COLORADO RIVER RECOVERY PROGRAM
FY 2009 ANNUAL PROJECT REPORT

RECOVERY PROGRAM
PROJECT NUMBER: C-18/19

I. Project Title: Chemically Fingerprinting Nonnative Fishes in Reservoirs

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III. Project Summary:

This proposal addresses movement of nonnative fish into river reaches of critical habitat from reservoirs known to support cool- and warmwater species of nonnative fish. These species include northern pike, smallmouth bass, largemouth bass, black crappie, and walleye. These species are believed to pose a significant predatory threat to the young life stages of endangered and other native fishes (Tyus and Saunders 1996; Martinez et al. 2001; Johnson et al. 2005). However, it is uncertain to what extent the presence of nonnative species in critical habitat is the result of escapement or illicit transfers from reservoirs. To date we have found that 87Sr/86Sr appears to be an excellent natural tracer for studying fish origins and movements. This tracer appears to be very consistent among species in a given reservoir, it appears to be temporally stable and all reservoir signatures (i.e., the 87Sr/86Sr signature of fish from a given reservoir) we have examined so far are unique and thus can be used to determine provenance of fish in critical habitat. Continuing work will focused on isotope analysis of otoliths gathered in 2009, with particular emphasis on systems in the vicinity of recent, illegal walleye introductions in some reservoirs on tributaries to the Green River.

IV. Study Schedule: FY06-FY11

V. Relationship to RIPRAP:

General Recovery Program Support Action Plan:
III. Reduce negative impacts of nonnative fishes and sport fish management activities.
III.A.2. Identify and implement viable control measures.

Colorado River Action Plan: Main stem
III. Reduce negative impacts of nonnative fishes and sport fish management activities.
III.A.4.a. Evaluate sources of nonnative fishes and make recommendations.

VI. Accomplishment of FY 2009 Tasks and Deliverables, Discussion of Initial Findings and Shortcomings:

Task 1. Field Collections

Colorado State University coordinated field collections and reservoir and river sampling conducted by state and federal crews through September, 2009. Agencies providing fish to the project included the Colorado Division of Wildlife (CDOW), Utah Division of Wildlife Resources (UDWR), U.S. Fish and Wildlife Service (USFWS), and the Colorado State University Larval Fish Lab (LFL). We requested samples with an emphasis on waters and species where target sample sizes were not achieved in previous years. We added some new water bodies to be sampled when illegally stocked walleye were discovered in Red Fleet Reservoir. We also sought samples of river-resident species that we could be confident had not emigrated from reservoirs to give us a baseline of river signatures with which to compare signatures of reservoir escapees and to examine year to year variation in river signatures.

We completed a thorough inventory of the otoliths that have been extracted from fish samples collected from study waters in 2006-2009. Since 2006 we have gathered at total of 1,809 sets of otoliths from nonnative species (Table 1). Some of the fish samples collected during 2009 are in possession of agencies, pending transfer to CSU and are thus not included in the totals in Table 1. To complete our desired sample size 386 fish are still needed.

Task 2. Microchemical Analysis of Otoliths

The graduate student (Brian Wolff) completed his thesis research proposal and it was approved by his graduate advising committee. We presented our research findings at the 2009 Upper Basin Researchers' meeting in January (Johnson et al. 2009a), the Colorado-Wyoming Chapter of the American Fisheries Society (Wolff et al. 2009a, the CSU Student Chapter of the American Fisheries Society (Wolff et al. 2009b), and at a graduate seminar at CSU (Johnson et al. 2009b).

We continued to refine our otolith sectioning and polishing methods so we can use the same otolith sections for both microchemical analysis as well as age determination. We also perfected image capture and analysis techniques to obtain digital micrographs of otolith sections. Age determination is an important aspect of our microchemical work because we are interested in relating chemical changes in laser ablation spots or transects to when in the fish's life a change occurred. The ability to estimate the age at which a fish's chemical signature changes is important for several reasons. We would like to determine at what life stage river fish that exhibit a shift in chemical signature suggestive of having emigrated from a reservoir occurred. In fish which did not appear to have emigrated from a reservoir, or in fish that are sampled from reservoirs and that have resided in the reservoir for several years, we would like to be able to assess temporal stability of signatures. We are now able to estimate multiple age- and year-specific isotopic signatures from within an otolith which allows us to look at year-to-year variation in the mean chemical signature of fish from a given location.

We completed two trips to the Woods Hole Oceanographic Institute to perform trace element and isotopic analysis of otoliths, in December 2008 and July 2009. In the July trip Brian Wolff was able to meet with Dr. Simon Thorrold, a world's authority on otolith microchemistry. Dr. Thorrold provided much information and advice that we have been using to interpret our data and perfect our methodology for laser ablation inductively coupled mass spectrometry (LA-ICPMS), the laboratory technique that we are using to obtain chemical analysis of the otoliths.

In general, we have found that stable isotope ratios of strontium ($^{87}Sr/^{86}Sr$) are an excellent tracer for fish origins and movements. Here we present our findings relative to three research questions: a) inter-annual variation among water bodies, b) species variation among water bodies, c) movements of river fishes, and d) basin-wide signatures.

Inter-annual variation among water bodies

Using laser ablation paths parallel to annuli bands, instead of transverse transects, we were able to obtain year-specific strontium isotope ratios ($^{87}Sr/^{86}Sr$) for individual fish in all study reservoirs (Figure 1). There were some fluctuations of chemical signatures across years; however, these changes were usually small (within 150 parts per million) suggesting that these signatures were not different (Jurek Blusztajn, Woods Hole Oceanographic Institution, personal communication). In almost every reservoir examined, there were very limited inter-species differences within or among years. One exception is a largemouth bass collected from Rio Blanco Reservoir in 2007, where the signature near the core of the otolith was significantly below the other largemouth bass signatures. This difference could have arisen if that fish recruited from another location and subsequently moved into Rio Blanco Reservoir.

It is not currently understood why reservoir signatures fluctuate over time. Factors such as water residence time, reservoir bedrock types, and dam operations need to be examined further. Smaller, shallower reservoirs will likely have the largest fluctuations in water residence times and have the largest inter-annual variation. Additionally, large reservoirs could have different isotope ratios at different locations, e.g. epilimnion vs. hypolimnion or upstream vs. downstream.

Species variation among water bodies

There was generally little variation among species within the same water body, when averaged across all years (Figure 2). However, there were some cases where differences among species were observed. Differences in Elkhead Reservoir probably arose as an artifact of residual river signatures in smallmouth bass transplanted from the Yampa River. Laser ablation near the edge of the otolith (corresponding to time spent in the reservoir) probably also ablated material deposited while the fish were in the Yampa River, thereby inflating the strontium ratio and leading to higher variability among fish. It is difficult to gather enough data from the last years of growth on an otolith from adult fish because the annuli are very closely spaced.

