

CALIFORNIA COOPERATIVE FISH & WILDLIFE RESEARCH UNIT

ANNUAL
REPORT
2019



pudding Creek, Fort Bragg. © Natalie Okun

Contents

Accomplishments at a Glance 1

Unit Scientists and Staff 2

Graduate Students 3

Research Staff and Associates 4

Unit Cooperators 5

University Service and Teaching 6

Student Awards 7

Completed Projects 8

Current Projects 13

New Projects 20

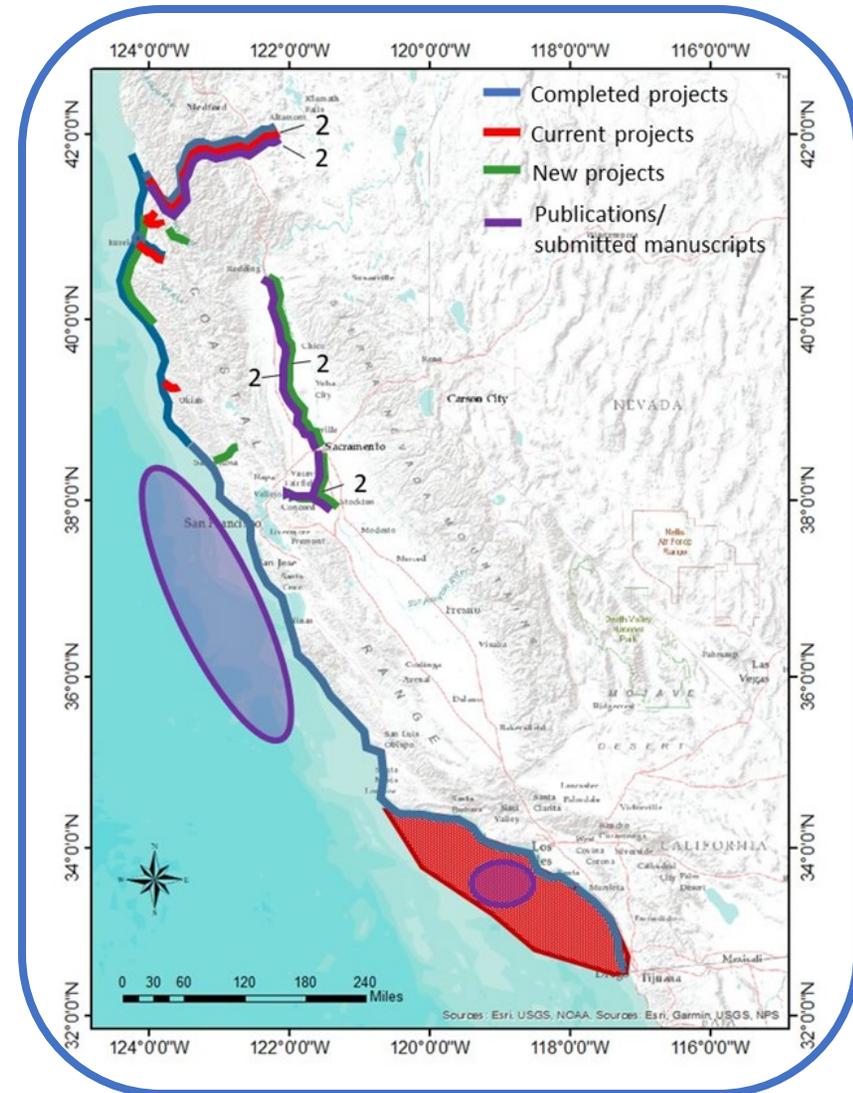
Products 28

Accomplishments at a Glance

Research at the California Cooperative Fish and Wildlife Research focuses on improving management of multiple species, especially those that have been listed under the Endangered Species Act. This primarily includes salmonids in coastal watersheds (e.g., the Klamath and Russian Rivers, and Redwood Creek), the Central Valley's Sacramento River, and the San Francisco Bay-Delta.

Our accomplishments in 2019 include:

- 7 graduate students completed their degrees
- Published 5 peer-reviewed scientific articles relevant to fisheries management in 3 CDFW regions (Region 1, Region 2, and Marine)
- Submitted an additional 5 manuscripts relevant to fisheries management in 4 CDFW regions (Region 1, Region 2, Bay-Delta, and Marine)
- We received 3 grants totaling over \$700k, and we now have more than \$3.3 million in grant funds in 4 out of the 7 CDFW regions.
- Our grants support 15 graduate students and the salaries of 23 staff!



Map illustrating the location of research projects and study sites of publications from the California Coop unit. Numbers indicate locations with multiple projects

Unit Scientists and Staff



Mark Henderson started as an assistant unit leader at the California Cooperative Unit in 2016 and has been the acting unit leader since 2017. His current research primarily focuses on incorporating environmental covariates into ecological models to understand the processes that affect fish population dynamics.



JoAnna Pifferini joined the Cooperative unit this year as the new administrative support coordinator. She came to the unit after working for the Student Health & Wellbeing Service (SH&WS) at Humboldt State University for four years.



Leslie Farrar retired in 2019 after nine years of providing administrative support for the California Unit, and over 20 years of working at Humboldt State University. We will be forever grateful for her extremely dedicated and diligent work. Of course, her retirement was well-deserved and we are excited she now has more time to spend with her family and in her garden

Graduate Students



Cory Dick started as a masters student in January of 2019 and will be using laboratory experiments to determine the feasibility of using molecular methods to estimate the total consumption of salmon smolts by predators in the San Francisco Bay-Delta.



Emerson Kanawi is getting ready to defend his masters thesis during the spring of 2019. His masters examined the potential of using environmental DNA to quantify the abundance of Coho salmon populations. This could reduce the cost of surveying threatened populations and verifying the effectiveness of restoration efforts.



Nissa Kreidler is getting ready to defend her masters thesis in spring 2019. Her research uses submersible survey data to develop species distribution maps for deep-sea coral and sponges, which provide important habitats for demersal fishes and other invertebrates. These maps will be useful to managers seeking to identify areas to protect threatened species.



Natalie Okun started the graduate program in Fall 2018 and plans to defend in fall 2020. Her masters thesis examines how large woody debris restoration in Mendocino affects survival, growth, and abundance of Coho salmon and steelhead in a paired watershed Before-After-Control-Impact (BACI) study.

