**Update Report**

Period: 6/1/2012 - 2/28/2013

**Project: E/I-19 - NMFS Population Dynamics Sea Grant Graduate Fellowship: Exploring mechanisms of mortality in the first ocean year of Chinook salmon (Oncorhynchus tshawytscha). James Anderson in support of Jeffrey Rutter.**

## STUDENTS SUPPORTED

Rutter, Jeffery, jdrutter@uw.edu, University of Washington, Quantitative Ecology and Resource Management, status:new, field of study:Modeling of Ecological Systems, advisor:James Anderson, degree type:PhD, degree date:2015-12-01, degree completed this period:No
Student Project Title: Growth and mortality of Chinook salmon (Oncorhynchus tshawytscha) in the first ocean year—exploring mechanisms underlying weak relationships between smolts and adults

Involvement with Sea Grant This Period: fellow

Post-Graduation Plans: NOAA or consulting work

## CONFERENCES / PRESENTATIONS

No Conferences / Presentations Reported This Period

## ADDITIONAL METRICS

K-12 Students Reached:
Acres of degraded ecosystems restored as a result of Sea Grant activities:
Curricula Developed:
Resource Managers who use Ecosystem-Based Approaches to Management:
Volunteer Hours:
HACCP - Number of people with new certifications:
Cumulative Clean Marina Program - certifications:

## PATENTS AND ECONOMIC BENEFITS

No Benefits Reported This Period

## TOOLS, TECH, AND INFORMATION SERVICES

No Tools, Tech, or Information Services Reported This Period

## HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

## ADDITIONAL MEASURES

Safe and sustainable seafood

| | |
|---|---|
| Number of stakeholders modifying practices | Number of fishers using new techniques |
| Actual (6/1/2012 - 2/28/2013) : | Actual (6/1/2012 - 2/28/2013) : |
| Anticipated (6/1/2013 - 2/28/2014) : | Anticipated (6/1/2013 - 2/28/2014) : |
| Sustainable Coastal Development | Coastal Ecosystems |
| Actual (6/1/2012 - 2/28/2013) : | Actual (6/1/2012 - 2/28/2013) : |
| Anticipated (6/1/2013 - 2/28/2014) : | Anticipated (6/1/2013 - 2/28/2014) : |

## PARTNERS

No Partners Reported This Period

## IMPACTS AND ACCOMPLISHMENTS

No Impacts or Accomplishments Reported This Period

## PUBLICATIONS

No Publications Reported This Period

## OTHER DOCUMENTS

No Documents Reported This Period

## LEVERAGED FUNDS

No Leveraged Funds Reported This Period

## UPDATE NARRATIVE

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## Project Goal

Develop a model of size, growth, size-selective mortality, food competition, and maturation which captures the essential dynamics observed for 1-ocean returning (and not returning) fish.

## Update Outline

My work over the past seven months can be placed in three broad categories: literature review, theory development, and data activities. The literature review can be further broken down into (1) mathematical frameworks upon which I can build my model, (2) size-selective mortality, (3) precocious maturation, and (4) food competition. Progress on theory development can be categorized as acquiring system knowledge, exploration of data/hypothesis testing, and tool construction. My data activities involved establishing connections to data sources and learning to access publicly available data.

## Literature Review (and Meetings)

My review of mathematical frameworks for incorporating both growth and size-selective mortality have led me to the McKendrick-vonFoerster (MKVF) partial differential equation model and a similar model using a system of ordinary differential equations detailed by Munch (Munch et al., 2003) (MODE). The MKVF model is very flexible—able to accommodate growth and mortality models as complex as desired.

$$\frac{\partial n}{\partial t} + \frac{\partial (g \cdot n)}{\partial x} = -mn$$

where $n(t,x)$ is the density of fish with length $x$ at time $t$, $N(t) = \int_X n(t,x)dx$ is the number of fish at time $t$, $g(t,x)$ is the growth function ($g = \frac{dx}{dt}$), and $m(t,x)$ is the per-capita mortality rate function ($m = -\frac{1}{n}\frac{dn}{dt}$).

