Paul Starr

Summary of Literature on Four Factors Associated with Salmon & Trout Fresh Water Life History

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ABSTRACT

This report collates available information regarding four primary factors in the freshwater life history of salmon and trout. These factors are: water temperature, stream hydraulics, spawning gravel and juvenile migration. This report also reviews some flow characteristics and gravel sizes used in enhancement projects in British Columbia. This report directly cites 133 references while more than four hundred additional references were also reviewed but not included in the summary tables. An annotated bibliography of many papers is included.

Key words: fisheries habitat parameters; enhancement projects; bibliography; (water temperature, stream hydraulics, spawning and juvenile migration).

RÉSUMÉ

Le présent rapport réunit l'information existante sur quatre principaux facteurs du cyle évolutif du saumon et de la truite en eau douce: la température de l'eau, l'hydrologie, le gravier des frayères et la migration des juvéniles. Il renferme aussi des renseignements sur les caractéristiques du courant et la granulométrie du gravier, employés pour des projets d'aménagement en Columbie-Britannique. On y cite 133 sources de référence bien qu'on en ait examiné au delà de 400 autres, qui ne sont cependant pas présentées dans les tableaux synoptiques. Le rapport comprend une bibliographie annotée comportant de nombreux titres.

Mots clés: Paramètres de l'habitat du poisson; projets d'aménagement; bibliographie; température de l'eau; hydrologie; frai; migration des juvéniles.

INTRODUCTION

In British Columbia, there are growing conflicts over water resources, not only between the various water users but also between water users and the fish and wildlife agencies. Because of this, the need to establish instream flow requirements is becoming more widely recognized, although, as yet, there is no such provision in the Provincial Water Act.

Instream flow requirements for fish is a topic which is receiving increasing research attention by resource agencies in Western Canada and the United States. In 1976, the Habitat Protection Division of Fisheries and Marine Service established a Water Use Unit to concentrate on water use problems. Hamilton (1978)[1] describes the methodology used by the Water Use Unit to establish fisheries resource maintenance flows for Pacific salmon. This methodology employs both quantitative and qualitative techniques so that the maximum use can be made of the biologists' experience and knowledge even though largely qualitative.

This report collates available information regarding four primary factors in the freshwater life history of salmon and trout, and is designed to aid the biologist in his contribution to the determination of fisheries resource maintenance flows. This work was also recognized as a tool for salmonid enhancement planners to facilitate retrieval of information on biological and hydrological optima and tolerances of a certain species in a given area. Furthermore, stream inventory data collected by fisheries resource agencies could be more easily related to fishery resource potential.

The report directly cites 133 references while more than four hundred additional references were also reviewed but not included in the summary tables. Most of the available information to 1977 has been covered.

Water Temperature

Water temperature is a principal regulator of biological activity in the aquatic environment and is one of the major determinants in assessing the suitability of a salmonid-producing stream. Temperature can induce direct mortality or severely stress organisms making them susceptible to predation or disease; influence the level of dissolved oxygen; control algal blooms; affect growth, condition and behaviour.

1. Hamilton, R.E. 1978. Fisheries Resource Maintenance flows for Pacific Salmon MASc thesis University of British Columbia

Tables 1 to 6 list water temperatures for spawning, incubation and rearing of salmonids in natural, experimental and enhanced situations.

Standard formulae for calculating degree-days (in Fahrenheit and Celcius) and thermal units (B.T.U.'s and C.T.U.'s) are shown in Figure 1 below.

Degree-days

D.D. in Celcius = $\sum$ Daily mean water temperature in $^{\circ}C$ from date of fertilization

D.D. in Fahrenheit = $\sum$ Daily mean water temperature in $^{\circ}F - 32$, from date of fertilization

Thermal Units (in Kcal):

B.T.U. = $(^{\circ}F) \times (\text{no. of days}) \times (.252)$

C.T.U. = $(\text{B.T.U.}) \times (3.97 \times 10^{-3})$

Figure 1. Standard calculations for determining degree-days and thermal units.

Stream Hydraulic

The importance of stream hydraulics to the understanding of stream ecosystems and development of flow recommendations for maintenance of aquatic life is obvious. The stream characteristics: water depth, velocity and width, channel shape, gradient, and bed roughness strongly affect the aquatic biota of a stream. Data of this kind is extremely important to the determination of instream flow needs of fish and invertebrate communities.

Tables 7 to 12 list water depth, velocity, gradient and discharge for the various life history phases. It is important to recognize that the data available for depth and velocity may be biased towards low flow situations since reduced flow is often the reason these studies have been initiated.

Spawning Gravel

Stream substrate is fundamentally important to the production of salmonids since high mortality rates often occur during egg and alevin subgravel development. Various researchers have examined redd and gravel characteristics and their findings are summarized in Tables 13 to 18.

Spawning gravel size and particle size variation is related to such factors as the quality of intragravel flows, predation and alevin support and movement. Gravel is usually determined by the percentage, by weight, of substrate passing through a sieve of a certain size. For this reason, the tables are given in both inches and centimeters as the value of their mathematical conversion is doubtful.

Depth of eggs in the gravel is also noted; however, this factor is extremely variable and the depths cited refer to depths of the majority of eggs. Some eggs may even be scattered on the gravel surface.

No mention is made of the size of fish or eggs in determining preferred gravel size - this is probably a relevant point but for the present will have to be confined to species generalizations (e.g. chinooks, pinks).

Downstream Migration

Downstream migration usually takes place in the late spring or early summer and is often promoted by high freshet flows. Although flows are seldom a problem, during this phase, the migration pattern can be critical. Available information regarding migration behaviour can be used as a guide in the design and situation of various water use structures. The seasonal and diurnal timing as well as horizontal and vertical distribution of fish is summarized in Tables 19 to 24.

Enhancement Facilities

Flow characteristics of spawning channels in British Columbia are compared in Table 25. These flows were considered favourable for each species and location so that each facility is unique. Varying degrees of success may be attributed to many factors including different degrees of flow control, temperature, or siltation.

Table 26 summarizes gravel incubation box projects from Bams and Simpson (1977). The gravel sizes used in these projects were determined through site and species (and thus egg size) recommendations as well as technical availability. Each project may have round, crushed or mixed gravel or even gravel substitutes (e.g. "Astroturf"); however, this factor is still relatively experimental and is not included here. The egg depth parameter is also excluded as under these conditions eggs may be planted a meter or more deep.

Table 1. Literature summary of temperature ranges associated with spawning, incubation and rearing of sockeye salmon.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Burrows, 1963	Experiment re: water temperature requirements	7.2-12.8 (22.2 max.)	5.8-12.8 (1.7 min.)			After spawning, 50% mortality at 35°F; After 128-cell stage, low mortality.
Hunter, 1948, 1949	Hook Nose Ck. (central coast B.C.)			1305-2880 1337-2995		Back-calculated from peak spawning and emergence dates and Burrows, 1963 temperature requirements.
Anon, 1974	Chilko R. (north interior (B.C.)			876-2714		"
Anon, 1954	Okanagan R. (south interior B.C.)	(8.3-17.6)		1056-2275		"
Anon, 1954	Wenatchee R. (Wash.)	6.1-13.8			0-12.7	During fry migration.
Withler, 1952	Six Mile Ck. (north interior B.C.)			1317-2906		Back-calculated from Burrows, 1963, as above.
Hartman et al, 1967	Ugashik Lk. (Alaska)				3.3-7.2	During smolt migration. Temperature surges could increase or decrease number of smolts migrating.
	Alegnagik Lk. (Alaska)				4.4-9.4	
	Kitoi Lk. (Alaska)				4.4-12.8	
	Cultus Lk. (south coast B.C.)				4.4-9.4	
	Chilko Lk. (north interior B.C.)				3.3-10.0	
Bjornn et al, 1968	Redfish Lk. (Idaho)				3.3-10.0	Peak during kokanee juvenile migration.
Groot, 1972	Babine Lk. (north interior B.C.)				10-15	During smolt migration.
Acara & Smith, 1971	Meadow Ck. (south interior B.C.)				7.2-8.1	During kokanee fry migration.
Withler, 1951	Babine Lk.				7.7-9.2 (7-14)	During smolt migration.
Robertson, 1949	Port John area streams (central coast B.C.)				Mean 7.9 (4-11)	"
Foerster, 1934	Sweltzer Ck. (south coast B.C.)				Mean 10.6 (5-20)	During fry migration.
Ferguson, 1958	Cultus Lk.				14.5	"
Shelbourn et al, 1973	Babine Lk. stock				15	Optimum growth.
Brett et al, 1969	Experiment re: optimum rearing temperature				15 (5-17)	Physiological optimum for food conversion and growth.
Brett, 1951	Experiment re: temperature tolerance				12-13 (6.7-24.4)	During fry migration.
Donaldson & Foster, 1941	Skaha Lk. (south interior B.C.)				11.7-16.7 (25.6 max.)	Improved growth rate and food utilization.

Table 1. Literature summary of temperature ranges associated with spawning, incubation and rearing of sockeye salmon, cont.

Reference	System	Spawning in ^oC Range (Limits)	Incubation in ^oC Range (Limits)	Degree-days to emergence	Rearing in ^oC Range (Limits)	Comments
Black, 1953	Summerland Hatchery (South interior B.C.)				22	Kokanee acclimated to 11^oC.
Brett, 1956	Experiment re: temperature requirements	(20.3-23.6 max.)			3.1-24.8	
Anon., 1973	Okanagan R. (south interior B.C.)	10.5-12.5	(.4-14.5)			Hatching limits: 4.5-13.3^oC. Adult migration ranges over 7.5-15.6^oC. Upper limit is 21.2^oC.
Chambers, 1955	Natural spawning areas in Wash.	8.3-12.8 (mean 11.1)				
Mains & Smith, 1956	Snake R. (Wash.) Columbia R. (Wash.)				4.4-15.4	During smolt migration.
Burner, 1951	Okanagan R. Wenatchee R. Little Wenatchee R. White R. (all in Wash.)	8.3-8.9 12.2-2.8 8.9-10.6 6.7-9.4				
Foerster, 1937	Cultus Lk. (south coast B.C.)			Surface lake temp.	4.4-5.0	- Threshold for smolt migration.
				"	10	- Smolts rise to surface.
				"	13	- Smolt migration decreased.
				"	14.4-20.1	- Migration ends - smolts withdraw to deeper waters.

Table 2. Literature summary of temperature ranges associated with spawning, incubation and rearing of chinook salmon.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Reimers & Loeffel, 1967	Columbia R. tributaries (Wash.)		5.8-14.2	1050-2570		487 degree-days to hatching (fall race).
Slater, 1963	Sacramento R. (Cal.)	10.0-13.9 (11.1-22.8 max.)	10-13.9 (13.6-17.4 max.)	1053-1481		502-719 degree-days to hatching.
Combs & Burrows, 1957	Entiat R., Skagit R. (Wash.)		5.8-14.0 (4.4-15.6) (mean 8.5)		5.8-14.2 (4.4-5.8 min.) (14.2-15.6 max.)	Constant-temperature experiments.
Shelton, 1955	Little White Salmon R. Hatchery (Wash.)			1282		Degree-days to eyed: 392, to hatching: 538.
Anon., 1974	Homathko R. and Lk. (south coast B.C.) Chilko R. and Lk. (north interior B.C.) Chilcotin R. (north interior B.C.)			1763-4317 876-3010 1230-3451		Back-calculated from Combs & Burrows, 1957, temperature requirements for normal development.
Johnson & Brice, 1953	Dorena Dam (Wash.)		7.2-16.7 3.3-12.2 mean 18.3 mean 12.2 7.2-12.8	222 (to eyeing 86-317 " 311 " 243 " 202-358 "		Fall race Fall race Spring race Spring race Spring race A daily mean temperature of 15.6 during incubation produces excess mortality.
Olson & Foster, 1955	Priest Rapids (Wash.)		5.6 7.8 8.9 10.0 12.2	1058 1037 907 850 854		High initial incubation temperatures also associated with high fry mortality.
Burrows, 1963	Experiment re: temperature requirements	(4.4 min.)	5.8-14.2 (1.7 min.)		10.0-15.6	Summer race.
Chambers, 1955	Natural spawning areas (Wash.)	5.0-13.3 (mean 10.0) 4.4-12.8 (mean 12.2)				Fall race (decreasing temperature). Spring race (increasing temperature).
Burner, 1951	Entiat R. (Wash.) Wenatchee R. (Wash.) White R. (Wash.) Kalama R. (Wash.) Toutle R. (Wash.) Ohanapecosh R. (Wash.) Nason Ck. (Wash.)	4.4-12.8 12.8-16.7 8.3-10.6 11.1-16.1 5.6-14.4 10.6-11.7 8.3-11.1				Summer race. Summer race. Summer race. Fall race. Fall race. Spring race. Spring race.
Brett, 1956	Experiment re: thermal requirements				(.8-25.1)	During fry stage.
Brett, 1951	Experiment re: temperature tolerance				12-13 (7.4-25.1)	Fry acclimatized to temperatures between 10 and 20.
Mains & Smith, 1956	Columbia R. (Wash.) Snake R. (Ore.)				4.4-15.6	During smolt migration.
Raymond, 1968	Columbia R. (Wash.) Snake R. (Ore.)				10-13	During smolt migration.

Table 2. Literature summary of temperature ranges associated with spawning, incubation and rearing of chinook salmon, cont.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation in °C Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Reimers, 1973	Sixes R. (Ore.) - tributaries - mainstem				 13-20 17-27	During smolt migration.
Wales & Coots, 1954	Klamath R. (Cal.)	3.9-11.1			3.9-11.1	
Lister & Genoe, 1970	Big Qualicum R. (E. Vancouver Is.)				4-15	During study.
Monan et al, 1969	Snake R. (Wash.)				7.8-15.6	During smolt migration.
Stein et al, 1972	Sixes R. - tributaries	8 (mean)			13.5-29	Summer.
Bjornn, 1971	Lemhi R. (Idaho) Big Springs Ck. (Idaho)				8.3-17.3 13.3-22.3	During smolt migration.
Ferguson, 1958	Experiment re: preferred temperature and distribution				11.5	From Brett, 1951.
Olson & Foster, 1955	Columbia R. (Wash.)	5.6-18.1	(18.4 max.)		2.2-13.9	
Maltson, 1947, 1948	Willamette R. (Ore.)	6.1-18.1				Spring race.
Reingold, 1968	Rapid R.] (Idaho) Snake R.]	(.6-10.0) 2.8-21.1				Prespawning temperatures for viable eggs.
Banks et al, 1971	Experiment re: effects of rearing temperature				15.6	Optimum growth if disease absent.
Higgins, 1970	Benson R. Link R. Marble R. (N.W. Vancouver Is.)	6.1 7.2-15.0 8.3				During peak spawning.

Table 3. Literature summary of temperature ranges associated with spawning, incubation and rearing of pink salmon.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation in °C Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Bams, 1972	Tsolum R. (E. Vancouver Is.)		4.7	960		Gravel Incubator. Eggs planted at 14°, emergence at 7°.
Walker & Lister, 1971	Cheakamus R. (south coast B.C.)		4.8	970		Eggs removed from redds and transplanted to Big Qualicum R. (E. Vancouver Is.).
	Cheakamus R. transplanted		7.4	1310		
	Bear R. (south coast B.C.)		5.7	1100		
	Bear R. transplanted		6.3	1153		
Pritchard, 1944	McClintock Ck. (Queen Charlotte Is.)		6.1	1353		In this study, air temperatures were used to derive water temperatures and degree-days.
			4.4	1079		
			5.0	1220		
			5.0	1155		
			7.8	1771		
			7.8	1615		
Ferguson, 1958	Experiment				11.7	From Brett, 1951.
Brett, 1951	Experiment				17.7 (23.9 max.)	
Burrows, 1963	Experiment				(3.3 min.)	From Vernon, 1958.
Hunter, 1959	Hook Nose Ck. (central coast B.C.)	2-16 (mean 12)			0-14	
Heard, 1972	Lovers Cove Ck. (Alaska) Experiment	6.1-7.8				
Neil, 1968	Sashin Ck. (Alaska)		11-12 (preferred)			Poor survival to fry stage occurs with late spawners having low initial incubation temperatures.
Neave, 1955	Datlamen Ck. (Queen Charlotte Is.)				4.3-5.2	62% of pink fry caught were in water of this temperature.

