I. Project Title: Chemically Fingerprinting Nonnative Fishes in Reservoirs

II. Principal Investigator(s):

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III. Project Summary:

This project 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. We have found that strontium isotope ratio ($^{87}Sr/^{86}Sr$, "Sr ratio") is an excellent natural tracer for studying fish origins and movements. This tracer is very consistent among species in a given reservoir, is temporally stable and all reservoir signatures (i.e., the Sr ratio of fish from a given reservoir) we have examined are unique and thus can be used to determine provenance of fish in critical habitat.

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 2010 Tasks and Deliverables, Discussion of Initial Findings and Shortcomings:

Task 1. Field Collections

We completed field collections for the project with the addition of more samples of walleye from Red Fleet Reservoir and the Green River. Agencies providing fish to the project have 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 received only a single fish from Midview Reservoir, thus further evaluation of nonnative fish emigration from this system into critical habitat was not feasible and this reservoir was dropped from the study.

Since 2006 we have gathered and processed at total of 1851 sets of otoliths from nonnative species collected from 15 reservoirs and 7 rivers (Table 1). Otoliths that were not used for chemical analysis are being archived in air-tight microcentrifuge tubes for possible future work.

Task 2. Microchemical Analysis of Otoliths

Microchemical analysis of otoliths is complete. Overall, Sr ratio was an excellent natural marker for fish origins and movements. We found that Sr ratio in otoliths differed greatly among reservoirs (Figure 1) and were temporally stable (Figure 2), did not differ across the 8/9 species examined (Figure 3), and was distinct from Sr ratio measured in fish from rivers downstream of reservoirs.

In addition to completing $^{87}Sr/^{86}Sr$ analyses, we gathered data on carbon, hydrogen, and oxygen isotopes ($\delta^{13}C$, $\delta^{2}H$, and $\delta^{18}O$) in otoliths to investigate how the additional information would affect our ability to trace origins of nonnative fish. Otoliths from the Colorado River, Rifle Gap Reservoir, Flaming Gorge Reservoir, Red Fleet Reservoir, Starvation Reservoir, Elkhead Reservoir, Loudy Simpson Ponds, Stagecoach Reservoir and the Yampa River were processed for $\delta^{13}C$, $\delta^{2}H$, and $\delta^{18}O$ at the University of Alaska-Fairbanks. In nearly all cases the sources were clearly discriminated (Figure 4) by canonical discriminant function analysis (CDFA) using the supplementary isotopes.

A considerable amount of our work in FY10 was directed at determining appropriate statistical procedures for handling this project's complex and unbalanced dataset. Numerous and fruitful meetings with CSU statistical consultants and Postdoc Andre' Breton resulted in what we believe are appropriate, powerful and cutting edge analytical approaches, as well as very clean and clear findings. Complete presentation and interpretation of our otolith microchemistry findings will be presented in the Final Report.

We presented our research findings at the 2010 Upper Basin Researchers' meeting in January (Wolff et al. 2010), and at a meeting of the Rocky Mountain Flycasters in October (Wolff and Johnson 2010).

M.S. student Brian Wolff has completed coursework for the degree and is preparing a draft of his thesis, which we hope to submit to a peer-reviewed journal soon. Brian's thesis/manuscript will become a major portion of our final report, due in September,

2011.

A persistent question during our study has been how to determine expected Sr signatures of river-resident fish. Because untagged fish captured in rivers have spent an unknown amount of time in the capture location and could have emigrated from a reservoir or connecting river system we cannot know if the Sr signature they exhibit reflects that of the capture location. Testing the Sr signature of river water is not a practical solution to this problem because river signatures fluctuate seasonally with unknown correlation to fish otolith signatures. What is needed is a sessile river organism that can be used to infer Sr signatures of fish residing in that vicinity. Based on preliminary work in our lab, we believe that crayfish could provide this "sentinel" function, displaying the seasonally-integrated environmental signature of the capture location. Further research to evaluate utility of crayfish as Sr ratio sentinels is needed.

Task 3. Reservoir Emigration Risk Assessment.

We have nearly completed data acquisition of reservoir hydrology, water operations and nonnative fish present for Catamount, Crawford, Elkhead, Flaming Gorge, Harvey Gap, Kenney, McPhee, Paonia, Red Fleet, Ridgway, Rifle Gap, Rio Blanco, Stagecoach, 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.

