Temperature and Incubation in Pacific Salmon and Rainbow Trout: Compilation of Data on Median Hatching Time, Mortality and Embryonic Staging

F. P. J. Velsen

Department of Fisheries and Oceans
Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

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ABSTRACT

Velsen, F. P. J. 1987. Temperature and incubation in Pacific salmon and rainbow trout: compilation of data on median hatching time, mortality, and embryonic staging. Can. Data Rep. Fish. Aquat. Sci. 626: 58 p.

This report compiles numerical data on the influence of temperature on the incubation of Pacific salmon: Oncorhynchus tshawytscha (chinook), O. keta (chum), O. kisutch (coho), O. gorbuscha (pink), and O. nerka (sockeye); and Salmo gairdneri (rainbow and steelhead trout) eggs. These data, from published and unpublished sources, were gathered to allow a comprehensive examination of the relationship between temperature and development time. They form the data base for an examination of a number of models, published elsewhere (Aquaculture MS).

As available data were gathered, portions of the temperature ranges were noted that were poorly represented. Where possible these poorly represented ranges were reduced by conducting experimental incubations. The temperatures reported are divided into two groups, constant (mean ± 1°C) and ambient (variable). In general the records provide information on time to median hatch and rates of mortality from fertilization to median hatch. Further information is provided on the timing to development of various embryonic stages prior to hatching in the six species.

RÉSUMÉ

Velsen, F. P. J. 1987. Temperature and incubation in Pacific salmon and rainbow trout: compilation of data on median hatching time, mortality and embryonic staging. Can. Data Rep. Fish. Aquat. Sci. 626: 58 p.

Le présent rapport compile des données numériques carceruont l'influence qu'a la température sur l'incubation du saumon du Pacifique: Oncorhynchus tshawytscha (saumon quinnat), O. keta (saumon kéta), O. kisutch (saumon coho), O. gorbuscha (saumon rose) et O. nerka (saumon rouge) ainsi que des oeufs de Salmo gairdneri (truite arc-en-ciel). Ces données, venant de sources publiées et inédites, ont été rassemblées pour permettre de faire un examen détaillé de la relation entre la température et le temps de développement. Elles forment la base de données pour un examen d'un certain nombre de modèles, publié ailleurs (Aquaculture MS).

Lorsque les données disponibles ont été rassemblées, on a noté que des parties des échelles de température étaient mal représentées. Dans la mesure du possible, on a réduit ces échelles mal représentées en procédant à des incubations expérimentales. Les températures signalées sont divisées en deux groupes, constantes (moyenne 1°C) et ambiantes (variables). Dans l'ensemble, les données fournissent des informations sur le temps jusqu'à la valeur médiane éclosion et sur les taux de mortalité de la fécondation à la valeur médiane d'éclosion. De plus amples informations sont fournies sur le moment écoulé jusqu'au développement des divers stades embryonnaires trécédant l'éclosion chez les six espèces.

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INTRODUCTION

This report is a compilation of data in the literature on embryonic development of Pacific salmon (Oncorhynchus) and rainbow trout (Salmo gairdneri), in relation to temperature, augmented by experimental work to fill gaps in the temperature relationships. A new modelling procedure was used to examine these relations (to be published elsewhere) and the information in this report forms the data base for that publication. This work was conducted to provide some of the data required to automate certain procedures in British Columbia salmonid hatcheries. This required an efficient method of estimating incubation time. Relevant numerical data were collected from the literature as a first step. From these compilations it became obvious there were portions of the useful temperature range that were inadequately represented. These gaps then were filled or reduced experimentally.

The species considered are presented in the following order: chinook (O. tshawytscha), chum (O. keta), coho (O. kisutch), pink (O. gorbuscha), sockeye (O. nerka) and rainbow trout and steelhead (S. gairdneri). Data for rainbow trout (the non-anadromous form of S. gairdneri) have been combined with those of steelhead, as their embryonic development appears to be very similar.

The information gathered on the six species, for the period from fertilization to median hatch, is presented in four categories: 1) time to median hatch at constant temperature, 2) time to median hatch at ambient temperatures, 3) mortality rate at various temperatures, and 4) rate of embryonic development to 23 developmental stages.

Temperatures were considered constant if the range around the mean value was not >2°C. Ambient temperatures are variable and are based on average daily temperatures over the incubation period. Degree-days (°d, ATU, TU, HU) are not shown in view of the fact that the thermal sums method does not hold true for low and high temperatures (Alderdice and Velsen 1978).

The data sources for Table 1 provide 783 data points on time to median hatch at constant and ambient temperatures, and 216 points on mortality. The majority of these data are of North American origin, while four are from the east coast of the USSR (Smirnov 1953, 1958, 1975; Disler 1953), two are from Japan (Kawajiri 1928; Timoshina 1972) and one is from Europe (Vernier 1969).

Data on mortality at constant and ambient temperatures of development generally is scarce, especially for chum, coho, and pink salmon, and is virtually lacking for temperatures less than 5°C for all six species.

Embryonic development stages of salmonids have been described by several authors, as reviewed by Ballard (1973a), but not for Pacific salmon. Developmental stages for rainbow trout described by Vernier (1969) and Ballard (1973a), together with information on techniques and internal development (Affleck 1952; Ballard 1968, 1972, 1973a, 1973b, 1976; Ballard and Dodes 1968;

Devillers et al. 1954; Ginzburg 1968; Long 1968; Morton 1948) were used to establish chronological development tables for Pacific salmon and rainbow trout. A description of the 23 stages used in determining embryonic development is found in Table 26.

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Table 1. Source and frequency of data points on time to median hatch and percent mortality.

No.	Author/Source	Species	Data point frequency 50% hatch	Mortality
1	Alderdice et al. (1958)	chum	4	4
2	Bailey and Evans (1971)	pink	4	3
3	Bamford (1978)	steelhead	3	-
4	Brannon (1965)	sockeye	1	-
5	Burrows (1956)	chinook	23	18
6	Combs (1965)	sockeye	-	11
7	Craig P. personal communication Dept. Fish. Oceans, Pac. Biol. Stn., Nanaimo, B.C.	chum	8	8
8	Disler (1953)	chum	1	-
9	Donaldson (1955)	chinook	45	10
10	Dong (1979)	coho	16	18
11	Eddy (1971)	chinook	16	-
12	Embody (1934)	rainbow	23	-
13	Foerster (1968)	sockeye	17	-
14	Fowler and Banks (1981)	chinook	-	8
15	Garside (1966)	rainbow	7	-
16	Godin, J. G., personal communication, Dept. Fish. Oceans, Pac. Biol. Stn., Nanaimo, B.C.	pink	1	-
17	Griffioen, W., personal communication, Dept. Fish. Oceans, Pac. Biol. Stn., Nanaimo, B.C.	chinook	2	-
18	Harvey, R., personal communication, Dept. Fish. Oceans, Big Qualicum Project, Qualicum Beach, B.C.	chinook	6	-
19	Heming (1977)	chinook	4	-
20	Jensen (1980)	steelhead	3	-
21	Jensen (1986)	steelhead	1	-
22	Jensen and Alderdice (1983)	coho	1	-
23	Johnston, G., personal communication, Dept. Fish. Oceans, Pac. Biol. Stn., Nanaimo, B.C.	chum pink sockeye	2 1 2	- - -
24	Kawajiri (1928)	rainbow	11	-
25	Knight (1963)	rainbow	2	-
26	Kwain (1975)	rainbow	5	5
27	Kwain (1982)	pink	5	-
28	Leitritz and Lewis (1976)	rainbow	5	-
29	MacCrimmon and Kwain (1969)	rainbow	1	1
30	MacDonald, D., personal communication, Dept. Fish. Oceans, 1090 West Pender, Vancouver, B.C.	coho chinook chum steelhead	63 61 20 22	- - - -

Table 1 (cont'd)