Variability among species also tended to be greater in some water bodies with black crappie and bluegill (e.g., Elkhead Reservoir and Rifle Gap Reservoir). Bluegill in Rio Blanco Reservoir (not shown) had isotope signatures that were significantly higher than the reservoir signature of black crappie and largemouth bass. The reasons for these species differences are unknown, but could be caused by factors such as movements downstream into a reservoir, movements upstream from a reservoir, inhabiting portions of the reservoir with a different isotope ratio, or physiological effects. Physiological effects seem unlikely because fractionation of strontium isotopes has not been reported and otolith signatures have been highly correlated with ambient water conditions (Gibson-Reinemer et al. 2009; Barnett-Johnson et al. 2008; Ingram and Weber 1999; Kennedy et al. 2000). However, there has been little research on the freshwater species under investigation for this study so it cannot be ruled out with certainty at this point. Behavioral differences which exposed fish to isotopically different water seem more likely, as there were some reservoirs where species differences occurred (e.g. northern pike and walleye in Stagecoach Reservoir), and others where they are not different (e.g. northern pike and walleye from Harvey Gap and Rifle Gap Reservoir).

It is unclear why some reservoirs demonstrate interspecific differences whereas other reservoirs do not. When origins and movements of bluegill or black crappie are of interest then we recommend that reservoir signatures for these species be derived from bluegill and black crappie otoliths. Fortunately, there we have found minimal interspecific differences for the main species of concern in the upper Colorado River basin (northern pike, smallmouth bass, and walleye) suggesting that samples of any of these species will be similar to that of the others and suffice for fingerprinting a reservoir.

Movements of river fishes

Due to low sample sizes and incomplete information on source locations for comparison, we cannot make quantitative estimates of the degree of fish escapement into rivers at this time. However, we were able to detect some patterns of likely source locations in some river systems that may be beneficial to managers.

We found that origins of fishes may be tracked to a likely source location to within a year of movement using laser transects within otolith annuli. This is particularly evident for walleye caught in the Colorado River near Rifle, CO in 2006 and 2007 (Figure 3), which showed a clear shift from a signature consistent with Rifle Gap Reservoir for several years to a river signature between 1996 and 1998.

Smallmouth bass captured in the upper Green River likely originated from Flaming Gorge Reservoir (n=2), entering the river sometime after age 2+ (Figure 4). The walleye captured in the upper Green River originated from another location consistent with Starvation Reservoir. One walleye showed a movement that was indicative with movement from Starvation Reservoir, into the White River ($^{87}Sr:^{86}Sr$ ratio: 0.70878 ± 0.00034) briefly in 2001, and subsequently into the upper Green River where it was captured.

Northern pike captured in the Yampa River showed a wide variety of potential recruitment locations (Figure 5). Three of the five fish exhibited signatures indicative of originating from Lake Catamount (Lake Catamount data are from age-0 northern pike data provided by Dr. Dana Winkelman, Colorado Cooperative Fish and Wildlife Research Unit). However, Catamount and the Yampa River strontium ratios are close enough that we cannot rule out the possibility that these pike originated in the river without more data. Samples from more years from Lake Catamount and the addition of deuterium assays could resolve this question. Two pike had initial isotope ratios well above any reservoir examined (^{87}Sr:^{86}Sr ratio = 0.71936 and 0.71218); thus, we cannot say where they originated from. We will be examining additional water bodies that are potential recruitment sources in the Yampa River for the next trip to Woods Hole Oceanographic Institution in January 2010.

Strontium signatures of smallmouth bass from the Yampa River (Figure 6) were particularly enlightening because some of these fish had periods of life in both the Yampa River and Elkhead Reservoir as a result of transplantation from the River to Elkhead and, in some cases, subsequent escape from Elkhead back into the Yampa River. Transplanted fish that were sampled from Elkhead Reservoir showed the Elkhead Reservoir signature corresponding to years when they resided in the reservoir; earlier in life their otoliths reflected a Yampa River signature. One smallmouth bass (closed circles in Figure 6) was captured from the Yampa River, tagged and released into Elkhead Reservoir in 2007.This fish was then recaptured in the Yampa River in 2009. Its otolith showed no evidence of having spent significant time in Elkhead and therefore this fish must have escaped back into the Yampa River soon after being released in the reservoir.

Movement patterns of fish captured in the Dolores River (Figure 7) were difficult to interpret. This is partially due to the similarity of signatures between the Dolores River and McPhee Reservoir. Many of these samples show a river origin, but some show a movement pattern that looks like they move upstream toward McPhee Reservoir's tailwater. It remains unclear if that scenario actually happened or not given the current data. As with the pike in the Yampa River, assays of deuterium in these otoliths may provide more clues to movement patterns of smallmouth bass in the Dolores-McPhee system.

Basin-wide signatures

Because inter-species and inter-annual variation within reservoirs were low we averaged signatures for all species and years to represent each reservoir's expected signature (Figure 8). Fortunately, many of the reservoirs that share similar signatures are located in different river systems. This implies that fish captured in a river can be traced to the true source by proximity, i.e. if a fish was captured in the Yampa River it would not be likely that it came Kenny Reservoir, even though the two reservoirs share similar strontium isotope signatures.

Reservoirs that do share similar isotope signatures and are within the same river system may need additional chemical assays, e.g. deuterium (2H), to distinguish them from each other, e.g. Elkhead Reservoir and Stagecoach Reservoir in the Yampa River basin.

Fortunately our data shows that this rarely occurs and most reservoirs are indeed isotopically unique.

<u>Task 3. Reservoir Emigration Risk Assessment.</u>
This task is behind schedule because we were unable to recruit a student from the CSU College of Engineering to assist with developing dam operations and hydro-climate scenarios because students there are currently fully funded with their own graduate projects. Instead, we have begun gathering and analyzing dam operations data ourselves. At present we have gathered inflow, outflow and surface elevations from Bottle Hollow, Crawford, Flaming Gorge, McPhee, Paonia, Ridgway, Rifle Gap, and Starvation reservoirs. We also have information about outlet configuration and spillway design for each reservoir, and have compiled flow data for the Colorado (at Cameo), Dolores, Duchesne, Green, North Fork of the Gunnison, Uncompahgre, White and Yampa rivers.

Estimation of escapement risk will be facilitated by knowledge of nonnative fish age and growth but we have not had funds to support the large amount of aging work that is required.

While we believe we can accurately determine the source of nonnative fish, our estimates of escapement of nonnative fish from reservoirs into critical habitat are based on relatively small numbers of otoliths collected during a relatively brief time interval. One way to evaluate emigration risk from reservoirs would be to quantify the proportion of nonnative fish in rivers below reservoirs that have otolith strontium ratios indicative of a reservoir origin. However, much larger sample sizes would likely be required to conduct that assessment and this would be well beyond the scope and budget of the present study.

