhead Reservoir into the Yampa River, thereby increasing escapement compared to that just for translocated bass.

Of the 281 estimated escapees from post-reconstruction cohorts, 95% immigrated to Hayden-Craig, South Beach or Little Yampa Canyon, reaches closest to the Yampa River-

Elkhead Creek confluence (mile 148.2 on the Yampa River). Combined post-reconstruction cohort density estimates in these reaches were 1.45, 6.68 and 5.59 fish/river mile, respectively (Figure 3). However, the estimate from Hayden-Craig is misleading and low given that none of the escapees were recaptured upstream of the Elkhead Creek confluence and that typically (a trend across years), smallmouth bass were captured in a backwater about two miles downstream of Elkhead Creek following releases over the Elkhead Dam spillway (A. Webber pers. comm.). Excluding the section of the Hayden-Craig reach above the Elkhead Creek confluence, our estimate of post-reconstruction escapees per river mile doubles from 1.45 to 3.93 for the remaining 13.7 river miles of the Hayden-Craig reach below the Elkhead Creek confluence.

Smallmouth bass have high reproductive potential and thus the ability to establish populations from relatively few individuals (Baylis *et al.* 1991, 1993; Gross and Kapuscinski 1997; Martinez *et al.* 2012), certainly far fewer than the number that have escaped from Elkhead Reservoir. For example, Martinez *et al.* (2012) suggested mean propagule pressure for smallmouth bass, the density of adult fish needed to start a population in an uninhabited location, ranged from 0.23-3.2 fish per acre. This equated to actual bass numbers introduced into large reservoirs that ranged from 100 to 278 adults (mean = 147 fish, using only the lowest five estimates, Table G-1), which is far lower than total escapement (n = 1,329) or post-reconstruction escapement (n = 281 through 2009, many more have since escaped) from Elkhead Reservoir. Martinez *et al.* (2012) also suggested that "only a few adult pairs may be responsible for large numbers of smallmouth bass in successful year classes that sustain invasive impacts to native riverine food webs". Thus, based on the understanding that relatively few adult smallmouth bass are capable of establishing populations and causing harm to native food webs, we view escapement rates from Elkhead Reservoir as unacceptable, because the high fecundity of escaped bass would render even 100% removal rates of smallmouth bass from the Yampa River ineffective in a short time. In the context of the invasive threat of smallmouth bass from very low propagule densities (Baylis *et al.* 1991, 1993; Gross and Kapuscinski 1997; Martinez *et al.* 2012), we find the collective evidence compelling and recommend that translocation of smallmouth bass to Elkhead Reservoir, or any other waters where escapement into upper basin streams is possible, should be discontinued until it can be determined that the rate of escapement has fallen below a threshold at which escaped fish could establish a self-sustaining population. Additionally, reducing escapement of all bass (and other taxa) from Elkhead Reservoir and other water bodies that support resident non-native fishes seems justified.

Conclusions

- Escapement criteria in the 2007 Lake Management Plan for Elkhead Reservoir, based on new information presented here, are obsolete.
- Escapement of smallmouth bass from Elkhead Reservoir continued in the post-reconstruction period beginning in 2006.
- Escapement was particularly high prior to and during Elkhead Dam modifications from 2003–2005.
- High spring flows exceeded the capacity of infrastructure to screen outflows to some degree every year even in the post-reconstruction period, resulting in bass escapement from Elkhead Reservoir via the unscreened spillway.
- Escapement rates of translocated smallmouth bass are sufficient to partially offset removal efforts in the Yampa River.
- Escapement rates of resident smallmouth bass produced in Elkhead Reservoir have not been quantified but are likely similar to tagged, translocated bass.

- Escapement rates from Elkhead Reservoir reported here are unacceptable because fecundity potential of escaped translocated bass is likely sufficient to restart a population in the Yampa River even if removal efforts there were 100% efficient.
- Management efforts to reduce effects of smallmouth bass in the Yampa River would be enhanced if translocations ceased and escapement rates of bass produced in the Elkhead Reservoir were reduced or eliminated.

