

Upper Colorado River Endangered Fish Recovery Program

USE OF OTOLITH ELEMENTAL SIGNATURES IN ESTIMATING SOURCES OF  
NORTHERN PIKE RECRUITMENT IN THE YAMPA RIVER, COLORADO

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## Disclaimer

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## List of Keywords

Esox, otolith, microchemistry, elemental signature, Yampa River, recruitment

## Executive Summary

Predation from nonnative northern pike, *Esox lucius*, has caused extensive problems for native fish assemblages in the Yampa River and evaluating potential control options for northern pike requires a clearer understanding of recruitment. If recruitment sources can be identified, then management efforts can focus on these areas to reduce reinvasion. We used otolith microchemistry to identify trace elemental signatures that could be used to identify sources of northern pike recruitment throughout the Yampa basin. We found that 2-3 elements (Sr, Ba, and Mn) were useful in discriminating among sites on the Yampa River. Due to annual variation in the trace elemental signatures, age 0 northern pike would need to be collected and analyzed each year to use these signatures to classify unknown fish. Our analyses indicate that classifying northern pike is variable, particularly among small off-channel ponds. When all sampling sites were included in the analysis the percentage of fish correctly classified to their natal area, averaged 64% in 2005 and 58% in 2006. However, classifying fish from larger reservoirs was more successful. Classification rates between Stagecoach Reservoir and Lake Catamount ranged from 73-100% from 2004 to 2007, with an overall average of 90%. Classification rates were higher in low runoff years than in high runoff years. Despite challenges associated with the technique, we believe that otolith microchemistry is a useful tool for explaining northern pike recruitment and can help managers focus control efforts. We recommend that managers; 1) continue collections of age-0 northern pike in the Yampa River and develop a database of annual signatures. 2) We recommend that managers of Lake Catamount continue to monitor pike elemental signatures to address rates of immigration from Stagecoach Reservoir to Lake Catamount to address the efficacy of pike removal. We recommend that future research; 1) examine other potential markers such as strontium isotopes. 2) Otolith trace elemental analyses



should continue to allow examination of interannual variability and determine if this challenge can be overcome.

## Introduction

Nonnative fish species have negatively affected native fish assemblages globally and nonnative introductions are acute in the arid western United States (Vander Zanden et al. 1999; Rahel 2000; Olden and Poff 2004). Schade and Bonar (2005) estimated that one in every four fishes in western streams and two of every three fishes in Colorado were nonnative. Typical management strategies for nonnative invasive fishes involve removal or reduction of non-natives by poisoning (Martinez 2004), gillnetting (Knapp and Matthews 1998), electrofishing (Kulp and Moore 2000), or dewatering (Copp et al. 2005). Usually reinvasion is prevented by the use of barriers and native fishes are subsequently reintroduced above the barrier. For example, Kulp and Moore (2000) removed nonnative rainbow trout (*Oncorhynchus mykiss*) in an Appalachian stream and stocked multiple age classes of the native southern Appalachian brook trout (*Salvelinus fontinalis*). The treatment area of their study had a waterfall (~10 m) that inhibited movement into the treatment area and native brook trout spawned successfully within one year of nonnative removal.

The effectiveness of nonnative fish removal will depend on reinvasion rates of non-natives. If reinvasion rates are high, then non-native removal may not be successful. Conversely, if reinvasion rates are low then removal may be an effective management strategy. Non-native fishes may invade by moving from an area not subject to the removal, and typical management to avoid such reinvasion is the construction of a barrier. If removal is not complete, reinvasion can occur through reproduction and recruitment. Reintroduction can also occur from movement by humans. For example, Copp et al. (2005) found human disturbance variables, such as distance to nearest road or footpath, as a significant factor related to introduction of nonnative fish into restored ponds. Estimating movement and sources of recruitment of nonnative fishes is

necessary to focus management efforts and define points of potential reinvasion and possible control.

The northern pike (*Esox lucius*) is an aggressive piscivore that has a circumpolar distribution throughout the northern hemisphere (Craig 1996) and has been stocked outside their native range to act as biological controls and to offer angling opportunities. Once introduced, northern pike have been implicated in declines in native fish populations (Findley et al. 2000; Labbe and Fausch 2000; Nesler 1995). The first documented stocking of nonnative northern pike into Colorado's west slope occurred in 1962 at Vallecito Reservoir to control a white sucker (*Catostomus commersoni*) population (Bergersen 2001). Since that time, agency-sanctioned and illegal movements of northern pike have taken place, and currently northern pike are found throughout the state.

The Yampa River, Colorado is home to four federally endangered species, the Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*) and the bonytail (*Gila elegans*). The section of river downstream of Craig, Colorado (river mile 139) has been identified as critical habitat for these fishes (Nesler 1995). Northern pike, as well as other nonnative predators, have been identified as major predatory threats to native fish in the river (Nesler 1995). The first stocking of northern pike into a reservoir with a direct connection into the Yampa was 580 fingerlings into Elkhead Reservoir in 1977 (Figure 1; Rogers et al. 2005). There were reports of escaped fish from Elkhead Reservoir as early as 1979 (Tyus and Beard 1990). Lake Catamount dam was completed in 1978 and there were northern pike detected below the Lake Catamount spillway in 1980, but not in the reservoir until 1995 which suggests the Lake Catamount dam blocked upstream movement. Rogers et al. (2005) suggest the establishment of northern pike in Lake Catamount was from fish escaping from

Stagecoach Reservoir which is located upstream of Lake Catamount and was constructed in 1989. Northern pike were first documented in Stagecoach Reservoir in 1994.

Hill (2004) studied the suitability of northern pike spawning habitat in backwaters along the Yampa River, including one off-channel pond. He speculated that spawning habitat within the river was not sufficient to sustain northern pike due to high variation in flows, especially through nursery areas. Suitable spawning habitat may be inundated with heavy flows within a few days of spawning, thus washing eggs from vegetation and killing them. Conversely, the river levels may drop significantly immediately following spawning, thus desiccating eggs. While Hill's study did not focus on off-channel ponds, he suggested they were the site of the majority of successful northern pike spawning along the river. He also suggested that northern pike recruit from ponds with a connection to the river, but ponds not connected directly to the river could allow immigration of northern pike into the river during flood events. With the high fluctuation of water levels in the Yampa River, flooding events may occur every few years. In addition to off-channel ponds, he implicated reservoirs in the study area as sources of recruitment and indicated future research to control northern pike recruitment should focus in these areas. Orabutt (2006) conducted further research in the study area by tagging northern pike in Lake Catamount and Stagecoach Reservoir in a mark recapture study. These tagged during this study were recaptured below the Lake Catamount dam in the main stem Yampa River within weeks of being tagged. Since Catamount Dam is the last dam on the river system before critical habitat of native fishes, it is a potential source and control point for northern pike into the Yampa River system.

In addition to the native fishes in the lower Yampa River, the upper Yampa River supports an economically important trout fishery. Trout anglers and managers are interested in

controlling northern pike because they are implicated in the decline of trout fisheries in the region. Northern pike can consume prey up to one-half their own body length (Craig 1996) and reach over 115 cm in total length in reservoirs on the Yampa River, resulting in northern pike able to consume trout up to 57 cm total length. Controlling the number of northern pike in the upper Yampa River would benefit the trout fishery by reducing trout predation.

The effectiveness of removing northern pike in specific areas will depend on how quickly northern pike are able to recolonize after removal. If there are several potential recruitment sources, or a single productive recruitment source, then reinvasion would be likely and removals may be ineffective. If recruitment sources are limited then removal may be an effective management option. To examine if removal may be effective, I focused on Lake Catamount.

Lake Catamount currently has a large northern pike population that is well studied. Orabutt (2006) marked northern pike and assessed habitat and the Colorado Division of Wildlife has extensive data on the reservoir as part of its annual monitoring. Historical records of changes in population structure will allow the efficacy of control efforts at Lake Catamount to be documented. Additionally, Lake Catamount had a highly productive trout fishery until northern pike were established and stakeholders are interested in reestablishing a rainbow trout fishery. Lake Catamount has highly favorable habitat for northern pike spawning and is the last reservoir on the main stem of the Yampa River, thus it may be responsible for northern pike recruitment into critical native fish spawning habitat. Control of northern pike in Lake Catamount may reduce recruitment into the Yampa River system. Lake Catamount is well suited for examination of removal efforts as it is relatively small, privately owned, and has a population of northern pike that has been studied. Northern pike control would be beneficial for both trout management and reduction of recruitment into the river. The most likely source of northern pike immigrants into

Lake Catamount is Stagecoach Reservoir which lies upstream of Lake Catamount. These two locations can be analyzed discretely from other locations in the basin because movement of northern pike upstream into Lake Catamount is precluded by its overflow dam.

As previously stated, the effectiveness of nonnative fish removal will depend on reinvasion rates of non-natives. To estimate movement of fish several methods of tagging have been used, including T-bar anchor tags (Parsons and Reed 2005), coded wire tags (Able et al. 2006), passive integrative transmitter tags (Roussel et al. 2004), and more recently pop-up satellite archival tags (Sibert et al. 2006). Tagging methods tend to be inefficient in estimating population size or movement of juvenile fish as small fishes are difficult to mark and have low recapture rates (Bergman et al. 1992). Stable isotopes in muscle tissues have also been used (Hesslein 1991); however, isotopic signatures change over time (Hobson 1999, Hesslein 1993), making this technique inappropriate for long term studies of fish movement.

Another technique to estimate movement and recruitment is the use of elemental and isotopic concentrations in calcified structures. These are commonly referred to as elemental fingerprints or signatures and can be used as a natural tag. Elemental fingerprints can potentially be used to discriminate among fish that have inhabited different water bodies, such as nursery areas (Gillanders and Kingsford 2000, Arai et al. 2007, Feyrer et al. 2007) and can help estimate the source and migration patterns of individuals. Otoliths are the most widely used calcified structure for stock discrimination and movement studies (Campana 1999). Growth of the otolith occurs daily, seasonally, and annually resulting in visible increments that can be used to reconstruct the age and life history of fishes (Campana and Neilson 1985). Since otoliths are metabolically inert, elemental information recovered at different locations within the otolith can be used to reconstruct events throughout the lifetime of a fish. Changes in elemental

composition reflect either changes in the water conditions, or modifications due to the physiological conditions of a fish at a specific time (Kalish 1989; Kennedy et al. 2000). The advantage of using otolith elemental composition is that each fish in the population has a signature, thus no effort needs to be expended to mark fish.

When evaluating the potential utility of using otolith elemental composition as a natural tag, certain characteristics should be examined. First, differences in otolith elemental composition are based on differences in water chemistry (Walther and Thorrold 2006) that are caused mainly by differences in the geology of the area and potentially diet (Buckel et al. 2004). The geology underlying the Yampa River is diverse and should result in diverse signatures (Untermann and Untermann 1949). We hoped this change in geology will be reflected in differences in water chemistries in locations downstream. Second, the biology of the target species should be examined. Fishes well suited to studies of natal areas with otolith microchemistry have discrete and identifiable spawning habitats (e.g., Feyrer et al. 2007). Northern pike require lentic, heavily vegetated areas for spawning and leave river channels to find suitable spawning habitat in backwaters, reservoirs, or ponds. Water in these off channel areas may possess unique chemical compositions. Thus, the northern pike's reproductive biology makes this species a reasonable choice for studying natal areas with otolith microchemistry. Third, it is important to examine temporal variation when using otolith elemental signatures. Elemental signatures may vary due to annual differences in runoff or other environmental variables. If elemental signatures are not stable over time, then age-0 fish will need to be collected each year to obtain a baseline signature of each location. Adults will need to be collected, aged, then classified using the appropriate year's elemental signatures.

In addition to using otolith elemental signatures to classify fish, we also examined the potential utility of hydrogen and strontium isotopic signatures. Whitley et al. (2006) showed the utility of hydrogen isotopes in aquatic environments and otolith hydrogen isotopic ratios have a very strong relationship to water hydrogen isotopic ratios ( $r^2 \geq 0.97$ ). Differences in hydrogen isotopic ratios are driven by differences in evaporation rates. One would expect evaporation rates to differ between small, shallow ponds and large, deep reservoirs. We assessed hydrogen isotopes to either use in conjunction with elemental data to increase accuracy in basin wide classification rates, or as a filter to classify fish recruited from ponds and fish recruited from reservoirs, thereby reducing the number of locations to identify using elemental data.

Our first objective was to develop otolith elemental signatures by collecting age-0 northern pike from several different areas. We assumed that age-0 northern pike had spent their entire life in the pond or reservoir where they were collected. Our second objective was to estimate variation in elemental signatures among sites and years. Temporal variation is often ignored and has not been adequately addressed in most otolith studies. Our third objective was to examine the potential utility of hydrogen isotopes in increasing our ability to discriminate reservoirs and ponds.

### **Original Goals and Objectives from Scope of Work**

The original scope of work was developed from an early version of Ryan Fitzpatrick's MS thesis proposal and was submitted before his MS thesis was approved by his thesis committee. Several goals and objectives were abandoned to narrow the focus of the research due to concerns that the initial goals were too broad and couldn't be accomplished during a MS project. However, the scope of work was never revised to reflect changes to the thesis proposal. Additionally, the



project was funded from several sources and the scope of work reflected what we felt could be accomplished with the entire funding package and not just the portion of funding received from the Recovery Program. We outline the status of each goal and objective below.

**Goal 1.** Map degree of movement of pike within the Yampa River system via otolith microchemistry.

Objectives 1: Demonstrate differences in chemical signatures of otoliths of age-0 pike from various sources.

This objective was completed and is the focus of the research described in the report. We describe variability and uniqueness of chemical signatures from several sources on the upper Yampa River.

- Evaluate how quickly differences can be detected via laser ablation.

This objective was removed from the thesis proposal as suggested by the graduate committee. The committee felt that this objective was peripheral to the research and not necessary to accomplish the main objective of identifying chemical signatures.

- Estimate the proportion of pike recruited from reservoirs and other spawning areas in the Yampa River.

This objective has not been completed but the research reported below has laid the necessary groundwork to begin estimating recruitment. We had hoped to include data addressing this objective but underestimated the effort necessary to develop appropriate signatures. We have continued to examine recruitment using other funding sources and will keep the Recovery Program informed of our progress.

- Estimate the extent of pike movement from spawning sources and reservoirs to other habitats within the Yampa River system.

This objective was not completed. The data that we report below indicate that movement may be estimated between Stagecoach and Catamount reservoirs; however, due to the overlap in chemical signatures among other areas, it may be problematic to accurately estimate movement.

Goal 2. Evaluate trophic relationships of pike within Stagecoach Reservoir, Lake Catamount, Elkhead Reservoir, and portions of the Yampa River using stable isotope analysis.

