NOAA Technical Memorandum NMFS-AFSC-28

Effects of Water Temperature on Growth of Juvenile Pink Salmon *(Oncorhynchus goibuscha)*

by
Donald G. Mortensen[1] and Herman Savikko[2]

Auke Bay Laboratory'
Alaska Fisheries Science Center
11305 Glacier Highway
Juneau AK 99801-8626

Alaska Department of Fish and Game[2]
1255 W. Eighth Street
Juneau, AK 99801-8626

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary and Administrator
National Marine Fisheries Service
Rolland A. Schmitten, Assistant Adminstrator for Fisheries

December 1993

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Growth rates were calculated for recently emerged juvenile pink salmon *(Oncorhynchus gorbuscha)* held at constant water temperatures of 4°, 8°, and 12°_C for 6 weeks. The juveniles in all treatments were fed live zooplankton to excess, and exhibited a minimum growth rate of 1.64% body weight per day (bw/d) at 4°C and maximum growth rate of 3.25% bw/d at 12°C. Growth rates were significantly different ($P < 0.05$) between 4°, 8°, and 12°C treatment groups. A linear model of juvenile pink salmon growth was developed using data from this and five other studies. This model provides a simple and reliable means to project the potential growth rate of juvenile pink salmon when natural zooplankton prey is abundant and estuarine water temperatures are between 4.0° and 18.3°C.

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

INTRODUCTION

The pink salmon *(Oncorhynchus gorbuscha)* is the smallest and most abundant of the five species of Pacific salmon found in Alaska. After spending 12-14 months at sea, adult pink salmon return from the pelagic zones of the North Pacific, Ocean between July and September to spawn-in coastal streams (Bailey 1969). The eggs and alevins develop with-in interstices of the streambed gravel for several months. From mid-March to mid-June, the pink salmon emerge as fry and migrate downstream to the marine environment (Bailey et al. 1975). Once in the estuary, the pink salmon fry form tight schools in the nearshore surface waters and generally feed on small zooplankters (Bailey et al. 1975). During this period, surface water temperaturesrange from about 3.5° to 13°C (Ziemann et al. 1990) and prey-abundance ranges from 5 to 55 organisms per liter (Coyle and Paul 1990). Rapid growth of juvenile pink salmon (>4% body weight per day [bw/d]) during their early marine residence may be-an important mechanism that evolved to reduce size-dependent predation by larger fish (Parker 1971; Healey 1982; Hargreaves and LeBrasseur-1985). This rapid growth is-thought to be related to environmental conditions and food- availability. Water temperature is a significant environmental factor influencing the growth of juvenile chum salmon (0. keta) and sockeye salmon (O. nerka) (Paloheimo and Dickie 1966; Brett et al. 1969,; Brett 1979; Weatherley and Gill 1987). However, little work-has been done to isolate and assess the effects of water temperature on the growth of juvenile pink salmon.

Our objectives were to determine the maximum growth rate of recently emerged juvenile pink salmon over a range of-water temperatures most likely to be encountered. in the wild and to provide resource managers with a simple-'model of growth rate as a function of water temperature.

METHODS

Juvenile pink salmon were captured between late April and mid-May at a weir at the mouth of Auke Creek in Southeast Alaska. These fish were actively emigrating from their natal stream. The captured fish were reared at three different temperatures, with two aquaria for each temperature treatment.

We prepared the aquaria by pumping seawater (salinity 29%) directly from the 30 mm level (depth) of Auke Bay through a 10 µm sand filter to three head tanks at 5 l/min. A submersible electric water heater in each head tank warmed the water to 4°, 8°, or 12°.C (+ 0.l°C). Each head tank supplied a pair of 60 1 aquaria with warmed water at a rate of 1.0 l/min. Two broad-spectrum 25 W fluorescent lamps fitted with plastic light-diffuser panels provided each pair of aquaria with a water surface light intensity of 0.900 µW cm nm , approximating the natural light intensity (1 hour after sunrise on an overcast day at Auke Bay in mid-April) and day length (18 hours light) matched to the season and latitude.