Table 4. Literature summary of temperature ranges associated with spawning, incubation and rearing of coho salmon.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Shapovalov & Berrain, 1939	Big Creek Hatchery (Cal.)		8.9 9.4	427 to hatching 639 to emergent		To emergence, coho require fewer degree-days than pink, sockeye or chinook.
Brett et al, 1958	Experiment re: effect of temperature on cruising speed				20	Optimum cruising speed for coho - sockeye 15°.
Mason & Chapman, 1965	Experiment re: early behavioural ecology		6.1-14.4			Artificial stream channels.
Chapman, 1965	Deer Ck. (Ore.)	7.2-8.6			7.2-13.2 8.1-9.3 .3-7.0	- During fry rearing. - During emergence. - Winter rearing - fish in pools.
Sumner, 1952	Sand Ck. (Ore.)	5.3-10.4			5.1-14.6 6.7-9.9	During smolt migration.
Higgins, 1970	Upper Benson R. Link R. Marble R. (N.W. Vancouver Is.)	6.1-6.7 7.2-8.3 8.3				
Brett, 1956	Experiment re: thermal requirements				(.2-25.0)	Lethal limits determined after low and high acclimations at 5° and 20°.
Brett, 1951	Experiment re: temperature tolerance				(6.4-25.0)	
Hartman, 1965	Experiment re: early behavioural ecology				.3-7.2	
Monan et al, 1969	Snake R. (Wash.)				7.8-15.6 (mean 11.4)	During smolt migration, above Brownlee reservoir.
Stein et al, 1972	Sixes R. (Ore.) - tributaries	8 (mean)			13.5-21	Coho fry prefer cooler tributaries to warmer mainstem (18-29°).
Lister & Genoe, 1970	Big Qualicum R. (E. Vancouver Is.)				4.0-12.8	Fry rearing.
Burner, 1951	Toutle R. (Wash.)	5.6-14.4				
Chambers, 1955	Natural spawning areas (Wash.) Columbia R.	4.4-10.6				
Peck, 1970	Lk. Superior tributaries (Ont.)	9				
Griffiths & Alderdice, 1972	Experiment re: temperature and swimming speed				5-17 17-20 5-14 11-14 14-17 5-8	Optimum food conversion. Maximum growth (satiated). Early spring. Early summer. Late summer. Late winter.
Dill & Northcote, 1970b	Experiment re: environmental variables and incubation-emergence		6.5-10.9			Aquaria.

Table 4. Literature summary of temperature ranges associated with spawning, incubation and rearing of coho salmon, cont.

Reference	System	Spawning in °C	Incubation in °C		Rearing in °C	Comments
		Range (Limits)	Range (Limits)	Degree-days to emergence	Range (Limits)	
Shapovalov & Berrain, 1939	Big Creek Hatchery (Cal.) Experiment		9.0			

Table 5. Literature summary of temperature ranges associated with spawning, incubation and rearing of chum salmon.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation in °C Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Hunter, 1959	Hook Nose Ck. (central coast B.C.)	12 (mean)				Annual range 0-14°.
Sumner, 1952	Sand Ck. (Ore.)	7.9-10.4			5.1-14.6 6.7-14.6	Study year. 1947-49 mean.
Shelbourn & Shirahata, 1963					14-16	Preference.
Burner, 1951	Lower Columbia R. tributaries (Wash.)	4.4-6.7				Natural spawning.
Brett, 1951	Experiment re: temperature tolerance				12-13 (7.3-23.8)	
Brett, 1956	Experiment re: thermal requirements				(.5-23.7)	After acclimation to lower and upper limits of 10° and 20°.
Ferguson, 1958					14.1	Preferred, from Brett, 1951.

Table 6. Literature summary of temperature ranges associated with spawning, incubation and rearing of steelhead/rainbow trout.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	 Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Dodge & MacCrimmon, 1971	Bothwell's Ck. Hatchery (Ont.)	.3-10 (peak at 6-8)	.3-2.0 (27% hatch; natural incubation) 5-7 (50% hatch; artificial incubation)	16-104 (to eyeing) 33-220 (to hatching) 305-472 (to hatching)		Rainbow trout - natural spawning.
Embody, 1934	Hatchery-tests		3.2-15.5	326-279 (to hatching)		Rainbow trout.
Garside, 1966	Experiment re: oxygen, temperature and embryo development		2.5 15 17.5	265 330] to hatching 315		Rainbow minimum mortality at 9-16°C. Low O_2 retards development.
Ferguson, 1958	Midsummer, preferred				13.6	From Garside & Tait, 1958. Steelhead.
Reingold, 1968	Rapid R.] (Idaho) Snake R.] Hatcheries	.6-10.2 3.3-20.9				Steelhead held in water colder than their natural streams have inviable eggs and high prespawning mortality.
Summer, 1952	Sand Ck. (Ore.)	5.4-9.9			6.7-14.6 11.3-12.8	During smolt migration.
Hartman, 1965	Experiment re: early behavioural ecology				.3-7.2	Steelhead.
Bjornn, 1971	Lemhi R. (Ore.) Big Springs Ck. (Ore.)				16.3 21.7	During peak smolt migrations of Age 2 steelhead.
Black, 1953	Summerland Hatchery (south interior B.C.)				(24 max.)	Kamloops trout after acclimation to 11°.
Withler, 1966	B.C. streams U.S.A. streams				.6-15.6 4.4-21.1	Steelhead
Northcote, 1969	Lardeau R. (south interior B.C.) " Loon Lk. (south coast B.C.)				<11.7 >12.0 <14.0	Rainbow downstream migration. Rainbow upstream migration. Rainbow downstream migration.
Alexander & MacCrimmon, 1974	Bothwell's Ck. (Ont.)				8-18	Rainbow, emigration, mostly Age 1.
Stauffer, 1972	Black R. (Ont.)				7-17	"
Javaid & Anderson, 1967	Ontario, Hatchery				20 (22 max.)	Rainbow acclimatized to 20°, in horizontal temperature gradient.
McCauley & Pond, 1971	Experiment re: temperature selection				18.4 17-20	Rainbow, preferred means in temperature gradients, during first 1.5 hrs.
McColley, 1933	Paul Ck. (south interior B.C.)	4.2-10.0 (3.8-10+)				Rainbow.

Table 6. Literature summary of temperature ranges associated with spawning, incubation and rearing of steelhead/rainbow trout, cont.

Reference	System	Spawning in °C Range (Limits)	Incubation in °C Range (Limits)	Incubation in °C Degree-days to emergence	Rearing in °C Range (Limits)	Comments
Embody, 1934	Hatchery tests		9-16 (3.2-15.5)			Rainbow - preferred incubation temperature with minimum mortality.
Hooper, 1973	California streams - low level - 1,000 m. elev.	7.2-13.3 (mean 11.1) 2.2-8.3				Steelhead, preferred natural spawning.
Orcutt et al, 1968	Clearwater R.(Ore.) Salmon R. (Ore.)	2.2-8.3				Steelhead.
Coble, 1961	Needle Branch R. (Ore.)		2.6-10.0			Steelhead.

Table 7. Literature summary of stream depths, velocities, gradients and discharges of sockeye salmon spawning streams.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Anon., 1973	Okanagan R. (south interior B.C.)	.20-.46	.8-2.5 (near bottom)	.24-.76		300-450	8.5-12.7	Spawning.
						350-550	10.5-16.5	Spawning.
						175-1000	5.3-30.0	Incubation.
						min. 175	5.3	Fry migration.
Acara & Smith, 1971	Meadow Ck. (south interior B.C.)	.3-1.13	3-5 (at mid-depth)	.94-1.52		64-511	1.8-14.5	Kokanee fry migration.
Anon., 1954	Okanagan R.	.46-.61	1.5-2.0 (near bottom)	.46-.61				
Delisle, 1962	Below Bucks Lk. dam (Cal.)	.46-.61 $\bar{x}$ = .52	1.50-2.15 $\bar{x}$ = 1.85	.46-.67 $\bar{x}$ = .56 (near bottom)		100	2.8	Kokanee spawning.
Kerns & Donaldson, 1968	Iliama Lk. (Alaskan)	2-6			26.8-46.6			Lake spawning.
Hoopes, 1972	3 Rivers near Brooks Lk. (Alaska)	.15-.32 $\bar{x}$ = .24	1.3-2.3 $\bar{x}$ = 1.6	.39-.70 $\bar{x}$ = .48	.36-1.45	8.9-15.7 $\bar{x}$ = 11.2	.25-.44 $\bar{x}$ = .32	
Burner, 1951	White R.	.08-.94	1-1.8	.30-.55				
	"	$\bar{x}$ = .29	$\bar{x}$ = 1.6	$\bar{x}$ = .49				
	Little Wenatchee R.	.05-.61	1-1.9	.30-.58				
	"	$\bar{x}$ = .3	$\bar{x}$ = 1.7	$\bar{x}$ = .52				
	Wenatchee R.	.13-.71	1.7-2.0	.52-.61				
	"	$\bar{x}$ = .33	$\bar{x}$ = 1.8	$\bar{x}$ = .55				
	Okanagan R.	.10-.36	1.5-2.0	.46-.61				
	"	$\bar{x}$ = .23	$\bar{x}$ = 1.7	$\bar{x}$ = .52				
	(all in Wash.)							
Chambers, 1955	Natural Rivers,	.23-.69	1.25-2.50	.38-.76				Natural spawning.
	Wash.	.3-.46	1.75	.53				Recommended.
Anon., 1974	Taseko Lk. outlet					1660	46.9	Spawning.
	" "					450	12.7	Incubation.
	Chilko Lk. outlet					3100	87.7	Spawning.
	" "					705	20.0	Incubation.
	" "					1290	36.5	Smolt migration.
	(interior B.C.)							
Brett, 1945	Lakelse Lk. outlet (north coast B.C.)	1.22	.37	.11				Smolt migration.
Hartman et al, 1962	Hidden Ck. (Alaska)	.3				10-20	.28-.57	Fry migration.
Smith, 1973	Oregon Game Comm.	.061(min.)	.469-2.391	.143-.729				Kokanee.
	Smith recom.	.06(min.)	.49-2.39	.15-.73				Kokanee.

Table 8. Literature summary of stream depths, velocities, gradients and discharges of chinook salmon spawning streams.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Bjornn, 1971	Lemki R. (Idaho)	.3-.37 (.61 max.)				120-177	3.4-5.0	Rearing.
	Big Springs Ck. (Idaho)	.79-.82 (.85 max.)				28-35	.8-1.0	Rearing.
Lister & Genoe, 1970	Big Qualicum R. (E. Vancouver Is.)	.61-.98 $\bar{x}$ = .79	.3-1.9 $\bar{x}$ = 1.3	.09-.58 $\bar{x}$ = .40		2.01	2.8	Rearing.
			1.0-2.2 $\bar{x}$ = 1.5	.30-.67 $\bar{x}$ = .46		2.01	2.8	Rearing.
		.61-.95 $\bar{x}$ = .85	1.0-2.4 $\bar{x}$ = 1.8	.30-.73 $\bar{x}$ = .55		2.01	2.8	Rearing.
			.8-1.60 $\bar{x}$ = 1.3	.24-.49 $\bar{x}$ = .40		2.01	2.8	Rearing.
Hamilton, 1974	Deadman R. (interior B.C.)					20	.57	
						12-20	.34-.57	Incubation.
						15-60	.42-1.70	Rearing.
						30	.85	Emigration.
Lister & Walker, 1966	Big Qualicum R.				.6	20-1040	.57-29.43	
	Big Qualicum R.					$\bar{x}$ = 275	$\bar{x}$ = 7.78	
	B.Q.R.(controlled flow)					46-710	1.30-20.09	
	B.Q.R.(controlled flow)					$\bar{x}$ = 305	$\bar{x}$ = 8.63	
	Horne Lk. " "					40-250	1.13-7.08	Spawning.
						125-750	3.54-21.24	Incubation.
						40-750	1.13-21.24	Rearing.
Chambers, 1955	Natural Rivers	.38-.69	1.50-2.50	.46-.76				Spring chinook.
	Recommended	.46-.53	1.75-2.25	.53-.69				" "
	Columbia R. Wash.	1.2-2.0	2.75-3.75	.84-1.14				Fall chinook.
	Columbia R. tributaries	.38-.69	1.00-1.75	.30-.53				" "
	Recommended	.30-.53	1.00-2.25	.30-.69				" "
Burner, 1951	Ohanapecosh Ck.	.05-.91 ($\bar{x}$ = .36)						Spring chinook.
	Nason Ck.	.05-.91 $\bar{x}$ = .36	.5-3.5 $\bar{x}$ = 2.0	.15-1.07 $\bar{x}$ = .61				" "
	Entiat R.	.08-.46 $\bar{x}$ = .22	1.0-2.0 $\bar{x}$ = 1.5	.3-.61 $\bar{x}$ = .48				Summer chinook.
	Wenatchee R. Wash.	.18-.66 $\bar{x}$ = .41	1.0-3.0 $\bar{x}$ = 2.0	.3-.91 $\bar{x}$ = .61				" "
	White R.	.1-.76 $\bar{x}$ = .33	1.4-2.0 $\bar{x}$ = 1.7	.43-.61 $\bar{x}$ = .52				" "
	Kalama R.	.15-.41 $\bar{x}$ = .25	1.0-3.5 $\bar{x}$ = 2.0	.30-1.07 $\bar{x}$ = .61				Fall chinook.
	Tautle R.	.08-.61 $\bar{x}$ = .3	1.0-3.0 $\bar{x}$ = 1.3	.30-.91 $\bar{x}$ = .40				" "
Monan et al, 1969	Snake R. (Idaho)	$\bar{x}$ = 4				9719-49,723 $\bar{x}$ = 24,031	275-1407 $\bar{x}$ = 680	Smolt migration
Wood, 1966	Big Qualicum R.	.46	2.1	.64				

Table 8. Literature summary of stream depths, velocities, gradients and discharges of chinook salmon spawning streams, cont.

Reference	Species	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Shelton & Pollock, 1966	Chinook	Abernathy Ck. (Wash.)					$\bar{x}$ = 8	2.44	Incubation channel (1959-60).
Everest et al, 1972	Chinook	Crooked Fork Ck. (Idaho)	.6-.75	0-.5	0-1.5(bottom)				Preferred condition.
		" "		.5-1.0	.15-.3(surface)				
		Johnson Ck. (Idaho)	.15-.45	0-1.0	0-.3(bottom)	low			Rearing.
		"		0-1.5	0-.45(surface)	low			
		"	.15-.45	0-.5	0-.15(bottom)	steep			
		"		0-2.0	0-.6(surface)	steep			
Smith, 1973	Spring "	From Table of Oregon	.183	.71-2.11	.217-.644				Minimum depth.
	Fall "	Game Commission	.305	.61-2.64	.186-.805				
	Spring "	From Sams and	.183	.81-2.05	.247-.625				
	Fall "	Pearson, 1963.	.183	1.10-2.48	.336-.756				
	Spring "	From Chambers et al, 1955	.381-.686	1.50-2.50	.458-.763				
	"	(Columbia R.)	.220-1.983	2.75-3.75	.839-1.144				
	"	Kalema and Coweman Rivers.	.381-.686	1.00-3.75	.305-.534				
	Spring "	Recommended by	.18	.69-2.10	.21-.64				Minimum depth.
	Fall "	Smith for Oregon stocks.	.24	.98-2.49	.30-.76				
Wales and Coots, 1954		Fall Ck. (Cal.)		4-5	1.2-1.5	3.13	32-298	.91-8.43	General stream characteristics.
							35-78	.99-2.21	
							35-184	.99-5.21	Incubation.
							40-184	1.13-5.21	Emigration.
Raymond, 1968		Columbia R. (low flow)					150,124	4,248	Emigration.
		Columbia R. (moderate flow)					300,213	8,495	"
		Snake R. (low flow)					50,041	1,416	"
		Snake R. (moderate flow) (Wash.)					80,045	2,265	"
Mains & Smith, 1956		Snake R. (Wash.) (central ferry)					70,000+	1980+	Emigration.
Shelton, 1955		Little White Salmon Stn. (Wash.) (during incubation)					1.2	.03	25-33% emergence.
							1.2	.03	89-88% emergence.
							1.2-9.7	.3-.27	95-98% hatching.
Platts, 1974		South Fork Salmon R. and tributaries (Idaho)	.22			5.8			Rearing. (Mean of 12.)

Table 9. Literature summary of stream depths, velocities, gradients and discharges of pink salmon spawning streams.

Reference	System	Depth (m)	Velocity		Gradient	Discharge		Comments
			fps	mps	(Percent)	cfs	cms	
Bams, 1970	Hook Nose Ck. (central coast B.C.)					.02	5.4×10^{-4}	Incubation box.
Hourston & MacKinnon, 1956	Jones Ck. spawning channel (south coast B.C.)	.31-.48 $\bar{x}$ = .39	1.5-2.4 $\bar{x}$ = 1.9	.52-.73 .58	.8	25-30 .5	.71-.85 .42	Spawn preference (discharge during incubation).
Wickett, 1952	Nile Ck. (E. Vancouver Is.)	.05-.08						
McNeil, 1968	Sashin Ck. (Alaska)				.1-.7	35-106	1-3	Low gradient preferred.
Heard, 1972	Lovers Cove Ck. (Alaska)	.21-.3	.7-1.1	.21-.34				
Walker & Lister, 1971	Qualicum R. (E. Vancouver Is.)					$\bar{x}$ = 60	1.7	Incubation channel.
Bams, 1972	Tsolum R. (E. Vancouver Is.)					.2	5.4×10^{-4}	Incubation box.
Anon., 1973	Alouette R. (south coast B.C.)					>50	1.4	
Hunter, 1959	Hook Nose Ck.					10-600	.28-16.8	During entry of 50% of spawners.