The MODE model more readily exposes the solutions to a broad variety of simple growth and mortality models. It is developed from the same principles as the MKVF model, but assumes time-independent forms of the growth and mortality functions.

$$S(t;x_0) = \exp\left(-\int_{x_0}^{x_t} \frac{m(x)}{g(x)}dx\right)$$

where $S(t;x_0)$ is the survivorship of fish with initial size $x_0$ over time $t$, $g(x)$ is the growth function (as in the MKVF model), $x_t$ is the size at time $t$, and $m(x)$ is the mortality rate.

My literature review for fish maturation suggests that the most common model is the size-at-age model. For each possible age of return (maturation) there is a critical size (and time)—if by the critical time a fish has reached the critical size for that age of return it will mature at that age. Moving forward, I will be modeling critical times as uniform across individuals and considering the corresponding critical sizes to vary across individuals.

There does not seem to be much consensus on how to model size-selective mortality, although my review of this literature is far from exhaustive. My review of food competition literature is in its early stages.

I attended the Salmon Ocean Ecology Meeting in Newport, Oregon. This helped me to get up-to-speed on the leading edge of research on Pacific salmon in the marine environment and get a basic understanding of the kinds of data that may be available to help tune my model.

In discussions with Brian Beckman at NOAA's Northwest Fisheries Science Center (an expert on maturation processes in Pacific salmon) I have learned (among other things) that many 1-ocean fish show signs of precocious maturation before they leave freshwater. This suggests that I cannot focus entirely on the marine environment, but will need to consider how freshwater processes may impact salmon maturation.

## Theory Development

My examination of data from PIT-tagged out-migrants in the years 2007-2011 has shown that many populations had an increased propensity to precocious maturation during the years of 2008 & 2010. This was most easily noted in the hatchery populations (in which the great majority of PIT tags are implanted), but was also seen in many wild-reared populations. Not only did the number of 1-ocean fish returning in 2009 & 2011 increase markedly over other years, but the number of "mini-jacks" (mature 0-ocean fish) was notably higher. Mini-jacks were only detected in hatchery populations—no evidence of wild-reared mini-jacks was found.

**Table 1 Environmental covariates tested for impact on the percentage of a cohort returning as 1-ocean fish. (P-values have not been adjusted for multiple comparisons.)**

| Covariate | Type | direction | Δ AIC | p-value | Comments |
|---|---|---|---|---|---|
| no environmental inputs | | | 0 | | |
| Lower Snake Water Temperature (Winter) | Fresh | - | 74.49 | < 0.001 | wrong sign |
| Air Temp (from PNI) | Fresh | - | 54.77 | < 0.001 | wrong sign |
| Lower Snake Water Temperature (Spring) | Fresh | - | 48.18 | < 0.001 | wrong sign |
| Growth Index | Fresh | + | 34.82 | < 0.001 | FINAL MODEL |
| Pacific Northwest Index (PNI) | Fresh | - | 34.38 | < 0.001 | wrong sign |
| Length at Release | Individual | + | 34.15 | < 0.001 | FINAL MODEL |
| Lower Snake Water Flow (Winter) | Fresh | - | 33.08 | < 0.001 | |
| Sea Surface Temp (NH05, previous winter) | Marine | - | 30.47 | < 0.001 | |
| Total Precipitation (from PNI) | Fresh | - | 18.01 | < 0.001 | |
| Pacific Decadal Oscillation (PDO, Summer) | Marine | - | 11.85 | < 0.001 | |
| Upwelling (amount) | Marine | + | 10.75 | < 0.001 | FINAL MODEL |
| Lower Snake Water Temperature (Summer) | Fresh | - | 9.06 | 0.001 | wrong sign |
| Lower Snake Water Flow (Spring) | Fresh | - | 5.38 | 0.008 | |
| log( Copepod Biomass ) | Marine | + | 3.54 | 0.025 | |
| Lower Snake Water Flow (Summer) | Fresh | + | 2.78 | 0.028 | FINAL MODEL |
| Sea Surface Temp (46050) | Marine | - | 1.79 | 0.056 | |
| Upwelling (duration) | Marine | - | -0.44 | 0.212 | |
| Copepod Type Index | Marine | - | -1.31 | 0.409 | |
| Snowpack (from PNI) | Fresh | + | -1.44 | 0.451 | |
| Run (Spring/Summer/Fall) | Individual | + | -1.97 | 0.870 | |
| Sea Surface Temp (NH05, summer) | Marine | - | -1.98 | 0.893 | |
| Pacific Decadal Oscillation (PDO, Winter) | Marine | - | -2 | 0.974 | |

