Exploring Drivers in Declining Marine Survival in Pacific Salmon

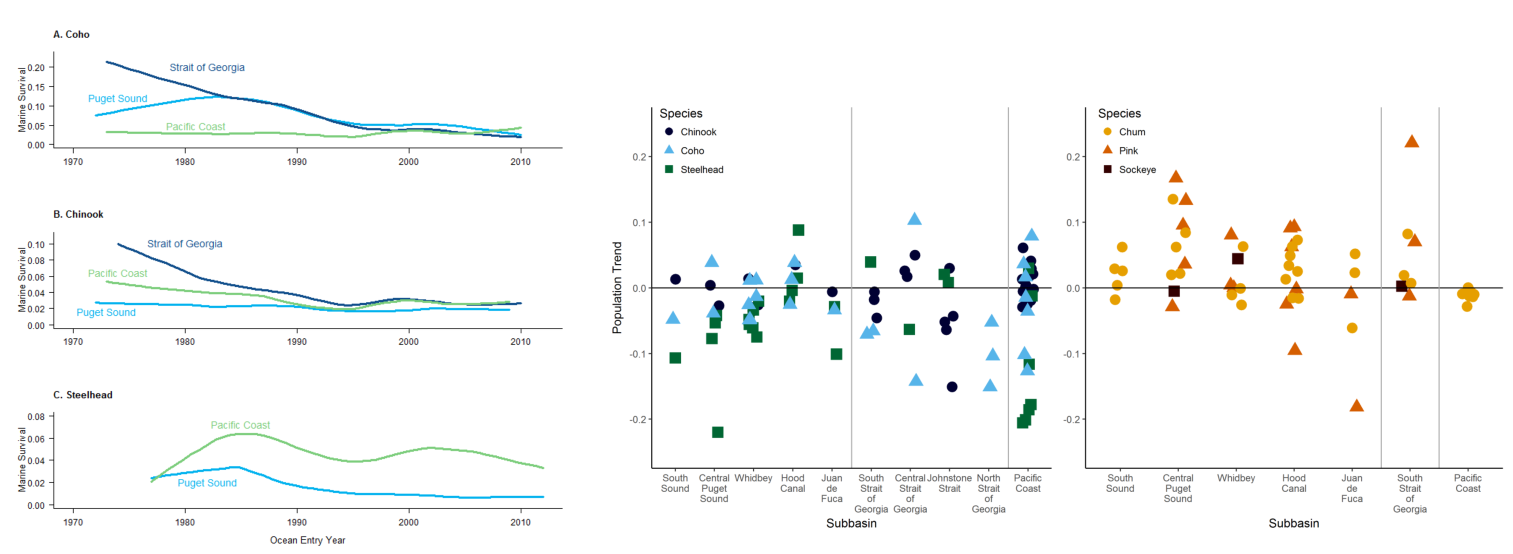
K.L. Sobocinski[1,2], C. Greene[1], M. Schmidt[2]

