The following supplement accompanies the article

Spatial variation in potential and realized growth of juvenile Pacific cod in the southeastern Bering Sea

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Supplement. Model parameters used in bioenergetics model of age-0 Pacific cod.

Parameterization of the growth model

We used a "Wisconsin type" bioenergetic model (Hewett and Johnson, 1992) to describe the growth of juvenile Pacific cod. The model predicts growth (G) as the difference between consumption (C) and metabolic demand after accounting for losses of energy to waste production (F), excretion (U), and specific dynamic action (D_S):

$G = C – (R + D_S + F + U)$ (S1)

Values for F, U, D_S were taken from a walleye pollock model described by Cianelli et al. (1998). Respiration and consumption are found from allometric relationships with fish size and adjusted for temperature as shown below.

$R = AM (A_R W^{B_R}) f_R(T)$ (S2)

W is the fish weight, A_R and B_R are respectively the allometric intercept and slope, AM is an adjustment for metabolic activity and $f_R(T)$ is the temperature adjustment. The allometry for consumption follows a similar form:

$C = P (A_C W^{B_C}) f_C(T)$ (S3)

where A_C and B_C are respectively the allometric intercept and slope, P is the consumed fraction of maximum consumption and $f_C(T)$ is the temperature adjustment.

The allometric relationships for respiration and consumption have not been previously reported for cod, but data describing growth (Laurel et al. 2016) and respiration (Oh et al. 2010) responses to temperature do exist. We used these responses to estimate the parameter values for the respiration and consumption rate allometries using least squares minimization. Values for the respiration rate parameters were estimated by minimizing:

$Min = \sum(A_R W^{B_R} \cdot f_R(T) – M_T)^2$ (S4)

Oh et al. (2010) described the functional response of respiration to temperature as

$M_T = (-1.04 \cdot 10^{-5} \cdot T^2) + (3.38 \cdot 10^{-4} \cdot T) - 1.02 \times 10^{-3}$ (S5)

where T is temperature between 4 and 16 °C. Setting the derivative of equation (S5) equal to zero produces the temperature at which metabolic rate is maximized (T_{RM}). In equation (S2) $f_R(T)$ scales the allometric respiration rates to the rate observed at T_{RM} to account for temperature affects. It was found by fitting (M_T / M_{TRM}) to a second order polynomial over a range of temperatures. For juvenile cod $f_R(T)$ was found to be:

$f_R(T) = (-0.006 \cdot T^2) + (0.1954 \cdot T) – 0.5883$ (S6)

The values of A_R and B_R were used to estimate the consumption allometry by substituting them into the growth model and minimizing

$$Min = \sum (((A_C W^{B_C} f_C(T) - F - U) - (A_R W^{B_R} f_R(T) + D_S)) - G_T)^2 \quad (S7).$$

Laurel et al. (2016) provides the growth rate (% wet mass per day) of a cod weighing ~ 6.8 g at temperature T as:

$$G_T = (0.2494 + (0.3216 \cdot T) + (-0.0069 \cdot T^2) - (0.0004 \cdot T^3)) \quad (S8)$$

The function for adjusting consumption to account for temperature, $f_C(T)$, was estimated by predicting the energy consumed by a 6.8 g fish over a range of temperatures and fitting scaled values of the predicted consumption to a second order polynomial with temperature as the predictor. The energy consumed by cod in the Laurel et al. (2016) study was estimated by summing the energy produced as tissue (growth) and the amount of energy respired using the following:

$$C_T = [(G_T \cdot ED_C \cdot W) + (A_R W^{B_R} \cdot f_r(T) O)] \quad (S9)$$

where ED_c is the energy density (4300 J · g wet mass^{-1}) of cod, W is cod weight (6.8 g) and O is the calorific equivalent for oxygen consumption (13.560 joules per mg O_2). The values of C_T and their corresponding temperatures were fit to a second order polynomial. The derivative of the resulting function was set to zero to find the temperature at which consumption is maximized (T_{CM}). Values of (C_T/C_{TCM}) were fit to T using a second order polynomial to find the scaling function $f_C(T)$.

$$f_C(T) = -0.1424 + 0.1859T - 0.0076T^2 \quad (S10)$$

LITERATURE CITED

Cianelli L, Brodeur RD, Buckley, TW (1998) Development and application of a bioenergetics model for juvenile walleye pollock. J Fish Biol 52: 879-898

Hewett SW, Johnson BL (1992) Fish bioenergetics model 2: An upgrade of 'A generalized bioenergetics model of fish growth for microcomputers'. University of Wisconsin Sea Grant Tech Rep WIS-SG-92-250, University of Wisconsin, Madison, WI

Laurel BJ, Spencer M, Iseri P, Copeman LA (2016) Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids. Polar Biol 39:1127-1135

Oh SY, Park HS, Kim CK (2010) Effect of water temperature and photoperiod on the oxygen consumption rate of juvenile Pacific cod *Gadus macrocephalus*. Ocean Polar Res 32:229-236

Table S1. Parameters used in bioenergetics model of age-0 Pacific cod.

Parameter	Description	Value
Consumption parameters		
A_C	Intercept of consumption allometry	0.063
B_C	Slope of consumption allometry	-0.070
$f_C(T)$	Temperature dependent consumption function	$-0.1424 + 0.1859T - 0.0076T^2$
P	Relative foraging rate	1.0
Respiration parameters		
A_R	Intercept of respiration allometry	0.003
B_R	Slope of respiration allometry	-0.291
$f_R(T)$	Temperature dependent respiration function	$-0.5885 + 0.1955T - 0.006T^2$
D_S	Proportion of energy lost to SDA	0.12
AM	Activity multiplier for respiration	1.0
Waste parameters		
F	Egested proportion of consumed energy	0.15
U	Excreted proportion of consumed energy	0.11