Completion Report

Period: 2/1/2014 - 1/31/2015

Project: R/LME-7 - *Recovery of Elwha River Salmon and Trout after Dam Removal: Recolonization and the Awakening of Dormant Life History Diversity*

STUDENTS SUPPORTED

Thornton, Emily, ethorn10@uw.edu, University of Washington, School of Aquatic and Fishery Sciences, status: cont, field of study: Aquatic and Fishery Sciences, advisor: Thomas Quinn, degree type: MS, degree date: 2015-05-01, degree completed this period: No
Student Project Title:
Ecological interactions between resident, non-native brook trout and re-colonizing coho salmon in the Elwha River
Involvement with Sea Grant This Period:
Gradaute student supported by the grant
Post-Graduation Plans:
graduate school at UME Orono

CONFERENCES / PRESENTATIONS

Western Division American Fisheries Society Annual Meeting. Mazatlan, Mexico, public/profession presentation, 20 attendees, 2014-04-09
Presentation to Pacific Coast Steelhead Management Meeting, public/profession presentation, 100 attendees, 2014-03-20

ADDITIONAL METRICS

P-12 Students Reached:	**P-12 Educators Trained:**
Participants in Informal Education Programs:	**Volunteer Hours:**
Acres of coastal habitat protected, enhanced or restored:	**Resource Managers who use Ecosystem-Based Approaches to Management:**
Annual Clean Marina Program - certifications:	**HACCP - Number of people with new certifications:**

ECONOMIC IMPACTS

No Economic Impacts Reported This Period

SEA GRANT PRODUCTS

Description	Developed?	Used?	ELWD?	Number of Managers	Names of Managers
Method to distinguish origin of fish (resident	Yes	Yes	No	0	

trout and sea-run steelhead) using redd size.				
Non-invasive fat meter technique to assign individual steelhead to runs.	Yes	Yes	No	0
Stable isotope methods to differentiate between steelhead and rainbow trout fry.	Yes	Yes	No	0

HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

ADDITIONAL MEASURES

Number of stakeholders modifying practices:	Sustainable Coastal Development **# of coastal communities:**

PARTNERS

Partner Name: Coastal Watershed Institute
Partner Name: Department of Fish and Wildlife
Partner Name: Lower Elwha Klallam Tribe
Partner Name: National Park Service
Partner Name: NOAA
Partner Name: Peninsula College
Partner Name: US Fish and Wildlife Service (US DOI
Partner Name: US Geological Survey
Partner Name: Western Washington University

IMPACTS AND ACCOMPLISHMENTS

Title: **Washington Sea Grant chronicles transformational encounters between**

salmon populations separated for nearly a century by the Elwha dams
Type: accomplishment
Description:
Relevance: The removal of the Elwha River dams during 2012-2014 reopened fishes' access to highly productive habitat and raised fascinating scientific questions. What happens when landlocked and oceangoing populations of salmon and trout species comingle after almost a century apart? What can we learn from their interactions, and how do they and a rapidly evolving physical environment influence each other?
Response: Washington Sea Grant-supported researchers joined a collaborative team of tribal, state, federal, and university scientists to gather extensive physiological, behavioral, and reproductive data on this complex ecosystem's numerous salmon and trout species. The team also gathered vital environmental baseline data, taking a multi-species approach to research on adult and juvenile life-history stages in the river, studies on various estuarine habitats, and work on feeding and seaward migration.
Results: Rapid change is still yielding almost as many questions as answers. But as the physical environment of the river transforms to a new equilibrium, fish populations are moving into habitats from which they were excluded for nearly a century. The partnerships developed as a result of the project will be lasting ones and have been essential to the success of the project. The team has completed six peer-reviewed papers that are now published or in press and made progress on 15 studies monitoring colonization activity by eight fish species. Accomplishments in research, community engagement, and educational outreach have exceeded team expectations.
Recap:
Recap: Washington Sea Grant-supported research explores multiple aspects of the rapidly recovering Elwha River system with findings that will inform future dam removals and large-scale salmon restoration efforts.
Comments:
Primary Focus Area: OCEH (HCE)
Secondary Focus Area: LME (SSSS)
Associated Goals: Protect and restore marine, coastal, and estuarine habitats. (HCE Restore)
Support conservation and sustainable use of living marine resources through effective and responsible approaches, tools, models, and information for harvesting wild and cultured stocks and preserving protected species. (SSSS Supply)
Partners:
Coastal Watershed Institute
Lower Elwha Klallam Tribe
Northwest Fisheries Science Center (US DOC, NOAA, NMFS, NWFSC)
Peninsula College
US Fish and Wildlife Service (US DOI, FWS)
US Geological Survey (US DOI, USGS)
US National Park Service (US DOI, NPS)
Washington State Department of Fish and Wildlife
Western Washington University (WWU)