Management Recommendations

- Discontinue translocation of smallmouth bass to waters such as Elkhead Reservoir where escapement is possible.
- Continue to tag any nonnative fish that are translocated from the Yampa River to other waters to monitor escapement.
- Continue to assess tag recaptures of smallmouth bass in the Yampa and Green rivers so that these data can be used to update estimates of escapement rates from Elkhead Reservoir for (in particular) post-reconstruction cohorts.
- Better understand potential escapement rates of resident smallmouth bass from Elkhead Reservoir using mark-recapture techniques. Minimally, this involves understanding the population size of smallmouth bass in the reservoir and their propensity to escape.
- Minimize escapement of translocated and non-translocated smallmouth bass (and other taxa) from Elkhead Reservoir and other water bodies that support resident non-native fishes.

Literature Cited

Anderson, R. 2004. Riverine fish flow investigations. Federal Aid Project F-289-R7. Job Progress Report. Colorado Division of Wildlife, Fort Collins.

Bailey, C., and R. Alberti. 1952. Lower Yampa River and tributaries study, Job 4. Job Completion report F-3-R-1. Federal Aid Division, Colorado Game and Fish Department, Denver, Colorado.

Baylis, J. R., N. S. Rafeto, D. Weigmann, C. Annett, and M. H. Hoff. 1991. Measurements of reproductive success: reproduction and recruitment in a closed population. First International Smallmouth Bass Symposium, pg. 163.

Baylis, J. R., D. D. Wiegmann and M. H. Hoff. 1993. Alternating life histories of smallmouth bass. Transactions of the American Fisheries Society, 122:500–510.

Beamesderfer, R. C., and J. A. North. 1995. Growth, natural mortality, and predicted response to fishing for largemouth bass and smallmouth bass populations in North America. North American Journal of Fisheries Management 15: 688–704.

Bestgen, K. R., J. A. Hawkins, G. C. White, K. Christopherson, M. Hudson, M. Fuller, D. C. Kitcheyan, R. Brunson, P. Badame, G. B. Haines, J. Jackson, C. D. Walford, and T. A. Sorensen. 2007. Population status of Colorado pikeminnow in the Green River Basin, Utah and Colorado. Transactions of the American Fisheries Society 136:1356–1380.

Borchers, D. L., S. T. Buckland and W. Zucchini. 2002. Estimating Animal Abundance: Closed Populations. Springer-Verlag, London.

Breton, A. R., J. Hawkins, K. R. Bestgen, D .L. Winkelman, and G. C. White. 2013. A retrospective assessment of the Upper Colorado River Recovery Program's efforts to control nonnative smallmouth bass. Report for the Upper Colorado River Endangered Fish Recovery Program, Project Number 161, US Department of the Interior, Fish and Wildlife Service, Denver, Colorado. Larval Fish Laboratory Contribution Number 169.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multi-model Inference: A practical information-theoretic approach, 2nd ed. Springer, New York, NY.

Carlson, C. A., C. G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W. D. Fronk. 1979. Fishes and macroinvertebrates of the White and Yampa Rivers, Colorado. United States Bureau of Land Management, Biological Sciences Series 1, Denver, Colorado.

Coble, D. W. 1975. Smallmouth bass. In: Black bass biology and management. H. Clepper, ed. Sport Fishing Institute, Washington, D.C., 534 pp.

Gross, Mark L., and A. R. Kapuscinski. 1997. Reproductive success of smallmouth bass estimated and evaluated from family-specific DNA fingerprints. Ecology 78:1424–1430.

Guy, C. S., H. L. Blankenship and L. A. Nielsen. 1996. Tagging and marking. Pages 353–383 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Haines, G. B., and T. Modde. 2007. A review of smallmouth bass removal in Yampa Canyon, with notes on the simulated effort needed to reduce smallmouth bass in the Green River sub-basin. U.S. Fish and Wildlife Service, Colorado River Fishery Project, Vernal, Utah.