1. NOAA-Fisheries NWFSC

2. Long Live the Kings

Background

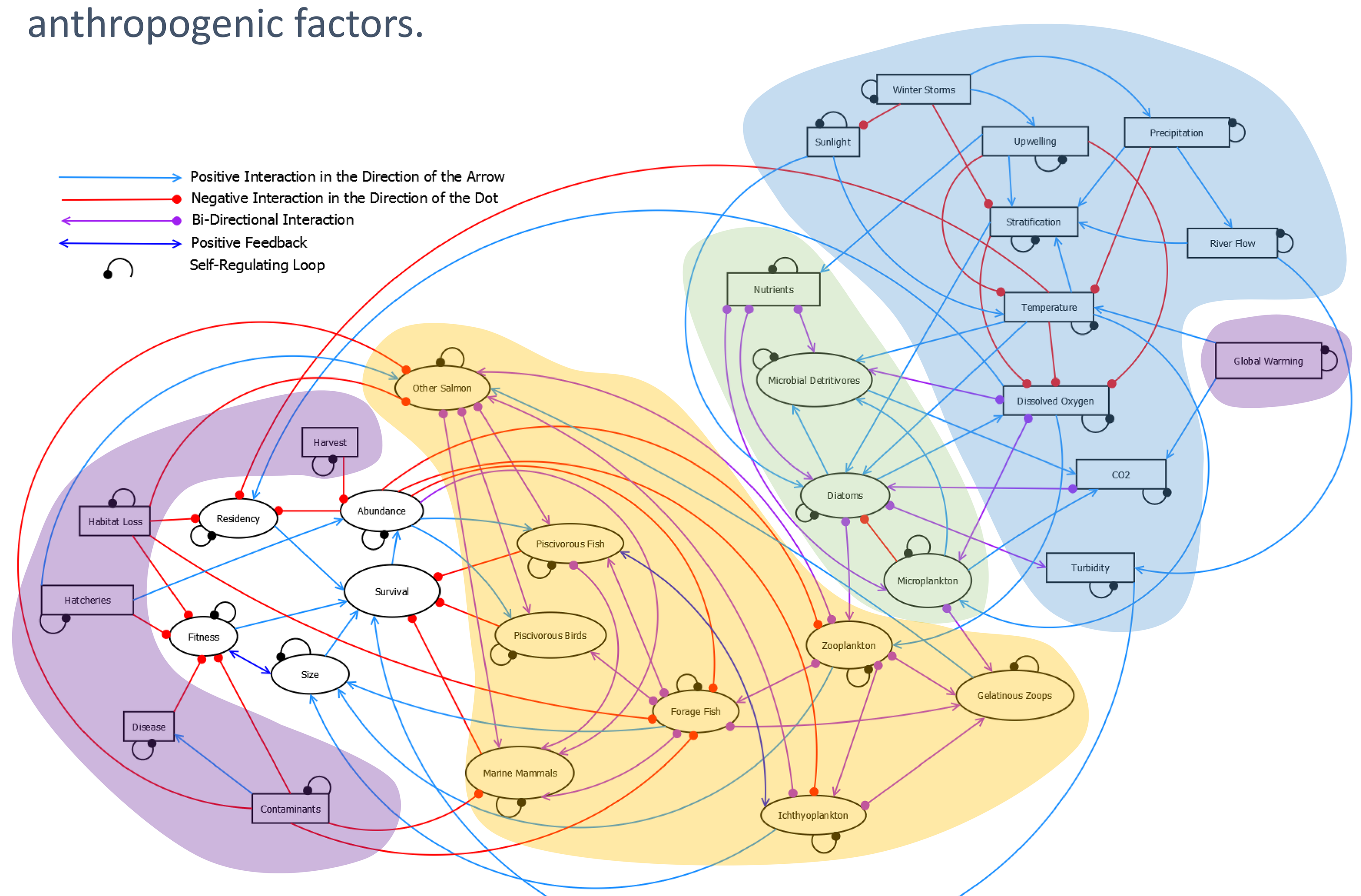
Coho (*Oncorhynchus kisutch*), Chinook (*O. tshawytscha*), and Steelhead (*O. mykiss*) have shown declines in marine survival in Puget Sound and the Strait of Georgia over the last 40 years.



The Salish Sea Marine Survival Project aims to tease out drivers of this decline (http://marinesurvivalproject.com/). Using a qualitative network model, we evaluated hypothesized drivers of marine mortality, ran simple scenarios of cumulative effects for example Salish Sea basins which show differences in abundance trends, and describe the results here.

Methods

To begin, we built a conceptual diagram (a digraph), consisting of 33 hypothesized drivers (nodes) and the directed links (edges) among them. Relationships between any two nodes could be positive or negative. The nodes included environmental, foodweb, and anthropogenic factors.



Qualitative Network Modeling is a data-free, flexible modeling approach. We included attributes of the focal salmon species (survival, abundance, fitness, etc.) and environmental, foodweb, and anthropogenic drivers in the model. This type of analysis has been used to model shellfish response to stressors (Reum et al. 2015), Antarctic ecosystems (Melbourne-Thomas et al. 2012), and fisheries management actions (Harvey et al. *in press*).

Once the conceptual model was developed, we used an existing modeling package (*QPress*) in the *R* programming language to assess the relative impacts of the suite of drivers on the nodes related to salmon. While salmon survival was of primary interest, related attributes such as abundance, size, fitness, and residence time were also included as response variables. Additionally, we represented other salmon species (Chum, Sockeye, and Pink Salmon, grouped as Other Salmon) that have not seen the same decline in survival.

We aimed to answer:

Which drivers had the strongest impact (positive and negative) on survival and other nodes of interest?

How do the cumulative impacts of multiple factors manifest in basin-to-basin comparisons?

Which edges were the most sensitive to change?