Research Staff and Associates

Associated Graduate Students

Aaron Gottesman, Wildlife

Amon Armstrong, Biology

Branden Herman, Fisheries

Doyle Coyne, Fisheries

Ely Boone, Fisheries

Ian Butler, Fisheries

Jason Shaffer, Fisheries

Madison Halloran, Fisheries

Max Grezlik, Fisheries

Research Staff and Cooperators

Nick Som, Affiliate Scientist

Eve Robinson, Research Associate

Colin Anderson, Biologist

John Deibner-Hanson, Biologist

Student Technicians

Mary Clarquist

Katherine Stonecypher

Technicians

Ryan Arsenault

John Deibner-Hanson

Aaron Gottesman

Reed Hamilton

Nathan Harris

Rachael Iverson

Curtis Newell

Erin Phillips

Billie Prosser

Melissa Reneski

Heather Robinson

Regie Rodriguez

Alexandra Singh

Christopher Tevini

Unit Cooperators

Humboldt State University

- **College of Natural Resources**
 - Dale Oliver, Dean
- **Department of Fisheries Biology**
 - Andrew P. Kinziger
 - Andre Buchheister
 - Darren Ward
 - Jose Marin Jarrin
 - Rafael Cuevas Uribe
 - Eric P. Bjorkstedt
- **Department of Wildlife Biology**
 - Micaela Szykman Gunther
 - Matthew Johnson
 - Daniel Barton
 - Jeff Black
 - Richard Brown
 - Mark Colwell
 - Barbara Clucas
 - Tim Bean

US Fish & Wildlife Service

- **Sacramento Office**
 - Larry Rabin
- **Arcata Fisheries Program**
 - Nicholas Hetrick
 - Nicholas A. Som
 - Heather Eve Robinson

NOAA Fisheries

- **Northwest Fisheries Science Center**
 - David Huff
 - Joe Smith
- **Southwest Fisheries Science Center**
 - Cyril Michel
 - Jeremy Notch
 - Eric Danner

California Dept of Fish and Wildlife

- **Director**
 - Charlton 'Chuck' Bonham
- **Wildlife and Fisheries Division**
 - Stafford Lehr
- **Fisheries Branch**
 - Kevin Shaffer
 - Roger Bloom
- **Science Institute**
 - Christina Sloop
- **Northern Region**
 - Tony LaBanca
 - Phil Bairrington
 - Seth Ricker
 - Mike Sparkman
 - Justin Garwood
 - Sean Gallagher
 - Jason Roberts
- **North Central Region**
 - Colin Purdy
- **Bay-Delta Region**
 - Eric Larson
 - Marty Gingras
- **Marine Region**
 - Craig Shuman
 - James Ray
 - Rebecca Garwood

U.S. Geological Survey

- **Cooperative Research Units**
 - Dr. John Thompson
 - Dr. Kevin Whalen
- **Other**
 - Russell Perry
 - Fred Feyrer

University Service and Teaching

Courses Taught

Fish River Restoration Ecology (3 units)

Henderson

Fall 2019

Graduate Student Major Advisor

Henderson

Hannah Coe – MS Fisheries, Humboldt State University
 Emily Chen – MS Fisheries, Humboldt State University
 Cory Dick – MS Fisheries, Humboldt State University
 John Deibner-Hanson – MS Fisheries, Humboldt State University
 Emerson Kanawi – MS Fisheries, Humboldt State University
 Nissa Kreidler – MS Fisheries, Humboldt State University
 Christopher Loomis – MS Fisheries, Humboldt State University
 Natalie Okun – MS Fisheries, Humboldt State University
 Nicholas Van Vleet – MS Fisheries, Humboldt State University

Graduate Committee Service (unit scientists serve as members, not major advisors)

Henderson

Grace Ghrist – MS Fisheries, Humboldt State University
 Madison Halloran – MS Fisheries, Humboldt State University
 Max Grezlik – MS Fisheries, Humboldt State University
 Max Ramos – MS Fisheries, Humboldt State University
 Josh Cahill - MS Fisheries, Humboldt State University
 Chris O'Keefe – MS Fisheries, Humboldt State University
 Bobbie Suarez – MS Tropical Conservation Biology and
 Environmental Science, University of Hawaii - Hilo

Som

John Deibner-Hanson – MS Fisheries, Humboldt State University
 Nicholas Van Vleet – MS Fisheries, Humboldt State University
 Emily Chen – MS Fisheries, Humboldt State University
 Natalie Okun – MS Fisheries, Humboldt State University
 Chad Martel - MS Fisheries, Humboldt State University
 Jasmine Shen – MS Environmental Science & Management,
 Humboldt State University
 Thomas Starkey-Owens - MS Environmental Science &
 Management, Humboldt State University

UNIVERSITY AND OTHER SERVICE

Henderson

HSU Klamath Connection affiliate
 Klamath PIT tag database steering committee
 North American Journal of Fisheries Management Best Paper
 Award Committee
 Ecological Applications Subject Matter Editor
 Interagency Ecological Program Predator Project Work Team

Student Awards

Chen, Emily:

- AFS Marine and Estuary Travel Award

Coe, Hannah:

- Granite Bay Flycasters Bill Carnazzo Fellowship

Halloran, Madison:

- AFS Marine and Estuary Section Travel Award
- CSU Council on Ocean Affairs, Science, & Technology Travel Award
- Roelofs Humboldt Fisheries Fund
- Fisheries Founding Faculty Scholarship

Kanawi, Emerson

- CSU Council on Ocean Affairs, Science, & Technology Travel Award
- Joseph Bania scholarship

Kreidler, Nissa:

- NOAA Nancy Foster Scholar 2017 – 2019
- CSU Council on Ocean Affairs, Science, & Technology Graduate Student Award

Okun, Natalie:

- CSU Council on Ocean Affairs, Science, & Technology Graduate Student Award
- Humboldt Area Foundation Woolford Scholarship

Completed Projects

Using Environmental DNA and Occupancy Modeling to Estimate Rangewide Metapopulation Dynamics of the Endangered Tidewater Goby

PIs: Andrew Kinziger, Robert Dorazio, & Mark Henderson
Graduate Students: Michael Sutter & Chad Martel

Objective: We used environmental DNA (eDNA) surveys and multiscale occupancy models to examine metapopulation rates of the endangered tidewater goby, a species endemic to California estuarine habitats.

Results: We analyzed range wide eDNA data from 190 geographically isolated sites (813 total water samples) surveyed from two years (2016 and 2017). Rangewide estimates of the proportion of sites that were occupied varied little between 2016 (0.524) and 2017 (0.517). However, there was evidence of extinction and colonization dynamics. The probability of extinction of an occupied site (0.106) and probability of colonization of an unoccupied site (0.085) were nearly equal. Stability in site occupancy proportions combined with nearly equal rates of extinction and colonization suggests a dynamic equilibrium between the two years surveyed. Assessment of covariate effects revealed that colonization probability increased as the number of occupied neighboring sites increased and as

distance between occupied sites decreased.

Management Implications: The Tidewater Goby Recovery plan calls for rangewide monitoring of geographic distribution and for an assessment of how this distribution is changing through time. We show that eDNA surveys can rapidly provide a snapshot of a species distribution over a broad geographic range, and when these surveys are paired with dynamic multiscale occupancy modeling, can uncover metapopulation dynamics and their drivers. This information will provide managers critical information for assessment of species recovery.



A tidewater goby

Funding Source:

U.S. Fish and Wildlife Service

Research and development in support of the Klamath Basin Stream Salmonid Simulator (S3) Model

PIs: Nicholas Som, Russell Perry, & Mark Henderson

Postdoc: Christopher Manhard

Objective: To update the Stream Salmonid Simulator (S3) model, which is currently designed for Chinook Salmon, so that it can be applied to Coho Salmon in the Klamath Basin.

