Estimating potential habitat for chum salmon (*Oncorhynchus keta*) in the Western Arctic using a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model

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Migration route of Japanese chum salmon
(modified Urawa, 2000)

① Japanese chum salmon juveniles are released in spring from Hokkaido, Japan, and are distributed in the Okhotsk Sea in the first summer and autumn.

② Immature chum salmon enter the Bering Sea by the following summer.

③ Overwinter in the western North Pacific.

④ Migrate to the Gulf of Alaska during winter.

⑤ Migrate to the Bering Sea during summer to remain in preferred water temperature.

⑥ They repeat the southward/northward migration for 3-4 times seasonally.

⑦ When they are ready to mature in the fourth/fifth year summer, they return to their home rivers in Hokkaido.
Optimal Temp. for chum salmon: 5°C – 10°C (Kishi et al., 2010)

SST in the Bering Sea
Present & 2095yr under the SRES-A1B

Water temperature (°C)

JUN JUL AUG SEP OCT NOV

WOA05
2095-A1B

(Kawamiya et al., 2005)
Objectives

- SST increase affect to salmon northing directly. Japanese chum salmon migrated to northern areas in the Bering Sea during summer (Sato et al., 2012).

- Focus on chum salmon migrating northward to the Western Arctic during summer

- To estimate the potential habitat for chum salmon in the Western Arctic using a bioenergetics model coupled 3D-NEMURO
**Bioenergetics model**

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

where:

- **C**: Consumption
- **R**: Respiration
- **SDA**: Specific dynamic action
- **F**: Egestion & feces
- **E**: Excretion
- **CAL_z**: Caloric equivalent of zooplankton
- **CAL_f**: Caloric equivalent of fish

\[ C = C_{MAX} \times \rho \times f_c(T) \]

- **C_{MAX}**: Maximum consumption rate

(Rudstam, 1988; Kamezawa et al., 2007; Kishi et al., 2010)

![Graphs](Image)
Definition of potential habitat

“an area where chum salmon can grow up (i.e., $\frac{dW}{dt} > 0$)”
Water temperature, salinity, and prey density in the bioenergetics model: obtained from the 3-D NEMURO results simulated by Watanabe et al. (2012)

3-D NEMURO (Watanabe et al., 2012)

COCO 3.4 (Hasumi, 2006) + NEMURO (Kishi et al., 2007)

- Horizontal: 2.5 km, Vertical: 25 levels (surface to 4000 m)
- Run for nine months from March to November 2003
Inputs from 3-D NEMURO

Water temperature (°C)

Horizontal ~ at surface from June to November

Prey density (μmol l\(^{-1}\))

Monthly vertical ~ from the surface to 100 m (averaged horizontally in the entire model domain)
Global warming scenario

- Monthly water temperature anomaly modeled under the SRES-A1B of IPCC simulated by Kawamiya et al. (2005) using the MIROC (Hasumi and Emori, 2004).

\[
\text{Anomaly} = \text{2095yr} - \text{2005yr}
\]

Aver. (2091 to 2100) (2001 to 2010)

Target!

North Pacific
Anomaly (or normalized anomaly) = 2095 yr – present

**Water temperature (°C)**

**Prey density (μmol l\(^{-1}\))**

Horizontal ~ at surface from June to November

Monthly vertical ~ from the surface to 100 m (averaged horizontally in the entire model domain)
2000 gWW chum salmon under 2003 case

Maximum growth rate (%)
Comp: Gmax M: 03 D: 01 W: 2000

Water temperature at the MGD
Comp: Tmax M: 03 D: 01 W: 2000

Maximum Growth Depth (m)
Comp: Hmax M: 03 D: 01 W: 2000

Predatory zooplankton at the MGD
Comp: Zmax M: 03 D: 01 W: 2000
Potential habitat for chum salmon June to November

The potential habitat is restricted to the southwestern Alaskan coast on June and is expanded to the Chukchi Sea and along the Alaskan northwestern coast from July to September and is reduced from October.
While, on August, the potential habitat increased for smaller chum salmon (~1500 g) but decreased for larger chum salmon (>2000 g). **WHY??**

- Under the global warming scenario, the potential habitat increased for all chum salmon on June and July due to the water temperature increase,
Water temperature exceeds the optimal temperature during summer.
Under the global warming scenario, the potential habitat increased for smaller chum salmon (~1500 g) but decreased for larger chum salmon (>2000 g) on September, while the potential habitat increased for all chum salmon on June and July due to the water temperature increase,
Vertical potential habitat at CS1

Present 500 2000 2095-A1B

$f_c(T)$

$\rho$

$G_{max} 500$

$G_{max} 2000$
Vertical potential habitat at CS2

Present  500  2000  2095-A1B

\( f_c(T) \)
\( \rho \)
\( G_{\text{max}500} \)
\( G_{\text{max}2000} \)
Vertical potential habitat at BC

Present  500  2000  2095-A1B

\[ f_c(T) \]
\[ \rho \]
\[ G_{\text{max}500} \]
\[ G_{\text{max}2000} \]
Summary

- This study is the first attempt for estimating the potential habitat for chum salmon in the Western Arctic using a bioenergetics model.

- The potential habitat was restricted to the southwestern Alaskan coast on June and expanded to the Chukchi Sea and along the Alaskan northwestern coast from July to September and reduced from October.

- Under the global warming scenario, the potential habitat increased for all chum salmon during early summer and autumn due to the water temperature increase, while, during summer, the potential habitat increased for smaller chum salmon (~1500 g) but decreased for larger chum salmon (>2000 g) because the water temperature exceeded the optimal temperature.
Questions? & Comments (plz!)

Sorry, Dr. Watanabe.
I do not have your picture.