Related Partners: *none*

PUBLICATIONS

Title: **Use of egg size differences in anadromous (sockeye salmon) and non-anadromous (kokanee) forms of Oncorhynchus nerka to infer ancestral origins of the Elwha River's landlocked population**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2015
Uploaded File: Quinn_et_al_sockeye_eg....5.pdf, 341 kb
URL: *none*
Abstract:
Life history traits reflect interactions between evolutionary lineage and environmental conditions. Translocations of populations to new environments, and changes in their natal environment, provide insights into the factors controlling life history. For example, the trade-off between egg size and egg number is a well-studied adaptation in fishes, and especially salmon and trout. We used existing and new data on this tradeoff in anadromous sockeye salmon, Oncorhynchus nerka, and the non-anadromous form of the species (kokanee), to investigate the likely origin of a population of uncertain ancestry, land-locked for a century above an impassable dam. Native kokanee have smaller eggs than do the larger-bodied anadromous sockeye salmon. However, the land-locked population in Lake Sutherland, in the Elwha River system, Washington, U.S.A. had much larger eggs for their body size than any other kokanee population, similar only to the land-locked descendants of anadromous sockeye salmon in New Zealand. After evaluating and rejecting a series of competing explanations for the unusually large eggs, we infer that the population was mostly likely of anadromous origin, retaining the ancestral tendency to produce large eggs, despite the sacrifice in fecundity that is necessitated by the limited female energy resources. This study revealed the utility of life history traits for studying the ancestral origins of a population for which molecular genetic tools were not informative. Worldwide, many populations have been transplanted or exposed to new conditions, affording similar opportunities to investigate phenotypic plasticity and evolutionary adaptations.
Citation:
Quinn, T. P., M. H. Bond, and H. Berge. Use of egg size differences in anadromous (sockeye salmon) and non-anadromous (kokanee) forms of Oncorhynchus nerka to infer ancestral origins of the Elwha River's landlocked population. Ecological Researc
Copyright Restrictions + Other Notes:
Journal Title: Ecological Research

Title: **Re-colonization of Atlantic and Pacific rivers by anadromous fishes: Linkages between life history and the benefits of barrier removal**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2014
Uploaded File: Pess_et_al_2014_recolo....f.pdf, 842 kb
URL: *none*
Abstract:
The last two decades have seen a rapid increase in barrier removals on rivers of the

Northern Hemisphere, often for the explicit purpose of expanding the abundance, spatial distribution, and life history diversity of migratory fishes. However, differences in life history such as seasonal timing of migration and reproduction, iteroparity vs. semelparity, and the extent of natal homing are likely to affect the capacity for expansion and re-colonization by taxa such as alosines, lamprey, and salmonids. We first review some basic life history traits that may affect re-colonization by migratory fishes, and then present selected examples from Atlantic and Pacific basins to illustrate these patterns and their implications for the success of barrier removal as a measure to advance the goal of fish conservation. We conclude that diadromous fishes have the capacity to rapidly re-colonize newly available habitats, though the life history patterns of each species, the proximity to source populations in the same or nearby river systems, and the diversity of habitats available may control the patterns and rates of re-colonization.
Citation:
Pess, G. R., T. P. Quinn, S. R. Gephard, and R. Saunders. 2014. Re-colonization of Atlantic and Pacific rivers by anadromous fishes: Linkages between life history and the benefits of barrier removal. Reviews in Fish Biology and Fisheries 24: 881-900
Copyright Restrictions + Other Notes:
Journal Title: Reviews in Fish Biology and Fisheries