Results: The S3 model is a synchronized series of sub-models that reflects the array of physical and biological processes that interact to affect the growth, movement, and survival of fish at a given lifestage. A benefit to this method of model construction lies in the ability to update sub-models as new data, new analyses, or new scientific discoveries arise. This project successfully developed demographic models of Coho Salmon growth, movement, survival, and habitat selection, as well as information related to the environmental characteristics of off-channel habitats.

Management Implications: Our smolt migration model in regulated rivers suggests that emigration probability increases dramatically during and following periods of decreasing discharge, especially early in the emigration period. These results suggest the potential for water management alternatives to impact the migratory behavior of Coho Salmon residing in the Klamath Basin.

Funding Source:

U.S. Fish and Wildlife Service



The view of the Klamath River from the Kinsman rotary screw trap (Photo: Nick Som)

Effects of Longline Oyster Aquaculture on Benthic Invertebrate Communities in Humboldt Bay, California

PIs: Mark Henderson

Graduate Student: Hannah Coe

Objective: To understand how benthic and epibenthic macroinvertebrate communities are affected by the presence of longline oyster aquaculture.

Results: We collected benthic and epibenthic invertebrate samples from Humboldt Bay's North Bay and compared invertebrate community composition between eelgrass and mudflat habitats with and without aquaculture. We found that invertebrate communities responded most to the presence of structure and were not significantly different between aquaculture and eelgrass habitats. Transects conducted to measure eelgrass cover revealed significantly lower eelgrass coverage and shoot count when aquaculture was present.

Management Implications: This study found that benthic invertebrate communities were comparable between aquaculture and eelgrass habitats but that eelgrass densities were reduced in aquaculture habitats, which should be considered when managing current and future oyster aquaculture in Humboldt Bay.



Collecting longline oyster samples to sample the macroinvertebrate community (Photo: Hannah Coe)

Funding sources:

Confluence Environmental Co.
Humboldt State University

Using Environmental DNA Water Samples to Determine the Timing and Abundance of Outmigrating Coho Salmon Smolts in Two Coastal California Watersheds

PIs: Mark Henderson and Andrew Kinziger
Graduate Student: Emerson Kanawi

Objective: The goal of this project was to determine if it was feasible to measure the abundance of Coho Salmon in two creeks in Northern California using environmental DNA (eDNA).

Results: Water samples for eDNA were taken concurrently with downstream migrant traps that are installed seasonally to capture outmigrating Coho Salmon smolts over two outmigration seasons. The results of this study found only a small correlation between eDNA concentrations and abundances of Coho smolts within the trap. On separate creeks in different years, temperature, dissolved oxygen, and conductivity all showed a relationship with eDNA concentrations that warrants further investigation. The dynamics of eDNA within lotic systems are not yet well understood and will need continued research to sufficiently understand how and when the use of eDNA is appropriate for determining abundances of study species.

Funding sources:

CDFW
Save the Redwoods League
Humboldt State University
CSU COAST

Management Implications: Due to the relative simplicity and lower costs of eDNA, there is potential for it to replace traditional sampling methods and provide managers and conservation organizations with a rapidly deployable survey method to quantify the status of target species. However, this study found that further research is needed before this approach is used to quantify the abundance of Coho Salmon in California streams.



Emerson Kanawi collecting eDNA water samples

Basal Hollow Roost Selection by the Townsend's Big Eared Bat and Other Bat Species on the North Coast of California

PIs: Joseph Szewczak & Mark Henderson
Graduate Student: Amon Armstrong

Objective: To determine the extent that Townsend's big-eared bat (*Corynorhinus townsendii*), which is a species of greatest conservation need, is using basal hollows and understand how season and basal hollow habitat covariates influence their roosting activity.

Results: Guano traps were left in 140 trees with basal hollows for at least one year throughout the north coast of California to observe seasonal changes in tree hollow use by bat species over a landscape scale. Based on the guano samples that were collected in the hollows throughout the year (n=944), roosting activity varied greatly by season and peaked during the summer months. Regression models indicate that roosting activity increased in larger trees (larger diameter, height, and width of opening) and in areas closer to clearings.

Management Implications: This information can be used to provide land managers with specific criteria to identify and protect the roosting habitat of Townsend's big-eared bat throughout northern California.



A Townsend's Big Eared Bat emerging from a roost

Funding Source:
CDFW

Current Projects

Humboldt Bay Coho Salmon population monitoring

PIs: Darren Ward and Mark Henderson

Graduate Students: Grace Ghrist and Madison Halloran

Objective: To provide annual juvenile and adult abundance estimates for the Coho salmon population in Freshwater Creek, which is included in the threatened Southern Oregon Northern California Coho Salmon ESU.

Results: This monitoring effort provides a means to evaluate the response to habitat restoration and assess the role of diverse life history strategies in supporting population recovery. Results show that the stream-estuary ecotone of Humboldt Bay supports a substantial component of the juvenile population and that these juveniles return as adults at rates similar to fish that rear upstream habitats. Both juvenile and adult Coho salmon move among adjacent watersheds, but generally at low rates such that the individual watershed is an appropriate scale for monitoring population trends.

Funding sources:

CDFW
American Fisheries Society
CSU COAST
Humboldt State University

Management Implications: Long-term salmonid population monitoring, including the abundance of outmigrating smolts and the number of adults that return to spawn, is essential to separate freshwater and marine mortality rates. Recent research using these data have used mark-recapture data from juvenile Coho salmon tagged in the fall and spring to determine how life history diversity influences overwinter survival and migration patterns. These data can be utilized to inform restoration and recovery for this threatened species.



A juvenile Coho salmon about to be implanted with a passive integrated transponder (PIT) tag during fall tagging (Photo: Colin Anderson)

Life cycle monitoring of Coho Salmon in Prairie Creek

PIs: Mark Henderson

Graduate Students: John Deibner-Hanson, Nicholas Van Vleet, & Emerson Kanawi

Objective: To provide annual juvenile and adult abundance estimates for the Coho salmon population in Prairie Creek, which is included in the threatened Southern Oregon Northern California Coast (SONCC) Coho Salmon ESU.

Results: Coho Salmon adult escapement in Prairie Creek since 2010 has ranged from 320 to 1,076. Adult escapement estimate for the past two years (2017-18 and 2018-19) were both above average. Coho Salmon smolt estimates from Prairie Creek since 2011 ranged from 8,446 to 24,698, yet no directional trend has been observed. Overwinter survival and early emigration rates have shown little variability among years with survival ranging from 28-35% each year and most migrants leaving the stream in the spring. The watershed is managed by Redwood National and State Parks and is one of the most pristine watersheds in Northern California, which may help explain the stability of vital rates in its Coho Salmon population over the most recent decade.

Management Implications: Long-term salmonid population monitoring, including the abundance of outmigrating smolts and the number of adults that

return to spawn, is essential to separate freshwater and marine mortality rates. Additionally, this life-cycle monitoring station has also provided insight that: 1) environmental DNA (eDNA) may not be feasible to monitor abundances of Coho salmon in California streams, and 2) SONCC Coho salmon exhibit large inter-basin variability with regards to survival and movement behaviors.