Hawkins, J. A., C. D. Walford, and A. A. Hill. 2009. Smallmouth bass control in the middle Yampa River, 2003–2007. Report for the Upper Colorado River Endangered Fish Recovery Program, Project Number 125, US Department of the Interior, Fish and Wildlife Service, Denver, Colorado. Larval Fish Laboratory Contribution Number 154.

Holden, P.B. and C.B. Stalnaker. 1975. Distribution and abundance of fishes of the upper Colorado River basin. Transactions American Fisheries Society. 104:217–231.

Huggins, R. M. 1989. On the statistical analysis of capture-recapture experiments. Biometrika 76:133–140.

Huggins, R. M. 1991. Some practical aspects of a conditional likelihood approach to capture experiments. Biometrics 47:725–732.

Johnson, B. M., P. J. Martinez, J. A. Hawkins and K. R. Bestgen. 2008. Ranking predatory threats by non-native fishes in the Yampa River, Colorado via bioenergetics modeling. North American Journal of Fisheries Management 28:1941–1953.

Martinez, P. J., D. Speas, M. Trammell, K. Wilson, P. Cavalli, H. Crockett, B. Albrecht, and D. Ryden and H. Crockett. 2012. Upper Colorado River Basin nonnative and invasive aquatic species prevention and control strategy. Draft report, Upper Colorado River Endangered Fish Recovery Program.

McAda, C. W., J. W. Bates, J. S. Cranney, T. E. Chart, W. R. Elmblad and T. P. Nesler. 1994. Interagency Standardized Monitoring Program: Summary of Results, 1986–1992. Final Report to the Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, Colorado.

Miller, W. J., D. E. Rees, and J. A. Ptacek. 2005. Elkhead Reservoir Escapement. Final Report to the Recovery Program for the Endangered Fishes of the Upper Colorado River. Project No. 118, Miller Ecological Consultants, Fort Collins, Colorado.

Roehm, G. W. 2004. Management plan for endangered fishes in the Yampa River Basin and Environmental Assessment. U.S., Fish and Wildlife Service, Mountain-Prairie Region 6. Denver.

Ruddy, B. C. 2010. Streamflow gain-loss characteristics of Elkhead Creek downstream from Elkhead Reservoir near Craig, Colorado, 2009. U.S. Geological Survey Scientific Investigations Report 2010–5198, 14 pgs.

URS 2001. Construction alternatives for Elkhead Dam Raise, Moffat County, Colorado. Final report to Colorado River Water Conservation District by URS, Corp. Denver, Colorado

Walsh, M. G., and D. L. Winkelman. 2004. Short-term retention of floy anchor tags by stream-dwelling smallmouth bass. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 58:38–43.

Wick, E. J., J. A. Hawkins and C. A. Carlson. 1985. Colorado squawfish and humpback chub population and habitat monitoring 1981–1982. Division of Wildlife, Denver, CO. Environmental Wildlife Investigations Job Progress Report SE-3-6.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120–138.

Williams, B. K., J. D. Nichols and M. J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, 817 pp.

Table 1. Reaches on the Yampa River, including their length and location in river miles measured from the confluence of the Green and Yampa rivers (mile 0), where smallmouth bass escapees from Elkhead Reservoir were recaptured between 2003 and 2010.

	River Mile		
Reach	**Start**	**End**	**Length**
Hayden to Craig	171.5	134.5	37
South Beach	134.2	124	10.2
Little Yampa Canyon	124	100	24
Juniper†	100	91	9
Upper Maybell	88.7	79.2	9.5
Sunbeam	71	60.6	10.4
Lily Park	55.5	47.5	8

† Juniper is just upstream (adjacent) to Juniper Canyon, the latter is a short, canyon-bound reach that has been rarely sampled for smallmouth bass and was not included in the escapement analysis.