Table 10. Literature summary of stream depths, velocities, gradients and discharges of coho salmon spawning streams.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Wood, 1966	Big Qualicum R. (E. Vancouver Is.)	.46	2.1	.64				
Lister & Walker, 1966	Big Qualicum River					20-1040	.57-29.43	1959-63.
	Big Qualicum River					$\bar{x}$ = 225	7.78	1961-63.
	B.Q.R.(controlled flow)					46-710	1.3-20.09	1964-65.
	Horne Lk. (" ")					150-250	4.2-7.1	Adult migration.
						125-750	3.5-21.2	Spawning.
						125-400	3.5-11.3	Incubation.
						40-750	1.1-21.2	Rearing.
						40-400	1.1-11.3	Smolt migration.
Monan et al, 1969	Snake R. (Idaho)	4+				275-1407	7.8-39.8	Smolt migration.
						$\bar{x}$ = 680	19.2	
Hamilton, 1974	Deadman R. (interior B.C.)					15-20	.42-.57	Spawning.
						12-15	.34-.42	Incubation.
						12-60	.34-1.70	Rearing.
						20-60	.57-1.70	Smolt migration.
Chambers, 1955	Washington Rivers	.3-.46	.25-2.00	.08-.61				Recommended.
		.3-.38	1.20-1.80	.37-.55				"
Burner, 1951	Toutle R. (Wash.)	.05-.66 $\bar{x}$.2						
Sumner, 1952	Sand Ck. (Ore.)					2.2-400	.06-11.3	Spawning migration.
						<400	<11.3	Smolt migration.
Lister & Genoe, 1970	Big Qualicum R. channels	.30-.88 $\bar{x}$ = .64	0-1.51 $\bar{x}$ = .69	0-.46 $\bar{x}$ = .21		201	5.7	Rearing.
		.43-.85 $\bar{x}$ = .61	.20-.79 $\bar{x}$ = .39	.06-.24 $\bar{x}$ = .12		201	5.7	Rearing.
		-- --	0-1.90 $\bar{x}$ = .79	0-.58 $\bar{x}$ = .24		201	5.7	Rearing.
		.61-.91 $\bar{x}$ = .85	.79-1.61 $\bar{x}$ = 1.31	.24-.49 $\bar{x}$ = .40		201	5.7	Rearing.
Peck, 1970	Th. Superior tributaries	$\bar{x}$ = .15-.55				3.5-55.3	.1-1.0	
Chapman, 1965	Deer Ck. (Ore.)					19-57	.54-1.61	Adult migration.
						19-45.6	.54-1.29	Spawning.
						1-57	.03-1.61	Incubation.
						12.8-45.6	.36-1.29	Rearing.
Mason & Chapman, 1965	Experiment		$\bar{x}$ = .8-.9	.24-.27		.45	.01	Rearing.
Shapovalov & Berrain, 1939	Big Ck. State Hatchery (Cal.)	.025						
Dill & Northcote, 1970b	Experiment		3.4×10^{-3}	1.03×10^{-3}				Through gravel.
			1.3×10^{-3}	4×10^{-4}				Through gravel.
Smith, 1973	From Table of Ore. Game Commission	.122(min.)	.63-2.27	.192-.692				Spawning.
	Sams & Pearson,1963	.153(min.)	.90-2.32	.247-.708				Spawning.
	Chambers et al,1955	.305-.458	.25-2.00	.076-.610				Spawning.
	Recommended by Smith	.15(min.)	.69-2.30	.21-.70				Spawning.

Table 10. Literature summary of stream depths, velocities, gradients and discharges of coho salmon spawning streams, cont.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Bustard, 1973	Carnation Ck. (W. Vancouver Is.)	.3-1.05+ $\bar{x}$ = .73	0-.5	0-.15	2.4	< 106	< 3.0	Age 0 rearing.
		.75-1.05+ $\bar{x}$ = .89	0-.5	0-.15	2.4	< 106	< 3.0	Age 1 rearing.
Anon., 1973	Alouette R. (south coast B.C.)					50	1.41	Minimum
Hamilton, 1974	Deadman R. - suggested min. flows (interior B.C.)					15-20	.42-.57	Spawning.
						12-20	.34-.57	Incubation.
						10-60	.29-1.70	Rearing.
						20-60	.57-1.70	Smolt migration.
Mundie, 1968 (ref. 81)		.07-.60		.6				With 3-6m channel width, silt control, cover. (Ideal coho rearing stream).

Table 11. Literature summary of stream depths, velocities, gradients and discharges of chum salmon spawning streams.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Bams, 1970	Hook Nose Ck. (central coast B.C.)					.02	5.4×10^{-4}	Incubation box.
Hourston & McKinnon, 1956	Jones Ck. (south coast B.C.)	.32-.42 $\overline{x}$ = .37	1.6-3.2 $\overline{x}$ = 2.1	.49-.98 $\overline{x}$ = .64	.8	25-30 15	.71-.85 .42	Spawning channel during incubation.
Wood, 1966	Big Qualicum R. (E. Vancouver Is.)	.46	2.1	.64				Spawning channel.
Wickett, 1952	Nile Ck. (E. Vancouver Is.)	.05-.08						
Lister & Walker, 1966	Big Qualicum R. Big Qualicum R. B.Q.R.(controlled flow) Horne Lk.(" ")					20-1040 $\overline{x}$ = 225 46-710 150-750 150-750 135-750 135-400	.57-29.43 $\overline{x}$ = 7.78 1.3-20.09	1959-63. $\overline{x}$ 1961-63. 1964-65. Spawning. Spawning. Incubation. Fry migration.
Hunter, 1959	Hook Nose Ck.					10-600	.28-17	
Burner, 1951	Lower Columbia R. tributaries (Wash.)	.05-.76 $\overline{x}$ = .25						
Sumner, 1952	Sand Ck. (Ore.)					2.2-400		
Smith, 1973	From Oregon Game Commission From Smith for Oregon stocks	.183(min.) .18(min.)	1.48-3.29 1.51-3.31	.451-1.003 .46-1.01				
Shelton et al, 1966	Abernathy Ck. (Wash.)					3 (1960-62)	.92	Incubation channel.

Table 12. Literature summary of stream depths, velocities, gradients and discharges from steelhead/rainbow trout spawning streams.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Cobler, 1961	Needle Branch R. (Ore.)		$\bar{x}$=.02-.33	.05-1.09		$\bar{x}$=.78-5.83	.02-.16	Apparent in-gravel velocity (incubation).
Everest & Chapman, 1972	Crooked Fork Ck. (Idaho)	0-.45	0-.49	0-.15(surface)				Age 0 rearing.
	"		0-.49	0-.15(bottom)				" "
	"		.98-1.97	.3-.6(surface)				Age 1+ "
	"		1.48-2.95	.45-.9(bottom)				" "
	Johnson Ck. (Idaho)	.15-.3	1.48-1.97	.45-.6(surface) low				Age 1+ "
	"		2.95-3.94	.9-1.2(bottom) low				" "
	"	0-.15	0-.49	0-.15(surface) steep				Age 0 "
	"		0-.49	0-.15(bottom) steep				"
	"	.75-.9	.98-1.48	.3-.45(surface) steep				Age 1+ "
	"		2.95-3.44	.9-1.05(bottom) steep				
Platts, 1974	South Fork Salmon R. (Idaho)	.21			7.1			Rearing, rainbow, (mean of 19). Chinook preferred steeper gradients.
Bjornn, 1971	Lemhi R. (Idaho)	.3-.37				120-177	3.4-5.0	Rearing, rainbow.
	" "	.61(max.)						"
	Big Springs Ck.	.79-.82				28-35	.8-1.0	"
	" (Idaho)	.85(max.)						
Northcote, 1969	Upper Lardeau R. (south interior B.C.)	1.22-2.29				4948	140	Rearing, rainbow.
Hooper, 1973	Cal. Dept. Fish. Game	>.15	.5-3.0	.15-.91				Rainbow, spawning.
			.2	.06 (near bottom)				"
	Hooper	>.21	1.4-2.7	.43-.82				"
	"		$\bar{x}$2.0	.61				"
	California $3\text{-}5 \times 10^3$ ft. elevation		2.8-3.5	.85-1.07 (surface)				"
			2.3-2.5	.70-.76 (near bottom)				"
Dodge & MacCrimmon, 1971	Bothwell's Ck. (Ontario)	.13-.33			.54-1.0	3.5-67.1	.1-1.9	Rainbow, spawning.
Orcutt et al, 1968	Clearwater R.	.21-1.52	2.8-3.5	.85-1.07 (surface)				Spawning steelhead.
	and Salmon R. (Ore.)		2.3-2.5	.70-.76 (near bottom)				
McColley, 1933	Paul Ck. (U.S.A.)					1612	45.6	Rainbow spawners preferred Paul Ck. 815:15.
	Agnes Ck. (U.S.A.)					32	.91	
Stauffer, 1972	Black R., Lake Michigan (Ont.)					7-170	.2-4.8	Rainbow juvenile migration, Age 1, 64%.
						31.8	.9	
Alexander & MacCrimmon, 1974	Bothwell's Ck.	.08-.28			1.6			Rainbow, juvenile migration, Age 1, 91%.

Table 12. Literature summary of stream depths, velocities, gradients and discharges from steelhead/rainbow trout spawning streams, cont.

Reference	System	Depth (m)	Velocity fps	Velocity mps	Gradient (Percent)	Discharge cfs	Discharge cms	Comments
Delisle & Eliason, 1961	Middle Fork Feather R. (Cal.)	.08-.91	.5-3.0	.15-.91		300+	8.5+	Suggested for spawning and rearing of rainbow.
Pitney, 1969	Mill Ck. (Ore.)	.18						
Anon., 1973	Alouette R. (south coast B.C.)					50+	1.4+	
Smith, 1973	Oregon Game Comm.	.244	1.27-2.91	387-.869 (near bottom)				Winter sthd.
	Deschutes R.	.244	1.42-3.18	.433-.970 (near bottom)				Summer sthd.
	Rogue R.	.153	1.48-3.00	.451-.915 (near bottom)				Summer sthd.
	Deschutes R.	.153	1.60-2.98	.488-.909 (near bottom)				Rainbow.
	Smith's criteria	.24	1.31-2.98	.40-.90 (near bottom)				Winter sthd.
	Sams & Pearson, 1963	.244	1.28-2.98	.389-.909 (mean vel. of water column)				Winter sthd.
Bustard, 1973	Carnation Ck. (% of fish found at:) (W. Vancouver Is.)	0-.45(80%) x=.32	0-.5	0-.15(87%	2.4	106	3.0	Age 0 rearing.
		0-.3	0-.5	0-.15(87%)	2.4	106	3.0	" "
		.75-1.05 (67%)	0-.5	0-.15(77%)	2.4	106	3.0	Age 1+ "
		x=.90	.5-1.0	.15-.30(23%)	2.4	106	3.0	" "
Withler, 1966	Coquitlam R. (south coast B.C.)				1.29			Gradient to upper limit of steelhead ascent.
	Alouette R.				.64			
	Chehalis R.				.95			
	Chilliwack R.				1.08	817-5350	23.14-151.52	
	Cheakamus R.				.47	1030-10,200	29.17-515.43	
	Capilano R.				1.25	377-2370	10.68-67.12	
	Seymour R.				1.14	78-1560	2.21-44.18	
	Coquitalla R.				1.23			

Table 13. Literature summary of gravel sizes and egg depths associated with spawning sockeye salmon.

Reference	System	Gravel Size inches	Gravel Size cm	Egg Depth inches ($\bar{x}$)	Egg Depth cm ($\bar{x}$)	Comments
Anon., 1973	Okanagan R. (south interior B.C.)	1.5-4	3.8-10.2			
Anon., 1974	Okanagan R.	.25-1.5	.6-3.8			
Kerns & Donaldson, 1958	Iliama Lk. (Alaska)	4.0-12.0 (73%)	10.2-30.5			Slope 15-25° and water depth 2-6m. Islands and reefs.
Hoopes, 1972	Brooks Lk. tributaries (Alaska)	≤.5-3.0 (89%)	≤1.3-7.6			Intermediate stream gradient (.36-1.45%).
Burner, 1951	White R.	3-6(93%)	7.6-15.2	3-9 (5.5)	7.6-22.9 (14.0)	Depth of majority of eggs assumed equal to depth of redd.
	Little Wenatchee R.	3-6(89%)	7.6-15.2	3-11 (5.7)	7.6-27.9 (14.5)	
	Wenatchee R. Wash.	3-6(94%)	7.6-15.2	2-8 (4.2)	5.1-20.3 (10.7)	
	Okanagan R.	3-6(93%)	7.6-15.2	2-9 (5.0)	5.1-22.9 (12.7)	
McNeil, 1967				4.3-7.5 3.5	11-19 9	Depth in redds.
Chambers, 1955	Washington Rivers	≤.13-6.0 .5-1.5(80%)	.3-15.2 1.3-3.8			Areas where natural spawning occurs.

Table 14. Literature summary of gravel sizes and egg depths associated with spawning chinook salmon.

Reference	System	Gravel Size inches	Gravel Size cm	Egg Depth inches ($\bar{x}$)	Egg Depth cm ($\bar{x}$)	Comments
Bjornn, 1971	Lemhi R. (Idaho)	13	33			Large rubble substrate for rearing.
	Big Springs Ck. (Idaho)	32	81			
Lister & Genoe, 1970	Big Qualicum R. (E. Vancouver Is.)	.4-2.0	1-5			Spawning channel - plus 20 cm. boulders.
		.8-3.9	2-10			
		5.9-14.2	15-36			Natural river.
		<.4-2.0	<1-5			
Shelton, 1955	Little White Salmon Stn. (Wash.)	≤1	≤2.5	3	7.6	25-33% emergence. .03m³/sec.
		1-3	2.5-7.6	6	15.2	88-89% emergence.
		≤1-3	≤2.5-7.6	3-12	7.6-15.2	95-98% hatching.
Wood, 1966	Big Qualicum R.	.75-4.0	1.9-10.2			Upper B.Q.R. egg-to-fry survival was 42%. Stream depth .46m and discharge .64m³/sec.
Shelton & Pollock, 1966	Abernathy Ck. (Wash.)	1-1.5(40%)	2.5-3.8			Incubation channel gave 95% egg-to-fry survival with .08m³/sec. flow and siltation control.
		1.5-2.0(40%)	3.8-5.1			
		>2.0(20%)	>5.1			
Everest & Chapman, 1972	Crooked Fork Ck. (Idaho)	7.9-15.7	20-40			Preferred conditions.
	Johnson Ck. (Idaho)	<2.5	<5			
	" (Idaho)	7.9-15.7	20-40			
Chambers, 1955	Washington Rivers	<.13-6.0	.3-15.2			Spawning and incubation experiments performed using substrates with diameters of <2.5cm to 10.2 cm, on spring and fall chinook.
		.5-2.0 (88%+)	1.27-5.1			
		.5-2.0 (92%+)	1.27-5.1			
Burner, 1951	Ohanapecosh Ck. (Wash.)	3-6(55%)	7.6-15.2	3-20 (9)	7.6-50.8 (22.9)	Spring race.
	Nason Ck. (Wash.)	" (86%)	"	4-14 (8.5)	10.2-35.6 (21.6)	Spring race.
	Entiat R. (Wash.)	" (85%)	"	4-19 (10)	10.2-48.3 (25.4)	Summer and fall races.
	Wenatchee R. (Wash.)	" (86%)	"	4-18 (9.7)	10.2-45.7 (24.6)	Summer and fall races.
	White R. (Wash.)	" (95%)	"	5-14 (9.3)	12.7-35.6 (23.6)	Summer and fall races.
	Kalama R. (Wash.)	" (56%)	"	2-17 (10)	5.1-43.2 (25.4)	Fall race.
	Toutle R. (Wash.)	" (86%)	"	4-18 (10.7)	10.2-45.7 (27.2)	Fall race.
	Green R. (Wash.)	" (89%)	"			Fall race. Depth of majority of eggs assumed equal to depth of redd.

Table 15. Literature summary of gravel sizes and egg depths associated with spawning pink salmon.

Reference	System	Gravel Size inches	Gravel Size cm	Egg Depth inches ($\bar{x}$)	Egg Depth cm ($\bar{x}$)	Comments
McNeil, 1967	Lovers Cove Ck. (Alaska)			4.3-7.5 (max.) 3.5 (mean)	11-19 9	Average redd area per spawner .87-1.1m^2.
Wickett, 1952	Nile Ck. (E. Vancouver Is.)			8	20.3	Artificially buried. Had a greater egg-to-fry survival rate than naturally-spawned eggs.
Bams, 1974	Tsolum R. (E. Vancouver Is.)	.75	1.9			Gravel incubator.
Bams, 1972	Tsolum R.	.75-1.25	1.9-3.2			
Pritchard, 1944	McClinton Ck. (Queen Charlotte Is.)			12-36	30-91	Found in natural streams.
Heard, 1972	Lovers Cove Ck.	1-4	2.5-10.2			
Walker & Lister, 1971	Big Qualicum R. (E. Vancouver Is.)	.75-4.0	1.9-10.2	4-6	10.2-15.2	Spawning channel.
Hunter, 1959	Hook Nose Ck. (central coast B.C.)	.05-5.0	1.3-12.7			
Bams, 1970	Hook Nose Ck.	.28-1.02 (mean .79)	.7-2.6 (mean 2.0)	35.4	90	Gravel incubator.
Neave & Wickett, 1955	Jones Ck. (south coast B.C.)			8	20.3	Artificially buried in spawning channel. Egg-to-fry survival 42%.
Hourston & MacKinnon, 1956	Jones Ck.	.25-1.5	.6-3.8			Spawning channel.
McNeil, 1968	Sashin Ck. (Alaska)	.07-.5	.18-1.27			Smallest gravel at lowest gradient preferred (.1% gradient).

