TENTATIVE ESTIMATION OF DAILY RATION OF SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) IN BRISTOL BAY PRIOR TO ASCENDING MIGRATION*

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The sockeye salmon bound for western Alaska appear extensively in the central area of the Bering Sea in early June, and accomplish a distant travel of about 1,000 to 1,200 miles toward the mouth of the bay for almost a month. By mark-and-recapture experiment, Hartt (1966) has revealed that mature sockeye salmon run eastward in the Bering Sea at an average calculated speed of 28~30 miles a day. It is natural to consider that during this migration, the necessary energy required for the movement, the growth as well as the development of gonads should be obtained from adequate food supply available in the area of distribution.

For the purpose of clarifying the relation between food supply, growth and energy expenditures of the fish at sea, an attempt was made in this report to estimate tentatively the daily ration of sockeye salmon 2.2 age fish in Bristol Bay before ascending into fresh water.

Materials and Methods

The following procedures were provided with: examination of food in natural habitat, chemical analyses on the nutritional value of food animals, computation of growth rates of the body and gonads and finally estimation of daily ration.

Observation of the food in nature was made on a considerable number of stomach contents of the sockeye salmon in June 1965 and 1966 (Fig. 1), sampled roughly from three sea areas, namely, the Bering Sea (location No. of sampling; 4~8 in 1965 and 4~7 in 1966), Bristol Bay on the continential shelf (12~15 in 1965 and 12~17 in 1966) and the area in between (9~11 in 1965 and 8~11 in 1966). Food animals were identified and grouped into the following eight categories of animals; copepods, euphausiids, amphipods, pteropods, zoea, squids, fish larvae and others. The wet weight was measured for each respective category.

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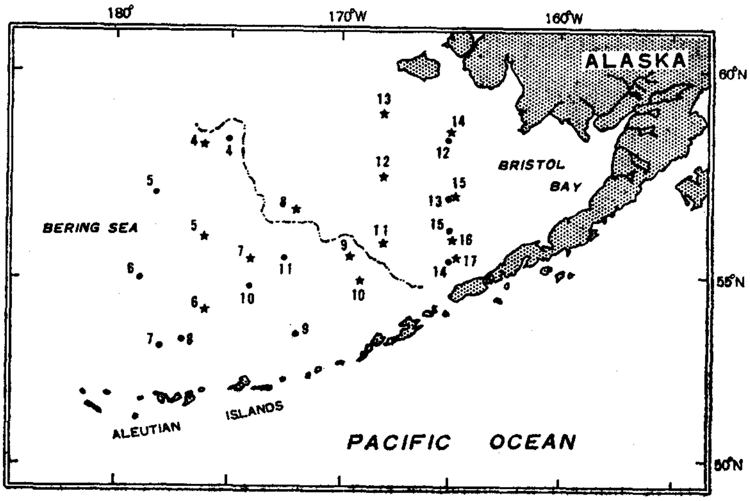

Fig. 1. Locations of sampling station of stomach contents of the Bristol Bay sockeye salmon in late June, 1965 (●) and 1966 (★). Figures stand for the location number of fishing

Prey animals corresponding to the species found dominantly from the stomachs were concurrently collected in the fishing locations by Norpac plankton net or fish larvae net. After drying, the chemical compositions of these animals were analyzed to decide their caloric value. Protein was determined by micro-Kjeldahl method, a fatty substance by ether-extraction in the Soxhlet apparatus and ash by combustion method. The carbohydrate content was then computed by subtracting the sum of the dry weight from the sample. A caloric value of 4.2 kcal per gram was given for carbohydrates, 5.6 kcal for protein and 9.4 kcal for the fatty substance, respectively.

For the computation of the growth rate of fish and the rate of gonadal development a number of fishes were sampled at eleven different and two identical locations in the Bering Sea and Bristol Bay in late June of 1967 and 1968 (Table 1). Measurements of body size in weight and gonad weight were carried out on the fish caught by gillnet consisting of four mesh sizes, i.e. 115, 121, 130 and 136 mm in stretched measure, cast by a training ship, the *Oshoror Maru*. The data of both years were wholly combined.

