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Biochemical Composition and Energy Content of Salmonid Fish in the Sea of Okhotsk

by

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Abstract

The main bioenergetic parameters of Pacific salmon are estimated in this study. Juvenile salmon demonstrate maximum fat accumulation rates at the end of feeding migrations in the Sea of Okhotsk in October-November. That makes possible its successful overwintering in the Pacific Ocean. In the Sea of Okhotsk, juvenile pink salmon gain 532 kcal or 27% of the total amount of energy accumulated during marine life period before returning to the sea basin. In the north-western Pacific Ocean, pink salmon, without ranking by sex, gain 1442 kcal in average or 73% of the total accumulated energy for that period. Juvenile chum salmon gain 492 kcal in the Sea of Okhotsk that is 11% of the total energy accumulated during marine life period. Mature chum without ranking by age and sex gain 4,071 kcal in the northwestern Pacific Ocean in average, or 89% of the total accumulated energy in marine life period.

Key words: Okhotsk Sea, Pacific salmon, energy content, lipids, proteins, carbohydrates.

Introduction

Caloric content of fish body mainly depends on its physiological status during the life cycle. One of the most effective methods of fish physiological study is investigation of the deposit fat dynamics in relation to the biological status of fish. According to literature, fish families are quite distinct by distribution of total deposited lipids between organs and tissues (Kiesewetter 1971). For salmonids, accumulation of deposited lipids is more typical in muscle tissue and subcutaneous fat layer (Kiesewetter 1971, Shulman 1972, Shatunovsky 1980, Sidorov 1983).

Energy content gained by Pacific salmon in ontogenesis defines their survival rate and general success of life history (Radchenko 2012). Comprehensive database on dynamics of biochemical composition and caloric value of salmon body at different life cycle stages, especially at the point of "critical periods" (Beamish & Mahnken 2001) including wintering, is necessary to more accurately determine the relationship between bioenergetic parameters and the rates of natural mortality of Pacific salmon at sea.

The main goal of this research is to analyze the dynamics of the biochemical composition of salmon body during ontogenesis based on the caloric content of salmon migrating in the Sea of Okhotsk.

Material and Methods

Pacific salmon body energetic content were studied in the Sea of Okhotsk in 2003–2015. No significant differences were observed in the chemical composition and caloric content of salmon muscles for males and females (Gorbatenko et al. 2008). Therefore, the data presented below were averaged by sex. We paid a special attention to lipid content since salmon actively use lipids during pre-spawn migrations, when salmon foraging almost stop or, at least, significantly decreased (Sidorov 1983).

Biochemical composition of salmon body was studied to evaluate its caloric content in the Sea of Okhotsk. The sampling map applied in the integrated TINRO-Center expeditions is shown on Figure 1. For fish species, a piece of muscle tissues weighing from above 20 to 30 g was taken from the dorsal musculature behind the head (for mature salmon, also gonads). Samples were stored in a sealed bag at a temperature below −18° C. For each fish specimen, data records included a species, length, sex, maturity stage, coordinates of the sample collection site (latitude and longitude), and stomach contents.

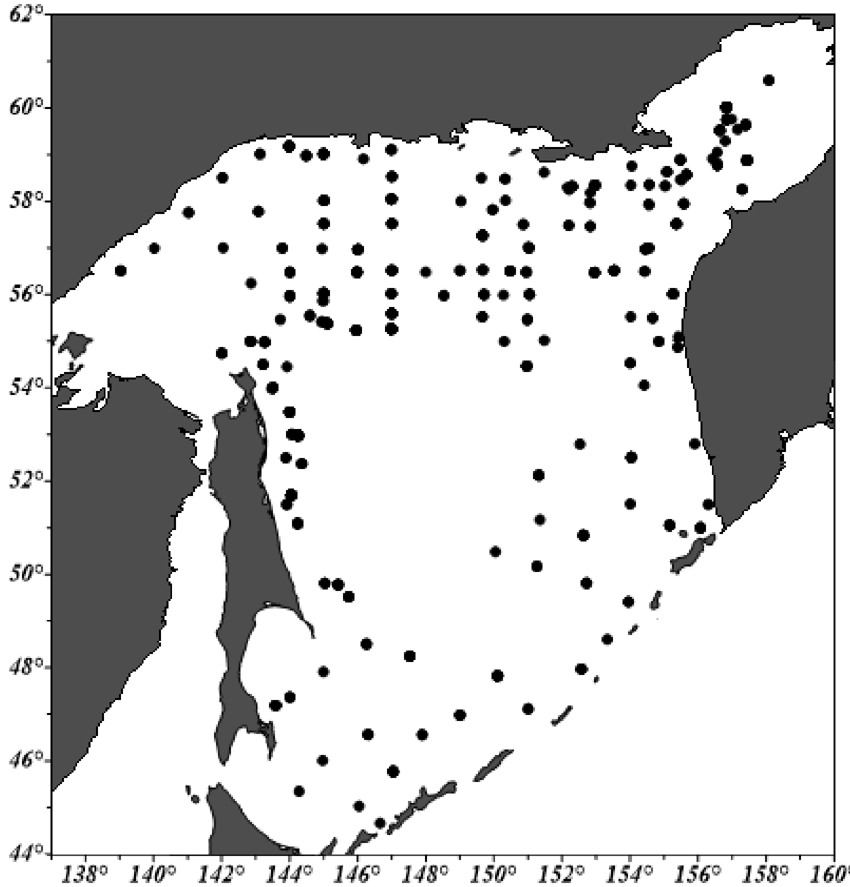

Figure 1. Sampling map for biochemical analysis of fish species in 2003-2015.