Table 2. Spill dates for Elkhead Reservoir, 2003–2010. Spill dates reflect the start of the first spill and the end of the last spill within a year and therefore are not (necessarily) continuous. Data provided by an unpublished flow and spill model (R. Tenney, Colorado River Water Conservation District).

	Spill	
Year	**Start**	**End**
2003	4/26	6/4
2004	4/29	6/5
2005	4/15	6/8
2006	4/13	5/24
2007	3/27	5/3
2008	4/30	6/8
2009	4/21	6/5
2010	4/20	6/2

Table 3. Counts of smallmouth bass (*Micropterus dolomieu*) that escaped from Elkhead Reservoir to the Yampa River following translocation from the Yampa River. Untagged smallmouth bass that were translocated to Elkhead Reservoir in 2003 and 2004 (n = 1,175) are not included in the number translocated.

Year	**Number**	**Recapture Year**								
Translocated	**Translocated**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Total**
2003	231	0	0	2	6	2	0	0	0	10
2004	1601	0	4	23†	49	12	0	0	0	88
2005	648	0	0	4†	54	26	5	2	0	91
2006	307	0	0	0	0	2	2	0	0	4
2007	871	0	0	0	0	1	15†	28	5	49
2008	348	0	0	0	0	0	0	1	9	10
2009	928	0	0	0	0	0	0	0	9	9
2010	685	0	0	0	0	0	0	0	0	0
Total	**5619**	**0**	**4**	**29**	**109**	**43**	**22**	**31**	**23**	**261**

† Not included in these counts is a single escapee, in each case, captured in the spillway.

Table 4. Estimates of the number ($\widehat{N}$) and escapement rate ($\hat{E}$) of smallmouth bass (*Micropterus dolomieu*) for seven translocation cohorts, 2003–2009, that escaped from Elkhead Reservoir between 2003 and 2010. Estimates are provided for nine scenarios reflecting high (0.9), medium (0.75) or low (0.6) tag retention, on the left (e.g., High–), and high (0.85), medium (0.75) or low survival (0.65) on the right (e.g., –High).

Cohort	**Number Translocated**	**Number Recaptured**	**High–High**		**High–Med**		**High–Low**		**Med–High**		**Med–Med**		**Med–Low**	
			$\widehat{N}$	$\widehat{E}$	$\widehat{N}$	$\widehat{E}$	$\widehat{N}$	$\widehat{E}$	$\widehat{N}$	$\widehat{E}$	$\widehat{N}$	$\widehat{E}$	$\widehat{N}$	$\widehat{E}$
2003	231	10	34	0.15	50	0.22	78	0.34	60	0.26	88	0.38	138	0.60
2004	1601	88	275	0.17	338	0.21	433	0.27	373	0.23	465	0.29	607	0.38
2005	648	91	246	0.38	293	0.45	363	0.56	318	0.49	386	0.60	489	0.75
2006	307	4	13	0.04	16	0.05	19	0.06	17	0.05	20	0.06	24	0.08
2007	871	49	108	0.12	133	0.15	170	0.19	146	0.17	182	0.21	236	0.27
2008	348	10	18	0.05	23	0.07	30	0.09	25	0.07	32	0.09	43	0.12
2009	928	9	14	0.02	16	0.02	19	0.02	17	0.02	20	0.02	23	0.02
	4934	**261**	**709**		**869**		**1112**		**957**		**1193**		**1560**	

Table 4. Continued.

	Number	Number	Low–High		Low–Med		Low–Low		Cohort Average	
Cohort	**Translocated**	**Recaptured**	$\hat{N}$	$\hat{E}$	$\hat{N}$	$\hat{E}$	$\hat{N}$	$\hat{E}$	$\hat{N}$	$\hat{E}$
2003	231	10	120	0.52	179	0.77	231	1.00	109	0.47
2004	1601	88	557	0.35	708	0.44	943	0.59	522	0.33
2005	648	91	453	0.70	562	0.87	648	1.00	418	0.64
2006	307	4	23	0.07	27	0.09	33	0.11	21	0.07
2007	871	49	217	0.25	274	0.31	361	0.41	203	0.23
2008	348	10	39	0.11	50	0.14	66	0.19	36	0.10
2009	928	9	22	0.02	24	0.03	28	0.03	20	0.02
	4934	**261**	**1430**		**1824**		**2311**		**1329**	