Table 16. Literature summary of gravel sizes and egg depths associated with spawning coho salmon.

Reference	System	Gravel Size		Egg Depth		Comments
		inches	cm	inches ($\overline{x}$)	cm ($\overline{x}$)	
Lister & Genoe, 1970	Big Qualicum R. (E. Vancouver Is.)	<.4	<1.0			Rearing channel.
Burner, 1951	Toutle R. (Wash.)	3-6 (85%)	7.6-15.2	3-2 (8)	7.6-50.8 (20.3)	Natural spawning.
Peck, 1970	Lk. Superior tributaries (Mich.)	Gravel 43%; Boulder 31%				Natural spawning.
Shapovalov & Berrain, 1939	Big Ck. Hatchery (Cal.)			5	12.7	Hatching eggs in gravel.
Dill & Northcote, 1970b	Experiment re: environmental variables and incubation-emergence	.75-1.25 1.25-2.50	1.9-3.2 3.2-6.3	8-12 8-12	20-30 20-30	Experimental stream aquaria.
Carl, 1939	Cowichan Lk. (E. Vancouver Is.)			6-8	15.2-20.3	Hatchery.
Wood, 1966	Big Qualicum R.	.75-4.0	1.9-10.2			Spawning channel.
Chambers, 1955	Natural Rivers (Wash.)	<.13-6.0 .5-2.0 (49%+)	<.3-15.2 1.3-5.1			

Table 17. Literature summary of gravel sizes and egg depths associated with spawning chum salmon.

Reference	System	Gravel Size inches	Gravel Size cm	Egg Depth inches($\bar{x}$)	Egg Depth cm($\bar{x}$)	Comments
Dill & Northcote, 1970	Robertson Ck. (W. Vancouver Is.)	.4-1.5 2-4	1.0-3.8 5.1-10.2	8-12 8-12	20.3-30.5 20.3-30.5	Experimental stream aquaria.
Shelton & Pollock, 1966	Abernathy Ck. (Wash.)	1-1.5(40%) 1.5-2.0(40%) 2.0(20%)	2.5-3.8 3.8-5.1 5.1			Incubation channel.
Bams, 1970	Hook Nose Ck. (central coast B.C.)	.28-1.02 (mean .8)	.7-2.6 (mean 2.0)	35.4	90	Gravel incubator.
Hourston & MacKinnon, 1956	Jones Ck. (south coast B.C.)	.25-1.5	.64-3.81			Spawning channel.
Wood, 1966	Big Qualicum R. (E. Vancouver Is.)					Spawning channel.
Wickett, 1952	Nile Ck. (E. Vancouver Is.)				8-20.3	Controlled stream.
Burner, 1951	Lower Columbia R. tributaries (Wash.)	3-6(81%)	7.6-15.2	3-17 (18.5)	7.6-43.2 (21.6)	Depth of majority of eggs assumed equal to depth of redd.

Table 18. Literature summary of gravel sizes and egg depths associated with spawning steelhead/rainbow trout.

Reference	System	Gravel Size inches	Gravel Size cm	Egg Depth inches ($\bar{x}$)	Egg Depth cm ($\bar{x}$)	Comments
Orcutt et al, 1968	Clearwater R. (Ore.) Salmon R.	.25-4.0 (70%)	.64-10.2			Rainbow.
Delisle & Eliason, 1961	Middle Fork Feather R. (Ore.)	.25-3.0	.64-7.62			Suggested, rainbow.
Bustard, 1973	Carnation Ck. (W. Vancouver Is.)	3.9-7.9 (80%)	10-20			Steelhead.
Coble, 1961	Alsea R. (Ore.)	Silt-3	Silt-7.62	10	25.4	Steelhead.
Everest & Chapman, 1972	Crooked Fork Ck. (Idaho)	3.9-15.7 >15.7	10-40 >40			Rearing, Age 0. Rearing, Age 1+.
Platts, 1974	South Fork Salmon R. (Idaho)	Boulder (37.8%) Rubble (26.7%) Gravel (15.6%) Fine (20.4%)				Rearing, rainbow.
Bjornn, 1971	Lemhi R. (Idaho) Big Springs Ck. (Idaho)	9.5 30.7	24 78			Rearing, rainbow.
Hooper, 1973	California - low level streams - 1,000-1,500m elev.	.25-3.0 (mean .25-1.5) .5-4.0	.64-7.62 (mean .64-3.81) 1.3-10.2			Rainbow/steelhead spawning occurs later in higher altitude streams.
Dodge & MacCrimmon, 1971	Bothwell's Ck. (Ontario)	.79-11.8	2-30			Rainbow.

Table 19. Literature summary of downstream migration timing and water column distribution of juvenile sockeye salmon, cont.

Reference	System	Seasonal Timing: Range	Seasonal Timing: Peak	Diurnal Timing: %Sample	Diurnal Timing: Hours	Vertical Dist'n: %Sample	Vertical Dist'n: Depth(m)	Horizontal Dist'n: %Sample	Horizontal Dist'n: Depth(m)	Comments
Hartman et al, 1962	Brooks Lk. (Alaska) -Hidden Ck.	Apr.25-June13 (1960)	May11-21		2000-0400 Peak 2200-0100					Fry migration.
					Daytime holding		.3		Banks	
Bjornn et al, 1968	Salmon R. (Idaho)		May3-18	.4	0600-1200					Smolt migration, 1955-66 means.
				3.3	1200-1800					
				75.4	1800-2400					
				28.8	0000-0600					
				Peak	2230-2300					
Foerster, 1937	Cultus Lk. (south coast B.C.)	Feb.16-July20	Apr.18-May18 (80% of run)							Smolt migration, 1926-36.
Robertson, 1949	Hook Nose Ck. (central coast B.C.)	May13-July16	June11	Dusk to dawn Peak-midnight						Fry migration.
Hartman et al, 1967, cont.	Karluk Lk. (Alaska) -Canyon Ck. (1963)	Apr.15-May28 (summer spawners)	May5	100	1900-0700					Fry migration.
	-Canyon Ck. (1963)	June10-July18 (fall spawners	July4	100	2000-0700					
	Cultus Lk. (1926-36) (south coast B.C.)	end Feb.-early June	Apr.25							Smolt migration.
	Bolshaya R. (U.S.S.R.)		May12							
	Lakelse Lk. (1946,47,50,52) (north coast B.C.)	May5-June14	May23							
	Babine Lk. (north coast B.C.)		May 13 June 4							
	Chignik Lk.	May10-July5	June3							
	Karluk Lk.	May14-July4	June3	92-96	2000-0300					
	Lower Ugashik Lk.	May12-July9	May3							
	Becharof Lk.	May23-June28	June1							
	Kitoi Lk.		June5							
	Ruth Lk. Alaska		June14							
	Auke Lk.		May28							
	Brooks Lk.	May8-June30	May31	>95	1600-0400					
	Naknek R.	May20-July30	June16	100	2100-0600					
	Iliama Lk.	May15-July25	June2	91	2200-0200					
				60	2400-0100					
	Alegnagik Lk.	May27-Aug.2	June22	95	2100-0200					
	Tazlina Lk.		July1							
Raleigh, 1967	Karluk Lk. -tributaries/ outlet -outlet	Apr.12-early Aug.		73	Night			99	Banks (<.91m from shore)	Fry migration.
Withler, 1951	Babine Lk. (north interior B.C.)	mid-May - mid-June		Most	1800-2300					Smolt migration.

Table 19. Literature summary of downstream migration timing and water column distribution of juvenile sockeye salmon, cont.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Can. Dept. Fish. and I.P.S.F.C., 1955	Chilko Lk.									Smolt migrations.
	-outlet	Apr.15-June15	May							
	-past Hope	Apr.18-June18	May							
	Adams Lk.									
	-outlet	Apr.20-May30	May							
	-past Hope	Apr.24-June3	May							
	Shuswap, Mabel Lks. (all in interior B.C.)	Apr.1-July30								
	Babine Lk. (north interior B.C.)	May15-July15								
Meehan & Siniff, 1962	Taku R. (Alaska)	Apr.12-June15	June3-5	peak	0200-0400	most	.061 (top 5% of water column)			Period of study. Age 2 smolts predominate over Age 3.
Hunter, 1948	Port John (central coast B.C.)		May							Smolt migration.
Hunter, 1949	Port John	3rd wk.Apr.-June10								Smolt migration.
Withler, 1952	Six Mile Ck. (Babine Lk.)	Apr.15-June26								Fry migration.
Foerster, 1934	Cultus Lk. (south coast B.C.)	Apr.29-June11	May7							Fry migration.
Foerster, 1952	Lakelse Lk. (north coast B.C.)	May11-June14	May21-22 and June1							Smolt migration.
Hartman et al, 1967	Brooks Lk. (Alaska)									Fry migrations.
	-Hidden Ck.	Apr.24-June8	May8-14	100	2200-0400					
	-One Shot Ck.	May9-June22	June7	100	2200-0400					
	Karluk Lk. (Alaska)									
	-Upper Thumb R.	Apr.8-June11	June5							
	-Grassy Pt. Ck.	Apr.6-June23	May7-18							
	-Meadow Ck.	Apr.5-June17 (summer spawners)	May3-24							
	-Meadow Ck.	June10-July18 (fall spawners)	July1							

Table 19. Literature summary of downstream migration timing and water column distribution of juvenile sockeye salmon.

Reference	System	Seasonal Timing		Diurnal Timing		Vertical Dist'n		Horizontal Dist'n		Comments
		Range	Peak	%Sample	Hours	%Sample	Depth(m)	%Sample	Depth(m)	
Mains & Smith, 1956	Columbia R. (Wash.)	May12-June22		100	1500-2100					Smolt migration.
Rees, 1956	Columbia R. (Wash.)	May14-June22				88.6	0-4.6		near shore	Smolts, during study period.
Westwater Res., 1974	Fraser R. (south coast B.C.)	Mar.-early Apr.	Mid-May							Smolt migration.
Long, 1968	Columbia R. (Wash.) -Dallas Dam	Apr.28-May12 (1960)			1530-0830	58.1 30.1 11.8	0-4.4 4.6-9.0 9.2-13.6			Smolt migration.
	-McNary Dam	Apr.24-May26 (1961)			1900-0500	62 26 12	0-4.4 4.6-9.0 9.2-13.6 Depths measured from ceiling of intake at gatewell			
Acara & Smith, 1971	Meadow Ck. (south interior B.C.)	Early Apr.-June24 Apr.22-June16 Apr.1-June29 (1968)	May10-20	45.6 (mean)	2100-2300 to 2200-2400	64.5 27.2 7.4 .8	0-.3 .3-.6 .6-.9 .9-1.2	56.9% 43.1%	banks centre	Kokanee fry migration.
Brett & McConnell, 1950	Lakelse Lk. (north coast B.C.)	May1-June15 (1947)	May17-30 (80% of run)							Smolt migration.
McDonald, 1960	Lakelse Lk. (Williams Ck.)	Apr.15-June6 (1954-55)		50	2330-0030			28.8%	centre at .71m/sec. velocity	Fry migration.
Johnson & Groot, 1963	Babine Lk. (north interior B.C.)	May-June			1800-2400		near surface			Smolt migration.
McDonald, 1969	Babine Lk.	May14-June17 (1967)	May19 and June8							Smolt migration. 12.7% Fulton R. egg-to-smolt surv. 14.3% Fulton Channel egg-to-smolt surv.
Groot, 1972	Babine Lk.	May20-June22		Peaks-Dawn, Dusk						Smolt migration during study period. Migration rate 41-51cm/sec.
Anon., 1954	Okanagan R. (south interior B.C.) -from Osoyoos Lk.	Apr.21-May11 (1953)								Smolt migration.
	-into Osoyoos Lk.	Mar.10-Apr.28 (1952)	Mar.31							Fry migration.
Hoar, 1954	Experiment re: depth preference					100 >70	0-1.8 1.5-1.8 (from bottom)	Prefer faster water		Fry migration.

Table 20. Literature summary of downstream migration timing and water column distribution of juvenile chinook salmon.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Mains & Smith, 1956	Snake R.	Mar.-June	Mid-Apr.	peak	0300-0600	even distribution		50-60 40-50	Banks Centre	80-93% Age 1+.
	Tucannon R.	Year-round	Apr.-May	peak	1900-2100					
	Columbia R. Wash.	Mar.-July	mid-Apr. June,July	70	1800-0600	43.6 27.5 28.9 (C.P.U.E.)	0-.8 1.2-6.3 Bottom	50-60 40-50	Banks Centre	Approx. 75% Age 0+.
	Yakima R.	Apr.-July	mid-May							
Raymond, 1968	Columbia, Snake R. (Wash.,Ore.)	early Apr.-end May								Smolt migration.
Needham et al, 1940	Sacramento R. (Cal.) -at Ball's Ferry	Jan.6-Apr.25 (1899)	Feb.1-15							Smolt migration, Age 0+ fish, prior to construction of Shasta dam.
		(1938/39)	Mar.20-25							
		Dec.14-May28 (1939/40)	end Feb.							
	-at Redding	Apr.28-June8 (1938)								
		Sept.13-Nov.15 (1939)	Sept.20-25							
Reimers, 1968	Elk, Sixes R. (Ore.)	Mar.-June (tributaries) All summer (mainstem)								Smolt migration (two populations).
Hamilton, 1974	Deadman R. (south interior B.C.)	June								Emergent fry.
Reimers, 1973	Sixes R. (Ore.)	Mar.29-May8	Apr.14-15	98.8 1.2	night day					Emergent fry.
	-overall movement	mid-May (tributaries) late-June (mainstem) late-July, early-Aug. (estuary)								Age 0+ smolts.
Bjornn, 1971	Lemhi R., Big Springs Ck.(Idaho)	Jan.-June spring	Apr. Mar.-June							- Fry, Age 0+. - Age 1+ smolts.
Westwater Res., 1974	Fraser R. (south coast B.C.)	mid-Mar. - mid-June	end Apr.-early May							Smolts.

Table 20. Literature summary of downstream migration timing and water column distribution of juvenile chinook salmon, cont.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Long, 1968	Columbia R. (Wash.) -Dallas Dam	Apr.7-27 (during study)		67	1900-0700 Age 0+					
				33	0700-1900 Age 0+					
				95	1900-0700 Age 1+					
				5	0700-1900 Age 1+					
		Apr.28-May12			1530-0830	47.7	0-4.4 Age 0+			Smolt positions in turbine intakes. Depths measured from ceiling of intake at gatewell.
						32.9	4.6-9.0 Age 0+			
						19.6	9.2-13.6 Age 0+			
						74.0	0-4.4 Age 1+			
						19.7	4.6-9.0 Age 1+			
						6.3	9.2-13.6 Age 1+			
	-McNary Dam	Apr.24-May21			1900-0500	79	0-4.4 Age 1+			
						18	4.6-9.0 Age 1+			
						3	9.2-13.6 Age 1+			
Wales & Coots, 1954	Klamath R. (Cal.)	Dec.27-Apr.4 Dec.24-Apr.8 Jan.5-Apr.3 Dec.31-Mar.25								Emergent fry from broods 1950-53.
Slater, 1963	Sacramento R. (Cal.)	Nov.1-May27	Jan.20-29 Feb.19-Mar.19							Age 1+
Reimers & Loeffel, 1967	Columbia R. tributaries (Ore.)	complete by July 1								Smolts. Extended residence due to stream temperature, small fry size.
Meehan & Siniff, 1962	Taku R. (Alaska)	Apr.12-June15	May7-13	peak	0200-0600	most (top 5% of water column)	0-.6			94% Age 1+. 6% Age 2+.
Lister & Walker, 1966	Big Qualicum R. (E. Vancouver Is.)	mid-Mar. - mid-July	end-Mar. - mid-Apr. (emergent fry) mid-June (smolts, Age 0+)							
Lister & Genoe, 1970	Big Qualicum R.	Mar.-June	Apr.7 (fry) June11 (smolts)							
Stein et al, 1972	Sixes R. (Ore.)	mid-May - early Sept.	July							Smolts.

