A comparison of reproductive characteristics and strategies between walleye Pollock (Theragra (Gadus) chalcogramma) and Arctic cod (Boreogadus saida)

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Outline of our presentation

1. Why will the walleye pollock be called “Gadus chalcogramma”, not “Theragra”? 

2. Comparison of reproductive characteristics among gadid fish

3. Reproductive characteristics of Pacific gadid fish related to physical condition of spawning grounds


5. Laboratory studies on the response of walleye pollock eggs and larvae to temperature change
Why will the walleye pollock be called “Gadus chalcogramma”, not “Theragra”? (Coulson, 2006)

New classification of the Gadidae based on their morphology and phylogenetic analysis (Grant et al, 2010)

(Teletchea et al, 2006)

(Graphic representation of the new classification of Gadidae species, focusing on the walleye pollock and related species.)
Comparison of reproductive characteristics among gadid fish

- **Atlantic cod** (*G. morhua*)
  - Brawn (1961)
  - Hawkins *et al.* (1967)
  - Hislop *et al.* (1978)
  - Sound production by male during mating
  - Single-pair, ventral mounting, midwater spawner
  - Multiple spawning
  - Pelagic and separable egg

- **Haddock** (*M. aeglefinus*)
  - Sound production is not confirmed
  - Maybe, single-pair; spawning is not confirmed
  - Multiple spawning

- **Walleye pollock** (*T. chalcogramma*)
  - Sound production is not confirmed
  - Maybe, single-pair; spawning is not confirmed
  - Multiple spawning

- **Arctic cod** (*B. saida*)
  - Sakurai *et al.* (1998)
  - Single-pair; following, bentho-pelagic spawner
  - Single spawning
  - Demersal and week adhesive egg

- **Pacific cod** (*G. macrocephalus*)
  - Sakurai & Hattori (1996)
  - Single-pair; following, bottom spawner

- **Saffron cod** (*E. gracilis*)
  - Chen *et al.* (2008)
  - No sound production by male during mating
  - A few males to one female; following, bottom spawner

**Legend**:
- Red: confirmed by the previous studies
- Blue: confirmed by the previous studies
Reproductive characteristics of Pacific gadid fish related to physical condition of spawning grounds

Walleye pollock

Saffron cod

Pacific cod

Arctic cod
Schematic illustration of spawning strategy and reproductive characteristics of Pacific cod and walleye pollock. (Sakurai, 1989; Sakurai & Hattori, 1996)
Schematic illustration of spawning strategy of Arctic cod and saffron cod
(after Sakurai et al, 1996; Chen et al, 2008)
Do temperature and salinity of sea surface layer have a threshold values to survivals during the early life stages of walleye pollock and Arctic cod?
Range of estimated optimum temperature for survival of egg and larvae of Pacific gadid fish.

(Based on Sakurai et al. (1998); K. Okazi (2009), Y. Kurihara (2010), and C. Watanabe (2010), Master theses, Graduate School of Fisheries Sciences, Hokkaido University)

http://www2.fish.hokudai.ac.jp/fac/ship/oshoro/oshoro00.htm
1. Normal egg development occurs at temperature below 3.0 °C, and at salinities between 32 and 41.
2. Embryos can survive and develop under the ice below 0 °C and highly saline.
3. Hatching larvae can survive under the widely fluctuated salinities after ice melting.

Sakurai et al. (1998)

Sampling gears

* Bottom trawl
* Bong net (oblique tows, 0-75m)
South of St. Lawrence Isd • • • Cold pool ($\leq 2^\circ$C)

Chukchi Sea

Bering Strait ~ Coastal area • • • ($>2^\circ$C)

Northern offshore of 70° N • • • $<0^\circ$C

(Watanabe, 2010)
Arctic cod is an important indicator species of climate change including the global warming in the marginal sea of Arctic Ocean.

- Arctic cod distribute in water below 2 °C
- Some of adult male and female can survive after spawning, which depend on their food availability in habitat.