Presently we are computing water residence time (WRT = capacity/outflow) for each reservoir during 1990-2009. Monthly mean WRT (Figure 5) is being used as one indicator of fish emigration risk, since the likelihood of fish being entrained in reservoir outflows should be proportional to the proportion of the reservoir that is released per unit time. We are also computing vertical distance from the reservoir's surface to the spillway as another indicator of emigration risk (Figure 6). When distance to spillway is 0 it is assumed that the reservoir spilled, and for those reservoirs with unscreened spillways these conditions represent high emigration risk. Life history and ontogeny of problematic nonnative fish found in each reservoir will be compared to periods of high emigration risk to determine what species/life-stages should be expected to have the greatest potential to leave the reservoir.

The monthly mean WRT and distance to spillway are also being compared to basin hydrologic conditions (e.g., very wet, wet, normal, dry, very dry) to seek generalizations about how climate/hydrology affect species-specific emigration risks.

VII. Recommendations:

Complete the project as outlined in the Scope of Work.
Prepare manuscript from Brian Wolff's M.S. for submission to peer-reviewed journal.
Complete acquisition of historic reservoir operations and stream flow data.
Complete computation of WRT and correlation with hydrological conditions.
Complete emigration risk analysis.
Seek funding to test the utility of crayfish as Sr isotope sentinels.

VIII. Project Status:

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

IX. FY 2010 Budget Status

A. Funds Provided: $46,597

B. Funds Expended: $45,255

C. Difference: $ 1,342, difficulty recruiting undergraduate help for laboratory assistance set us behind a bit. We will expend leftover funds in spring semester when our lab team is complete.

D. Percent of the FY 2010 work completed, and projected costs to complete: Task 1: 100%; Task 2: ICPMS work 100% complete, FY11 funds to support personnel for data analysis and reports; Task 3: 75%- we are catching up and will complete the task in FY11 despite exhausted funding.

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

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

XI. Signed:

Brett M. Johnson — 12/03/10
Principal Investigator — Date

Patrick J. Martinez — 12/03/10
Principal Investigator — Date

XII. References:

Johnson, B. M., G. Whitledge, M. Sullivan, and D. Gibson-Reinemer. 2005. Stable isotopes and statistics. Progress report, Colorado Division of Wildlife, Grand Junction, Colorado, 22 pages.

Martinez, P. J., B. M. Johnson, and J. D. Hobgood. 2001. Stable isotope signatures of native and nonnative fishes in Upper Colorado River backwaters and ponds. The Southwestern Naturalist 46: 311-322.

Tyus, H. M., and J. F. Saunders, III. 1996. Nonnative fishes in natural ecosystems and a strategic plan for control of nonnatives in the Upper Colorado River basin. Recovery Implementation Program DRAFT REPORT. Cooperative Agreement No. 14-48-006-95-923. U.S. Fish and Wildlife Service, Denver, Colorado.

Wolff, B.A., B.M. Johnson, P.J. Martinez, and D.L. Winkelman. 2010. Strontium isotope ratios (^{87}Sr:^{86}Sr) as tracers of origins and movements of nonnative piscivores in the Upper Colorado River Basin. Annual Upper Colorado River Basin Endangered Fish Recovery Program Researcher's Meeting, Grand Junction, CO.

Wolff, B. and B.M. Johnson. 2010. Tracing the origins and movements of invasive fishes in the Upper Colorado River Basin. Rocky Mountain Flycasters, Oct 16th 2010, Fort Collins, CO.

Table 1. Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2010. 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
Colorado River (COR)	4	99	0	113	8	23	N/A	N/A	20	267
Rifle Gap Reservoir (RGR)	45	0	135	49	14	N/A	N/A	157	0	400
Harvey Gap Reservoir (HGR)	10	12	7	9	N/A	3	N/A	16	0	57
Dolores River (DOR)	0	0	0	15	0	0	N/A	N/A	0	15
McPhee Reservoir (MCP)	N/A	0	N/A	29	13	0	N/A	0	0	42
Duchesne River (DUR)	0	0	0	17	0	0	N/A	N/A	0	17
Starvation Reservoir	N/A	N/A	9	22	35	N/A	N/A	N/A	0	66
Midview Reservoir (MID)	0	0	0	0	1	0	N/A	0	0	1