I further examined the influence of environmental covariates on the percentage of cohort returns which matured as 1-ocean fish (but excluding 0-ocean fish) for out-migrating cohorts in the years from 1998-2008. I used both freshwater and marine variables that have been deemed relevant to the growth of salmon. The results of this analysis (and the increased presence of mini-jacks previously noted) suggest a strong influence from the freshwater environment and a somewhat weaker influence from the marine environment (see Table 1).

Water temperatures in the Lower Snake River and the Pacific Northwest air temperature index were highly influential, but had a non-intuitive direction: a greater percentage of jacks in cooler temperatures. This suggests that lower temperatures may repress the expression of slower-growing fish in the cohort returns (which would not mature precociously) rather than enhance the expression of faster-growing fish (more likely to mature precociously). The fit of the final model chosen was not great, and did not capture the dramatic rise in the frequency of jacks in the 2008 out-migrating cohort.

I constructed a solver for the MKVF model, examining the differences in behavior using simple growth and mortality functions—with and without simple density dependent effects. These simple models failed to replicate the general finding in the data—that jack returns are effectively decoupled from the number of out-migrating smolts. Adding some complexity to the model may improve results. In particular, I am working to (1) add a winter period in which growth is minimal, but size-selective mortality is active and (2) to distinguish between the migratory period and the free-feeding period which follows it.

I constructed a solver for the MODE model, as well as a parameter estimation algorithm, largely based on the ideas in Munch (2003) (and see Figure 1). I am wrapping up a theoretical examination of these algorithms to improve growth estimates made using two-samples of individual length and am assembling a poster of this work to present at the NPAFC workshop on April 25-26, 2013.

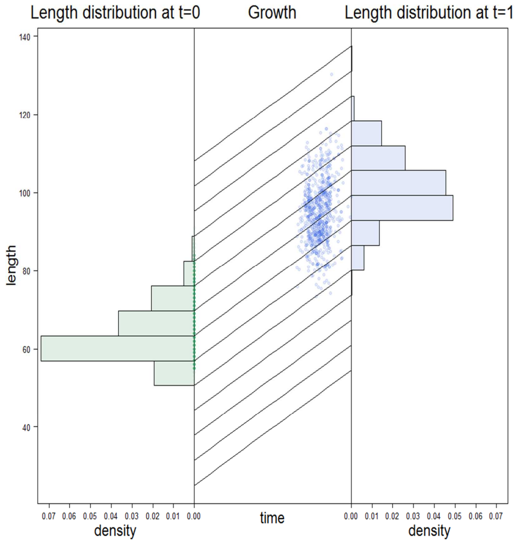

**Figure 1 Pictograph of the method of parameter estimation: (1) the initial sample is binned [green histogram & points], (2) guesses are made at appropriate parameters for growth and mortality, (3) the bins are projected forward in time [parallel lines] to cover the observations [blue points], (4) average survival & expected count are computed for each bin at the mean future time [blue histogram], (5) repeat (2)-(4) until the best fit between the blue histogram and the projected data is found.**

## Data Activities

I have established contacts with CRITFC and have begun to access their annual data on fish return. I have taught myself how to procure data from PTAGIS, the Columbia River Basin PIT tag database. I have assembled sources and datasets for a diverse array of environmental covariates which may be relevant (see Table 1 for a selection of these).

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Munch, S.B., Mangel, M., Conover, D.O., 2003. Quantifying Natural Selection on Body Size from Field Data: Winter Mortality in Menidia Menidia. Ecology 84, 2168-2177.