# Quantifying Trophic Interaction and Energetics of Juvenile Pink Salmon in the Gulf of Alaska and Prince William Sound

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## Abstract

Pink salmon are one of the predominant planktivores in the Gulf of Alaska and are a culturally and economically important species in the North Pacific. The goal of our Global Ocean Ecosystem Dynamics (GLOBEC) research is to quantitatively model spatial and temporal patterns in distribution, feeding, food supply, and growth by juvenile pink salmon in Prince William Sound and the coastal Gulf of Alaska. Field data collected over multiple years during GLOBEC cruises provide broad spatial coverage around the coastal, shelf, and off-shelf regions of the Gulf of Alaska during mid-July through mid-August, as well as enhanced temporal resolution in Prince William Sound and along the Seward Line during July-October. By applying this mechanistic approach within a spatial-temporal framework over multiple years, we hope to develop a functional understanding of the relative importance of climate, oceanographic conditions, and planktivore density and distribution on the growth and survival of juvenile pink salmon.

## Introduction

The Gulf of Alaska (GOA) has a surface area of approximately 370,000 km², and many species of ecological and commercial value (Weingartner et al., 2002). The GOA is quite productive despite having hydrologic properties characteristic of low-productivity systems (down-welling, large and cold freshwater inputs). Although climatic influences on regional marine productivity have been recognized (Mantua et al., 2002), the underlying mechanisms for these relationships are poorly understood. Mechanisms regulating primary and secondary production are currently under investigation by other GLOBEC studies. The goal of this study is to investigate the effect of physical and biological variations caused by changing "*climatic regimes"* on the growth, feeding ecology, and distribution of juvenile pink salmon (*Oncorhynchus gorbuscha*) in the GOA. Particular emphasis will be placed on addressing the mechanistic relationships controlling foraging and growth. Such an approach should shed light on the most important ecological factors affecting juvenile pink salmon and other pelagic planktivorous fish inhabiting the GOA.

## Project Objectives

- Identify temporal and spatial variations in juvenile pink salmon prey, diet, and environment during their migration from Prince William Sound (PWS) through the GOA, to the Pacific Ocean.
- Estimate consumption demand by pink salmon and compare to the supply of exploitable prey to identify spatial or temporal patterns in food limitation.
- Experimentally parameterize a foraging model for juvenile pink salmon, and simulate spatially-explicit growth potential for salmon, based on environmental variations observed in the GOA and PWS. Compare spatial and temporal patterns in simulated growth potential to observed distribution and growth of juvenile pink salmon.

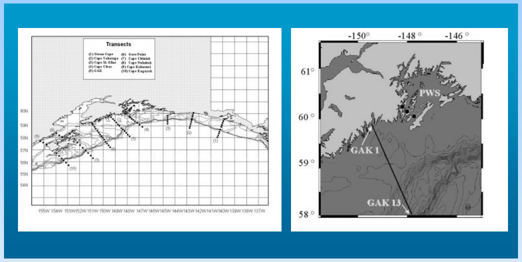


**Figure 1. Map showing oceanographic transects in the Gulf of Alaska and Prince William Sound**

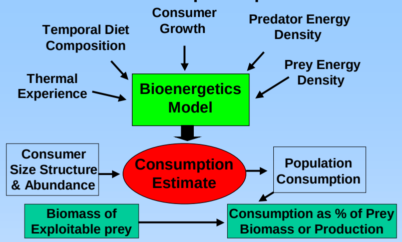
## Sampling

Spatial and temporal coverage of the coastal GOA has been accomplished by combining comparable sampling from GLOBEC LTOP and process studies (University of Alaska and University of Washington) and the NOAA-NMFS Ocean Carrying Capacity (OCC) study. Broad spatial coverage of the GOA was accomplished by annual OCC cruises (Helle 2003; Cokelet 2003) aboard F/V Great Pacific which sampled 11 transects beginning with Icy Point and ending at Cape Kaguyak (**Figure 1**) during the expected peak migration of juvenile pink salmon from mid July until early August. Study transects extended perpendicular to shore past the 200 m shelf break. Temporal variations in fish distribution and size structure (Haldorson and Boldt 2003), forage, feeding (Armstrong et al. 2003), and environmental conditions were documented in July, August, September, and October aboard R/V Pandalus at seven stations along the Seward Line and three stations in PWS. All cruises sampled and recorded catch per effort of fish by species, length, weight, diet, otoliths and scales, surface zooplankton, and oceanographic data. Fish samples were collected using a mid-water rope trawl towed at the surface between 3.5 and 5 knots. Oceanographic data were collected at each station prior to each trawl effort. Depth profiles of salinity, dissolved oxygen, and temperature were collected using a Sea-Bird SBE 191 Seacat profiler. Zooplankton samples were collected using a 1-m² Tucker trawl fitted with a 505-µm mesh net towed at the surface for 5 min. These data will enable comparisons of distribution, diet, growth, and the feeding environment at interannual, seasonal, and diel time scales.