The energy content of hydrobionts was evaluated by determining the total content of proteins, lipids, carbohydrates, ash, and moisture. Such a biochemical composition study makes it possible to identify the specific biochemical specificity of different aquatic species at various stages of the life cycle (Kiesewetter 1971).

Weight ratio of water and ash was estimated by standard methods (Zhuravskaya et al. 1985). The Kjeldahl method of nitrogen analysis to calculating the protein content was applied using the nitrogen analyzer “Kjeltec 2300” (Japan). Carbohydrates content was determined photocolorimetrically using an anthrone reagent (Krylova & Lyaskovskaya 1965). Estimation of total lipid amount in a sample was performed by gravimetry after the Folch extraction (Folch et al. 1957).

Caloric value (cal/g) was calculated for nekton species in terms of wet and dry matter as well as the energy equivalent that is needed to compare our data with results of other studies and for quantitative estimation of energy flux at different trophic levels. The energy equivalent is the product of the fish body weight (g) per caloric value (cal/g).

Results and Discussion

Summary data on biochemical composition of Pacific salmon body are presented in Tables 1 and 2. Notable differences in biological and ecological status of studied species contribute to the fact that their biochemical indices vary widely.

The content of dry matter in salmon muscle tissues varies in the range from 22.7 to 31.6% (Table 1). The ash content in dry matter ranged from 2.2% to 8.8%.

Table 1

Biochemical composition and caloric content of dry matter of muscular tissue of salmonid fish in the Sea of Okhotsk

Species	Biological status, fork length	dry matter, %	proteins, % of dry matter	lipids, % of dry matter	carbohydrates, % of dry matter	ash,% of dry matter	caloric content of dry matter*, cal/g	number of samples
Oncorhynchus gorbuscha	juvenile (10-20 cm)	22.9	83.4	6.1	3.4	7.4	5426	8
Oncorhynchus gorbuscha	juvenile (20-30 cm)	25.1	77.7	12.4	3.3	6.8	5692	20
Oncorhynchus gorbuscha	maturing (stages III, III-IV)	25.0	81.8	12.8	2.7	2.8	5943	31
Oncorhynchus gorbuscha	maturing (stage IV)	24.0	86.3	7.5	2.9	3.3	5704	2
Oncorhynchus keta	juvenile (10-20 cm)	22.3	86.6	4.7	2.5	6.2	5440	2
Oncorhynchus keta	juvenile (20-30 cm)	25.3	78.4	11.8	2.9	7.1	5667	14
Oncorhynchus keta	immature (35-55 cm)	26.7	77.5	15.7	2.5	4.5	5970	13
Oncorhynchus keta	maturing (stages II-III, III, III-IV)	26.4	79.2	16.7	1.7	2.7	6118	28
Oncorhynchus keta	maturing (stage IV)	25.7	85.4	7.6	1.6	5.4	5605	11
Oncorhynchus kisutch	juvenile (20-30 cm)	25.2	84.3	9.6	1.6	4.5	5740	2
Oncorhynchus kisutch	immature (30-40 cm)	25.8	81.7	13.2	2.3	2.8	5955	2
Oncorhynchus kisutch	maturing (stages III, III-IV)	27.1	80.3	15.5	2.1	2.2	6085	2
Oncorhynchus kisutch	maturing (stage IV)	25.9	81.9	10.0	1.2	6.9	5621	2
Oncorhynchus masou	juvenile (20-30 cm)	24.5	89.3	6.3	2.5	1.9	5746	2
Oncorhynchus masou	immature (30-40 cm)	25.3	78.7	13.2	2.8	5.4	5803	5
Oncorhynchus nerka	juvenile (10-20 cm)	23.2	90.6	3.0	2.2	4.2	5493	2
Oncorhynchus nerka	juvenile (20-30 cm)	23.8	84.7	7.5	3.1	5.0	5625	3
Oncorhynchus nerka	immature (30-40 cm)	27.2	74.9	13.9	2.6	8.8	5653	2
Oncorhynchus nerka	immature (50-60 cm)	27.1	76.4	18.1	2.2	3.4	6113	2
Oncorhynchus nerka	maturing (stages III, III-IV)	27.0	75.6	20.0	1.1	3.3	6204	4
Oncorhynchus tschawytscha	juvenile (10-20 cm)	22.7	90.1	3.4	1.1	5.7	5458	2
Oncorhynchus tschawytscha	juvenile (20-30 cm)	23.6	86.9	7.6	4.0	1.7	5794	4
Oncorhynchus tschawytscha	immature (30-40 cm)	25.8	79.1	16.3	0.8	3.9	6038	2
Oncorhynchus tschawytscha	immature (50-60 cm)	27.2	75.4	19.1	2.9	2.6	6185	2
Oncorhynchus tschawytscha	immature (60-82 cm)	31.6	65.0	28.4	3.2	3.5	6484	3
Salvelinus malma	30-40 cm	26.4	78.8	14.6	4.5	2.2	6022	2

*- average caloric content of the whole body

Average lipid content in dry matter of salmon body varied by almost an order of magnitude. The minimum lipid content in dry muscle tissue was observed in juvenile sockeye salmon (0-20 cm) – 3.0% and juvenile Chinook salmon (10-20 cm) – 3.4%. Maximum amount of lipids contained in larger immature Chinook salmon - 28.4% (Table 1). In general, few groups of juvenile salmon have less than 10% of lipids in the dry muscle that might be related to their intensive growth. The protein content in dry salmon muscle varied from 65.0% (immature Chinook salmon of 60-82 cm) to 90.6% (sockeye salmon of 10-20 cm) (Table 1).

