Diel Energy Consumption and Food Requirements by Juvenile Sockeye Salmon during Their Fall Migration in the Okhotsk Sea

Maxim V. Koval

Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO),
18, Naberezhnaya Street, Petropavlovsk-Kamchatsky 683602, Russia

Keywords: Energy, consumption, energy expenditure, metabolism, activity coefficient, daily ration, total consumed energy, balance equation, growth, food requirements

During fall, migrating Pacific salmon juveniles live in marine waters near their natal river (Birman 2004). In Contrast to later periods in their marine life, during their fall migration, since hydrological characteristics are relatively stable, mortality is not high (Karpenko 1998). Consequently, during the fall migration, numbers of fish per generation in proportional to numbers later in salmons marine life (Erokhin 2002). Thus, the principle role of the fall migration in the life cycle of Pacific salmon is their rapid growth and accumulation of energy resources, required later during wintering.

Since 1981 KamchatNIRO has conducted trawling researchers to study the biology of Pacific salmon juveniles during their fall migration in the waters adjacent to Kamchatka (September–October). These long-term studies demonstrated that during the migration from the coast of Kamchatka to offshore waters of the Okhotsk Sea, the daily growth and caloric content of juvenile pink salmon (*Oncorhynchus gorbuscha*) increased (Yerokhin and Shershneva 2000; Erokhin 2002; Erokhin and Shershneva 2007). This was found to be caused by the following reasons: with the distance from the coast of Kamchatka the summary biomass of macroplankton increases, consequently food supplies of plankton-eating species improved (Table 1); the intensity of feeding and the daily rations of juvenile pink salmon increased; the total caloric value of fish rations and surface water temperature increased; and the diel dynamics of juvenile salmon activity and feeding changed. As a result of differences in diel energy consumption and expenditure by juvenile salmon in different areas of the Okhotsk Sea, differences in their diel growth rates and energy accumulation occurs.

As known, most juvenile sockeye salmon (*O. nerka*) in the Okhotsk Sea inhabit the shelf over the south-west coast of Kamchatka. Thus, sockeye migrations westward are limited mostly within 150-mile coastal zone (Erokhin 1998; Birman 2004). At the same time, some sockeye salmon can also be found outside the shelf in the offshore waters of the Okhotsk Sea. Therefore, the offshore waters of the Okhotsk Sea also play some role in the fall migration of this species.

We determined the diel dynamics of food energy consumption and expenditure by juvenile sockeye salmon in different areas of the Okhotsk Sea. For our calculation we use by following parameters: weight and caloric content of fishes and their prey items; temperature; estimated standard metabolism indices; generalized diel fish activity dynamics (determinated by information of diel feeding rhythm); and data on the ratio between sockeye salmon metabolism rates under different activities and the standard metabolism (Hoar et al. 1979).

Energy consumption for sockeye salmon in the different areas of the Okhotsk Sea were estimated based on the daily ration value and caloric content of prey items (Shershneva and Koval 2005). Total energy value of daily rations by juvenile sockeye salmon were 1.150 kcal/g (11.270 kcal/ind by wet weight) in the coastal waters and 1.270 kcal/g (15.113 kcal/ind by wet weight) in offshore waters (Table 1).

The energy expended by juvenile sockeye salmon for the total metabolism (Q, kcal/ind per day) was calculated from the equation:

$$Q = \sum_{j=1}^{24} a_i (0.36 \cdot W^{0.78} \cdot 4.8/q) \cdot 10^{-3} \qquad (1)$$

where a = the "activity coefficient" or the ratio between metabolism for different types of activity and sockeye salmon standard metabolism (Hoar et al. 1979); 0.36 = the amount of oxygen consumed by sockeye per a unit of weight, ml O_2/g of wet weight per hour (Brett 1965) ; W = the weight of fish (g); 0.78 = an index determining the speed of metabolism rate transformation in the course of sockeye salmon weight growth; 4.8 = the oxycalorie coefficient (cal); q = temperature correction to make the meaning of standard metabolism answering to a certain temperature according to the "normal curve" by Krogh.

Diel energy expended by sockeye salmon for the total metabolism calculated from equation (1) are 4.250 kcal/ind. for 140 g fish (i.e. from coastal waters) and 5.800 kcal/ind. for 170 g fishes(i.e. from offshore waters). In both cases expenditures use about 40% of total energy values of daily ration (C).

All correspondence should be addressed to M. Koval.
e-mail: koval@kamniro.ru.

Table 1. The basic biological, chemical and energy indices of pink and sockeye salmon juveniles and environmental characteristics in the different areas of the Okhotsk Sea during the fall migration.