## Bioenergetics, Growth, and Distribution

A bioenergetics model will be used to quantify the amount of energy required to achieve the growth rates observed for juvenile pink salmon under the thermal regime and diet experienced at different times and areas in GOA and PWS (Cross et al. 2003). Consumption and growth are influenced by temperature, prey quantity and quality (e.g., energy density) and by the size of the consumer. Diet and prey quality are determined by sampling stomach contents of consumers in different spatial temporal cells. The species composition and size structure of prey in stomachs defines the dimensions of the prey exploited by consumers and the average energy return per gram of food consumed. The bioenergetics model estimates the daily consumption rate of each prey type by consumers. These consumption estimates can be compared to estimates of the biomass and density of exploitable prey in each cell to determine whether food limitation exists and to identify temporal and spatial patterns in the magnitude of food limitation. The bioenergetics model also estimates growth efficiency and feeding rate as a proportion of the theoretical maximum daily consumption rate. These metrics can be used to compare growth performance and feeding conditions to distribution and growth patterns of juvenile salmon among areas through time.

### Bioenergetic Modeling Process in Each Temporal-Spatial Cell



Consumer Growth

Temporal Diet Composition

Predator Energy Density

Thermal Experience

Bioenergetics Model

Prey Energy Density

Consumer Size Structure & Abundance

Consumption Estimate

Population Consumption

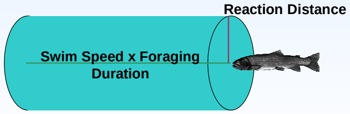
Biomass of Exploitable prey

Consumption as % of Prey Biomass or Production

## Foraging Model

Pelagic salmon rely on vision to detect prey; therefore, a visual foraging rate model can be a useful approach for mechanistically linking feeding behavior, consumption, and growth to the foraging environment in a more predictive framework. A visual foraging model estimates the search volume covered by consumers during a foraging bout and estimates consumption from prey encounter rates by overlaying the density of exploitable prey on the search volume. Visual feeding is affected by optical conditions (light, turbidity) and the prey field experienced during foraging periods (prey species composition, density, and size). The reaction distance of salmon to prey increases rapidly with increasing light, then remains relatively constant above a threshold light level that approximates sea-surface light levels at mid-dusk or dawn. Reaction distance declines with increasing turbidity, but increases with prey size. To construct a visual foraging model for GOA, we needed to characterize the foraging times, depths, and associated optical properties and relevant prey fields experienced by pink salmon. Diel field observations and stomach analysis revealed that juvenile pink salmon foraged in surface waters (top 10 meters) during daylight hours. Monthly measurements of light extinction and turbidity indicated that neither turbidity nor daylight light levels in 0-10m depths would reduce reaction distances to prey (**Figure 2**).

### Visual Foraging Model

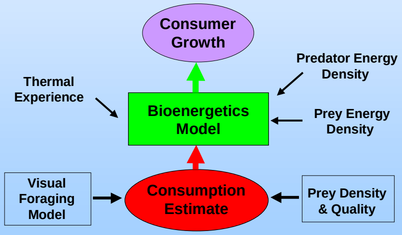


Reaction Distance

Swim Speed x Foraging Duration

$$\text{Search Volume} = \Pi \times RD^2 \times (SS \times Time)$$

### Spatially-Explicit Growth Model



Consumer Growth

Predator Energy Density

Thermal Experience

Bioenergetics Model

Prey Energy Density

Visual Foraging Model

Consumption Estimate

Prey Density & Quality

In order to predict feeding rates of juvenile pink salmon under different prey densities, we conducted initial feeding trials in the laboratory under the high light, low turbidity conditions observed in GOA. Young pink salmon (35-45 mm) exhibited a Type II functional response to 2-mm calanoid copepods (**Figure 2**). Further trials will be required to examine the effects of prey type (e.g., copepods, pteropods, euphausiids), prey size, and consumer size on the functional response curves.

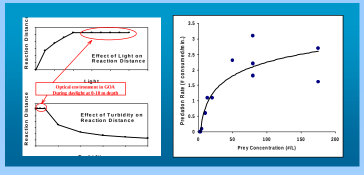


**Figure 2. The turbidity and light conditions during summer in the GOA, and the functional response of 35-45mm pink salmon feeding on 2mm copepods at 160 lux.**

## Summary

- Models of pink salmon foraging capabilities and physiology will provide insight into the relative importance of factors controlling distribution, feeding, and growth, and extent to which ocean conditions limit the distribution and growth of juvenile pink salmon.
- To link pink salmon and other pelagic planktivores to other biological models, estimates of numerical density and size structure of exploitable prey species that are available during daylight hours in near-surface waters (0-10 m depths) will be needed as an output or conversion of the output from NPZ models or crustacean population dynamics models.
- The spatial and temporal scales for input and output among various models will need to be resolved.

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