Caloric content in dry muscle varied in relatively narrow limits – from 5426 to 6484 cal/g (Table 1). Maximum caloric content (more than 6000 cal/g) was recorded in larger chum, sockeye, coho, Chinook salmon, and Dolly Varden trout.

Data on biochemical composition and caloric content caloric content of wet weight (Table 2) enable direct transfer of biomass into calories that is necessary for determining the energy supply of individual fish and stocks. The protein content of wet muscle weight of salmonid species varied from 19.1% to 21.9%, lipids – from 0.7% to 9.0%, carbohydrates – from 0.2% to 1.2%.

Table 2

Biochemical composition and caloric content of wet muscular tissue of salmonid fish in the Sea of Okhotsk

ВИД	Подгруппа, длина, см	water, %	proteins, % of wet matter	lipids, % of wet matter	carbohydrates, % of wet matter	ash,% of wet matter	caloric content of wet matter*, cal/g	number of samples
Oncorhynchus gorbuscha	juvenile (10-20 cm)	77.1	19.1	1.4	0.8	1.7	1255	8
Oncorhynchus gorbuscha	juvenile (20-30 cm)	74.9	19.5	3.1	0.8	1.7	1439	20
Oncorhynchus gorbuscha	maturing (stages III, III-IV)	75.0	20.5	3.2	0.7	0.7	1499	31
Oncorhynchus gorbuscha	maturing (stage IV)	76.0	20.7	1.8	0.7	0.8	1379	2
Oncorhynchus keta	juvenile (10-20 cm)	77.7	19.3	1.1	0.6	1.4	1223	2
Oncorhynchus keta	juvenile (20-30 cm)	74.7	19.9	3.0	0.7	1.8	1448	14
Oncorhynchus keta	immature (35-55 cm)	73.3	20.7	4.2	0.7	1.2	1604	13
Oncorhynchus keta	maturing (stages II-III, III, III-IV)	73.6	20.9	4.4	0.5	0.7	1622	28
Oncorhynchus keta	maturing (stage IV)	74.3	21.9	1.9	0.4	1.4	1444	11
Oncorhynchus kisutch	juvenile (20-30 cm)	74.8	21.3	2.4	0.4	1.1	1455	2
Oncorhynchus kisutch	immature (30-40 cm)	74.2	21.1	3.4	0.6	0.7	1547	2
Oncorhynchus kisutch	maturing (stages III, III-IV)	72.9	21.8	4.2	0.6	0.6	1658	2
Oncorhynchus kisutch	maturing (stage IV)	74.1	21.2	2.6	0.3	1.8	1460	2
Oncorhynchus masou	juvenile (20-30 cm)	75.5	21.9	1.5	0.6	0.5	1416	2
Oncorhynchus masou	immature (30-40 cm)	74.7	19.9	3.3	0.7	1.4	1480	5
Oncorhynchus nerka	juvenile (10-20 cm)	76.8	21.0	0.7	0.5	1.0	1282	2
Oncorhynchus nerka	juvenile (20-30 cm)	76.2	20.2	1.8	0.7	1.2	1353	3
Oncorhynchus nerka	immature (30-40 cm)	72.8	20.4	3.8	0.7	2.4	1551	2
Oncorhynchus nerka	immature (50-60 cm)	72.9	20.7	4.9	0.6	0.9	1667	2
Oncorhynchus nerka	maturing (stages III, III-IV)	73.0	20.4	5.4	0.3	0.9	1680	4
Oncorhynchus tschawytscha	juvenile (10-20 cm)	77.3	20.5	0.8	0.3	1.3	1245	2
Oncorhynchus tschawytscha	juvenile (20-30 cm)	76.4	20.5	1.8	1.0	0.4	1382	4
Oncorhynchus tschawytscha	immature (30-40 cm)	74.2	20.4	4.2	0.2	1.0	1561	2
Oncorhynchus tschawytscha	immature (50-60 cm)	72.8	20.5	5.2	0.8	0.7	1695	2
Oncorhynchus tschawytscha	immature (60-82 cm)	68.4	20.5	9.0	1.0	1.1	2062	3
Salvelinus malma	30-40 cm	73.6	20.8	3.9	1.2	0.6	1608	2

*- average caloric content of the whole body

The energy content in muscle tissues ranged from 1223 cal/g in juvenile chum salmon to 2,062 cal/g in larger immature Chinook (wet weight, Table 2). In general, the caloric content of the wet weight, as well as in the dry muscle, was largely determined by the percentage of lipids in the muscle tissue and by the total body weight.

