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**Coexisting and adapting: Feeding behaviour of juvenile pink and chum salmon in B.C.**

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**Chapter 2: From gauntlet to refuge: Juvenile pink and chum salmon dietary overlap**

**2.1 Introduction**

Pacific salmon are opportunistic foragers, shifting their diets according to the available prey fields, environmental conditions, and potential interspecific competition. Physical and biogeochemical properties of the ocean facilitate phytoplankton production, which stimulates zooplankton blooms, which then become prey for higher level predators. Availability of prey in the dynamic ocean environment can influence the trophic niches of predators such as salmon and occupying the same niche can lead to competitive exclusion. Two species that coexist can either occupy different niches and consume different prey or occupy the same niche, but one will have the advantage and drive the other into extinction.

Pink salmon remain planktivorous throughout their short life cycle and in higher abundance years have been shown to outcompete other species for zooplankton resources (Ruggerone & Nielsen, 2004). Pink salmon have an obligate two-year life cycle, with genetically distinct odd-year and even- year broods, and in many areas one of the broods is more abundant than the other, creating biennial patterns of numerical dominance and absence, a natural treatment effect to study. Research has shown pink salmon have negatively impacted the growth and survival of chum, sockeye, chinook and coho salmon, as well as planktivorous trout and sea birds.

Chum salmon, the Pacific salmon species with the highest biomass, can be either planktivorous or piscivorous, but have also been shown to prey shift to gelatinous items. Consumption of gelatinous prey has been found in chum diet studies in different regions of the Pacific Ocean and in different life stages, reflecting a common strategy of the species. Juvenile chum are considerably flexible and adaptive salmon species, not only in prey choice but in life history as well, varying the amount of time they spend growing in the ocean. Since there are such large amounts of chum salmon released from hatcheries in the Pacific, their ecology, survival and interactions with other species requires further scientific inquiry.

Juvenile Pacific salmon foraging trends and interspecific competition during early marine migration can impact their survival to adulthood but is still not yet well understood. In order to survive the first ocean winter, juvenile salmon must achieve sufficient growth to reach a critical size to better catch food, avoid predators and survive periods of starvation. Prey quality and quantity mediates salmon growth and therefore growth and survival are closely coupled to the environmental conditions that salmon experience during the outmigration. Competition between salmon species for prey resources further compound effects of food limitation during the early phase and competitive interactions also likely shift with conditions.

The majority of juvenile salmon in southern British Columbia migrate northward through the Strait of Georgia pathway, where they encounter diverse coastal conditions. First, the Discovery Islands is an archipelago with complex oceanographic conditions and multiple routes for migrating salmon, which has been shown to affect early marine survival. The next leg of the migration is the Johnstone Strait, hypothesized to be a “trophic gauntlet” salmon have to endure before entering improved conditions in the Queen Charlotte Strait.

The conditions salmon encounter in this region of B.C. will likely be comparable to environments they will continue to migrate through, along the coast into the Gulf of Alaska. Coastal ocean conditions can vary from high freshwater inputs to purely oceanic, sheltered inlets to exposed areas, rocky shores to eelgrass habitats and high to low productivity levels. Therefore, not only does the Discovery Islands and Johnstone Strait region represent an important section of the salmon migration route, but is a microcosm of coastal conditions, transitioning from warm, fresh, stratified channels to a cold, saline, well-mixed, deep strait.

The purpose of this study is to classify the trophic niches that juvenile pink and chum salmon occupy, determine overlap and how niche and overlap change with feeding intensity. How does juvenile pink and chum salmon dietary overlap vary across coastal regions with unique zooplankton communities and what are main prey types for each salmon species? Does dietary overlap between species increase or decrease in relation to foraging intensity? Analyzing the Discovery Islands and Johnstone Strait regions as a case study, this research will dive into the relationships between pink and chum salmon, their prey and environment.

**2.2 Methods**

In an effort to understand the early marine phase of Pacific salmon, the Hakai Institute, UBC and Salmon Coast Field Station partnered up and created a field program. Since 2015, every field season researchers head out on oceanographic surveys, starting in May, to capture outmigrating salmon species, zooplankton samples and oceanographic data. First, a visual survey of salmon surface activity is performed, before setting the purse seine net on a targeted school of fish, where up to 30 sockeye, 10 pink and 10 chum salmon are collected. In 2015 and 2016, zooplankton were gathered with horizontal surface tows and preserved in 95% ethanol, before oceanographic surveys were done, collecting YSI and CTD information.

Back at the lab, researchers processed zooplankton samples and dissected juvenile salmon for various samples, the salmon stomachs removed and preserved in 95% ethanol. The zooplankton samples were poured over sieves to be size fractionated and then weighed before they were split into a subsample, to be identified to species, counted and measured. The salmon stomachs required more steps for processing, removing ethanol and soaking for 30 minutes in water to reduce brittleness of sample, before dissecting the stomach open. After the food contents were removed, the entire bolus was weighed, placed on a petri dish with water added, to rearrange the prey items by species, size, life stage and digestive state. For each prey group, minimum and maximum lengths were measured with an ocular micrometer, individuals were counted, and the group was weighed to a ten of a milligram. Subsamples of ¼ were analyzed if there were more than 800 individuals within one stomach. Data were recorded in a notebook and entered into an excel sheet for subsequent analyses.