Each aquarium was stocked with 250 juvenile pink salmon (4.2 fish/l). After the first 24 hours, any dead fish were replaced with live fish. Initially, average fish weight ranged from 266 to 290 mg (Table 1).

The fish were fed zooplankton collected from nearshore areas (3 to 20 m from shore) of Auke Bay by towing a 0.233 mm mesh, 1 m diameter conical net about 1 m below the water surface behind a small skiff. The live zooplankton were immediately placed in a 250 1 holding tank with about 200 1 of 6°C filtered and aerated seawater. Zooplankton were collected continuously during the day to ensure an adequate supply of prey for the experiment. The collected zooplankton consisted primarily of small calanoid copepods (Pseudocalanus sp. and *Acartia* sp.), copepodids and copepod nauplii, euphausiid larvae; polychaetes, barnacle nauplii and cyprids, and bivalve larvae. The relative number of each of the zooplankters was not determined. Occasionally when the amount of live zooplankton collected was not sufficient to feed the fish to satiation, the diet was supplemented with frozen zooplankton concentrate collected in Auke Bay before the experiment.

Zooplankton were placed in each aquarium at 2-hour intervals during the 18-hour light cycle, providing a standing zooplankton crop of at least 100 plankters per liter (pl/l).

For 6 weeks, 25 juvenile salmon were removed weekly from each tank (15 from each 12°C tank for weeks 5 and 6) and immobilized with a solution of MS-222 (methane tricaine-sulfonate) at the appropriate water temperature. The salmon were then weighed to the nearest milligram and allowed to recover in a tank of seawater held at the appropriate temperature before being returned to-the test aquaria.

The growth rate of the fish in each aquarium was described using an exponential model,

$$W_1 = W_0 * e^{Gd}, \qquad \text{(Eq. 1)}$$

where d *is* time in days, G is the daily growth rate, and W_0 and W_1 are the fish weight at the beginning and end of the time-period. Using this model, weight can be expressed as a linear function of time,

$$\ln(W_1) = Gd + \ln(W_0). \qquad \text{(Eq. 2)}$$

Linear regression was used to fit the natural log of observed weights to this equation. The computed slope of the regression equation is then the specific growth rate over the interval, which, when multiplied by 100, can be expressed as percent body weight gained per day (%bw/d).

Table 1.--Mean weights (mg) and standard deviations (in parentheses) of juvenile pink salmon reared at water temperatures of 4°, 8°, and 12°C over a 42-day period (*n* = 25).

	4°C Replicate		8°C Replicate		12°C Replicate	
Day	1	2	1	2	1	2
0	290 (30.52)	283 (18.82)	285 (17.78)	274 (23.66)	279 (34.69)	266 (25.57)
7	310 (33.99)	294 (25.67)	306 (30.79)	331 (38.04)	302 (31.49)	311 (22.82)
14	366 (34.40)	362 (39.01)	412 (25.56)	430 (48.90)	448 (64.89)	406 (54.59)
21	388 (35.17)	424 (27.04)	473 (76.68)	472 (47.43)	543 (89.91)	520 (66.68)
28	462 (70.43)	450 (49.66)	607 (59.48)	634 (53.38)	646 (74.89)*	648 (74.89)*
35	503 (21.99)	501 (83.57)	718 (73.97)	734 (59.93)	831 (52.86)*	831 (88.53)*
42	587 (48.73)	567 (59.01)	848 (86.64)	872 (34.16)	987 (77.39)*	1010 (97.96)*

* (*n* = 15)

An analysis of covariance (ANCOVA) was used to determine whether growth rates (slopes of the regression lines) among different treatment groups of fish were equal (Zar 1974). If the growth rates were significantly different ($P < 0.05$), then the Newman-Keuls multiple-range-test was used to test for differences between each pair of growth rates (Zar 1974).