VII. Recommendations: Continue the project as outlined in the Scope of Work.

<u>Task 1. Field Collections</u>

• We would like to get 100 more walleye samples from the Duchesne and Green River systems (the rivers plus Midview and Redfleet reservoirs; collections at Starvation are complete). These samples will allow us to determine which reservoir walleyes in these rivers may have originated from, with particular reference to Redfleet Reservoir where illegally introduced walleye have recently been discovered.

• In order to achieve desired sample sizes from all reservoirs and rivers in the present study, a total of 386 additional fish samples are required.

• Because the number of nonnative fish escaping from reservoirs likely varies from year to year, and our samples were collected over a short time period, estimates of escapement from our study probably do not represent the overall expected escapement rate.

• The Recovery Program should consider funding a new study to address the most cost-effective and statistically powerful sampling design to address this key management question.

<u>Task 2. Microchemical Analysis of Otoliths</u>.

• Continue LA-ICPMS analyses of otoliths at Woods Hole Oceanographic Institution, focusing on "spot" or within-annulus ablation.

• Investigate walleye origins and movements in the Upper Green River basin (including Starvation, Midview, and Redfleet reservoirs).

• Continue aging otoliths to facilitate assignment of year-specific signatures

• Quantify and investigate potential factors leading to fluctuation in reservoir signatures.

• Analyze otoliths from additional water bodies that are potential recruitment sources of northern pike in the Yampa River during the next trip to Woods Hole Oceanographic Institution in January 2010

• Determine locations where assays for deuterium ($^{2}H/^{1}H$) would enhance ability to identify reservoir emigrants (e.g., in the Dolores River/McPhee Reservoir system).

Task 3. Reservoir Emigration Risk Assessment.

• Continue accumulating historic reservoir operations and stream flow data. We should also seek information on limnological conditions (particularly dissolved oxygen and temperature profiles) in study reservoirs.

• Obtain information on first year growth of nonnative fish in study reservoirs; this information may be estimated from ageing structures (including otoliths) removed from fish collected for microchemical analysis.

• Seek additional funds to support the age-growth work which was not originally anticipated but now appears to be important to accomplishing this task and Task 2.

• All of these efforts should be completed before the final stage of this task, the emigration risk analysis, can be accomplished.

VIII. Project Status:

This project will continue through FY 2011 and it should be considered on track and ongoing. Despite delays, there have been no significant changes in project direction, probability of success, or alignment with RIPRAP objectives and deadlines.

IX. FY 2009 Budget Status

A. Funds Provided: $66,184

B. Funds Expended: $43,222

C. Difference: $22,962

We continue to have some unspent funds because we are being careful to expend funds on laboratory analyses in an incremental fashion (laboratory analytical costs = $10K per trip). As we learn more about procedures and limitations of the approach we are adapting our methods and analytical settings to maximize the information we can gain from microchemical analysis of the otoliths. We also had a difficult time getting access to the laboratory at Woods Hole; thus, we did not spend funds on analytical work at the desired time.

We need these FY09 funds plus the FY10 budgeted funds in order to complete all the required lab work. We will also require the remaining funds to support continued work on Task 3, Reservoir Emigration Risk Assessment.

D. Percent of the FY 2009 work completed, and projected costs to complete: Task 2-lab work (LA-ICPMS): 70% complete. We expect to complete all this lab work on 2006-2009 samples with the leftover funds shown above, during FY10. Task 3: 30% complete. Remaining funds will be expended in FY10.

E. Recovery Program funds spent for publication charges: $0

X. Status of Data Submission (Where applicable): N/A

XI. Signed: Brett M. Johnson 11/13/09
Principal Investigator Date

Patrick J. Martinez 11/13/09
Principal Investigator Date

XII. References:

Barnett-Johnson, R., T. E. Pearson, F. C. Ramos, C. B. Grimes, and R. B. MacFarlane. 2008. Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. Limnology and Oceanography 53(4):1633-1642.

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Wolff, B., B.M. Johnson, and D. Winkelman. 2009a. Strontium isotopes can trace origins and movements of nonnative piscivores in the Yampa River basin. Colorado-Wyoming Chapter of the American Fisheries Society, Loveland, CO.

Wolff, B., B.M. Johnson, and D. Winkelman. 2009b. Strontium isotopes can trace origins and movements of nonnative piscivores in the Yampa River basin. CSU Student Chapter of the American Fisheries Society, Colorado State University, Fort Collins, CO.

Table 1. Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2009. N/A indicates that that species is not known to occur in that water body, or it is not targeted for sampling at that location. Species codes are: BCR = black crappie, LMB = largemouth bass, NPK = northern pike, SMB = smallmouth bass, WAL = walleye, BGL = bluegill, BUR = burbot, YPE = yellow perch, WHS = white sucker.

Water Body	**BCR**	**LMB**	**NPK**	**SMB**	**WAL**	**BGL**	**BUR**	**YPE**	**WHS**	**Grand Total**	**COMMENTS**
Colorado River	**4**	**99**	**0**	**113**	**8**	**23**	N/A	N/A	30	**277**	Field Collections Complete
Rifle Gap Reservoir	**45**	**0**	**135**	**49**	**14**	N/A	N/A	**157**	0	**400**	Field Collections Complete
Harvey Gap Reservoir	**10**	**12**	**7**	**9**	**N/A**	**3**	N/A	**16**	0	**57**	Need: 11 SMB, 13 NPK
Dolores River	**0**	**0**	**0**	**15**	**0**	**0**	N/A	N/A	0	**15**	Need: 5 SMB
McPhee Reservoir	N/A	**0**	N/A	**29**	**13**	**0**	N/A	**0**	0	**42**	Need: 7 WAL
Duchesne River	**3**	**1**	**11**	**45**	**0**	**0**	N/A	N/A	0	**60**	Need: 20 WAL
Starvation Reservoir	N/A	N/A	**9**	**22**	**40**	N/A	N/A	N/A	0	**71**	Field Collections Complete
Midview Reservoir	**0**	**0**	**0**	**0**	**0**	**0**	N/A	**0**	0	**0**	Need: 20 SMB, 20 WAL

Table 1 (continued). Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2009. N/A indicates that that species is not known to occur in that water body, or it is not targeted for sampling at that location. Species codes are: BCR = black crappie, LMB = largemouth bass, NPK = northern pike, SMB = smallmouth bass, WAL = walleye, BGL = bluegill, BUR = burbot, YPE = yellow perch, WHS = white sucker.