Title: **Documentation of unusual, fall spawning by Coastal Cutthroat Trout in the Elwha River system, Washington**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2014
Uploaded File: mcmillan_et_al_2014_un....S.pdf, 324 kb
URL: *none*
Abstract:
The timing of breeding is a key trait, reflecting selective forces acting on the adults and offspring in the population, contributing to reproductive isolation, and affecting the population's success during rapid environmental change. Salmon and trout populations vary greatly in the peak and range of breeding dates, and timing is a defining trait for salmonid populations. This study reports the occurrence and details of spawning by Coastal Cutthroat Trout, Oncorhynchus clarkii clarkii, in Indian Creek in the Elwha River, Washington State, in October and November, unusually early in the season for this characteristically spring-spawning species. This timing is much earlier than conspecifics elsewhere in the river system and the region. We hypothesize that the stream's low gradient and lake-dampened hydrologic regime reduce the depth of fall gravel scouring, and thus have permitted the evolution of such early breeding date by these small-bodied (ca. 20 - 35 cm) fish. The exclusion of otherwise sympatric, fall-spawning Coho Salmon, O. kisutch, for the past century from the habitat by Elwha Dam may also have contributed to this adaptation, and the re-colonization by the larger and later-spawning Coho Salmon may affect the Coastal Cutthroat Trout through redd disturbance.
Citation:
McMillan, J. R., G. R. Pess, M. L. McHenry, R. Moses, and T. P. Quinn. 2014. Documentation of unusual, fall spawning by Coastal Cutthroat Trout in the Elwha River system, Washington. Transactions of the American Fisheries Society 143:

1605-1611
Copyright Restrictions + Other Notes:
Journal Title: Transactions of the American Fisheries Society

Title: **Juvenile Chinook salmon, Oncorhynchus tshawytscha, use of the Elwha River estuary prior to dam removal**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2014
Uploaded File: Quinn_et_al._2014_Elwh....n.pdf, 1115 kb
URL: *none*
Abstract:
The estuary of the Elwha River, on Washington's Olympic Peninsula, has been degraded and simplified over the past century from sediment retention behind two large dams, levee construction, and channelization. With the removal of Elwha Dam and initiation of Glines Canyon Dam's removal in fall 2011, sediment deposits will change the estuary and affect anadromous and nearshore marine fishes. Juvenile Chinook salmon commonly use estuaries and the river's population is part of an Evolutionarily Significant Unit listed as Threatened under the U.S. Endangered Species Act. This study reports on monthly sampling in part of the river's estuary from March 2007 through September 2011 to characterize the seasonal changes in relative abundance of yearlings and sub-yearlings, and size distributions prior to dam removal. Most (69%) of the yearlings were caught in April, when this life history type was released from the hatchery, and to a lesser extent in May (28%) and June (3%). Yearlings caught in the estuary were smaller than those released from the hatchery (means: 153 mm ± 28 SD vs. 175 mm ± 5 SD), suggesting more rapid departure by larger fish. Sub-yearlings were much more abundant in the estuary, and were caught from March through November, increasing in mean fork length by 8.7 mm month-1. The hatchery-origin sub-yearlings were not marked externally and so were not distinguishable from natural origin fish. However, 39% of the sub-yearlings were caught prior to June, when sub-yearlings were released from the hatchery, indicating substantial use of the estuary by natural-origin fish. Thus, even in a reduced state after a century of dam operation, the highly modified estuary was used over many months by juvenile Chinook salmon. The information on juvenile Chinook salmon prior to dam removal provides a basis for comparison to patterns in the future, when the anticipated increase in estuarine complexity may further enhance habitat use by juvenile Chinook salmon.
Citation:
Quinn, T. P., J. A. Shaffer, J. Brown, N. Harris, C. Byrnes, and P. Crain. 2014. Juvenile Chinook salmon, Oncorhynchus tshawytscha, use of the Elwha River estuary prior to dam removal. Environmental Biology of Fishes 97: 731-740
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **Juvenile coho salmon, Oncorhynchus kisutch, in the Elwha River estuary prior to dam removal: Seasonal occupancy, size distribution, and comparison to nearby Salt Creek**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2013