A simple linear model,

$$G = a + bt, \qquad \text{(Eq. 3)}$$

where G is growth rate (%bw/d), a is the water temperature at a zero growth rate, *b* is growth acceleration rate, and t is water temperature was then used to predict maximum growth rates of juvenile pink salmon fed at maximum rations at various water temperatures between 4° and 18.3°C. Data were incorporated into the analysis from five additional studies which cultured juvenile pink salmon: two studies involved short-term rearing in seawater net-pens (Martin et al. 1981; A. C. Wertheimer, Fisheries Biologist, Auke Bay Lab. Pers. commun., September 1989), and three involved culture of juvenile pink salmon in laboratory aquaria (Brett 1974; Kepshire 1976; Moles and Rice 1983). In all five studies the fish were fed to excess with a commercially prepared fish food, and water temperatures were calculated as meanvalues over the rearing period.

RESULTS

Growth rates of juvenile pink salmon in each treatment group in our study ranged from 1.64% to 3.25% bw/d (Table 2). Fish held at 12°C grew significantly faster (3.25% bw/d) ($P < 0.05$) than those at 4°C and 8°C, and fish held at 8°C (2.77% bw/d) grew significantly faster than those at 4°C (1.71% bw/d). There was no significant difference ($P < 0.05$) between paired temperature groups. Assuming these rates remain constant, it would-take 41-42 days for a juvenile pink salmon to double in weight at 4°C; at 12°C it would take 21-22 days.

During the experiment, fish in both 12°C aquaria became diseased. This epizootic, diagnosed as a combination of several stress-related bacterial infections, began at day 33 of the experiment with the death of a few fish in each aquarium. At this point each of the tanks was treated with Diquat at levels recommended by personnel at the State of Alaska Fish Pathology Laboratory in Juneau, Alaska. However, within a week, the 12°C aquaria lost 102 and 107 fish,

---

'Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

respectively. The remaining fish continued to feed actively but exhibited a low-level chronic infection rate. Dissolved oxygen levels in each tank averaged about 5.5 ppm throughout the epizootic. The 4°C and 8°C aquaria each lost fewer than 20 fish over the 42-day study period.

The simple linear growth model, based on data from our study and five others (Table 3), provided a satisfactory fit (r^2 = *0.92, P = 0.00,* Fig. 1). The parameters of the linear regression were G = *0.925 + 0.224t,* where G = growth as %bw/d and t = water temperature.

Table 2.--Growth rates with upper and lower confidence limits (CL) for juvenile pink salmon held at 4°, 8°, and 12°C. Growth rate was determined as the slope resulting from the regression of the natural log of weights of individual fish as a function of time in days and expressed as percent body weight gained per day (%bw/d). The coefficients of determination (r^2) are also presented.

Water temperature (°C)	Replicate	Growth rate			
		% bw/d	Lower CL	Upper CL	r^2
4	1	1.64	1.59	1.68	0.72
4	2	1.71	1.67	1.74	0..83
8	1	2.71	2.68	2.75	0.91
8	2	2.77	2.73	2.81	0.92
12	1	3.11	3.07	3.15	0.88
12	2	3.25	3.21	3.30	0.88

DISCUSSION

The growth pattern displayed by juvenile pink salmon was similar to that documented for juvenile sockeye salmon (Brett et al. 1969) and for juvenile rainbow trout (0. *mykiss)* (Hokanson et al. 1977). The growth rates of the juvenile sockeye and rainbow trout were roughly linear between l° and 12°C but declined to an asymptote near 15°C. Observed growth rates of juvenile pink salmon from our study seemed to approach an asymptote at 12°C but it may be an artifact of the disease outbreak in these groups. The actual temperature where an asymptote is reached could be higher.

Table 3.--Daily growth rates of juvenile pink salmon from this study compared to the growth rates of juvenile pink salmon from other studies. Water temperatures remained constant except where parentheses enclose temperature range during the study period. All juvenile salmon were fed near maximum ration with wild zooplankton or a prepared diet.