**This goal was not completed or attempted due to concerns of the graduate committee that it was not directly relevant to our main objectives of identifying pike recruitment sources.**

### **Site Description**

The Yampa River is located in northwest Colorado (Figure 1) and is critical habitat to four federally listed fishes, the Colorado pikeminnow (*Ptychocheilus lucius*), bonytail (*Gila elegans*), razorback sucker (*Xyrauchen texanus*), and the humpback chub (*Gila cypha*). It flows from its headwaters in the Flat Tops Wilderness, through Steamboat Springs, to the Green River near the Colorado/Utah border. The Yampa River is one of few rivers remaining in Colorado with largely unregulated flows. Seasonal runoff creates extreme variation in discharge. The majority of northern pike spawning locations were located in the upper river, but northern pike movement has been documented throughout the river system (Martin 2005).

Reservoirs in the study include Stagecoach Reservoir, Lake Catamount and Elkhead Reservoir. Stagecoach Reservoir is 316 ha with a mean depth of 13 m and aquatic vegetation coverage of <1%, but there is a substantial amount of terrestrial vegetation that the northern pike used for spawning (Orabutt 2006). Densities of northern pike in Stagecoach Reservoir are not as high as some other reservoirs in the study area, but has an estimated 1.24 fish/ha greater than or equal to 710 mm (Orabutt 2006). Lake Catamount is 228 ha with a mean depth of 4 m. The upper portion of Lake Catamount is relatively shallow with extensive vegetation, making it very

productive northern pike habitat. Northern pike densities are very high in Lake Catamount, with 7.38 fish/ha greater than or equal to 350 mm and 4.60 fish/ha greater than or equal to 530 mm (Orabutt 2006). Elkhead Reservoir is located on Elkhead Creek, which has a direct connection to the Yampa River. When the reservoir is at capacity, it is 223 ha with a mean depth of 7.5 m. During the course of our study, the water level in Elkhead Reservoir was lowered by 18 m for dam repairs. The drop in water probably precluded northern pike spawning and due to this, only adult northern pike were collected in 2005 and no northern pike were collected in 2006. We are comfortable using adults from Elkhead Reservoir for establishing baseline elemental signatures because movement from other locations was unlikely. However, illicit stocking of northern pike could confound our results. Residence time for reservoirs was calculated based on the mean monthly discharge from April through August as recorded by U.S.G.S. gage stations.

Ponds in our study included Haymaker Golf Course Pond, Lafarge Pond, Ski Pond and the Yampa River State Wildlife Area Ponds. The first three ponds have a direct outlet into the Yampa River, and the Yampa River State Wildlife Area ponds are in the Yampa River floodplain. During high water years, any of the ponds may be flooded and provide recruitment of northern pike into the main stem of the river. Ski Pond is an old gravel quarry, so we expected water chemistry to be different due to multiple layers of strata being exposed. Haymaker Golf Course pond is a spring fed pond that has high turnover rates due to irrigation needs of the golf course. Lafarge is a large, deep, spring fed pond with low water turnover rates. The Yampa River State Wildlife ponds are small, shallow man-made ponds that flood almost annually.

## Methods

Collection techniques for age-0 northern pike depended on conditions at a particular site. Sites with steep dropoffs and vegetation were sampled using boat electrofishing. Sites with a slowly tapering dropoff and sparse vegetation were sampled with seines. Backpack shocking units were used during 2004 but were discontinued because young northern pike were not very susceptible to this gear. Adult northern pike at Elkhead Reservoir were collected using electrofishing boats and gill nets. Northern pike were placed in plastic storage bags and placed on ice. Upon return to the laboratory northern pike were frozen until the otoliths were removed.

Water samples were collected at each fish sampling location in acid washed polyethylene bottles following protocols set forth in Shiller (2003) within 24 hours of fish collected. The site of collection at each site was where the majority of fish were collected. If collection of fish caused the water to become turbid, the sample was collected the following day to allow the water to settle. Samples were filtered through a 0.45  $\mu\text{m}$  filter into a storage vial. If field conditions were windy the water was kept in the polyethylene container until return to a calm location to avoid contamination. Samples were kept in the polyethylene bottle for a maximum of three hours. Once filtered the samples were kept on ice until returned to the laboratory, and then were placed in the refrigerator until shipped for analysis at the Stennis Space Station (2609 West 4<sup>th</sup> St. Hattiesburg, MS 39406).

Plastic utensils and working areas were used to reduce the risk of metal contamination. The workspace and all utensils were cleaned with diluted nitric acid (10:1) prior to removing otoliths and before fish from another location were processed. Fish were measured (mm) and weighed (g). Otoliths were placed into a Petri dish with distilled water to remove remaining

tissue, dried on a paper towel, and placed into a labeled 10 ml plastic centrifuge tube and stored in an envelope. Left and right otoliths were kept in separate vials; only right otoliths were used in the analyses, unless otherwise noted.

To prepare otoliths for elemental analysis, a mold was half filled with EPO-FIX epoxy from Electron Microscopy Sciences and allowed to cure for at least 24 hours. After 24 hours a drop of Quick Fix Adhesive (Cyanoacrylate) from 3M was placed in the center of the mold to hold the otolith in place and the otolith was placed in center of the mold with acid washed plastic forceps. The mold was then filled with the epoxy and allowed to cure for at least 24 hours.

Embedded otoliths were removed from the mold and placed into individually labeled 10-mL plastic centrifuge tubes and placed in a coin envelope. Otoliths were cut on a Buehler IsoMet low speed saw to a thickness of approximately 1.3 mm. The sectioned otolith was cleaned, dried and placed into a clean, labeled 10-mL plastic centrifuge tube. The cutting blade was cleaned with a cleansing block between each otolith. Otoliths were polished with five grades of sandpaper (400, 500, 600, 800, and 1000 grain) and lapped for one minute. Sandpaper was changed between each fish and the lapping paper was changed after five fish and was always changed before processing fish from different locations. Lapping was done using a polishing wheel and each side of the otolith was lapped for approximately one minute. Thin sections were prepared for ablation by cutting a 1"x 3" glass slide in half and acid washing with a 1M ultrapure nitric acid (HNO<sub>3</sub>) solution. Otolith thin sections were applied to the slide with double sided tape. Slides were labeled with the otolith identification code. Five to fourteen otoliths were placed on each slide and were then stored in an acid washed Petri dish.

Once mounted on the slide, otoliths were sprayed with a small amount of ultrapure water and placed into an ultrasonic cleaner (Cole Parmer Model 8848) for five minutes. After five minutes otoliths were removed from the sonic cleaner and placed in a laminar flow hood overnight. All steps following applying tape to the slide were done wearing latex gloves that were changed between otoliths from different sites. After the otoliths dried, slides were placed in labeled Petri dishes that were taped shut and were stored in acid washed Tupperware containers.

The chemical composition of otoliths was analyzed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the USGS laboratory in Lakewood, Colorado using a Perkin Elmer ALAN6000 ICP-MS and a CETAC Technologies LSX-500 laser system with a 25 $\mu$ m spot size, 10 Hz pulse frequency and 8-9 J energy. The particles ablated during the analyses were entrained in a carrier gas (Ar) and transported directly to the ICP-MS. With the use of standard reference materials specifically designed for in-situ analyses (e.g., Wilson et al. 2002) the raw LA-ICP-MS data could be converted to quantitative concentrations. The raw signals were qualitatively evaluated for distinct changes in elemental response. Once the integration area was selected data were converted to concentration using the methods of Longerich et al. (1996). Calcium (40% in CaCO<sub>3</sub>) was used as the internal standard. A subsample of left otoliths was sent to the Alaska Stable Isotope Facility at the University of Alaska Fairbanks (306 Tanana Dr. Fairbanks, AK 99775) for hydrogen isotopic analysis. Stable hydrogen isotopic data was obtained using continuous-flow isotope ratio mass spectrometry (CFIRMS).  $\delta^2\text{H}$  values are measured using pyrolysis elemental analysis with isotopic ratio mass spectrometer. This method used a ThermoFinnigan MAT high temperature thermally coupled elemental analyzer with a Conflo III interface and a DeltaV Mass Spectrometer.

Otolith elemental concentrations were  $\log_{10}$  transformed to meet the assumption of homogeneity of variance (Tabachnick and Fidell 2007). Concentrations of three elements, strontium, barium and manganese were analyzed using a Discriminant Function Analysis (DFA). This suite of three elements and one isotopic ratio was selected because they had concentrations above detection limits for every fish, in every sampling occasion. Sodium and zinc also fit this criterion, but sodium was removed due to potential contamination concerns and zinc was removed due to the fact it is incorporated into the protein layer of the otolith and not in the crystalline matrix (Robyn Hannigan, personal communication, Department of Environmental, Earth, and Ocean Sciences, University of Massachusetts at Boston). Discriminant functions using the three elements were compared to those including hydrogen isotopic ratios to see if classification rates improved.

Water chemistry samples were analyzed using multi-variate analysis of variance (MANOVA) and the same suite of three elements. To estimate the classification efficiency of elemental signatures we used a nonlinear discriminant function analysis. A nonlinear analysis was performed due to differences in sample sizes among locations and potential differences in variation of the elemental signatures (Tabachnick and Fidell 2007). We examined classification accuracy using reclassification to avoid an individual fish's elemental signature affecting the discriminant function (DF) constructed. This method removes one fish from the analysis, runs the DF, then estimates where that fish would be classified. This process was iterated for every fish in the data set. To address basin-wide northern pike recruitment, the DF was used to classify northern pike among all sites. To address efficacy of northern pike removal in Lake Catamount, the DF was used to classify northern pike between Stagecoach Reservoir and Lake Catamount. Temporal variation in elemental signatures was examined using MANOVA and the same suite of

three elements. There has been concern raised over machine drift for LA-ICP-MS, so to be certain any temporal differences in elemental signatures were not caused by drift in the machine a subset of left otoliths from Stagecoach Reservoir and Lake Catamount from 2005 and 2006 were analyzed using MANOVA with the same suite of elements. Pillai's trace was used as the test statistic to detect annual differences in elemental signatures since it is robust to violations of the homogeneity of covariance assumption (Quinn and Keough 2002). Percent variation between groups, eigenvalues and canonical correlations for each axis are reported for canonical axes that contributed at least 10% of the variation in the DF. Otolith elemental concentrations were compared within years using linear regression. Water residence time was calculated by taking the mean flow from U.S.G.S. gage stations from April 1 through August 31 for each year. The volume of each reservoir was then divided by the flow to calculate residence time.

## **Results**

### *Water chemistry*

Overall, otolith elemental concentrations were significantly correlated with water elemental concentrations in five of nine within year comparisons (Appendix A). Barium's correlation was significant in all three years, while strontium and manganese were correlated in one out of three years. During the highest runoff year, 2006, only barium was significantly correlated.

### *Classification*

Classification rates including all sample locations averaged 65% over three years and ranged from 8% to 100% (Table 1). Lake Catamount had consistently high classification rates at 60% in 2004, 78% in 2005, and 69% in 2006. Stagecoach Reservoir had the highest variation in



classification rates (8% - 100%). Off-channel pond classification was highly variable and no location had classification rates greater than 60% for multiple years. Elemental signatures among sites were significantly different within years ( $1.16 < \text{Pillai's trace} < 1.56$ ). The first two canonical axes explained at least 89% of the overall variability in otolith elemental signatures (Table 2). Eigenvalues of the first two canonical axes were consistently high, with only the second canonical axis in 2006 being less than one (0.84). Canonical correlations of each axis and each element showed strontium had the highest correlation in two of the three first canonical axes. Manganese had the highest correlation on the first axis in 2006 (Table 2). The otolith elemental concentration data for each fish are given in Appendices B, C, D and E.

When the analyses were restricted to Lake Catamount and Stagecoach Reservoir, MANOVA indicated that elemental signatures among sites within years were significantly different ( $0.33 < \text{Pillai's trace} < 0.94$ ). Classification accuracy improved to an average of 90% with a range of 73% to 100% (Figure 2). Strontium had the highest canonical correlations in 2004, 2005 and 2007 and barium had the highest in 2006 (Table 2).

### *Temporal Variation*

MANOVA indicated temporal variation in otolith elemental signatures for each location when comparing between years (Table 3). A subset of left otoliths from Stagecoach Reservoir and Lake Catamount were analyzed with laser ablation on the same day to examine if observed variation between years was due to machine drift in the LA-ICP-MS. Analysis of these otoliths shows differences between years in Stagecoach Reservoir and Lake Catamount (Figure 3). Therefore, differences in elemental signatures among years can be attributed to temporal variation in the otolith elemental composition and not to drift in the laser ablation machine.

### *Residence Time*

A positive relationship between otolith classification rate and water residence time was discovered between Lake Catamount and Stagecoach Reservoir (Figure 4). Lake Catamount had an average residence time of only 85 days, while Stagecoach Reservoir retained water for an average of 310 days. Both locations displayed a similar trend with a rapid increase in classification rates between 2004 and 2005 and a moderate increase in classification rates between 2005 and 2006. Linear regression of classification rate on residence time was not significant for either Lake Catamount or Stagecoach Reservoir but had  $r^2$  values of 0.66 and 0.45 respectively. The positive relationship between classification rates and residence time indicates the amount of snow-melt runoff may influence the precision of using otolith elemental signatures to identify natal areas of fish.

### *Hydrogen Isotopic Utility*

The addition of hydrogen isotopic ratios as a fourth variable in the DF improved classification rates by an average of 17% in 2005 (Table 4). Five out of seven locations showed increased classification rates, one location did not change, and one location decreased. In 2006, the average classification rate increased by an average of 11% with the addition of hydrogen isotopic data. Three out of six locations increased their classifications rates, two locations did not change, and one location's classification rate decreased (Table 4). Yampa River State Wildlife Area had large increases in classification rates in both 2005 (+45%) and 2006 (+30%). Stagecoach Reservoir and Lake Catamount had improved classification rates for both years with hydrogen isotopic data included. The hydrogen isotopic data are provided in Appendix F.

## Discussion

### *Water chemistry*

There was not strong correlation between water elemental concentrations and otolith elemental concentrations of the three elements used in this analysis. This may be due to water samples being collected only once at one location while the fish were integrating the water chemistry over several months. Wells (2003) had strong correlations for strontium and barium, but this may be due to his study sites being 2-4 m wide streams while our study sites included reservoirs up to 316 ha. One would expect the largest bodies of water to be more heterogeneous in terms of water chemistry than a relatively small stream.

### *Classification*

Our ultimate goal was to estimate the amount of northern pike recruitment in the Yampa River originating from ponds and reservoirs. Our classification rates using otolith elemental composition to estimate natal areas of northern pike from Stagecoach Reservoir to Lake Catamount over three years (90%) compares well with other published microchemistry studies in freshwater. Wells et al. (2003) had classification rates of 100% for cutthroat trout (*Oncorhynchus clarkii lewisi*), and other studies achieved overall success rates of 86% for yellow perch (*Perca flavescens*) (Brazner et al. 2004), 71% for *Pogonichthys macrolepidotus* (Feyrer et al. 2007), and 45% for *Coregonus artedi* (Bronte et al. 1996). Classification rates are not as high when all sites were included, averaging 65%. Previous research indicates that most northern pike reproduction occurs in off-channel ponds and reservoirs and not in the river channel (Hill 2004). Due to our relatively high accuracy in classifying fish when restricting the analysis to two locations (Stagecoach Reservoir and Lake Catamount), it may be possible to estimate the

natal areas of fish inhabiting the upper river, from the Lake Catamount and Stagecoach Reservoir. In 2005 and 2006, the majority of misclassifications from Lake Catamount were classified as Yampa River State Wildlife Area (Y.R.S.W.A) fish. It is unlikely that northern pike captured in Lake Catamount came from any location downstream because the dam is an impassable barrier. Incorporating these likely misclassifications into Lake Catamount, the classification rate increases from 82% to 95% in 2005 and from 69% to 82% in 2006. However, studies indicate that adult northern pike can disperse widely in this system (Martin 2005) and, in future studies; it is possible that unknown fish from the Yampa River could have recruited from either location. Despite this possibility, we feel it is likely that northern pike collected in the upper Yampa River probably recruited from Lake Catamount.