No.	Author/Source	Species	Data point frequency 50% hatch	Mortality
31	MacLean, I., personal communication, Dept. Fish. Oceans, Tlupana Inlet Project, Tahsis, B.C.	chum	22	-
32	Mahon and Hoar (1956)	coho	1	-
33	McIntyre and Blanc (1973)	steelhead	1	-
34	Nebeker et al. (1978)	steelhead	4	-
36	Rankin (1979)	sockeye	1	1
37	Riddle (1917)	chinook	1	18
38	Rockwell (1956)	pink	1	1
39	Rombough (1986)	steelhead	4	4
40	Schroder, S., personal communication, Big Beef Res. Stn., Bremerton, Washington, USA	chum	1	-
41	Seymour (1956)	chinook	51	17
42	Shapolov (1937)	steelhead	2	-
43	Shumway et al. (1964)	steelhead	6	3
		coho	8	-
45	Silver et al. (1963)	chinook	9	3
		steelhead	4	-
46	Smirnov (1953)	chum	2	-
47	Smirnov (1958)	sockeye	3	-
48	Smirnov (1975)	pink	2	-
		chinook	2	-
		chum	3	-
		coho	8	-
		pink	7	-
		sockeye	3	-
49	Timoshina (1972)	rainbow	5	-
50	Van Tine, J., personal communication, Dept. Fish. Oceans, Quinsam Hatchery, Campbell River, B.C.	chum	6	-
		steelhead	15	-
51	Velsen (1980)	sockeye	6	3
52	Velsen, F. P. J., unpublished data			
a	Big Qualicum River, B.C. 1975	chinook	-	2
b	Big Qualicum River, B.C. 1976	chinook	2	2
c	Quinsam River, B.C. 1977	chinook	5	5
d	Robertson Creek, B.C. 1978	chinook	4	2
e	Big Qualicum River, B.C. 1981	chinook	5	-
f	Big Qualicum River, B.C. 1976	chum	5	5
g	Big Qualicum River, B.C. 1978	chum	5	4

Table 1 (cont'd)

No.	Author/Source	Species	Data point frequency 50% hatch	Mortality
h	Big Qualicum River, B.C. 1979	chum	3	3
i	Big Qualicum River, B.C. 1981	chum	5	1
j	Big Qualicum River, B.C. 1983	chum	1	2
k	Quinsam River, B.C. 1978	coho	5	5
l	Quinsam River, B.C. 1979	coho	2	-
m	Quinsam River, B.C. 1981	coho	5	-
n	Glendale River, B.C. 1975	pink	3	3
o	Glendale River, B.C. 1976	pink	20	-
p	Glendale River, B.C. 1978	pink	3	3
q	Quinsam River, B.C. 1981	pink	5	2
s	Fulton River, B.C. 1976	sockeye	20	11
t	Fulton River, B.C. 1978	sockeye	3	3
u	Fulton River, B.C. 1981	sockeye	5	-
v	Stikine River, B.C. 1984	sockeye	8	7
w	Nimpkish, River, B.C. 1984	sockeye	8	8
x	Big Qualicum River, B.C. 1978	steelhead	-	3
y	Big Qualicum River, B.C. 1979	steelhead	5	-
z	Big Qualicum River, B.C. 1980	steelhead	1	1
aa	Big Qualicum River, B.C. 1984	steelhead	4	4
53	Vernier (1969)	rainbow	1	-
54	Wales (1941)	steelhead	5	0
55	Wallich (1901)	chinook	57	-
56	Wild (1973)	chum	9	-
57	Withler and Morley (1970)	chum	5	1
		pink	4	-
		sockeye	4	-

Table 1 (cont'd)

No.	Author/Source	Species	SOS Batch	Data point Frequency Mortality
h	Big Qualicum River, B.C. 1979	chum	3	3
i	Big Qualicum River, B.C. 1981	chum	5	1
j	Big Qualicum River, B.C. 1983	chum	1	2
k	Quinsam River, B.C. 1978	coho	5	5
l	Quinsam River, B.C. 1979	coho	2	-
m	Quinsam River, B.C. 1981	coho	5	-
n	Glendale River, B.C. 1975	pink	3	3
o	Glendale River, B.C. 1975	pink	20	-
p	Glendale River, B.C. 1978	pink	3	3
q	Quinsam River, B.C. 1981	pink	5	2
s	Fulton River, B.C. 1976	sockeye	20	11
t	Fulton River, B.C. 1978	sockeye	3	3
u	Fulton River, B.C. 1981	sockeye	5	-
v	Stikine River, B.C. 1984	sockeye	8	7
w	Nimpkish, River, B.C. 1984	sockeye	8	8
x	Big Qualicum River, B.C. 1978	steelhead	-	3
y	Big Qualicum River, B.C. 1979	steelhead	5	-
z	Big Qualicum River, B.C. 1980	steelhead	1	1
aa	Big Qualicum River, B.C. 1984	steelhead	4	4
53	Vernier (1959)	rainbow	1	-
54	Wales (1961)	steelhead	5	0
55	Wallitch (1901)	chinook	57	-
56	Wild (1973)	chum	9	-
57	Wither and Morley (1970)	chum	5	1
		pink	4	-
		sockeye	4	-

Tables 2-25

Published and unpublished data on times to median hatch and percentage mortality at constant and ambient temperatures, and experimental data on stages of embryonic development at constant temperatures for chinook (Oncorhynchus tshawytscha), chum (O. keta), coho (O. kisutch), pink (O. gorbuscha), sockeye (O. nerka) and rainbow and steelhead trout (Salmo gairdneri).

CHINOOK
Oncorhynchus tshawytscha

Table 2. Chinook salmon egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source Code	Temp.	Days	Source Code
1.6	206.3	5	9.9	52.2	5	12.8	41.	9
1.7	204.0	5	10.	55.	19	12.8	41.	9
3.0	160.3	5	9.5	53.0	52.c	12.8	42.	9
3.0	157.5	5	9.9	54.8	52.e	12.8	41.	9
3.4	148.	48	10.1	50.9	41	12.8	41.	9
2.9	145.0	52.c	10.1	50.	55	12.8	40.0	41
4.3	128.6	41	10.3	50.2	41	12.8	42.	9
4.4	121.1	5	10.5	49.0	11	12.8	41.	9
4.5	123.5	5	10.5	49.5	11	12.9	46.4	41
4.5	120.1	5	10.4	51.2	52.d	12.3	39.2	52.e
4.7	108.8	52.e	10.5	50.	11	13.0	39.7	41
5.0	109.4	52.d	10.5	50.	11	13.1	38.0	41
5.8	94.7	5	10.8	46.0	30	13.5	36.5	11
5.9	94.0	5	11.0	47.3	52.d	13.5	38.0	11
5.9	92.4	5	11.1	46.	45	13.5	37.0	11
6.	95.	19	11.1	46.	45	13.5	36.5	11
5.8	94.1	52.c	11.1	46.	45	13.9	36.0	52.b
6.0	85.3	30	11.3	44.	45	14.2	36.7	5
6.1	95.	48	11.3	46.0	17	14.2	36.7	5
6.3	95.5	30	11.3	44.	45	14.3	34.0	41
6.4	79.5	52.e	11.3	44.	45	15.0	33.1	52.b
7.1	79.1	41	11.4	43.	45	15.0	33.0	11
7.1	78.9	5	11.4	44.	45	15.0	34.0	11
7.2	78.9	5	11.4	43.	45	15.1	34.6	52.d
7.2	76.8	5	11.7	43.0	30	15.0	33.5	11
7.3	73.4	41	11.6	43.2	52.c	15.0	34.0	11
7.3	73.1	30	12.	44.	19.	15.3	34.3	5
7.8	72.8	30	12.0	43.	11	15.3	34.3	5
8.	71.	19	12.0	43.5	11	15.4	32.1	41
8.	70.1	52.c	12.0	43.0	11	15.7	34.0	41
8.0	69.0	30	12.0	42.5	11	14.9	30.5	52.e
8.0	69.2	30	12.0	46.0	17	16.7	30.7	41
8.2	68.0	30	12.6	46.7	41	16.9	31.4	41
8.2	75.1	30	12.6	38.8	41	17.2	33.	9
8.6	63.4	5	12.7	41.9	5	17.2	34.	9
8.6	63.4	5	12.7	41.9	5	18.1	28.0	41
9.5	52.6	30	12.8	41.	9	18.3	36.	9
9.6	55.4	5	12.8	42.	9	18.3	36.	9
9.8	59.	37	12.8	42.	9	19.4	37.	9
						19.4	40.0	9

*See Table 1.