Table 20. Literature summary of downstream migration timing and water column distribution of juvenile chinook salmon, cont.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Monan et al, 1969	Snake R. (Idaho)	spring-early summer		69	dawn & dusk			25	centre	Distribution of salmon and debris examined.
				19	daylight	66	top 1/3	75	banks	
						22	middle 1/3			
						12	bottom 1/3			
				12	darkness (2200-0400)	30	top 1/3			
						29	middle 1/3			
						41	bottom 1/3			
Can. Dept. Fish. & I.P.S.F.C., 1955	Nicola R. (south interior B.C.)	Apr.15-June30								- Emergent fry.
		Apr.15-June30								- Age 0+ smolts.
	Babine Lk. (north interior B.C.)	Apr.15-July1								- Emergent fry.
		May15-July15								- Age 0+ smolts
Rees, 1956	Baker Dam (Wash.)	Mar.14-June22 (during study)				88.6	0-4.6	33.4%	shore	Age 0+ fry.
Everest & Chapman, 1972	Johnson, Crooked Fork Cks.(Idaho)	May-June								Age 1+ present.

Table 21. Literature summary of downstream migration timing and water column distribution of juvenile pink salmon.

Reference	System	Seasonal Timing Range	Peak	Diurnal Timing %Sample	Hours	Vertical Dist'n %Sample	Depth(m)	Horizontal Dist'n %Sample	Depth(m)	Comments
Neave et al, 1953	Honna, Mamin, Brown's Cabin, McClinton Ck. (Queen Charlotte Is.)		Apr.26-May2	most	night					
Bams, 1974	Tsolum R. (E. Vancouver Is.)									River fry less energy-efficient during incubation.
	-Incubation box	Apr.3-Apr.28	Apr.8							
	-Headquarters Ck.	Mar.20-Apr.25	Apr.8							
Bams, 1972	Tsolum R.									
	-Incubation box	Apr.7-May13	Apr.19							
	-Headquarters Ck.	Mar.15-May10	Apr.14							
Walker & Lister, 1971	Qualicum R. transplants (E. Vancouver Is.)									Transplanted stocks develop at same rate (degree-days) as donor stream. Eggs planted in river.
	-Qualicum R. stock	Mar.1-25	Mar.12							
	-Cheakamus R. stock	Mar.12-Apr.25	Apr.6							
	-Tsolum R. stock(1963)	Apr.3-May6	Apr.17							
	-Qualicum R. stock	Apr.20-May4	Apr.26							
	-Bear R. stock	Apr.20-May24	May6							
	-Tsolum R. stock(1964)	Apr.9-30	Apr.16							
Pritchard, 1944	McClinton Ck.	spring			night	near surface				Migration rate approx. 4.6-6.1 mps.
Hunter, 1948	Pt. John Bay		Apr.16							
Hunter, 1949	Pt. John Bay	Mar.25-June10								
Hunter, 1959	Hook Nose Ck. (central coast B.C.)	Mar.24-June9	Apr.19-May26	>60	2100-2300	83.3% of fish caught near centre were in surface 0-.15m. 92.4% of fish caught near banks were in surface 0-.15m.		60 40	centre bank	

Table 21. Literature summary of downstream migration timing and water column distribution of juvenile pink salmon, cont.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
McDonald, 1960	Skeena R. tributaries									
	-Lakelse R. site 1			100	2101-0459	(depth sampled)	.3	29.2	centre: highest vel. at .71m/sec.	
	-Lakelse R. site 2			90-98	2101-0459		"			
	-Kalum R.			69	2101-0459		"			Percentage of daylight migration related to turbidity, distance to estuary.
	-Kitwanga R. (all on north coast B.C.)			61-89	2101-0459		"			
	-Kispiox R. (north interior B.C.)			35-69	2101-0459		"			
					night	42	.4-.6 (stream depths from .6-1.5)			
					day	25	.4-.6 (stream depths from 1.2-1.5m)			
					day	39	.7-.9 (stream depths from 1.2-1.5m)			
Foerster & Ricker, 1953	Cultus Lk. (south coast B.C.)	Mar.1-May14	Apr.5-9							
Neave, 1955	Hook Nose Ck.	Apr.21-May7		50	by 2200					
	Datlamen Ck. (Queen Charlotte Is.)	Apr.15-20		50	by 2330	62	0-.15		fastest water	
	McClinton Ck. (Queen Charlotte Is.)	Apr.14-May5		50	by 2400					
	Honna Ck. (Queen Charlotte Is.)	Apr.16-May8		50	by 2400					
	Mamin Ck. (Queen Charlotte Is.)	Apr.16-May12		50	by 0100					
		start of season		100	2030-0500					
		end of season		100	2100-0400					
Westwater Res., 1974	Fraser R. (south coast B.C.)	end Feb. - early June	early Apr. - early May							
Dept. Fish Can. & I.P.S.F.C., 1955	Seton Ck. (south interior B.C.	May1-31								
	Babine Lk. (north interior B.C.)	Apr.15-July1								

Table 22. Literature summary of downstream migration timing and water column distribution of juvenile coho salmon.

Reference	System	Seasonal Timing		Diurnal Timing		Vertical Dist'n		Horizontal Dist'n		Comments
		Range	Peak	%Sample	Hours	%Sample	Depth(m)	%Sample	Depth(m)	
Meehan & Siniff, 1962	Taku R. (Alaska)	Apr.12-June15 (study period)	May14-27	peak	2400-0200	most	0-.6 (top 5% of water column)			Age 1+, 46%. Age 2+, 54%.
Hoar, 1954	Experiment re: depth preference					38	0-.5			Fry.
						20	.3-.6			
						15	.6-.9			
						24	.9-1.5			
Sumner, 1952	Sand Ck. (Ore.)	end Feb. - early Apr.	Mar.16-22							Fry migration; some Age 1+.
Lister & Walker, 1966	Big Qualicum R. (E. Vancouver Is.)	early May - early June								Age 1+, 97%. Age 2+, 3%.
Lister & Genoe, 1970	Big Qualicum R.	Mar.26-June9	May7-19 May28							Fry.
		Apr.28-June18	May15 May28							Age 1+.
Chapman, 1965	Deer Ck. (Ore.)	early Feb. - end May								Age 1+.
	Flynn Ck. (Ore.)	"								
	Needle Br. Ck. (Ore.)	"								
	all three systems	June (fry)								
Hamilton, 1974	Deadman R. (south interior B.C.)	Apr.-June								Age 1+.
Monan et al, 1969	Snake R. (Idaho)	spring - early summer		69	dawn&dusk			25	centre	Age 1+.
				19	daylight	66	top 1/3	75	bank	
						22	middle 1/3			
						12	bottom 1/3			
				12	darkness (2200-0400)	30	top 1/3			
						29	middle 1/3			
						41	bottom 1/3			
Chapman, 1962 ref. 29	Deer Ck.									
	-1959/60	Feb.14-July18	May23-June6	most	night(fry)					
		Jan.16-May21	Mar.12-26	most	day(Age1+)					
	-1960/61	Feb.14-July30	Mar.26-Apr.9	most	night(fry)					
		Jan.14-May7	Feb.26-Apr.9	most	day(Age1+)					
	Flynn Ck.									
	-1959/60	incomplete		most	night(fry)					
		Jan.16-May21	Mar.26-Apr.9	most	day(Age1+)					
	-1960/61	Feb.14-July16	May7-21	most	night(fry)					
		Jan.1-May21	Mar.26-Apr.9	most	day(Age1+)					
	Needle Br. Ck.									
	-1959/60	incomplete		most	night(fry)					
		Feb.27-May21	Mar.26-Apr.9	most	day(Age1+)					
	-1960/61	Apr.23-July16	May21-June5	most	night(fry)					
		Jan.15-May21	Mar.26-Apr.9	most	day(Age1+)					
Foerster, 1952	Lakelse R. (north coast B.C.)	May13-June14 (study period)	May27-29							Age 1+.

Table 22. Literature summary of downstream migration timing and water column distribution of juvenile coho salmon, cont.

Reference	System	Seasonal Timing: Range	Seasonal Timing: Peak	Diurnal Timing: %Sample	Diurnal Timing: Hours	Vertical Dist'n: %Sample	Vertical Dist'n: Depth(m)	Horizontal Dist'n: %Sample	Horizontal Dist'n: Depth(m)	Comments
Hunter, 1948	Pt. John Bay (central coast B.C.)		May							Fry.
Hunter, 1949	Pt. John Bay	Apr.14-June10								Fry.
McDonald, 1960	Williams Ck. (north coast B.C.)			58.5	2300-0100			all across creek		Age 1+.
Foerster & Ricker, 1953	Sweltzer Ck. (south coast B.C.)	May10-July12 May1-June8 Mar.1-June28 Feb.6-June8 end Mar. - early May (Age 2+)	June12(fry) June3(Age1+) Apr.5-9(fry) May25-29(Age1+)							
Westwater Res., 1974	Fraser R. (south coast B.C.)	mid-Mar. - mid-June	mid-Apr. - early May							
Dept. Fish. Can. & I.P.S.F.C., 1955	Nicola R. (south interior B.C.) Babine Lk. (north interior B.C.)	May1-June30 (fry) Apr.15-June30 (Age 1+) Apr.15-July1 (fry) May15-July15 (Age 1+)								
Wickett, 1951	Nile Ck. (E. Vancouver Is.)	Apr.-June (fry)								
Rees, 1956	Columbia R. (Wash.)	Mar.14-June22 (study period)				88.6	0-4.6	33.4	near shore	Age 1+.

Table 23. Literature summary of downstream migration timing and water column distribution of juvenile chum salmon.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Hunter, 1948	Pt. John Bay (central coast B.C.)		May6							
Hunter, 1949	Pt. John Bay	Mar.25-June10								
Hunter, 1959	Pt. John Bay	Mar.31-June9	Apr.17-May17	>50 peak	2100-2200 2200	82% of fish caught near centre were in surface 0-.15m. 89% of fish caught near bank were in surface 0-.15m.				
								58 42	centre bank	
McDonald, 1960	Skeena R. (north coast B.C.)			90.6	2100-0500			uniform		
Foerster & Ricker, 1953	Sweltzer Ck. (south coast B.C.)	Feb.25-June8	Apr.5-24 May25-29							
Neave, 1955	Hook Nose Ck. (central coast B.C.)	Apr.21-May7		50	by 2200					
	Datlamen Ck. (Queen Charlotte Is.)	Apr.15-20		50	by 2330	62	0-.15			
	McClinton Ck. (Queen Charlotte Is.)	Apr.14-May5		50	by 2400					Data as per pink fry.
	Honna Ck. (Queen Charlotte Is.)	Apr.16-May8		50	by 2400					
	Mamin Ck. (Queen Charlotte Is.)	Apr.16-May12 start of season end of season		50 100 100	by 0100 2030-0500 2100-0400					
Hoar, 1951	General			at night —		near surface —		mid-stream		
Westwater Res., 1974	Fraser R. (south coast B.C.)	end Feb. - mid June	early Apr. - early July							
Meehan & Siniff, 1962	Taku R. (Alaska)	Apr.12-June15 (study period)	Apr.30-May6	peak	2200-2400	most	0-.61 (top 5% of water column)			
Dept. Fish. Can. & I.P.S.F.C., 1955	Babine Lk. (north interior B.C.)	Apr.15-July1								
Hoar, 1954	Experiment re: depth preference					38 21 18 18	.9-1.2 .6-.9 0-.3 1.2-1.5			
Sumner, 1952	Sand Ck. (Ore.)	end-Feb. - Apr.29	Apr.7-14							
Lister & Walker, 1966	Big Qualicum R. (E. Vancouver Is.)	mid-Apr. - end May								

Table 24. Literature summary of downstream migration timing and water column distribution of juvenile steelhead/rainbow trout.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Bjornn, 1971	Lemhi R., Big Springs Ck. (Idaho)	Aug.-July	Dec.(fry Aug.-Dec. (Age 1+) Apr.-Aug. (Age 1+) May(Age 2+)							
Long, 1968	Columbia R. (Wash.)									
	-Dallas Dam	Apr.7-27 (study period)		86	1900-0700 (Age 1+)					
				14	0700-1900 (Age 1+)					
		Apr.28-May12 (study period)			1530-0830	72.7	0-4.4 (Age 1+)			
						21.1	4.6-9.0 (Age 1+)			
						6.2	9.2-13.6 (Age 1+)			
	-McNary Dam	Apr.24-May26 (study period)			1900-0500	73.5	0-4.4 (Age 1+)			
						24.2	4.6-9.0 (Age 1+)			
						2.3	9.2-13.6 (Age 1+)			
Mains & Smith, 1956	Snake R.	early Apr. - June	mid-May	peak	0300-0600	high water, prefer middle and bottom; low water, prefer surface layer		80	centre	Age 1+
	Tucannon R.	some all yr.	Apr.-May	peak	1900-2100					
	Columbia R.		Apr.18-22					80	centre	
	Yakima R.	Apr.-July	mid-May							
Stauffer, 1972	Black R. (Ontario)	end Apr. - end July	end May - end June (77.9%)	54	1700-2230 (Age 1+,2+)					Rainbow.
				39	2230-0830 (Age 1+,2+)					
				7	0830-1700 (Age 1+,2+)					
		Age 1+ - 71% June Age 2+ - 74% May11-June10 Age 3+ - 75% May								
Wagner, 1968	Alsea R. (Ore.)	Apr.-May	mid Apr. - mid May							Wild smolts, from Withler, 1966.
Maher & Larkin, 1954	Chilliwack R. (south coast B.C.)	Mar.-Apr.								Age 2+.
Alexander & MacCrimmon, 1974	Bothwell's Ck. (Ont.)	May3-July3	May21 May30-June5	96.6	May14, night					Ages 1+, 2+.
Northcote, 1969	Lardeau R. (south interior B.C.)	Downstream before late July		most	1900-0800				midstream	Rainbow fry.
				peak	2000-2100					
		Upstream after July to Aug.		daytime movement					along shores	

Table 24. Literature summary of downstream migration timing and water column distribution of juvenile steelhead/rainbow trout, cont.

Reference	System	Seasonal Timing Range	Seasonal Timing Peak	Diurnal Timing %Sample	Diurnal Timing Hours	Vertical Dist'n %Sample	Vertical Dist'n Depth(m)	Horizontal Dist'n %Sample	Horizontal Dist'n Depth(m)	Comments
Sumner, 1952	Sand Ck. (Ore.)	May7-mid June	June7-14							Steelhead smolts.
Dept. Fish. Can. & I.P.S.F.C., 1956	Babine Lk. (north interior B.C.)	May15-July15								Steelhead smolts.
	Nicola R. (south interior B.C.)	Apr.15-July15								
Everest & Chapman, 1972	Crooked Fork, Johnson Cks. (Idaho)	During 2nd & 3rd summer								Steelhead smolts.
Rees, 1956	Columbia R. (Wash.)	Mar.14-June22 (study period)				88.6	0-4.6	33.4	shore stations	Steelhead smolts.

Table 25. Sites, species, flow specifications and mean survival rates of spawning channels in British Columbia (summarized from Salmonid Enhancement Program Annual Report 1977, and A.C. Cooper, I.P.S.F.C. Progress Report, 1977).

Site	Species	Depth (cm)	Velocity (m/sec)	Gradient (%)	Average Discharge (l/sec)	Egg-to-Fry Survival (%)
Jones Ck.	Pink	45	.61	.10	700- 850	37
Robertson Ck.[a]	Pink, Chinook	45	.46	.12	2800	--
Big Qualicum R. #1[a]	Chum	45	.61	.09	1700	18
Big Qualicum R. #2	Chum	30	.73	.20	2300-2800	79
Fulton R. #1	Sockeye	40	.55	.09	2100	49
Fulton R. #2	Sockeye	30	.64	.20	2800	44
Pinkut Ck.[b]	Sockeye	40	.55	.09	1300-1600	35
Seton Ck. Upper	Pink	46	.38	.06	1130	59
Seton Ck. Lower	Pink	38	.45	.10	1130	58
Weaver Ck.	Sockeye	24	.37	.06	570	74
Gates Ck.	Sockeye	38	.45	.10	1130	74
Nadina R.	Sockeye	48	.36	.05	1130	69

[a] Not in operation - converted to rearing channels.
[b] Specifications prior to reconstruction in 1977.

Table 26. Summary of gravel incubation projects, gravel sizes used and early survival rates (summarized from Bams and Simpson, 1977, MS.).

			Gravel Size (cm)		Percent Survival	
No.	Location	Species	Range	Mean	To Eyed Egg	To Emergence
1	Hook Nose Ck.	Chum	(.7-2.6)	2.0	50.9	76
2	Tsolum R.	Pink	(1.9-3.2)	2.5	84.1	93
3	Auke Bay[a]	Pink	(.6-5.1)	1.0	-	82.7
4	Inches Ck.	Chum	(1.9-3.8)	2.9	92.5	93.5
5	Auke Bay	Pink	(1.3-3.2)	1.9	95	84.5
6	Auke Bay	Pink	(1.3-3.2)	1.9	94	92
7	Little Port Walter[a]	Pink	(1.3-3.2		-	84
8	Tsolum R.	Pink	(1.9-3.2)	2.5	88	93.3
9	Auke Bay	Pink	(1.3-3.2)	1.9	79	71.6
10	Blaney Ck.	Chum	(1.9-3.2)	2.5		90
11	Big Kitoi Ck.[b]	Pink	(1.9-3.2)			100[d]
12	Big Kitoi Ck.[b]	Sockeye	(1.9-3.2)			97.5
13	Fulton R.	Sockeye	(.5-1.9)			50.2
14	Fulton R.	Chinook	(2.5-3.2)			75
15	Fulton R.	Sockeye	(2.5-3.2)			80
16	Bear R.	Pink	(1.3-3.8)		92	87
17	Bear R.	Pink	(1.3-3.8)		94	98
18	Exploits R.[c]	Atl. Salmon	(1.9-3.8)			63.8

[a] Southeast Alaska.
[b] Alaska.
[c] Newfoundland.
[d] Actual survival rate was 107%; therefore, loading error.