Water Body	**BCR**	**LMB**	**NPK**	**SMB**	**WAL**	**BGL**	**BUR**	**YPE**	**WHS**	**Grand Total**	**COMMENTS**
Green River-Lower	**0**	N/A	**0**	**19**	**12**	**0**	N/A	**N/A**	0	**31**	need: 20 river residents; 8 WAL
Green River-Upper	**13**	**N/A**	**40**	**45**	**36**	**0**	N/A	**N/A**	16	**150**	need:20 river resident fish; 20 smaller WAL (to get possible Red Fleet fish)
Red Fleet Reservoir	**0**	**0**	**0**	**0**	**8**	**0**	N/A	**N/A**	0	**8**	Need: 20 WAL
Flaming Gorge Reservoir	N/A	N/A	**0**	**20**	**0**	N/A	10	N/A	0	**30**	Field Collections Complete
Gunnison River	**1**	**0**	**0**	**0**	**0**	**1**	N/A	**0**	0	**2**	Need: 20 each species available
Juniata Reservoir	**0**	**0**	**0**	**16**	**10**	**0**	N/A	**0**	0	**26**	Field Collections Complete
Paonia Reservoir	N/A	N/A	**6**	N/A	N/A	N/A	N/A	N/A	0	**6**	Need: 14 NPK
Crawford Reservoir	**0**	**1**	**35**	**0**	N/A	**0**	N/A	**23**	0	**59**	Field Collections Complete

Table 1 (continued). Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2009. N/A indicates that that species is not known to occur in that water body, or it is not targeted for sampling at that location. Species codes are: BCR = black crappie, LMB = largemouth bass, NPK = northern pike, SMB = smallmouth bass, WAL = walleye, BGL = bluegill, BUR = burbot, YPE = yellow perch, WHS = white sucker.

Water Body	BCR	LMB	NPK	SMB	WAL	BGL	BUR	YPE	WHS	Grand Total	COMMENTS
White River	**0**	**0**	**0**	**5**	**0**	**0**	N/A	N/A	0	**5**	Need 16 SMB, 20 NPK, 20 LMB, 20 WHS
Kenney Reservoir	**20**	N/A	N/A	N/A	N/A	**0**	N/A	**0**	0	**20**	Field Collections Complete
Rio Blanco Reservoir	**13**	**20**	**1**	**0**	N/A	**0**	N/A	N/A	0	**34**	Need: 7 BCR, 19 NPK, 20 SMB
Yampa River	**111**	**1**	**66**	**234**	**0**	**57**	N/A	N/A	21	**490**	Field Collections Complete; only tagged fish if desired
Stagecoach Reservoir	**0**	**0**	**4**	**0**	**11**	N/A	N/A	N/A	0	**15**	Need: 16 NPK, 9 WAL
Lake Catamount	N/A	N/A	**0**	N/A	**0**	N/A	N/A	N/A	0	**0**	Need Dana Winkelman's samples
Elkhead Reservoir	**8**	**0**	**38**	**22**	N/A	N/A	N/A	N/A	0	**68**	Field Collections Complete; only tagged fish if desired
Loudy Simpson Pond	N/A	N/A	**12**	N/A	N/A	N/A	N/A	N/A	N/A	**12**	Need: 9 NPK
All waters	**228**	**134**	**364**	**643**	**152**	**84**	**10**	**196**	**67**	**1878**	

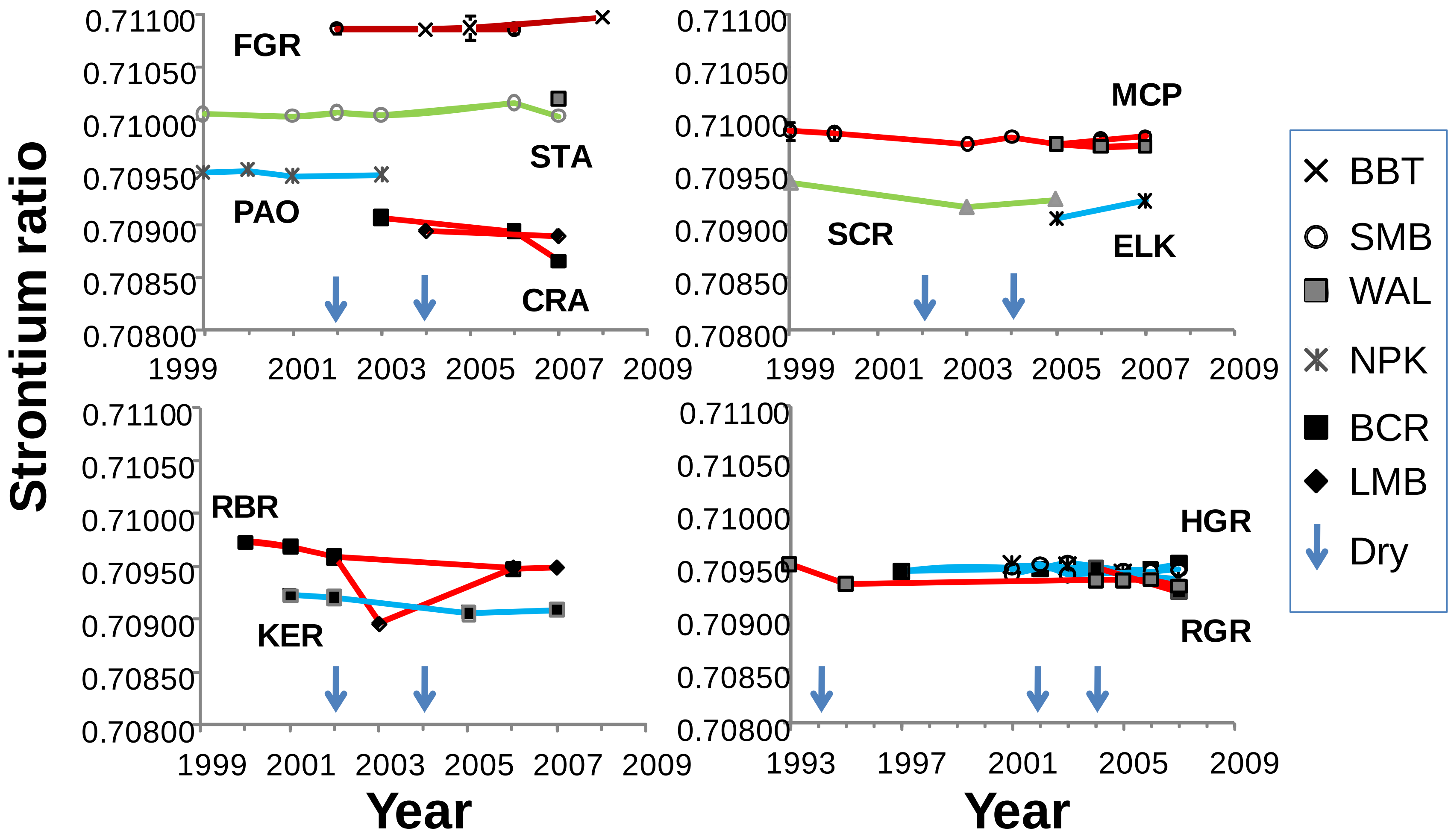

Figure 1. Interannual variation of strontium isotope ratio (± 2*standard error) in six species and 11 reservoirs. Signatures with multiple fish comparisons in each year were averaged. Some error bars are too small to see on this plot and others are missing (when sample size = 1). Particularly dry years are indicated with a downward arrow.

