Proposal submission for the CALFED 2007 Supplemental PSP

Name of PI: Lynn Ingram
Institution: University of California, Berkeley

Title of Supplemental Proposal: The Role of the San Francisco Bay-Delta in Juvenile Rearing for Winter and Spring Run Chinook Salmon, to be Determined by Otolith Microchemistry

Funding Amount Requested: $ 228,092

Original Proposal Title: Chinook Salmon Rearing in the San Francisco Bay-Delta System: Identification of Geochemical Markers to Determine Delta Use

Year of Original Proposal Submission: 2004

UNIVERSITY OF CALIFORNIA, BERKELEY

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SPONSORED PROJECTS OFFICE
2150 Shattuck Ave, Suite 313
BERKELEY, CA 94704-5940
PHONE: (510) 642-8117
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January 14, 2005

Shem Ayalew
CALFED Science Program
State of California
shemeles@calwater.ca.gov

Re: Agreement Number: U05SC038
Principal Investigator: B. Lynn Ingram

Dear Shem Ayalew:

Enclosed for your consideration is the *continuation* proposal for the above referenced project, submitted on behalf of the Regents of the University of California at Berkeley.

Please direct any questions of a business or contractual nature to Dan Jacobs at (510) 643-7365 or dan_jacobs@berkeley.edu. If this request is approved, please issue award documents in the University's corporate name: The Regents of the University of California, c/o Sponsored Projects Office, 2150 Shattuck Ave, Suite313, Berkeley, California 94704-5940.

Thank you for your consideration of this proposal.

Sincerely,

Patricia A. Yates

for Jyl Baldwin
Assistant Director
Sponsored Projects Office
2150 Shattuck Avenue, Suite 313
University of California
Berkeley, CA 94704-5940

The role of the San Francisco Bay Delta in juvenile rearing for winter and spring run Chinook salmon, to be determined by otolith microchemistry

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January 17, 2008

Project Purpose:

The importance of the San Francisco Bay-Delta system to native juvenile salmonid rearing is poorly understood. Fish surveys in this system provide snap shots of the population as it travels down the rivers and enter and exit the Bay-Delta complex (Kjelson et al. 1982; Brandes et al. 2001; MacFarlane and Norton, 2002). But existing techniques are unable to address the critical question, How does residence in the Delta and the Bay relate to success in later life stages and specifically, to becoming a successful spawner (Fig. 1)? Under our current CalFed-funded research, we have developed otolith microchemical methods that can be applied to adult spawners to answer this question.

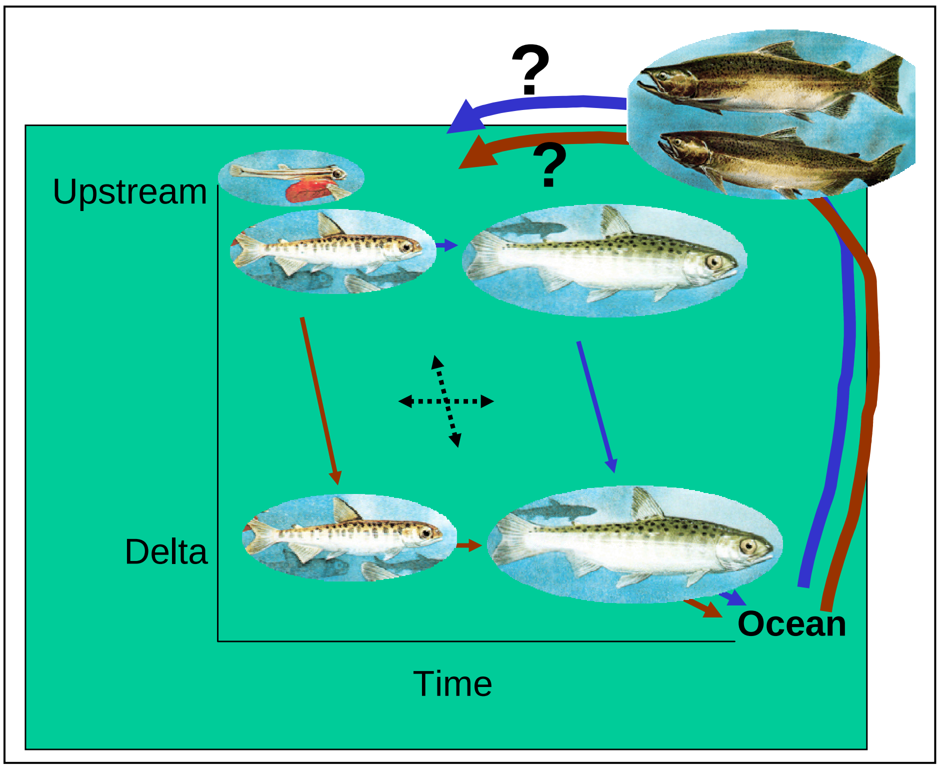

Figure 1. In this proposal we apply the methods that we developed under CalFed funding to address the question, What is the role of the Delta in salmon rearing? This figure shows a schematic representation of the continuum of rearing and outmigration possibilities for juvenile Chinook salmon, and poses the question, which history is more likely to result in adults returning to spawn. The methods developed under our original proposal will now be applied to specific populations, closing the loop between juvenile behavior and adult spawning success.

Here we propose to apply our newly developed methods to adult winter and spring-run Chinook salmon otoliths to determine for the first time the duration and timing of San Francisco Bay Delta usage by juveniles that successfully return to spawn. Our approach will enable us to determine the extent of Delta rearing for returning adults—as well as other key aspects of juvenile life history—for the region's most at-risk salmonid populations. Data on modern Delta use for these runs will be compared to in-stream and Delta monitoring of juvenile migrants. We will also analyze archival Chinook salmon otolith samples to place the modern data in an historical context.

This work is time-critical because we have generated baseline data for the Delta that can be correlated with returning adults in the next few years. Also, under our current funding we have initiated the study of winter and spring-run adults. Continuing funding will enable us to analyze multiple years, giving our results significantly greater context than a single year study. Furthermore, with continuing funding we will have the opportunity to continue to employ Corey Phillis, the primary scientific staff member on this project, giving it highly valuable personnel continuity.