ANNOTATED BIBLIOGRAPHY

1. Anonymous. 1954. The salmon problems associated with the proposed flood control project on the Okanagan River in British Columbia, Canada. (Publ) U.S. Fish & Wildl. Ser., The Wash. State Dept. of Fish., The Dept. of Fish., Vancouver, B.C., Canada.

2. Anonymous. 1973. Pacific Salmon: Population and Habitat requirements. Task 162, Preliminary Rep. No. 16. Canada-B.C. Okanagen Basin Agreement. Fish. Ser., Dept. of the Envir., Canada; Wash. State Dept. of Fish. pp. 1-44.

3. Anonymous. 1974. Homathko River development - Fisheries Resources & Concerns. Environment Canada, Unpub. M.S., pp. 1-19.

4. Acara, A.H. and H.D. Smith. 1971. A technique for enumerating kokanee salmon (Oncorhynchus nerka) fry migrating through streams, with an appendix for processing catch data by IBM 360 Fortran IV computer programs. J. Fish. Res. Bd. Canada 28: 573-585.

A technique for enumerating kokanee salmon (Oncorhynchus nerka) fry migrating downstream was developed in Meadow Creek (a tributary to the Duncan River and Kootenay Lake, B.C.) and was used to obtain an estimate of 10.06 million kokanee fry in 1968. The hyperbolic relation between the nightly mean catch per net per minute (C) and nightly probable error (E) as the percent of the nightly total was expressed by $\log E = -0.5703 - 0.4568 \log C$; E was largest at the beginning and end, and smallest at the peak of fry migration. E was also calculated as the percent of the seasonal total, and in 1968 was ±5.8%. Of this total, ±0.7% was accumulated during April, when 6.4% of the migration occurred; ±3.9% was accumulated in May, when 82.2% of the migration occurred; and the final ±1.2% was accumulated in June, when 11.2% of the migration occurred. The variability in abundance of fry and spacing of groups of fry are considered to be the most important factors controlling the magnitude of error.

Some aspects of migratory behaviour of kokanee fry in Meadow Creek were revealed and their effects on estimates of abundance are discussed.

A series of IBM 360 Fortran IV computer programs for processing catch data are also given in an appendix.

5. Alexander, D. Ross, and Hugh R. MacCrimmon. 1974. Production and movement of juvenile rainbow trout (Salmo gairdneri) in a headwater of Bothwell's Creek, Georgian Bay, Canada. J. Fish. Res. Board Can. 31: 117-121.

Within the 21,500 m^2 headwater, the standing population of juvenile rainbow trout reached a high of 7.05 g/m^2 in October. Production was maximum during August at 1.77 g/m^2. Total annual production is calculated at 284.5 kg (13.2 g/m^2). Spring emigrants (no less than 4830 fish weighing 69 kg) were age I (91%) and age II. Minimum calculated ratio of production to yield as emigrants was 4.1:1. Comparatively few age 0 fish emigrated during summer. Because of their demonstrated capability to produce juveniles, sensitive headwaters must be preserved from ecological disturbance to assure self-perpetuating rainbow trout populations in the Great Lakes.

6. Bams, R.A. 1970. Evaluation of a revised hatchery method tested on pink and chum salmon fry. J. Fish. Res. Bd. Canada 27: 1429-1452.

An artificial incubation method employing filtered river water and a gravel substrate was compared with natural propagation in a test on pink (Oncorhynchus gorbuscha) and chum (O. keta) salmon, at Hooknose Creek, King Island, B.C. At time of migration, about 70% of the hatchery pink fry were similar to the wild fry in stage of development; the remainder were immature. A similar but less pronounced difference occurred in the chum. Average rates of development were the same in the hatchery and the creek for each species. These two phenomena combined resulted in the hatchery fry of both species migrating, on average, from 1 to 2 weeks earlier than the wild fry.

Growth during incubation was the same in hatchery and creek, i.e., no loss of potential size occurred in this hatchery environment. Survivals in the hatchery were higher than in the creek, but were less than expected on the basis of experiments carried out elsewhere. Hatchery pink fry showed a lower variability in mean lengths and weights than did creek fry, possibly in response to greater homogeneity of the incubational environment. Chum fry from the last part of the creek runs showed evidence of postemergent growth in fresh water.

7. Bams, R.A. 1972. A quantitative evaluation of survival to the adult stage and other characteristics of pink salmon (Oncorhynchus gorbuscha) produced by a revised hatchery method which simulates optimal natural conditions. J. Fish. Res. Bd. Canada 29: 1151-1167.

7. Cont'd.

To evaluate a hatchery method utilizing a gravel medium and filtered water during incubation, comparisons were made between naturally and artificially propagated parts of one native stock of pink salmon (Oncorhynchus gorbuscha) of the Tsolum River, B.C. Yolk utilization (growth rate) of fry was unimpeded in the hatchery environment, but hatchery fry migrated about 6 days earlier than creek fry. Hatchery survival was about six times that in the creek. The main test criterion - relative survival to the adult stage of fish from both treatments following migration from the creek - was tested by release of two similar groups of fry identified by a double finclip and recovery of marked adults upon return. Both groups survived at virtually the same rate. Numbers of actual mark recoveries were adequate to demonstrate statistically that survival of hatchery fish following release was not less than 90% of creek fry survival and that the final gain ratio of the hatchery treatment was not less than 5.44 ($P < .005$). Adult size, sex ratio, fecundity, and timing were not adversely affected by the hatchery treatment.

8. Bams, Robert A. 1974. Gravel incubators: a second evaluation on pink salmon, Oncorhynchus gorbuscha, including adult returns. J. Fish. Res. Board Can. 31: 1379-1385.

A hatchery method designed for mass production of unfed Pacific salmon fry and utilizing a gravel medium during most of the incubation period is being evaluated on successive cycles of a stock of pink salmon, Oncorhynchus gorbuscha, of the Tsolum River, B.C. Possible treatment effects are studied at emergent fry and returning adult stages in artificially and naturally propagated populations. Average growth rate and, hence, efficiency of yolk conversion were unimpeded in the hatchery environment, but fry emerged 11 days prematurely. Survival from green egg to emergent fry averaged 74.9% in the hatchery and 20.6% in the creek, for a gain ratio at emergence of 3.63. Recovery of selectively marked populations of hatchery and creek fish demonstrated almost identical survival rates from fry to adult stages and a final gain ratio of 3.46. Adult lengths and weights, fecundity, and timing of migrations were unaffected generally by the hatchery treatment.

9. Bams, R.A. and K.S. Simpson. 1976. Substrate Incubators Workshop - 1976. Report on Current State-of-the-Art. Fish. Mar. Ser. Res. Dev. Tech. Rep. No. 689: 67 p.

Under auspices of the Salmonid Enhancement Program, Department of the Environment, Fisheries and Marine Service, Pacific Region, a 2-day workshop was held in June, 1976, at

9. Cont'd.

Vancouver, B.C., to evaluate the "state-of-the-art" of gravel-incubation methodology for Pacific salmon.

This report covers the main topics discussed at the meetings under the following headings: Basic biological requirements in incubation; Available options in substrate incubation; Design criteria; Performance criteria (systems evaluation); Research Questions; Bibliography; and three appendices listing details of construction, operation, and evaluation of 28 projects employing different substrate-incubation techniques.

10. Banks, Joe, L., Laurie G. Fowler, and Joseph W. Elliott. 1971. Effects of rearing temperature on growth, body form, and hematology of fall chinook fingerlings. Prog. Fish-Cult. 33: 20-26.

11. Belding, David L. 1928. Water temperature and fish life. Trans. Amer. Fish. Soc. 58: 98-105.

12. Bjornn, T.C. 1971. Trout and Salmon Movements in Two Idaho Streams as Related to Temperature, Food, Stream Flow, Cover, and Population Density. Trans. Amer. Fish Soc. 100: 423-438.

Many juvenile salmon and trout migrated from the Lemhi River drainage each fall-winter-spring period. Seaward migration of anadromous trout and salmon normally occurred in the spring but pre-smolt anadromous and non-anadromous fishes also left the stream usually beginning in the fall. I compared data on temperature, food abundance, stream flow, cover and population density with movements and conducted field and laboratory tests to determine reasons for the two types of movements.

Smolts of the anadromous species migrated for an obvious reason but none of the factors I examined appeared to "stimulate or release" their seaward migration. Movement frequently coincided with changes in water temperature and stream flow, but I could not establish a consistent causal relationship and concluded that photoperiod and perhaps growth must initiate the physiological and behavioral changes associated with seaward migration.

Non-anadromous and pre-smolt anadromous species emigrated from the streams for different reasons than the smolts. I postulated that fish found the stream environment unsuitable during the winter. Stream temperature declined in the fall as fish began moving from the streams but I could not induce more fish to stay in test troughs with 12°C water versus troughs with 0-10°C water. Fish emigrated before

12. Cont'd.

abundance of drift insects declined in winter. Emigration occurred in spite of the relatively stable flows in both streams. Population density modified the basic migration pattern by regulating the number and percentage of fish that emigrated and to a limited extent time of emigration.

Movements of non-smolt trout and salmon correlated best with the amount of cover provided by large rubble substrate. Subyearling trout emigrated from Big Springs Creek which contained no rubble substrate but remained in the Lemhi River which did. In both field and laboratory tests more fish remained in troughs or stream sections with large rubble substrate than in troughs or sections with gravel substrate. Trout and salmon in many Idaho streams enter the substrate when stream temperatures declined to 4-6°C. A suitable substrate providing adequate interstices appears necessary or the fish leave.

13. Bjornn, T.C., D.R. Craddock, and D.R. Corley. 1968. Migration and Survival of Redfish Lake, Idaho, Sockeye Salmon, Oncorhynchus nerka. 1968. Trans. Amer. Fish. Soc. 97: 360-373.

Most adult sockeye salmon returning to Redfish Lake had spent two years in the ocean. Survival from smolt to returning adult at the lake ranged from 0.14 to 1.83%. The sex-ratio was nearly even.

Survival of sockeye in the lake from potential egg deposition to smolt migration was usually less than 6%. In at least one year, smolts originating from kokanee and/or residual sockeye may have comprised a large proportion of the migration. There was little relationship between egg deposition and smolts produced.

Sockeye salmon smolts migrated from Redfish Lake primarily from 1800 to 2400 hr. There was no consistent relationship between seasonal timing of the migration, lake ice cover, temperatures or flow of the outlet stream. The role of photoperiod in timing of the migration and the parr-smolt transformation is unclear.

Growth of juvenile sockeye in the lake was inversely related to population density and age at migration was dependent upon first year growth in the lake. More than half the fish of a year class migrated as yearlings when their mean length was more than 85 mm. When the mean length of yearlings was less than 85 mm less than half the fish of a year class migrated as yearlings.

14. Black, Edgar C. 1953. Upper Lethal Temperatures of Some British Columbia Freshwater Fishes. J. Fish. Res. Bd. Canada. 10(4): 196-210.

During the summers of 1950 and 1951 the upper lethal temperature was measured for 14 species of freshwater fishes, representing five families. The fish were captured from lakes in the southern Okanagen Valley, and the experiments were conducted in the Summerland Trout Hatchery, Summerland, B.C. The upper temperature (°C) at which 50 percent of the fish died in 24 hours was estimated as follows, the approximate acclimation temperature being given in brackets: Salmo gairdneri kamloops fingerlings, 24.0(11); Oncorhynchus nerka kennerlyi fry, 22(11); Catostomus catostomus, 27(11.5) 26.6(14); Mylocheilus caurinus, 27(10), 27.1(14); Rhinichthys falcatus, 28.3(14); Richardsonius balteatus, 25(9-11), 27.6(14); Cottus asper, 24.1(18-19); Catostomus macrocheilus, 29.4(19); Micropterus salmoides, 28.9(20-21); Ptychocheilus oregonensis, 29.3(19-22); Ameiurus melas melas, 35.0(23); Perca flavescens, 26.5(18), 29.2(22-24); Lepomis gibbosus, 28.0(18), 30.2(24); Cyprinus carpio, 31-34(20), 34.7(26).

15. Brett, J.R. 1945. The Design and Operation of a Trap for the Capture of Migrating Young Sockeye Salmon. Trans. Amer. Fish. Soc. 75: 97-104.

A means of obtaining young sockeye salmon, Oncorhynchus nerka, during their seaward migration by use of a netting fence and a central trap has been found successful in the Lakelse River, British Columbia. By operating at the point of maximum width and minimum rate of flow, the problems of current force and accumulation of debris were overcome. Increased rate of flow into the trap, which served to attract the fish, was obtained by use of a funnel entrance. It was discovered that the size of the openings of the trap must be such as to allow the entrance of schools of sockeye rather than individuals. These schools were found to converge and enter the trap more readily through slits in a horizontal plane than through those in a vertical position.

16. Brett, J.R. 1950. A Study of the Skeena River Climatological Conditions with Particular Reference to their Significance in Sockeye Production. J. Fish. Res. Bd. Canada 8(3): 178-187.

From an analysis of climatological conditions in the Skeena River watershed no climatic variations or cyclic trends which might account for a declining sockeye fishery have been detected.

16. Cont'd.

Most of the area in which sockeye spawn has an annual rainfall of less than 20 inches. A significant relation between sockeye production and rainfall in the spawning months of August and September was apparent for the years 1920 to 1934. While successful prediction cannot be anticipated, conservation through stream-level control is supported.

17. Brett, J.R. 1951. Temperature Tolerance in Young Pacific Salmon Genus Oncorhynchus. J. Fish. Res. Bd. Canada 9(6): 265-309.

18. Brett, J.R. 1956. Some Principles in the Thermal Requirements of Fishes. Quart. Rev. Biol. 31(2): 75-87.

19. Brett, J.R. and D.F. Alderdice. 1958. The Resistance of Cultured Young Chum and Sockeye Salmon to Temperatures Below 0°C. J. Fish. Res. Bd. Canada 15(5): 805-813.

Recent efforts to establish Pacific salmon in Hudson Bay posed the question of low temperature tolerance in these species. A series of lethal temperature tests at -0.5, -1.0 and -1.5°C demonstrated that resistance to temperatures slightly below 0°C was limited. Freezing of the blood and aqueous humour occurred at temperatures of -1.0 and -1.5°C.

20. Brett, J.R. and J.A. McConnell. 1950. Lakelse Lake Sockeye Survival. J. Fish. Res. Bd. Canada 8(2): 103-110.

The number of young sockeye migrating seaward from Lakelse Lake, B.C., was 557,000 (1946) and 373,000 (1947). From seeding estimates in the parent years percent survivals of 1.1 and 1.04 have been calculated.

Stomach analyses of 623 squawfish caught by gill nets in the late spring and summer months (1944-1947) show an average fish content of 83% by volume. Of this total fish content sockeye constitute 31%. The heavy losses in young sockeye could be attributed to the feeding of predacious fish and variation in sockeye survival may be a result of fluctuations in the abundance of "buffer" species.

21. 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. Bd. Canada 26: 2363-2394.

21. Cont'd.

The growth of young sockeye salmon (Oncorhynchus nerka) was studied at temperatures ranging from 1 to 24°C in relation to rations of 0, 1, 2, 3, 4, 5, and 6% of dry body weight per day, and at an "excess" ration. Optimum growth occurred at approximately 15°C for the two highest rations, shifting progressively to a lower temperature at each lower ration. The maximum growth rate for sockeye 5-7 months old was 2.6%/day; that for fish 7-12 months old was 1.6%/day. At 1°C a ration of 1.5%/day was sufficient to provide for a maximum growth rate of 0.23%/day. The maintenance ration was found to increase rapidly above 12°C, amounting to 2.6%/day at 20°C. No growth took place at approximately 23°C despite the presence of excess food.

Isopleths for gross and net food-conversion efficiencies were calculated. A maximum gross efficiency of 25% occurred in a small area with a center at 11.5°C and a ration of 4.0%/day; a maximum net efficiency of 40% occurred within a range of 8-10°C for rations of 1.5%/day down to 0.8%/day, the maintenance level.

Gross body constituents changed in response to the imposed conditions, varying in extreme from 86.9% water, 9.4% protein, and 1.0% fat for starved fish at 20°C to 71.3% water, 19.7% protein, and 7.6% fat on an access ration at 15°C.

It is concluded on the basis of growth and food-conversion efficiency that temperatures from 5 to 17°C are most favourable for young sockeye, and that a general physiological optimum occurs in the vicinity of 15°C.

22. Brett, J.R., M. Hollands, and D.F. Alderdice. 1958. The Effect of Temperature on the Cruising Speed of Young Sockeye and Coho Salmon. J. Fish. Res. Bd. Canada 15: 587-605.