As we move downriver, there are more potential recruitment sources and the utility of otolith elemental chemistry for identifying specific ponds becomes less certain. Our ability to classify natal habitats of northern pike throughout the upper Yampa River averaged 60% when all locations were considered, making it difficult to confidently estimate provenance of unknown fish. Ski Pond had the highest proportion of fish misclassified (21%). Our original hypothesis was Ski Pond would be unique because it is an old quarry with geological strata exposed. The hypothesis that exposure of strata would differentiate it from other ponds was not supported. The case may actually be that having multiple layers of strata exposed made the Ski Pond water chemistry similar to several locations and decreased the classification rate.

One potential reason for low classification rates is the number of locations in our analysis. As more locations are added it is more difficult to use Discriminant Analysis to discriminate among them. The number of Discriminant Functions used to classify populations is a function of the number of variables, or one less than the number of sample locations. In our

case, we had four elements and up to seven locations, resulting in a maximum of four discriminant functions being used to classify seven sample locations. If the number of elements remains the same, then increasing the number of locations to be classified will result in even lower classification rates. For our 2005 data, classification rates averaged 90% for all combinations of two locations. As additional sites are added classification rates dropped to 81%, 75%, 70%, 66% and 62% for all combinations of three, four, five, six and seven sites respectively. Movement of age-0 northern pike would have also reduced classification rates. Downstream movement is possible from Stagecoach Reservoir to Lake Catamount, but unlikely between the other locations due to lack of suitable pike habitat and the short time interval from hatching to collection.

Low classification could result from fish movement from one location to another. However, we believe age 0 pike movement is unlikely because young northern pike tend to remain near vegetation for protection and food (Craig 1996). Stagecoach and Elkhead Reservoirs have dams that do not allow upstream movement, so these two locations are isolated from the other sites that we sampled. Yampa River State Wildlife Ponds were not directly connected to the Yampa River during the course of this study. Haymaker Golf Course Pond has an outflow approximately two meters wide and half a meter deep into the Yampa River, but there is an approximately 2 m high cascade inhibiting upstream movement from the river into the pond (Spens et al. 2007). Lafarge Pond also has a direct outlet into the Yampa River, but is only passable during runoff due to water depth. Since runoff occurs during and shortly after northern pike spawning, age-0 northern pike are not yet large enough to move upstream into Lafarge Pond. Lake Catamount lies downstream of Stagecoach Reservoir and age-0 northern pike could potentially move from Stagecoach Reservoir into Lake Catamount. Therefore, fish collected in

Lake Catamount that classified as Stagecoach Reservoir may not be misclassified and may have originated from Stagecoach Reservoir. However, due to the biology of age-0 northern pike, the small size of fish used in this study, and the physical characteristics of our study sites, we believe age-0 movement among most sites was minimal. Finally, otolith elemental transects were stable, indicating the age-0 fish had not moved from their capture location.

### *Temporal Variation*

Temporal variation has been documented in otolith elemental signatures previously (Thorrold et al. 1998, Gillanders 2002, Patterson et al. 2004, Feyrer et al. 2007, Schaffler and Winkelman 2008) and was significant in our study as well. Temporal variation was related to the residence time of water in Lake Catamount and Stagecoach Reservoir, indicating that winter precipitation and subsequent runoff are influencing otolith elemental composition. However, more data is needed to conclusively demonstrate this relationship. In addition to temporal variation, differences in temperature between sites may be responsible for differences in otolith elemental composition. For instance, Lake Catamount is shallower than Stagecoach Reservoir and its mean temperature may be higher and research has shown that otolith Sr:Ca ratios were positively related to water temperature (Bath Martin et al. 2004).

Due to annual variation in elemental composition, age-0 northern pike will need to be collected each year and site-specific signatures assessed. Then, to accurately classify unknown fish, individuals will need to be aged and classified using the signatures developed from the year the fish was hatched. Annual collection and analysis will increase the amount of labor and cost involved, but it is still potentially less labor intensive and more cost effective than mechanical tagging methods deployed on a basin wide scale.

### *Additional Approaches*

Whitledge et al. (2006) showed the utility of hydrogen in aquatic environments to discriminate between bodies of water with different evaporation rates. We decided to assess the potential of hydrogen isotopes to discriminate between pike collected in large reservoirs and smaller pond environments. We did not analyze every fish using hydrogen isotopes; however, classification rates of otoliths analyzed improved an average of 17% in 2005 and 11% in 2006. Our results support the conclusions of Whitledge et al. (2006) and we believe that hydrogen isotopes have utility in discriminating sources of recruitment when water bodies differ in evaporation rates.

### *Conclusions*

Classification rates using otolith elemental signatures of reservoir populations are relatively high, indicating that it may be possible to estimate the proportion of northern pike in the Yampa River that have come from the three major reservoirs. Estimating recruitment from off-channel ponds is more challenging because classification rates were low and variable. However, in both instances, the use of hydrogen isotopes improved classification dramatically. We also believe that other isotopic techniques are promising, such as the use of Strontium isotopes (Fitzpatrick, unpublished data).

Removal efforts have started in Lake Catamount and we feel that otolith trace elemental signatures can inform managers of the efficacy of these removals and the immigration rates from Stagecoach Reservoir that are likely to occur. Our data also indicate that we can estimate pike recruitment into the Yampa River from Catamount reservoir.

Annual variation in otolith elemental composition has an impact on using the technique and we suggest collecting age 0 northern pike annually to build a database of elemental signatures that can be used to classify adult northern pike of unknown origin living in the Yampa River.

### *Recommendations*

We believe that otolith microchemistry is a valuable technique that can help identify sources of northern pike recruitment in the Yampa River. The Yampa River has many potential off-channel recruitment sources, including many ponds and three reservoirs. We have identified elemental signatures for each reservoir and several ponds. Although we have not used these data to identify northern pike from unknown sources, it appears to us that we can delineate pike that may have recruited from the reservoirs but identifying northern pike that have recruited from pond habitats may be difficult. Ongoing research may clarify our uncertainty but we make the following management and research recommendations based on our current results.

### *Management*

1. We recommend continued collections of age-0 northern pike in the Yampa River to address the annual variability we observed in trace elemental signatures. Although collecting northern pike every year is inconvenient, a database of annual signature would be valuable to assess recruitment. Since small age 0 northern pike would be difficult to mechanically mark, we feel that this effort is warranted.
2. We recommend that managers of Lake Catamount continue to monitor pike otolith trace elemental signatures to address rates of immigration from Stagecoach Reservoir to Lake Catamount. Removal efforts are currently being undertaken to reduce the northern pike



population in Lake Catamount. To address the efficacy of pike removal in Lake Catamount it will be necessary to understand the dynamics of reinvasion from Stagecoach Reservoir. Additionally, continued monitoring of Lake Catamount will also inform managers of the effect of pike removals in the Yampa River below Lake Catamount.

### *Research*

1. Due to inter-annual variability in trace elemental signatures, other potential markers such as strontium isotopes should be examined for their utility in discriminating recruitment and movement. For instance, it appears that strontium isotope ratios discriminate well among fish collected from various sources and do not vary from year to year (Fitzpatrick, unpublished data).
2. We also recommend that age-0 pike collection continue so an archive of northern pike otolith elemental signatures is available to address recruitment and examination of interannual variability.
3. We see the usefulness of correlating elemental composition in the water to that in otoliths to understand underlying mechanisms of otolith composition. However, understanding the relationship between water elemental concentrations and those in otoliths will require extensive water sampling and analyses that may not be necessary for using otoliths signatures as markers.

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**Table 1.** Classification rates from a nonlinear discriminant function analysis of age-0 northern pike collected from ponds and reservoirs in the Yampa River system, Colorado. A dash indicates fish were not collected from that location in the given year. Elements analyzed included strontium, barium and manganese. Sample sizes are given in parenthesis.

Year	Stagecoach	Catamount	Elkhead	Haymaker	Lafarge	Ski Pond	Y.R.S.W.A.
2004	100% (11)	60% (10)	83% (12)	-	-	-	-
2005	62% (34)	78% (55)	76% (35)	44% (55)	80% (45)	31% (52)	80% (44)
2006	8% (40)	69% (39)	-	77% (22)	59% (27)	82% (39)	53% (32)

**Table 2.** Results of multivariate discriminant function analysis of elemental concentrations of strontium, barium and manganese from age-0 northern pike otoliths collected in the Yampa River system, Colorado. Only canonical axes explaining greater than 10% of the variation were included. All canonical axes shown were highly significant ( $p < 0.001$ ). The element with the highest correlation for each analysis is shown in bold.

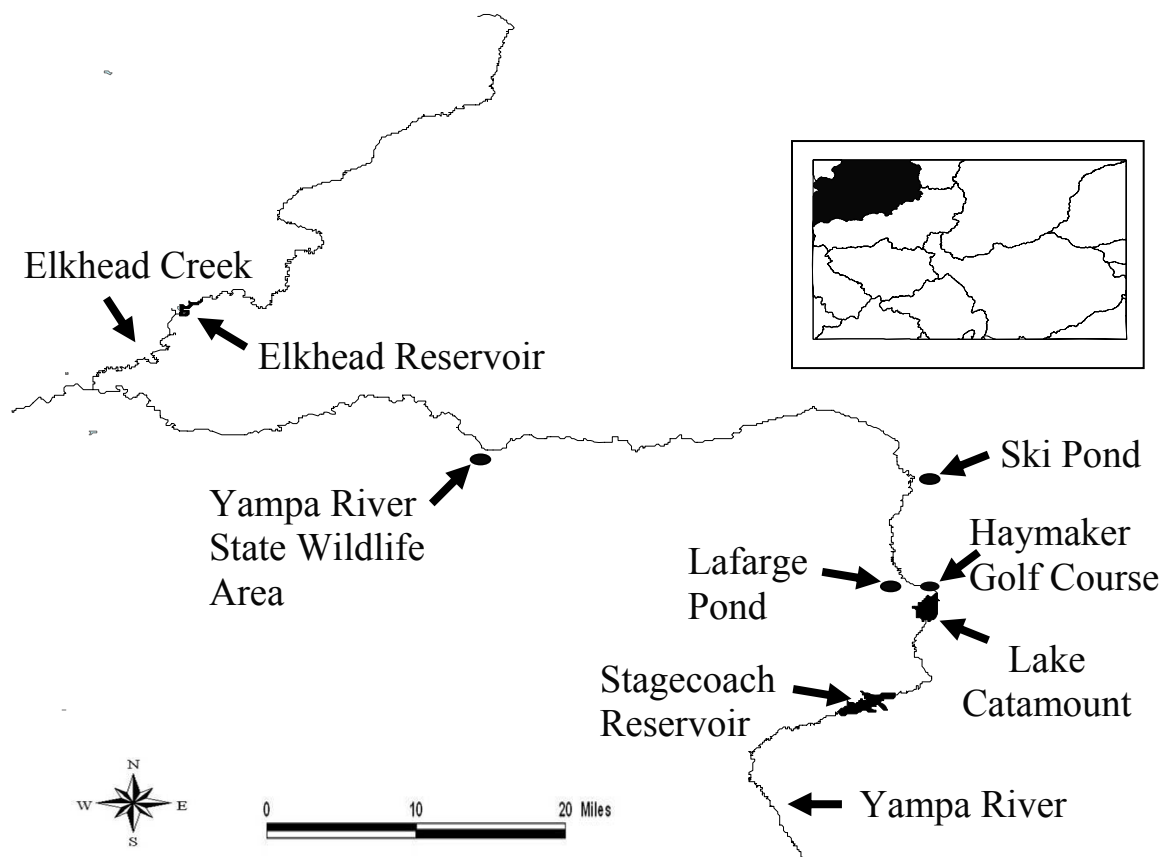
Scope of analysis	Year	Canonical axis number	Percent variation between groups explained	Eigenvalue	Canonical correlations for each axis		
					Sr	Ba	Mn
All Sites	2004	1	90%	9.95	<b>0.96</b>	0.40	0.14
		2	10%	1.12	0.24	0.78	<b>0.97</b>
	2005	1	57%	2.29	<b>-0.61</b>	0.26	0.39
		2	32%	1.3	0.40	<b>0.77</b>	0.39
		3	10%	0.42	0.68	0.58	<b>0.86</b>
	2006	1	58%	1.38	-0.21	0.00	<b>0.89</b>
		2	35%	0.84	0.86	<b>0.99</b>	0.41
	Stagecoach and Catamount	2004	1	100%	16.8	<b>1.00</b>	0.81
2005		1	100%	2.24	<b>0.55</b>	-0.46	-0.28
2006		1	100%	0.5	0.37	<b>0.76</b>	0.66
2007		1	100%	1.11	<b>0.81</b>	0.54	0.34

**Table 3.** Results of discriminate function analysis with MANOVA output examining the temporal variation of otolith elemental signatures of age-0 northern pike collected throughout the Yampa River system, Colorado. Elements used in the analysis included strontium, barium and manganese. Pillai's trace statistic is reported with the probability in parentheses (\* indicates  $p < 0.01$ ).