The energy content in marine hydrobionts in the far-eastern seas and the northwestern Pacific Ocean was determined in a number of previous studies (Kiesewetter 1971, Shershneva 1991, Shershneva & Koval 2004, Davis et al. 1998, Gorbatenko et al. 2007, 2008). Salmonid fish have distinct taxonomic traits, when comparing them as a whole group to other fish families. Particularly, salmonid fish accumulate more lipids in muscles and caviar (Sidorov 1983). In Pacific salmon, 45-55% of the total lipid reserves are deposited in muscles. During pre-spawning period, up to 15-20% of total lipid reserves are deposited in the mature ovaries of salmonids and the ovary mass reaches 20-25% of the total fish biomass (Kiesewetter 1971).

Pink salmon have the shortest life span among Pacific salmon species. Juvenile pink salmon migrate downstream in May-June at body length of 3-4 cm and weight of 0.2-0.3 g, and by the end of next summer, average pink salmon specimen grow till average length of 46-50 cm and body weight of 1300-1650 g (Heard 1991, Shuntov 1994).

After entering marine environment, an average body length of pink salmon increases to 10.3 cm by August, doubles in September – up to 21.8 cm, and reaches 25.0 cm at late October while average body weight reaches 218 g (Gorbatenko et al. 2008). Dry matter content in salmon body also increases with growth – from 22.9% to 25.1% (Table 1). Pink salmon body energy content also increases with gaining high-energy matters: fat – from 1.4% to 4.4%, proteins – from 16.0% to 18.7% of the wet weight (Table 2, Figure 2). The caloric content of the wet weight increased from 1255 to 1439 cal/g from August to October, dry matter – from 5426 to 5692 cal/g.

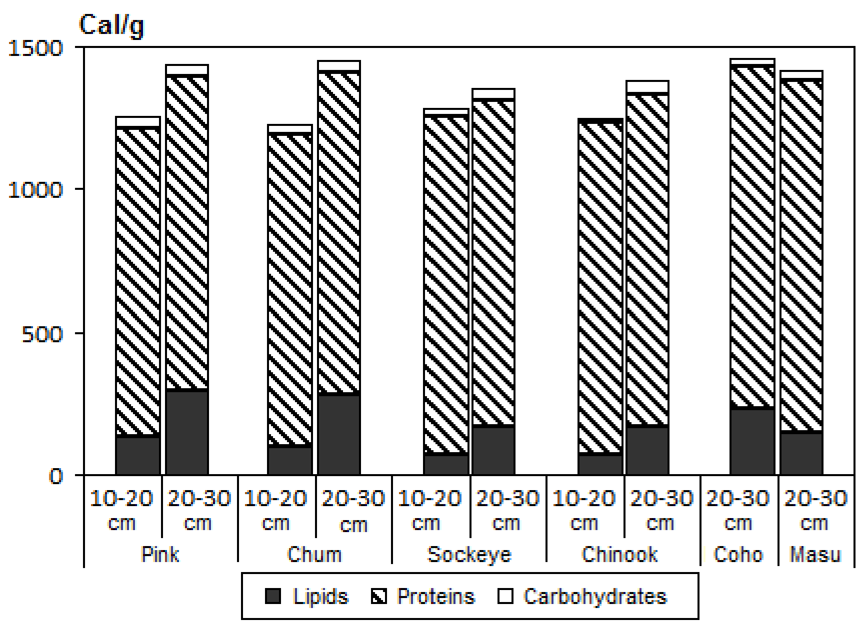

Figure 2. Biochemical composition and caloric content of wet muscular tissue of juvenile Pacific salmon in the Sea of Okhotsk

As well as pink salmon, chum salmon fry begin migrating downstream in spring–summer soon after emerging from the gravel spawning beds. In August, chum juveniles had an average body length of 16.2 cm and weight of 43 g. By late October, they grew up to 24.9 cm and 158 g (Table 3).

Table 3

Average size and weight of Pacific salmon in the Sea of Okhotsk by selected groups

Time of sampling	Species of *Oncorhynchus*	Maturity	Size group, cm	Stage of gonad maturity	Average fork length, cm	Average weight, g
August	O. gorbuscha	juvenile	10-20 cm	Juv	16.7	48
October	O. gorbuscha	juvenile	20-30 cm	Juv	25.3	171
November	O. gorbuscha	juvenile	20-30 cm	Juv	28.8	370
June-August	O. gorbuscha	maturing	40-50 cm	III, III-IV	45.8	1 264
June-August	O. gorbuscha	maturing	40-50 cm	IV	45.6	1 319
August	O. keta	juvenile	10-20 cm	Juv	16.2	43
October	O. keta	juvenile	20-30 cm	Juv	24.9	158
November	O. keta	juvenile	20-30 cm	Juv	27.0	340
June-August	O. keta	immature	>50 cm	II	58.9	2 741
June-August	O. keta	maturing	>50 cm	III, III-IV	57.3	2 514
August-October	O. keta	maturing	>50 cm	IV	60.8	2 835
October	O. kisutch	juvenile	20-30 cm	Juv	29.8	370
September-October	O. kisutch	immature	30-40 cm	II	37.7	719
August-September	O. kisutch	maturing	>50 cm	III, III-IV	62.0	3 205
August-September	O. kisutch	maturing	>50 cm	IV	64.8	3 496
October	O. masou	juvenile	20-30 cm	Juv	26.4	255
October-November	O. masou	immature	30-40 cm	II	34.8	578
September	O. nerka	juvenile	10-20 cm	Juv	18.8	68
October	O. nerka	juvenile	20-30 cm	Juv	24.8	219
August	O. nerka	immature	30-40 cm	II	38.4	688
August	O. nerka	immature	>50 cm	II	57.6	2 704
July-August	O. nerka	maturing	>50 cm	III, III-IV	58.0	2 920
August	O. tschawytscha	juvenile	10-20 cm	Juv	19.6	95
October	O. tschawytscha	juvenile	20-30 cm	Juv	26.9	262
June-August	O. tschawytscha	immature	35-50 cm	II	43.9	1 018
June-August	O. tschawytscha	immature	50-60 cm	II	59.2	2 701
October-December	O. tschawytscha	immature	60-82 cm	II	72.1	5 652