Table 1 (continued). Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2010. 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
Green River-Lower	0	N/A	0	23	11	0	N/A	N/A	0	34
Green River-Upper	33	N/A	40	57	55	1	N/A	N/A	49	235
Red Fleet Reservoir (RFR)	0	0	0	0	18	0	N/A	N/A	0	18
Flaming Gorge Reservoir (FGR)	N/A	N/A	0	20	0	N/A	23	N/A	0	43
Gunnison River	1	0	0	0	0	1	N/A	0	0	2
Juniata Reservoir (JUR)	0	0	0	16	10	0	N/A	0	0	26
Paonia Reservoir (PAO)	N/A	N/A	6	N/A	N/A	N/A	N/A	N/A	0	6
Crawford Reservoir (CRA)	0	1	35	0	N/A	0	N/A	23	0	59

Table 1 (continued). Number of nonnative fish collected for microchemical analysis of otoliths during 2006-2010. 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
White River	0	0	0	5	0	0	N/A	N/A	0	5
Kenney Reservoir (KER)	20	N/A	N/A	N/A	N/A	0	N/A	0	0	20
Rio Blanco Reservoir (RBR)	13	20	1	0	N/A	0	N/A	N/A	0	34
Yampa River	39	0	56	181	1	57	N/A	N/A	21	355
Stagecoach Reservoir (SCR)	0	0	4	0	11	N/A	N/A	N/A	0	15
Lake Catamount (CAT)	N/A	N/A	0	N/A	0	N/A	N/A	N/A	0	0
Elkhead Reservoir (ELK)	23	0	38	44	N/A	5	N/A	N/A	0	110
Loudy Simpson Pond (LSP)	N/A	N/A	24	N/A	N/A	N/A	N/A	N/A	N/A	24
All waters	188	132	355	600	177	90	23	196	90	1851