Results

1. Examination of stomach contents

The weight composition of dominant food animals found in the stomach is shown in Table 2. Generally, in the Bering Sea and Bristol Bay, food consisted mainly of squids, fish larvae, euphausiids and amphipods, whereas copepods were

Table 1. Locations of sampling station

Date		Location of sampling		No. of fish	
		Latitude	Longitude	Female	Male
1967 June	18	55°44′N	174°02′W	2	2
	19	53°35′	174°02′	26	20
	20	54°30′	172°00′	62	39
	21	55°26′	170°02′	54	52
	24	57°20′	162°00′	30	22
	25	56°55′	162°00′	46	47
1968 June	20	55°58′	172°00′	11	5
	21	54°53′	168°43′	26	23
	25	56°33′	164°49′	25	28
	27	57°30′	163°00′	9	5
	28	56°55′	163°03′	20	16
	29	56°42′	163°03′	23	21
	30	56°42′	163°03′	16	20

little used, though yearly occurrence was dissimilar. As illustrated in Fig. 2, when both years were combined, squids were predominantly utilized in the Bering Sea, followed by pteropods. In the intermediate area the amount of squids largely diminished whereas fish larvae and euphausiids appeared as dominant diet. In Bristol Bay, euphasiids substituted for squids as principal food source for this salmon.

2. Caloric value of food animals

The results of chemical analyses on the dietary organisms collected in the Bering Sea and Bristol Bay are represented in Table 3. Caloric values differed from animal to animal; euphausiids (*Euphausia pacifica* and *Thysanoëssa* sp.), fish larvae (*Theragra chalcogramma*, *Ammodytes hexapterus*, *Pleurogrammus monopterygius*, *Hexagramos* sp., *Hemilepidotus* sp. and *Pleuronectidae* sp.) and squids contained

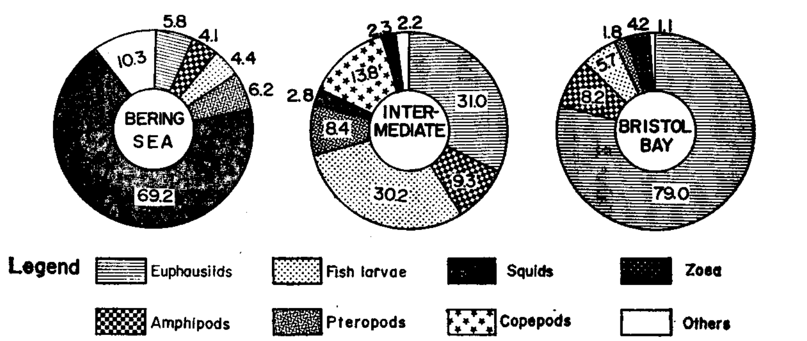

Fig. 2. Percentage fraction in wet weight of food organisms occurring in the stomachs of the Bristol Bay sockeye salmon in late June, 1965 and 1966 combined

Table 2. Weight composition(g) of stomach contents of the Bristol Bay sockeye salmon in June, 1965 and 1966

Year	Area	No. of stomach	Food animal							
			Euphausiids	Amphipods	Fish larvae	Pteropods	Squids	Copepods	Zoea	Others
1965	Bering Sea	115	130 (14.1%)	116 (12.5%)	53 (5.7%)	215 (23.2%)	57 (6.2%)	0 (0%)	0 (0%)	354 (38.3%)
	Intermediate	90	225 (43.8%)	42 (8.2%)	49 (9.5%)	61 (11.9%)	20 (3.9%)	100 (19.5%)	17 (3.3%)	0 (0%)
	Bristol Bay	90	1522 (82.3%)	95 (5.1%)	125 (6.7%)	10 (0.5%)	0 (0%)	0 (0%)	100 (5.4%)	0 (0%)
1966	Bering Sea	58	71 (2.0%)	26 (0.7%)	99 (2.8%)	0 (0%)	3350 (94.4%)	0 (0%)	0 (0%)	3 (0.1%)
	Intermediate	14	0 (0%)	26 (12.3%)	170 (80.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	16 (7.5%)
	Bristol Bay	33	374 (71.9%)	99 (19.0%)	11 (2.1%)	33 (6.3%)	0 (0%)	0 (0%)	0 (0%)	3 (0.6%)