Measuring the diameter of large woody debris © John Diebner-Hanson

Funding Sources:

CDFW
Humboldt State University

Redwood Creek Chinook Salmon monitoring and life cycle model

PIs: Mark Henderson

Graduate Student: Emily Chen

Objective: To provide annual juvenile and adult abundance estimates for the Chinook salmon population in Redwood Creek, which is included in the threatened California Coastal Chinook Salmon ESU.

Results: Adult Chinook Salmon escapement estimation methods (i.e., spawning ground surveys and DIDSON monitoring) in Redwood Creek since 2010 were similar but demonstrated that spawner surveys in Redwood Creek may underestimate the Chinook Salmon population. This work suggests that sonar monitoring is preferable to spawning ground surveys in large systems which have segregated run-timing among adult salmonids. Analysis of scale and otolith recoveries from adult Chinook Salmon carcasses in Redwood Creek helped to quantify the minimal contribution of estuary-rearing juveniles to the spawning adult population and point out current limitations associated with rearing in the Redwood Creek estuary. The Chinook Salmon life cycle model suggests temperature increases in future years may cause earlier outmigration, further reducing contributions from the estuary-type life history.

Management Implications: Long-term salmonid population monitoring, including the abundance of outmigrating smolts and the number of adults that return to spawn, is essential to separate freshwater and marine mortality rates. The life-cycle model found that the estuary may be a major bottleneck for production of the Redwood Creek Chinook Salmon population, mostly likely due to poor growth conditions. Restoration of the estuary could help this population recover.



Emily Chen holds up an otolith collected during a spawner survey

Funding Sources:

CDFW
Humboldt State University
American Fisheries Society

Habitat Suitability Mapping for Southern California Bight Deep Sea Coral and Sponge Species

PIs: Andre Buchheister and Mark Henderson
Graduate Student: Nissa Kreidler

Objective: This study will identify locations within the Southern California Bight that have suitable habitat for multiple species of deep sea coral and sponge taxa and identify the environmental variables most correlated with those distributions.

Results: Preliminary model results show hotspots of deep sea coral probability of presence woven between the Channel Islands and along the mainland coast. Several hotspot areas are found outside of protected areas such as the Channel Islands National Marine Sanctuary, suggesting a need to survey these areas for deep sea coral and sponge taxa of conservation interest.

Management Implications: Deep sea corals and sponges can be hot-spots of biodiversity and provide important structures for fish habitat. The maps developed in this project using species distribution models can be used as a tool for management decisions, such as where to draw boundaries for new areas of conservation and protection.

Funding Sources:

NOAA Nancy Foster Scholarship
CSU COAST



A Flag rockfish swim among gorgonian deep sea corals off Catalina Islands (left) and gorgonian deep sea corals drift in the currents off the coast of California (right) (Photo: Marine Applied Research and Exploration/ California Department of Fish and Wildlife)

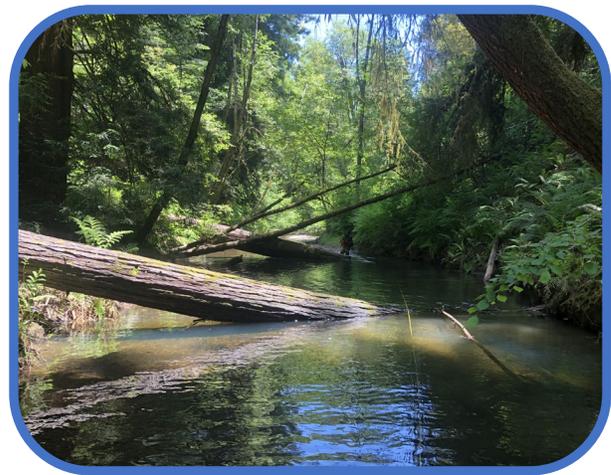
Large Wood Restoration Effectiveness for Salmonids in Pudding Creek, California: A Before-After-Control-Impact Experiment

PIs: Sean Gallagher, Elizabeth Mackey, Emily Lang, & Mark Henderson
Graduate Student: Natalie Okun

Objective: This project will evaluate the growth and survival response of endangered Central California Coast Coho Salmon (*Oncorhynchus kisutch*) and threatened Northern California steelhead (*Oncorhynchus mykiss*) to large woody debris (LWD) treatments on Pudding Creek in Fort Bragg, California.

Results: This analysis comes from data collected in a Before-After-Control-Impact (BACI) study initiated in 2012 based on monitoring salmon populations on both Caspar and Pudding creeks. In 2015, LWD was strategically placed in 80% of mainstem Pudding Creek while Caspar Creek was the untreated control. The standardized mean abundance estimates of Coho Salmon parr captured in outmigrant traps followed a similar trend in both creeks, suggesting the creeks work well as paired watersheds for the BACI design. A growth analysis using summer and fall electrofishing data found that steelhead have not been greatly impacted by wood treatment while Coho Salmon growth per day ($\text{mm}\cdot\text{d}^{-1}$) after treatment was significantly higher in Pudding Creek than Caspar Creek.

Management Implications: Billions of dollars have been spent on watershed restoration in California in recent decades, yet relatively few studies have linked habitat improvements with any effects on fish survival, growth, or abundance. This study will quantitatively measure the effect of large woody debris supplementation on the survival, growth, and abundance of Coho salmon and Steelhead trout so that managers can make informed decisions on how to most efficiently spend the limited amount of restoration funds available.



Surveying large woody debris in Pudding Creek

Funding Source:
CDFW

Comparison of Standard and Environmental DNA Methods for Estimating Chinook Salmon Smolt Abundance in the Klamath River, California

PIs: Andrew Kinziger, William Pinnix, & Mark Henderson

Graduate Student: Doyle Coyne

Objective: To determine if environmental DNA (eDNA) can be used to estimate Chinook Salmon smolt abundances in the Klamath River, California.

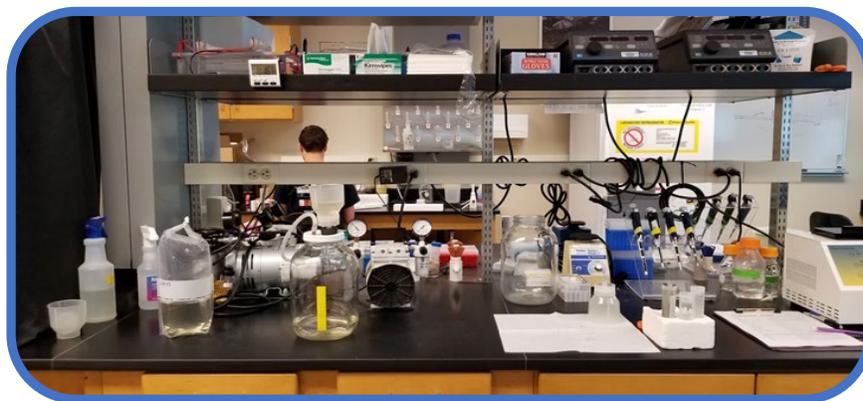
Results: A critical monitoring parameter for Chinook Salmon on the mainstem Klamath River is determination of smolt (age-0) outmigration timing, weekly abundance, and overall abundance. These data are used for assessing status and trends of Chinook Salmon in the Klamath River and also provide information for disease monitoring and salmon production models. Currently, weekly counts of age-0 Chinook Salmon are determined using a rotary screw traps, but eDNA may be a simpler and more cost-effective approach. Thus far, the first year of eDNA data has been

collected and is currently being analyzed and compared to the rotary screw trap catches from the Klamath River at the Kinsman site.