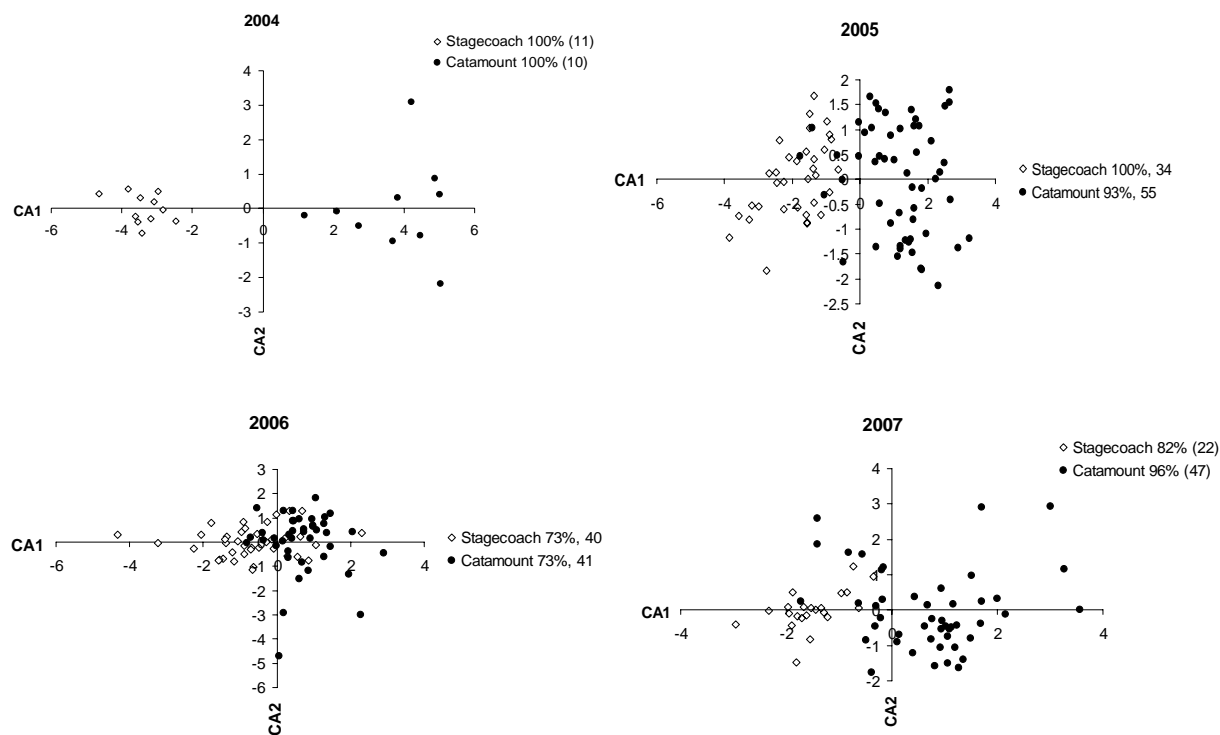
Location	2004 vs. 2005	2004 vs 2006	2005 vs. 2006
Stagecoach	0.293 (*)	0.309 (*)	0.082 (0.111)
Catamount	0.760 (*)	0.478 (*)	0.558 (*)
Elkhead	0.125 (0.121)	-	-
Haymaker	-	-	0.169 (*)
Lafarge	-	-	0.361 (*)
Ski Pond	-	-	0.131 (*)
Y.S.W.A.	-	-	0.438 (*)

**Table 4.** Classification rates comparing age-0 northern pike when hydrogen isotopic ratios were included as a fourth variable and when they were not. Sample sizes are given in parentheses.

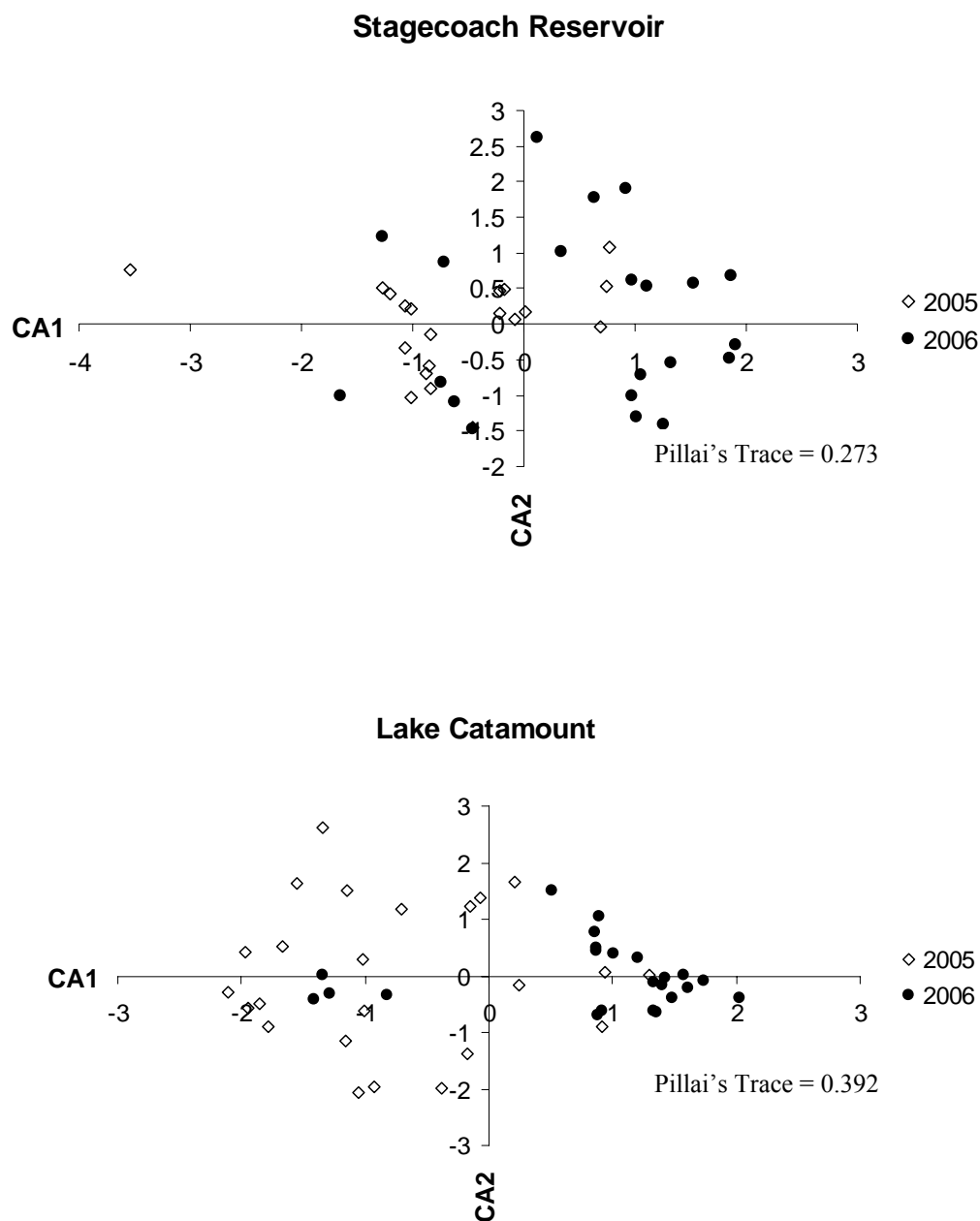
Year	Location	$\delta^2\text{H}$ excluded	$\delta^2\text{H}$ included	Change
2005	Stagecoach (10)	80%	90%	+ 10%
	Catamount (9)	67%	89%	+ 22%
	Elkhead (10)	60%	70%	+ 10%
	Haymaker (10)	20%	60%	+ 40%
	Lafarge (10)	70%	70%	0%
	Ski Pond (9)	33%	22%	- 11%
	Y.S.W.A. (8)	44%	89%	+ 45%
2006	Stagecoach (10)	10%	60%	+ 50%
	Catamount (10)	50%	60%	+ 10%
	Haymaker (8)	63%	38%	- 25%
	Lafarge (10)	40%	40%	0%
	Ski Pond (10)	80%	80%	0%
	Y.S.W.A. (10)	40%	70%	+ 30%



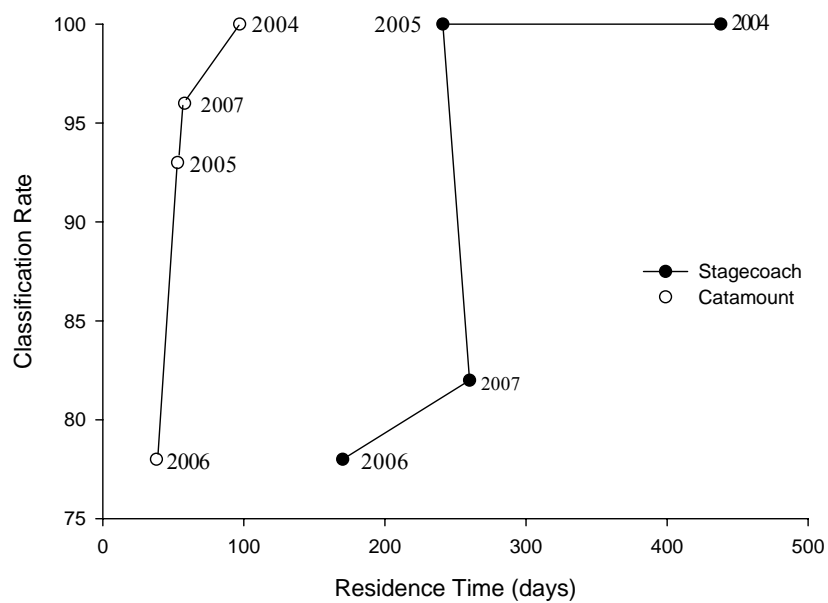
**Figure 1.** The study area was located in northwest Colorado between Stagecoach Reservoir and Elkhead Reservoir. The Yampa River flows in a westerly direction.



**Figure 2.** Canonical correlation analysis of age-0 northern pike otolith elemental signatures collected 2004, 2005, 2006 and 2007 from Stagecoach Reservoir and Lake Catamount, Colorado. Elements analyzed included barium, strontium and manganese. Classification rates and sample sizes are also given. Classification rates were obtained using a nonlinear discriminant function analysis.



**Figure 3.** Canonical correlation analysis of age-0 northern pike otolith elemental signatures collected 2005 and 2006 from Stagecoach Reservoir and Lake Catamount, Colorado showing temporal variation in the signatures between years. Elements analyzed included strontium, barium and manganese. The otoliths were analyzed with laser ablation inductively coupled plasma mass spectrometry. To avoid any temporal variation in the machine, all otoliths were run on the same machine on the same day.

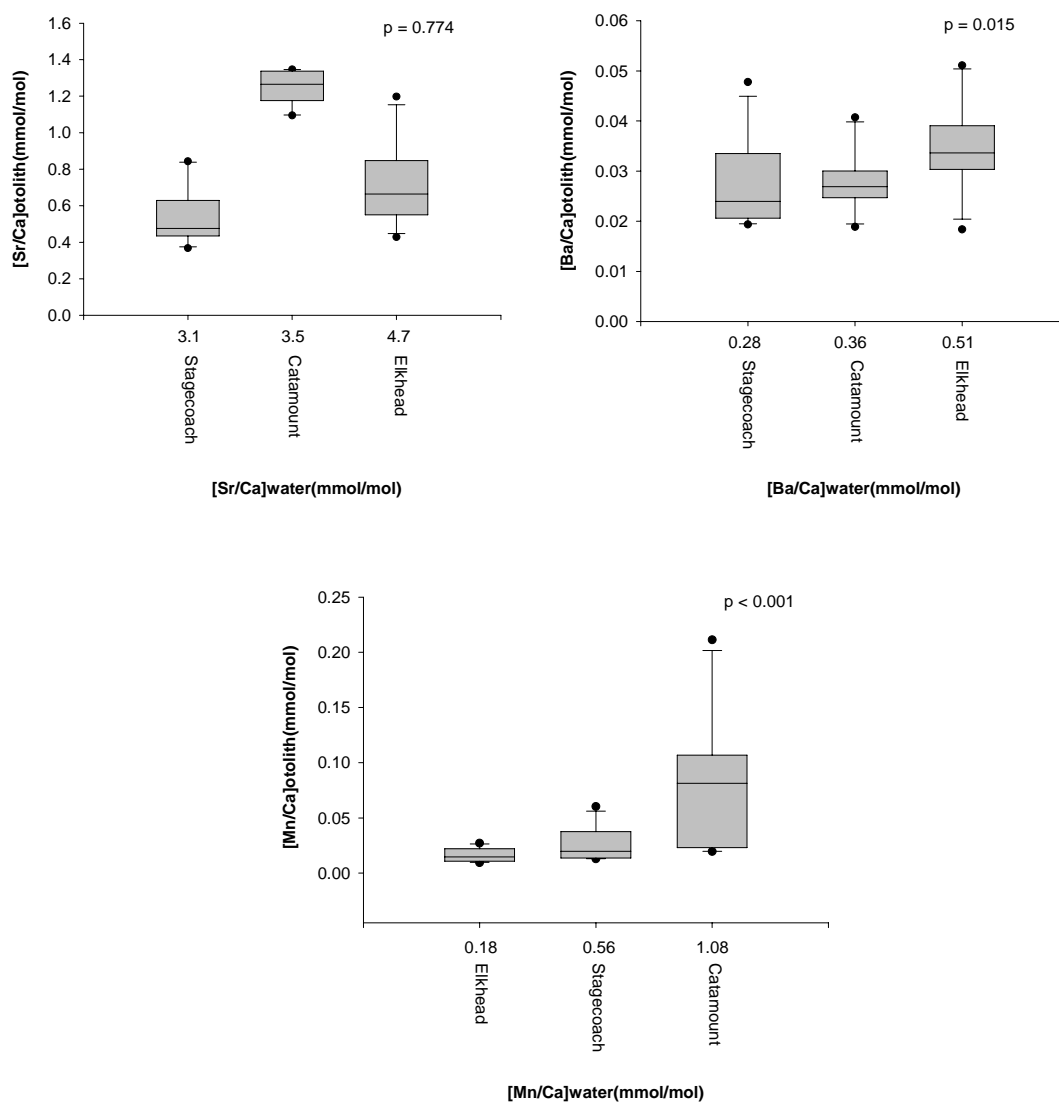


**Figure 4.** Relationship between residence time in Stagecoach Reservoir and Lake Catamount and the classification rates of age-0 northern pike collected 2004, 2005, 2006 and 2007. Residence time was calculated based on the mean monthly discharge from April through August.