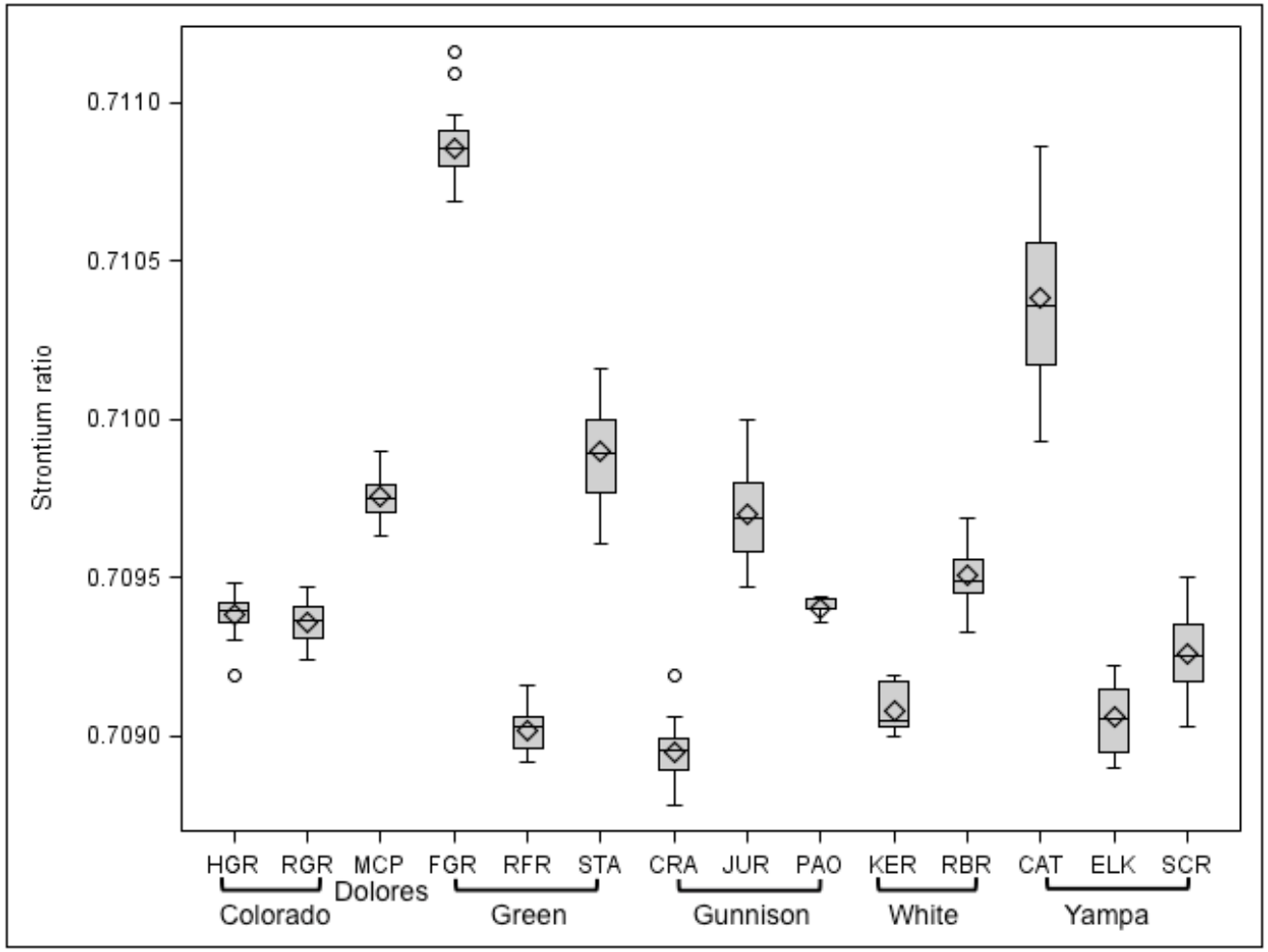

Figure 1. Box-and-whisker plots (mean, median, 25th-75th quartile range and 1.5*interquartile range) of strontium isotope ratios ($^{87}Sr/^{86}Sr$) among reservoirs of the Upper Colorado River Basin, pooled across species and years. Values outside the whiskers are considered mild outliers but were retained in all analysis. Refer to Table 1 for reservoir codes.