Management Implications: If eDNA can be used to accurately predict outmigration numbers of Chinook salmon, it may provide managers with alternative tool for species monitoring that is less expensive than traditional approaches. Further, eDNA approaches are flexible and will also allow for simultaneous estimation of abundance of other species, such as parasites, that are detrimental to juvenile Chinook salmon

Funding Source:

National Fish & Wildlife Foundation



Environmental DNA lab filtration setup (Photo: Emerson Kanawi)

Modelling the density of a parasite impacting salmonids in the Klamath River

PIs: Nicholas Som and Mark Henderson
Postdoc: Eve Robinson

Objective: To generate a predictive model of weekly waterborne *Ceratonova shasta* parasite spore density to improve estimates of mortality risk for juvenile salmonids in the Klamath River

Results: *Ceratonova shasta* is a parasite endemic to the Klamath River basin that has been linked to population declines in native salmonids. High densities of waterborne spores of the parasite are known to cause increasing infection and mortality risk for juvenile salmonids. A recently constructed population dynamics model for Klamath River salmonids, the Stream Salmonid Simulator (S3 model), includes a sub-model to simulate *C. shasta* disease and mortality risk for outmigrating juveniles in response to potential management alternatives.

This sub-model uses inputs of spore density, however, spores vary spatially and temporally within years, and vary over several orders of magnitude among years. Through the development of the spore model, associations between peaks in spore density and the prevalence of infection in hatchery-origin juveniles were found.

Management Implications: Developing models that are able to better estimate mortality risk for juvenile salmonids will provide a means to incorporate these models into the S3 model. This then provides an adaptive management tool for managers to understand how different management decisions (e.g. flow) might affect the population.

Funding Source:

U.S. Fish and Wildlife Service



A Chinook salmon smolt infected with C. shasta has a distended abdomen (Photo: Nick Som)

New Projects

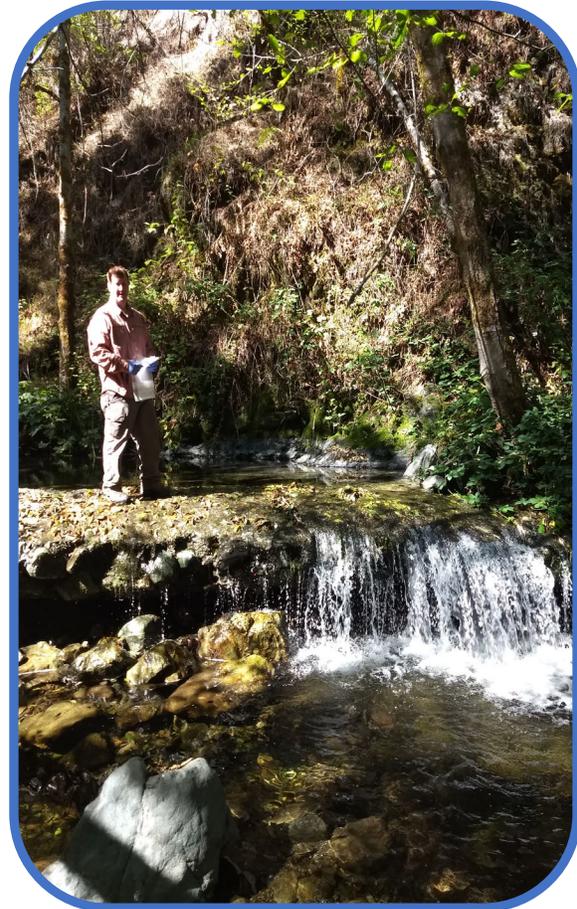
Coho Ecology- Hoopa Valley

PIs: Darren Ward and Mark Henderson
Graduate Student: Ely Boone

Objective: To assess Coho Salmon use of restored, and unrestored, tributaries to the Trinity River that have reduced habitat capacity due to mining, logging, and dams.

Expected Results: As Coho Salmon are thought to be at very low abundance in the study streams, relying only on visual observation and in-hand capture of Coho Salmon is likely to underestimate the extent of their distribution. Therefore, project sampling efforts will combine standard visual surveys (via snorkeling) with environmental DNA (eDNA) sampling (via water samples analyzed for presence of Coho Salmon DNA). This multi-method approach will also provide insight into the potential for eDNA surveys to evaluate small-scale patterns in Coho Salmon distribution associated with restoration activities.

Management Implications: The Hoopa Tribe recently made substantial investments in habitat restoration and improvement projects to aid in Coho Salmon recovery in streams on tribal land. Results of this project will provide information necessary to assess Coho Salmon use of restored and unrestored sites to guide future restoration efforts.



Ely Boone sampling Coho Salmon on Socktish Creek

Funding Source:

Hoopa Valley Tribal Council

Standardizing Environmental DNA Methodologies for Coho Salmon

PIs: Andrew Kinziger, Eric Bjorkstedt, Andre Buchheister, and Mark Henderson
Graduate Students: Braden Herman, Ian Butler, & Jason Shaffer

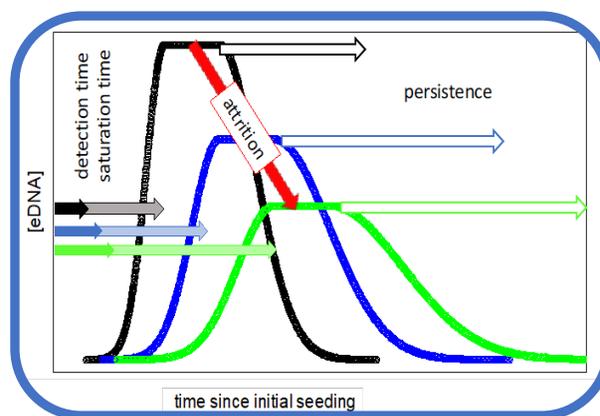
Objective: This research is designed to provide guidance for the application of environmental DNA (eDNA) approaches for monitoring the presence, distribution, and abundance of Coho Salmon.

Expected Results: While eDNA has the potential to revolutionize our ability to detect fish and to conduct monitoring in larger areas with higher efficiency and lower cost, it is not generally applied in standardized survey protocols developed by federal and state regulatory agencies. The initial steps involve conducting a series of laboratory and field experiments to study the ecological dynamics of eDNA, such as production, decay, and transit rates. Using the information from these initial experiments, a predictive statistical model will be developed and applied for estimating local- and broad-scale species distribution and abundance in river networks using eDNA. The eDNA model predictions of local- and broad-scale occupancy will be assessed by comparison to traditional field observations.