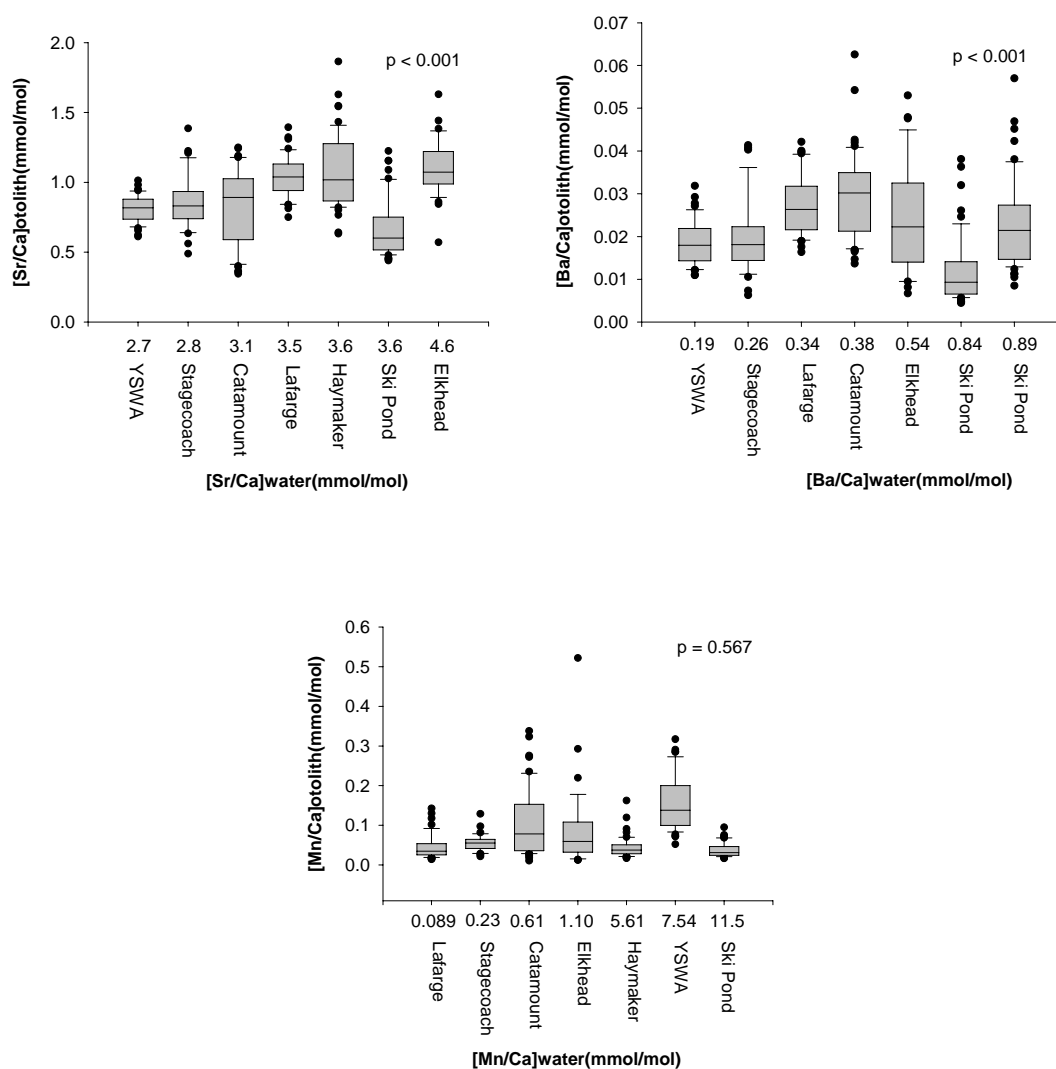


## Appendix A: Otolith elemental composition correlations with water elemental concentrations.

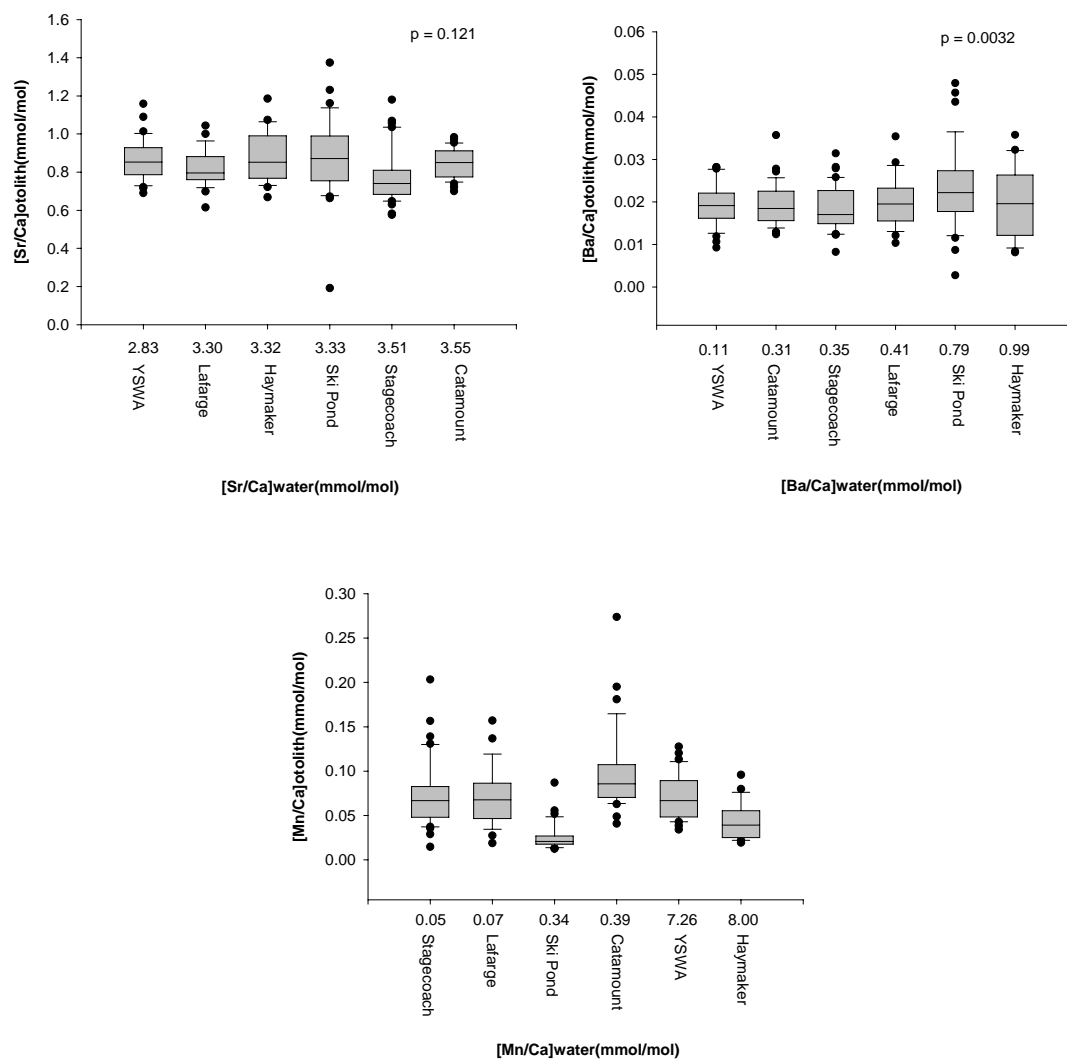
Northern pike were collected in various spawning areas of the Yampa River, Colorado. Water samples were collected as close to the fish collection site as possible.



**Figure A1.** Comparison of water elemental concentration and otolith elemental concentration of samples collected in 2004 from three locations in the Yampa River basin. P-value given is from linear regression between the two variables. YSWA refers to the Yampa River State Wildlife Area.



**Figure A2.** Comparison of water elemental concentration and otolith elemental concentration of samples collected in 2005 from three locations in the Yampa River basin. P-value given is from linear regression between the two variables. YSWA refers to the Yampa River State Wildlife Area.



**Figure A3.** Comparison of water elemental concentration and otolith elemental concentration of samples collected in 2006 from three locations in the Yampa River basin. P-value given is from linear regression between the two variables. YSWA refers to the Yampa River State Wildlife Area.

**Appendix B:** Mean strontium (ppm), barium (ppm), and manganese (ppm) otolith elemental concentrations +/- one standard error of age-0 northern pike collected 2004 to 2006 from spawning habitats throughout the Yampa River, Colorado. Otoliths were analyzed using laser ablation inductively coupled plasma mass spectrometry. The average detection limit for strontium is 1.687 ppm, barium 0.773 ppm, and manganese 0.638 ppm.

Location	Year	Sr	SE	Ba	SE	Mn	SE	n
Stagecoach	2004	668	11.2	19.8	1.97	14.8	2.47	11
	2005	750	17.7	28.9	29	30.7	2.04	34
	2006	787	22.7	32.9	1.95	39.9	3.24	40
Catamount	2004	1095	25.5	38.3	2.47	44.2	10.1	10
	2005	585	27	37.8	1.67	55.3	6.15	50
	2006	893	24	48	2.03	54.3	4.02	41
Haymaker	2005	857	23.1	34.7	1.52	23.9	1.87	55
	2006	981	24.7	39.9	2.07	23.6	2.44	22
Lafarge	2005	534	18.7	13.1	0.84	24.7	2.41	45
	2006	666	18.2	22.2	1.32	38.6	3.45	27
Ski Pond	2005	757	19.3	28	1.39	20.9	1.37	52
	2006	742	10.6	27.2	1.04	14.3	1.28	39
YSWA	2005	679	22.4	24.9	1.21	85.1	5.48	45
	2006	754	16.6	26.5	1.19	39.1	2.39	32
Elkhead	2004	990	31	21.8	2.53	8.98	0.952	10
	2005	1055	32.7	28.5	2.43	46.9	8.92	34

**Appendix C:** Location, fish identification number, date collected, total length (mm), weight (g), date ablated, manganese concentration (ppm), strontium concentration (ppm), and barium concentration (ppm) of northern pike collected 2006 in various locations throughout the Yampa River, Colorado.

Location	Fish ID #	Date collected	Length (mm)	Weight (g)	Date ablated	Mn55	Sr86	Ba137
Catamount	1	9/24/2006	188	34	10/2/2006	43.0	942.1	56.5
Catamount	2	9/24/2006	210	48	10/2/2006	39.4	809.0	34.1
Catamount	4	9/24/2006	200	40	10/2/2006	84.8	849.0	31.9
Catamount	6	9/24/2006	196	42	10/2/2006	48.1	823.5	34.5
Catamount	7	9/24/2006	180	31	10/2/2006	59.8	733.0	58.4
Catamount	8	9/24/2006	205	47	10/2/2006	53.0	1033.7	55.8
Catamount	9	9/24/2006	128	13	10/2/2006	38.0	721.0	49.5
Catamount	10	9/24/2006	192	41	10/2/2006	40.4	1014.4	57.6
Catamount	11	9/24/2006	177	29	10/2/2006	74.8	1026.5	46.2
Catamount	12	9/24/2006	185	35	10/2/2006	99.3	908.1	42.6
Catamount	13	9/24/2006	157	21	10/2/2006	78.0	954.3	85.8
Catamount	14	9/24/2006	118	43	10/2/2006	59.0	985.5	42.6
Catamount	15	9/24/2006	221	60	10/2/2006	53.7	1093.3	47.2
Catamount	16	9/24/2006	202	43	10/2/2006	43.6	1032.3	50.2
Catamount	17	9/24/2006	190	38	10/2/2006	35.1	811.7	45.6
Catamount	18	9/24/2006	169	23	10/2/2006	55.8	1029.2	47.5
Catamount	19	9/24/2006	203	46	10/2/2006	35.6	764.1	43.8
Catamount	20	9/24/2006	197	41	10/2/2006	36.1	807.5	31.5
Catamount	21	9/24/2006	198	45	10/2/2006	34.9	872.2	45.5
Catamount	22	9/24/2006	179	31	10/2/2006	26.8	686.0	52.1
Catamount	23	9/24/2006	189	40	10/2/2006	47.0	1087.4	46.2
Catamount	24	9/24/2006	183	34	10/2/2006	42.0	1040.9	36.8
Catamount	25	9/24/2006	185	36	10/2/2006	34.4	585.6	74.4
Catamount	26	9/24/2006	215	53	10/2/2006	44.1	908.7	44.6
Catamount	27	9/24/2006	196	43	10/2/2006	41.6	738.7	26.6
Catamount	28	9/24/2006	225	61	10/2/2006	52.0	808.9	53.1
Catamount	29	9/24/2006	195	41	10/2/2006	107.0	962.1	41.6
Catamount	30	9/24/2006	232	67	10/2/2006	81.4	877.9	36.9
Catamount	31	9/24/2006	179	32	10/2/2006	22.3	498.7	39.7
Catamount	32	9/24/2006	206	52	10/2/2006	38.0	809.4	39.2
Catamount	34	9/24/2006	205	43	10/2/2006	52.9	1211.3	72.7
Catamount	36	9/24/2006	188	36	10/2/2006	38.6	903.9	48.4
Catamount	37	9/24/2006	185	36	10/2/2006	90.4	932.5	39.7
Catamount	38	9/24/2006	181	29	10/2/2006	49.0	828.3	30.7
Catamount	40	9/24/2006	186	38	10/2/2006	54.1	1142.5	65.7
Catamount	41	9/24/2006	176	30	10/2/2006	38.9	752.1	47.0
Catamount	42	9/24/2006	156	21	10/2/2006	45.9	924.9	65.3
Catamount	43	9/24/2006	190	37	10/2/2006	50.1	1009.1	58.0

Catamount	44	9/24/2006	192	37	10/2/2006	150.2	924.6	44.8
Haymaker	1	8/26/2006	206	51	9/29/2006	12.1	1068.2	36.1
Haymaker	6	8/26/2006	135	14	9/29/2006	22.4	920.6	40.1
Haymaker	7	8/26/2006	132	12	9/29/2006	14.5	834.7	26.0
Haymaker	8	8/26/2006	139	18	9/29/2006	13.3	1073.5	41.9
Haymaker	10	8/26/2006	163	25	9/29/2006	29.5	1146.8	54.1
Haymaker	11	8/26/2006	155	21	9/29/2006	12.0	1086.5	42.1
Haymaker	12	8/26/2006	138	15	9/29/2006	15.8	933.7	35.8
Haymaker	15	8/26/2006	179	33	9/29/2006	28.5	828.2	24.1
Haymaker	16	8/26/2006	136	13	9/29/2006	43.7	1220.3	53.7
Haymaker	18	8/26/2006	144	16	9/29/2006	25.0	927.1	41.9
Haymaker	21	8/26/2006	137	15	9/29/2006	25.4	909.5	30.5
Haymaker	22	8/26/2006	128	12	9/29/2006	21.8	1157.8	54.5
Haymaker	24	8/26/2006	165	25	9/29/2006	37.2	1027.7	48.4
Haymaker	26	8/26/2006	144	18	9/29/2006	15.4	872.5	29.5
Haymaker	27	8/26/2006	144	16	9/29/2006	33.5	987.3	34.3
Haymaker	29	8/26/2006	259	109	9/29/2006	10.5	806.7	28.1
Haymaker	30	8/26/2006	280	139	9/29/2006	12.9	860.5	28.4
Haymaker	31	8/26/2006	244	90	9/29/2006	21.1	952.4	43.9
Haymaker	32	8/26/2006	232	80	9/29/2006	13.9	882.9	33.8
Haymaker	33	8/26/2006	274	109	9/29/2006	52.6	1071.0	49.8
Haymaker	34	8/26/2006	287	149	9/29/2006	20.1	1008.6	35.8
Haymaker	35	8/26/2006	253	96	9/29/2006	37.1	1010.8	52.2
Lafarge	1	8/26/2006	178	31	10/2/2006	22.3	558.7	11.4
Lafarge	2	8/26/2006	189	41	10/2/2006	59.9	608.5	23.0
Lafarge	4	8/26/2006	208	51	10/2/2006	15.0	490.9	10.1
Lafarge	5	8/26/2006	169	32	10/2/2006	27.3	813.4	20.3
Lafarge	6	8/26/2006	155	23	11/2/2006	86.1	684.2	29.7
Lafarge	7	8/26/2006	158	31	10/2/2006	42.4	673.8	26.9
Lafarge	9	8/26/2006	229	75	10/2/2006	10.3	427.8	8.6
Lafarge	10	8/26/2006	215	64	10/2/2006	39.2	769.1	24.8
Lafarge	11	8/26/2006	152	20	10/2/2006	41.7	795.1	24.9
Lafarge	12	8/26/2006	184	35	11/2/2006	41.6	566.1	19.4
Lafarge	13	8/26/2006	78	33	10/2/2006	44.9	648.9	19.1
Lafarge	14	8/26/2006	202	44	10/2/2006	47.4	716.7	28.4
Lafarge	15	8/26/2006	173	29	10/2/2006	63.1	768.1	38.0
Lafarge	16	8/26/2006	155	21	10/2/2006	55.4	739.9	27.3
Lafarge	17	8/26/2006	183	35	10/2/2006	21.0	696.6	19.8
Lafarge	18	8/26/2006	187	41	10/2/2006	25.5	565.0	17.5
Lafarge	19	8/26/2006	148	19	10/2/2006	27.5	747.7	23.8
Lafarge	20	8/26/2006	177	31	10/2/2006	31.3	642.6	20.1
Lafarge	21	8/26/2006	169	27	10/2/2006	33.3	663.4	28.4
Lafarge	22	8/26/2006	167	29	10/2/2006	26.6	627.4	14.5
Lafarge	23	8/26/2006	177	32	10/2/2006	48.0	768.1	23.8
Lafarge	24	8/26/2006	164	42	11/2/2006	19.9	722.7	19.3

