Exploring Drivers in Declining Marine Survival in Pacific Salmon

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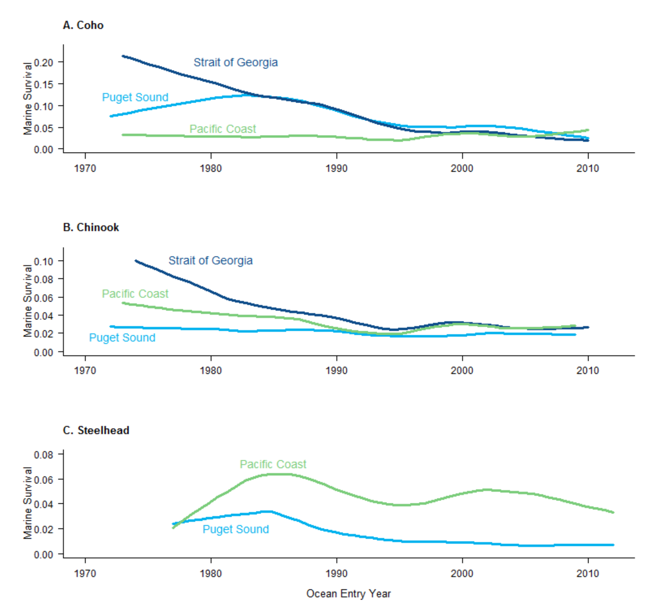
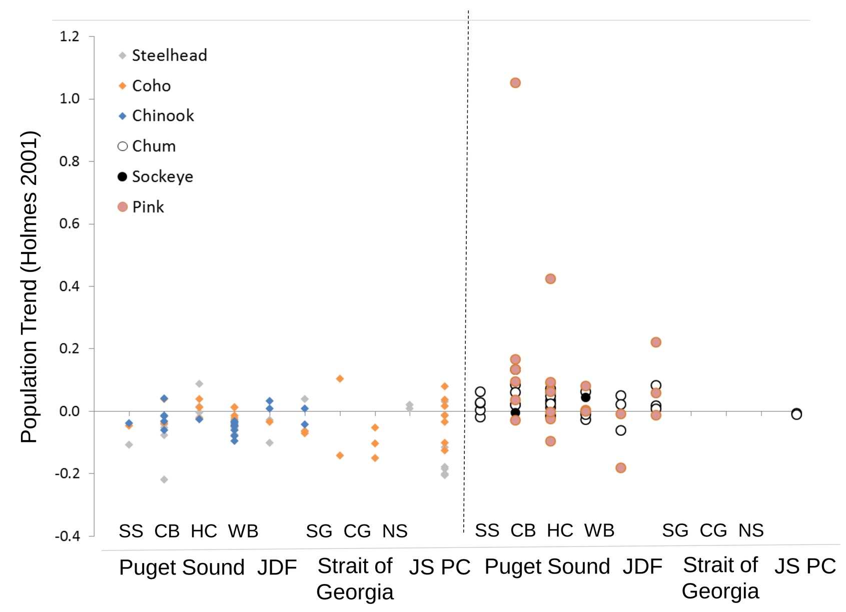
Background

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.