Funding Source:

California Department of Transportation

Management Implications: Federal and state resource management and conservation groups will benefit from the development of eDNA approaches that allow efficient and high accuracy predictions of species geographic distribution at local- and broader scales that are not achievable using currently applied field approaches. Development of eDNA distribution and monitoring methodologies will enable efficient, no-take approaches to establish environmental baseline conditions at culvert and bridge project sites, evaluate mitigation for project impacts, and demonstrate the efficacy of mitigation projects in aquatic habitats and at fish passage remediation project locations.



Example output from an eDNA dosing experiment that will be used to standardize sampling methodologies

Integration of molecular methods into predator diet analyses to advance understanding of juvenile Chinook salmon predation mortality in the Delta

PIs: Mark Henderson, Wes Larson, Suresh Sethi, Nann Fanguie, Fred Feyrer, and Russell Perry

Graduate Student: Cory Dick

Objective: To measure the detectability half-life of juvenile Chinook Salmon DNA within the digestive tract of two common predators in the Sacramento-San Joaquin Delta and use this information to compare consumption estimates based on visual and molecular analyses from field collected stomachs.

Expected Results: High mortality rates of juvenile Chinook in the Sacramento – San Joaquin Delta have been considered a result of non-native species predation on migrating smolts. Although this is the most common hypothesis, it has been difficult to test because predator stomach contents quickly becomes unidentifiable. In contrast, molecular analyses of gut content can identify species and estimate number of individuals in a mixture for a longer duration. We hypothesize that visual stomach analyses underestimate the amount of juvenile Chinook salmon consumption that occurs in the Delta due to rapid digestion rates. Molecular analyses, on the other hand, can identify trace amounts of prey content, possibly strengthening the estimates and understanding of predation on juvenile Chinook in the Delta.

Management Implications: Although it is hypothesized that predation is detrimental to outmigrating salmon smolt survival, it has been difficult to quantify this effect at the population level. The molecular stomach content data, and subsequent models based on those data, in this study will provide valuable information necessary to assist managers in understanding the impact of predation on salmon populations in the Delta.



A juvenile Chinook salmon smolt that was consumed by a smallmouth bass (Photo credit: FISHBIO)

Funding Source:

Metropolitan Water District

Development of environmental DNA assays for Central Valley Chinook salmon ecotypes

PIs: Andrew Kinziger and Mark Henderson

Objective: To develop a CRISPR assay to differentiate between the four Central Valley Chinook salmon ecotypes using environmental DNA methods.

Expected Results: This project will make use of an existing DNA alignment of whole genome sequence data from 128 Chinook salmon representative of all four Chinook salmon run-time ecotypes (winter, spring, fall, and late-fall) available through collaboration with NOAA Southwest Fisheries Science Center. It is hoped that by screening such a large extent of genomic variation we will be able to identify a sequence region suitable for development of an eDNA assay that is specific for winter-run Chinook salmon. By using CRISPR technology, instead of quantitative PCR (qPCR), we have the potential advantage of differentiating between closely related species due to the three levels of sequence complementarity required. Because CRISPR technology requires fewer DNA mismatches it may provide the ability to develop a specific assay for Chinook salmon ecotypes when qPCR approaches fail to produce a specific assay.

Management Implications: A recent study used isotopes from adult winter-run otoliths to determine that juvenile rear in diverse non-natal habitats (e.g. Sacramento River tributaries and the Sacramento-San Joaquin Delta), most of which are not currently listed as critical habitat under the Endangered Species Act. This study will develop a method to quickly and efficiently identify winter-run rearing habitats, and when they outmigrate from the Sacramento River, which will greatly improve the ability of managers to conserve this species.



Winter run juvenile Chinook salmon released into Battle Creek in California's Central Valley

Funding Source:

Metropolitan Water District

eDNA Abundance Estimates of Chinook salmon in the Sacramento River

PIs: Mark Henderson, Corey Phyllis, and Russell Perry
Graduate Student: Jacqueline Bridegum

Objective: To utilize environmental DNA (eDNA) to create a quantitative, and consistent, method to estimate juvenile Chinook salmon (*Oncorhynchus tshawytscha*) abundances throughout the Sacramento River.

Expected Results: Current monitoring for threatened and endangered Chinook Salmon in the Sacramento River uses a network of monitoring locations focusing on different life stages. Monitoring locations include sites in the upper river, lower river, and the Bay-Delta region. Although these monitoring locations exist throughout the system, the reliability of the monitoring techniques to measure annual population status varies by location. This study will develop a regression to correlate the daily abundance of out-migrating juvenile Chinook at the Red Bluff Diversion Dam rotary screw trap site to eDNA concentrations.

Funding Sources:

California Sea Grant (submitted)

Management Implications: This study would provide a system specific 'eDNA calibration curve' that would be a cost-effective technique to modernize winter-run monitoring on the Sacramento-San Joaquin Delta. Furthermore, this monitoring method will provide water managers with a more reliable means to determine when to close the Delta Cross Channel gate to prevent salmon from being entrained into the interior Delta, where survival rates are much lower.



Rotary screw trap at Red Bluff Diversion Dam used to monitor abundances of outmigrating juvenile salmon

Restoration of Redwood Creek Estuary: A degraded habitat critical for ESA listed salmonids

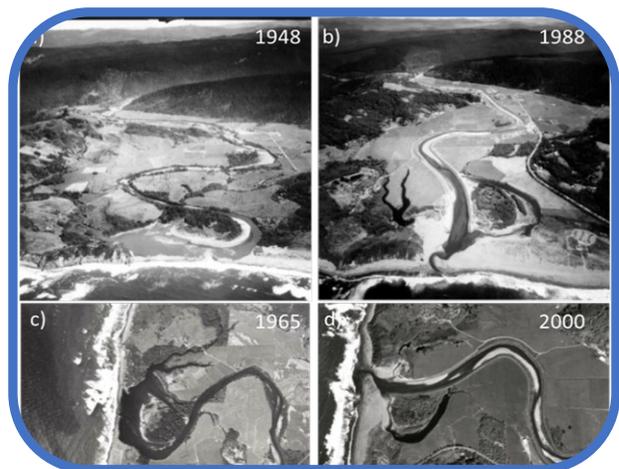
PIs: Mark Henderson, Vick Ozaki, Margaret Lang, Bret Harvey, & Steve Railsback
Graduate Students: TBA (2)

Objective: Determine how different estuary restoration scenarios will affect the Redwood Creek salmonid population, which includes multiple ESA listed populations (California Coastal (CC) Chinook, Southern Oregon Northern California Coast (SONCC) Coho, Northern California (NC) Steelhead).

Expected Results: The water quality conditions of the Redwood Creek estuary are severely degraded due to the construction of levees over 50 years ago that straightened and shortened the channel, reducing the estuaries habitat complexity. These flood control levees impair biological and physical processes, and hence water quality, by eliminating deepwater pools, disrupting sediment transport process and natural water circulation patterns, and significantly reducing the overall size of the tidal prism, estuary, and lagoon. Recent research found that juveniles that reared in this bar-built estuary contributed less to the spawning population than juveniles that entered the ocean before the mouth closed, most likely because of poor growth and survival in the estuary. A simulation based on this research found that an estuary restoration could improve the contribution of estuary rearing juveniles to the adult spawning population

three-fold and the total population abundance after 10 years by approximately 36%.