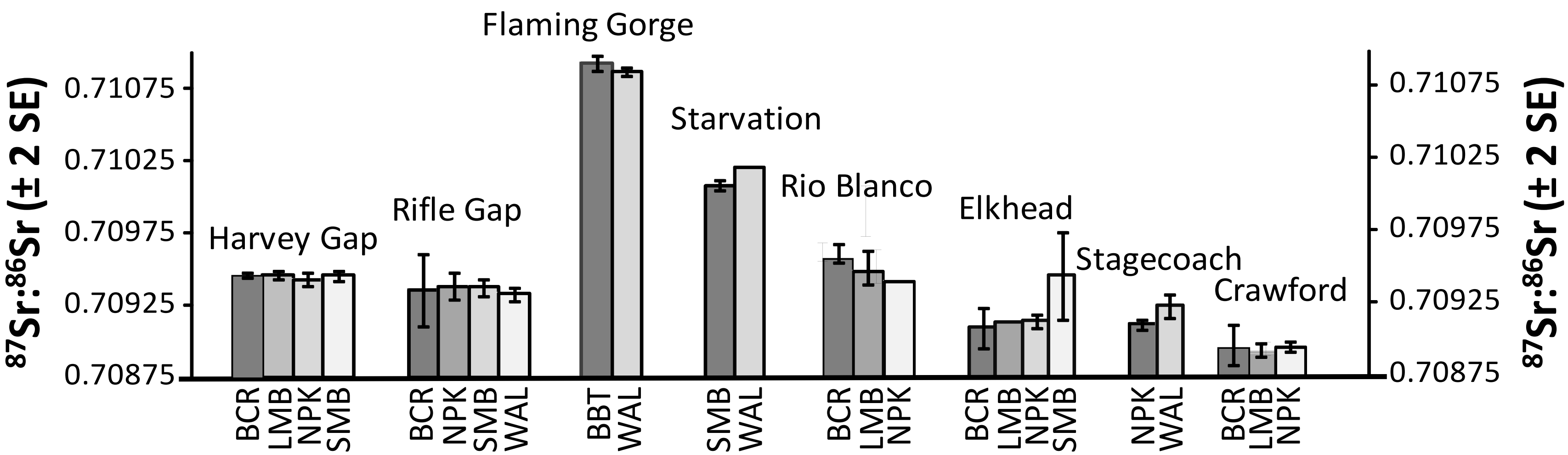

Figure 2. Interspecific variation of strontium isotope ratio (± 2*standard error) among black crappie (BCR), largemouth bass (LMB), northern pike (NPK), smallmouth bass (SMB), walleye (WAL), and burbot (BBT) in eight reservoirs.

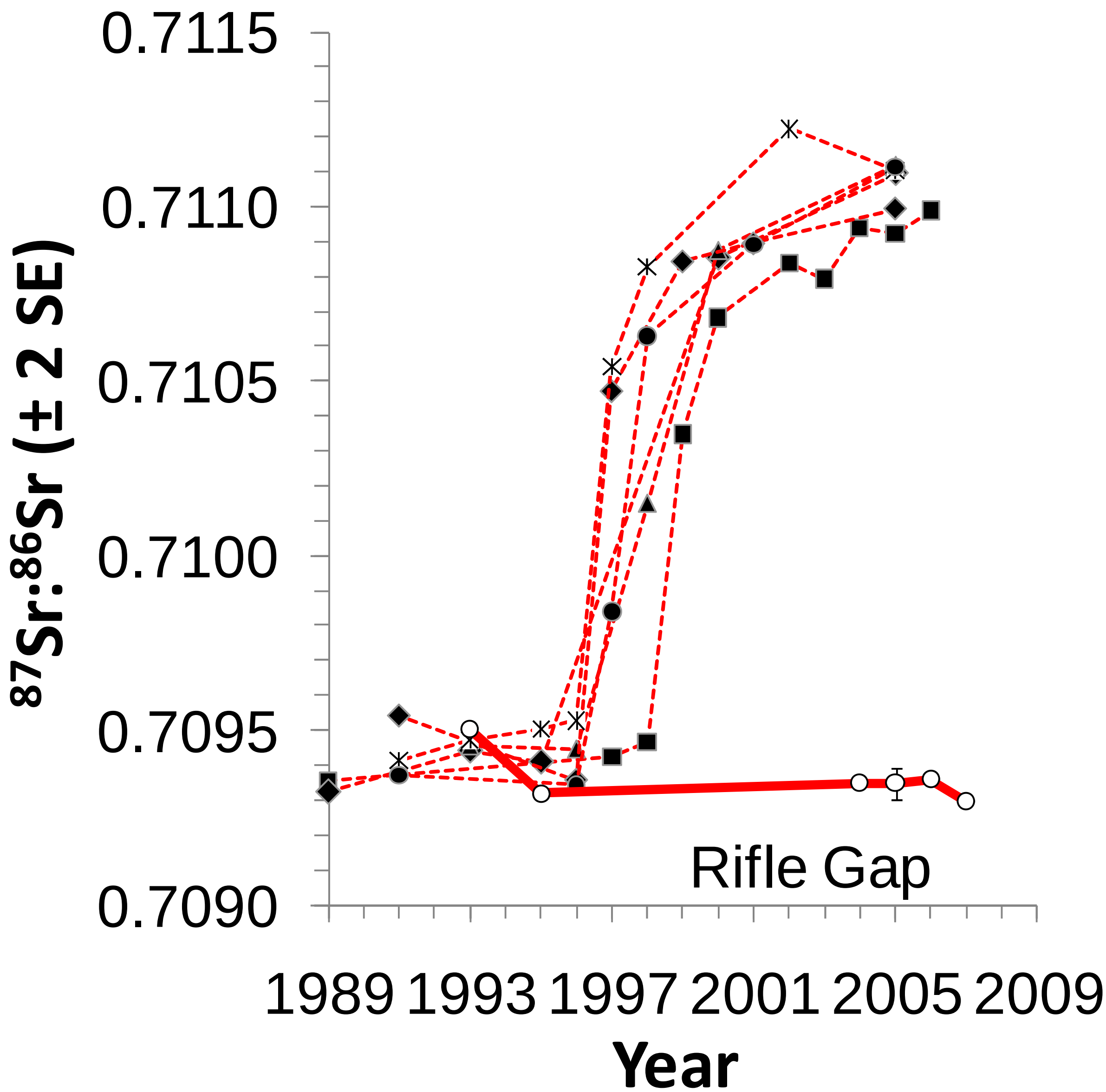

Figure 3. Average interannual variation in strontium ratio of walleyes sampled from Rifle Gap Reservoir (solid line), and five walleyes captured in the Colorado River near Rifle, Colorado (dashed lines).