Characteristics	Coastal waters		Offshore waters	
	*Pink	Sockeye	*Pink	Sockeye
Biological and chemical indices of fish (by wet weight)				
Avg. weight, g	96.1~100.0	137.1~140.0	108.7~110.0	170.5~170.0
Avg. content of lipids, %	4.4	6.2	4.8	2.6
Avg. content of protein, %	13.2	12.4	14.2	24.1
Avg. content of water, %	79.4	79.0	78.1	68.6
Avg. content of ash, %	2.9	2.4	2.9	4.6
Min–Max daily ration, % by fish weight	5.9–9.4	6.0–7.7	8.0–13.2	7.0–7.0
Avg. daily ration, g	7.569	9.800	10.016	11.900
Avg. daily growth, % by fish weight	2.3	1.8	3.5	2.0
Avg. daily growth, g	2.280	2.520	3.358	3.400
Energy indices of fish (by wet weight)				
Avg. calorie content, kcal/g	1.084	1.290	1.186	1.608
Avg. calorie content of food, kcal/g	1.083	1.150	1.122	1.270
Total energy value of daily ration (*C*), kcal/ind	8.197	11.270	11.238	15.113
Total consumed energy (*Q* + *P*), kcal/ind	6.558	9.016	8.990	12.090
Energy expended for the total metabolism (*Q*), kcal/ind	4.230	4.250	5.107	5.800
Energy expended for the total metabolism (Q), % by total energy value of daily ration	51.6	37.7	45.4	38.4
Energy expended for the growth (*P*), kcal/ind	2.328	4.766	3.884	6.290
Energy expended for the growth (*P*), % by total energy value of daily ration	28.4	42.3	34.6	41.6
Avg. "activity coefficient" (*a*)	6.4	7.6	6.1	6.8
Environmental characteristics				
Avg. water temperature, °C		8.0	10.0	
**Avg. biomass of makroplankton (layer 0–50 m), mg/m^3		949.0	2963.5	

*Basis of data by V. G. Erokhin (2007)

**Data for September 1999

According to the balance equation (Winberg 1956; Shulman and Love 1999):

$C = 1.25\ (Q + P)$ (2)

the total energy expended by juvenile sockeye salmon for growth (P) is 4.766 kcal/ind per day in coastal waters and 6.290 kcal/ind per day in offshore waters.

Analysis of sockeye salmon energy expenditure for 24 hours has indicated that during periods of maximum feeding activity in coastal waters (day time), energy expended by fishes can increase to 0.250 kcal/ind per hour and in the offshore waters (in the morning and evening), to 0.370 kcal/ind per hour (Fig. 1). In periods of minimal night activity, expenditure decreased to 0.040 and 0.060 kcal/ind per hour, respectively. Thus, in the coastal waters of West Kamchatka average value of diel energy expended by sockeye salmon for the total metabolism is 7.6 times higher then to the standard metabolism, and in the offshore waters of the Okhotsk Sea, it is 6.8 times higher (Table 1).

As shown, in waters adjacent to Kamchatka, the portion of energy expended by fishes for their total metabolism is higher and energy required for their growth is lower, compared with fish in offshore waters of the Okhotsk Sea. Moreover, sockeye salmon (like pink salmon) is mainly a plankton-eater, so it seems logical that the food supply for sockeye is better in the offshore waters of the Okhotsk Sea. Despite this fact, the fall migrations of most juvenile sockeye salmon occurs in the West Kamchatka shelf waters. It is known that sockeye salmon are more cold-resistant than other Pacific salmon. Brett (1971) demonstrated that effective food conversion by sockeye salmon was possible only in environments with lower temperature ranges than for pink salmon. Therefore, during migration in the Okhotsk Sea, juvenile sockeye salmon inhabit coastal waters of Kamchatka where water temperature are optimal for this species.

On the basis of the balanced equation (2) we calculated the diel food requirements of juvenile sockeye salmon during their fall migration. As follows from Fig. 2, at a daily ration of less than 3.5% (by fish weight), fish growth does not occur, as all the total consumed energy is expended for metabolism. Thus, the ration 3.5% is a "supporting ration". At a daily ration of 6.5%, approximately equivalent energy is expended for total metabolism and growth. With increases of daily ration more then 7%, the part of the total assimilated energy expended for metabolism is reduced, and the part of energy expended for the growth increases. Pleas note, for our studies, juvenile sockeye salmon daily rations more then 8% were not registered (Table 1). Thus, the ration 6–8% is an "optimal daily ration" for juvenile sockeye salmon and which is generally observed during the fall migration in the Okhotsk Sea.

Fig. 1. Diel dynamics of energy expended by juvenile sockeye salmon for the total metabolism in the coastal (A) and offshore (B) waters during the fall migration in the Okhotsk Sea.