This work is synergistic with other work in the SF Bay Delta, and more generally, in the Central Valley. We are receiving juvenile Chinook salmon samples from the Delta from the US Fish and Wildlife Service (USFWS), and we are receiving returned adult Chinook salmon otoliths from USFWS and the California Department of Fish and Game (CDFG), and from the East Bay Municipal Utility District as part of a study of the abundance of hatchery reared fish. We have received permission to receive otoliths and scales from spawning Chinook salmon from federally and state listed runs collected as part of surveys by USFWS and CDFG. In addition, we will have access to USFWS fin clip DNA data documenting the abundance of winter and spring run juvenile salmon exiting the Delta as a reference for our work (Pat Brandes, USFWS, pers. comm.).

Background

The winter and spring-run Central Valley Chinook are currently in danger. The National Marine Fisheries Service in the 2005 "Updated Status of Federally Listed ESUs of West Coast Salmon and Steelhead" (Good et al. 2005) reaffirmed its listing of the winter-run and spring-run as endangered and threatened, respectively, under the Federal Endangered Species Act.

The completion of the Shasta Dam in 1945 and Keswick Dam in 1950 eliminated habitat that historically may have supported more than 200,000 winter-run spawning adults (Rectenwald 1989). As late as 1971, the limited spawning habitat below the Shasta Dam saw a return 53,089 spawning adults (K. Niemela, USFWS, pers. comm.). The winter-run was classified as threatened in 1990 before being reclassified as endangered in 1994. The Sacramento River winter-run Evolutionarily Significant Unit (ESU; Waples 1991) currently consists of one independent population spawning at the base of the Shasta Dam. This population is assisted by the artificial propagation program at Livingston Stone National Hatchery. Recent adult returns had increased dramatically from 1,352 in 2000 to 17,303 in 2006; however, 2007 escapement was down to only 2,623 returning adults, a figure more in line with winter-run escapement totals observed in the two decades preceding the increased returns seen this century (K. Niemela, USFWS, pers. comm.).

Spring-run historically were prevalent throughout the California Central Valley; rivers and streams with habitat above 500 meters supported populations where flows and water temperature allowed adults to over-summer until the fall spawning season (Yoshiyama et al. 2001). Between 1894 and 1968, construction of dams blocked this higher elevation habitat on most rivers throughout the Sacramento-San Joaquin River watershed, in the process eliminating up to 19 populations from the ESU (Schick and Lindley, 2007). Recent wild returns are thought to be approximately 25% of historic levels; however, the wild to hatchery-origin ratio is unknown (Good et al., 2007). The proximity of the three remaining independent populations on Mill Creek, Deer Creek, and

Butte Creek, as well as concerns over the potential decline in genetic integrity due to hybridization of spring-run and fall-run fish at the Feather River Hatchery, lead to the ESU being listed as threatened in 1999 and reaffirmed as such in 2005 (Good et al. 2005).

Delta Significance

While effects of the elimination of upstream habitat are well documented on the spring (Schick and Lindley, 2007) and winter-run (Yoshiyama et al., 2001), the role alteration to the Delta habitat has played in the ESU declines is not. USFWS has documented use of the Delta habitat by all four California Central Valley Chinook salmon runs, however the value rearing in the Delta habitat for spring and winter-run is not clear (Pat Brandes, USFWS, pers. comm.). It is assumed that the Delta, at least historically, provided suitable alternative to upstream habitat , allowing for the expression of varied life-histories within the ESUs, ensuring their persistence through general year-to-year or decade-to-decade environmental variability, as well as safeguarding their survival through episodic catastrophes.

With significant physical and biological alterations to the Delta, populations may be artificially selected for life histories that best fit the altered landscape, while potentially decreasing the total number of individuals, viable life histories, and, ultimately, the population's insulation from environmental and demographic stochasticity. Appropriate recovery plans for the California Central Valley spring and winter-run ESUs require a thorough understanding of their various life histories, where their resources and habitats utilized differ, and which, if any, life history appears disproportionately in the adult reproductive life stage. Our research will address these questions by focusing on the present and historical value of the Sacramento-San Joaquin River Delta to Chinook salmon survival.

Method development under CalFed funding:

Under CalFed funding starting in 2006, we have been developing otolith microchemistry methods to determine the timing and duration of juvenile Chinook salmon use of the San Francisco Bay Delta. This work follows up on our previous method development, in which we identified geochemical markers in otoliths to characterize the early life history of juvenile Chinook salmon in the Sacramento-San Joaquin river system (Ingram and Weber, 1999; Weber et al., 2002; Weber, 2002; Weber et al., 2005; Solomon et al., 2006). We use otoliths because they form daily bands during the juvenile life stage, which can be used to construct a chronology of an individual fish's early life (Neilson and Geen, 1982; Campana and Neilson, 1985; Campana, 1999). We perform micro-chemical analyses that provide between 1 day and two-week temporal resolution in juveniles (<5 to 60-micron lateral resolution) (Weber et al., 2002; Weber et al., 2005; Phillis et al., 2006; Phillis et al., 2007; Phillis et al., in prep). To date, we have developed geochemical tracers for Sacramento River salmon otoliths that (1) distinguish between hatchery-raised and naturally spawned salmon using sulfur isotopes ($\delta^{34}S$), (2) determine a fish's natal river of origin using strontium isotopes ($^{87}Sr/^{86}Sr$), and (3) can identify the timing of downstream migration from spawning grounds using carbon isotopes ($\delta^{13}C$) and (4) of ocean entry using strontium-calcium ratio (Sr/Ca). The missing piece in our work in this river system had been a marker or set of markers to determine the timing and duration of use of different parts of the San Francisco Bay-Delta system (Fig. 2), which has been the focus of our CalFed funded work.