Table 3. Chinook salmon egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source code	Temp.	Days	Source code
2.3	172.0	41	5.9	84	55	8.6	62.3	41
2.5	158.0	41	5.9	88	55	8.6	63.0	30
2.8	144.0	41	5.9	84	55	8.6	62.0	30
3.8	132.0	41	5.9	84	55	8.6	63.3	30
3.8	133.0	41	6.0	82	55	8.7	39.9	30
3.8	124.2	30	6.0	84	55	8.7	63.0	30
3.9	124.0	41	6.0	87	55	8.8	59	18
3.9	125.0	41	6.1	83	55	8.9	56	55
4.3	112.0	41	6.1	81	55	8.9	61	18
4.7	98.2	30	6.1	81	55	9.0	60.0	30
4.8	102.0	41	6.1	83	55	9.1	62.2	41
5.1	104.0	30	6.1	82	55	9.1	59.2	30
5.3	97.6	41	6.1	82	55	9.2	59.0	30
5.3	97.4	41	6.1	81	55	9.3	57.7	30
5.6	89	55	6.1	84	55	9.4	60.2	30
5.6	88	55	6.1	82	55	9.4	57.5	30
5.6	89	55	6.3	83.0	30	9.4	54	55
5.6	88	55	6.3	84.0	30	9.5	58.7	30
5.6	88	55	6.3	80	55	9.6	58.7	30
5.6	86	55	6.3	82	55	9.6	53.0	30
5.6	88	55	6.5	82.9	30	9.7	56.0	41
5.7	87	55	6.5	80	55	9.7	52	55
5.7	85	55	7.1	83.7	30	9.8	52	55
5.7	89	55	7.1	69.3	30	9.9	57.8	41
5.7	87	55	7.3	69	18	10.0	50	55
5.7	90	55	7.6	69.1	30	10.1	51.8	41
5.7	90	55	7.8	70.3	30	10.1	50	55
5.7	89	55	7.8	66	18	10.2	52.0	30
5.7	86	55	7.8	67.3	30	10.2	49.0	30
5.7	86	55	7.9	70.3	30	10.3	48.1	30
5.7	86	55	7.9	82.6	30	10.3	50.0	30
5.7	87	55	8.0	68.0	30	10.3	49	55
5.7	86	55	8.0	66.9	30	10.3	48.6	41
5.7	87	55	8.1	62.1	30	10.4	48	55
5.7	85	55	8.2	61.5	30	10.5	50.0	30
5.8	87	55	8.2	51	18	10.5	48	55
5.8	95.7	30	8.3	65.0	41	10.6	48.0	30
5.8	86	55	8.3	56.1	41	10.6	61.7	30
5.8	87	55	8.3	57.8	30	10.6	48.0	30
5.8	87	55	8.3	52	18	10.7	50.3	41
5.9	87	55	8.3	62.1	30	10.8	44.0	30
5.9	86	55	8.4	62.5	41	10.8	46.4	30
5.9	85	55	8.4	66.8	30	10.9	49.0	30

Table 3 (cont'd)

Temp.	Days	Source code*	Temp.	Days	Source code	Temp.	Days	Source code
10.9	49.0	30	13.5	38.1	41	14.7	32.4	41
11.2	46.3	30	13.5	37	9	15.0	35	9
11.5	45.2	30	13.5	37	9	15.0	32.7	41
12.7	43.3	41	13.5	37	9	15.0	35	9
12.9	42.3	41	13.6	35.5	41	15.0	32.7	41
13.0	40.	9	13.8	37	9	15.0	32.7	41
13.0	39	9	13.9	37	9	15.2	36	9
13.2	39	9	13.9	36	9	15.2	36	9
13.2	39	9	14.0	35	9	15.6	36	9
13.2	38	9	14.0	37	9	15.6	36	9
13.2	43.4	41	14.0	36	9	16.3	33.5	41
13.2	39	9	14.4	37	9	16.3	34	9
13.3	40.3	41	14.4	36	9	16.3	31.9	41
13.3	40.9	30	14.5	40	9	16.4	33	9
13.3	38.7	41	14.5	35	9	16.8	28.4	41
13.4	38	9	14.5	35	9			

*See Table 1.

Table 4. Chinook egg mortality (%) during incubation from fertilization to 50% hatch at various temperatures (°C).

Temp.	%	Source code*	Temp.	%	Source code
1.10	100.0	37	10.30	13.0	41
1.60	98.7	37	10.50	9.1	52.d
1.60	98.7	5	11.00	13.5	52.a
1.70	99.6	5	11.40	1.8	45
1.70	99.6	37	11.40	0.0	45
2.90	30.9	5	11.40	7.7	45
2.90	30.9	37	12.00	16.6	14
3.00	52.6	37	12.00	4.5	14
3.00	52.6	5	12.00	9.6	14
3.50	49.9	52.c	12.00	4.0	14
4.30	6.0	41	12.00	15.2	14
4.40	2.7	37	12.00	5.4	14
4.50	10.2	5	12.00	10.0	14
4.50	18.5	5	12.00	4.9	14
4.50	18.5	37	12.00	22.1	52.c
4.50	10.2	37	12.00	10.7	41
5.00	21.2	52.a	12.60	5.7	37
5.80	1.3	5	12.60	2.0	41
5.80	2.1	37	12.70	5.7	5
5.80	1.3	37	12.80	4.1	9
5.90	6.1	5	12.80	5.0	41
5.90	2.1	5	12.80	5.1	9
5.90	6.0	37	12.80	4.2	9
6.00	19.3	52.c	12.80	4.0	9
6.00	7.1	4	12.80	4.4	9
7.00	0.7	37	12.80	4.0	9
7.10	6.0	41	12.80	3.3	9
7.10	0.7	5	12.80	3.3	9
7.15	0.9	37	12.80	2.0	9
7.20	18.4	5	12.80	5.9	9
7.20	0.9	5	14.00	11.1	52.b
7.30	1.0	41	14.10	6.1	37
8.00	11.4	52.c	14.20	6.1	5
8.00	8.3	41	14.30	2.0	41
8.50	0.6	5	15.00	40.1	52.d
8.50	0.6	37	15.00	11.0	52.b
9.60	1.1	5	15.30	12.4	37
9.80	7.1	37	15.30	12.4	5
9.90	7.1	5	15.40	35.0	41
10.00	10.0	52.c	15.70	22.0	41
10.00	9.3	41	16.70	85.0	41
10.10	2.0	41	16.90	78.0	41
			18.10	99.0	41

*See Table 1.

Table 5. Embryonic development in the chinook egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at seven nominal (constant) temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
3.5	3.0	36.0	2	8.0	7.7	13.0	2
	3.0	39.0	3		7.7	17.0	3
	3.1	55.0	4		7.7	23.0	4
	3.1	60.0	5		7.8	27.0	5
	3.1	73.0	6		7.8	35.5	6
	3.1	100.0	7		7.8	44.5	7
	3.7	136.0	8		7.8	65.0	8
	3.2	315.0	9		7.8	163.0	9
	3.4	650.0	10		8.0	291.0	10
	3.2	740.0	11		8.0	382.0	11
	3.3	867.0	12		8.0	390.0	12
	3.2	950.0	14		8.0	411.0	14
	3.3	1020.0	16		8.0	455.0	16
	3.2	1120.0	17		8.0	485.0	17
	3.2	1270.0	18		8.0	580.0	18
	3.1	1725.0	19		8.0	700.0	19
	3.1	1850.0	20		8.0	771.0	20
	3.1	1875.0	21		8.0	795.0	21
	3.2	2163.0	22		8.0	915.0	22
	3.0	3050.0	23		8.0	1515.0	23
	2.9	3480.0	50%h		8.0	1680.0	50%h
6.0	5.7	16.2	2	10.0	9.5	10.0	2
	5.7	23.0	3		9.5	13.5	3
	5.7	33.0	4		9.5	17.0	4
	5.7	37.0	5		9.5	21.0	5
	5.7	43.5	6		9.7	25.0	6
	5.7	56.0	7		9.7	29.0	7
	5.7	100.0	8		9.7	52.0	8
	5.7	220.0	9		9.8	167.0	9
	5.7	387.0	10		9.9	200.0	10
	5.7	437.0	11		9.9	240.0	11
	5.7	555.0	12		9.9	315.0	14
	5.7	610.0	14		9.9	339.0	16
	5.7	620.0	16		9.9	360.0	17
	5.8	723.0	17		9.9	430.0	18
	5.8	771.0	18		9.9	520.0	19
	5.8	960.0	19		9.9	603.0	20
	5.8	1155.0	20		9.9	651.0	21
	5.8	1179.0	21		9.9	747.0	22
	5.8	1280.0	22		9.9	1131.0	23
	5.8	1995.0	23		9.9	1316.0	50%h
	5.8	2259.0	50%h				