Lafarge	25	8/26/2006	185	37	10/2/2006	44.2	732.5	23.7
Lafarge	26	8/26/2006	204	50	11/2/2006	75.1	683.1	34.6
Lafarge	27	8/26/2006	172	31	10/2/2006	37.2	683.7	21.3
Lafarge	28	8/26/2006	185	38	10/2/2006	25.1	555.0	16.2
Lafarge	30	8/26/2006	160	22	11/2/2006	31.1	641.7	24.3
Ski Pond	2	8/27/2006	139	14	10/2/2006	7.0	718.8	23.3
Ski Pond	3	8/27/2006	132	13	10/2/2006	9.7	708.1	28.2
Ski Pond	4	8/27/2006	118	8	10/2/2006	7.3	686.0	17.5
Ski Pond	5	8/27/2006	144	18	10/2/2006	47.7	768.2	33.4
Ski Pond	6	8/27/2006	126	11	10/2/2006	11.4	793.1	32.1
Ski Pond	7	8/27/2006	125	13	10/2/2006	6.8	860.6	22.9
Ski Pond	8	8/27/2006	131	12	10/2/2006	23.9	831.8	28.9
Ski Pond	9	8/27/2006	120	9	10/2/2006	13.4	755.3	38.1
Ski Pond	10	8/27/2006	153	20	10/2/2006	9.0	669.8	19.9
Ski Pond	11	8/27/2006	144	18	10/2/2006	11.4	740.7	24.4
Ski Pond	13	8/27/2006	138	15	10/2/2006	10.9	773.3	32.3
Ski Pond	15	8/27/2006	149	19	10/2/2006	13.3	746.6	35.2
Ski Pond	16	8/27/2006	125	11	10/2/2006	14.7	677.0	20.9
Ski Pond	17	8/27/2006	141	18	10/2/2006	13.5	711.5	22.8
Ski Pond	18	8/27/2006	110	8	10/2/2006	13.6	612.7	16.9
Ski Pond	19	8/27/2006	132	14	10/2/2006	13.0	630.6	17.7
Ski Pond	20	8/27/2006	119	8	10/2/2006	30.5	798.0	28.6
Ski Pond	21	8/27/2006	137	13	10/2/2006	28.4	806.3	27.1
Ski Pond	22	8/27/2006	151	17	10/2/2006	10.6	669.6	24.3
Ski Pond	23	8/27/2006	144	19	10/2/2006	12.0	736.1	25.2
Ski Pond	24	8/27/2006	148	19	10/2/2006	17.3	733.6	29.0
Ski Pond	25	8/27/2006	147	18	10/2/2006	18.7	851.6	49.0
Ski Pond	26	8/27/2006	149	19	10/2/2006	11.0	680.5	21.4
Ski Pond	27	8/27/2006	150	19	10/2/2006	14.8	801.3	29.2
Ski Pond	28	8/27/2006	128	12	10/2/2006	7.5	678.2	21.4
Ski Pond	29	8/27/2006	128	12	10/2/2006	11.2	828.0	29.5
Ski Pond	30	8/27/2006	123	10	10/2/2006	8.6	762.5	24.9
Ski Pond	31	8/27/2006	136	14	10/2/2006	11.5	647.2	19.1
Ski Pond	33	8/27/2006	137	14	10/2/2006	26.7	833.9	37.2
Ski Pond	34	8/27/2006	135	13	10/2/2006	13.8	691.5	29.5
Ski Pond	36	8/27/2006	125	9	10/2/2006	10.0	658.8	21.6
Ski Pond	37	8/27/2006	125	12	10/2/2006	21.7	763.9	30.2
Ski Pond	38	8/27/2006	117	8	10/2/2006	9.1	835.4	30.9
Ski Pond	39	8/27/2006	137	15	10/2/2006	12.8	744.3	25.3
Ski Pond	43	8/27/2006	117	8	10/2/2006	18.7	817.9	32.7
Ski Pond	44	8/27/2006	124	11	10/2/2006	10.3	780.3	33.2
Ski Pond	45	8/27/2006	155	23	10/2/2006	8.6	654.6	23.5
Ski Pond	46	8/27/2006	128	11	10/2/2006	9.1	733.1	28.3
Ski Pond	47	8/27/2006	143	17	10/2/2006	10.0	748.6	23.4
Stagecoach	2	8/26/2006	140	15	10/2/2006	31.9	773.6	35.3

Stagecoach	4	8/26/2006	151	21	9/29/2006	45.7	913.7	48.5
Stagecoach	6	8/26/2006	137	15	10/2/2006	8.0	687.4	16.6
Stagecoach	8	8/26/2006	115	10	9/29/2006	43.1	875.3	28.4
Stagecoach	10	8/26/2006	159	25	10/2/2006	41.1	649.2	21.3
Stagecoach	11	8/26/2006	133	13	9/29/2006	40.8	834.7	33.3
Stagecoach	12	8/26/2006	158	23	10/2/2006	23.5	654.4	25.9
Stagecoach	13	8/26/2006	149	20	10/2/2006	21.5	769.5	31.0
Stagecoach	14	8/26/2006	174	29	10/2/2006	31.6	632.1	24.4
Stagecoach	15	8/26/2006	132	14	10/2/2006	35.2	598.1	19.3
Stagecoach	16	8/26/2006	125	12	10/2/2006	67.9	712.8	36.7
Stagecoach	17	8/26/2006	125	11	10/2/2006	29.6	723.8	20.0
Stagecoach	18	8/26/2006	170	27	10/2/2006	44.2	713.4	26.4
Stagecoach	19	8/26/2006	161	24	10/2/2006	32.7	761.6	25.2
Stagecoach	20	8/26/2006	169	29	9/29/2006	23.4	848.6	50.1
Stagecoach	22	8/26/2006	157	24	9/29/2006	37.5	1202.9	65.7
Stagecoach	23	8/26/2006	166	28	10/2/2006	37.1	741.2	25.9
Stagecoach	24	8/26/2006	149	20	9/29/2006	46.6	937.1	35.8
Stagecoach	25	8/26/2006	152	22	9/29/2006	76.3	1016.0	36.6
Stagecoach	26	8/26/2006	164	29	9/29/2006	35.4	1077.2	49.2
Stagecoach	27	8/26/2006	153	23	9/29/2006	20.4	903.7	41.3
Stagecoach	29	8/26/2006	159	25	10/2/2006	38.2	807.1	35.3
Stagecoach	30	8/26/2006	121	11	10/2/2006	40.0	580.5	17.6
Stagecoach	31	8/26/2006	144	19	9/29/2006	33.5	859.2	36.1
Stagecoach	32	8/26/2006	128	12	9/29/2006	20.5	804.6	39.1
Stagecoach	33	8/26/2006	148	21	9/29/2006	26.2	901.4	37.5
Stagecoach	34	8/26/2006	156	23	9/29/2006	19.5	804.5	33.1
Stagecoach	35	8/26/2006	173	29	9/29/2006	71.7	794.7	30.5
Stagecoach	39	8/26/2006	164	27	10/2/2006	51.8	587.9	21.8
Stagecoach	40	8/26/2006	128	12	9/29/2006	15.9	925.3	35.5
Stagecoach	41	8/26/2006	165	26	9/29/2006	38.2	928.4	62.6
Stagecoach	43	8/26/2006	149	21	9/29/2006	67.6	762.9	27.0
Stagecoach	44	8/26/2006	145	17	9/29/2006	111.5	995.0	59.7
Stagecoach	46	8/26/2006	180	39	10/2/2006	41.2	665.9	24.4
Stagecoach	47	8/26/2006	165	27	10/2/2006	21.5	660.5	20.7
Stagecoach	49	8/26/2006	143	18	10/2/2006	49.2	751.4	40.3
Stagecoach	50	8/26/2006	138	15	10/2/2006	85.9	666.2	25.4
Stagecoach	51	8/26/2006	153	19	10/2/2006	26.9	759.8	34.8
Stagecoach	52	8/26/2006	134	13	10/2/2006	36.2	608.9	26.4
Stagecoach	53	8/26/2006	100	7	10/2/2006	28.0	592.0	11.9
YSWA	5	8/26/2006	143	16	9/29/2006	36.8	887.2	35.2
YSWA	6	8/26/2006	128	10	9/29/2006	57.7	818.9	29.2
YSWA	7	8/26/2006	128	11	9/29/2006	32.5	660.3	28.5
YSWA	11	8/26/2006	151	18	9/29/2006	38.9	734.2	32.2
YSWA	13	8/26/2006	154	20	9/29/2006	51.4	769.6	38.6
YSWA	15	8/26/2006	151	18	9/29/2006	39.5	953.5	38.1



YSWA	16	8/26/2006	133	12	9/29/2006	18.8	715.3	23.9
YSWA	17	8/26/2006	125	11	9/29/2006	42.3	716.8	21.6
YSWA	18	8/26/2006	145	20	9/29/2006	26.0	785.2	37.5
YSWA	19	8/26/2006	144	18	9/29/2006	62.2	822.9	26.8
YSWA	21	8/26/2006	132	10	9/29/2006	49.3	1013.7	28.4
YSWA	22	8/26/2006	127	11	9/29/2006	56.3	759.8	27.1
YSWA	26	8/26/2006	127	13	9/29/2006	30.6	603.4	12.7
YSWA	27	8/26/2006	126	10	9/29/2006	33.9	747.6	30.0
YSWA	30	8/26/2006	125	9	9/29/2006	23.9	631.8	19.7
YSWA	33	8/26/2006	130	13	9/29/2006	26.8	691.5	24.8
YSWA	35	8/26/2006	137	15	9/29/2006	66.0	774.5	29.3
YSWA	37	8/26/2006	124	10	9/29/2006	26.2	667.1	22.5
YSWA	41	8/26/2006	128	11	9/29/2006	35.2	753.7	23.5
YSWA	43	8/26/2006	129	11	9/29/2006	38.3	784.1	29.5
YSWA	44	8/26/2006	144	15	9/29/2006	21.1	704.1	22.6
YSWA	50	8/26/2006	121	9	9/29/2006	23.5	650.1	14.6
YSWA	56	8/26/2006	132	11	9/29/2006	36.5	688.7	19.7
YSWA	57	8/26/2006	128	11	9/29/2006	26.4	626.4	16.3
YSWA	58	8/26/2006	144	15	9/29/2006	39.5	856.4	38.6
YSWA	59	8/26/2006	131	12	9/29/2006	32.7	664.8	25.7
YSWA	60	8/26/2006	126	10	9/29/2006	48.1	794.6	23.6
YSWA	61	8/26/2006	132	11	9/29/2006	26.2	689.0	22.1
YSWA	62	8/26/2006	139	14	9/29/2006	52.7	853.6	24.9
YSWA	68	8/26/2006	129	13	9/29/2006	35.3	716.8	20.5
YSWA	70	8/26/2006	132	13	9/29/2006	70.0	832.7	30.4
YSWA	71	8/26/2006	133	13	9/29/2006	45.5	743.9	30.6

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**Appendix D:** Location, fish identification number, date collected, total length (mm), weight (g), date ablated, manganese concentration (ppm), strontium concentration (ppm), and barium concentration (ppm) of northern pike collected 2005 in various locations throughout the Yampa River, Colorado.

Location	Fish ID #	Date collected	Length (mm)	Weight (g)	Date ablated	Mn55	Sr86	Ba137
Stagecoach	1	10/7/2005	204	53	11/21/2005	20.3	763	28.9
Stagecoach	2	10/7/2005	168	27	11/21/2005	34.4	866	40.8
Stagecoach	4	10/7/2005	168	28	11/21/2005	70.6	914	36.4
Stagecoach	5	10/7/2005	169	26	11/21/2005	53.4	1037	49.0
Stagecoach	6	10/7/2005	208	50	11/21/2005	17.5	701	19.0
Stagecoach	7	10/7/2005	151	19	11/21/2005	44.8	880	43.5
Stagecoach	8	10/7/2005	163	24	11/21/2005	36.3	825	24.1
Stagecoach	9	10/8/2005	133	14	11/21/2005	23.9	805	27.2
Stagecoach	10	10/8/2005	156	21	11/21/2005	40.7	939	44.2
Stagecoach	11	10/8/2005	185	37	11/21/2005	16.3	698	15.8
Stagecoach	12	10/8/2005	168	25	11/21/2005	31.3	834	31.3
Stagecoach	13	10/8/2005	150	19	11/21/2005	24.6	869	36.1
Stagecoach	14	10/8/2005	160	23	11/21/2005	35.4	778	32.7
Stagecoach	16	10/8/2005	189	38	11/21/2005	21.5	766	18.3
Stagecoach	19	10/1/2005	185	41	4/14/2006	11.7	669	22.9
Stagecoach	21	10/1/2005	150	19	4/14/2006	41.1	671	19.2
Stagecoach	22	10/1/2005	164	25	4/14/2006	39.3	703	31.9
Stagecoach	23	10/1/2005	141	17	4/14/2006	25.3	696	29.2
Stagecoach	24	10/1/2005	168	28	4/14/2006	23.5	711	39.0
Stagecoach	25	10/1/2005	147	19	4/14/2006	34.3	655	26.8
Stagecoach	26	10/1/2005	140	17	4/14/2006	15.6	691	22.2
Stagecoach	27	10/1/2005	154	22	4/14/2006	34.8	665	21.0
Stagecoach	28	10/1/2005	135	16	4/14/2006	26.5	611	20.6
Stagecoach	29	10/1/2005	150	18	4/14/2006	27.9	673	22.5
Stagecoach	30	10/1/2005	154	21	4/14/2006	29.4	790	34.9
Stagecoach	31	10/7/2005	167	25	4/14/2006	34.1	750	30.6
Stagecoach	32	10/7/2005	158	22	4/14/2006	18.5	707	28.1
Stagecoach	33	10/7/2005	154	22	4/14/2006	41.6	756	28.2
Stagecoach	34	10/7/2005	157	24	4/14/2006	27.7	782	31.7
Stagecoach	35	10/7/2005	164	28	4/14/2006	34.2	771	40.2
Stagecoach	36	10/7/2005	160	19	4/14/2006	25.8	691	21.4
Stagecoach	37	10/7/2005	154	23	4/14/2006	32.9	665	23.7
Stagecoach	38	10/7/2005	124	14	4/14/2006	14.4	538	14.2
Stagecoach	39	10/7/2005	156	25	4/14/2006	35.4	633	21.8
Catamount	1	7/25/2005	163	32	10/28/2005	50.9	519	45.0
Catamount	2	7/25/2005	175	36	10/28/2005	93.0	1048	34.6
Catamount	3	7/25/2005	94	6	10/28/2005	26.3	584	40.9