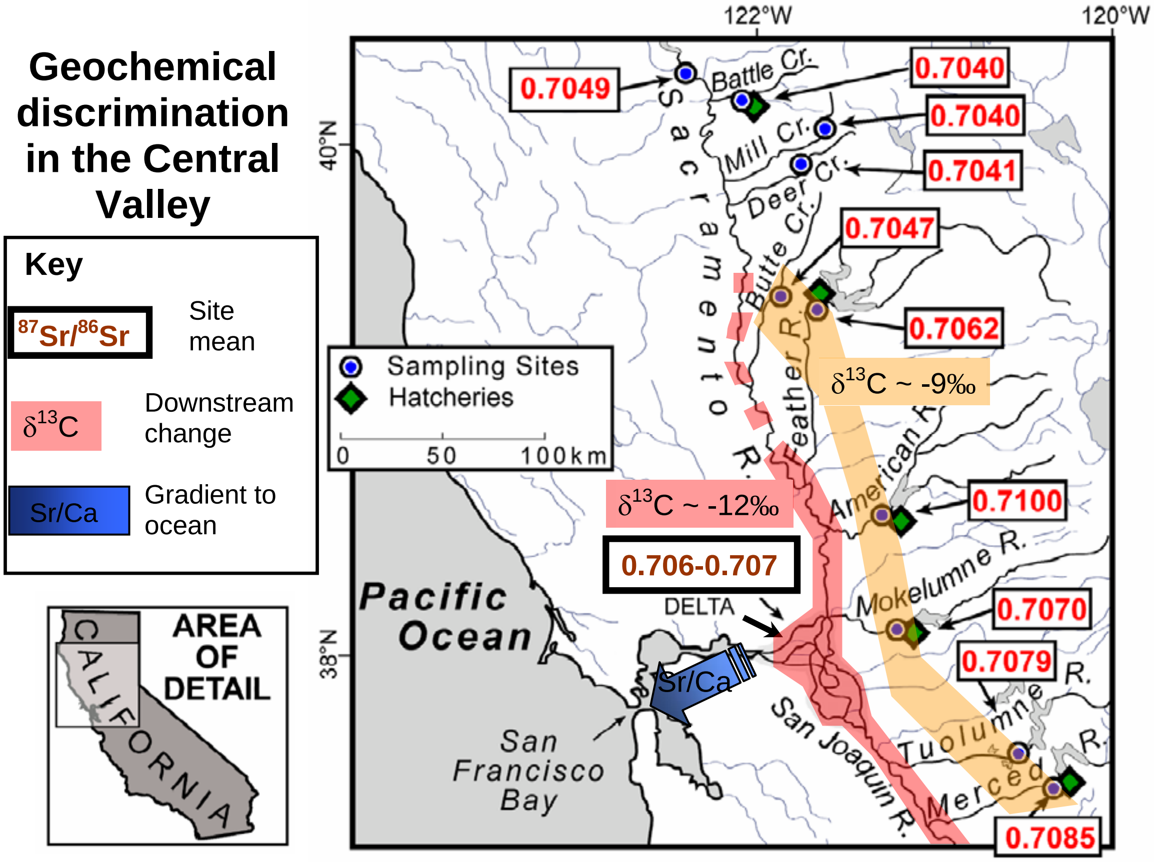

Figure 2. Map of the distribution of key geochemical markers in the Sacramento-San Joaquin river system. Our proposal will primarily use Sr isotopes to discriminate rearing habitats and river/hatchery of origin of spawning adult salmon.

To date, the primary focus of our CalFed work to constrain Delta residence has been Sr isotopes ($^{87}Sr/^{86}Sr$). The $^{87}Sr/^{86}Sr$ ratio is a particularly good otolith marker because the otolith Sr isotopic composition directly reflects the water Sr isotopic composition, with the exception of in hatcheries, where the fish are given a marine-based fish meal. The $^{87}Sr/^{86}Sr$ ratio is also a particularly good marker in the Sacramento-San Joaquin River system because of systematic differences among the tributaries (Fig. 2). The key factors that we have been addressing under CalFed funding are (1) the discriminatory power of $^{87}Sr/^{86}Sr$ for the Delta and (2) the $^{87}Sr/^{86}Sr$ analytical method.

We have been working on establishing the discriminatory power of $^{87}Sr/^{86}Sr$ as an otolith marker because data from our previous work was inconclusive regarding the ability of $^{87}Sr/^{86}Sr$ to distinguish Delta use from Sacramento River use, in particular. (San Joaquin River use is relatively easily distinguished from Delta use because Sacramento River water is predominant in the Delta.) This work can be very expensive because water $^{87}Sr/^{86}Sr$ analysis cost on the order of $300 per sample. Therefore, we developed a new method for determining the absolute value and stability of the Sr isotopic composition of water at a site by using clams. Clams provide a continuous record of the local water $^{87}Sr/^{86}Sr$ ratio in their shells. This record can be analyzed by the same method as the otoliths (see below), which is significantly cheaper than water $^{87}Sr/^{86}Sr$ analyses. We correlated water $^{87}Sr/^{86}Sr$ analyses with clam collection at sites within the Delta and upstream in the mainstem Sacramento River for this study (Fig. 3). The differences among sites and the relative temporal stability of the $^{87}Sr/^{86}Sr$ ratio at our sites is sufficient that Delta use can be distinguished from use of the Sacramento River upstream of the city of Sacramento (Elkhorn boat ramp) based on this marker alone. The water data collected for the winter and spring period suggest that Delta use can be even more tightly constrained if the otolith $^{87}Sr/^{86}Sr$ can be related to conditions at the time of outmigration.

Sr-isotopes will be sufficient to track downstream migration and Delta residence in fish from most regions of the Central Valley, but in cases where natal river and Delta water $^{87}Sr/^{86}Sr$ values overlap (e.g. Feather River), additional marker would be very useful and would potentially distinguish Sacramento River and Delta residence even better. The most promising marker is Se, which is a common Delta contaminant, which can be measured at high resolution in otoliths by ion microprobe at LLNL.