Table 5 (cont'd)

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
10.5	9.8	12.4	3				
	10.1	36.8	7	12.0	11.7	220.0	12
	10.2	87.0	8		11.7	240.0	14
	10.3	136.0	9		11.7	267.0	16
	10.4	185.0	10		11.7	310.0	17
	10.4	237.0	11		11.7	332.0	18
	10.4	283.0	12		11.7	433.0	19
	10.4	309.0	14		11.7	470.0	20
	10.3	376.0	17		11.6	507.0	21
	10.3	400.0	18		11.6	579.0	22
	10.3	494.0	19		11.6	943.0	23
	10.4	525.0	20		11.6	1038.0	50%h
	10.3	593.0	21				
	10.3	712.0	22	15.0	15.1	12.4	5
	10.4	1051.0	23		15.1	77.0	9
	10.4	1230.0	50%h		15.1	136.0	10
					15.1	185.0	12
12.0	12.0	9.0	2		15.1	190.0	14
	12.0	10.8	3		15.1	210.0	16
	12.0	14.0	4		15.1	258.0	17
	12.0	15.0	5		15.1	283.0	18
	12.0	17.0	6		15.1	309.0	19
	12.0	23.0	7		15.1	352.0	20
	11.7	36.0	8		15.0	400.0	21
	11.7	76.0	9		15.1	525.0	22
	11.7	163.0	10		15.1	664.0	23
	11.7	200.0	11		15.1	831.0	50%h

*Egg source, Quinsam River Hatchery, B.C.

CHUM
Oncorhynchus keta

Table 6. Chum salmon egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source code
3.0	130.2	52.j	8.6	65.8	23
3.4	125.	46	8.7	60.	40
3.5	127.	52.g	9.3	57.3	7
4.8	102.8	52.i	9.3	58.1	7
5.0	99.	52.g	9.3	58.2	7
6.0	80.8	52.f	9.3	57.6	7
6.4	78.1	52.g	9.3	58.1	7
6.5	76.1	52.i	9.3	58.0	7
7.2	68.5	30	9.3	57.6	7
7.2	69.4	56	9.3	57.2	7
7.2	71.4	56	9.5	53.5	52.f
7.2	72.2	56	9.9	60.8	1
7.31	77	31	9.5	52.9	52.i
7.31	76	31	10.0	57.5	1
7.4	68.1	30	10.0	52.3	56
7.41	77	31	10.0	51.8	56
7.41	77	31	10.0	52.	52.h
7.41	77	31	10.0	52.1	56
7.43	75	31	10.1	48.0	30
7.43	75	31	10.2	52.0	1
7.43	75	31	10.2	52.1	1
7.43	75	31	10.4	51.	46
7.43	75	31	10.4	46.8	52.g
7.46	75	31	11.1	48.7	57
7.46	77	31	11.1	47.6	57
7.48	77	31	11.1	48.6	57
7.48	77	31	11.1	50.2	57
7.49	76	31	11.1	48.4	57
7.50	76	31	11.9	48.	23
7.51	75	31	12.0	42.6	52.f
7.52	77	31	12.78	40.7	56
7.56	74	31	12.78	40.7	56
7.58	75	31	12.78	40.7	56
7.6	66.6	30	12.3	41.0	52.i
7.61	77	31	13.0	42.5	52.h
7.62	75	31	14.0	38.6	52.f
7.8	62.9	30	15.0	35.6	52.f
7.8	69.4	30	14.9	35.	52.g
7.8	67.1	30	15.1	34.0	52.i
8.2	65.5	30	16.0	35.	52.h
8.3	61.7	30			

*See Table 1.

Table 7. Chum salmon egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*
3.2	127.0	50
3.2	127.0	50
3.2	127.0	50
3.3	125.0	8
3.3	125.0	48
3.4	118.0	50
3.5	117.0	50
3.6	120.0	50
4.1	130.	30
4.2	120.	30
4.2	114.	30
5.5	91.3	30
6.1	74.8	30
6.6	77.0	30
6.8	73.9	30
6.9	72.	30
7.0	78.6	30
8.8	60.0	48
8.8	84.2	30
9.9	53.0	48
10.1	66.2	30

*See Table 1.

Table 8. Chum egg mortality (%) during incubation, from fertilization to 50% hatch, at various temperatures (°C).

Temp.	%	Source code*
1.1	100.0	52.j
3.0	10.5	52.j
3.5	24.6	52.g
5.0	9.0	52.g
6.0	3.2	52.f
6.5	10.0	52.g
9.3	10.0	7
9.3	4.0	7
9.3	1.0	7
9.3	1.0	7
9.3	3.0	7
9.3	0.0	7
9.3	4.0	7
9.3	16.0	7
9.5	4.8	52.f
9.9	0.0	1
10.0	1.8	52.h
10.0	0.0	1
10.2	0.0	1
10.2	0.0	1
11.1	3.0	57
12.0	4.3	52.f
13.0	2.4	52.h
14.0	8.4	52.f
15.0	16.2	52.f
15.0	31.1	52.g
16.0	6.7	52.h
16.0	14.5	52.i

*See Table 1.

Table 9. Embryonic development in the chum egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at five nominal (constant) temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
3.5	3.5	26.0	2	6.5	6.4	12.8	2
	3.5	34.1	3		6.4	17.5	3
	3.5	46.0	4		6.4	26.0	4
	3.5	59.0	5		6.4	33.0	5
	3.5	84.0	6		6.4	40.0	6
	3.5	119.0	7		6.4	47.0	7
	3.5	201.0	8		6.4	84.0	8
	3.5	360.0	9		6.4	188.0	9
	3.5	590.0	10		6.4	303.0	10
	3.5	937.0	11		6.4	432.0	11
	3.5	1110.0	12		6.4	508.0	12
	3.5	1150.0	14		6.4	570.0	14
	3.5	1190.0	16		6.4	600.0	16
	3.5	1300.0	17		6.4	683.0	17
	3.5	1443.0	18		6.4	715.0	18
	3.5	1510.0	19		6.4	890.0	19
	3.4	1685.0	20		6.4	910.0	20
	3.5	1760.0	21		6.4	950.0	21
	3.5	2110.0	22		6.4	1265.0	22
	3.5	3050.0	50%h		6.4	1665.0	23
					6.4	1875.0	50%h
5.0	5.1	17.4	2				
	5.1	23.0	3	10.5	10.4	9.0	2
	5.1	36.0	4		10.4	12.0	3
	5.1	40.0	5		10.4	17.0	4
	5.2	53.0	6		10.4	20.0	5
	5.2	68.0	7		10.4	23.0	6
	5.2	115.0	8		10.4	29.5	7
	5.2	260.0	9		10.4	51.0	8
	5.1	454.0	10		10.4	110.0	9
	5.0	600.0	11		10.4	168.0	10
	5.0	690.0	12		10.4	247.0	11
	5.0	766.0	14		10.4	269.0	12
	5.0	1004.0	18		10.4	295.0	14
	5.0	1120.0	19		10.4	300.0	16
	5.0	1245.0	20		10.4	356.0	17
	5.0	1280.0	21		10.4	380.0	18
	5.0	1580.0	22		10.4	450.0	19
	5.0	2290.0	23		10.4	500.0	20
	5.0	2375.0	50%h		10.4	525.0	21
					10.4	660.0	22
					10.4	945.0	23
					10.4	1124.0	50%h

Table 9 (cont'd)

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
15.0	15.3	6.0	2
	15.3	8.3	3
	15.3	12.0	4
	15.3	13.3	5
	15.3	15.0	6
	15.3	17.5	7
	15.0	36.1	8
	15.1	75.0	9
	15.1	110.0	10
	15.0	155.0	11
	15.0	170.0	12
	15.0	190.0	14
	14.9	201.0	16
	14.9	215.0	17
	15.0	235.0	18
	15.0	286.0	19
	15.0	331.0	20
	15.0	356.0	21
	15.0	480.0	22
	15.0	655.0	23
	14.9	840.0	50%h

*Egg source, Big Qualicum River.