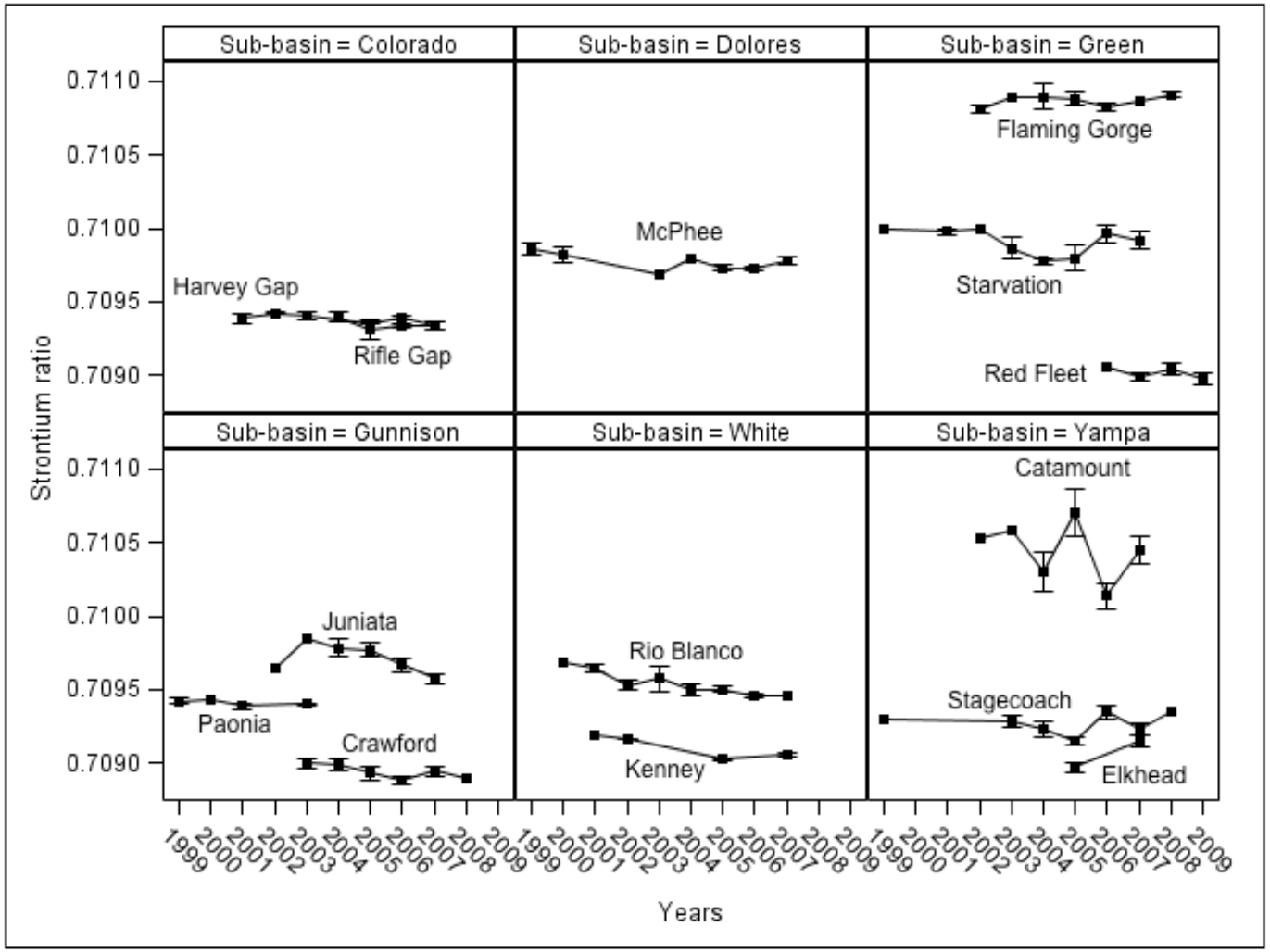

Figure 2. Strontium ratio ($^{87}Sr/^{86}Sr$, ±SE) in otoliths of fish sampled from 14 reservoirs in the Upper Colorado River basin.