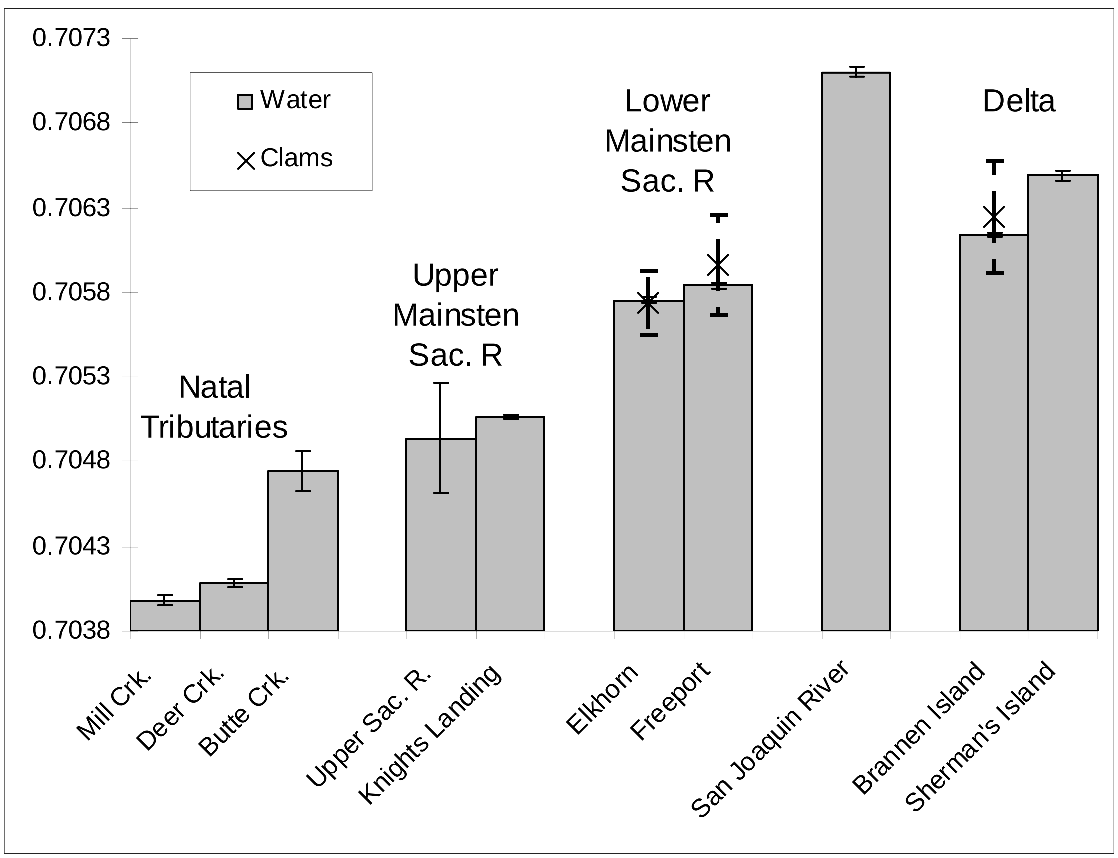

Fig. 3. Water Sr isotopic composition of the San Joaquin River and selected sites along the Sacramento River through the Delta. These data show that the Delta can be distinguished from the Sacramento and San Joaquin rivers based on $^{87}Sr/^{86}Sr$ ratio, and that the Sacramento River can also be broken down into reaches based on $^{87}Sr/^{86}Sr$ ratio. Mean and two standard deviations of correlated clam samples are plotted for Elkhorn boat ramp, Freeport, and Brannen Island. Note that the variation in water $^{87}Sr/^{86}Sr$ at the lower Sacramento and Delta sites is very small. Clam data, which spans a longer period, show more variability.

Method development has been a key component of our $^{87}Sr/^{86}Sr$ work. We have focused on laser sampling coupled with the multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICPMS), which is a relatively new method and powerful method. We have been working at the UC Davis LA-MC-ICPMS facility to ensure method accuracy and find the optimal balance between method precision and spatial resolution; spatial resolution (number of bands analyzed) determines temporal resolution. We determined that the optimal method is a transect of 60 micron spots perpendicular to the daily bands along the axis of maximum extension in a sagital section. The temporal resolution of this method is on the order of two weeks and precision is ~0.2‰. Forty micron spots result in precision of ~0.5‰. We attempted to increase this resolution by developing a depth-profile method whereby the laser made successive passes across an otolith sectioned transversally to the juvenile region of interest; however, the UCD laser system is not good for depth-profiling because of inhomogeneity of the laser profile, and we have settled for the spot transect method. The temporal resolution of this method is sufficient to compare the relative value of rearing upstream vs. rearing in the Delta.