Table 9 (cont'd)

Mon. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
15.0	15.3	6.0	2
	15.3	8.3	3
	15.3	12.0	4
	15.3	13.3	5
	15.3	15.0	6
	15.3	17.5	7
	15.0	36.1	8
	15.1	75.0	9
	15.1	110.0	10
	15.0	155.0	11
	15.0	170.0	12
	15.0	190.0	14
	14.9	201.0	16
	14.9	215.0	17
	15.0	235.0	18
	15.0	286.0	19
	15.0	331.0	20
	15.0	356.0	21
	15.0	480.0	22
	15.0	655.0	23
	14.9	840.0	SOXH

*Egg source, Big Quelicum River.

COHO
Oncorhynchus kisutch

Table 10. Coho salmon egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source code
1.3	194.	10	8.4	58.	10
2.5	162.	10	8.5	58.8	30
3.0	144.	10	8.5	58.8	30
3.0	147.	10	9.2	49.	43
3.5	125.	52.k	9.2	50.	43
4.0	115.	10	9.2	50.	43
4.0	114.	10	9.2	49.	43
4.5	94.0	48	9.9	45.	22
4.0	93.0	52.m	10.2	44.	43
4.0	93.1	52.m	10.2	47.	10
4.0	95.1	52.m	10.2	46.	10
4.0	93.0	52.m	10.2	44.	43
4.0	93.0	52.m	10.2	44.	43
5.7	80.3	30	10.2	44.	43
6.0	78.3	30	10.4	44.0	52.k
6.0	78.3	30	10.4	43.	52.k
6.1	83.	10	12.0	35.	32
6.1	83.	10	12.4	37.	10
6.4	74.0	52.k	12.4	38.	10
7.6	65.9	30	13.5	30.7	52.k
7.8	69.1	30	14.4	32.	10
8.4	58.	10	14.4	32.	10

*See Table 1.

Table 11. Coho salmon egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source code
2.2	148.	48	5.9	81.4	30
2.2	181.1	30	5.9	79.1	30
3.5	105.9	30	5.9	79.1	30
3.8	113.0	30	6.1	78.4	30
3.9	107.7	30	6.1	80.4	30
4.0	87.6	30	6.2	72.7	30
4.0	115.7	30	6.2	76.9	30
4.0	111.9	30	6.2	74.5	30
4.1	124.	48	6.3	72.7	30
4.2	112.6	30	6.3	74.0	30
4.3	118.2	30	6.3	74.0	30
4.4	112.8	30	6.6	70.7	30
4.5	99.0	30	6.8	66.9	30
4.6	99.6	30	6.9	61.0	30
4.7	103.1	30	6.9	66.8	30
4.7	104.4	30	7.1	59.3	30
4.8	120.0	30	7.1	68.3	30
4.8	107.6	30	7.5	63.9	30
5.3	73.6	30	7.6	71.1	30
5.5	82.3	30	7.7	61	33
5.5	83.8	30	7.8	54.4	30
5.5	85.2	30	7.9	46.3	30
5.5	83.4	30	7.9	53.4	30
5.5	85.0	30	8.7	45.1	30
5.6	87.7	30	8.9	47	48
5.6	85.0	30	8.9	48	48
5.7	73.2	30	9.3	48.4	30
5.8	84.1	30	10.0	40.8	30
5.8	82.7	30	10.5	44.2	30
5.8	101.7	30	10.7	38	48
5.9	81.4	30	10.7	36	48
5.9	81.7	30			

*See Table 1.

Table 12. Coho egg mortality (%) during incubation, from fertilization to 50% hatch, at various temperatures (°C).

Temp.	%	Source code*
1.3	15.2	10
2.5	13.6	10
3.0	13.8	10
3.0	5.8	10
3.5	3.9	52.k
4.0	7.7	10
4.0	4.8	10
6.1	17.5	10
6.1	19.5	10
6.5	12.0	52.k
8.4	10.0	10
8.4	10.0	10
10.2	7.5	10
10.2	27.5	10
10.2	7.0	43
10.5	22.8	52.k
12.4	13.0	10
12.4	21.4	10
13.5	27.3	52.k
14.4	84.8	10
14.4	85.8	10
15.0	100.0	52.k
17.0	100.0	10
17.0	100.0	10

*See Table 1.

Table 13. Embryonic development in the coho egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at five nominal (constant) temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
3.5	3.5	21.3	2	6.5	6.4	12.8	2
	3.5	29.8	3		6.4	18.2	3
	3.5	42.0	4		6.4	24.5	4
	3.5	47.7	5		6.4	27.3	5
	3.5	59.6	6		6.4	32.6	6
	3.5	80.0	7		6.4	39.0	7
	3.5	118.0	8		6.4	68.0	8
	3.5	350.0	9		6.4	176.0	9
	3.5	467.0	10		6.4	278.0	10
	3.5	580.0	11		6.4	310.0	11
	3.5	640.0	12		6.4	410.	12
	3.5	670.0	14		6.4	430.0	14
	3.5	760.0	16		6.4	450.0	16
	3.5	860.0	17		6.4	500.0	17
	3.5	990.0	18		6.4	588.0	18
	3.5	1280.0	19		6.4	766.0	19
	3.5	1443.0	20		6.4	890.0	20
	3.5	1668.0	21		6.4	910.0	21
	3.5	1700.0	22		6.4	1008.0	22
	3.5	2500.0	23		6.4	1678.0	23
	3.5	2947.0	50%h		6.4	1780.0	50%h
5.0	5.1	14.0	2	10.5	10.4	7.0	2
	5.1	23.0	3		10.4	11.0	3
	5.1	31.0	4		10.4	13.0	4
	5.1	33.0	5		10.4	16.0	5
	5.1	42.0	6		10.4	20.0	6
	5.2	50.0	7		10.4	33.0	7
	5.2	80.0	8		10.4	49.0	8
	5.2	262.0	9		10.4	120.0	9
	5.1	352.0	10		10.4	175.0	10
	5.1	452.0	11		10.4	203.0	11
	5.1	508.0	12		10.4	240.0	12
	5.1	575.0	14		10.4	270.0	14
	5.1	585.0	16		10.4	303.0	16
	5.0	680.0	17		10.4	340.0	17
	5.0	828.0	18		10.4	360.0	18
	5.0	1010.0	19		10.4	446.0	19
	5.0	1100.0	20		10.4	530.0	20
	5.0	1125.0	21		10.4	590.0	22
	5.0	1300.0	22		10.4	800.0	23
	5.0	1900.0	23		10.4	1010.0	50%h
	5.0	2282.0	50%h				

Table 13 (cont'd)

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
13.5	13.6	4.0	2
	13.6	7.0	3
	13.6	11.3	4
	13.6	15.2	5
	13.6	17.0	6
	13.6	22.8	7
	13.6	39.0	8
	13.6	100.0	9
	13.6	140.0	10
	13.6	165.0	11
	13.6	172.0	12
	13.6	195.0	14
	13.6	230.0	16
	13.6	250.0	17
	13.6	270.0	18
	13.6	351.0	19
	13.6	360.0	20
	13.5	446.0	21
	13.5	496.0	22
	13.5	736.0	50%h

*Egg source, Quinsam River.