Mean initial wet weight (mg)	Days	Growth rate (%bw/d)	Mean water temperature (°C)	Source
290	42	1.64	4.0	Our study
283	42	1.71	4.0	" "
285	42	2.71	8.0	" "
274	42	2.77	8.0	" "
279	42	3.11	12.0	" "
266	42	3.25	12.0	" "
270	30	2.37	4.7 (4.0 - 6.8)*	Martin et al. 1981
236	28	2.19	7.9 (7.8 - 8.1)	Wertheimer (pers. comm.)
325	40	3.23	8.0	Moles and Rice 1983
236	34	3.25	9.6 (7.8 - 11.1)	Wertheimer (pers. comm.)
1810	40	3.95	12.8	Kepshire 1976
2870	28	4.49	15.0	Brett 1974
1800	40	4.74	15.6	Kepshire 1976
2110	40	5.13	18.3	" "
1770	40	4.80	18.3	" "

*Heard et al. (1977)

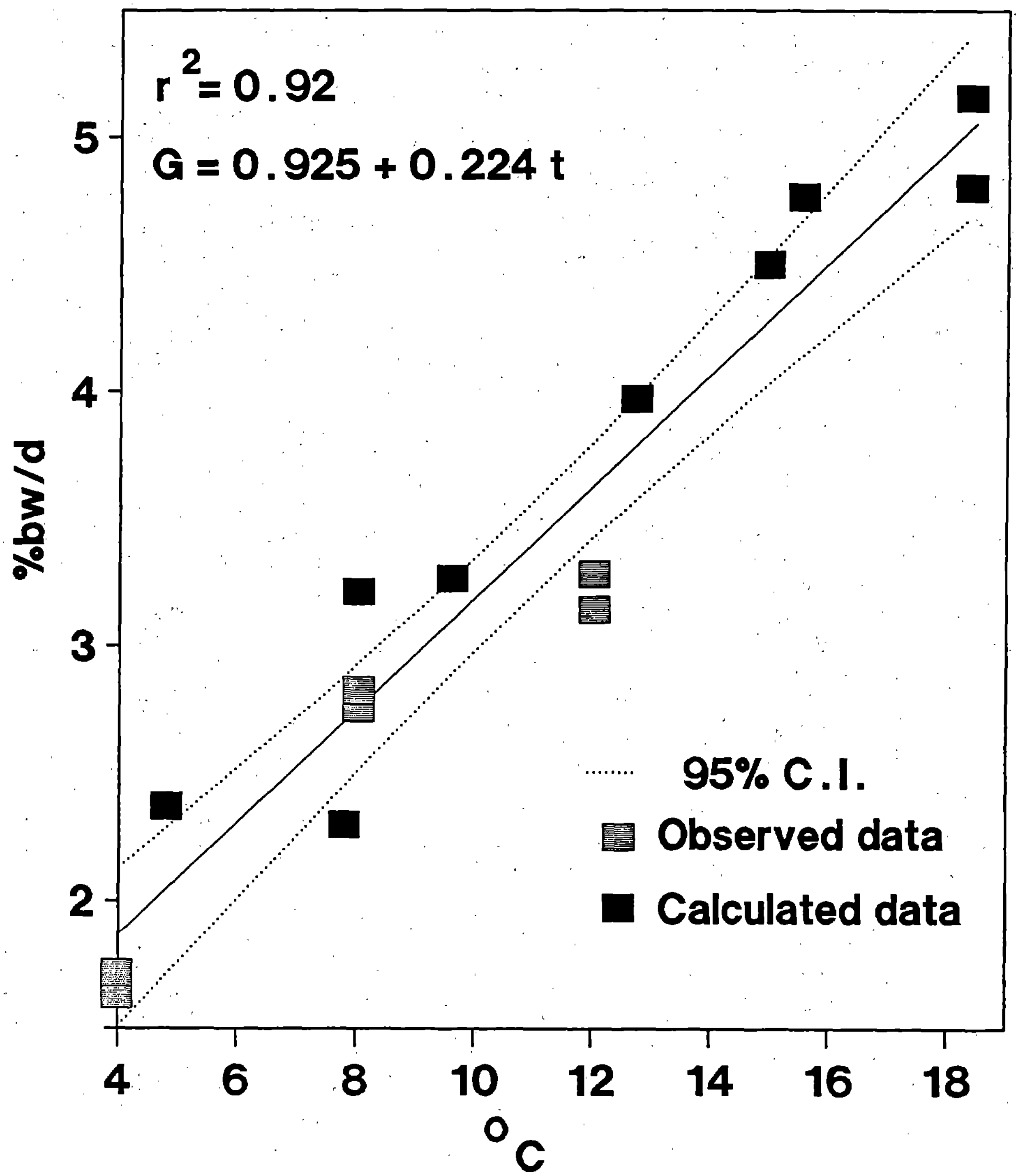

Figure 1.--Predicted growth rate (%bw/d) and 95% confidence interval (CI) for growth data presented in Table 3. *G* = growth rate; t = water temperature; observed data = data solely from our study; calculated data = combined data from our study and Brett 1974, Kepshire 1976, Martin et al. 1981, Moles and Rice 1983, and Wertheimer (pers. commun.).