Dynamics of biochemical composition of juvenile chum and pink salmon bodies demonstrates a common pattern (Figure 3). Intensity of fat accumulation, protein synthesis, and increase in mineral substances content are associated with an increase in salmon body weight. High level of deposited lipids in the juvenile pink and chum salmon in the Sea of Okhotsk in June-October is likely due to a good food supply and favorable temperature regime (Shuntov & Temnykh 2008). Juvenile sockeye, coho, and masu salmon demonstrate lower energy accumulation rate in the Sea of Okhotsk (Figure 2).

As for larger Pacific salmon, their physiological status (degree of the gonad maturity, Table 4-5) and body size (Figure 3) mainly determine an energy content of their bodies.

Data on salmon weight (Table 5), the caloric content of wet muscle (Table 2) and gonad in chum and pink salmon (Table 4) made it possible to calculate an energy equivalent of their body weight and estimate dynamics of the energy accumulation process in the dominant Pacific salmon species during the life cycle (Table 6).

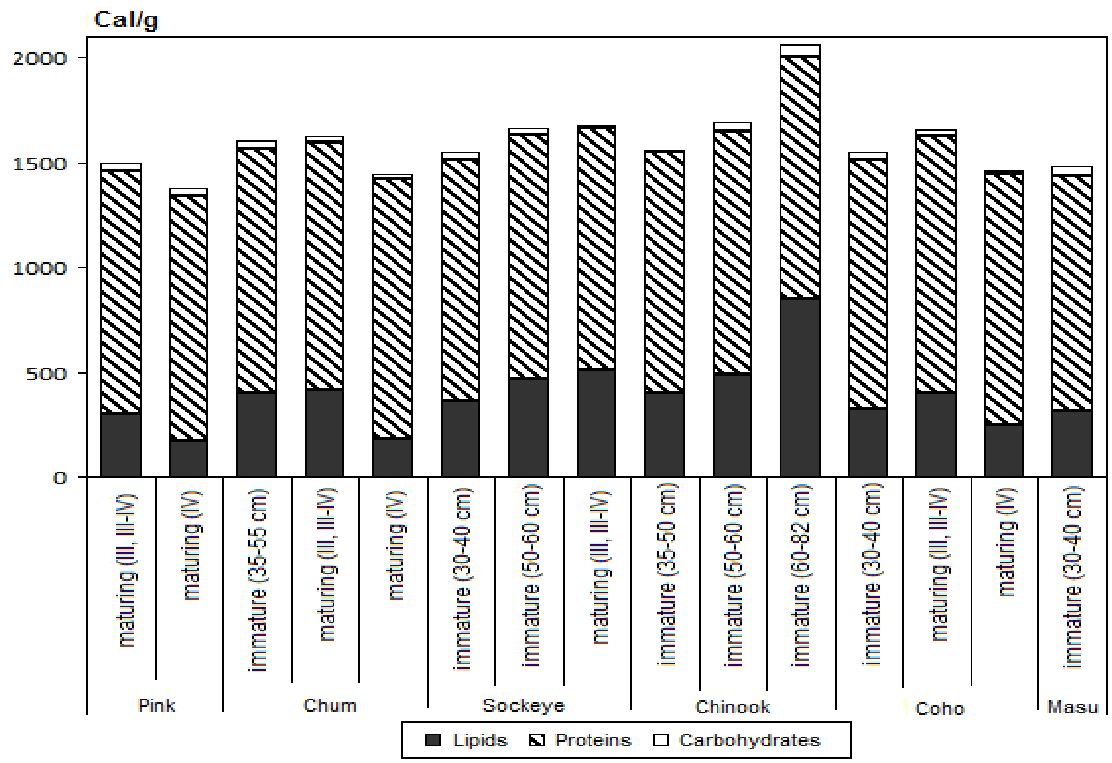

Figure 3. Biochemical composition and caloric content of wet muscular tissue of adult Pacific salmon in the Sea of Okhotsk

Table 4

Biochemical composition and caloric content of gonads of pink and chum salmon in the Sea of Okhotsk by sex and stage of fonad maturity