Table 13 (cont'd)

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
13.5	13.6	4.0	Z
	13.6	7.0	3
	13.6	11.3	4
	13.6	15.2	5
	13.6	17.0	6
	13.6	22.8	7
	13.6	39.0	8
	13.6	100.0	9
	13.6	140.0	10
	13.6	165.0	11
	13.6	172.0	12
	13.6	195.0	14
	13.6	230.0	16
	13.6	250.0	17
	13.6	270.0	18
	13.6	351.0	19
	13.6	360.0	20
	13.5	446.0	21
	13.5	496.0	22
	13.5	736.0	SOSM

*Egg source, Quinsam River.

PINK
Oncorhynchus gorbuscha

Table 14. Pink salmon egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*	Temp.	Days	Source code
3.4	125.0	47	11.0	57.	52.n
3.5	145.8	52.p	11.04	58.2	57
4.8	108.8	52.q	11.04	58.7	57
5.0	112.0	52.n	11.07	57.1	57
6.0	99.5	52.o	11.07	57.2	57
6.0	99.5	52.o	11.9	56.5	52.o
6.0	99.5	52.o	11.9	56.5	52.o
6.0	98.8	52.o	11.9	56.5	52.o
6.4	92.9	52.p	11.9	56.5	52.o
7.	74.	27	13	51	27
6.6	93.0	52.q	12.8	50.0	52.q
7.9	79.0	16	14.0	52.8	52.o
8.0	74.	52.n	14.0	52.8	52.o
9.	69.	27	14.0	52.8	52.o
9.5	68.5	52.o	14.0	52.8	52.o
9.5	68.5	52.o	15	47	27
9.5	68.5	52.o	15.0	50.6	52.p
9.5	68.5	52.o	15.0	51.5	52.o
9.9	59.7	38	15.0	51.5	52.o
9.4	61.9	52.q	15.0	51.5	52.o
10.4	61.0	47	15.0	51.5	52.o
11.	62	27	16.2	49.0	52.q

*See Table 1.

Table 15. Pink salmon egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*
2.9	124	48
3.1	154	2
4.0	128	2
4.1	115	48
5.1	107	2
5.4	99	48
6.2	93	2
6.9	85	48
7.5	82.	23
8.9	67	48

*See Table 1.

Table 16. Pink egg mortality (%) during incubation, from fertilization to 50% hatch, at various temperatures (°C).

Temp.	%	Source code*
2.0	100.00	2
3.0	82.00	2
3.5	67.30	52.p
4.5	7.00	2
5.0	21.60	52.n
6.5	11.10	52.p
8.0	4.13	52.n
9.9	10.50	38
11.0	2.30	52.n
13.0	6.60	52.q
15.0	12.00	52.p
16.0	70.50	52.q

*See Table 1.

Table 17. Embryonic development in the pink egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at six nomial (constant) temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
3.5	3.5	33.0	2	6.5	6.4	16.8	2
	3.5	39.0	3		6.4	21.8	3
	3.5	41.8	4		6.5	26.4	4
	3.6	54.0	5		6.5	33.8	5
	3.6	66.8	6		6.5	42.5	6
	3.6	90.0	7		6.6	51.0	7
	3.6	163.0	8		6.5	86.0	8
	3.6	403.0	9		6.4	204.0	9
	3.5	630.0	10		6.4	326.0	10
	3.5	960.0	11		6.4	452.0	11
	3.5	1060.0	12		6.4	540.0	12
	3.5	1315.0	14		6.4	588.0	14
	3.5	1380.0	16		6.4	610.0	16
	3.5	1510.0	18		6.4	665.0	17
	3.5	1841.0	20		6.4	724.0	18
	3.5	2009.0	21		6.4	842.0	19
	3.4	2347.0	22		6.4	908.0	20
	3.4	3186.0	23		6.4	948.0	21
	3.5	3498.0	50%h		6.4	1330.0	22
					6.4	2000.0	23
5.0	4.9	19.8	2		6.4	2243.0	50%
	4.9	30.5	3				
	4.9	40.0	4	8.0	8.0	12.3	2
	4.9	44.0	5		8.0	15.0	3 h
	4.9	50.0	6		8.0	20.0	4
	4.9	63.0	7		8.0	25.0	5
	4.9	102.0	8		8.0	32.5	6
	4.9	172.0	9		8.0	39.5	7
	4.9	260.0	10		8.0	58.0	8
	4.9	645.0	11		8.0	91.0	9
	4.9	850.0	12		8.0	255.0	10
	4.9	932.0	14		8.0	340.0	11
	4.9	1100.0	17		8.0	500.0	12
	4.9	1160.0	18		8.1	520.0	14
	4.9	1244.0	19		8.0	595.0	16
	4.9	1260.0	20		8.0	638.0	18
	4.9	1650.0	21		8.0	660.0	19
	5.0	2470.0	23		8.0	755.0	20
	5.0	2688.0	50%h		8.0	790.0	21
					8.0	1650.0	23
					8.0	1776.0	50%h

Table 17 (cont'd)

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
11.0	11.0	8.7	2	15.0	15.3	7.4	2
	11.0	11.7	3		15.3	8.1	3
	11.0	14.2	4		15.3	9.9	4
	11.0	17.2	5		15.3	12.8	5
	11.0	19.8	6		15.3	16.3	6
	10.4	25.0	7		15.3	21.0	7
	10.4	42.0	8		15.2	34.6	8
	10.4	61.0	9		15.1	60.0	9
	11.0	158.0	10		15.1	114.0	10
	11.0	233.0	11		15.1	143.0	11
	11.0	290.0	12		15.1	170.0	12
	11.0	330.0	14		15.1	192.0	14
	11.0	340.0	16		15.1	210.0	16
	11.0	370.0	17		15.1	240.0	17
	11.0	451.0	18		15.1	244.0	18
	11.0	470.0	19		15.1	296.0	19
	11.0	500.0	20		15.1	326.0	20
	11.0	565.0	21		15.1	376.0	21
	11.0	750.0	22		15.1	488.0	22
	11.0	1300.0	23		15.0	883.0	23
	11.0	1368.0	50%h		15.0	1215.0	50%h

*Egg source, Glendale River, B.C.

Table 17 (cont'd)

Hom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Hom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
11.0	11.0	0.7	2	15.0	15.3	7.4	2
	11.0	11.7	3		15.3	8.1	3
	11.0	14.2	4		15.3	9.9	4
	11.0	17.2	5		15.3	12.8	5
	11.0	19.8	6		15.3	16.3	6
	10.4	25.0	7		15.3	21.0	7
	10.4	42.0	8		15.2	34.6	8
	10.4	61.0	9		15.1	60.0	9
	11.0	158.0	10		15.1	114.0	10
	11.0	233.0	11		15.1	143.0	11
	11.0	260.0	12		15.1	170.0	12
	11.0	330.0	14		15.1	192.0	14
	11.0	340.0	16		15.1	210.0	16
	11.0	370.0	17		15.1	240.0	17
	11.0	451.0	18		15.1	244.0	18
	11.0	470.0	19		15.1	256.0	19
	11.0	500.0	20		15.1	326.0	20
	11.0	565.0	21		15.1	376.0	21
	11.0	750.0	22		15.1	488.0	22
	11.0	1300.0	23		15.0	883.0	23
	11.0	1368.0	SOKh		15.0	1215.0	SOKh

*Egg source, Glendale River, B.C.