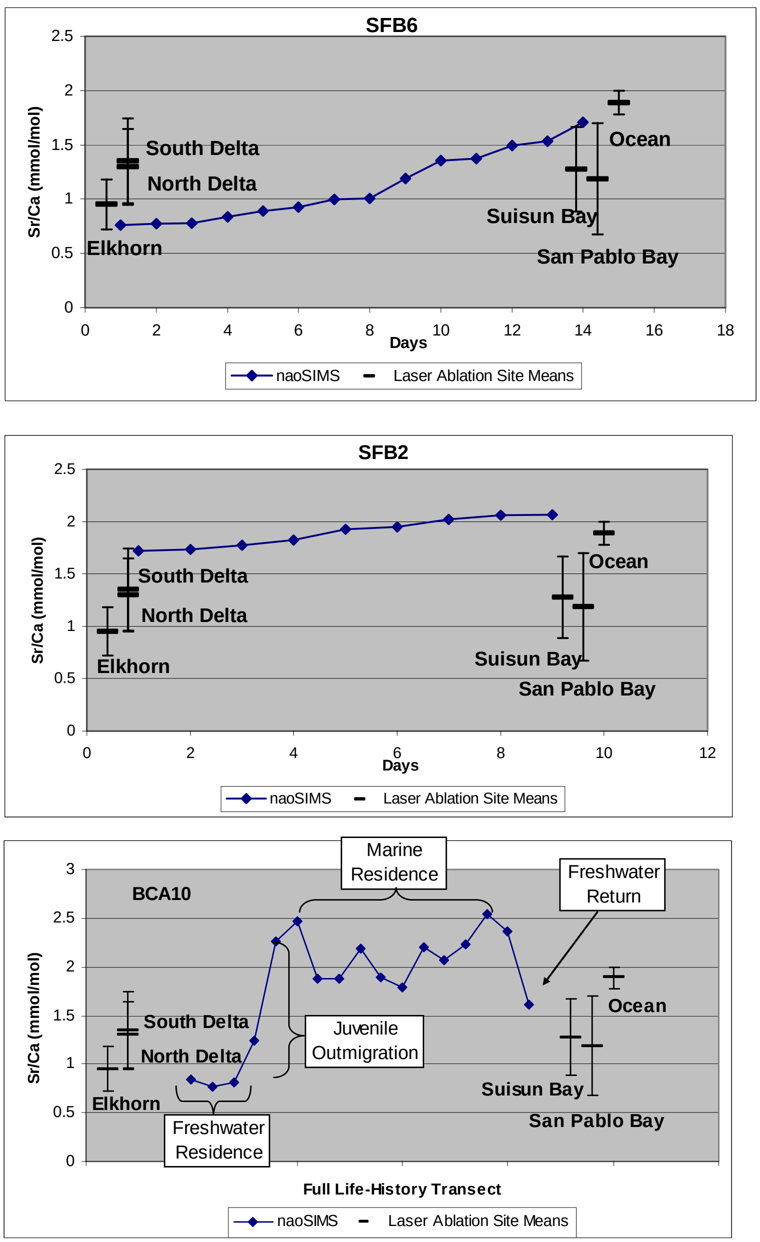

Fig. 4. Sr/Ca Results from a Suisun Bay caught juvenile (SFB6), San Pablo Bay caught juvenile (SFB2), and Butte Creek adult Chinook salmon (BCA10) analyzed by nanoSIMS edge analysis. The laser ablation Sr/Ca site means are plotted for comparison (ocean mean is from the marine portion of a nanoSIMS analyzed adult). For SFB6 and SFB2, the area analyzed represents otolith growth over the last ~2 weeks before capture. BCA10 is a full life-history transect from natal river origin to return spawning migration.

We have also done high resolution trace element analysis by nanometer-scale secondary ion mass spectrometry (nanoSIMS) at Lawrence Livermore National Laboratory (LLNL) to determine if we could precisely locate the exit from the Delta using otolith Sr/Ca. Temporal resolution of nanoSIMS is as good as 1 day (<5 micron). Because of the marine influence on the water in the Bay, the Sr concentration is higher relative to Ca than inland of the Delta. Although the relationship between otolith Sr/Ca and water Sr/Ca is not as tight as for Sr isotopes (Phillis et al. in prep), we expect this change to show up in the otolith upon exit from the Delta. We analyzed otoliths by nanoSIMS from outmigrating juvenile salmon collected by CDFG in the bays west of Chipps Island. The results show otolith Sr/Ca rises quickly as the fish move from the Delta to the Bay, and that nanoSIMS can extract this information. Therefore, Sr/Ca can be used can be used as a high resolution indicator of Delta departure (Fig. 4).

While we are continuing to work on developing our methodology, the progress that we have made to date is sufficient for us to apply our methods to the practical question of Delta use by salmonids.

Initial application of our method:

Based on our CalFed-funded work, we can discriminate between San Joaquin or upper Sacramento River residence and Delta rearing using $^{87}Sr/^{86}Sr$. Our first test of these methods were on marked and recaptured juveniles, and then we began analyzing otoliths of returning Chinook salmon from Sacramento River tributaries Feather River, Butte Creek, and Battle Creek.

We analyzed 1999 CWT juvenile Chinook salmon released at Elkhorn on the lower Sacramento River and recaptured at the same location and at Chipps Island. The $^{87}Sr/^{86}Sr$ analyses for the fish that were recaptured at Elkhorn showed the expected $^{87}Sr/^{86}Sr$ ratio for the lower Sacramento River, which is distinct from the Delta (0.70576 and 0.70615-0.7070, respectively). The fish that migrated from Elkhorn to Chipps Island did not spend sufficient time in the Delta to enable the Delta $^{87}Sr/^{86}Sr$ ratio to be detected.

To date we have analyzed otoliths from 17 Chinook salmon collected during the 2001 Feather River fall-run spawner carcass survey. In addition to identifying various life-histories and tracking downstream migration patterns, we were also able to distinguish wild and hatchery origin adults due to marine based hatchery feed used at Feather River Hatchery (Ingram and Weber, 1999; Fig. 5). The Feather River, however, is not an ideal study site for this work because its $^{87}Sr/^{86}Sr$ ratio is similar to the Delta signature; slow migration between the Feather River and the Delta is necessary to distinguish residence at the two locations. The development of additional Delta markers, such as Se, would enable these sites to be more readily distinguished.

The optimal application of our method is in systems where there is a strong, unidirectional gradient in water $^{87}Sr/^{86}Sr$, eliminating the possibility of habitats with overlapping Sr isotopic signals. We have identified Mill, Deer, and Butte Creeks, and the upper Sacramento River between Keswick and Red Bluff Diversion Dams as ideal study sites due to their favorable water chemistries relative to the Delta (Fig. 2, 3) and the potential to apply our methods to at-risk salmonid populations.