Uploaded File: Quinn_et_al._2013_Elwh....n.pdf, 471 kb
URL: *none*
Abstract:
In addition to the downstream migration of smolts in spring, coho salmon also enter estuaries throughout the year but especially in spring as fry and in fall as parr. The removal of two large dams on the Elwha River, Washington has increased the area accessible to salmon and is affecting many aspects of the system. For comparison with the post-dam period, when the estuary will likely expand in size and complexity, monthly sampling was conducted from 2007 – 2011 in the estuaries of the Elwha River and Salt Creek, a nearby undammed stream, to determine patterns of coho salmon presence and size. The spring smolt migration in the Elwha River included a large fraction of unmarked fish primarily of natural origin, as well as marked fish from a hatchery on the river. Sub-yearlings entered both estuaries during much of the year, with a peak in September. Coho salmon from the Elwha River (including wild and hatchery origin fish) were larger than those from Salt Creek and were more heavily represented in the fall, relative to the spring smolt migration. Future patterns in the Elwha River may include reduced pre-smolt use of the estuary if the center of distribution is farther upriver but improved estuarine habitat may make it more suitable for pre-smolts.
Citation:
Quinn, T. P., N. Harris, J. A. Shaffer, C. Byrnes, and P. Crain. 2013. Juvenile coho salmon, Oncorhynchus kisutch, in the Elwha River estuary prior to dam removal: Seasonal occupancy, size distribution, and comparison to nearby Salt Creek. Transactions of the American Fisheries Society 42: 1058-1066
Copyright Restrictions + Other Notes:
Journal Title: *none*

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

No Leveraged Funds Reported This Period

COMPLETION NARRATIVE

Uploaded File: Quinn_9251_completion_....2.pdf, 167 kb

Recovery of Elwha River Salmon and Trout after Dam Removal: Recolonization and the Awakening of Dormant Life History Diversity

Funding from Sea Grant began in April 2012 and we recruited Emily Thornton as a master's student at the School of Aquatic and Fishery Sciences, University of Washington. She selected and completed her thesis and will defend it in spring 2015. In addition, as proposed, we directed efforts towards a variety of species and questions in an effort to accomplish as much as possible, given the funding in hand and the complexity of the task. We feel very good about what has been done, though inevitably there are many things still in progress or that could not be attempted for one reason or another. Overall, we have established very strong links to all the major collaborators in the Elwha River system and project begun under this grant will continues into the future.

The pace of work in the Elwha River system is exceptionally fast as the river is changing constantly, and the agencies are making rapid decisions and taking quick action, sometimes with little notice to groups outside the circle of decision-makers. These challenges are revealing the wisdom in our proposal's broad approach rather than rigidly defined studies, notwithstanding the skepticism of the proposal reviewers. The report below is in outline form to facilitate review but our success in research, local involvement, and education has been above our expectations. In addition to the project co-investigators, all of whom have contributed greatly, special mention should be made of John McMillan, an exceptionally talented and dedicated biologist who has contributed a great deal in terms of data collection and insights. Many biologists working for the Lower Elwha Klallam Tribe (LEKT, e.g., Rebecca Paradis, Matt Beirne and Raymond Moses) have also been tremendously helpful, reflecting their expertise and dedication. Without the efforts of such skilled and motivated people, on-site, a project of this kind simply could not be carried out. In addition, Emily Thornton has been a wonderful graduate student, contributing new ideas and hard work to the tasks, and already accomplishing much.

