# Quantitative estimation of the ecosystem services supporting the growth of Japanese chum salmon

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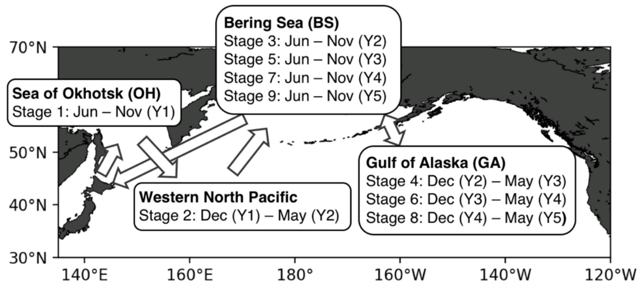
## 1. Introduction

Chum salmon (Oncorhynchus keta) are distributed widely in the subarctic North Pacific. The Japanese stock is maintained by artificial release procedures. Chum salmon, including the Japanese stock, provide important ecosystem services for humans that are related to provisioning, culture and support. These ecosystem services are supported by the supply of prey and habitat that the fish use. We regard the supply of prey and habitat as supporting services for salmon. We developed a procedure to estimate supporting services quantitatively, based on the prey biomass consumed by individual salmon, by coupling a bioenergetics model and a lower trophic level ecosystem model. Using this procedure, we estimated the prey biomass consumed by a cohort of Japanese chum salmon released in a single year. The phytoplankton biomass indirectly consumed by a cohort was also estimated and considered to be the primary production supporting the fish.

## 2. Methods

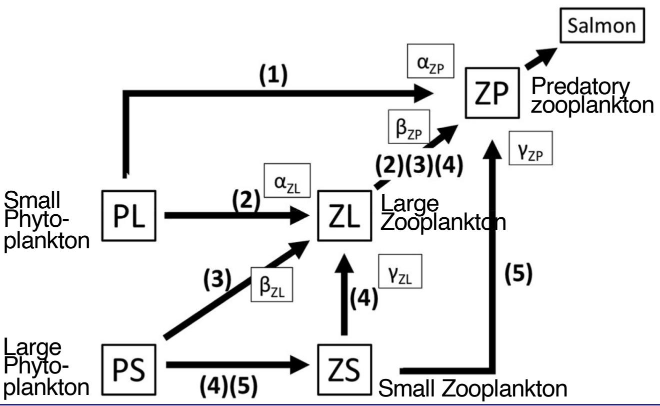
It was assumed that $1.8 \times 10^9$ Japanese chum salmon fry were released in Japan on March 1. In our analysis, we adopted the 4-box lower trophic level ecosystem model NEMURO (Kishi et al., 2007) to represent the migration habitats of Japanese chum salmon.




The growth of individual Japanese chum salmon was represented by the following expression:

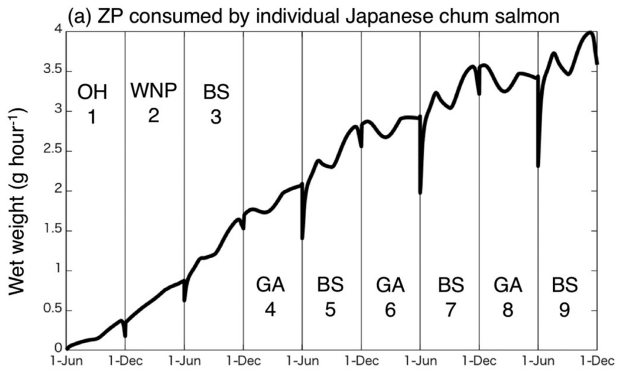
$$\frac{\mathbf{dW}}{\mathbf{dt}} = [\mathbf{C} - (\mathbf{R} + \mathbf{SDA} + \mathbf{F} + \mathbf{E})] \cdot \frac{\mathbf{CAL_z}}{\mathbf{CAL_f}} \cdot \mathbf{W}$$

The prey density input to our bioenergetics model was estimated by NEMURO (Kishi et al., 2007).
The primary production that supports Japanese chum salmon was estimated from the small and large phytoplankton (PS and PL, respectively) that were directly or indirectly consumed by ZP, which were consumed by Japanese chum salmon through five pathways in the NEMURO, as shown in the following figure.




## 3. Results

The lower panel depicts a time series of ZP wet weight consumed by individual Japanese chum salmon per hour. Consumption gradually increased up to ca. 4 g wet weight $h^{-1}$ as the body weight of salmon increased through the end of Stage 9.




We next integrated the values in the upper figure for each migration area, as shown in the table. We also estimated wet weight of ZP consumed by a salmon cohort.

| Region | Stage | Wet weight of ZP consumed by individual salmon (kg) | Wet weight of ZP consumed by a salmon cohort ($10^8$ kg) |
|---|---|---|---|
| Sea of Okhotsk | 1 | 0.8 | 1.5 |
| Western North Pacific | 2 | 2.8 | 3.2 |
| Bering Sea | 3/5/7/9 | 45.8 | 28.4 |
| Gulf of Alaska | 4/6/8 | 35.3 | 21.8 |
| Total | | 84.7 | 55.0 |

Considering interannual variation of returning age composition (Miyakoshi et a., 2013), that is, assuming that only 25%–50% of salmon reached Stages 8 and 9 in our model, the total ZP consumption and primary production were estimated to be 4.2–4.7 x $10^9$ kg and 2.0–2.2 x $10^9$ kg C, respectively, and Japanese chum salmon were estimated to be supported by 0.17%–0.19% of the integrated primary production across all regions.

## 4. Discussion

We calculated the monetary value of ZP consumed by Japanese chum salmon assuming that the monetary value of ZP is equivalent to that of krill. We used the average price in the Tokyo Metropolitan Central Wholesale Market for the period 2002–2018 i.e. 476 Japanese yen $kg^{-1}$ wet weight. Using the market price of krill, the total value of ZP consumed by Japanese chum salmon was estimated to be 2.0–2.2 x $10^{12}$ Japanese yen (18–20 x $10^9$ US dollars) far exceeds the value of the Japanese chum salmon harvest (0.06 x $10^{12}$ Japanese yen or 0.5 x $10^9$ US dollars averaged over the period 2001–2017). Thus, the harvest of ca. 0.06 x $10^{12}$ Japanese yen was supported by a shadow cost (prey) of up to 2.0–2.2 x $10^{12}$ Japanese yen.

## Reference

Karasawa, Y., H. Ueno, R. Tanisugi, R. Dobashi, S. Yoon, A. Kasai, M. Kiyota, Quantitative estimation of the ecosystem services supporting the growth of Japanese chum salmon, Deep-Sea Research Part II, 175, 104702, https://doi.org/10.1016/j.dsr2.2019.104702 (2020)