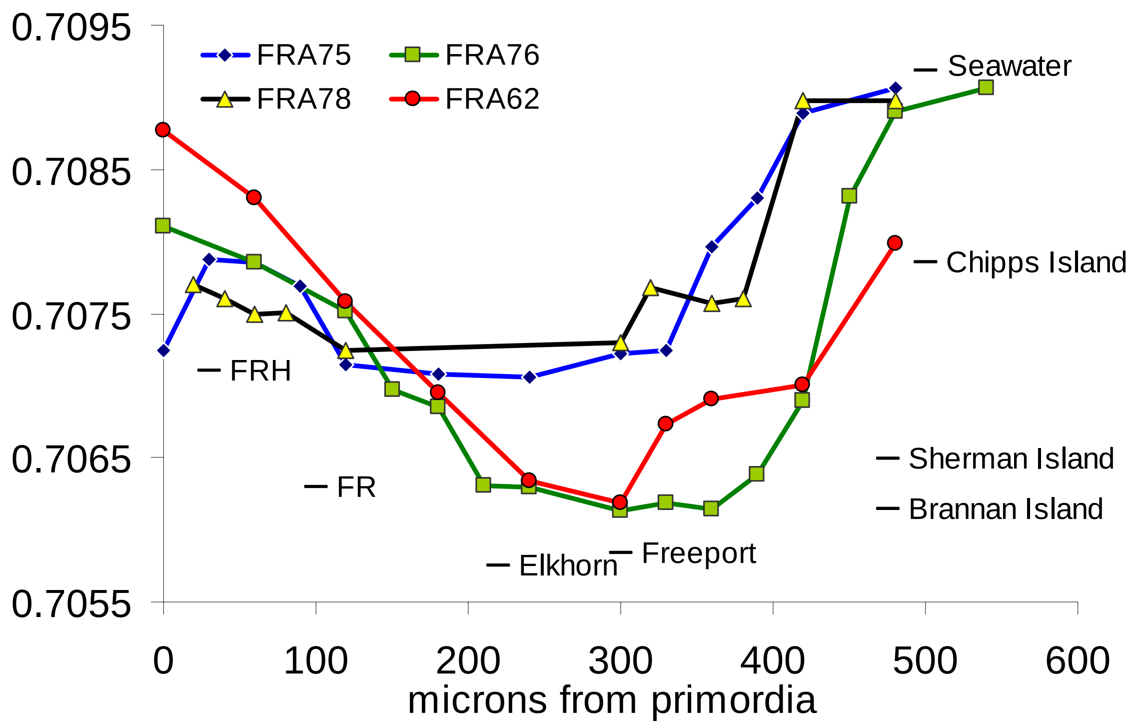

Figure 5. Adult salmon otolith strontium isotopes ($^{87}Sr/^{86}Sr$; y-axis) reveal different juvenile life-histories. Individuals FRA 76 and FRA 62 are wild fish, FRA 75 and FRA 78 are of hatchery origin. Following moving downstream, FRA 78 and FRA 62 appear to rear in the Delta before outmigrating. FRA 75 (hatchery; FRH) and FRA 76 (in-river; FR) rear upstream before moving through the Delta rapidly.

In November we received otoliths from 30 adult winter-run Chinook salmon from the 2007 Livingston Stone Hatchery spawning program, and we have arranged to receive spring-run Chinook salmon otoliths from 2007 carcass surveys in Butte, Mill, and Deer Creeks (~40 from Butte Creek and ~40 total between Mill and Deer Creeks). These will be analyzed under current funding.

Approach and Scope of New Work:

The goal of our proposed work is to characterize Delta use by at-risk salmon runs, and to place this information in the broadest possible context. The central scientific questions are:

1. What is the extent of juvenile salmon use of the Delta?
2. How does this usage compare to in-river and Delta juvenile salmon surveys?
3. How does it compare to historical usage?

We will analyze a total of 130 to 160 otoliths per year for two additional years, giving a three year picture of Delta use. In addition, we will analyze archival samples, to place the current day samples in an historical context.

We will work with the following samples:

- Otoliths from adult winter-run Chinook salmon collected as part of the Livingston Stone Hatchery spawning program and supplemented by carcass survey as necessary (~40/year; our contact: Kevin Niemela, USFWS)
- Otoliths from adult spring-run Chinook salmon collected as part of the Butte Creek carcass survey (~40/year; our contact: Tracy McReynolds, CDFG) and Mill, Deer and Antelope Creek carcass surveys (~40/year; our contact: Colleen Harvey Arrison, CDFG)
- Archival otoliths and shells from California Academy of Sciences (D. Catania, CAS)
- Additional 20 to 40 otoliths from steelhead and/or fall-run Chinook salmon, in consultation with CalFed and the Interagency Ecological Program Satelite Project Team on Salmonid Rearing in the Delta
- Clam samples for tributary, lower Sacramento River and Delta sites

The exact number of samples at a site in a given year will depend on the size of the run and the availability of spawned carcasses. Where available, we will analyze clams collected at spawning sites, the lower Sacramento River, and the Delta (1-2 per site per year) to characterize the seasonal and year-to-year variability of the water $^{87}Sr/^{86}Sr$ signal. Archival shells or shells from cores will be used to reconstruct past Delta water Sr isotopic composition.

By focusing on Chinook salmon populations native to the northern Central Valley, we maximize our capability to distinguish in-river from Delta rearing because the rivers in the northern Central Valley are isotopically distinct from the Delta (Fig. 2 & 3). As a result, additional markers will not be as necessary as they would be for other sites closer to the Delta. Therefore, additional markers will be used only for checks on the $^{87}Sr/^{86}Sr$ data.

All sample preparation will be carried out at UCB. Otolith and clam Sr isotope data will be collected with a laser sampling system coupled to the multicollector ICP-MS at the UC Davis Interdiscpinlary Center for Plasma Mass Spectrometry. The data will be compared to our database of geochemical signatures for the Sacramento River system, and to the marine signatures, to reconstruct juvenile life history and Delta usage. From our experience working with the UCD instrument, we anticipate analysis time to be approximately one hour per transect per sample (10-20 spots per transect), with 130-160 otolith and clam samples expected to be run per spawning year. We will complete the analysis of otoliths from the 2007 spawning year and then analyze spawning year 2008 along with all clam and archive samples, before running 2009 spawning year samples. In addition to the spring and winter-run samples, we have included funding in the budget for analysis time to work with additional populations (i.e. steelhead and/or fall-run). We are particularly interested in analyzing steelhead otoliths to the extent that agency spawner carcass surveys can provide us with otolith samples.

To examine whether any life-histories appear disproportionately in the adult reproductive life stage compared to the juvenile life stage of the same cohort, we will work with Pat Brandes of USFWS to characterize the make-up (i.e., young-of-the-year vs. yearling) of the outmigrating spring and winter-run juveniles in the Chipps Island mid-water trawl. We anticipate having access to USFWS DNA data from fin clips collected during their juvenile salmon surveys characterize the abundance and out-migration timing of the winter and spring-runs, which would be superior to size-based classification.