Table 5. The average, minimum, and maximum fish lengths (mm), probabilities of being detected, $\hat{p}^*_{i,all}$, and contributions made to the adjusted count by individual fish, $1/\hat{p}^*_{i,all}$, by recapture reach based on 261 smallmouth bass (*Micropterus dolomieu*) translocated from the Yampa River to Elkhead Reservoir and subsequently recaptured in the Yampa River. Data are 2003–2010 recaptures of cohorts translocated to Elkhead Reservoir from 2003–2009.

Recapture	Number	Fish Length (mm)			$\hat{p}^*_{i,all}$			$1/\hat{p}^*_{i,all}$		
Reach	Recaptured	Average	Min	Max	Average	Min	Max	Average	Min	Max
Hayden-Craig	29	316	225	416	0.2977	0.0988	0.9267	4.74	1.08	10.12
South Beach	59	357	269	469	0.5371	0.0881	0.9963	2.56	1.00	11.36
Little Yampa Canyon	157	352	189	450	0.9649	0.6516	1.0000	1.04	1.00	1.53
Juniper	7	372	254	443	0.7316	0.1089	0.9721	2.35	1.03	9.18
Upper Maybell	6	391	352	429	0.9668	0.8513	0.9999	1.04	1.00	1.17
Sunbeam	1	327	327	327	0.9983	0.9983	0.9983	1.00	1.00	1.00
Lily Park	2	403	329	476	1.0000	0.9999	1.0000	1.00	1.00	1.00