Table 3. Mean caloric values of food organisms in the Bering Sea and Bristol Bay in June, 1966 and 1967 combined

Organism	No. of sample	Moisture (%)	Dry weight (%)	Calories in wet weight 100 g (kcal)
Copepods	6	83.8	16.2	85.3
Euphausiids	7	76.4	23.6	128.0
Amphipods	5	81.5	18.5	82.7
Pteropods	4	86.6	13.4	70.9
Polychaeta	2	85.1	14.9	75.7
Zoea	3	80.6	19.4	81.1
Squids	4	83.9	16.1	93.4
Fish larvae	5	78.6	21.4	110.0
Mean	36	82.1	17.9	88.2

high energy, whereas pteropods (*Clione limacina* and *Limacina helicina*) and zoea had relatively low. Amphipods (*Parathemisto pacifica*, *Parathemisto japonica*, *Euthemisto libellula* and *Hyperuche kröyeri*), and copepods (*Calanus cristatus*) also furnished relatively high caloric values.

Provided that the food composition is maintained proportionally to the percentage in wet weight, as shown in Fig. 2, the potential energy of each sea area in caloric value per 100 g wet weight is anticipated, as shown in Table 4. It is presumable that each geographic area maintains different potentialities for sockeye salmon. High energy tends to occur in Bristol Bay.

Table 4. Potential energy of food per 100 gram wet weight in three sea areas (kcal)

Bering Sea	Intermediate	Bristol Bay
94.34	104.74	119.82

3. Growth rate and rate of gonadal development

In this study, the growth increment of weight of fish was divided into the growth of the body and gonadal development. Growth curves were regarded as linear in this report because a relatively short period of time was dealt with (Figs. 3 and 4). Using equations showing the relation between the date and the body or gonad weight, the growth rate of the body, the rate of gonadal development and the daily increment of weight were computed in two average-sized fish (Table 5). From this tabulation, it is found that the growth rate of the body was higher in male fish than in female fish. It is also indicated that the growth rate of the body was lower than that of the gonad, approximately a third or a fourth. The gonad increment attained a day about 10 percent of the body increment.

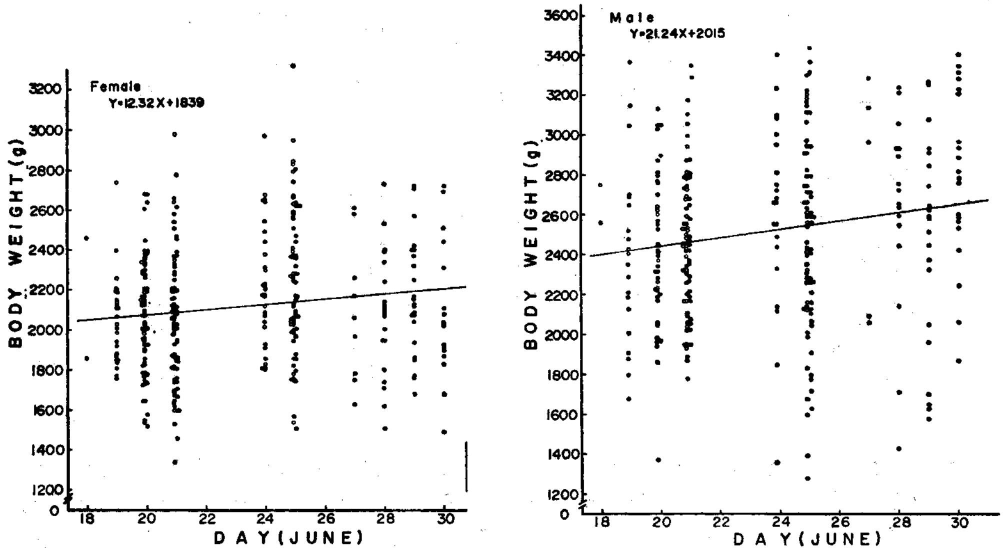

Fig. 3. Relation between date and body weight in the Bristol Bay sockeye salmon 2.2 age in late June, 1967 (○) and 1968 (●)