Several studies-have computed growth rates of wild juvenile pink salmon during seaward migration. Phillips and Barrclough (1978) found that juvenile pink salmon sampled in the Straits of Georgia, British Columbia, grew about 3.6-4.5% bw/d during 70-88 days between April and June. Lebrasseur and Parker (1964) established that in the marine waters of central British. Columbia the juvenile pink salmon grew about l.8-5.5% bw/d between mid-April and mid-July. Although neither study presented water temperature data, Healey (1979) reports that estuarine temperatures in British Columbia can range from l0° to 15°C during these months. Coded-wire tagged juvenile pink salmon in Auke Bay, Alaska, grew from 3.6% bw/d *(over 63* days, mean temperature 8.1°C) to 4.9% bw/d (over 71 days, mean temperature l1.4°C) from April to June (Mortensen and Wertheimer 1988).

In comparison, the observed growth rates and those predicted by the simple linear model for juvenile pink salmon in our study were lower than growth rates calculated from juveniles actually captured in estuarine rearing areas. Higher growth rates of the fry captured in estuaries may result from several factors. The simple linear model that we developed by including data from other studies may not accurately predict the growth of juvenile salmon. Those studies were not originally designed to determine growth rates of juvenile pink salmon at various temperatures under controlled conditions. The juvenile pink salmon in the estuary were probably a mixture of ages, resulting in mixed growth rates which would differ from juveniles in our study. Size-selective predation (Parker 1971) may eliminate smaller fish-from the natural population, resulting in artificially high calculated growth rates. Also, at times the water temperatures may have exceeded 12°C, resulting in higher growth rates during those studies.

Alternatively, lower growth rates may have been precipitated by the types of prey fed to juvenile pink salmon reared in tanks and net-pens. For example, Volk et al. (1984) found that the epibenthic harpacticoid copepod *Tigriopus californicus* was converted more efficiently than the pelagic calanoid copepod *Pseudocalanus minutus.* Therefore, the consistently lower growth rates indicated by. our prediction model may have resulted from the use of small pelagic organisms and commercially prepared food.

A fifth explanation may be that stress from crowding, confinement, and handling may have reduced growth rates of cultured pink salmon relative to free-ranging fish. The disease problem observed at 12°C in our study is evidence of stress-related complications of crowding or confinement.

Although the data presented in our study may not reflect the exact growth rates of juvenile pink salmon under natural conditions, the results demonstrate that growth rate is directly related to water temperature over the normal temperature range encountered by these fish. A simple linear model describes the relationship; fishery biologists and hatchery manager can use the model to optimize release timing to achieve the maximum growth rate in the early marine environment

CITATIONS

Bailey, J. E. 1969. Alaska's fishery resources: the pink salmon. U.S. Fish and Wildl. Serv., Bur. Commer. Fish. Leafl. 619, 8 p.

Bailey, J. E., B. L. Wing, and C. R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon, *Oncorhynchus gorbuscha,* and chum salmon, *Oncorhynchus keta,* in Traitors Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull., U.S. 73:846-861.

Brett, J. R. 1974. Tank experiments on the culture of pan-size sockeye *(Oncorhynchus nerka)* and pink salmon (0. *gorbuscha)* using environmental control. Aquaculture 4.:341-352.

Brett, J. R. '1979. Environmental factors and growth. *In* W. S. Hoar, D. J. Randall, and J. R. Brett (editors), Fish physiology, vol. VIII, p. 599-675. Academic Press, New York.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969: Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka,* in relation to temperature and ration size. J. Fish. Res. Board Can. 26:2363-2394.