Management Implications: To aid in the sustainable recovery of these species, the Coho recovery plan has recommended the Redwood Creek restoration as the highest priority recovery action (i.e., essential for the recovery of the species range wide). The Multispecies Recovery Plan for CC Chinook salmon and NC steelhead also recommends Redwood Creek estuary restoration as essential to recovery of these species.



Aerial images of Redwood Creek estuary before (left) and after (right) the levees were constructed.

Funding Sources:

NOAA (submitted)
 USGS/National Park Service (submitted)

Comparing capture and non-capture survey methods to estimate piscivore abundance and predation of juvenile Chinook salmon in the Sacramento-San Joaquin Delta

PIs: Mark Henderson, Wes Larson, Megan McPhee, Devon Pearse, Cyril Michel, Suresh Sethi, & Shaara Ainsley

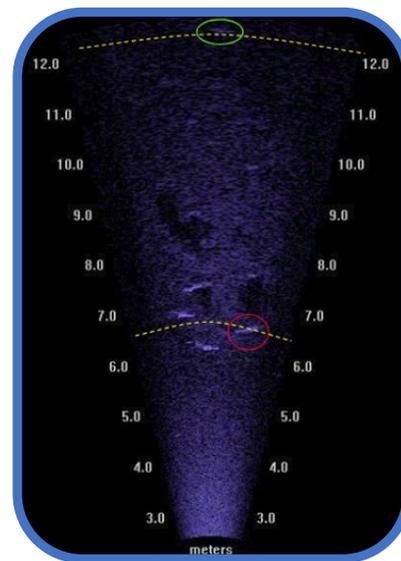
Graduate Student: TBA

Postdoctoral Scholar: TBA

Objective: To quantify the abundance and distribution of piscivorous fishes in the Delta, as well as their consumption of juvenile Chinook salmon.

Expected Results: We will collect data on predator abundance using a variety of methods (electrofishing, hoop-net, active acoustics, and mark-recapture), to assess how predator abundance and distribution is related to abiotic conditions such as temperature, flow, tidal state, submerged aquatic vegetation, and proximity to structures (i.e. water diversions). Recent results indicate DIDSON acoustic cameras are able to quickly survey large areas, identify individual targets, and distinguish predators from non-predators based on size. This would make acoustic surveys extremely cost-effective for assessing piscivore populations in the Delta. We will also collect piscivore stomachs so diet contents can be assessed using a novel molecular method to quantify the number of salmon consumed by an individual piscivore. The estimates of prey consumption will be input into a bioenergetics model to estimate the total consumption of juvenile salmonids migrating through the Delta.

Management Implications: This study will provide information to managers on how to most cost effectively survey piscivore populations in the Delta and will also provide valuable information on how different restoration efforts and fisheries management actions could impact Central Valley salmon populations. Finally, our study will provide quantitative data so managers can prioritize actions to reduce predation related mortality as salmon migrate through the Delta.



Images of fish (most likely striped bass) captured by a DIDSON acoustic camera

Funding Sources:

CDFW

Tools to Model Stage-Specific Survival and Abundance of the Anadromous Salmonid Life Cycle

PIs: Gregg Horton, Mariska Obedzinski, Daniel Barton, Nicholas Som, Seth Ricker, John Deibner-Hanson, Mark Henderson

Objective: Develop a mark-recapture analysis method to disentangle stage-specific survival from pre-smolt emigration and jacking rate

Expected Results: A difficulty in modeling stage-specific survival of the full anadromous salmonid life cycle is the ability to decouple mortality from emigration. Stationary, multi-antenna passive integrated transponder (PIT) arrays offer that possibility provided they are operated throughout the migration period of interest. Multi-state mark recapture models have been used to provide such estimates; however, due to low population size and incomplete antenna detection datasets (e.g. from winter storms), marine survival estimates have not always been possible. Using a Bayesian framework, we will leverage data from multiple years of physical capture and PIT antenna detections in the Russian River, and ocean survival data from nearby populations with larger sample sizes, to assist in overcoming these issues.

Funding Sources:
Unfunded

Management Implications: There is an immediate need to gain a more complete understanding of bottlenecks to survival that may be limiting progress toward salmon recovery. The choices made by individuals to move or stay may indicate underlying ecological processes. Such information could immediately inform recovery strategies and help to prioritize recovery actions.



PIT tag array and a fyke trap in the Russian River © Gregg Horton

Products

MS Theses:

- Chen, E. K. (2019). Contribution of Juvenile Estuarine Residency in a Bar-Built Estuary to Recruitment of Chinook Salmon (*Oncorhynchus tshawytscha*). Humboldt State University, Arcata, CA.
- Coe, H. C. (2019). Effects of Longline Oyster Aquaculture on Benthic Invertebrate Communities in Humboldt Bay, California. Humboldt State University, Arcata, CA.
- Deibner-Hanson, J.D. (2019). Overwinter Survival and Movement of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Relation to Large Woody Debris and Low-Velocity Habitat in Northern California Streams. Humboldt State University, Arcata, CA.
- Ghrist, G. K. (2019). Freshwater and Marine Survival of Coho Salmon (*Oncorhynchus kisutch*) as a Function of Juvenile Life History. Humboldt State University, Arcata, CA.
- Halloran, M. (2019). Coho Salmon Life History Variants in Humboldt Bay Tributaries: Population Connectivity in Adjacent Watersheds. Humboldt State University, Arcata, CA.
- Loomis, C. (2019) Density and Distribution of Piscivorous Fishes in the Sacramento-San Joaquin Delta. Humboldt State University, Arcata, CA.
- Van Vleet, N (2019). A Time- and State-Based Approach to Estimate Winter Movement and Survival of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Freshwater Creek, California. Humboldt State University, Arcata, CA.

Publications (* indicates a student author):

Peer-reviewed

- Manhard, C. V., N. A. Som, R. W. Perry, J. M. Plumb. 2018. A Laboratory-Calibrated Model of Coho Salmon Growth with Utility for Ecological Analyses. *Canadian Journal of Fisheries and Aquatic Sciences* 75(5): 682-690. doi: 10.1139/cjfas-2016-0506.
- Rub, AMW, Som, NA, Henderson, MJ, Sandford, BP, Van Doornik, DM, Teel, DJ, Tennis, MJ, Langness, OP, van der Leeuw, BK, and Huff, DD. 2019. Changes in adult Chinook salmon (*Oncorhynchus tshawytscha*) survival within the lower Columbia River amid increasing pinniped abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 76: 1862-1873.
- Henderson, MJ, Iglesias, IS, Michel, CJ, Ammann, AJ, Huff, DD. 2019. Estimating spatial-temporal differences in Chinook salmon outmigration survival with habitat and predation related covariates. *Canadian Journal of Fisheries and Aquatic Sciences* 76: 1549-1561.