Steelhead – rainbow trout

1) **Title**: Characterization of redds by made steelhead and rainbow trout.
   Leads: John McMillan and George Pess (NOAA), Thomas Quinn (UW)
   Goal: Find ways to correctly classify redds by origin of mother to facilitate assessment of spatial distribution of breeding by the two forms, relative abundance, progress of colonization, and habitats used when sympatric.
   Method: Measure redd area and gravel at known rainbow and steelhead redds.
   Results/status: Data have been collected with excellent classification success indicated by univariate analyses. We combined these data with #2 below in one paper, which is currently in review in North American Journal of Fisheries Management.
2) **Title:** Use of steelhead and rainbow trout fry size for classification, and otolith chemistry for validation of maternal origins.
   Leads: John McMillan and George Pess (NOAA), Lance Campbell (WDFW) and TQ (UW)
   Goal: Determine whether steelhead fry (spawned earlier and from larger eggs) differ enough in size from rainbow trout for use to assess distribution, relative abundance, and in-stream ecology of age-0 fish after dam removal.
   Methods: Measure fry from areas occupied by rainbow and steelhead prior to dam removal as a function of date, develop a classification system, and then validate it with "unknown" fish collected in the post-dam period, identified with otolith micro-chemistry.
   Results/status: The pre-dam-removal data show excellent classification success, and samples of "unknown" fish were processed as well. These data were integrated into the MS #1 above.

McMillan, J. R., G. R. Pess, M. Liermann, S. Morley, M. McHenry, L. Campbell, and T. P. Quinn. The use of redd characteristics and fry fork length and density to distinguish spawning areas used by steelhead and resident rainbow trout (*Oncorhynchus mykiss*): Application to the recolonization of

the Elwha River after dam removal. North American Journal of Fisheries Management (in review)

3) **Title**: Use of nitrogen stable isotope signal to distinguish steelhead and rainbow trout fry.
Leads: Emily Thornton, and Ron Hardy (U of Idaho) and Thomas Quinn (UW)
Goal: Develop and test methods to classify *O. mykiss* fry by maternal origin from stable isotopes to facilitate in-stream sampling and identification of mixed origin fish.
Method: Obtained eyed eggs from steelhead, reared some fry on non-marine derived food and some on a diet with marine sources, and sampled fry periodically as they grew for stable isotopes in fin tissue to see the decline in ^{15}N enrichment from the marine maternal signal to baseline.
Results/status: The experiment was a success and we submitted a paper, which received favorable reviews. The revised paper is now in review.

Thornton, E. J., R. W. Hardy and T. P. Quinn. Experimental determination of the limits of using stable isotopes to distinguish steelhead and Rainbow Trout offspring. North American Journal of Fisheries Management.

4) **Title**: Wild and hatchery steelhead life history inferred from archived scale data.
Lead: Patrick Crain (NPS, formerly WDFW), George Pess (NOAA), Michael McHenry (LEKT) and Thomas Quinn (UW)
Goal: Test the hypothesis that wild and hatchery steelhead in the Elwha River were similar with respect to return timing against the alternative that wild fish returned later, as would be expected if they retained ancestral traits. The secondary goals are to describe the return timing of wild steelhead in the past for evidence of summer vs. winter runs, and to determine the basic life history of the wild fish in the period prior to dam removal.
Method: Examine data from Elwha River gill-net caught steelhead from 1981 – 2001 (N = 18212 in total), including freshwater and marine age, capture date, and wild/hatchery origin and length.
Results/status: The data are in well-organized spread-sheets. Preliminary analysis (TQ) suggested some interesting patterns of overall arrival timing and linkage between freshwater age and return date, etc. There are some uncertainties regarding the nature of the fisheries (i.e. possible sampling bias) so analysis must be cautious. Given the termination of Sea Grant funding it was not possible to accomplish this task.

5) **Title**: Wild and hatchery steelhead life history inferred from body fat content
Lead: Mara Zimmerman and Jamie Lamperth (WDFW), Thomas Quinn (UW)
Goal: Test the hypothesis that body fat of adult steelhead varies with return date, seasonal run (winter vs summer) and between wild and hatchery origin fish. Do fish adapted to return early (i.e., summer steelhead) arrive with more body fat than winter steelhead? Given the variation in return date observed from gillnet catch data (#4) and recent weir counts, are there remnant summer steelhead in the Elwha River or just early fish on the edge of a normal distribution?
Method: Sample wild and hatchery summer and winter steelhead at the Kalama River to quantify the variation in long-established populations in body fat content at arrival for subsequent comparison with Elwha River fish. Scales were also taken for age determination.
Results/status: The meter was used to assess fat content in wild and hatchery summer and winter steelhead at the Kalama River for an entire year. All the data are now in, and we are in the process of preparing the manuscript, combined with objective #6 (below).