Results

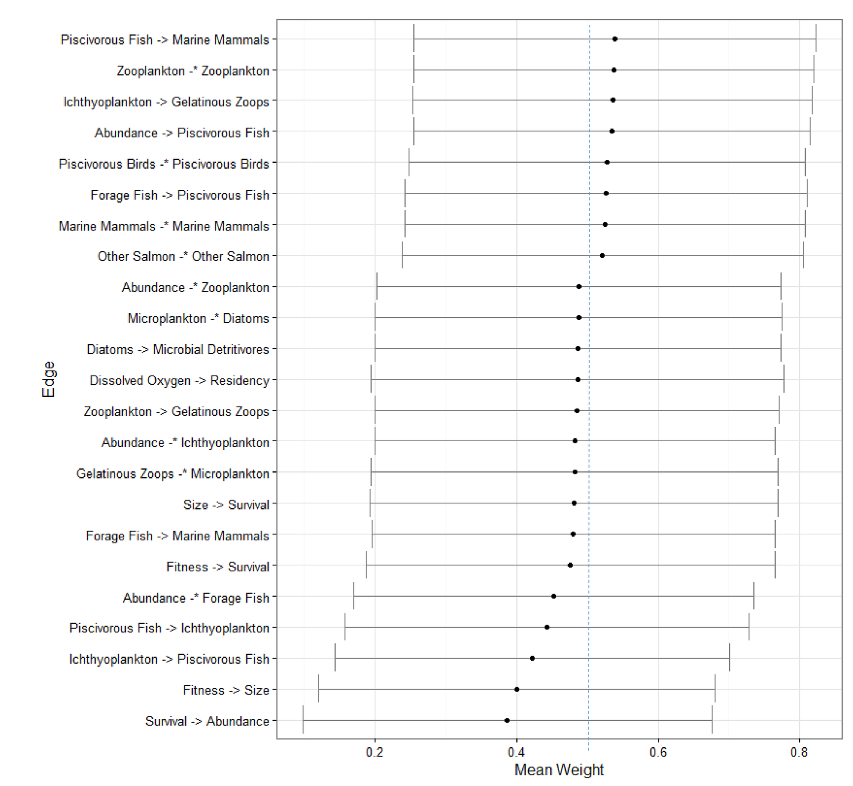
We invoked a perturbation to each node (direction of the perturbation based on known trends) and evaluated the response of the other nodes in 10,000 model simulations.

Strong Neg. Effect (>80% of runs negative)	Strong Neg.
Weak Neg. Effect (60-80% of runs negative)	Weak Neg.
Neutral (40-60% of runs positive/negative)	Neutral
Weak Pos. Effect (60-80% of runs positive)	Weak Pos.
Strong Pos. Effect (>80% of runs positive)	Strong Pos.

Drivers	Variables	Invoked Perturbation	Response Variables: Survival	Abundance	Fitness	Size	Residency	Other Salmon
Environmental	Sunlight	↑	Neutral	Neutral	Weak Neg.	Weak Neg.	Strong Neg.	Neutral
	Winter Storms	↑	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.	Weak Pos.	Neutral
	Precipitation	↑	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.	Neutral	Weak Neg.
	Upwelling	↓	Weak Neg.	Weak Neg.	Neutral	Neutral	Neutral	Neutral
	Stratification	↑	Neutral	Neutral	Neutral	Neutral	Weak Neg.	Neutral
	Temperature	↑	Weak Neg.	Weak Neg.	Neutral	Neutral	Strong Neg.	Neutral
	River Flow	↑	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.	Strong Neg.	Weak Neg.
	Turbidity	↓	Weak Neg.	Weak Neg.	Strong Pos.	Strong Pos.	Weak Pos.	Weak Pos.
	Dissolved Oxygen	↓	Weak Neg.	Weak Neg.	Neutral	Neutral	Weak Neg.	Weak Neg.
Production	Nutrients	↑	Neutral	Neutral	Neutral	Neutral	Weak Neg.	Neutral
	Microplankton	↑	Weak Neg.	Weak Neg.	Weak Neg.	Weak Neg.	Neutral	Neutral
	Microbial Detritivores	↑	Neutral	Neutral	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.
	Diatoms	↓	Strong Neg.	Strong Neg.	Weak Neg.	Weak Neg.	Weak Pos.	Neutral
Foodweb	Zooplankton	↓	Neutral	Neutral	Strong Neg.	Strong Neg.	Neutral	Weak Neg.
	Gelatinous Zooplankton	↑	Weak Neg.	Weak Neg.	Weak Neg.	Weak Neg.	Weak Pos.	Weak Pos.
	Forage Fish	↓	Weak Neg.	Weak Neg.	Weak Neg.	Strong Neg.	Neutral	Strong Pos.
	Ichthyoplankton	↓	Neutral	Neutral	Neutral	Neutral	Neutral	Weak Neg.
	Other Salmon	↑	Strong Neg.	Strong Neg.	Neutral	Neutral	Strong Pos.	Strong Pos.
	Piscivorous Fish	↓	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.	Weak Neg.	Neutral
	Piscivorous Birds	↓	Weak Pos.	Weak Pos.	Weak Neg.	Weak Neg.	Weak Neg.	Neutral
	Marine Mammals	↑	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Anthropogenic	Hatcheries	↑	Strong Neg.	Strong Neg.	Strong Neg.	Weak Neg.	Strong Pos.	Strong Pos.
	Harvest	↑	Strong Pos.	Neutral	Neutral	Neutral	Neutral	Neutral
	Habitat Loss	↑	Strong Neg.	Strong Neg.	Strong Neg.	Neutral	Neutral	Weak Pos.
	CO2	↑	Strong Pos.	Strong Pos.	Neutral	Neutral	Weak Neg.	Neutral
	Global Warming	↑	Neutral	Neutral	Weak Neg.	Weak Neg.	Strong Neg.	Neutral
	Contaminants	↑	Strong Neg.	Strong Neg.	Strong Neg.	Weak Neg.	Strong Pos.	Weak Pos.
	Disease	↑	Strong Neg.	Strong Neg.	Strong Neg.	Weak Neg.	Strong Pos.	Weak Pos.