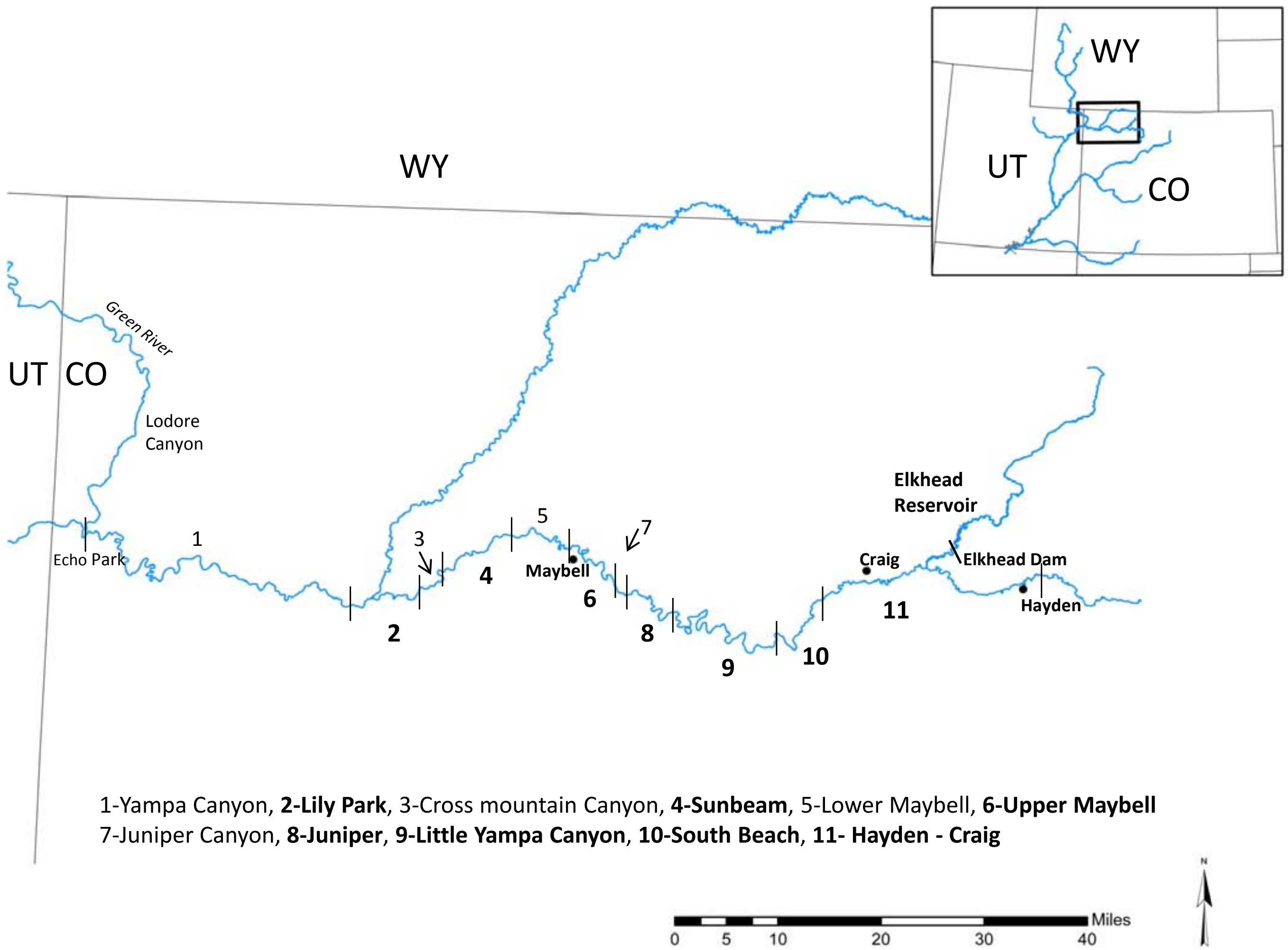

Figure 1. The Yampa River including Elkhead Reservoir and the 11 study reaches where smallmouth bass were collected, 2003–2010. Reaches in bold font were included in the escapement analysis; all others were excluded (see text for more details).