The cruising speeds of underyearling and yearling sockeye and coho salmon were determined in a rotating annular trough, for acclimation temperatures ranging from 1° to 24°C. Variation in swimming speed characterized the first 40 to 50 minutes; subsequently a relatively steady state was obtained.

Optimum cruising speeds occurred at 15°C for sockeye and 20°C for coho. Maximum sustained levels fell mainly between 1.0 and 1.5 ft. per second (30 and 45 cm. per sec.).

23. Burner, Clifford J. 1951. Characteristics of Spawning Nests of Columbia River Salmon. U.S. Fish. and Wildl. Ser., Fish. Bull. 52(61): 97-110.

24. Burrows, Roger E. 1963. Water Temperature Requirements for Maximum Production of Salmon. pp. 29-35 In Proceedings of the 12th Pacific Northwest Symposium on Water Pollution research. Pacific Northwest Water Laboratory, U.S. Public Health Service, Corvallis, Oregon.

25. Bustard, David R. 1973. Some Aspects of the Winter Ecology of Juvenile Salmonids with Reference to Possible Habitat Alteration by Logging in Carnation Creek, Vancouver Island. Fish. Res. Bd. Canada, Manuscript Report Series No. 1277 pp. 1-85.

26. Cairns, John Jr. 1956. Effects of Heat on Fish. Industrial Wastes. (May-June). pp. 180-183.

27. Canada Department of Environment, Fisheries and Marine Service, 1973. "Minimum Flow Requirements for the Alouette River". Prepared by F.F. Slaney and Co. Ltd. for the Dept. of Envir., Fish and Marine Ser., Pacific Region, Vancouver. 24 p.

28. Canada Department of Fisheries and International Pacific Salmon Fisheries Commission. 1955. A Report on the Fish Facilities and Fisheries Problems related to the Fraser and Thompson River dam site investigations. Prepared in collaboration with the British Columbia Dept. of Fish. and the British Columbia Game Commission, Vancouver, B.C.

29. Carl, G. Clifford. 1939. Comparison of Coho Salmon Fry from Eggs Incubated in Gravel and in Hatchery Baskets. Trans. Amer. Fish. Soc. 69: 132-134.

Eggs of Coho salmon (*Oncorhynchus kisutch*) were planted in gravel, and placed in open and in covered hatchery baskets in hatchery troughs to determine the possibility of the production of differences in eye diameter by incubation under the different conditions. No significant difference was found between any two of the three lots. In the gravel planting a number of eggs was unaccounted for, which fact may explain the high rates of efficiency obtained by basing estimates of losses in redds only upon the number of dead eggs remaining in the gravel.

30. Chambers, John S. 1955. Research related to the study of spawning grounds in natural areas. Annual Report, Washington Dept. of Fisheries to the U.S. Army Corps of Engineers. North Pacific Division. (Fish. Eng. Res. Program).

31. Chapman, D.W. 1962. Aggressive Behavior in Juvenile Coho Salmon as a Cause of Emigration. J. Fish. Res. Bd. Canada 19(6): 1047-1080.

Large numbers of coho fry (called nomads) move downstream from shortly after emergence through early fall. These fry are smaller than residual coho. Study of behavior showed coho to be aggressive and territorial or hierarchical. Nomadic coho placed in stream aquaria barren of resident fish tended to remain in the aquaria rather than continuing downstream movement, while nomads added to resident groups of coho were dominated by the resident dominant fish and tended to leave the channels. Hierarchies were organized on the basis of fish size, with larger fry having better growth opportunities. Feeding of coho in excess of requirements did not alter holding capacity of stream aquaria. Aggression observed in natural stream areas was frequent, probably virtually continuous. Nomads transferred to natural stream areas barren of other coho remained there, while nomads added to resident populations tended to move downstream. It was concluded that aggressive behavior is one important factor causing downstream movement of coho fry.

32. Chapman, D.W. 1965. Net Production of Juvenile Coho Salmon in Three Oregon Streams. Trans. Amer. Fish. Soc. 94: 40-52.

Net production of juvenile coho salmon was estimated in three small streams in Oregon for 4 consecutive years. Annual net production of coho was greatly different in the 4 years, but production per unit area was similar among streams, averaging about 9 g/m^2 per year. No significant differences were found among streams in production per unit area for 14 months from emergence of fry one spring through seaward migration the next spring. For 4 years biomass averaged 5-12 g/m^2 shortly after emergence of fry, declining to 2-3 g/m^2 by July and remaining at about 2-4 g/m^2 until emigration of smolts in the following spring. In all years, mean production declined from 1.9-2.8 g/m^2 per month after emergence to 0.2-0.3 g/m^2 per month in winter, then increased to 0.5-0.6 g/m^2 per month prior to emigration. Monthly instantaneous growth rates were highest shortly after emergence of fry, declining until late winter, then increasing just before smolt emigration. The mean monthly instantaneous growth rate was about 0.19 for all streams and years. Yield of smolts as seaward emigrants ranged from 18 to 67 per 100 m^2. Net production was 1.5 to 3.0 times greater than yield as biomass of smolts. Net production of all fish in one stream containing coho, steelhead and cutthroat trout, and cottids was estimated to be 16 g/m^2 per year and compared with data from other waters. Relatively large freshets appeared to cause large downstream movements of juvenile coho. Downstream drift of postemergence fry and emigration of yearlings tended to bias estimates of growth and net production in the residual populations.

33. Chapman, D.W. 1966. Food and Space as Regulators of Salmonid Populations in Streams. The Amer. Naturalist 100(913): 345-357.

34. Coble, Daniel W. 1961. Influence of Water Exchange and Dissolved Oxygen in Redds on Survival of Steelhead Trout Embryos. Trans. Amer. Fish. Soc. 90: 469-474.

A field study of spawning gravel conditions affecting the survival of steelhead trout (*Salmo gairdneri* Richardson) embryos was conducted in two small streams in the Alsea River Basin in Lincoln County, Oregon, from February to June 1959. Holes 10 inches deep, approximating natural redds, were dug in arbitrarily selected spawning locations. Plastic mesh sacks containing gravel and 100 fertilized trout eggs were placed in the upstream end of each hole. A standpipe was placed in the lower end of each excavation about 10 inches away from the eggs, and the hole was filled with gravel to the streambed level. Periodically, determinations were made of gravel permeability and of the apparent velocity and dissolved-oxygen content of the intra-gravel water. A month after calculated hatching times, the bags were removed from the streambed, and the fry contained in them were counted and preserved. The permeability of the spawning gravel fluctuated while embryos were in the gravel. During this period mean gravel permeabilities ranged from 80 to 400 meters per hour; apparent velocities from 5 to almost 110 centimeters per hour; and dissolved-oxygen concentrations from 2.6 to 9.25 milligrams per liter. Embryonic survival percentages ranged from 16 to 62. There was positive correlation between the apparent velocity of ground water and embryonic survivals, and between the dissolved-oxygen levels of the gravel water and survivals. Apparent velocities and dissolved-oxygen concentrations were closely related in the intra-gravel water, and effects of these factors could not be separated.

35. Combs, Bobby D. and Roger E. Burrows. 1957. Threshold Temperatures for Normal Development of Chinook Salmonid Eggs. Prog. Fish-Cult. 19(1): 3-6.

36. Cooper, A.C. 1977. Evaluation of the Production of Sockeye and Pink Salmon at Spawning and Incubation Channels in the Fraser River System. Int. Pac. Sal. Fish. Comm. Prog. Rep. No. 36.

A description is presented of each of the five spawning channels and one incubation channel operated by the Commission. Details of survival from eggs deposited to returning adults are presented together with the costs and benefits.

36. Cont'd.

The six channels were built over the period 1960-1974 at a cost of $1,682,000. Five of them, costing $921,000, have produced sockeye and pink salmon with a landed value of $10,000,000 in this period. As utilization of these channels increases to optimum levels, it is expected that the average annual landings will be doubled.

The construction of additional similar facilities as recommended by the Commission is considered fully justified.

37. Delisle, Glenn E. 1962. Water Velocities Tolerated by Spawning Kokanee Salmon. Calif. Fish. & Game 48(1): 77-78.

38. Delisle, G.E. and B.E. Eliason. 1961. Stream Flows Required to Maintain Trout Populations in the Middle Fork Feather River Canyon. (Publ.) State of Calif., Dept. of Fish & Game, Region II, Water Projects Report No. 2. pp. A-1 - A-19.

39. Dill, L.M. and T.G. Northcote. 1970a. Effects of Some Environmental Factors on Survival, Condition, and Timing of Emergence of Chum Salmon Fry (Oncorhynchus keta). J. Fish. Res. Bd. Canada 27: 196-201.

In an experiment in incubation channels at Robertson Creek, B.C., survival of chum salmon from planting of eggs to emergence of fry was higher in large gravel (2-4 inches, 5.1-10.2 cm) than in small gravel (0.4-1.5 inches, 1.0-3.8 cm). Neither condition coefficient nor timing of emergence was affected by gravel size. There were no significant effects of egg burial depth (8 and 12 inches, 20.3 and 30.5 cm) or density (50 and 100 per treatment) on condition coefficient, or timing of emergence.

40. Dill, L.M. and T.G. Northcote. 1970b. Effects of Gravel Size, Egg Depth, and Egg Density on Intragravel Movement and Emergence of Coho Salmon (Oncorhynchus kisutch) Alevins. J. Fish. Res. Bd. Canada 27(7): 1191-1199.

In experimental aquaria with large gravel (3.2-6.3 cm), vertical and lateral movements of coho salmon (Oncorhynchus kisutch) alevins were more extensive and area utilized per alevin was greater than in small gravel (1.9-3.2 cm). At low density (50 per aquarium) the alevins moved farther towards the inlet, but the mean area occupied per alevin was the same as that at high density (100 per aquarium). Burial depths tested (20 and 30 cm) had no significant effect on vertical or lateral movements or on area utilized per alevin. Alevin orientation in the gravel, survival to emergence, and timing of emergence were not affected by any of the environmental variables examined.

41. Dodge, Douglas P. and Hugh R. MacCrimmon. 1971. Environmental Influences on Extended Spawning of Rainbow Trout (Salmo gairdneri). Trans. Amer. Fish. Soc. 100: 312-318.

Variations in discharge and water temperature influenced movements of spawning rainbow trout between Lake Huron and Bothwell's Creek. Adults entered the stream between 29 October and 15 May, with numerical peaks in late December, and between 16 February and early April following major freshets and associated rising water temperatures. Between 31 January and 13 February, during a period of minimal stream discharge and low water temperatures to 0.3°C, no new fish entered the stream, but spent and spawning-scarred fish moved downstream, and disappeared after a mid-February freshet. Spent trout of the later run moved downstream during late April and early May.

Spawning occurred first on 27 December in the upper reaches at 6°C, and by early January elsewhere in the stream. Activity increased with rising water temperatures, peaking during late March and early April at water temperatures of 6 to 8°C. Aborted attempts at spawning occurred on 2 June. Viable eggs resulted from December and January spawning at water temperatures of 0.3 and 2.0°C.

42. Donaldson, Lauren R. and Fred J. Foster. 1940. Experimental Study of the Effect of Various Water Temperatures on the Growth, Food Utilization, and Mortality Rates of Fingerling Sockeye Salmon. Amer. Fish. Soc. 70: 339-346.

Experiments were conducted with sockeye salmon fingerlings to determine the effect of various water temperatures on the growth, mortality, and food conversion of the fish. Maximum tolerance temperatures were determined, as were the optimum growth zones, as found in Skaha Lake, British Columbia, during the summer and fall months. The experimental data tend to confirm the field observations that young sockeye salmon have a preference for water temperatures similar to those found near the thermocline during the summer and fall months. The temperature of the surface layer of water in the lake was too high for optimum growth, survival, and efficient utilization of food.

43. Ellis, Derek V. 1966. Swimming Speeds of Sockeye and Coho Salmon on Spawning Migration. J. Fish. Res. Bd. Canada 23: 181-187.

The speed at which sockeye and coho salmon swim while on spawning migration through a river was determined by direct timing of individual fish over measured river sections and by measurement of opposing water velocities. Migration

43. Cont'd.

was accomplished by two locomotory patterns; dart and steady swimming. For steady swimming there was a critical opposing water velocity from 1.1 to 1.7 ft/sec (mean 1.4 ft/sec). Against currents slower than the critical range steady swimming to a maximum speed of approximately 3.4 ft/sec (1.7 body lengths (L)/sec) was sustained through the observation areas, but against currents faster than the critical range salmon broke into position-holding behaviour at intervals. The calculated inter-decile range of swimming speeds (excluding slowest 10% and fastest 10%) against water velocities below the critical range was 1.75-3.18 ft/sec (0.9-1.7 L/sec) for sockeye salmon and 1.70-3.14 ft/sec (0.9-1.7 L/sec) for coho salmon. These swimming speeds were below maximum sustained values which have been determined experimentally.

44. Embody, G.C. 1934. Relation of Temperature to the Incubation Periods of Eggs of Four Species of Trout. Trans. Amer. Fish. Soc. 64: 281-292.

45. Everest, F.H. and D.W. Chapman. 1972. Habitat Selection and Spatial Interaction by Juvenile Chinook Salmon and Steelhead Trout in Two Idaho Streams. J. Fish. Res. Bd. Canada. 29: 91-100.

During summer sympatric steelhead trout and summer chinook salmon segregated in Crooked Fork and Johnson creeks. In short-term allopatry, each species occupied the same types of habitat as in sympatry. Most age 0 steelhead lived over rubble substrate in water velocities and depths of less than 0.15 m/sec and 0.15 m, respectively; most age 0 chinook lived over silt substrate in water velocities of less than 0.15 m/sec and depths of 0.15-0.3 m; most age I steelhead resided over large rubble substrate in water velocities of 0.15-0.3 m/sec (near bottom) and 0.75-0.9 m/sec (near surface), and in depths of 0.6-0.75 m. As fish of each species became larger they moved into faster, deeper water. Juvenile chinook and steelhead of the same size used the same physical space. But steelhead spawn in spring and chinook spawn in early fall, and disparate times of spawning create discrete intra- and inter-specific size groups of pre-smolts. The size differences minimize potential for social interaction, both intra- and inter-specific.

46. Ferguson, R.G. 1958. The Preferred Temperature of Fish and their Midsummer Distribution in Temperate Lakes and Streams. J. Fish. Res. Bd. Canada. 15: 607-624.

46. Cont'd.

Laboratory studies of preferred temperature with yellow perch (<u>Perca flavescens</u>) are compared with results from 21 other species. These show that temperature, if acting alone, can determine the distribution of fish in laboratory apparatus. Factors such as light, conditioned responses related to feeding routines, and social behaviour can interfere with the expression of the response to temperature. Subdued lighting conditions were necessary in the experiments with <u>Oncorhynchus</u>, <u>Salvelinus</u> and <u>Coregonus</u>, whereas full daylight was required in experiments with <u>Perca flavescens</u>.

The level of thermal acclimation influences the range of temperature preferred. In general the preferred temperature is considerably higher than the acclimation temperature at low thermal acclimations, but this difference decreases up to the final preferendum, where both coincide. The final preferendum and the relation between acclimation and preferred temperature is characteristic for the species. The shape of the resulting curve may have some value in interpreting observations of fish mortalities and distribution in nature. The final preferendum of the yellow perch from the present work was 24.2°C, from other work using older fish it was 21.0°C.

Summer field observations of yellow perch in Lake Nipissing, Costello Lake and Opeongo Lake, in Ontario, showed average thermal distribution of 19.7°C, 21.0°C and 21.2°C, respectively. This agrees well with 20.8°C observed for four Wisconsin lakes. Oxygen depletion reported for Tennessee Valley reservoirs, distribution of primary prey species of lake trout in New York waters, and other factors, have been shown to modify the thermal distribution in nature. Differential sex response to temperature may be important in the perch. Field observations of thermal distributions for other species are also presented.

A comparison of the laboratory and field data shows good agreement with fish having colder final preferenda: <u>Salvelinus fontinalis</u>, <u>Salvelinus namaycush</u>, <u>Salvelinus hybrid</u> and <u>Coregonus clupeaformis</u>. Fish with warmer final preferenda, such as <u>Micropterus salmoides</u>, <u>Micropterus dolomieu</u> and <u>Lota lota lacustris</u>, showed higher temperatures in the laboratory than was shown by field observations. Young <u>Perca flavescens</u> showed similar results, but experiments with older perch showed excellent agreement between laboratory results and field observations. The lack of agreement between laboratory results and field observations is attributed to age differences; laboratory experiments being performed with young fish and field observations being made on older fish.

47. Foerster, R.E. 1934. Fry Production from Eyed-Egg Planting. Trans. Amer. Fish. Soc. 64: 379-381.

48. Foerster, R.E. 1937. The Relation of Temperature to the Seaward Migration of Young Sockeye Salmon (*Oncorhynchus nerka*). J. Fish. Res. Bd. Canada. 3(5): 421-438.