6) **Title**: Wild and hatchery steelhead marine ecology inferred from stable isotope analysis
Lead: Mara Zimmerman (WDFW), Jamie Lamperth, (WDFW) and Thomas Quinn (UW).

Goal: Use stable isotopes from scales to determine whether wild and hatchery fish make different use of the ocean for feeding, as an indirect inference method.
Method: Take scales from wild and hatchery steelhead from Kalama River fish to determine whether stable isotopes of N and C indicate differences in marine ecology.
Results/status: Full sets of scales were collected from wild and hatchery summer and winter steelhead from the Kalama River for an entire year. They have been processed for stable isotopes and the data examined. A paper is being prepared combining these data and the fat content data.

Sockeye salmon - kokanee

1) **Title**: Life history of Lake Sutherland kokanee: Implications for ancestral origins
Lead: Thomas Quinn and Morgan Bond (UW) and Hans Berge (King County)
Goal: The first goal is to characterize the current life history and phenotypic traits of *O. nerka* in Lake Sutherland as a baseline against which anadromous fish can be compared. The second goal is to be able to determine, in the future, whether anadromous sockeye originated from non-anadromous parents or whether they were colonists from elsewhere, with the eventual goal of determining the mix of anadromous and non-anadromous fish in the lake. The third goal is to help determine whether the sockeye salmon are descended from native or stocked fish.
Methods: Obtain specimens of adult *O. nerka* from Lake Sutherland, process for length, weight, egg size and fecundity if possible, measure body shape, take digital photos, sample muscle for stable isotopes, and remove otoliths for age determination and later micro-chemical analysis. Augment these data with data from sockeye and kokanee from other populations for comparisons.
Results/status: Marcia House (NWIFC) and Rebecca Paradis (LEKT) provided us with adult samples. The results showed patterns of life history suggestive of anadromous ancestry (large egg size for a given body size). A paper reporting these data has been accepted for publication.

Quinn, T. P., M. H. Bond, and H. Berge. Use of egg size differences in anadromous (sockeye salmon) and non-anadromous (kokanee) forms of *Oncorhynchus nerka* to infer ancestral origins of the Elwha River's landlocked population. Ecological Research

2) **Title**: Ecology and nutrient cycling of Lake Sutherland
Lead: Rebecca Paradis and Matt Beirne (LEKT), Thomas Quinn, Morgan Bond, Adam Hansen, David Beauchamp (UW)
Goal: Characterize the current ecology and nutrient base in Lake Sutherland as a baseline against which future years, when anadromous fish enter the system, can be compared. The question is whether (or when) the sockeye salmon will make detectable contributions to the ecosystem of the lake, and what the carrying capacity would be for anadromous rather than resident fish.
Methods: LEKT limnology sampling provides monthly depth-specific data at six stations in the lake. We have initiated monthly zooplankton sampling and these data will be very valuable for assessing the productive capacity of the lake for sockeye salmon. We will also use bioenergetics models to estimate the eventual carrying capacity for sockeye rather than kokanee, based on volume of water, thermal and oxygen conditions, and plankton density.
Results/status: The limnology data have been examined and indicate a possible temperature-DO squeeze in late summer. Zooplankton species have been identified and stable isotope analysis indicated sufficiently low ^{15}N levels that an increase in the future from salmon carcasses should be detectable. We have received notice that there will be some continued funding from Sea Grant and we plan to pursue this project in the next cycle, in collaboration with Drs. David Beauchamp and Adam Hansen (Washington Cooperative Fish and Wildlife Research Unit).