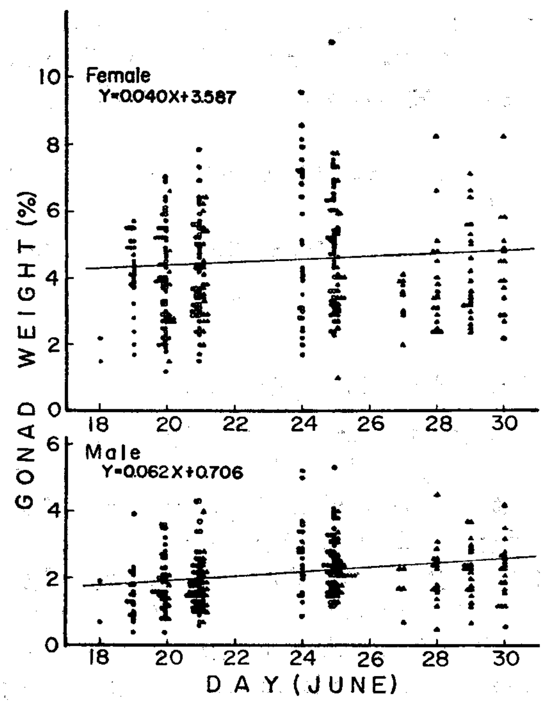

Fig. 4. Relation between date and percentage of gonad to body weight in the Bristol Bay sockeye salmon 2.2 age in late June, 1967 (○) and 1968 (△)

4. Estimation of daily ration

Winberg (1956) proposed a basic balanced equation between the ration and the metabolism in wild fish, as follows;

$$0.8\,R = P + T$$

where R is ration, P growth and T expenditures for metabolism. This equation involves that 80 percent of consumed food is utilizable for growth and metabolism. Referring to this equation, an estimation of daily ration for the Bristol Bay sockeye salmon was tried in this paper.

As described above, the increment of body and gonad weight are presented. To obtain the value of expenditures of metabolism, speed of migration is employed as the index of active metabolism in the present study. Strictly speaking, therefore, the active metabolism described here differs from that defined by Brett (1962). According to Hartt (1966), the Bristol Bay sockeye salmon in adult form swim at an average speed of about 30 miles a day. This velocity corresponds to 64 cm per second in the case of the average-sized fish concerned here. The relation between the maximum swimming speed of fish and the body length in sockeye salmon has been demonstrated by Brett (1965) in the following empirical equation;

$$\mathrm{Log}\,Y = 1.29 + 0.50 \log X$$

where Y is speed (cm/sec) and X body length (cm). According to this equation, the maximum swimming speed is calculated to be 152~154 cm/sec or 2.5 body length/sec for the average-sized fish. The relationship between body weight and oxygen consumption in maximum sustained swimming activity has been also examined by Brett (1965). His empirical equation is shown by the following formula;

$$\mathrm{Log}\,Y = -0.064 + 0.963 \log X$$

where Y is oxygen consumption (mg O_2/hour) and X body weight (g). For the present purpose, the value of oxygen consumption was obtained by extrapolating the body size into Brett's equation. An equation showing the relation between body length and fork length for the Bristol Bay sockeye salmon of 2.2 age is prepared by the present author as

$$Y = 0.951\,X + 5.268$$

where Y is body length (cm) and X fork length (cm).