With respect to the application of our method to archival samples, we are confident that we can sufficiently constrain the historical $^{87}Sr/^{86}Sr$ range to determine Delta use by fish coming from the northern Sacramento River. The lithological characteristics that control water $^{87}Sr/^{86}Sr$ are stable over hundreds of years. The primary potential causes of changes in Delta water $^{87}Sr/^{86}Sr$ ratio are reduction in flows from the San Joaquin River to the Delta, and the Delta pumping stations drawing Sacramento River water across the Delta (Ingram and Sloan, 1992). Both of these factors would serve to decrease the difference between the lower Sacramento River and the Delta. Therefore, before these changes water flow, the change in the otolith $^{87}Sr/^{86}Sr$ ratio upon entering the Delta from the northern Sacramento River would have been larger than today. The $^{87}Sr/^{86}Sr$ signatures of the upper Sacramento River and northern tributaries would be largely unchanged. We will use the mixing model established by Prof. Ingram to estimate Delta Sr isotopic composition before water diversions (Ingram and Sloan, 1992), along with current water chemistry and hydrologic models to estimate the water $^{87}Sr/^{86}Sr$ ratio of the Delta at the relevant era for archived otoliths.

In addition to answering the central question of Delta usage, this work will provide the first data on the full life history patterns for successful spawners, including duration of in-river residence and age at migration to the ocean. The data set will also provide lower-bound estimates of hatchery straying.

Relevance to the CALFED Science Program

This research is relevant to the goals of managing the freshwater fishery, mitigating habitat loss and contamination, and managing and planning ecosystem restoration. The application of geochemical markers and otolith microchemistry specific to the Delta will provide managers with previously unobtainable data on Delta use by salmonids. The information that could be gained by this study would be more comprehensive than could be gained by previous methods, because it would allow Delta and Bay use to be placed within the context of the entire life history of a spawning fish. This information is critical to viability analyses and recovery planning for the at-risk spring and winter-run populations. Results from this work will help guide decisions ranging from water management to Delta restoration efforts.

Deliverables

- Otolith $^{87}Sr/^{86}Sr$ by LA-MC-ICPMS for at least 130 otoliths per year of funding, placed in the context of our Central Valley and Delta geochemical data base
- Clam $^{87}Sr/^{86}Sr$ by LA-MC-ICPMS from 10-15 sites of interest in the Sacramento River Watershed
- Otolith Se, Sr/Ca by secondary ion mass spectrometry as necessary
- Otolith C and O isotopes sampled by micromill for isotope ratio mass spectrometry (IRMS) as necessary
- Data analysis in context of juvenile out-migration surveys and archival samples

- Presentations at conferences including the CALFED Science Conference
- Semi-annual reports will be submitted every 6 months following the project start date
- Final report will be submitted 24 months from the project start date
- Draft manuscript will be substituted for a project closure summary report and submitted 24 months from the project start date
- Final manuscripts will be submitted upon publication

New Project Staff and Qualifications

Not applicable.

Budget and Justification

The majority of the budget (75 %) is allocated to support personnel. Scientific staff member Corey Phillis will be supported full time for two years, to perform sample preparation and analyses, data processing and writing. Co-PI Peter Weber will receive 1 month of salary per year over two years, to support ion microprobe analyses, oversight of data analysis and interpretation, writing and editing, and general oversight of the project.

Otolith Microchemistry Analyses will include Sr, C, and O isotopes. Sr isotopes will be run at the UC Davis Interdisciplinary Center for Plasma Mass Spectrometry. We anticipate running at least 130 sample hours per project year, actual analysis time contingent on the number of otoliths we receive from the spawning carcass survey crews. Because this facility is heavily used and instrument time is hard to get, we will use a combination of assisted ($96/hr) and unassisted ($40/hr) analysis time to maximize instrument time.

Stable isotopes C and O will be run on Prof. Ingram's Isotope Ratio Mass Spectrometer at UC Berkeley at a price of $20/sample. These analyses will be performed to distinguish habitats of similar Sr isotopic composition. The total number of analyses will depend on the Sr isotope results. Ion microprobe analysis time at LLNL are provided at no cost to the project.

Supplies and sampling expenses will cover petrographic and microscope slides; microscope slide cover slips; microscope slide boxes; microscope bulbs and fuses; sandpaper; embedding medium and casts; micro-centrifuge vials and trays; Imaging software for otolith ageing; general lab and office supplies.

Travel, conference, and presentation of results expenses will cover Corey Phillis' travel expenses when working at UCD, conference fees, including the biennial CalFed conference, and expenses associated with presenting and publishing results.

The role of the San Francisco Bay Delta in juvenile rearing for Winter and Spring run Chinook salmon, to be determined by geochemical markers

UC Berkeley

Corey Phillis, Staff Research Associate II, Year 1						
Salary						
$3,350	/mo. @	100%	x	12	mos.	$ 40,200
Benefits		26%				$ 10,452
Stable isotope analyses, IRMS, Year 1						
$20	/sample		x	TBD	samples	$ 3,125
Corey Phillis, Staff Research Associate II, Year 2						
Salary						
$3,400	/mo. @	100%	x	12	mos.	$ 40,803
Benefits		26%				$ 10,609
Stable isotope analyses, IRMS, Year 2						
$20	/sample		x	TBD	samples	$ 3,125
Supplies and sampling expenses						$ 6,000
Travel, Conference, and Presentation of Results Expenses						$ 8,000
					UCB SUBTOTAL	**$122,314**

UC Santa Cruz

Dr. Peter Weber, Research Associate, Institute of Marine Sciences, Year 1						
Salary						
$9,700	/mo. @	100%	x	1	mos.	$ 9,700
Benefits		57%				$ 5,500
LLNL Overhead		16%				$ 2,400
Dr. Peter Weber, Research Associate, Institute of Marine Sciences, Year 2						
Salary						
$9,700	/mo. @	100%	x	1	mos.	$ 9,700
Benefits		57%				$ 5,500
LLNL Overhead		16%				$ 2,400
					UCSC SUBTOTAL	**$ 35,200**

UC Davis

Otolith Microchemistry Analyses, Year 1						
Sr Isotope analyses, LA-MC-ICP-MS						
$96	/hour	1 sample/hr	x	80	samples	$ 7,680
$40	/hour	1 sample/hr	x	120	samples	$ 4,800
Otolith Microchemistry Analyses, Year 2						
Sr Isotope analyses, LA-MC-ICP-MS						
$96	/hour	1 sample/hr	x	80	samples	$ 7,680
$40	/hour	1 sample/hr	x	120	samples	$ 4,800
					UCD SUBTOTAL	**$ 24,960**
					SUBTOTAL	**$182,474**
UCB Overhead					25%	$45,618
				TOTAL		**$228,092**

Corey Phillis has a B.S. in Marine Biology and previously did salmon population work for NMFS in Santa Cruz. For the past five years he has worked developing otolith geochemical markers at UC Berkeley.