Cutthroat trout

1) **Title**: Life history and breeding timing of Indian Creek cutthroat trout

Lead: John McMillan and George Pess (NOAA), Michael McHenry (LEKT) and Thomas Quinn (UW)
Goal: Cutthroat trout were observed spawning in Indian Creek, the outlet of Lake Sutherland, in fall rather than the more normal spawning period in spring. This is a most unusual trait and worthy of full documentation. It is not clear how this trait might change in the post-dam removal period but change is certainly possible as the "fall-spawning" coho salmon spawn later than the "spring spawning" cutthroat, reversing the normal patterns, and perhaps disturbing the redds from the smaller trout. The goal was to formally document this phenomenon, and deploy temperature loggers to estimate developmental rates and emergence based on thermal sums models.
Methods: Direct observations of courting and redd construction, and positive ID of the fish (from photos) were obtained, redds were measured for size, and temperature loggers deployed.
Results/status: Data were collected and a MS has been published based on these data.

McMillan, J. R., G. R. Pess, M. L. McHenry, R. Moses, and T. P. Quinn. 2014. Documentation of unusual, fall spawning by Coastal Cutthroat Trout in the Elwha River system, Washington. Transactions of the American Fisheries Society 143: 1605-1611.

Elwha River estuary

1) **Title:** Use of the Elwha River estuary by juvenile salmon and trout
Lead: J. Anne Shaffer (CWI), Nicole Harris (WWU), Justin Brown, and Thomas Quinn (UW)
Goal: Determine the patterns of occupancy by salmon in the estuary of the Elwha River and nearby Salt Creek in the period prior to dam removal, for comparison to the future.
Methods: Monthly beach seining has been conducted at two sites in each estuary by the CWI since 2007, with all fish identified and counted, and a sub-set measured for length.
Results/status: Papers on coho salmon and on Chinook salmon were published. Analyses of data on chum salmon, bull trout and cutthroat trout are on-going but we will likely include data from the post-dam period and so these papers will be prepared in the future.

Quinn, T. P., N. Harris, J. A. Shaffer, C. Byrnes, and P. Crain. 2013. Juvenile coho salmon, *Oncorhynchus kisutch*, in the Elwha River estuary prior to dam removal: Seasonal occupancy, size distribution, and comparison to nearby Salt Creek. Transactions of the American Fisheries Society 42: 1058-1066.

Quinn, T. P., J. A. Shaffer, J. Brown, N. Harris, C. Byrnes, and P. Crain. 2014. Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, use of the Elwha River estuary prior to dam removal. Environmental Biology of Fishes 97: 731-740.

Pink salmon

1) **Title:** Migration timing and life history of pink salmon
Lead: Joseph Anderson (WDFW), George Pess (NOAA), Michael McHenry (LEKT), Krista Oke (McGill University) and Thomas Quinn (UW)
Goal: Determine the patterns of body size and return timing of Elwha River pink salmon for comparison with conspecifics in the Dungeness River. Does the Elwha River have early and late runs, as does the Dungeness? Is the timing similar or different between rivers? Are the fish of the same body size in the early and late components, and in the two rivers? Are the runs synchronous between rivers and between early and late or asynchronous, as might suggest that they are independent populations?
Methods: Monitor arrival timing or live counts in the two rivers, especially on odd-numbered years. Measure body size of carcasses in both rivers throughout the run(s).
Results/status: Preliminary data indicated bimodal run timing in the Elwha River, and we obtained data in 2013. We hope to include the data on timing and body size of even and odd year runs of pink salmon in a larger paper on life history differences between these lines but analysis is

still on-going. A broader assessment of the populations was not possible owning to funding issues.

Bull trout

1) **Title**: Non-lethal sampling to develop migration chronologies for bull trout
   Leads: Roger Peters (USFWS), Sam Brenkman (NPS), Lance Campbell (WDFW), Thomas Quinn (UW)
   Goal: Refine non-lethal techniques for reconstructing the migration history of fish from fin rays as an alternative to otolith extraction, to determine whether fish from the above-dam area become anadromous, and the extent of anadromy by fish below the dam sites.
   Methods: Obtain and prepare pectoral fin rays from anadromous and non-anadromous bull trout to determine the success in detecting their recent migrations from Sr/Ca ratio.
   Results/status: Campbell has already demonstrated that pectoral fin rays can archive migration history and the techniques are being refined to minimize harm to the fish. This project is on hold.