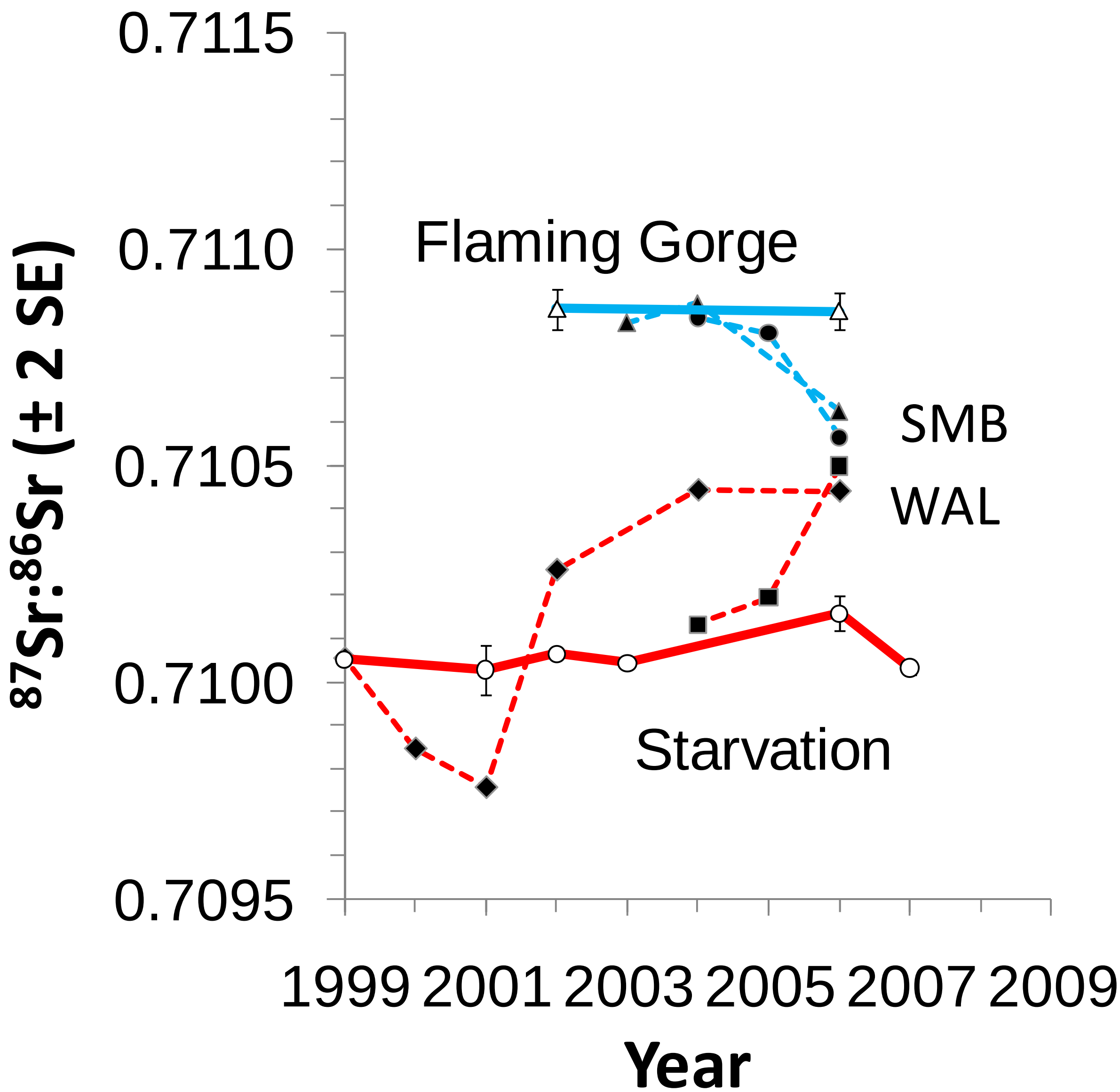

Figure 4. Average interannual variation in strontium ratio of walleyes and smallmouth bass sampled from Flaming Gorge and Starvation reservoirs (solid lines), and of two walleyes and two smallmouth bass captured in the Green River (dashed lines).