Dr. Peter Weber is an expert in otolith geochemistry and microchemical analysis. He has worked in the Sacramento-San Joaquin river system for nine years. Dr. Weber is a staff member at Lawrence Livermore National Laboratory and has an adjunct Research Associate position at the University of California, Santa Cruz at the Institute of Marine Science. He will be supported through his position at UCSC to minimize the cost to the project.

Prof. B. Lynn Ingram is an expert in geochemistry and has worked in the San Francisco Bay for 17 years.

Literature Cited

Brandes PL, and McLain JS. 2001. Juvenile chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. In: Brown RL, editor. Contributions to the Biology of Central Valley Salmonids. Fish Bulletin 179. Volume 2. Sacramento (CA): California Department of Fish and Game. p 39-136.

Campana, S. E., 1999, Chemistry and composition of fish otoliths: pathways, mechanisms and applications: Marine Ecology Progress Series, v. 188, p. 263-297.

Campana, S. E., and J. D. Neilson, 1985, Microstructure of fish otoliths: Canadian Journal of Fisheries and Aquatic Sciences, v. 42, p. 1014-1032.

Good, T. P., T. J. Beechie, P. McElhany, M. M. McClure, M. H. Ruckelshaus, 2007, Recovery planning for Endangered Species Act-listed Pacific salmon: Using science to inform goals and strategies: Fisheries, v. 32, p. 426-440.

Good, T. P., R. S. Waples, and P. Adams (editors). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-66.

Ingram, B. L., and D. Sloan, 1992, Strontium isotopic record of estuarine sediments as paleosalinity-paleoclimate indicator: Science, v. 255, p. 68-72.

Ingram, B. L., and P. K. Weber, 1999, Salmon origin in California's Sacramento-San Joaquin river system as determined by otolith strontium isotopic composition: Geology, v. 27, p. 851-854.

Kjelson, M. A., P. F. Raquel, and F. W. Fisher, 1982, Life history of Fall-run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary, California, *in* V. S. Kennedy, ed., Estuarine Comparisons, New York, Academic Press, p. 393-411.

MacFarlane RB, Norton EC, 2002, Physiological ecology of juvenile chinook salmon (Oncorhynchus tshawytscha) at the southern end of their distribution, the San

Francisco Estuary and Gulf of the Farallones, California: Fishery Bulletin, v. 100 (2), p. 244-257.
Neilson, J. D., and G. H. Geen, 1982, Otolith of chinook salmon (*Oncorhynchus tshawytscha*): daily growth increments and factors influencing their production: Canadian Journal of Fisheries and Aquatic Sciences, v. 39, p. 1340-1347.
Phillis, C.C., D.J. Ostrach, Michelle Gras, Quing-Zhu Yin, B.L. Ingram, J.G. Zinkl, P.K. Weber. A novel method to develop an otolith microchemistry model to determine Striped Bass Habitat Use in the San Francisco Estuary. *In Prep.*
Phillis, C.C., D.J. Ostrach, M.A. Gras, Q.Z. Yin , B.L. Ingram, J.G. Zinkl, P.K. Weber. A novel method to develop an otolith microchemistry model to determine Striped Bass Habitat Use in the San Francisco Estuary (*Oral*). CALFED Biennial Science Conference, Sacramento, CA, October 2006.
Phillis, C.C., P.K. Weber, M.A. Gras, B.L. Ingram. Chinook salmon rearing in the San Francisco Bay-Delta system: Identification of geochemical markers to determine Delta use (*Oral*). 137^{th} Annual AFS Meeting, San Francisco, CA, September, 2007.
Ramos, F.C., J.A. Wolff, and D.L. Trollstrup, 2004, Measuring $^{87}Sr/^{86}Sr$ in minerals and groundmass from basalts using LA-MC-ICPMS: Chemical Geology.
Rectenwald, H. 1989. CDFG memorandum to Dick Daniel, Environmental Services Division, concerning the status of the winter-run chinook salmon prior to the construction of Shasta Dam. August 16, 1989. 2 pp + appendices
Schick, R. S., and S.T. Lindley, 2007, Directed connectivity among fish populations in a riverine network. Journal of Applied Ecology, v. 44, 1116-1126.
Solomon C.T., P.K. Weber, J.J. Cech, B.L. Ingram, M.E. Conrad, M.V. Machavaram, A.R. Pogodina, and R.L. Franklin (2006). Experimental determination of the sources of carbon to fish otoliths, for application of stable isotope techniques to otolith chronosequences, *Canadian Journal of Fisheries and Aquatic Sciences* 63: 79-89.
Yoshiyama, R.M., E.R.Gerstung, F.W. Fisher, and P.B. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. In: Brown RL, editor. Contributions to the Biology of Central Valley Salmonids. Fish Bulletin 179. Volume 1. Sacramento (CA): California Department of Fish and Game. p. 71-176.
Waples, R. S. 1991. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Marine Fisheries Review 53:11-22.
Weber, P. K., 2002, Geochemical Markers in the Otoliths of Chinook Salmon in the Sacramento-San Joaquin River System, California: Ph.D. Dissertation thesis, University of California, Berkeley, California.
Weber, P. K., C. R. Bacon, I. D. Hutcheon, B. L. Ingram, and J. L. Wooden, 2005, Ion microprobe measurement of strontium isotopes in calcium carbonate with application to salmon otoliths: Geochimica et Cosmochimica Acta.
Weber, P. K., I. D. Hutcheon, K. D. McKeegan, and B. L. Ingram, 2002, Otolith sulfur isotope method to reconstruct salmon (*Oncorhynchus tshawytscha*) life history: Canadian Journal of Fisheries and Aquatic Sciences, v. 59, p. 587-591.