Anthropogenic impacts had strong negative impacts on survival, abundance, and fitness. Other factors producing negative responses to survival were: ↓ diatoms and ↑ in other salmon. Decreased zooplankton negatively impacted focal salmon fitness and size. These impacts are largely foodweb effects, either through direct predation or competition. Increasing CO_2, winter storms, and precipitation had largely positive impacts on salmon attributes; while increasing temperature and declining dissolved oxygen resulted in negative salmon response.

To assess the sensitivity of the model links in the simulation weighting routine, we calculated means and standard deviations of the weights in the accepted models (10,000 out of ~122,000 runs). While most links were not sensitive to the weights applied ($U(0,1)$), a subset were above or below the grand mean.



Where the mean is >0.5, balanced models had higher weights on this linkage.

Where the mean is <0.5, more accepted models had lower weights.

These linkages could be considered more sensitive within the model.

While we would expect the linkages among salmon attributes to be sensitive, the edges connecting foodweb components are important and sensitive indicators.

To evaluate the cumulative impacts to salmon as observed within Puget Sound, we generated 3 scenarios based upon observed changes in various regions. We then invoked all perturbations and plotted the response of all nodes.

Drivers	*Perturbations*	South Sound	Hood Canal	Central Basin
Oceanographic	Nutrients	↑		
	Stratification		↑	
	Dissolved Oxygen		↓	
	Turbidity		↓	
	Temperature		↑	
Foodweb	Diatoms			↓
	Gelatinous Zooplankton	↑		↑
	Forage Fish	↓		↓
	Other Salmon		↑	
Anthropogenic Impacts	Contaminants	↑		↑
	Habitat Loss			↑
	Hatcheries	↑		
	Survival	Strong Neg.	Weak Neg.	Strong Neg.
	Abundance	Strong Neg.	Weak Neg.	Strong Neg.
	Fitness	Strong Neg.	Weak Pos.	Strong Neg.
	Size	Weak Neg.	Weak Pos.	Weak Neg.
	Residency	Strong Pos.	Weak Neg.	Weak Pos.
	Other Salmon	Strong Pos.	Weak Pos.	Weak Pos.

Modeled salmon survival was strongly negative in South Sound and Central Basin, but less so in Hood Canal, which reflects observations to date.

Conclusions

Qualitative Network Modeling indicates that anthropogenic impacts and changing foodwebs should be further evaluated in the decline in marine survival of Coho, Chinook, and Steelhead. There are likely cumulative pathways to declining survival, mediated through a number of feedbacks expressed within our model.

References

Harvey, C.J., J.C.P. Reum, M.R. Poe, G.D. Williams, S.J. Kim. In Press. Using conceptual models and qualitative network models to advance integrative assessments of marine ecosystems. Coastal Management.

Melbourne-Thomas, J., S. Wotherspoon, B. Raymond, and A. Constable. 2012. Comprehensive evaluation of model uncertainty in qualitative network analyses. Ecological Monographs, 82(4): 505–519.

Reum, J.C.P., B.E. Ferriss, P.S McDonald, D.M. Farrell, C.J. Harvey, T. Klinger, and P.S. Levin. 2015. Evaluating community impacts of ocean acidification using qualitative network models. Marine Ecology Progress Series 536: 11-24.

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