Catamount	4	7/25/2005	143	24	10/28/2005	101	918	50.1
Catamount	5	7/25/2005	127	11	10/28/2005	18.9	471	43.9
Catamount	6	7/25/2005	118	11	10/28/2005	59.7	639	70.1
Catamount	7	7/25/2005	158	30	10/28/2005	129	776	66.9
Catamount	8	7/25/2005	111	9	10/28/2005	34.2	627	54.3
Catamount	9	7/25/2005	77	3	10/28/2005	15.7	514	47.2
Catamount	10	7/25/2005	88	3	4/14/2006	22.0	431	45.0
Catamount	11	7/25/2005	98	7	10/28/2005	48.5	578	51.4
Catamount	16	7/25/2005	105	7	4/14/2006	17.3	375	25.2
Catamount	17	7/25/2005	86	4	4/14/2006	10.1	417	36.0
Catamount	18	7/25/2005	70	3	4/14/2006	18.5	380	26.6
Catamount	21	7/25/2005	86	4	4/14/2006	20.5	431	28.3
Catamount	22	7/25/2005	130	15	4/14/2006	38.7	720	46.1
Catamount	23	7/25/2005	93	5	4/14/2006	27.3	737	65.5
Catamount	24	7/25/2005	102	7	4/14/2006	23.6	388	39.7
Catamount	25	7/25/2005	115	11	4/14/2006	19.1	550	46.0
Catamount	26	7/25/2005	124	13	4/14/2006	15.7	410	32.8
Catamount	27	7/25/2005	102	7	4/14/2006	23.2	322	28.5
Catamount	28	7/25/2005	129	14	4/14/2006	38.6	353	28.9
Catamount	29	7/25/2005	146	22	4/14/2006	72.1	536	27.2
Catamount	30	7/25/2005	85	4	4/14/2006	22.5	370	23.8
Catamount	31	7/25/2005	148	25	4/14/2006	57.0	517	18.7
Catamount	32	7/25/2005	75	2	4/14/2006	12.8	344	24.4
Catamount	33	7/25/2005	98	7	4/14/2006	19.9	379	26.8
Catamount	34	7/25/2005	101	7	4/14/2006	21.2	370	29.1
Catamount	35	7/25/2005	100	7	4/14/2006	21.4	605	41.9
Catamount	36	7/25/2005	77	3	4/14/2006	16.0	319	23.0
Catamount	37	7/25/2005	88	4	4/14/2006	5.8	351	22.6
Catamount	38	7/25/2005	76	3	4/14/2006	15.2	314	23.1
Catamount	39	7/25/2005	117	11	4/14/2006	17.8	370	26.6
Catamount	40	7/25/2005	106	9	4/14/2006	21.7	302	20.2
Catamount	41	7/25/2005	129	15	4/14/2006	49.9	509	41.4
Catamount	42	7/25/2005	137	18	4/14/2006	48.1	709	24.4
Catamount	44	7/25/2005	137	17	4/14/2006	45.5	473	27.1
Catamount	45	7/25/2005	128	14	4/14/2006	16.6	369	25.0
Catamount	46	7/25/2005	225	72	4/14/2006	185.1	826	43.7
Catamount	47	7/25/2005	219	67	4/14/2006	51.8	780	33.7
Catamount	48	7/25/2005	234	75	4/14/2006	42.9	499	35.5
Catamount	49	7/25/2005	218	67	4/14/2006	106.6	794	40.9
Catamount	50	7/25/2005	215	67	4/14/2006	104.9	867	48.0
Catamount	51	7/25/2005	259	123	4/14/2006	151.3	777	32.3
Catamount	52	7/25/2005	207	58	4/14/2006	111.0	761	46.9
Catamount	53	7/25/2005	196	49	4/14/2006	125.3	900	39.6
Catamount	54	7/25/2005	240	92	4/14/2006	84.1	655	40.7
Catamount	55	7/25/2005	202	56	4/14/2006	149.3	856	49.9

Catamount	56	7/25/2005	244	92	4/14/2006	67.8	826	52.1
Catamount	57	7/25/2005	228	77	4/14/2006	111.9	774	49.6
Catamount	58	7/25/2005	241	88	4/14/2006	60.6	733	27.8
Catamount	59	7/25/2005	240	70	4/14/2006	95.4	610	30.2
Catamount	60	7/25/2005	202	49	4/14/2006	54.5	898	29.5
Catamount	61	7/25/2005	240	95	4/14/2006	177.5	798	55.5
Catamount	62	7/25/2005	221	72	4/14/2006	48.0	791	46.9
Haymaker	1	7/27/2005	81	3	11/21/2005	15.0	963	41.44
Haymaker	2	7/27/2005	127	13	11/21/2005	29.2	776	27.99
Haymaker	3	7/27/2005	82	3	11/21/2005	38.0	1178	47.25
Haymaker	4	7/27/2005	112	9	11/21/2005	15.6	737	22.39
Haymaker	5	7/27/2005	81	3	11/21/2005	13.6	1002	34.24
Haymaker	6	7/27/2005	103	7	11/21/2005	25.8	729	23.97
Haymaker	7	7/27/2005	105	7	11/21/2005	31.8	916	38.99
Haymaker	8	7/27/2005	93	5	11/21/2005	22.1	811	33.01
Haymaker	10	7/27/2005	119	11	11/21/2005	15.5	759	21.00
Haymaker	11	7/27/2005	75	2	11/21/2005	45.1	1631	78.17
Haymaker	13	7/27/2005	104	7	11/21/2005	89.1	1188	58.03
Haymaker	14	7/27/2005	115	9	11/21/2005	28.0	797	29.20
Haymaker	15	7/27/2005	142	19	11/21/2005	21.4	1094	37.52
Haymaker	16	7/27/2005	94	5	4/14/2006	26.6	718	30.5
Haymaker	19	7/27/2005	137	16	4/14/2006	23.6	561	20.1
Haymaker	21	7/27/2005	83	4	4/14/2006	18.5	760	31.7
Haymaker	22	7/27/2005	85	4	4/14/2006	17.7	787	28.1
Haymaker	23	7/27/2005	98	6	4/14/2006	30.2	828	33.3
Haymaker	24	7/27/2005	80	4	4/14/2006	29.8	823	29.4
Haymaker	26	7/27/2005	83	3	4/14/2006	11.6	782	21.8
Haymaker	27	7/27/2005	96	5	4/14/2006	20.8	751	30.2
Haymaker	28	7/27/2005	90	4	4/14/2006	14.6	737	30.3
Haymaker	29	7/27/2005	89	4	4/14/2006	12.0	553	20.1
Haymaker	30	7/27/2005	87	4	4/14/2006	15.8	703	28.6
Haymaker	31	7/27/2005	78	3	4/14/2006	16.0	670	19.3
Haymaker	32	7/27/2005	82	3	4/14/2006	17.1	732	18.9
Haymaker	36	10/2/2005	137	11	4/21/2006	9.4	794	32.91
Haymaker	37	10/2/2005	153	19	4/21/2006	65.5	879	47.70
Haymaker	38	10/2/2005	141	16	4/21/2006	25.5	806	33.33
Haymaker	40	10/2/2005	145	16	4/21/2006	27.2	909	32.69
Haymaker	42	10/2/2005	149	17	4/21/2006	36.0	864	42.82
Haymaker	43	10/2/2005	157	23	4/21/2006	16.2	735	28.88
Haymaker	44	10/2/2005	162	24	4/21/2006	32.0	817	37.01
Haymaker	45	10/2/2005	125	11	4/21/2006	19.2	975	46.98
Haymaker	46	10/2/2005	165	26	4/21/2006	20.8	738	29.83
Haymaker	47	10/2/2005	192	41	4/21/2006	15.5	854	28.37
Haymaker	48	10/2/2005	145	21	4/21/2006	13.9	885	28.67
Haymaker	49	10/2/2005	142	20	4/21/2006	11.5	785	22.43

Haymaker	51	10/2/2005	128	11	4/21/2006	11.3	836	33.13
Haymaker	52	10/2/2005	173	27	4/21/2006	26.9	754	31.33
Haymaker	53	10/2/2005	220	62	4/21/2006	17.3	656	25.98
Haymaker	55	10/2/2005	147	19	4/21/2006	18.6	1027	44.34
Haymaker	56	10/2/2005	131	13	4/21/2006	33.7	1037	54.90
Haymaker	57	10/2/2005	154	21	4/21/2006	15.67	916	41.12
Haymaker	58	10/2/2005	154	20	4/21/2006	19.22	831	31.22
Haymaker	59	10/2/2005	143	16	4/21/2006	9.57	950	36.48
Haymaker	61	10/2/2005	147	18	4/21/2006	22.59	733	31.14
Haymaker	62	10/2/2005	170	26	4/21/2006	15.23	712	26.45
Haymaker	63	10/2/2005	126	10	4/21/2006	12.08	916	38.27
Haymaker	64	10/2/2005	127	11	4/21/2006	38.75	996	48.77
Haymaker	65	10/2/2005	131	12	4/21/2006	24.24	990	47.11
Haymaker	66	10/2/2005	129	14	4/21/2006	49.85	990	40.25
Haymaker	68	10/2/2005	168	27	4/21/2006	21.53	820	31.36
Haymaker	69	10/2/2005	171	29	4/21/2006	21.09	988	57.79
Haymaker	71	10/2/2005	145	17	4/21/2006	17.63	945	41.15
Lafarge	2	7/11/2005			10/28/2005	18.2	568	14.0
Lafarge	3	7/11/2005			10/28/2005	55.7	769	24.9
Lafarge	4	7/11/2005			10/28/2005	16.8	873	22.4
Lafarge	5	7/11/2005			10/28/2005	71.3	900	26.3
Lafarge	6	7/11/2005			10/28/2005	14.2	620	11.1
Lafarge	7	7/11/2005			10/28/2005	22.8	782	25.7
Lafarge	8	7/11/2005			10/28/2005	17.3	741	16.2
Lafarge	18	7/11/2005	111	9	4/14/2006	13.7	485	12.8
Lafarge	19	7/11/2005	107	7	4/14/2006	13.6	461	12.8
Lafarge	20	7/11/2005	100	7	4/14/2006	37.1	670	16.4
Lafarge	21	7/11/2005	61	1	4/14/2006	64.4	687	25.3
Lafarge	22	7/11/2005	93	5	4/14/2006	24.1	568	16.6
Lafarge	23	7/11/2005	92	5	4/14/2006	46.8	700	22.4
Lafarge	25	7/11/2005	127	13	4/14/2006	18.7	519	14.5
Lafarge	26	7/11/2005	82	3	4/14/2006	11.9	568	17.9
Lafarge	27	7/11/2005	104	7	4/14/2006	23.3	535	14.6
Lafarge	28	7/11/2005	108	8	4/14/2006	32.2	583	19.1
Lafarge	30	7/11/2005	96	7	4/14/2006	10.6	400	10.4
Lafarge	31	7/11/2005	75	3	4/14/2006	22.2	541	14.7
Lafarge	32	7/11/2005	91	4	4/14/2006	13.3	437	7.9
Lafarge	33	7/11/2005	103	7	4/14/2006	17.9	446	9.4
Lafarge	34	7/11/2005	105	7	4/14/2006	24.6	454	9.2
Lafarge	35	7/11/2005	110	8	4/14/2006	13.3	440	8.7
Lafarge	36	10/7/2005	201	49	4/14/2006	9.9	475	7.8
Lafarge	37	10/7/2005	170	32	4/14/2006	26.2	481	8.1
Lafarge	39	10/7/2005	179	34	4/14/2006	13.2	392	6.6
Lafarge	40	10/7/2005	156	24	4/14/2006	17.3	397	8.4
Lafarge	41	10/7/2005	192	45	4/14/2006	14.5	385	8.0

Lafarge	42	10/7/2005	160	28	4/14/2006	27.8	482	10.9
Lafarge	43	10/7/2005	200	52	4/14/2006	26.8	464	12.0
Lafarge	44	10/7/2005	131	15	4/14/2006	33.8	548	10.5
Lafarge	45	10/7/2005	185	44	4/14/2006	7.8	427	6.5
Lafarge	46	10/7/2005	165	30	4/14/2006	78.1	544	19.4
Lafarge	48	10/7/2005	174	30	4/14/2006	33.8	438	8.7
Lafarge	49	10/7/2005	160	25	4/14/2006	38.1	533	14.5
Lafarge	50	10/7/2005	165	28	4/14/2006	22.4	545	8.9
Lafarge	51	10/7/2005	191	41	4/14/2006	31.1	517	13.2
Lafarge	52	10/7/2005	174	31	4/14/2006	14.7	446	9.8
Lafarge	53	10/7/2005	160	24	4/14/2006	23.6	448	9.5
Lafarge	55	10/7/2005	178	35	4/14/2006	10.3	451	6.1
Lafarge	57	10/7/2005	175	34	4/14/2006	8.5	419	7.2
Lafarge	58	10/7/2005	189	41	4/14/2006	19.0	506	12.9
Lafarge	59	10/7/2005	221	82	4/14/2006	18.0	467	10.2
Lafarge	60	10/7/2005	192	49	4/14/2006	19.6	474	8.1
Lafarge	61	10/7/2005	149	19	4/14/2006	14.4	467	9.3
Ski Pond	1	7/15/2005	90	4	10/28/2005	13.6	960	31.6
Ski Pond	2	7/15/2005	67	2	10/28/2005	12.2	762	26.0
Ski Pond	3	7/15/2005	76	3	10/28/2005	15.7	900	28.2
Ski Pond	5	7/15/2005	89	4	10/28/2005	18.6	1071	56.7
Ski Pond	6	7/15/2005	92	5	10/28/2005	22.7	987	43.8
Ski Pond	7	7/15/2005	89	4	10/28/2005	14.6	999	32.5
Ski Pond	8	7/15/2005	96	6	10/28/2005	33.0	1213	56.0
Ski Pond	9	7/15/2005	88	4	10/28/2005	37.7	1058	55.3
Ski Pond	10	7/15/2005	91	5	10/28/2005	12.8	832	30.3
Ski Pond	16	7/13/2005	95	5	4/14/2006	15.2	574	20.6
Ski Pond	18	7/13/2005	74	33	4/14/2006	25.7	608	16.6
Ski Pond	19	7/13/2005	85	4	4/14/2006	11.4	633	22.0
Ski Pond	20	7/13/2005	72	2	4/14/2006	9.2	692	17.4
Ski Pond	21	7/13/2005	80	4	4/14/2006	13.9	663	17.9
Ski Pond	22	7/13/2005	96	5	4/14/2006	18.3	720	23.6
Ski Pond	23	7/13/2005	81	3	4/14/2006	15.3	656	23.7
Ski Pond	24	7/13/2005	83	4	4/14/2006	14.4	602	16.7
Ski Pond	25	7/13/2005	87	4	4/14/2006	25.4	536	18.9
Ski Pond	26	7/13/2005	89	4	4/14/2006	11.9	663	21.0
Ski Pond	27	7/13/2005	86	4	4/14/2006	23.5	648	18.0
Ski Pond	28	7/13/2005	112	9	4/14/2006	21.6	588	15.1
Ski Pond	29	7/13/2005	94	5	4/14/2006	15.4	618	17.0
Ski Pond	30	7/13/2005	87	4	4/14/2006	12.3	545	16.9
Ski Pond	31	7/13/2005	81	4	4/14/2006	12.6	607	15.1
Ski Pond	32	7/13/2005	77	3	4/14/2006	36.8	640	21.0
Ski Pond	34	10/9/2005	168	27	4/20/2006	26.7	770	29.3
Ski Pond	35	10/9/2005	155	24	4/20/2006	27.4	859	43.7
Ski Pond	36	10/9/2005	139	15	4/20/2006	51.9	695	33.6