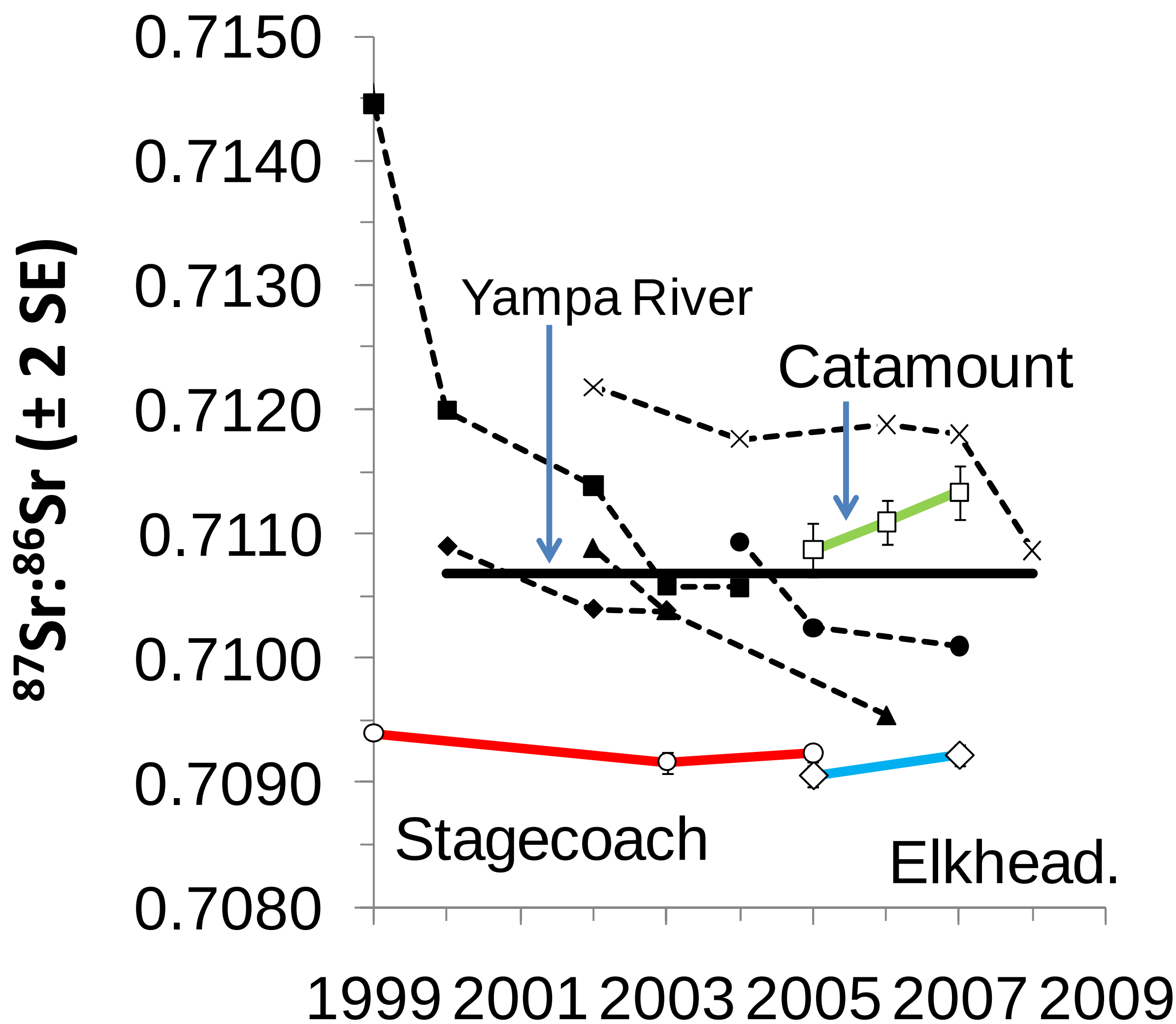

Figure 5. Average interannual variation in strontium ratio of four northern pike captured in the Yampa River (dashed lines), and strontium signatures of Lake Catamount (based on age-0 pike), Elkhead Reservoir (based on pike), and Stagecoach Reservoir (from walleye); the typical signature of the Yampa River is shown as a solid horizontal line (average of tagged SMB).

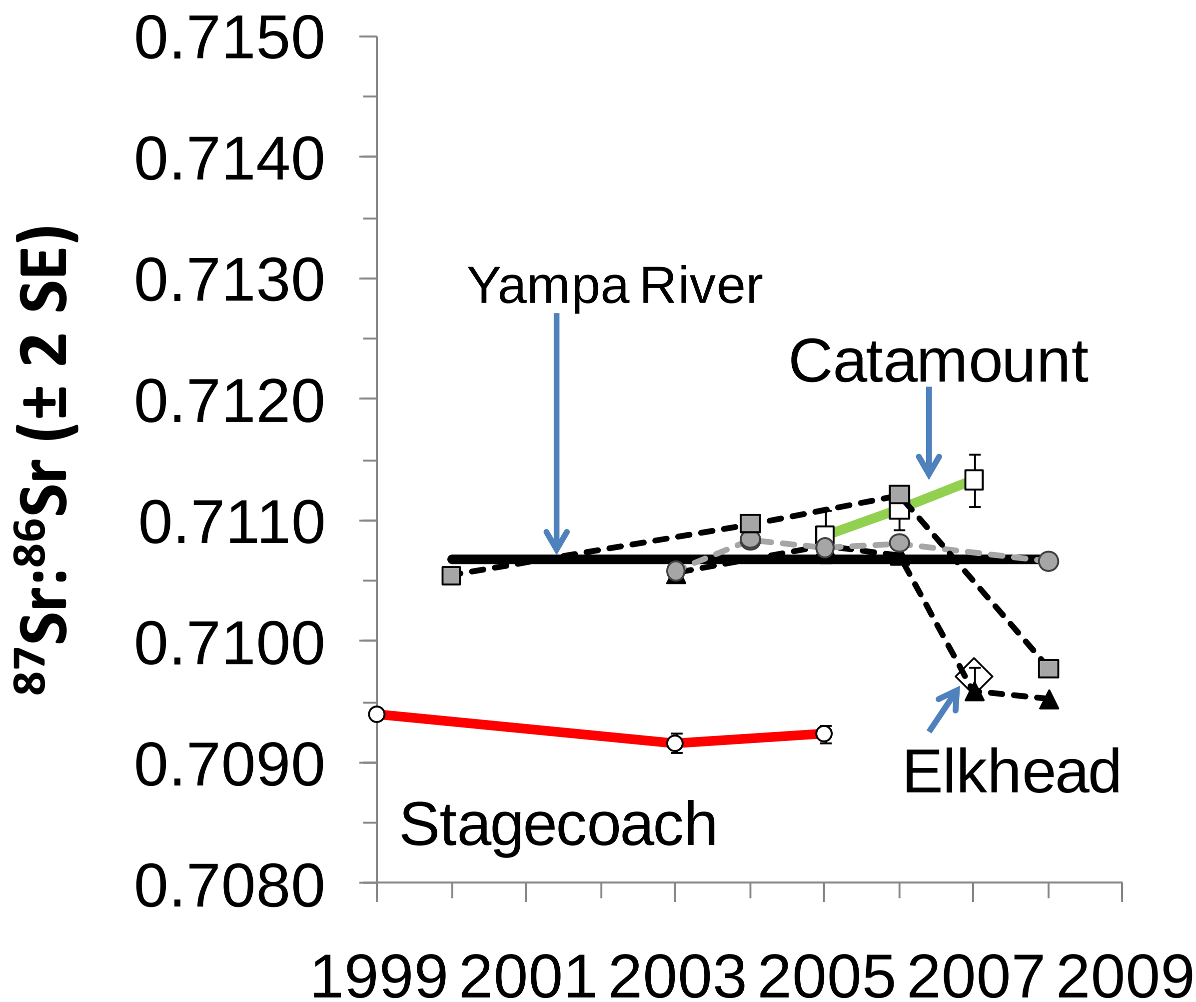

Figure 6. Average interannual variation in strontium ratio of smallmouth bass sampled from the Yampa River and Elkhead Reservoir (dashed lines) and strontium signature of Lake Catamount (based on age-0 northern pike), Elkhead Reservoir (open diamond, based on 1 SMB), and Stagecoach Reservoir (from walleye); the typical signature of the Yampa River is shown as a solid horizontal line (average of tagged SMB).