Thereby one can compute the energy expenditures in active metabolism for the average-sized Bristol Bay sockeye salmon (Table 6). Since the swimming velocity of 64 cm/sec correspondes to 40~41 percent of the maximum swimming speed, the amount of oxygen consumption at the speed of 30 miles/day is proportioned

Table 5. Growth and gonadal development of the Bristol Bay sockeye salmon 2.2 age during June 15~30 (both 1967 and 1968 combined)

Sex	Size of fish	Body weight (g)			Rate of growth in a day (%)	Increment of growth (g)	Gonad weight (g)			Rate of development in a day (%)	Increment of development (g)
		initial	end	mean			initial	end	mean		
Female	58cm 2211g	2024	2209	2116	0.58	12.27	85	106	95	1.46	1.39
Male	60cm 2546g	2334	2652	2493	0.85	21.19	38	68	53	3.75	1.99

Table 7. Estimation of ration per day for the Bristol Bay sockeye salmon 2.2 age at three sea areas

Sex	Size of fish	Growth and metabolism		Conversion into caloric value			Ration required in caloric value (kcal)	Food requirement at three sea areas in wet weight (g)		
		Increment of body & gonad weight per day (g)	Active metabolic rate per day (O_2 cc)	growth* (kcal)	metabolism** (kcal)	total (kcal)		Bering Sea	Inter-mediate	Bristol Bay
Female	58cm 2211g	13.66	3,528	13.66	17.64	31.30	39.13	41.6 (2.0%)	37.4 (1.8%)	32.7 (1.6%)
Male	60cm 2546g	23.18	3,984	23.18	19.92	43.10	53.88	57.1 (2.3%)	51.4 (2.1%)	45.0 (1.8%)

*1 gram body weight in wet condition=1,000 cal (Winberg, 1956)
**1 cc oxygen=5 cal (Winberg, 1956)

Table 6. Energy expenditures for active metabolism (swimming speed of 30 miles/day at 6°C) for the Bristol Bay sockeye salmon 2.2 age

Sex	Size of fish	Maximum active metabolic rate O_2cc/kg/h (15°C)	Coefficient for 30 miles/day	Temperature coefficient for 6°C	Active metabolic rate (O_2 cc) for body weight/day at 6°C
Female	58cm 2211g	1095	0.399	2.898	3,528
Male	60cm 2546g	1255	0.405	2.898	3,984

to 40∼41 percent of oxygen consumption at maximum sustained swimming activity. Further, as the prevailing water temperature in the zone where the sockeye salmon inhabitate has been reported as 6°C in the central Bering Sea and Bristol Bay during fourteen years from 1955 till 1968, computation was made on the assumption that the fish distributed in the area of this water temperature during migration. In the last column of Table 6, a daily active metabolic rate is estimated for the sex of the average-sized fish.

By using the information given by Winberg (1956), the growth and metabolism are converted into caloric values, as shown in Table 7 (column 4). Summing up the previous two values in the next column, the daily ration for the average-sized Bristol Bay sockeye salmon was finally estimated. In this table, it is seen that the female fish require as food 1.6∼2.0 percent of total body weight, and the male 1.8∼2.3 percent in a day for their growth both in body and gonad and metabolism for swimming. It is mentioned that the ration in wet weight slightly varies from area to area.

Discussion

Availability of food, rates of digestion and assimilation, growth rate as well as energy expenditures for metabolism have been studied to estimate the ration of fish, and several formulae have been proposed. Among these studies Winberg's basic balanced equation deriving from comprehensive survery on wild fish has rendered the author an initial estimation of the ration. Davis & Warren (1968) have discussed the reliability and limitation of availability of his equation.