Species	Sex	Stage of gonad maturity	water, %	proteins, % of wet matter	lipids, % of wet matter	carbohydrates, % of wet matter	ash,% of wet matter	caloric content of wet matter, cal/g	dry matter, %	proteins, % of dry matter	lipids, % of dry matter	carbohydrates, % of dry matter	ash,% of dry matter	caloric content of dry matter, cal/g
O. gorbuscha	F	III	58.8	27.2	10.3	0.7	3.0	**2 548**	41.2	66.0	25.0	1.7	7.4	**6 155**
		III-IV	60.8	25.6	11.1	0.5	2.0	**2 525**	39.2	65.2	28.4	1.3	5.1	**6 422**
		IV	56.3	28.0	10.8	0.7	4.2	**2 645**	43.8	64.0	24.8	1.5	9.7	**6 021**
	M	III	81.2	15.0	1.1	0.6	2.0	**990**	18.8	79.9	6.0	3.4	10.7	**5 218**
		III-IV	80.5	16.4	1.1	0.6	1.4	**1061**	19.5	83.8	5.5	3.3	7.3	**5393**
		IV	79.9	17.7	1.0	0.7	0.8	**1 132**	20.2	87.8	5.0	3.2	3.9	**5 568**
O. keta	F	III	68.4	18.5	11.2	0.5	1.5	**2 126**	31.7	58.5	35.3	1.4	4.8	**6 696**
		III-IV	64.5	23.1	11.2	0.4	0.8	**2 384**	35.5	65.1	31.6	1.0	2.3	**6 707**
		IV	58.1	26.7	10.6	0.4	4.2	**2 531**	41.9	63.7	25.2	1.1	10.1	**6 024**
	M	III	80.5	16.3	0.9	0.4	1.9	**1 030**	19.5	83.2	4.7	2.3	9.8	**5 239**
		III-IV	79.1	17.6	1.0	0.5	1.8	**1 117**	20.9	84.1	4.9	2.2	8.7	**5 312**
		IV	77.6	17.4	2.0	0.5	2.4	**1 203**	22.4	77.9	9.1	2.1	10.9	**5 346**

Table 5

Average body and gonad weight of pink and chum salmon in the Sea of Okhotsk by sex and stage of fonad maturity

Species, size group, cm	Sex	Stage of gonad maturity	Average fork length, cm	Total body weight, g	Soma weight, g	Gonad weight, g
Pink salmon, 40-50	F	III	44.8	1090	927	43.2
	F	III-IV	46.4	1217	1028	71.1
	F	IV	47.3	1288	1082	90.3
	M	III	47.9	1337	1169	24.6
	M	III-IV	48.8	1417	1240	55.3
	M	IV	49.8	1511	1266	76.2
Chum salmon, 45-70	F	III	55.6	2129	1802	69
	F	III-IV	58.1	2441	1969	156
	F	IV	60.1	2728	2299	216
	M	III	57.9	2412	2088	30
	M	III-IV	63.1	3186	2747	85
	M	IV	63.2	3198	2771	156

Table 6

Energy equivalent (kcal) accumulation in soma, gonads and in the whole body of pink and chum salmon during the life span

Species	Month	Size group, cm	Average fork length, cm	Sex	Stage of gonad maturity	Energy (kcal) content in soma	Energy (kcal) content in gonads	Energy (kcal) content in visceral organs*	Energy (kcal) content in the whole body	% in some	% in gonads	% in visceral organs*
Pink salmon	August	10-20	16.7	Juv	-	55	0	5	60	91.7	0	8.3
	October	20-30	25.3	Juv	-	227	0	19	246	92.4	0	7.6
	November	20-30	28.8	Juv	-	479	0	53	532	90.0	0	10.0
	June-August	40-50	44.8	F	III	1390	110	134	1634	85.0	6.7	8.2
			46.4	F	III-IV	1541	180	104	1824	84.5	9.8	5.7
			47.3	F	IV	1418	239	120	1776	79.8	13.4	6.7
			47.9	M	III	1752	24	227	2004	87.4	1.2	11.4
			48.8	M	III-IV	1859	59	207	2124	87.5	2.8	9.7
			49.8	M	IV	1746	86	252	2084	83.8	4.1	12.1
Chum salmon	August	10-20	16.2	Juv	-	49	0	4	53	93.0	0	7.0
	October	20-30	24.9	Juv	-	207	0	22	229	90.5	0	9.5
	November	20-30	27.0	Juv	-	443	0	49	492	90.0	0	10.0
	June-August	45-70	55.6	F	III	2923	147	384	3453	84.6	4.2	11.1
			58.1	F	III-IV	3194	372	394	3959	80.7	9.4	9.9
			60.4	F	IV	3320	547	120	3939	83.3	13.7	3.0
			57.9	M	III	3387	31	495	3912	86.6	0.8	12.6
			63.1	M	III-IV	4456	95	617	5168	86.2	1.8	11.9
			63.2	M	IV	4001	188	429	4618	86.6	4.1	9.3

* - visceral organs without gonads

The calculated energy equivalent shows that the main amount of energy is concentrated in the salmon soma. During the pink and chum salmon life span, it varies from 79.8% to 93.0% (Table 6) and directly depends on the amount of energy in gonads. The minimum amount of energy in the soma was observed in the pre-spawning females (stage IV of the gonad maturity), and the maximum – in juvenile salmon.

Dynamics of deposited lipids and total caloric content of muscle (Figure 2) reflects a feature of transformation of consumed food energy into the energy of growth. Intensive energy accumulation (increase of energy equivalent amount) occurs with the growth of juvenile pink and chum salmon correspondingly with an increase in body weight and basic energy indices (Figure 4). Enhanced food supply and appropriate temperature regime in the Sea of Okhotsk pelagic layer enable a high level of energy accumulation in juvenile pink and chum bodies in favorable years.