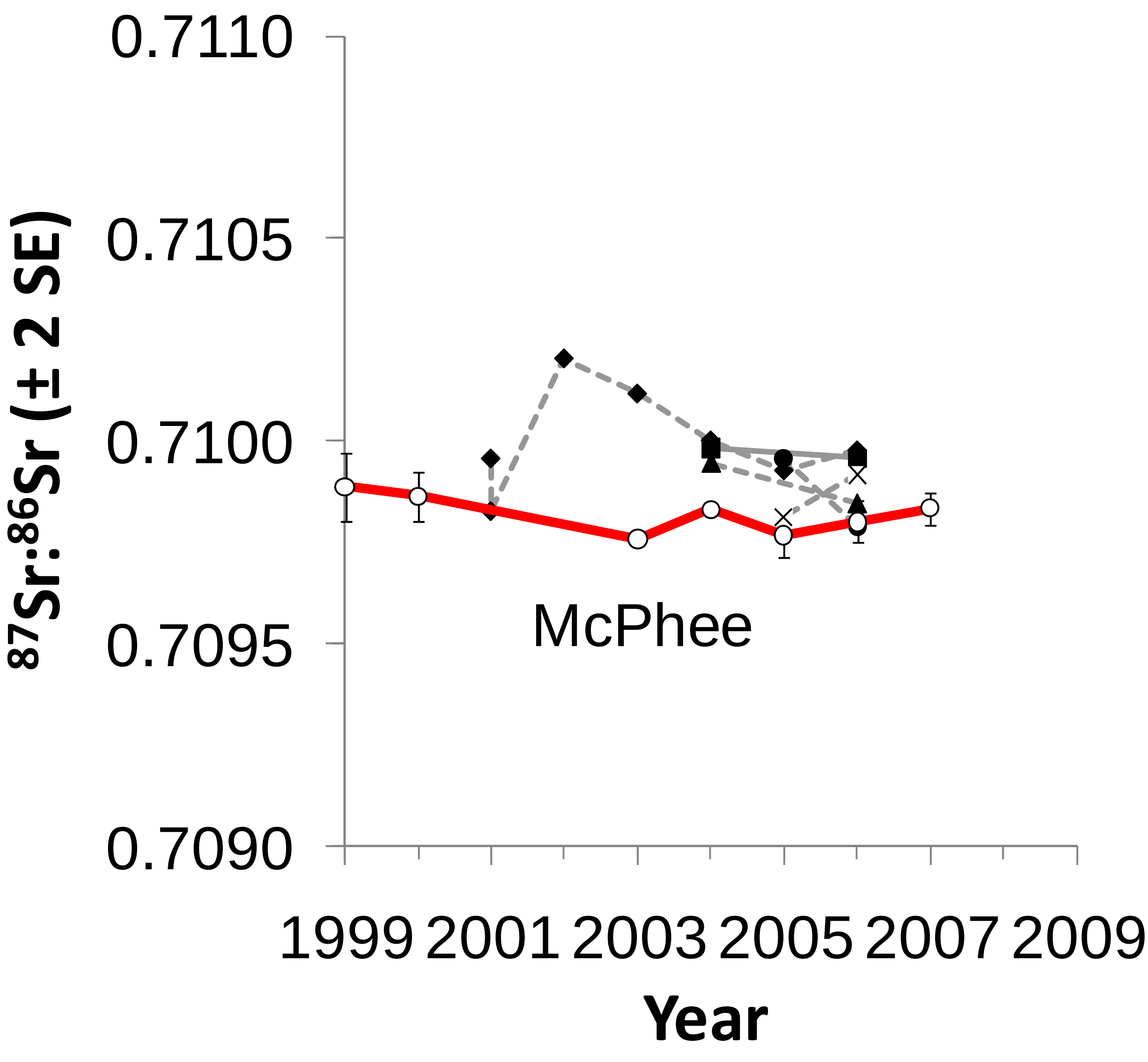

Figure 7. Average interannual variation in strontium ratio of smallmouth bass sampled from Mc Phee Reservoir (solid line) and of four smallmouth bass captured in the Dolores River (dashed lines). Note that the y-axis range is much lower than in Figures 3-5.

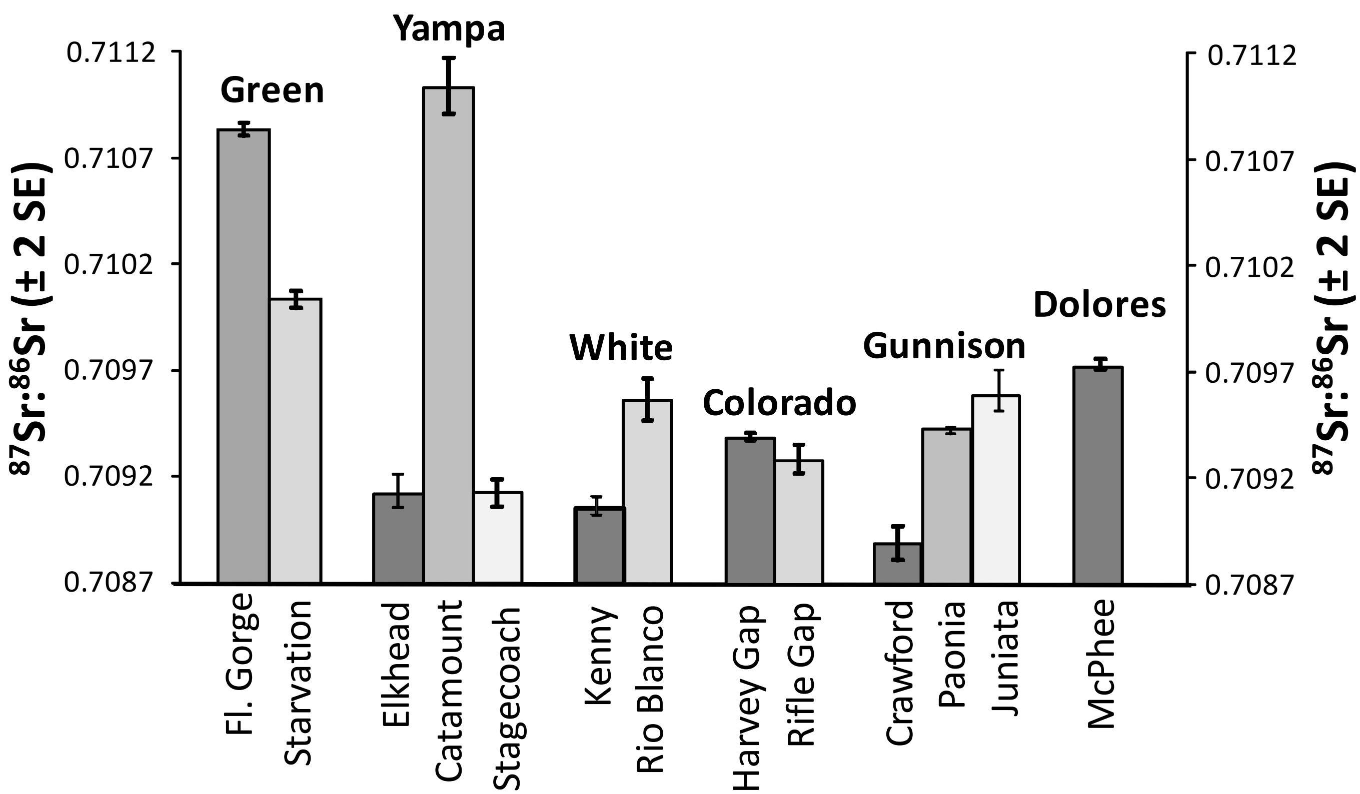

Figure 8. Average strontium isotope signatures (±2SE) of all fish sampled from 13 reservoirs grouped by river system.