Effects of the North Pacific Current on productivity of 163 Pacific salmon stocks

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Research Objective

Horizontal ocean transport can influence the dynamics of higher-trophic-level species in coastal ecosystems through multiple pathways, including by altering physical oceanographic conditions, predation, or the advection of food resources into coastal areas (Fig. 1).

In this study, we estimated the effects of two modes of variability in the North Pacific Current (NPC, Fig. 2) on productivity of 163 North American salmon stocks to better understand how pathways of horizontal ocean transport could influence population dynamics of Pacific salmon.

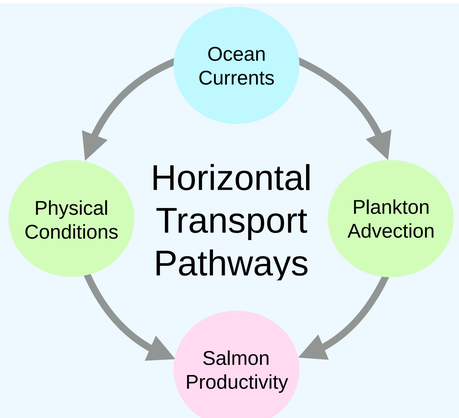


Fig. 1: Two potential horizontal transport pathways.

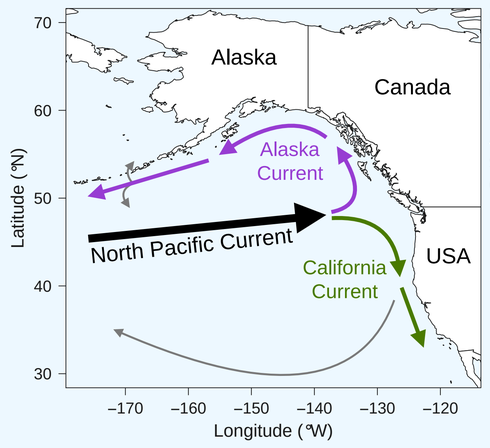


Fig. 2: Schematic of the North Pacific Current and its bifurcation into the northward flowing Alaska Current and southward flowing California Current.

163 Salmon Stocks

- We estimated productivity for each of the 163 salmon stocks.
  - Productivity = number of recruits produced per spawner.
  - Productivity time series spanned ocean entry years 1967-2010.
- Stocks were grouped into 3 large marine ecosystems based on the location of juvenile salmon ocean entry (Fig. 3):
  - West Coast (i.e., WA and BC)
  - Gulf of Alaska
  - Bering Sea

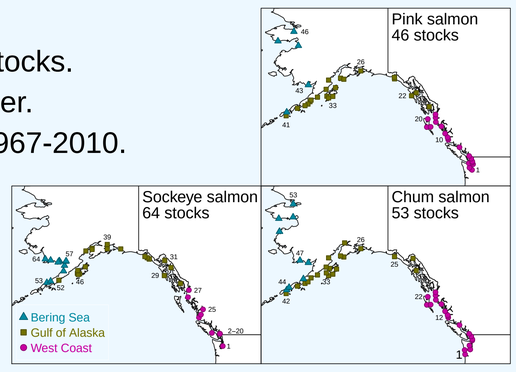


Fig. 3: Salmon stock ocean entry locations.

Bifurcation Index (BI)

- We indexed the north-south location of the NPC bifurcation as it hits the west coast of North America using simulated surface current trajectories output from the OSCURS model.
- The annual BI values were calculated as the proportion of 215 simulated drifter trajectories that ended south of their starting latitude in a particular year (Fig. 4).
- Annual values of the BI above 0.5 indicate a northward-shifted bifurcation, whereas index values below 0.5 indicate a southward-shifted bifurcation (Fig. 5).

Fig. 4: Simulated trajectories for 215 drifters. Purple trajectories indicate the drifter ended north of its start location, whereas green trajectories indicate the drifter ended south of its start location.