Preparing the data for analysis included combining rare taxonomic prey categories (occurs in less than three stomachs) into higher level groupings and ignoring “digested food.” The dataset was then transformed from long to wide format, relative prey biomass for each stomach was calculated and then arcsine square root transformed for multivariate analysis.

A Bray-Curtis dissimilarity matrix was created from transformed data, for the analysis of similarity (ANOSIM), similarity percentage (SIMPER), non-metric multidimensional scaling (NMDS) and agglomerative hierarchical cluster (AHC) analyses, to find trends in the data.

In addition to the multivariate statistics, various indices were calculated from the raw diet data, including frequency of occurrence of prey for each site and each species, which is the number of stomachs with that certain prey item, divided by the total number of stomachs.

Gut fullness indices were also calculated from the food content weight divided by the weight of the fish, multiplied by 100 to express as percent body weight, a proxy for feeding intensity. Schoener’s overlap index was calculated for each site, where relative biomass of prey for each species is compared, and the minimum values for each prey group are then summed. Shoener’s index is expressed as a percentage and overlap values over 60% are meaningful. Note, the few empty stomachs (those with no identifiable prey) in this study were excluded from all the multivariate analyses, but were included in the calculation of the above indices.

**2.3 Results**

The environment of Discovery Islands is characterized as warmer and fresher and Johnstone Strait is more oceanic in nature, and different zooplankton occur in each region. D07 has high freshwater influence, with a surface salinity of 25 and temperature of 17oC, at D09 it shifts to 28.5 salinity and 12oC and D11 and J06 are further transition points before the water properties stabilize to become oceanic at J08 and J02, with 32 salinity and 10oC. The zooplankton biomass throughout this area is mostly composed of small zooplankton, in the 250 μm size fraction, mainly calanoid and cyclopoid copepods and the ‘other’ prey types.

Juvenile chum salmon diets shift from *Oikopleura* in Discovery Islands to gelatinous then euphausiids in Johnstone Strait, whereas pink salmon prey on copepods along the way. In addition to active selection for large (>2 mm) calanoid copepods, pink salmon also fed upon decapod larvae, and nearshore animals such as insects and harpacticoid copepods. Discovery Islands can be characterized as *Oikopleura* dominant for chum salmon, with pink salmon also consuming *Oikopleura* but in much lower amounts, mostly eating crustaceans. At the first Johnstone Strait site J06, chum salmon shift to gelatinous prey (possibly Cnidaria jellyfish) and pink salmon have nearshore prey, calanoids and other (gammarids, barnacles). The following Johnstone Strait site J08, chum salmon still consume gelatinous prey but also have higher amounts of large calanoid copepods, and pink salmon dominantly eat calanoids. There is a complete diet shift at the last Johnstone Strait site J02, where both of the salmon species consume calanoids, chaetognaths and euphausiid prey, but in different proportions. Therefore, calanoids are important prey for pink salmon and chum salmon consume larger prey, either gelatinous zooplankton at most sites or euphausiids and chaetognaths at J02.

Feeding intensity was consistently low throughout this area of the salmon migration route, with the exception of incredibly full stomachs at the last site, Queen Charlotte Strait. Gut fullness indices were consistently below 1% body weight throughout the first four sites,

At mid-Johnstone Strait site J08, the gut fullness increases to around 1% body weight, which is still relatively low, compared to the around 5% body weight feeding intensity at site J02. Empty stomachs were found throughout the Discovery Islands and the first Johnstone Strait site, D07 had 2 empty pink salmon stomachs and D09 had 3 empty chum salmon stomachs. Further, 3 empty chum salmon stomachs were found at D11 and finally, 4 empty pink salmon stomachs from J06, giving a total of 12 empty stomachs in this study (n = 6 pink, 6 chum).

Dietary overlap between pink and chum salmon was relatively low and consistent in the Discovery Islands and shifted in Johnstone Strait from low to high species diet similarity. The first site of the migration route D07 had 25% dietary overlap, D09 saw a slight increase to 33%, then D11 decreased to 22%, and the lowest value was J06, with a mere 5% overlap. Mid-Johnstone Strait J08 had 14% dietary overlap and the final site near the entrance to Queen Charlotte Strait J02, had the highest diet overlap of 60% for pink and chum salmon. Therefore, the Schoener overlap index shows consistently low diet overlap between salmon species throughout this section of the migration route and one site of substantial similarity.

Overall diet composition of salmon species also had no observable trends within the Discovery Islands, whereas Johnstone Strait has a clear gradient of overlap and divergence. The NMDS plot reflects the variability in Discovery Islands, and Johnstone Strait locations show the highest differentiation between species at J06, the eastern most site, then J08 next shows semi-different pink and chum salmon diets and finally, J02 has complete diet overlap. A cluster analysis (appendix?) also displayed this same trend, where the two regions were separated into main clusters and Johnstone Strait was subdivided by both site and species.