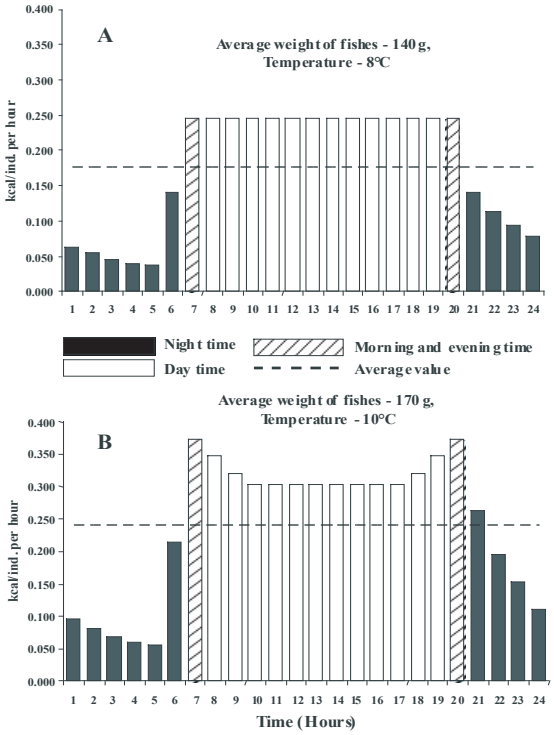
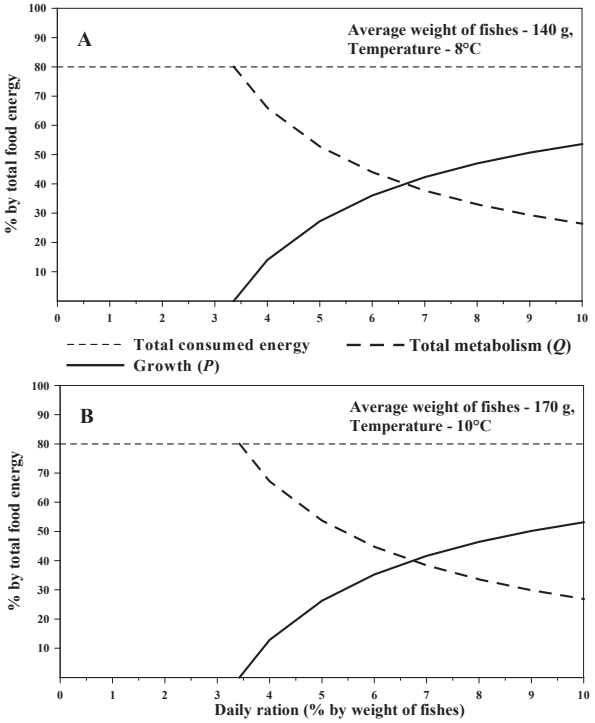


Fig. 2. Rate of total food energy expended by juvenile sockeye salmon for the total metabolism and growth with different daily rations in the coastal (A) and offshore (B) waters in the Okhotsk Sea.



REFERENCES

Birman, I.B. 2004. Marine period of life and matters of stock dynamics of Pacific salmon second edition, supplemented. FGUP Natsionalnye Rybnye Resursy, Moscow.

Brett, J.R. 1965. The relation of size to rate of oxygen consumption and sustained swimming speed of sockeye salmon (*Oncorhynchus nerka*). Fish. Res. Board Can. 22: 1491–1501.

Brett, J.R. 1971. Energetic response of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). Am. Zool. 11: 99–113.

Erokhin,V.G. 1998. Distribution and biological characteristics of juvenile sockeye salmon *Oncorhynchus nerka* (Walbaum) (Salmonidae) in the east of the Sea of Okhotsk. Research of biology and stock dynamics of commercial fishes in the Kamchatka shelf. Vol. 4. KamchatNIRO Publishing, Petropavlovsk-Kamchatsky. pp. 124–130. (In Russian).

Erokhin, V.G. 2002. The biology of Pacific salmon juveniles in the Kamchatkan waters of the Okhotsk Sea. Ph. D. thesis, Russia. KamchatNIRO Publishing, Petropavlovsk-Kamchatsky. (In Russian).

Erokhin, V.G., and V.I. Shershneva 2007. Energy consumption and expenditure of juvenile salmon during post-catadromous feeding migrations in the Okhotsk Sea. N. Pac. Anadr. Fish Comm. Tech Rep. 7: 124–127.

Hoar, W.S., D.J. Randall, and J.R. Brett. 1979. Bioenergetics and growth. Fish Physiol. Vol. 8.

Karpenko, V.I. 1998. The early sea life of Pacific salmons. VNIRO Publishing, Moscow. (In Russian).

Shershneva, V.I., and M.V. Koval. 2005. Calorie content mass zooplankton and ichthyoplankton species of the Kamchatka waters. Izv. TINRO 139: 349–369. (In Russian).

Shulman, G.E., and R.M. Love. 1999. The biochemical ecology of marine fishes. Adv. Mar. Biol. Vol. 36.

Winberg, G.G. 1956. Rate of metabolism and food requirements of fishes. Fish. Res. Board Can. Transl. Series 194.

Yerokhin V.G. and V.I. Shershneva. 2000. Feeding and energy characteristics of juvenile pink salmon during fall marine migrations. N. Pac. Anadr. Fish Comm. Bull. 2: 123–130.