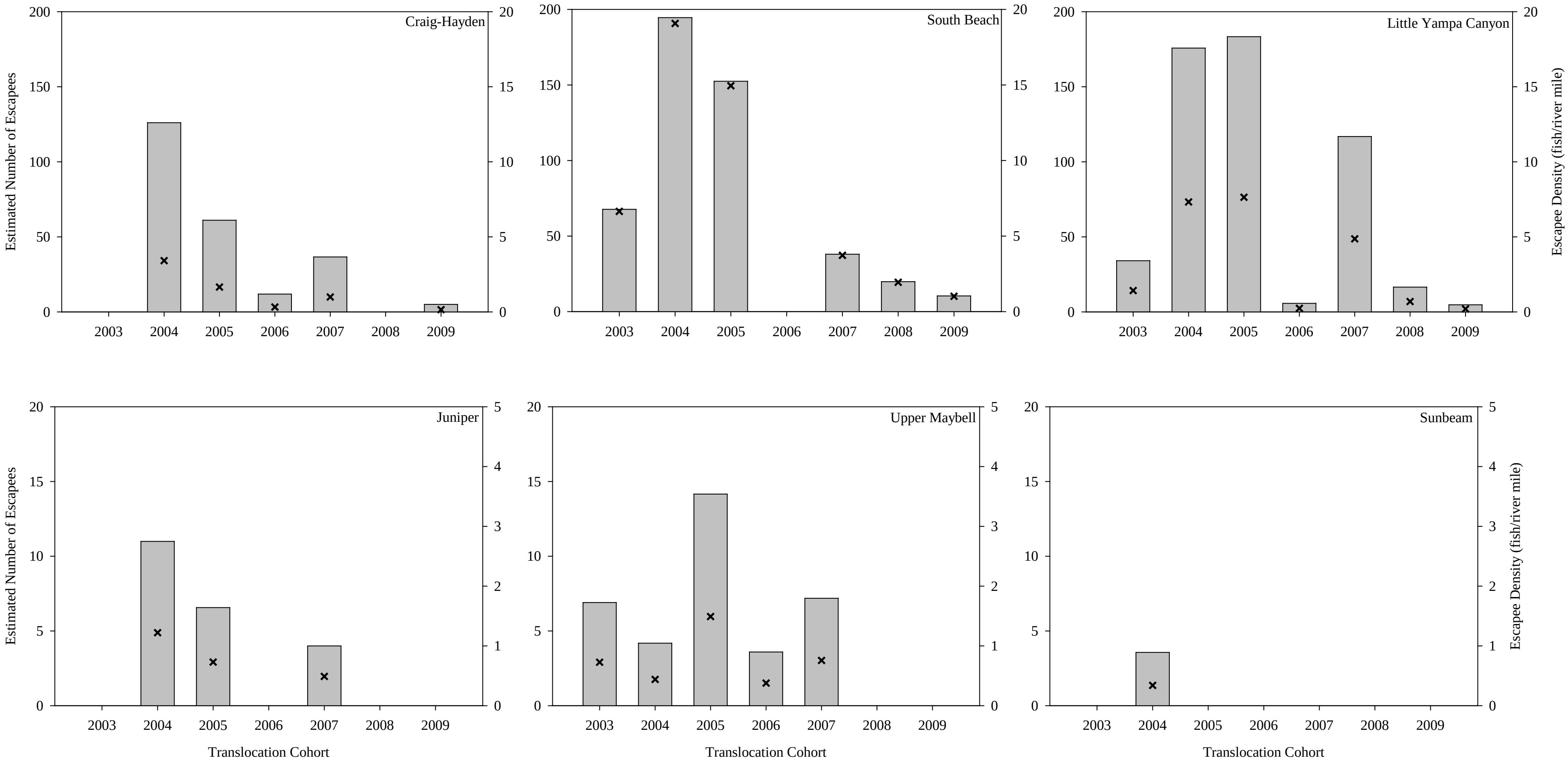

Figure 2. Cohort-specific estimates of the number of smallmouth bass escapees (left y-axis, bars) and number/river mile (right y-axis, **X**) that immigrated to each of the seven reaches included in the analysis of escapement from Elkhead Reservoir. Panels are organized left-to-right upstream to downstream on the Yampa River. Note the left and right y-axis scales are 0–200 escapees and 0–20 escapees/river mile, respectively, for the uppermost reaches closest to the Yampa River-Elkhead Creek confluence (top row). The y-axis scales decrease to 0–20 escapees and 0–5 escapees/river mile for lower reaches downstream of Little Yampa Canyon (bottom row and next page).

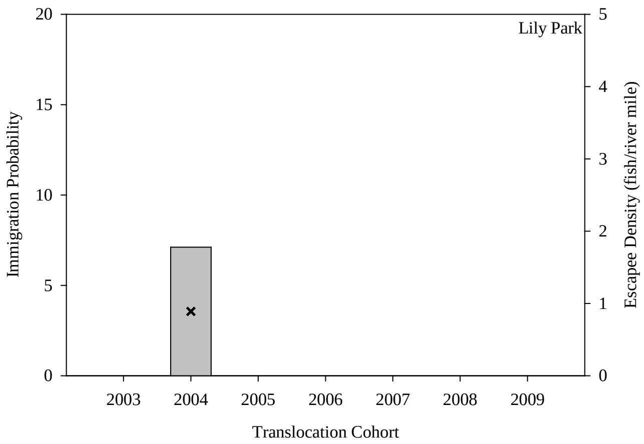

Figure 2. Continued.