The only site to distinctly cluster together was J02, near Queen Charlotte Strait, which was similar to the pink salmon diets from J08, mid-Johnstone Strait. The pink salmon diets were somewhat comparable to the chum salmon diets at J08, but the J06 chum salmon from East Johnstone Strait had a completely separate cluster and J06 pink salmon were outlier values.

**2.4 Discussion**

Juvenile pink and chum salmon have similar diets when feeding intensity is high but utilize different foraging strategies when feeding is low, dividing resources by trophic niche. Throughout most of the study sites, chum salmon filled the gelatinous prey niche and pink salmon were found foraging on nearshore insects, harpacticoids, caprellids and gammarids. The reliance on these niche strategies shifted with the foraging intensity, since at the Queen Charlotte Strait site with ~5% body weight stomach fullness, both species fed very similarly. Therefore, salmon will consume higher quality prey such as euphausiids and large calanoids when available and will otherwise divide up the resource space to limit potential competition.

Juvenile salmon appear to experience a trophic gauntlet during their migration, with areas of ‘winners and losers’, where prey availability dictates which feeding strategy prevails.

The first two sites of Discovery Islands seem to have semi-decent feeding conditions, with decapod larvae prey present at D07 and around 0.5% body weight stomach fullness at D09. The next two sites in the migration is the mid-way point, the transition between the regions, and D11 had more empty chum salmon stomachs and lower amounts of *Oikopleura* prey, whereas pink salmon still fed on nearshore prey and had no empty stomachs at this location. The next site of J06, found the opposite, with no empty chum salmon stomachs feeding on gelatinous prey and empty pink salmon stomachs and unusual prey when food was present. Thus, salmon species feeding strategies will either be beneficial or detrimental depending on prey availability, and how these relationships could shift over time requires further research.

While Discovery Islands has more of an environmental gradient, Johnstone Strait is a foraging gradient, as salmon move west it shifts from low to high feeding and diet similarities. Although Johnstone Strait has a very consistent temperature and salinity, the amount of zooplankton advection from coastal upwelling increases closer to Queen Charlotte Strait. The Johnstone Strait migration begins with little to no calanoid copepods, chum salmon feeding on jellyfish and pink salmon scouring the nearshore for insects and harpacticoids. Mid-way through Johnstone Strait, there is a shift, chum salmon still consume gelatinous but also large calanoids, and pink salmon prey on hundreds of calanoids of all shapes and sizes. Finally, at the last study site at the end of Johnstone Strait, pink and chum are found to have stomachs that are literally bursting full of diverse calanoids, euphausiids and chaetognaths. This region therefore shows the relationship between diet similarity and foraging intensity, and how as conditions improve, species can begin to safely occupy the same trophic niche.

In other areas with similar coastal conditions, pink salmon have been found to utilize nearshore foraging on small crustaceans and chum salmon often prey switch to gelatinous. Previous studies have shown harpacticoid copepods as a prey for both species, and calanoid copepods are another important component of pink and chum salmon diets. Recently, a study on sockeye salmon diets in this same area found *Oikopleura* to be very important prey in the Discovery Islands, similar to chum salmon, and larger calanoids to be dominant in Johnstone Strait, which is similar to the observed pink salmon diet composition. Other research that investigates dietary overlap of multiple species of salmon have found pink salmon to be most similar to either sockeye or chum salmon in their choices of prey.

While this research study focused on a snapshot of juvenile salmon feeding in June 2016 in this area, trends can’t be extrapolated without a seasonal or interannual component. The dynamics of each of these regions may shift over time, especially the Discovery Islands which naturally has more variability due to the freshwater influence on the ocean conditions. This study characterized salmon species interactions in high and low foraging scenarios, but other unknown factors could be contributing, and more research is needed to confirm trends. More accurate descriptions of these regions require a longer time series on salmon feeding during the outmigration period and across years, which is the focus of the next data chapter.

**2.5 Conclusion**

In conclusion, juvenile pink and chum diets appear to be influenced by availability of prey and the overlap between salmon species shows a clear relationship to feeding intensity. It is intuitive that prey determines diet composition but counter-intuitive that competition may decrease with increased diet similarity between salmon species utilizing the same resources. When food becomes scarcer, it seems juvenile salmon have strategies to fall back on, pink salmon focusing efforts in nearshore environments and chum salmon shift to gelatinous.

The diversity of conditions encountered by salmon migrating through this area shows how species can coexist by utilizing different trophic niches to partition their prey resources. Since pink salmon have the potential to outcompete other species for high quality prey such as large calanoid copepods, chum salmon require a different strategy in order to survive. Species occupy distinct trophic niches from one another, and this relationship shifts across the migration route relative to the foraging intensity of salmon and environmental conditions.

Therefore, juvenile pink and chum salmon interactions are an important component of coastal ecosystem dynamics, which can impact salmon early marine growth and survival. Outmigrating salmon have to adapt to shifting prey fields and other competitors for those resources, and in some areas one feeding strategy will benefit one species over the other. This study illustrates the importance of research on the interspecies competitive interactions, such as pink and chum salmon in high and low foraging opportunities to understand survival. Early marine growth of salmon is influenced by prey quality and quantity, a constant struggle.

**References**

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