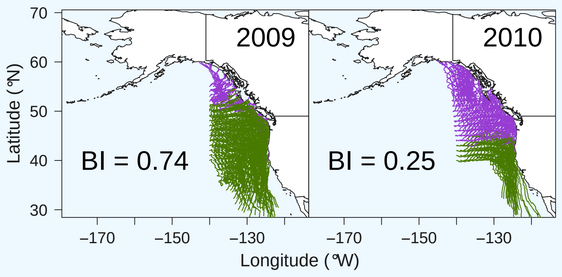
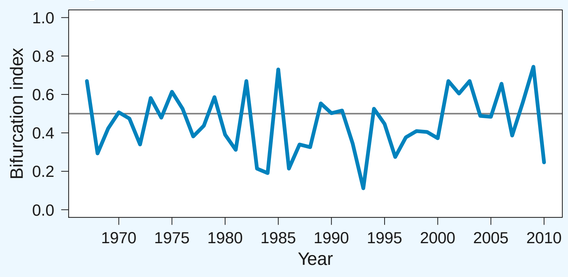


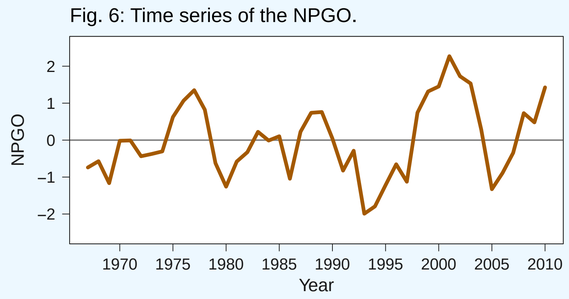
Fig. 5: Time series of the bifurcation index.



North Pacific Gyre Oscillation (NPGO)

- We indexed the strength of the NPC using the NPGO, which represents variability in sub-polar and sub-tropical gyre strengths in the North Pacific.
- Higher NPGO values indicate a strengthening of the gyres and increased NPC transport (Fig. 6).

Fig. 6: Time series of the NPGO.



Bayesian Hierarchical Models

- We used species-specific Bayesian hierarchical models to estimate how strongly productivity of salmon stocks was influenced by the two NPC indices (i.e., BI and NPGO).
- The models took the form of a generalized Ricker model in which the NPC indices were included as additional predictor variables:

BI and NPGO indices were weakly correlated (r = 0.24).

Hierarchical prior distribution across all stocks within a species.

Hierarchical prior distributions for stocks within the same ecosystem and species.

Ecosystem-level effects
Common effect across all stocks in an ecosystem. Estimated as the mean of the ecosystem-specific prior distribution.

$$log_e(R_{i,t}/S_{i,t}) = \alpha_i + \beta_i S_{i,t} + \gamma_{BI,i} BI_t + \gamma_{NPGO,i} NPGO_t + \epsilon_{i,t}$$

- $R_{i,t}/S_{i,t}$: total recruitment for stock i in time t
- $S_{i,t}$: spawner abundance
- α_i: stock productivity at low spawner abundances
- β_i: density dependence
- $\gamma_{BI,i}$: stock-specific BI coefficient
- BI_t: bifurcation index
- $\gamma_{NPGO,i}$: stock-specific NPGO coefficient
- $NPGO_t$: NPGO index
- $\epsilon_{i,t}$: autocorrelated error term