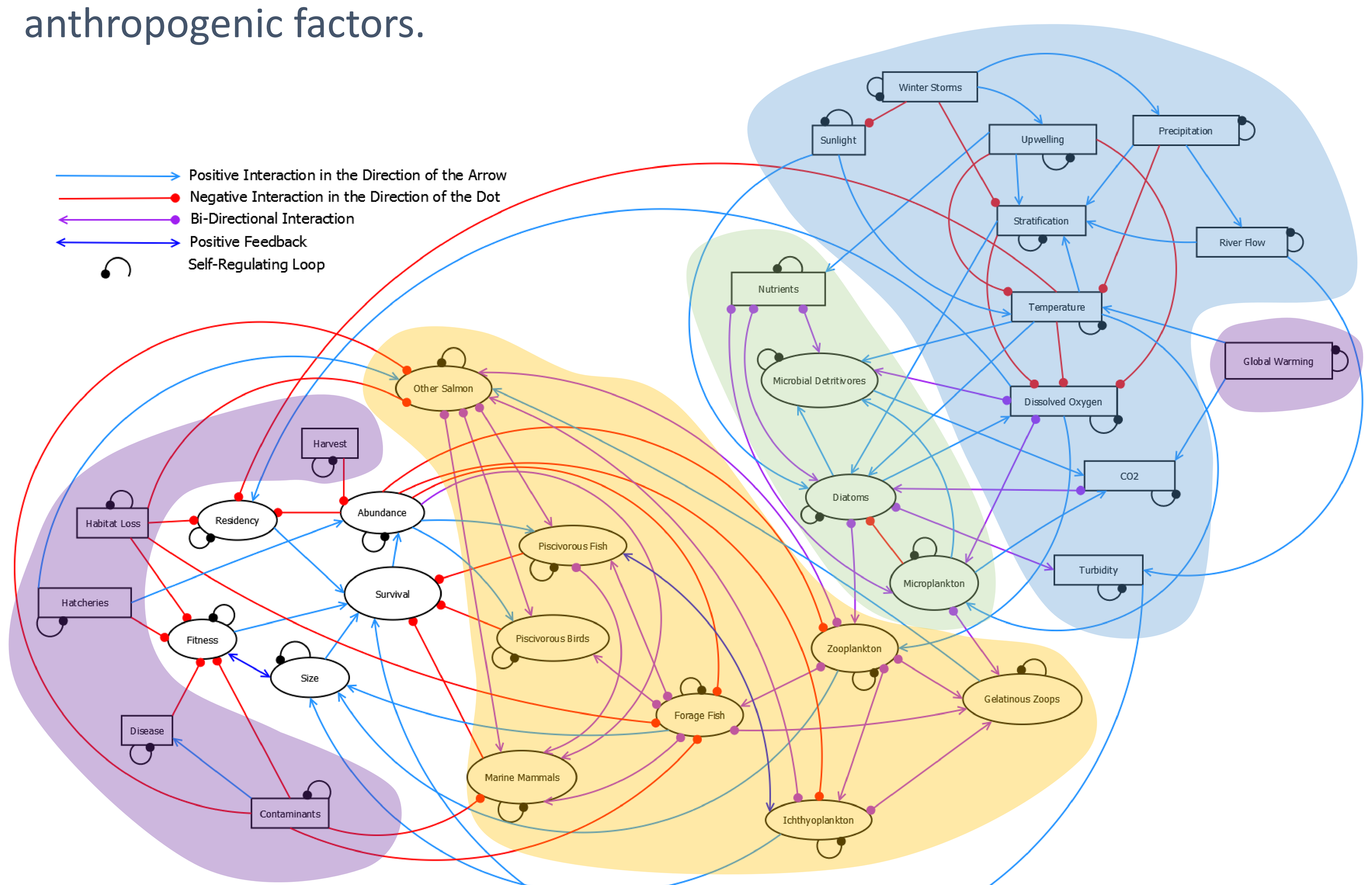




The Salish Sea Marine Survival Project aims to tease out drivers of this decline (http://marinesurvivalproject.com/). Using a qualitative network model, we evaluated hypothesized drivers of marine mortality, ran simple scenarios of cumulative effects for example Salish Sea basins, which show differences 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 Analysis is not strictly foodweb modeling. It's a data-free, flexible modeling approach. As a result, we included attributes of the focal salmon species (survival, abundance, fitness, etc.) 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 the nodes of interest (response variables)?

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

Which edges were the most sensitive to change?