General aspects of growth of sockeye salmon during a long period of life have been investigated by means of back calculation by using a scale, comparison of seasonal or annual difference of body size and theoretical analyses. A seasonal growth rate of the Bristol Bay sockeye salmon at marine life stage has been presented by Lander & Tanonaka (1964). Based upon five year data, from 1956 to 1960, they showed that the growth rate of the maturing sockeye salmon spending two years at sea was estimated to be 0.12 percent a day during 40 days from May to July. Compared with the data given by these authors, the present growth rate of the sockeye salmon, 2.2 age fish, that attained 0.6～0.9 percent per day during two weeks in late June seems to be exceedingly high. The difference between two estimates might be attributed to several factors such as the size of population when samples were obtained, the duration of term concerned, the mingling of age groups and the separation or combination of sex groups, as well as the difference in data processing. In particular, the size of population should be an important factor for the growth of fish since it is widely accepted that the larger the population size is, the smaller the size of individual fish and *vice versa*. A reliable growth rate of the Bristol Bay sockeye salmon, therefore, should be derived from a single age group, separately by sex, year and season. Moreover, when taken into account, age composition, time of migration, size of fish, sex ratio, origin of native water system and others, the Bristol Bay sockeye salmon substantially consist of several subpopulations. Growth rate and gonadal development are hence believed to be diverse by subpopulation even in a same age fish. Consequently, a precise estimation of ration should be given for respective subpopulation.

The last marine life stage of the sockeye salmon appears to be peculiar in growth. The increment of weight implies two heterogeneous phases, namely, the growth of body and the production of sex materials. It is likely that the gonad does not develop in parallel with the growth of the body during the time when maturation proceeds; the growth rate of gonads exceeds that of body weight. Faustov & Zotin (1968) have found a caloric value of 6.4 kcal per 1 g dry weight to be great in mature eggs of sockeye salmon, being about three times higher than that of the body proper. This suggests that a considerable part of food is converted into gonad production in the final marine stage. In other words, it is possible that developing gonads demand more energy than the body.

Although the oxygen consumption was employed here in accordance with the speed of migration given by Hartt, the validity of the reference to Brett's empirical equation for computation remains to be seen whether or not the average swimming speed can be always available as the index of active metabolism. Yet a lack of experiment on the active metabolic rate of sockeye salmon at sea has prevented accurate determination. Furthermore, the rate of food consumption awaits for further study for sockeye salmon instead of eighty percent being generalized in Winberg's equation. Besides, the environmental sea water is reported to range from 4°C to 12°C in the Bering Sea and Bristol Bay which may affect directly both growth and metabolism, though it was considered to be 6°C in the present estimation. These will undoubtedly modify the level of the ration given here.

The results of the present study suggest that different geographic area where the salmon were caught maintains a significance to promote the growth of fish. Incidentally, high calories and high fatty contents in euphausiids in Bristol Bay are suggestive of their advantageousness for sockeye salmon to provide with an accumulation of energy-rich material for the coming exhaustive migration as well as gonad production.

For the purpose of an ecological evaluation of the sea area where the fish distribute, further clarification should be elaborated on the relationship among the nutritional potentiality of the sea characterized by both quantity and quality of available foods, the exact utilization of food and precise computation of the growth rate of fish in a migration route.

Summary

For determination of food requirement of the Bristol Bay sockeye salmon during the last half of a month in the last marine life stage, a preliminary calculation of daily ration was made by referring to Winberg's basic equation (1956) that relates ration to growth and metabolism, and to Brett's empirical equation (1965) of the relationship between the rate of oxygen consumption and a sustained swimming speed.

The daily rate of growth of 2.2 age fish in late June of both year 1967 and 1968 combined is estimated to be 0.58% of body weight in females and 0.85% in males. The daily rate of gonadal development is also estimated to be 1.46% of gonad weight in females and 3.75% in males.

Caloric values of food animals in nature for sockeye salmon determined by chemical analyses are as follows: copepods 85 kcal, euphausiids 127 kcal, amphipods 83 kcal, pteropods 71 kcal, polychaeta 76 kcal, zoea 81 kcal, squids 93 kcal, and fish larvae 110 kcal per 100 gram wet weight, respectively.

Assuming that the fish with the size of 58～60 cm in fork length move in a 6°C sea at a speed of 64 cm/sec (30 miles/day) and consume the above-mentioned prey animals, the daily ration of sockeye salmon equivalent to the energy required for swimming and the growth as well as the development of gonads during the migration in Bristol Bay is expected to be about 2% of body weight.

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