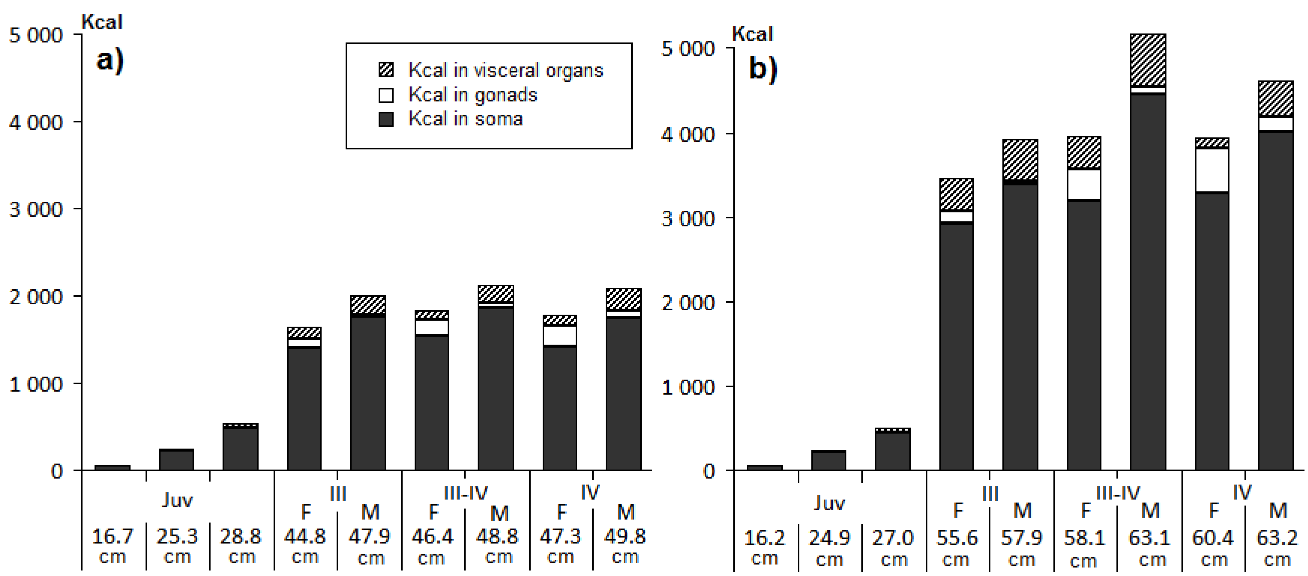

Figure 4. Energy accumulation (energy equivalent, kcal) in soma, gonads, and in the whole salmon body of pink (a) and chum (b) salmon during the life span

An energy content in gonads of all maturing salmon specimens grew with a stage of maturity (Figure 4) due to its caloric content increase and with a weight growth (Tables 4, 5). The energy equivalent of female gonads was higher despite a similar dynamics for both sexes. The maximum amount of energy in gonads (13.4-13.7%) was observed in pre-spawning females at the fourth stage of maturity (Table 6). As for the pre-spawning males (stage IV of maturity), the maximum amount of energy in gonads was only 4.1% of the total.

There are no direct observations on the viscera caloricity. Therefore, we calculated an unaccounted energy of visceral organs by subtraction of energy equivalent accumulated in the soma and gonads from amount of energy in the whole organism. It averaged about 10% (3.0-12.1%) of the total (Table 9).

Male salmon gain a higher total amount of energy than female (Table 6) due to their bigger size and body weight. For pink salmon, males gained 2,124 kcal in average while females – 1824 kcal. Male chum salmon accumulated 5168 kcal of energy during the life cycle while female – 3959 kcal. The energy content of salmon at the III-IV stage of maturity reached a maximum amount while, at the IV stage, total energy equivalent decreased despite continuing gonadal-somatic growth of salmon (Figure 4). That occurred due to decrease in deposited lipids and total caloric content of muscle tissues (Figure 3). There is a well-known effect of feeding intensity decline with salmon maturation and approaching to spawning rivers, when the energy intake from food decreases (Kuznetsova 2005; Chuchukalo 2006). Therefore, energy intake by Pacific salmon through foraging became noticeably lower than energy expenditures for metabolism during active migrations to rivers. After transition to the fourth stage of gonad maturity, maturing salmon begin spending of accumulated energy reserves, mainly deposited lipids (Sidorov 1983, Gorbatenko et al. 2008) that increase their vulnerability to environmental factors (Radchenko 2012).

In the Sea of Okhotsk, juvenile pink salmon after downstream migration gain 532 kcal from June to November, or 27% of the total amount of energy accumulated during marine life period before returning to the sea basin (Figure 5). In the northwestern Pacific Ocean, pink salmon, without ranking by sex, gain 1442 kcal in average or 73% of the total accumulated energy for that period.