Robinson, H.E., Strickler, J.R., Henderson, M.J., Hartline, D.K., and Lenz, P.H. 2019. Predation strategies of larval clownfish capturing evasive copepod prey. *Marine Ecology Progress Series* 614: 125-146.

Henderson, M., Fiechter J., Huff, D.D., and Wells, B.K. 2019. Spatial Variability in ocean-mediated growth potential is linked to Chinook salmon survival. *Fisheries Oceanography* 28: 334-344.

In review

Henderson, M.J., Huff, D.D., and Yoklavich, M.M. (*in review*). Demersal fish prefer deep-sea coral and sponge habitats even after accounting for depth and substratum relief. Submitted to *Marine Ecology Progress Series*.

Notch J.J., McHuron A.S., Michel C.J., Cordoleani F., Johnson M., Henderson M.J., and Ammann A.J. (*in review*) Outmigration survival of wild Chinook salmon smolts through the Sacramento River during historic drought and high water conditions. Submitted to *Environmental Biology of Fishes*.

Michel, CJ, Henderson, MJ, Loomis, CM*, Smith, JM, Demetras, NJ, Iglesias, IS, Lehman, BM, Huff, DD. (*in review*) Fish Predation on a Landscape Scale. Submitted to *Ecosphere*.

Robinson, H.E., Alexander, J.D., Hallett, S.L., and N.A. Som (*in review*) Prevalence of infection in hatchery-origin Chinook Salmon (*Oncorhynchus tshawytscha*) correlates with abundance of *Ceratonova shasta* spores: implications for management and disease risk. Submitted to *North American Journal of Fisheries Management*.

Winship A.J., Thorson J., Clarke E., Coleman H., Costa B., Georgian S., Gillett D., Grüss A., Henderson M., Hourigan T.F., Huff D., Kreidler N.*, Pirtle J., Olson J.V., Poti M., Rooper C.N., Sigler M.F., Viehman S., and Whitmire C.E. (*in review*) Good practices for species distribution modeling of deep-sea corals and sponges: data collection, analysis, validation, and communication. Submitted to *Frontiers in Marine Science*.

Reports

Deibner-Hanson, J. D., and M. J. Henderson. (2018). Life Cycle Monitoring of Coho Salmon in Prairie Creek: 2018 annual report prepared in partial fulfillment of Fisheries Restoration Grant Project No. P1610520.

Manhard, C. V., N. A. Som, E. C. Jones, and R. W. Perry. 2018. Estimation of Stream Conditions in Tributaries of the Klamath River, Northern California. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2018-32, Arcata, California.

Manhard, C. V., N. A. Som, R. W. Perry, J. R. Faulkner, and T. Soto. 2018. Estimating Freshwater Productivity, Overwinter Survival, and Migration Patterns of Klamath River

Coho Salmon. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2018-33, Arcata, California.

Presentations (* indicates a student author):

Armstrong, A*., Sanville, C. Walker, F., Sobek, C., and Szewczak, J. Tree Hollow Roost Selection by Bats on the North Coast of California. Western Section of The Wildlife Society conference, Feb. 4-8, Yosemite, CA. Available at:
http://www.iws.org/Publications/Posters/BattyPoster_4TWS6.pdf

Chen E. K.*, Henderson M.J. 2019. Barred from the Ocean: Consequences of a Unique Estuary Phenomenon on Recruitment of Chinook Salmon. American Fisheries Society 149th Annual Meeting, September 29 - October 3, 2019, Reno, NV.

Chen E. K.*, Henderson M.J. 2019. Contribution of Estuarine Rearing in a Bar-Built Estuary to Chinook Salmon Using a Hierarchical Life Cycle Model. Oregon Chapter of the American Fisheries Society 55th Annual Meeting, Bend, OR.

Chen E. K.*, Henderson M.J. 2019. Barred from the Ocean: Consequences of a Unique Estuary Phenomenon on Juvenile Growth and Population Recruitment of Chinook Salmon in Redwood Creek. 37th Annual Salmonid Restoration Conference, Santa Rosa, CA.

Ghrist, G.* and Halloran, M.* Juvenile Coho Salmon Life History Variants in Humboldt Bay Tributaries. 37th Annual Salmonid Restoration Conference. April 23-26, 2019. Santa Rosa, CA.

Halloran, M.*, and Ward, D. Coho Salmon Life History Variants in Humboldt Bay Tributaries: Population Connectivity in Adjacent Watersheds. 149th annual meeting of the American Fisheries Society, September 29 - October 3, 2019, Reno, NV.

Halloran, M.*, and Ward, D. Coho Salmon Life History Variants in Humboldt Bay Tributaries. 55th Annual Meeting of the Oregon Chapter of the American Fisheries Society. March 4-8, 2019. Bend, OR.

Henderson, M.J. Juvenile Chinook salmon mortality in different habitats during migration from freshwater to the ocean. University of Southern Mississippi. April 11, 2019.

Henderson, M.J. Central Valley Chinook salmon smolt outmigration mortality in freshwater and estuarine habitats. National Oceanic and Atmospheric Administration Northwest Fisheries Science Center Monster Seminar Jam. December 5, 2019.

Kanawi, E.* Comparing Environmental DNA and Traditional Monitoring Approaches to Assess the Abundance of Outmigrating Coho Salmon in California Coastal Streams. 149th annual meeting of the American Fisheries Society, September 29 - October 3, 2019, Reno, NV.

- Kanawi, E. *, Kinziger, A., and Henderson, M. Using Environmental DNA Water Samples to Determine the Timing and Abundance of Outmigrating Coho Salmon. 37th Annual Salmonid Restoration Conference. April 23-26, 2019. Santa Rosa, CA.
- Kanawi, E. *, Kinziger, A., and Henderson, M. Using Environmental DNA Water Samples to Determine the Timing and Abundance of Outmigrating Coho Salmon. 55th Annual Meeting of the Oregon Chapter of the American Fisheries Society. March 4-8, 2019. Bend, OR.
- Kreidler, N.* Buchheister, A. and Henderson, M. (2019) Habitat Suitability Mapping for Fish Indicative Deep Sea Corals and Sponges in the Southern California Bight. 7th International Deep Sea Coral Symposium, July 29 – August 2, 2019, Cartagena, Columbia.
- Okun, N.* and Henderson, M. Large Wood Restoration Effectiveness for Salmonids in Pudding Creek, CA: A Before-After-Control-Impact Experiment. 37th Annual Salmonid Restoration Conference. April 23-26, 2019. Santa Rosa, CA.
- Okun, N.* and Henderson, M. Large Wood Restoration Effectiveness for Salmonids in Pudding Creek, CA: A Before-After-Control-Impact Experiment. 149th annual meeting of the American Fisheries Society, September 29 - October 3, 2019. Reno, NV.
- Robinson, H.E. 2019 Modeling the Concentration of a Salmonid Parasite in the Klamath River. Humboldt State University, Fisheries Department Seminar, Arcata, CA
- Robinson, H.E. 2019 Modeling the Concentration of *Ceratonova shasta* in the Infectious Zone. Klamath River Fish Health Workshop, Ashland, OR