Coyle, K. O., and A. J. Paul. 1990. Interannual variations in zooplankton population and biomass during the spring bloom in an Alaskan subarctic embayment. *In* D. A. Ziemann and K. W. Fulton-Bennett (editors), APPRISE - Interannual variability and fisheries recruitment, p. 179-228. The Oceanic Institute, Makapuu Point, Waimanalo, HI 96795.

Hargreaves, N. B., and R. J. LeBrasseur. 1985. Species selective predation on juvenile pink *(Oncorhynchus gorbuscha)* and chum salmon (0. *keta)* by coho salmon *(0. kisutch).* Can. J. Fish. Aquat. Sci. 42:659-668.

Healey, M. C. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: I. Production and feeding"rates of juvenile chum salmon *(Oncorhynchus keta).* J. Fish. Res. Board Can. 36:488-496.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon *(Oncorhynchus keta)* during early sea life. Can. J. Fish. Aquat., Sci. 39:952-957.

Heard, W. R., R. M. Martin, and A. C. Wertheimer. 1977. Estuarine and freshwater culture of 1974 brbod coho salmon in net pens and floating raceways at Little Port Walter, Alaska. NWAFC Processed Rep., 55 p. Available

Auke Bay Lab., Alaska Fish. Sci. Cent.; 11305 Glacier Hwy., Juneau, AK 99801-8626.

Hokanson, K. E. F., C.F. Kleiner, and T. W. Thorslund. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, *Salmo gairdneri.* J. Fish. Res. Board Can. 34:639-648.

Kepshire, B. M. 1976. Bioenergetics and survival of chum *(Oncorhynchus* keta) and pink (0. *gorbuscha)* salmon in heated seawater. Ph.D. Thesis, Oregon State Univ., Corvallis, 112 p.

LeBrasseur, R. J., and R. R. Parker. 1964. Growth rate of central British Columbia pink salmon *(Oncorhynchus gorbuscha).* J. Fish. Res. Board Can. 21:1101-1128.

Martin, R. M., W. R. Heard, and A. C. Wertheimer. 1981. Short-term rearing of pink salmon *(Oncorhynchus gorbuscha)* fry: effect on survival and biomass of returning adults. Can. J. Fish. Aquat. Sci. 38:554-558.

Moles, A., and S. D. Rice. 1983. Effects of crude oil and naphthalene on growth, caloric content, and fat content of pink salmon juveniles in seawater. Trans. Am. Fish. soc. 112:205-211.

Mortensen, D. G., and A. C. Wertheimer. 1988. Residency and growth of juvenile pink salmon *(Oncorhynchus gorbuscha).* in Auke Bay. *In* APPRISE annual report, volume I, SFOS APP87-100, p. 501-544. School of Fisheries and Ocean Sciences, Univ. Alaska Fairbanks, Fairbanks, AK.

Paloheimo, J. E., and L. M. Dickie. 1966. Food and growth of fishes. III. Relations among food, body size, and growth efficiency. J. Fish. Res. Board Can. 23:1209-1248.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Phillips, A. C., and W. E. Barraclough. 1978. Early marine growth of juvenile Pacific salmon in-the Strait of Georgia and Saanich Inlet, British Columbia. Can. Fish. Mar. Serv. Tech. Rep. 830, 19 p. Nanaimo, BC.

Volk, E. C., R. C. Wissmar, C. A. Simenstad, and D. M. Eggers. 1984. Relationship between otolith microstructure and the, growth of juvenile chum salmon *(Oncorhynchus.keta)* under different prey rations. Can. J. Fish. Aquat. Sci. 41:126-133.

Weatherley, A. H., and H. S. Gill. 1987. The biology of fish growth. Academic Press, London, 443 p.

Zar, J. H. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, NJ, 620 p.

Ziemann, D. A., L. D. Conquest, K. W. Fulton-Bennett, and P. K. Bienfang. 1990. Interannual variability in the physical environment of Auke Bay, Alaska. *In* D. A. Ziemann and K. W. Fulton-Bennett (editors), APPRISE - Interannual variability and fisheries recruitment, p. 99-128. The Oceanic Institute, Makapuu Point, Waimanalo, HI 96795.