2) **Title**: Tracking of anadromous bull trout
   Lead: Roger Peters (USFWS), Jeffrey Duda (USGS), Sam Brenkman (NPS), Michael McHenry (LEKT) and Thomas Quinn (UW)
   Goal: Characterize the timing of movement upstream and downstream by anadromous bull trout and the distribution along the marine shoreline.
   Methods: Catch fish within the river for implantation with radio tags, and deploy self-contained receivers at strategic locations.
   Results/status: This project is moving forward, albeit somewhat slowly, with radio tracking of bull trout being conducted each year, in coordination with the fence being operated to count and tag adult salmon. The results of this work will be building over the next several years but we will endeavor to maintain this collaboration at a low level into the future.

Influence of species, size, and relative abundance on the outcomes of competitive interactions between brook trout and juvenile coho salmon

Brook trout – coho salmon

1) **Title**: Influence of species, size, and relative abundance on the outcomes of competitive interactions between brook trout and juvenile coho salmon.
   Leads: Emily Thornton (UW), Jeff Duda (USGS), Thomas Quinn (UW)
   Goal: Determine the extent to which competitive dominance might affect behavioral interactions between colonizing coho salmon and established (but non-native) brook trout.
   Method: Conduct paired laboratory experiments to assess dominance using the USGS experimental facility at Sand Point.
   Results/status: Experiments have been completed, data analyzed, and a paper is about to be submitted. This will be one thesis chapter for Emily Thornton.
2) **Title:** Trophic overlap and scope for competition between re-colonizing coho salmon and resident, non-native brook trout in the Elwha River system.
   Leads: Emily Thornton (UW), Sarah Morley and George Pess (NOAA), Thomas Quinn (UW)
   Goal: Determine whether juvenile coho salmon and brook trout occupy the same trophic position in the Elwha River system, in a manner that might lead to competition, affecting the success of recolonization by coho salmon.
   Methods: Fish were sampled for diet and stable isotope ratios in a series of habitat units, the diet samples were processed, as were the isotope samples.
   Results/status: The data have been fully analyzed and a paper is being prepared for publication. This will constitute the second chapter of Emily Thornton's master's thesis.

3) **Title**: Habitat use and spatial overlap between recolonizing coho salmon and resident brook trout in the Elwha River system.
   Leads: Emily Thornton, George Pess and John McMillan (NOAA) and Thomas Quinn (UW)
   Goal: Determine the extent of spatial overlap between established but non-native brook trout and recolonizing coho salmon in the Elwha River system.
   Method: Electrofishing and snorkeling surveys in tributaries and side-channels of the Elwha River were conducted to determine the distribution of these two salmonid species.
   Results/status: Sampling and data analysis are complete, and a paper is being prepared for publication. This will constitute the third chapter in Emily Thornton's master's thesis.

Conclusion

The proposal to take a multi-species approach to the recolonization of the Elwha River system was met with some skepticism in the initial round of reviews, and even more in the request for renewal (which was denied, though there are some funds to finish certain aspects of the project). Notwithstanding these reviews, I remain convinced that my approach was the correct one, rather than undertake a specific and narrow project with a tight hypothesis. So many unexpected physical, biological, and human processes have been at work that considerable agility is needed to maintain forward motion. We have successfully built collaborative relationships that will endure long after the funding has ended, and we have published or are in the process of publishing many papers, including work on adult and juvenile life history stages, in the river, lake, and estuarine habitats, and involving coho salmon, Chinook salmon, sockeye salmon, cutthroat trout, and steelhead. Other projects on pink salmon and bull trout are ongoing, and a major review paper was published. It is fair to say that no one of these individual papers encompasses the full scope of salmonid recovery in this system, but that was not really the intent. I think that we have more than fulfilled the promise of the proposed work, and the final tally will include a much more favorable ratio of published papers per dollar than most project produce, I surmise. There have also been notable successes in personnel training and capacity building.