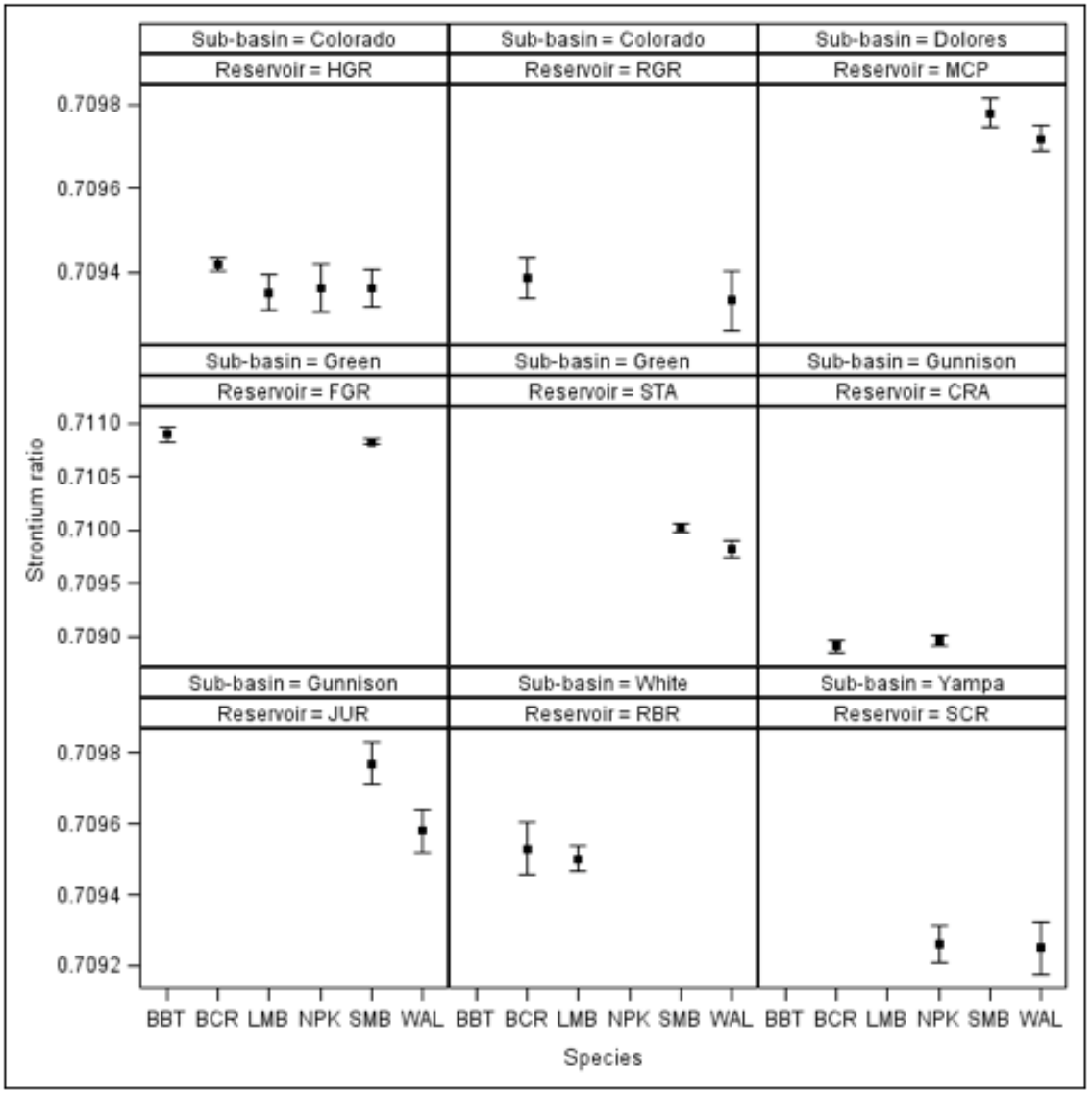

Figure 3. Strontium ratio ($^{87}Sr/^{86}Sr$, ±95% CL) among species within 9 reservoirs, pooled across years. Refer to Table 1 for reservoir codes.