SOCKEYE
Oncorhynchus nerka

Table 18. Sockeye salmon egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*
3.2	177	48
3.5	154.8	52.t
4.3	154	48
4.3	154	48
4.7	116.0	52.u
5.0	119.0	51
5.0	119.0	51
6.0	113.8	52.s
6.0	113.8	52.s
6.0	113.8	52.s
6.0	112.4	52.s
6.4	98.5	52.t
6.6	96.9	52.u
8.0	80.0	51
8.0	80.0	51
8.1	82.8	4
9.4	73.5	52.s
9.4	73.6	52.s
9.4	73.5	52.s
9.4	73.4	52.s
9.5	64.8	52.u
10.0	63.0	36
10.9	69.3	57
10.9	69.3	57
10.9	66.9	57
10.9	68.6	57
11.0	58.0	51
11.0	57.0	51
12.0	57.5	52.s
12.0	57.5	52.s
12.0	57.5	52.s
12.0	57.5	52.s
12.8	48.9	52.u
14.0	51.5	52.s
14.0	51.5	52.s
14.0	50.7	52.s
14.0	50.7	52.s
15.0	44.6	52.t
15.0	48.6	52.s
15.0	48.6	52.s
15.0	48.5	52.s
15.0	48.6	52.s
16.3	41.9	52.u

*See Table 1.

Table 19. Sockeye salmon egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*
1.1	203.5	52.v
1.1	202.5	52.v
1.3	223.2	52.w
1.3	222.0	52.w
2.1	179.5	52.v
2.1	178.0	52.v
2.2	165.	13
2.2	176.0	52.w
2.4	183.9	52.w
2.9	140.	13
3.1	153.6	52.v
3.1	154.8	52.v
3.1	155.0	52.w
3.1	158.2	52.w
3.2	140.	13
3.3	130.	13
3.6	117.	13
3.9	178.	13
4.1	126.8	52.v
4.1	131.2	52.v
4.1	139.0	52.w
4.1	140.6	52.w
4.1	145.	13
4.6	148.	47
4.8	115.	13
5.0	119.	13
7.05	94.	13
7.5	86.8	23
7.8	100.	13
8.2	92.	13
8.6	108.	13
9.4	76.	13
10.3	62.	13
10.6	60.	13
10.9	58.8	23
10.9	62.	47
11.05	52.	13
11.4	55.	47

*See Table 1.

Table 20. Sockeye egg mortality (%) during incubation, from fertilization to 50% hatch, at various temperatures (°C).

Temp.	%	Source code*	Temp.	%	Source code
1.1	4.1	52.v	8.01	11.8	52.r
1.1	4.1	52.v	9.50	21.1	52.r
1.3	92.3	52.w	9.50	23.8	52.s
1.3	64.3	52.w	9.50	22.5	52.s
1.65	80.3	6	9.50	20.3	52.s
2.1	5.6	52.v	10.00	18.8	36
2.2	3.0	52.w	10.00	8.6	6
2.4	2.8	52.w	10.00	13.0	6
3.00	37.3	6	11.00	16.1	52.r
3.1	1.1	52.v	12.00	23.2	52.s
3.1	4.2	52.v	12.00	22.9	52.s
3.1	5.0	52.w	12.00	21.7	52.s
3.1	1.2	52.w	12.00	18.0	52.s
3.50	26.4	52.t	12.70	14.2	6
4.1	1.7	52.v	14.00	25.8	52.s
4.1	3.2	52.v	14.00	26.0	52.s
4.1	15.0	52.w	14.00	24.0	52.s
4.1	4.0	52.w	14.00	27.1	52.s
4.50	13.6	6	14.10	26.8	6
5.00	12.3	52.r	15.00	36.8	52.r
5.80	9.1	6	15.00	36.1	52.s
5.80	2.7	6	15.00	43.4	52.s
6.00	18.6	52.s	15.00	22.8	52.s
6.00	28.0	52.s	15.00	35.8	52.t
6.00	25.6	52.s	15.50	43.5	6
6.00	26.3	52.s	16.90	83.0	6
6.50	21.2	52.t			

*See Table 1.

Table 21. Embryonic development in the sockeye egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at three nominal (constant) temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
5.0	4.9	15.0	2	8.0	8.0	390.0	14
	4.9	25.0	3		8.0	425.0	16
	4.9	30.0	4		8.0	485.0	17
	4.9	39.0	5		8.0	550.0	18
	4.9	46.0	6		8.0	665.0	19
	4.9	56.0	7		8.0	780.0	20
	5.0	120.0	8		8.0	820.0	21
	4.9	260.0	9		8.0	990.0	22
	4.9	380.0	10		8.0	1300.0	23
	4.9	550.0	11		9.0	1920.0	50%h
	4.9	630.0	12				
	4.9	670.0	14	11.0	11.0	7.0	2
	4.9	780.0	16		11.0	10.0	3
	4.9	825.0	17		11.1	14.0	4
	4.9	940.0	18		11.0	16.0	5
	4.9	1150.0	19		11.1	19.0	6
	4.9	1170.0	20		11.0	23.0	7
	4.9	1280.0	21		11.1	45.0	8
	4.9	1680.0	22		10.9	113.0	9
	5.0	2510.0	23		10.9	150.0	10
	5.0	2856.0	50%h		10.9	212.0	11
					10.9	250.0	12
8.0	8.0	10.2	2		10.9	280.0	14
	8.0	15.0	3		10.9	298.0	16
	8.0	20.8	4		10.9	338.0	17
	8.0	25.0	5		11.0	358.0	18
	8.0	31.0	6		11.0	428.0	19
	8.0	38.0	7		10.9	530.0	20
	8.0	70.8	8		10.9	575.0	21
	8.0	160.0	9		11.0	820.0	22
	8.0	245.0	10		11.0	1030.0	23
	8.0	310.0	11		11.0	1368.0	50%h
	8.0	375.0	12				

*Egg source, Fulton River.

RAINBOW AND STEELHEAD TROUT
Salmo gairdneri

Table 22. Rainbow (Rb) and steelhead (St) trout egg development from fertilization to 50% hatch (days) at various constant temperatures (°C).

Temp.	Days	Source code*	Type	Temp.	Days	Source code	Type	Temp.	Days.	Source code	Type
2.	115	49	Rb	8.7	40.3	24	Rb	11.3	30.	24	Rb
2.5	106.	15	Rb	8.85	35	50	St	11.5	30.3	24	Rb
2.8	93.0	24	Rb	9.04	34	50	St	11.5	27.0	12	Rb
3.	111	26	Rb	9.1	40.0	39	St	11.5	28.0	12	Rb
3.2	101.0	12	Rb	9.2	41	29	Rb	11.7	24.	24	Rb
4.0	84.9	52y	St	9.12	33	50	St	12.	27.1	20	St
4.4	79	34	St	9.26	35	50	St	12.0	27.9	39	St
4.5	80.	54	St	9.3	35.	24	Rb	12.0	25.0	12	Rb
4.5	72.9	24	Rb	9.42	38	50	St	12.2	26.	25	Rb
4.8	75.0	12	Rb	9.47	35	50	St	12.2	23.	25	Rb
5.	72	49	Rb	9.5	36.	45	Rb	12.4	24.0	12	Rb
5.	68	26	Rb	9.5	36.	45	Rb	12.5	27.	15	Rb
5.0	64.	15	Rb	9.5	36.	45	Rb	12.7	23.	34	St
5.8	63.0	12	Rb	9.5	36.	45	Rb	12.8	24.	54	St
6.0	61.7	39	St	9.51	33	50	St	12.8	24.5	12	Rb
6.0	51.9	33	St	9.52	35	50	St	12.9	18.	24	Rb
6.1	61.0	12	Rb	9.64	37	50	St	13.	28	49	Rb
6.2	61.0	12	Rb	9.7	36.	43	St	14.0	22.0	52y	St
6.5	57.5	24	Rb	9.76	33	50	St	14.5	21.0	12	Rb
7.	56	49	Rb	9.83	37	50	St	15.	26	26	Rb
7.	60	26	Rb	10.	38	26	Rb	15.0	22.	15	Rb
7.0	51.0	52y	St	10.	34	49	Rb	15.1	20.0	39	St
7.2	47	32	St	10.0	34.	43	St	15.5	18.0	12	Rb
7.2	45.0	12	Rb	10.0	30	34	St	15.6	19.	54	St
7.2	48	54	St	10.0	31.	54	St	16.0	20.	52.z	St
7.5	43.0	12	Rb	10.0	33.	15	Rb	17.5	18.	15	Rb
7.5	44.	15	Rb	10.0	35.5	53	Rb				
7.7	48	30	Rb	10.06	35	50	St				
7.7	44.0	12	Rb	10.1	34.4	20	St				
7.7	46.5	24	Rb	10.1	34	21	St				
7.8	48	30	Rb	10.1	33.	43	St				
7.8	49	30	Rb	10.2	33.	43	St				
7.8	44.0	12	Rb	10.24	33	50	St				
7.9	42	30	Rb	10.3	29.6	12	Rb				
7.9	43	30	Rb	10.3	28.0	12	Rb				
7.9	48.0	12	Rb	10.4	32.1	24	Rb				
7.9	46	30	Rb	10.40	38	50	St				
7.9	46	30	Rb	10.7	29.	43	St				
8.0	41.0	12	Rb	10.7	27.0	12	Rb				
8.1	46.2	20	St	10.7	29.2	12	Rb				
8.42	32	50	St	10.8	29.5	12	Rb				
8.5	45.0	52y	St	10.8	29.	43	St				

*See Table 1.