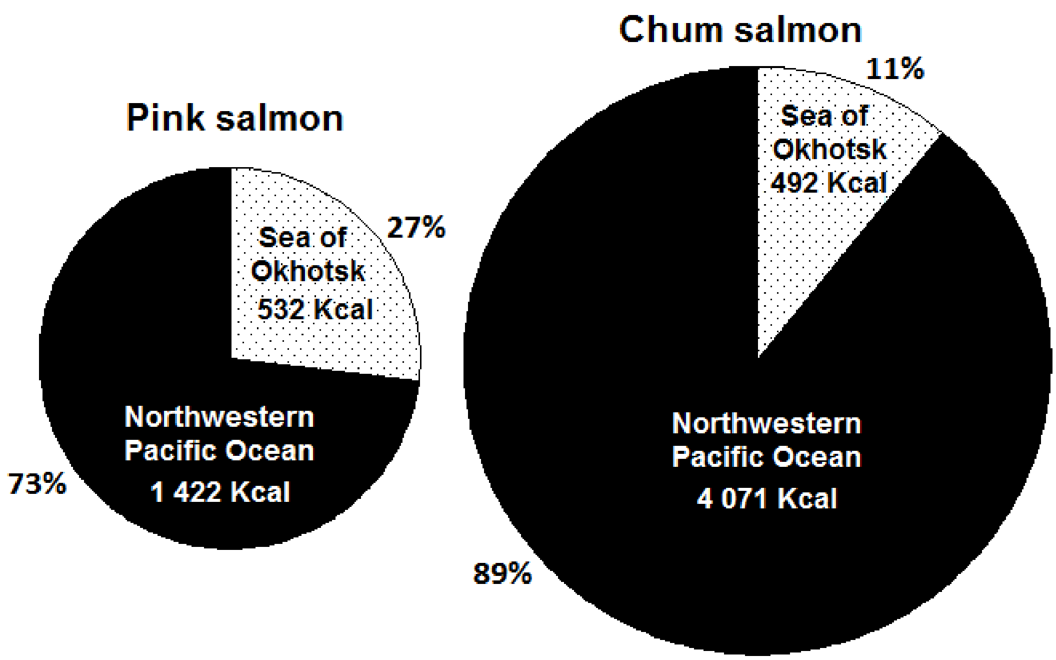

Figure 5. Energy accumulation (energy equivalent, Kcal) by pink and chum salmon in the Sea of Okhotsk and other areas of the northwestern Pacific Ocean during their life span

Juvenile chum salmon gained 492 kcal in the Sea of Okhotsk from June to November, after entering marine environment, which is 11% of the total amount of energy accumulated during the marine life period (Figure 5).

Chum salmon mainly spend 3-4 years in the northwestern Pacific Ocean with possible summer migrations to the eastern North Pacific Ocean and the Bering Sea. Some immature chum specimens may also visit the eastern Sea of Okhotsk. Maturing chum salmon aged 3+ and 4+ return to the Sea of Okhotsk in summer or autumn. On average, maturing chum salmon without ranking by size and sex gained 4,071 kcal, or 89% of the total accumulated energy after leaving the Sea of Okhotsk first time.

Conclusions

1. In juvenile salmon, content of of high-energy substances increases with their growth. A high level of lipids accumulation by juvenile pink and chum salmon in the Sea of Okhotsk in June-October is due to a good food supply and favorable temperature regime.

2. In adult salmon, an increase in total caloric content is observed with the progressive gonad development mainly due to increase of fat and dry matter content. After transition to the IV stage of gonad maturity, decrease in salmon soma caloric content occurred mainly due to reduction of deposited lipids in tissues, which is associated with progressive gonad maturation.

3. Older age groups of all the long-cycle salmon species have larger caloric content and fat deposition in muscle tissues.

4. In the period of anadromous migrations, females and males of chum and pink salmon have a similar ability to accumulate lipids in gonads, but the weight of gonads in chum is 1.5-2 times higher than in pink salmon.

5. Pink salmon and chum salmon roe contain a high amount of dry matter – 31.7-43.8% of total weight on average. The content of lipids in the wet gonads of females was in an order of magnitude higher than in males and was 10.3-11.2% vs. 1.0-2.0%, respectively. Of the wet weight, the caloric content of the female pink and chum salmon gonads varied from 2525 to 2645 cal/g and from 2126 to 2531 cal/g, respectively. In milt, the dry matter and caloric contents are more than twofold lower.

6. The process of accumulation of high-energy substances, especially lipids in salmon gonads is associated with changes of biochemical components ratio in their muscles. Significant decrease in deposited lipids and watering of proteins was observed in salmon muscle with transition to the IV stage of gonad maturity.

7. Proportion of energy accumulated in salmon soma varies from 79.8% to 93.0% during the life cycle and depends on the amount of energy accumulated in the gonads.

8. The energy equivalent of gonads in females is higher than in males despite some similarity is observed in the process of energy accumulation during a life span. The maximum amount of energy (13.4-13.7% of the total accumulated in salmon body) is observed in pre-spawning females at the fourth stage of gonad maturity. Pre-spawning males (at the stage IV of gonad maturity) contain the maximum proportion of energy in the gonads at 4.1% of the total energy of body.

9. Total amount of energy accumulated by juvenile pink salmon in the Sea of Okhotsk is 532 kcal or 27% of the total energy accumulated in the marine life period. In the northwestern Pacific Ocean, pink salmon, without ranking for males and females, accumulate 1442 kcal in average or 73% of the total accumulated energy.

10. Juvenile chum salmon accumulate 492 kcal in the Sea of Okhotsk, which is 11% of the total energy accumulated during the marine life. Maturing chum salmon, without ranking by age and sex, during the feeding season in the northwestern Pacific Ocean accumulates 4,071 kcal in average, or 89% of the total accumulated energy in the marine life period.

Obtained energetic characteristics of Pacific salmon in the Sea of Okhotsk may be used in trophodynamic models.

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