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**Competition or Coexistence? Pink and chum salmon trophic interactions through a dynamic and challenging section of the early marine migration route in coastal British Columbia**

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**Chapter 3: Salmon trophic interactions shift with prey phenology and migration timing**

**3.1 Introduction**

There are many different factors affecting the early marine survival of Pacific salmon, including migration run timing and whether it coincides with good quality and quantity of prey.

Zooplankton phenology is largely determined by ocean conditions and phytoplankton dynamics, and zooplankton community succession significantly impacts upper trophic levels.

Salmon diets have been found to be variable over time, therefore any interspecific interactions and competition for prey resources may also vary seasonally and inter-annually.

The size of salmon in relation to size of zooplankton prey is another important factor influenced by salmon size at ocean entry and growth rate during the first few months at sea.

Previous studies in coastal British Columbia have shown Discovery Islands to be very seasonally dynamic, whereas Johnstone Strait is more consistent with no seasonality.

Seasonal and interannual oceanography, prey dynamics and salmon migration timing are linked to salmon survival and requires better understanding within the Pacific Northwest.

This study will investigate the relationships between juvenile pink and chum salmon foraging and the zooplankton community composition throughout early salmon outmigration.

**3.2 Methods**

The Hakai Institute’s Juvenile Salmon Program was established in 2015 as a collaboration between the Hakai Institute, the University of British Columbia, Simon Fraser University, the University of Toronto and Salmon Coast Field Station. This program annually samples juvenile salmon as they migrate through the Discovery Islands and Johnstone Strait during the main outmigration period (May to July). The objective of the program is to improve understanding of the early marine phase of Pacific salmon, particularly factors contributing to health and survival (Hunt et al., 2018). This study focussed on 2015 and 2016, which had the highest frequency of sampling stations in an effort to resolve the primary migration dynamics.

Every field season since 2015, researchers head out on oceanographic surveys, starting in May, to capture outmigrating salmon species, zooplankton samples and oceanographic data. In the Discovery Islands, 12 sites were sampled in 2016, and in Johnstone Strait, 10 sites were sampled, to provide coverage of all possible salmon migration routes through these regions (Hunt et al., 2018). Sites were sampled every 4-7 days throughout the season, depending on weather conditions. For this study, two sites (one from each region) were selected, in order to obtain a sample size of 10 pink and 10 chum per set (n=120 total), still acquiring sufficient coverage for each region. The dates were chosen in mid-June (Table 1) to align with the peak out-migration of salmon (Johnson et al., 2019).

The salmon sampling begins with recording weather and sea state data, followed by a visual survey of salmon surface activity. Afterwards, the purse seine net (bunt: 27 m × 9 m with 13 mm mesh; tow: 46 m × 9 m with 76 mm mesh) on a targeted school of fish, up to 30 sockeye, 10 pink and 10 chum salmon are retained, the remaining salmon counted and released (Hunt et al., 2018). Salmon were euthanized with tricaine methane sulfonate (MS-222) upon removal from the seine net, lengths and weights recorded, and preserved at -196 oC with liquid nitrogen in a dry shipper until the salmon samples were stored in the -80 oC freezer at the lab.

In addition to salmon sampling, zooplankton samples and oceanographic data were also collected during each survey. The YSI measured temperature and salinity at the surface and 1-meter depth, recorded while salmon were held for processing in the net. The zooplankton were collected after salmon and oceanographic sampling with a 50 cm diameter and 250 μm mesh net, towed horizontally at the surface and preserved in 4% formaldehyde for future analysis.

In the lab, juvenile salmon were dissected, and the stomachs preserved in 95% ethanol. Prior to analysis, salmon stomachs were removed from ethanol and soaked unopened for 30 minutes in tap water to reduce the brittleness of the sample. The stomach was then dissected open and the food contents removed. The entire food bolus was weighed on an analytical balance and wet weight recorded to the nearest 0.1 mg. The bolus was then placed on a petri dish with water added, and prey rearranged by species, size, life stage and digestive state. Digestive states were defined as 1) fresh prey, intact, 2) semi-fresh prey, with lost appendages or color, 3) semi-digested prey, identified to group, and 4) fully digested, and unidentified prey. If prey could not be identified to species, it was identified to the most detailed taxonomic group possible, e.g. Ctenophora and Cnidaria jellyfish, collectively grouped as “gelatinous” hereafter. For each prey group, minimum and maximum lengths were measured with an ocular micrometer, individuals were counted, and the group wet weight recorded to nearest 0.1 mg.

If a stomach sample had over 1,000 prey of similar size, a subsample would be processed, first any rare or large prey were removed, data recorded and then ¼ of remaining prey processed. For example, counting and measuring a couple of decapods and amphipods before subsampling hundreds of *Oikopleura* and cladocerans, multiplying the data by 4 to estimate the sample data.

The zooplankton samples were poured over sieves into 250 μm, 1000 μm and 2000 μm size fractions before being weighed and analyzed. Wet weights were measured to the nearest 0.1 mg on an analytical balance, with non-gelatinous and gelatinous groups weighed separately. Each size fraction of zooplankton was identified to species and life stage, enumerated and measured with an ocular micrometer, and subsampled if necessary, using a Motodo splitter.

The spatial variation in prey composition was analyzed using a multivariate approach. Prior to the analysis, rare taxonomic prey categories (occurs in less than three stomachs) into were combined into higher level groupings, ignoring “digested food.” Fish stomach content wet weight was multiplied by 1.54 to correct weights for water loss after storage in ethanol (James, 2019). Relative prey biomass for each stomach was calculated and arcsine square root transformed before calculating Bray-Curtis dissimilarity. The dissimilarity matrix was used for non-metric multidimensional scaling (NMDS) ordination and agglomerative hierarchical clustering (AHC).

In addition to the multivariate statistics, various indices were calculated from the raw data. Frequency of occurrence (FO) of prey for each site and each species, was calculated as:

FO = # of stomachs with preyi / total # of stomachs

Gut fullness indices (GFI) were also calculated for each fish, expressed as percent body weight:

GFI = (food bolus weight / fish weight) \* 100

The Schoener percent similarity index (PSI) for species diet overlap was calculated for each site:

PSI = [Σ (minimum preyip, preyic)] \* 100

Where preyip is the proportion by weight of prey *i* in pink salmon stomachs and preyic is the proportion by weight of prey *i* in chum salmon stomachs (Chipps & Garvey, 2006; Krebs, 2013).

Note, the 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. The prey taxonomic detail was retained in analyses, but for summary tables and figures, “other” is prey grouped together that doesn’t contribute substantially to diets, such as amphipods, barnacle larvae, bivalve larvae, cladocerans, fish larvae/eggs, pteropods, polychaetes, to name a few.

**3.3 Results**

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**3.4 Discussion**

Microplastics were not the focus of this study but they were found in \*\*\*\*\*% of juvenile salmon stomachs, and one macroplastic was found to be 30% weight of a pink salmon stomach. That 6 mm macroplastic had the shape, color and texture of a broken straw piece and appeared larger than the sphincter could potentially pass, which would likely reduce survival for that fish. Impacts of plastics on salmon and occurrence in empty stomachs, with potential for cumulative effects, should be researched further to better understand the multiple threats salmon face.

**3.5 Conclusion**

TBD

**References**

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**Tables**

TBD

**Figures**

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