Ski Pond	37	10/9/2005	144	19	4/20/2006	41.4	824	37.2
Ski Pond	38	10/9/2005	162	23	4/20/2006	39.7	783	31.3
Ski Pond	39	10/9/2005	187	39	4/20/2006	23.9	713	27.9
Ski Pond	41	10/9/2005	143	18	4/20/2006	18.3	888	26.9
Ski Pond	42	10/9/2005	108	7	4/20/2006	13.1	810	29.4
Ski Pond	43	10/9/2005	232	69	4/20/2006	11.9	637	20.0
Ski Pond	44	10/9/2005	276	117	4/21/2006	13.7	766	28.57
Ski Pond	45	10/9/2005	251	96	4/21/2006	10.7	734	25.83
Ski Pond	46	10/9/2005	202	46	4/20/2006	11.8	770	30.2
Ski Pond	47	10/9/2005	222	61	4/20/2006	17.7	698	24.5
Ski Pond	48	10/9/2005	272	123	4/21/2006	22.6	731	24.61
Ski Pond	49	10/9/2005	254	88	4/20/2006	14.5	684	20.3
Ski Pond	50	10/9/2005	247	78	4/20/2006	25.5	818	26.7
Ski Pond	52	10/9/2005	285	151	4/21/2006	9.4	703	19.31
Ski Pond	53	10/9/2005	132	13	4/20/2006	24.2	742	26.3
Ski Pond	54	10/9/2005	149	22	4/20/2006	33.6	765	32.6
Ski Pond	55	10/9/2005	155	20	4/20/2006	34.5	832	34.8
Ski Pond	56	10/9/2005	132	12	4/20/2006	30.9	819	29.9
Ski Pond	57	10/9/2005	145	22	4/20/2006	20.8	715	23.4
Ski Pond	58	10/9/2005	129	11	4/20/2006	15.8	793	40.1
Ski Pond	59	10/9/2005	121	10	4/21/2006	11.5	731	25.19
Ski Pond	60	10/9/2005	115	8	4/20/2006	16.7	804	35.3
Ski Pond	61	10/9/2005	145	17	4/20/2006	37.9	744	31.9
Ski Pond	62	10/9/2005	138	14	4/20/2006	16.4	754	38.1
YSWA	2	8/26/2005	246	93	4/21/2006	47.9	838	16.54
YSWA	3	8/26/2005	171	31	10/28/2005	53.7	168	3.76
YSWA	6	8/26/2005	201	47	4/21/2006	28.6	606	15.80
YSWA	7	8/26/2005	167	27	10/28/2005	90.0	840	42.1
YSWA	8	8/26/2005	183	39	10/28/2005	39.5	867	25.7
YSWA	9	8/26/2005	244	97	4/21/2006	68.8	668	29.28
YSWA	10	8/26/2005	168	27	10/28/2005	107.0	935	35.4
YSWA	14	8/26/2005	193	42	4/21/2006	53.0	693	38.70
YSWA	15	8/26/2005	179	34	10/28/2005	126.4	906	33.3
YSWA	16	8/26/2005	154	19	10/28/2005	60.1	1033	38.2
YSWA	17	8/26/2005	198	41	4/21/2006	49.6	741	23.82
YSWA	18	8/26/2005	183	33	10/28/2005	94.5	925	34.7
YSWA	19	8/26/2005	175	31	10/28/2005	49.5	853	31.8
YSWA	20	8/26/2005	184	36	10/28/2005	121.7	894	43.1
YSWA	21	8/26/2005	194	43	4/21/2006	112.6	656	31.71
YSWA	22	8/26/2005	166	25	4/21/2006	60.9	905	33.81
YSWA	23	8/26/2005			4/14/2006	156.3	623	27.4
YSWA	24	8/26/2005			4/14/2006	101.8	618	21.8
YSWA	25	8/26/2005			4/14/2006	39.5	605	20.3
YSWA	27	8/26/2005			4/14/2006	72.1	647	21.3
YSWA	28	8/26/2005			4/14/2006	113.9	649	26.6

YSWA	29	8/26/2005			4/14/2006	49.6	620	16.8
YSWA	30	8/26/2005			4/14/2006	134.6	649	25.0
YSWA	31	8/26/2005			4/14/2006	173.9	668	25.4
YSWA	32	8/26/2005			4/14/2006	92.0	684	33.1
YSWA	33	8/26/2005			4/14/2006	71.8	577	20.9
YSWA	34	8/26/2005			4/14/2006	51.0	509	11.3
YSWA	35	8/26/2005			4/14/2006	145.1	815	28.3
YSWA	36	8/26/2005			4/14/2006	61.3	592	17.0
YSWA	37	8/26/2005			4/14/2006	95.0	636	20.7
YSWA	38	8/26/2005			4/14/2006	89.9	710	29.1
YSWA	39	8/26/2005			4/14/2006	84.9	601	25.9
YSWA	40	8/26/2005			4/14/2006	101.5	612	21.6
YSWA	41	8/26/2005			4/14/2006	42.2	706	21.6
YSWA	42	8/26/2005			4/14/2006	101.2	607	22.5
YSWA	43	8/26/2005			4/14/2006	55.8	567	17.3
YSWA	44	8/26/2005			4/14/2006	56.6	504	18.4
YSWA	45	8/26/2005			4/14/2006	62.2	606	20.7
YSWA	46	8/26/2005			4/14/2006	112.6	651	19.4
YSWA	47	8/26/2005			4/14/2006	75.8	597	18.8
YSWA	48	8/26/2005			4/14/2006	156.3	669	28.1
YSWA	49	8/26/2005			4/14/2006	62.2	573	17.0
YSWA	50	8/26/2005			4/14/2006	159.5	575	22.2
YSWA	51	8/26/2005			4/14/2006	76.9	587	22.9
YSWA	52	8/26/2005			4/14/2006	71.7	551	19.8
Elkhead	1	11/1/2005	454	534	11/21/2005	11.3	1050	16.8
Elkhead	3	11/1/2005	352	284	11/21/2005	6.7	894	11.1
Elkhead	4	11/1/2005	401	465	11/21/2005	17.5	1261	28.4
Elkhead	5	11/1/2005	363	305	11/21/2005	59.4	1138	22.3
Elkhead	6	11/1/2005	332	227	11/21/2005	20.3	1426	29.5
Elkhead	7	11/1/2005	355	274	11/21/2005	9.5	873	13.2
Elkhead	8	11/1/2005	585	1174	11/21/2005	7.0	975	11.7
Elkhead	9	9/30/2005	367	309	4/20/2006	66.0	1019	15.4
Elkhead	10	9/30/2005	430	486	4/20/2006	9.8	754	19.0
Elkhead	11	9/30/2005	504	815	4/20/2006	59.2	1425	64.3
Elkhead	12	9/30/2005	471	654	4/20/2006	29.5	1026	33.9
Elkhead	13	9/30/2005	659	1724	4/20/2006	26.1	899	30.2
Elkhead	14	9/30/2005	551	1105	4/20/2006	35.6	1085	22.8
Elkhead	15	9/30/2005	582	1132	4/20/2006	36.2	903	22.9
Elkhead	16	9/30/2005	362	284	4/20/2006	7.2	1075	24.7
Elkhead	17	9/30/2005	541	1000	4/20/2006	28.8	1193	48.9
Elkhead	18	9/30/2005	414	499	4/20/2006	160.5	848	18.9
Elkhead	19	9/30/2005	516	836	4/20/2006	18.6	1122	33.3
Elkhead	20	9/30/2005	546	1064	4/20/2006	55.5	1207	50.9
Elkhead	21	9/30/2005	518	747	4/20/2006	63.2	829	23.8
Elkhead	22	9/30/2005	622	1572	4/20/2006	75.2	1254	45.1



Elkhead	23	9/30/2005	568	1132	4/20/2006	41.7	1218	52.2
Elkhead	24	9/30/2005	528	770	4/20/2006	29.18	889	17.0
Elkhead	25	9/30/2005	582	1125	4/20/2006	15.58	720	20.4
Elkhead	26	9/30/2005	621	1385	4/20/2006	30.12	851	18.4
Elkhead	27	9/30/2005	530	823	4/20/2006	52.41	1128	33.2
Elkhead	28	9/30/2005	501	752	4/20/2006	32.97	891	18.2
Elkhead	29	10/15/2005	546	1064	4/20/2006	37.13	1349	42.4
Elkhead	30	10/15/2005	630	1740	4/20/2006	32.27	1117	30.6
Elkhead	31	10/15/2005	497	748	4/20/2006	120.35	1127	44.6
Elkhead	32	10/15/2005	501	853	4/20/2006	286.29	1353	62.0
Elkhead	33	10/15/2005	315	183	4/20/2006	51.51	1107	14.4
Elkhead	34	10/15/2005	462	549	4/20/2006	17.93	946	15.4
Elkhead	35	10/15/2005	520	941	4/20/2006	74.22	742	19.8

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**Appendix E:** Location, fish identification number, date collected, total length (mm), weight (g), date ablated, manganese concentration (ppm), strontium concentration (ppm), and barium concentration (ppm) of northern pike collected 2004 in various locations throughout the Yampa River, Colorado.

Location	Fish ID #	Date collected	Length (mm)	Weight (g)	Date ablated	Mn55	Sr86	Ba137
Stagecoach	1	11/6/2004	320	186	6/29/2005	8.60	676.66	20.69
Stagecoach	2	11/6/2004	320	181	6/29/2005	16.72	700.18	21.38
Stagecoach	3	11/6/2004	320	194	6/29/2005	21.31	661.38	23.89
Stagecoach	4	11/6/2004	315	192	6/29/2005	10.84	658.56	22.05
Stagecoach	5	11/6/2004	355	268	6/27/2005	7.48	585.19	11.51
Stagecoach	5	11/6/2004	355	268	6/27/2005	10.74	656.06	15.13
Stagecoach	7	11/6/2004	330	199	6/27/2005	20.65	727.45	26.45
Stagecoach	8	11/6/2004	325	217	6/27/2005	7.09	631.73	11.11
Stagecoach	9	11/6/2004	330	201	6/27/2005	18.94	689.74	16.90
Stagecoach	9	11/6/2004	330	201	6/27/2005	33.10	684.79	32.84
Stagecoach	10	11/6/2004	310	188	6/27/2005	7.50	676.28	15.80
Catamount	1	10/9/2004	200	50	6/29/2005	57.02	1175.92	40.28
Catamount	2	10/9/2004	209	54	6/29/2005	10.75	1074.74	35.81
Catamount	2	10/9/2004	209	54	6/29/2005	13.19	1119.60	35.97
Catamount	3	10/9/2004	241	85	6/29/2005	29.81	1178.13	55.82
Catamount	4	10/9/2004	199	58	6/29/2005	50.97	957.80	39.64
Catamount	6	10/9/2004	235	74	6/29/2005	63.36	1168.74	37.80
Catamount	7	10/9/2004	198	50	6/29/2005	11.27	977.12	25.89
Catamount	8	10/9/2004	195	45	6/29/2005	115.93	1154.30	33.83
Catamount	9	10/9/2004	185	34	6/29/2005	49.67	1046.95	43.83
Catamount	9	10/9/2004	185	34	6/29/2005	39.70	1094.81	33.87
Elkhead	1	11/7/2004	280	148	6/29/2005	6.10	1106.31	24.82
Elkhead	1	11/7/2004	280	148	6/29/2005	11.09	1183.36	33.88
Elkhead	2	11/7/2004	271	133	6/29/2005	13.63	1010.81	22.04
Elkhead	3	11/7/2004	243	89	6/29/2005	7.66	899.73	15.38
Elkhead	3	11/7/2004	243	89	6/29/2005	9.13	947.53	20.02
Elkhead	6	11/7/2004	264	125	6/29/2005	12.46	1096.13	36.63
Elkhead	5	11/7/2004	295	188	6/29/2005	5.22	841.84	9.18
Elkhead	7	11/7/2004	280	156	6/29/2005	7.43	1003.11	15.57
Elkhead	8	11/7/2004	290	149	6/29/2005	8.45	1058.41	25.93
Elkhead	9	11/7/2004	265	137	6/29/2005	14.90	945.63	30.41
Elkhead	10	11/7/2004	292	174	6/29/2005	5.91	832.19	12.98
Elkhead	11	11/7/2004	184	295	6/29/2005	5.76	949.61	14.23

**Appendix F.** Location, fish identification number and hydrogen isotopic ratios of age-0 northern pike collected in 2005 in various locations in the Yampa River, Colorado. If multiple samples per otolith were analyzed, the average value for the fish is given.

Location	Fish ID #	Hydrogen isotope ratio
Catamount	1	-151.88
Catamount	2	-157.09
Catamount	3	-151.95
Catamount	4	-154.21
Catamount	5	-151.01
Catamount	6	-152.84
Catamount	7	-151.96
Catamount	8	-157.22
Catamount	9	-155.01
Lafarge	18	-154.46
Lafarge	19	-155.98
Lafarge	20	-154.21
Lafarge	21	-149.89
Lafarge	22	-157.61
Lafarge	23	-151.93
Lafarge	25	-154.33
Lafarge	26	-147.91
Lafarge	27	-155.35
Lafarge	28	-158.03
Yampa River	2	-158.62
Yampa River	3	-159.49
Yampa River	6	-159.73
Yampa River	8	-160.61
Yampa River	9	-151.28
Yampa River	10	-158.10
Yampa River	12	-156.39
Yampa River	13	-157.74
Yampa River	14	-155.28
Yampa River	17	-157.26
Stagecoach	10	-152.49
Stagecoach	11	-148.82
Stagecoach	12	-152.47
Stagecoach	1	-162.00
Stagecoach	2	-161.99
Stagecoach	4	-163.79
Stagecoach	6	-160.47
Stagecoach	7	-159.92
Stagecoach	8	-151.68
Stagecoach	9	-145.99

YSWA	14	-141.35
YSWA	15	-141.69
YSWA	16	-140.96
YSWA	17	-138.28
YSWA	18	-138.45
YSWA	19	-142.57
YSWA	20	-144.33
YSWA	3	-140.87
YSWA	7	-146.85
YSWA	8	-140.80

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