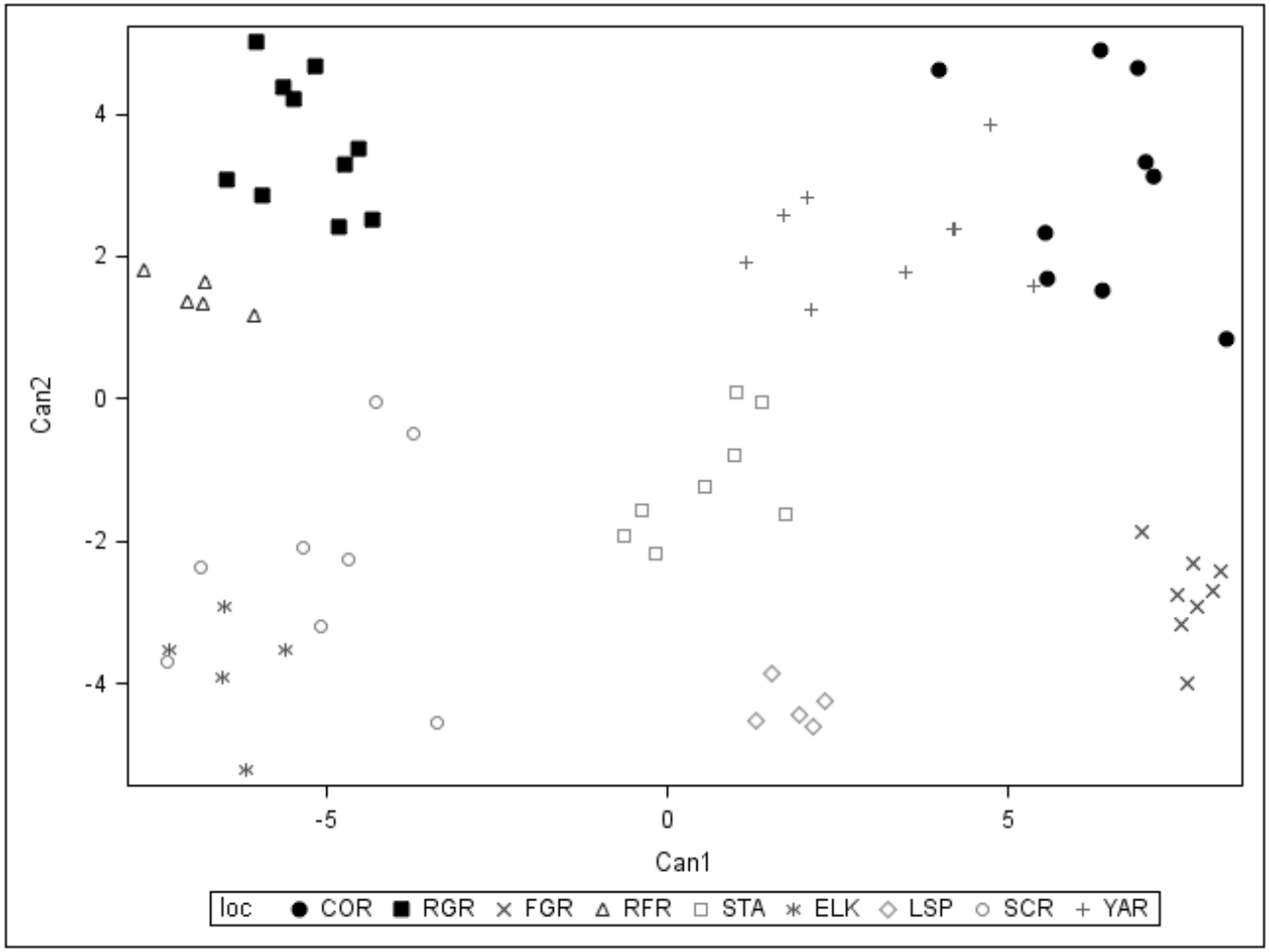

Figure 4. Results from canonical discriminant function analysis (CDFA) using stable isotopes and Sr ratios. Location codes: COR = Colorado River, ELK = Elkhead Reservoir, FGR= Flaming Gorge Reservoir, LSP = Loudy Simpson Ponds, RFR = Red Fleet Reservoir, RGR = Rifle Gap Reservoir, SCR = Stagecoach Reservoir, STA = Starvation Reservoir, and YAR = Yampa River.

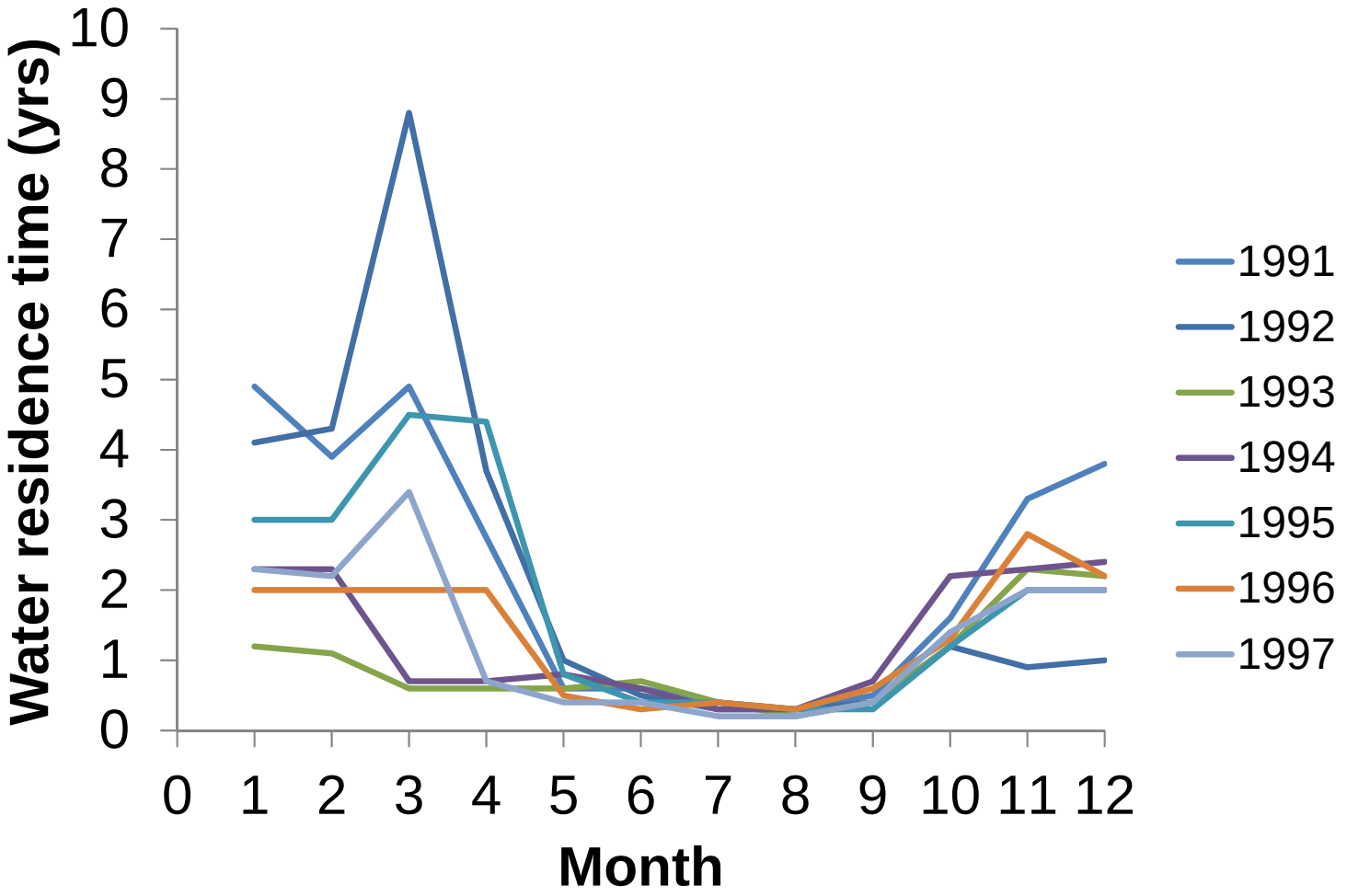

Figure 5. Water residence time (years) at Crawford Reservoir averaged by month for the 7 years during 1990-2009 when data were available.