Table 23. Rainbow and steelhead trout egg development from fertilization to 50% hatch (days) at various ambient temperatures (°C).

Temp.	Days	Source code*
2	124	52aa
3	108	52aa
4	79	52aa
4.4	80	28
6.5	52.5	30
6.6	53.7	30
7.1	50.7	30
7.2	48	28
7.6	44.0	30
8.1	43.2	30
8.6	43.8	30
8.6	38.0	30
8.7	36.0	30
8.9	37.0	30
8.9	40.0	30
9.4	34.0	30
9.6	33.0	30
10.0	31	28
10.4	30.0	30
10.5	31	3
10.5	28.	42
10.6	30	3
10.7	31.0	30
10.7	31.0	30
11.1	27	3
12.7	24	28
13.	24.	42
15.5	19	28

*See Table 1.

Table 24. Rainbow and steelhead trout egg mortality (%) during incubation, from fertilization to 50% hatch, at various temperatures (°C).

Temp.	%	Source code*
1.0	54.0	52.aa
2.0	36.0	52.aa
3.0	18.0	52.aa
4.0	8.0	52.aa
4.0	1.4	52.x
6	4.0	39
8.5	1.0	52.x
9	2.5	39
9.2	23.1	29
9.7	20.0	43
10.0	22.0	43
10.5	13.0	43
12	3.5	39
14.0	7.7	52.x
15	15.0	39
16.0	93.0	52.z

*See Table 1.

Table 25. Embryonic development in the steel- head egg,* from fertilization to hatching in 23 stages (Vernier 1969; Ballard 1973), and to 50% hatch (hrs), at four nominal (constant) various constant temperatures (see Table 26 for description of stages) (F. P. J. Velsen, unpubl. data).

Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage	Nom. Temp. (°C)	Mean Temp. (°C)	Time (hr)	Stage
4.0	4.1	15.0	2	8.5	8.5	9.4	2
	4.1	32.5	3		8.5	10.2	3
	4.1	39.5	4		8.5	16.3	5
	4.1	47.0	5		8.5	23.5	6
	4.1	63.0	6		8.3	32.2	7
	4.1	83.0	7		8.3	54.3	8
	4.1	208.0	8		8.4	129.0	9
	4.1	235.0	9		8.5	182.0	10
	4.0	372.0	10		8.5	215.0	11
	4.0	482.0	12		8.5	231.0	12
	3.9	528.0	14		8.5	242.0	14
	4.0	600.0	16		8.5	268.0	16
	4.2	718.0	17		8.5	360.0	17
	4.0	800.0	18		8.4	384.0	18
	4.0	888.0	19		8.4	448.0	19
	4.0	957.0	20		8.4	500.0	20
	4.1	1140.0	21		8.1	528.0	21
	4.3	1380.0	22		8.2	680.0	22
	4.0	1867.0	23		8.3	908.0	23
	4.0	2040.0	50%h		8.3	1080.0	50%h
7.0	7.6	11.0	2	14.0	13.8	6.8	2
	7.6	15.0	3		13.8	8.3	3
	7.6	18.0	4		13.8	9.5	4
	7.6	23.0	5		13.8	11.8	5
	7.4	27.0	6		13.8	15.8	6
	7.4	35.0	7		13.8	21.0	7
	7.4	70.0	8		13.8	33.0	8
	7.3	143.0	9		13.9	67.0	9
	7.3	230.0	10		14.0	100.0	10
	7.3	251.0	11		14.0	116.0	11
	7.3	280.0	12		14.0	128.0	12
	7.3	290.0	14		14.0	136.0	14
	7.3	330.0	16		14.0	147.0	16
	7.3	425.0	17		14.0	170.0	17
	7.3	440.0	18		14.0	176.0	18
	7.0	582.0	19		14.1	222.0	19
	7.0	620.0	20		14.1	251.0	20
	7.0	670.0	21		14.1	283.0	21
	7.0	820.0	22		14.1	351.0	22
	7.0	1050.0	23		14.1	467.0	23
	7.1	1219.0	50%h		14.1	528.0	50%h

*Egg source, Big Qualicum River.

Table 26. Embryonic development in Pacific salmon and rainbow (steelhead) trout eggs from fertilization to hatching, in 23 stages, and the characteristics identifying each stage as they appear in 3 phases: cleavage, epiboly and convergence, and organogenesis (Vernier 1969; Ballard 1973).

Stage	Identification of Stage
	CLEAVAGE
1	bipolar differentiation: gathering of cytoplasm into a high mound at the animal pole; (bipolar differentiation also occurs in activated eggs that are not fertilized)
2	2 cells (first cleavage); the first 5 divisions are in the horizontal plane only; shape and arrangement of individual cells (blastomeres) is regular.
3	4 cells
4	8 cells
5	16 cells
6	32 cells; successive divisions occur in the horizontal as well as the vertical plane
7	morula (mulberry blastodisc) with numerous small cells visible and the establishment of the periblast surrounding the morula; the morula changes into a high, nearly hemispherical mound with a cobbled surface, later to become a lower mound with more gradual slopes and a nearly smooth surface
8	blastodisc flattening and starting to spread to nearly cover the periblast and the small oil droplets underneath it; posterior region of the blastodisc may start bulging
	EPIBOLY AND CONVERGENCE
9	appearance of embryonic shield, germ ring and terminal node
10	1/3 epiboly; germ ring 1/3 of the way toward total overgrowth of the yolk; neural groove on the embryonic shield
11	1/2 epiboly; overgrowth of yolk half completed and germ ring at the equator; formation of axial strand and neural keel; first somites; Kupffer's vesicle

Table 26 (cont'd)

Stage	Identification of Stage
12	3/4 epiboly; germ ring 3/4 overgrown; optic anlagen and three brain vesicles
13	yolk plug less than head width; germ ring narrowing toward vegetal pole; blastoderm nearly covering entire yolk; otic and optic placodes
14	yolk plug closed; yolk enclosed in cellular envelope (blastoderm)
	ORGANOGENESIS
15	hindbrain (rhombencephalon) enlarging; trunk-tail mound raised but not undercut
16	tail bud just free from yolk; one or two branchial pouches detectable; hindgut visible in side view
17	heart beat; 1st branchial cleft formed; cloaca visible and free from yolk sac; metencephalon and myelencephalon clearly distinct; head not undercut; spontaneous C-coil (movement) of trunk
18	1/4 of yolk surface vascularized; pectoral fin buds present; posterior half of body free from yolk sac; faint eye pigmentation
19	2/3 yolk surface vascularized; pectoral fins disc-shaped; head undercut to jaw level; mouth not open
20	eyes fully pigmented; yolk sac 3/4 vascularized; head free and mouth open; cerebral hemispheres forming
21	caudal flexing of the vertebral column; mesenchyme concentrations in caudal and anal fins; pectoral fins twitching
22	operculum covers 1st branchial slit; dorsal mesenchyme present
23	operculum covers all branchial arches; beginning of hatching; rhythmic breathing movements and frequent body wriggling and twitching; fin rays developing in anal, caudal, and dorsal fins