(Watanabe, 2010)
Food chain between benthic fish in the Bering Sea and the Chukchi Sea in the summer, 2007 and 2008

(Okazi, 2009)
Distribution of Arctic cod larvae in the summer of 2007, 2008

Hatching larvae (BL:5-6mm) occur in water near sea ice

Hatching areas shift to the north with ice melting

(Kurihara, 2010)
Laboratory studies on the response of walleye pollock eggs and larvae to temperature change

Objectives

- To examine the response of walleye pollock eggs and larvae to temperature change such as artificial thermocline in tank.
- To determine their preferred temperature.
Material and Methods - Collect the eggs

1) Adult fish Sampling:
   Mouth of Funka Bay
   late Jan., 2007-2012

2) Rearing the adult fish:
   10 ton tank (Temp: 5°C, Sal: 29.1 and 33.0)

3) Collect the natural spawned eggs
Material and Method: the Optimal T-S ranges for hatching

Eggs were reared at 35 conditions (mean = 507 eggs / conditions)

7- Temperatures: -1.0, 0.0, 2.0, 5.0, 7.0, 9.0, 11.0 °C

5- Salinities: 24.0, 27.0, 30.0, 33.0, 35.0

Examined 1) Developmental time
          2) Normal hatching rate

Development stages (Kendall and Kim 1993)
Material and Method: Movement near the thermocline

Sharp density gradient

Temperature (°C): -2 - 0 (upper), 5 (lower)
Salinity: 28 (upper), 33 (lower)
Density ($\sigma_t$): 22.5 (upper), 26.1 (lower)
Eggs (n): 10

Actual photo of the experiment
Results: Hatching experiment under the 35 T-S conditions

Normal Hatching Rate (%)

Low (0 - 4%) : -1, 0 °C
High (78-95%) : 2-9 °C

No clear difference among the salinities except 11°C

Normal hatching is controlled by temperature rather than salinity.

Water mass with < 2°C is unfavorable condition for the hatching.
Results: Movement of the eggs near the thermocline

suggesting... Egg can hatch normal if they underwent the cold temperature at their late developmental stage

supporting... Eggs resist cold water after morula stage (Nakatani and Maeda 1984)
Discussion: Vertical movement of the eggs in the spawning areas

Stokes law

\[ \omega = \frac{\Delta \rho g D^2}{18 \eta} \]

- \( \omega \): velocity
- \( \Delta \rho \): difference of Dens.
- \( D \): eggs diameter
- \( \eta \): viscosity
- \( g \): gravity

Funka Bay

- Cold water ca. 20m
- morula stage
- 7 hrs to the surface
- 10.8m/h
- Spawning depth 100m

Nemuro Strait

- Cold water ca. 100m
- blastula stage
- 21 hrs to the surface
- 9.6m/h
- Spawning depth 300m
Two water column and the temperature controlling system. The column were surrounded by two water tanks, which contained circulating, temperature-controlled water.
Results

Fig. 3. [control experiment] Larvae have difficulty swimming probably due to the large yolk sac. While some larvae occurred in the mid and bottom of the water column, most occurred near the surface.

Fig. 4. Larvae occurred near the surface above warmer water.

Fig. 5. Some larvae occurred in the warm water and under the warm water, presumably larvae avoided the warm water.

Fig. 10. Extremely warm water occurred over cold water, larvae avoided the warm and cold water, and selected near the thermocline.

larvae≤1 day old showed less vertical change than older larvae

larvae≤15 days old avoided warm and cold water, and selected near the thermocline
Fig. 6. [control experiment] Swimming ability developed, and yolk sac become smaller. Larvae occurred throughout the water column.

Fig. 7. Most larvae occurred in the upper layer and a few larvae occurred in the cold lower layer.

Fig. 8. Most larvae occurred in the lower layer and a few larvae occurred in the cold upper layer.

Fig. 9. Larvae avoided warm water in upper layer by descending to cooler temperatures.

larvae≥4 days old altered their depth to stay a favorable temperature
Summary (Walleye pollock)

Temperature is the critical factor for hatching rather than salinity.

Eggs normally hatch at temp $\geq 2^\circ$C

Eggs probably reach to the unfavorable cold water at

- morula stage (●) in the Funka Bay
- blastula stage (●) in the Nemuro Strait

Egg can hatch normal if they underwent the cold temperature at their late developmental stage

The developmental stages reaching to the cold water probably affect the success of the hatching.

As the yolk was absorbed, the larvae were able to alter their position in the water column, which allowed them to select favorable temperatures.