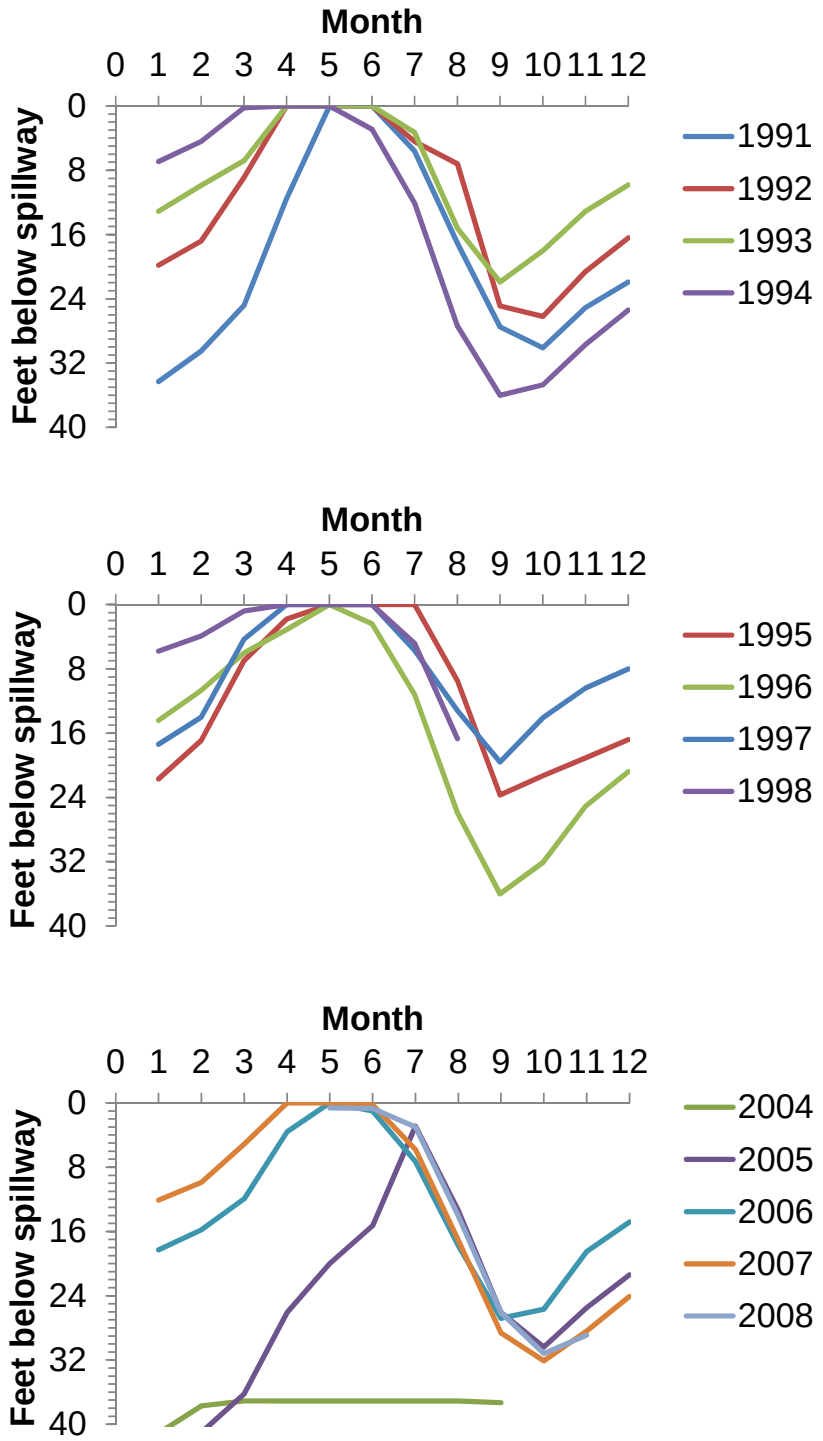

Figure 6. Crawford Reservoir's surface elevation expressed as distance below spillway elevation (feet) for the 13 years during 1990-2009 when data were available.