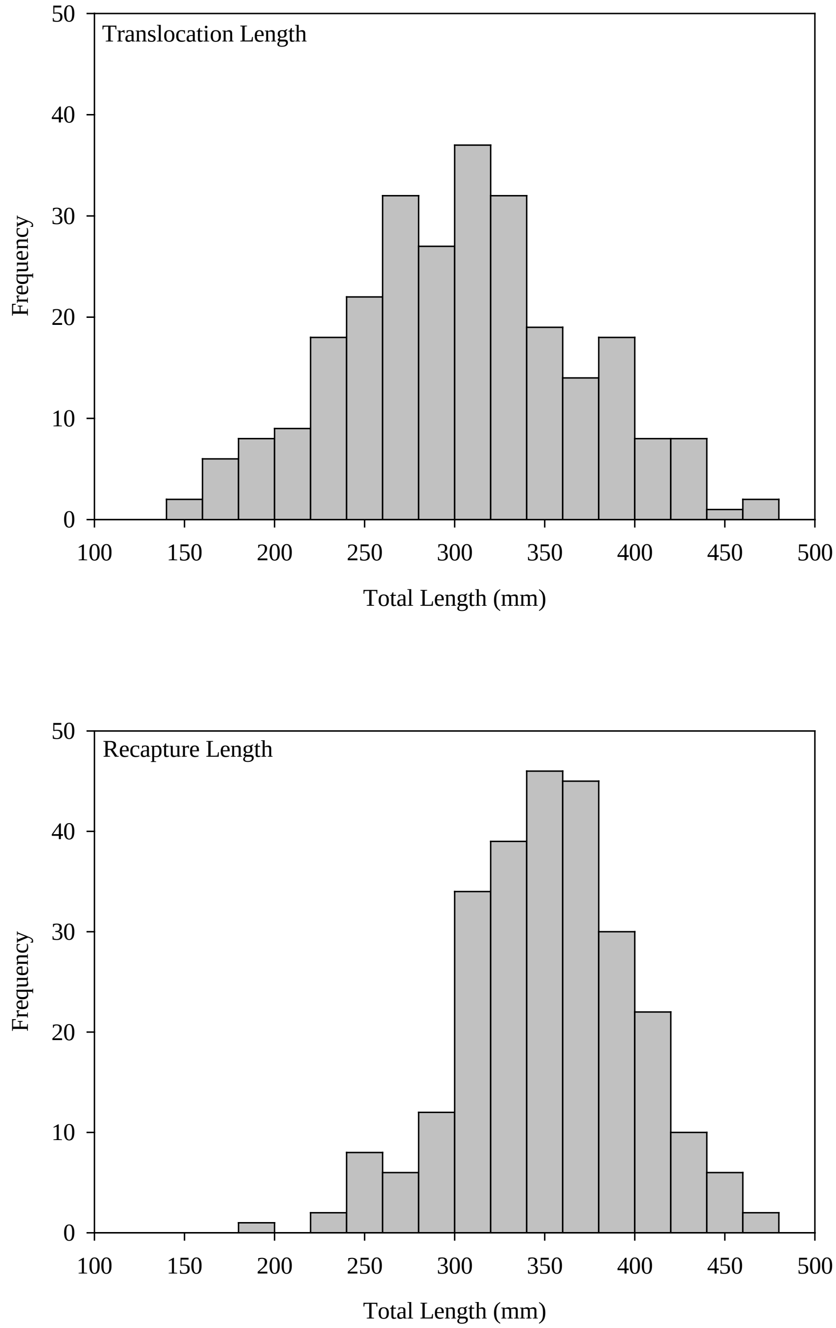

Figure 3. Length-frequency distribution of tagged smallmouth bass (*Micropterus dolomieu*) when translocated to Elkhead Reservoir from the Yampa River (top) and when subsequently recaptured in the Yampa River (bottom), 2003–2010 (n = 261).

Appendix I. Images of the Elkhead Dam spillway taken by the senior author on 6-26-2010. From top-to-bottom, (1) a view looking over the spillway towards Elkhead Reservoir; (2) looking downstream from the spillway towards the spillway pool, associated riprap and Elkhead Creek; and (3–4) a view of the riprap dam between the spillway pool and Elkhead Creek. At normal discharge, water flows through the riprap into Elkhead Creek; at high discharge water flows over the riprap directly into Elkhead Creek.