Results

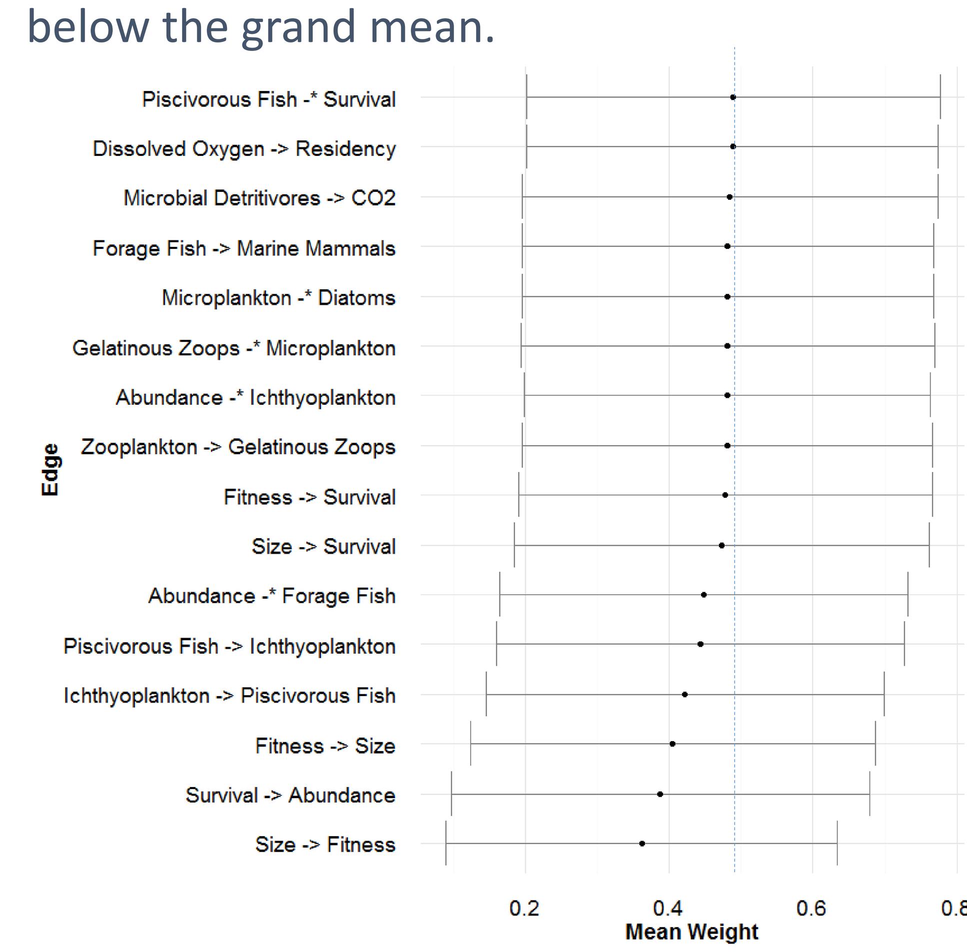
We invoked a perturbation to each node (direction of the perturbation based on known trends) and evaluated the response of the other nodes in 10,000 model simulations.

No Effect
Weak Negative Effect (60-80% of runs negative)
Strong Negative Effect (>80% of runs negative)
Neutral (40-60% of runs positive/negative)
Weak Positive Effect (60-80% of runs positive)
Strong Positive Effect (>80% of runs positive)

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

Anthropogenic impacts had strong negative impacts on survival, abundance, and fitness. Other factors producing negative responses were: ↑ microplankton, ↑ gelatinous zooplankton,↑ piscivorous birds,↓ diatoms, and an ↑ in other salmon. These 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, which would be expected from fish physiology.

To assess the sensitivity of the model links in the *QPress* 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, 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 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.

South Sound	Perturbation	**Hood Canal**	Perturbation	**Central Basin**	Perturbation
Gel. Zooplank.	↑	Stratification	↑	Diatoms	↓
Nutrients	↑	Dissolved Oxygen	↓	Gel. Zooplank.	↑
Forage Fish	↓	Turbidity	↑	Forage Fish	↓
Contaminants	↑			Habitat Loss	↑
Hatcheries	↑			Contaminants	↑

Salmon Traits	**South Sound**	**Hood Canal**	**Central Basin**
Survival	Strong Negative	Neutral	Strong Negative
Abundance	Strong Negative	Neutral	Strong Negative
Fitness	Strong Negative	Weak Negative	Strong Negative
Size	Weak Negative	Weak Negative	Weak Negative
Residency	Strong Positive	Strong Negative	Neutral
Other Salmon	Strong Positive	Weak Negative	Weak Positive

Modeled salmon survival was negative in South Sound and Central Basin, and less so in Hood Canal, which reflects observations to date. Salmon size was negatively impacted in all scenarios, likely due in part to foodweb interactions and competition from other salmon.

Conclusions

Qualitative Network Modeling indicates that anthropogenic impacts and changing foodwebs should be further evaluated in the context of declining marine survival of Coho, Chinook, and Steelhead. Additionally, there are likely multiple pathways to declining survival.

References

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