18 October 2016
Reference: Malick et al. Fisheries Oceanography (accepted)

Results

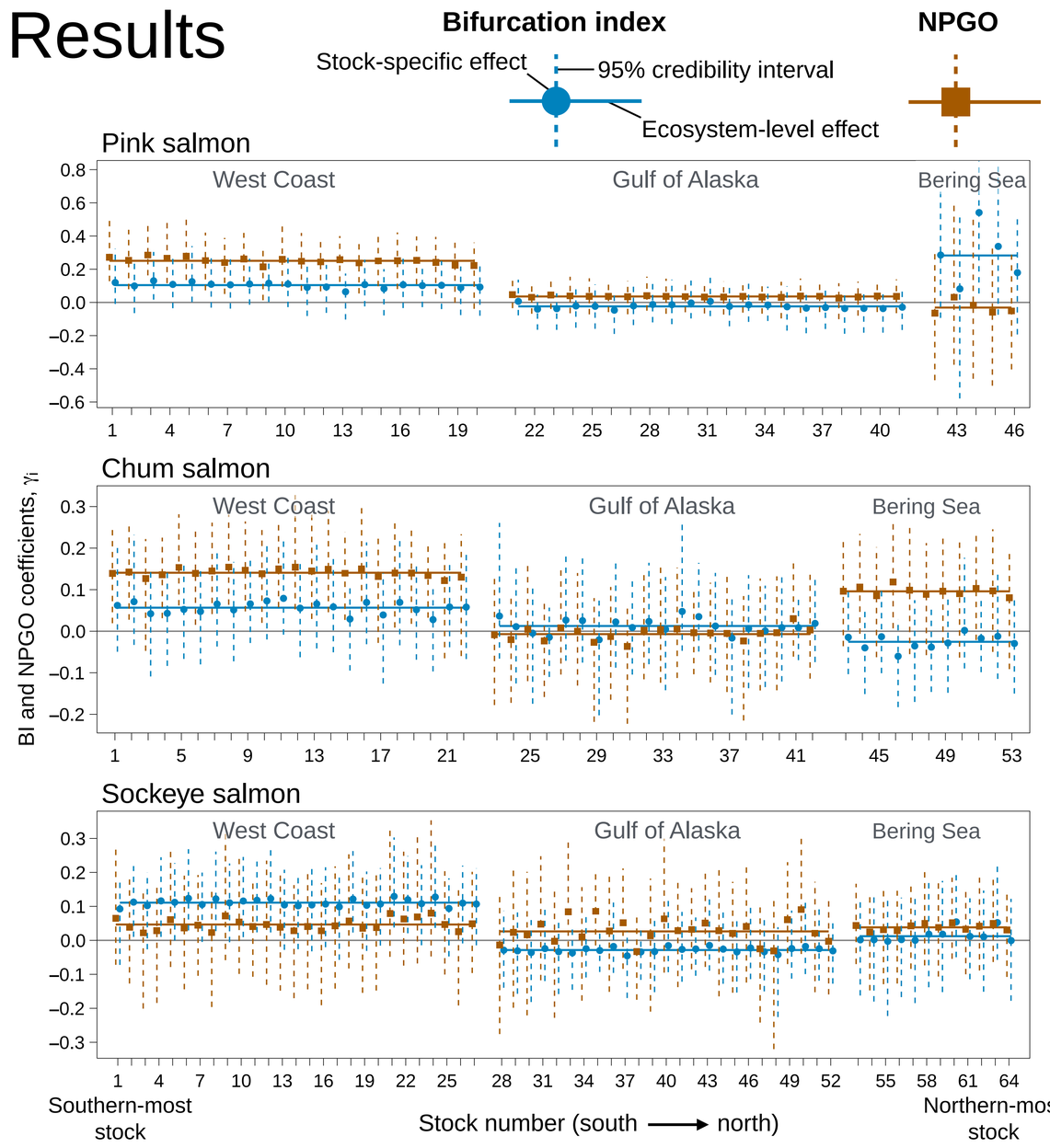


Fig. 7: Posterior medians and 95% credible intervals for the stock-specific BI and NPGO effects. Within each panel, stock-specific estimates are grouped by ecosystem, and stocks are ordered south (left) to north (right), where the stock number (x-axis) corresponds to the numbers in Fig. 3. Solid circles (blue) indicate BI coefficient median values and solid squares (gold) indicate NPGO coefficient median values. Dashed vertical lines indicate 95% credibility intervals for stock-specific medians. Solid horizontal lines indicate posterior medians for the ecosystem-level effects.

1. Hierarchical models that included the BI and NPGO indices fit the data substantially better than models without these terms for all species (results not shown).
2. In the West Coast ecosystem, both the BI and NPGO had significant positive effects on salmon productivity (Fig. 7), indicating that increased salmon productivity in this region is associated with a northward-shifted bifurcation (which may advect more lipid-rich food resources into the region) and a stronger NPC (which may increase nutrient supplies in the West Coast ecosystem).
3. In contrast to the West Coast ecosystem, the BI and NPGO effects on salmon productivity tended to be weaker for stocks in the Gulf of Alaska ecosystem and less consistent across species in the Bering Sea ecosystem (Fig. 7).

Conclusions

Our results indicated that horizontal transport pathways may strongly influence population dynamics of Pacific salmon in the southern part of their North American ranges, but not the northern part, suggesting that different mechanisms may underlie changes in salmon productivity in northern and southern areas for the species under consideration.

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