The period of seaward migration of young sockeye from Cultus Lake each spring is inversely correlated with temperature conditions prevailing during the months immediately preceding. Correlating temperature readings of the outflow stream with date when twenty percent migration occurred, a statistically significant correlation of -0.85 was obtained for February and March and -0.77 for January to March. Using air temperatures, coefficients of -0.91 for January to March and -0.74 for February and March were found. Commencement of migration coincides with vernal rise in lake temperatures. Under normal conditions, with low winter minimum, there appears to be a threshold migration temperature approximating 4.4°C (40°F) but in seasons when lake temperatures are not depressed to this level a slight rise stimulates migration. Progress of migration is largely influenced by prevailing weather conditions and their effect upon temperature trends. Cessation of migration appears to be related to the setting-up of a "temperature blanket" which inhibits migration from the lake of sockeye still resident therein. These latter, showing small growth during their first year, remain in the lake until the following spring and then are among the first to migrate.

49. Foerster, R.E. 1952. The Seaward-Migrating Sockeye and Coho Salmon from Lakelse Lake, 1952. Fish. Res. Bd. Canada, Prog. Rep. No. 93, Pac. Coast Stations, pp. 30-32.

50. Foerster, R.E. and W.E. Ricker. 1953. The Coho Salmon of Cultus Lake and Sweltzer Creek. J. Fish. Res. Bd. Canada 10(6): 293-319.

A few hundred to one or two thousand cohos enter Cultus Lake each year, while the Sweltzer Creek population below it is several times as large. "Jack" (age II) fish usually predominate over older male cohos at the lake. Spawning in the lake or in tributary streams above yields downstream migrations of some hundreds of fry and, a year later, up to a few thousand yearling smolts. These, on the average, amount to 0.13 percent of eggs in spawners, or only 3 smolts per female. This does not suffice to maintain the coho run into the lake, which is, therefore, heavily recruited from creek-bred fish each year. There are also a very few age-II seaward migrants, which largely return from the sea the same year. Of yearling smolts marked in 1927, 8 percent returned to the lake after one and a half year's absence.

50. Cont'd.

A large fraction, probably the majority, of yearlings produced in the lake fail to migrate from it and live there into their second or third year of life. They are readily taken by trolling or netting in the autumn of their second year and in the winter and spring of their third. Maturing fish of ages II (males) and III (both sexes) have been taken but they are scarce. For this or other reasons production of young by lake-resident cohos is negligible, or perhaps altogether lacking.

51. Garside, E.T. 1966. Effects of Oxygen in Relation to Temperature on the Development of Embryos of Brook Trout and Rainbow Trout. J. Fish. Res. Bd. Canada 23(8): 1121-1134.

52. Griffiths, J.S. and D.F. Alderdice. 1972. Effects of Acclimation and Acute Temperature Experience on the Swimming Speed of Juvenile Coho Salmon. J. Fish. Res. Bd. Canada 29: 251-264.

Swimming performance of juvenile coho salmon (*Oncorhynchus kisutch*), 7.5-9.5 cm in total length, was investigated in a stamina tunnel, generally at 3°C intervals of temperature over the range of thermal tolerance.

Optimum (ultimate maximum) performance (5.8 lengths/sec) occurred at a combination of acclimation and test temperatures near 20°C. A declining ridge of sub-optimum performance (test temperature ridge) was found at acclimation temperatures below 20°C; maximum performance at each acclimation temperature level was found on the ridge at test temperatures higher than those of acclimation. Conversely, maximum performance at given test temperatures occurred on a second ridge (acclimation temperature ridge) at acclimation temperatures near those of testing. There was an apparent shift in location of the acclimation temperature ridge, indicative of seasonal performance compensation and improved capacity to perform at low acclimation temperatures during the winter period. At test temperatures below 5°C, maximum performance occurred at acclimation temperatures of about 6-8°C. Lowest performance within the zone of thermal tolerance was associated with acclimation and test temperatures of 2°C.

53. Groot, C. 1972. Migration of Yearling Sockeye Salmon (*Oncorhynchus nerka*) as Determined by Time-Lapse Photography of Sonar Observations. J. Fish. Res. Bd. Canada 29: 1431-1444.

53. Cont'd.

The seaward migration of sockeye salmon smolts through the Babine Lake system to its outlet was examined by taking film records of the Plan-Position-Indicator display of a high-frequency sonar whereby each frame of film was exposed during one scan of the sonar unit. Frame-by-frame analysis of the films revealed information on speed, direction, and diurnal timing of migration of sockeye smolts during a 24-hr. period.

Migratory activity in the lake centered around dusk and dawn, a similar pattern to that near the outlet for smolts entering the river on their way to sea.

Speeds of movements were 19-51 cm/sec (mean 30 cm/sec). Greatest velocities occurred at dusk and dawn. They were close to the maximum sustained swimming speeds determined under laboratory conditions for sockeye smolts of the same size and within similar temperature ranges as in the field.

The most direct movements of targets were found at twilight, when migration activity was highest. In general, directional tendencies were consistent with the shortest route to the outlet. In some observations near the junction of Main Lake and Morrison and North arms, movements were observed which would lead the smolts away from the outlet. Consequences of such movements are discussed and compared with data from tagging operations.

54. Hamilton, Roy. 1974. Water Requirements for the Fisheries Resource of the Deadman River. Internal Report Series No. PAC/1-74-1, pp. 1-14. (Publ.) Southern Operations Branch, Pacific Region, Environment Canada, Fisheries and Marine Service.

55. Hart, J.L. 1973. Pacific Fishes of Canada, Bulletin 180, Fish. Res. Bd. Canada.

56. Hartman, G.F. 1965. The Role of Behavior in the Ecology and Interaction of Underyearling Coho Salmon (Oncorhynchus kisutch) and Steelhead Trout (Salmo gairdneri). J. Fish. Res. Bd. Canada. 22: 1035-1081.

Two similar salmonids, coho and steelhead, cohabit many coastal rivers of British Columbia. Field collections reveal that the distributions of underyearling coho and steelhead are similar along the length of these streams. However, the micro-distribution of the two species is different. In spring and summer, when population densities are high, coho occupy pools, trout occupy riffles. In autumn and winter, when numbers are lower, both species inhabit the

56. Cont'd.

pools. Nilsson (1956) stated that segregation (such as that shown by coho and trout in spring and summer) may be indicative of competition resulting from similar ecological demands. To test this hypothesis the distribution and behavior of coho and steelhead were compared in a stream aquarium at different seasons with gradients of light, cover, depth or depth/velocity, and in experimental riffles and pools. Distributions and preferences of the two species in the experimental environments were most similar in spring and summer, the seasons when segregation occurred in nature, and least similar in autumn and winter, the seasons when the two species occurred together in nature. Spring and summer segregation in the streams is probably the result of interaction which occurs because of similarities in the environmental demands of the species and which is accentuated by dense populations and high levels of aggressiveness. The species do not segregate in streams in winter because certain ecological demands are different, numbers are lower, and levels of aggressiveness are low. When the two species were together in the experimental riffle and pool environment, trout were aggressive and defended areas in riffles but not pools; coho were aggressive in pools but less inclined to defend space in the riffles. These differences in behavior probably account for the distribution of trout and coho in natural riffles and pools.

The data support the basic contention of Nilsson (1956) and illustrate the role of behavior in segregation produced by competition for space.

57. Hartman, Wilbur L., Charles W. Strickland, and David T. Hoopes. 1962. Survival and Behavior of Sockeye Salmon Fry Migrating into Brooks Lake, Alaska. Trans. Amer. Fish. Soc. <u>91</u>: 133-139.

This paper describes the behavior of sockeye salmon (<u>Oncorhynchus nerka</u>) during their migration from stream spawning gravels to lake nursery areas. Fry were negatively phototactic, sought holding areas along stream banks during daylight hours, and only left holding areas and gravel to migrate during the darkest hours of the night. Fry migrated as individuals, facing downstream, and usually exhibited swimming movements. Certain features of the migratory behavior are discussed in terms of survival values in the face of intense piscivorous predation.

58. Hartman, W.L., W.R. Heard, and B. Drucker. 1967. Migratory Behavior of Sockeye Salmon Fry and Smolts. J. Fish. Res. Bd. Canada. 24(10): 2069-2099.

Considerable new data on the characteristics of sockeye fry and smolt migrations, direct underwater observations of migrating smolts, and a review of the literature are presented here with a synthesis, evaluation, and interpretation of possible survival advantages of these phenomena. Most fry migrations from spawning areas to nursery lakes take place in the spring, when harsh winter conditions in lakes are moderating and the growing season is beginning. Smolt migrations to salt water closely follow spring breakup of the ice and warming of the lake water. The time of smolt migration is correlated closely with latitude: migration is earlier in southern streams than in northern streams. The duration of seasonal migration appears to be strongly related to travel distance to the trunk river outlet. The smolt exodus is rapid and regular in single-lake systems but irregular and extended in multilake or multi-basin systems. The frequency distribution of smolts migrating from two-lake or two-basin systems is usually bimodal. Most migrations commence as water temperatures near 40°F and are over when temperatures approach 50°F. Migrations of smolts and especially fry are mainly confined to the darkest hours of the night. In general, in any one season, the oldest and largest smolts in each age-group migrate first. Other factors, such as the thickness of the ice, effectiveness of solar radiation in melting ice and warming water, and daily weather (including sunlight and wind), also influence seasonal and diel migration patterns. Underwater observations of smolts at night during migration show that they are schooled, travel in the upper water levels in shallow rivers and deeper (but not near the bottom) in deeper rivers, and usually face downstream and swim as they migrate. During migrations, fry and smolts are both often subjected to a depensatory mortality from intense predation by birds and fish. A factor disproportionately affecting different smolt populations is the length and number of restricted passages along the route to the ocean. Smolts migrating in multilake systems must encounter heavier predation than smolts migrating from single-lake systems. Predation is probably minimized en route because of innate migratory behavior patterns. Exceptions to the general migratory behavior of fry and smolts are described to show the wide range in behavioral response to variable environment situations.

59. Heard, Williams R. 1972. Spawning Behavior of Pink Salmon on an Artificial Spawning Redd. Trans. Amer. Fish. Soc. 101: 276-283.

The spawning behavior of pink salmon (Oncorhynchus gorbuscha) was observed and photographed through a glass

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viewing port in the bottom of an artificial redd in an observation tank. Females readily accepted the artificial redd and completed the normal prespawning behavior sequences, including redd defense, digging and crouching, but did not complete the spawning act and extrude eggs. Males, however, frequently followed the courtship sequence through to milt ejections. In 14 incomplete spawning acts, milt was ejected by males but eggs were not released by females. Seven of these acts involved the same male, over a 9-day period. Failure of females to extrude eggs was attributed to some unknown limiting physical condition of the redd or tank - possibly the smooth surface of the viewing port in the redd.

60. Held, John H. 1969. Effect of John Day Reservoir on Migration Rate of Juvenile Chinook Salmon in the Columbia River. Trans. Amer. Fish. Soc. 98: 513-514.

61. Higgins, R. 1970. Biological Studies on the Marble River Watershed in 1970. (Publ.) Dept. of Environment, Fisheries Operations, Pacific Regional Library, 1090 W. Pender St., Vancouver, B.C. V6E 2P1. pp. 1-31.

62. Hoar, William S. 1951. The Behavior of Chum, Pink and Coho Salmon in Relation to Their Seaward Migration. J. Fish. Res. Bd. Canada. 8(4): 241-263.

In fresh water, chum and pink salmon fry form schools or mills, are constantly active both day and night, show positive rheotaxis and move into fast water. This activity takes them into the swiftest currents. At night loss of visual and contact stimuli reduces the intensity of the rheotactic response and results in downstream movement. An active swimming downstream occurs only with unusually high temperatures. Coho salmon fry occupy and defend territory, maintain definite positions in relation to particular objects in their environment, show a less marked tendency to move into fast water and are quiet at night. They are thus displaced downstream to a much lesser degree. Coho smolts, in contrast to the fry, demonstrate a lowered threshold for stimulation both day and night, a tendency to aggregate and a lessening in territory behavior. During the day smolts group in deeper water or under cover. At night they rise to the surface and manifest seaward. Pronounced changes in temperature modify these reactions. Sudden elevation of water levels hastens the downstream displacement.

63. Hoar, William S. 1954. The Behavior of Juvenile Pacific Salmon with Particular Reference to the Sockeye (Oncorhynchus nerka). J. Fish. Res. Bd. Canada. 11(1): 69-97.

Behavior patterns of juvenile sockeye salmon in fresh water are compared with those of chum and coho salmon. Both sockeye and chum fry are schooling fish, responding positively to currents and avoiding shallow waters. Of the two species, chums, however, form more active schools, travel more rapidly, have a less marked cover reaction and prefer stronger light and shallower water. Sockeye smolts, in contrast to coho smolts, are more active, show little thigmotactic and territorial behavior and a more persistent response to current. The experimental findings are discussed in relation to the migratory behavior of these fish. It is suggested that sockeye fry, emerging from cover as the light intensity falls are displaced downstream after dark. Moderate activity and a marked preference for deep water are mechanisms postulated for continued residence of sockeye fry in lakes. Further it is suggested that the smolt exodus is due to heightened general activity, both day and night, associated with strong response to current. This brings sockeye smolts into the outflow from the lake where they hold position during the day but are displaced down the river after dark. Coho smolts, responding less vigorously to currents and maintaining a measure of contact with specific objects in their environment, move seaward more slowly than sockeye.

64. Hoar, William S. 1956. The Behavior of Migrating Pink and Chum Salmon Fry. J. Fish. Res. Bd. Canada. 13(3): 309-325.

Pink salmon fry which have never schooled are negatively phototactic, prefer a cover of stones and do not emerge into bright light. Those which have schooled show a strong cover reaction when exposed to a rapid increase in light intensity but do not seek cover unless the change is abrupt. In general they remain in bright light after they have schooled. This change in behavior occurs rapidly (15 minutes or less) when the fry school for the first time. Chum salmon fry establish a definite direction of swimming in the quiet water of a circular channel or basin. The established direction is stable and not permanently disturbed by light or darkness, by water currents, by strong avoiding reactions, by changing the location or by excluding direct sunlight. The direction may be initially established in relation to water currents.

65. Hooper, Douglas R. 1973. Evaluation of the Effects of Flows on Trout Stream Ecology. Pac. Gas and Electric Co., Dept. of Engineering Res., Emerville, Calif., 94608. 97 p.

66. Hoopes, David T. 1972. Selection of Spawning Sites by Sockeye Salmon in Small Streams. Fish. Bull. 70(2): 447-458.

67. Hourston, W.R. and D. MacKinnon. 1956. Use of an Artificial Spawning Channel by Salmon. Trans. Amer. Fish. Soc. 86: 220-230.

Investigation of effect of a proposed hydro-electric development on the salmon spawning grounds in Jones Creek, British Columbia in 1949 indicated spawning areas would be so affected that only a small portion of existing runs could be maintained. Methods for preserving the run were suggested and one selected that involved the construction of an artificial spawning channel capable of supporting the existing run with provision for controlling the flow in the channel and by-passing surplus flows.

Behavior studies of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) spawning in the channel were made in 1955 and the survival from egg to fry was determined in 1956 when there was survival of 37 percent of the 428,000 pink salmon eggs calculated to have been available for deposition and 30 percent of the 251,000 chum salmon eggs calculated to have been available for deposition.

68. Hunter, J.G. 1948. Natural Propagation of Salmon in the Central Coastal Area of British Columbia. Fish. Res. Bd. Canada - Prog. Rep. No. 27, Pac. Coast Stations, pp. 105-106.

69. Hunter, J.G. 1949. Natural Propagation of Salmon in the Central Coastal Area of British Columbia. II the 1948 Run. Fish. Res. Bd. Canada - Prog. Rep. No. 79, Pac. Coast Stations, pp. 33-34.

70. Hunter, J.G. 1959. Survival and Production of Pink and Chum Salmon in a Coastal Stream. J. Fish. Res. Bd. Canada. 16(6): 835-886.

A study of the propagation of pink and chum salmon in the central coastal region of British Columbia was made for the years 1947 to 1956.

Timing, distribution and movement of the adults and fry are discussed. The effects of temperature, stream discharge, sex ratio and population density were considered in relation to survival of egg to fry. Within the limits observed, temperature, stream discharge and sex ratio were not affecting the population perceptibly, but population density was an important factor. The density of spawners in preceding years also affected the survival in subsequent years.

70. Cont'd.

Predation was an important factor in keeping the fry output low: the number of fry consumed was approximately 500,000 during each migration.

Ocean survival, including the effect of fishing mortality, ranged from 5.2% down to 0.7% for pink salmon, and from 2.6% to 0.85% for chum salmon. Ocean survival for pink salmon before fishing mortality occurred ranged from 10.8% down to 1.0%.

Combination of freshwater and ocean survival rates indicate that a variation up to 190 times the lowest rate recorded is possible.

71. Javaid, Yaqub M. and John M. Anderson. 1967. Influence of Starvation on Selected Temperature of Some Salmonids. J. Fish. Res. Bd. Canada. 24(7): 1515-1519.

The selected temperature for Atlantic salmon and rainbow trout, as determined in a horizontal gradient, increases with acclimation temperature over the acclimation range 5-20°C for salmon and 10-20°C for trout. The final preferendum for salmon is about 17°C. The results for rainbow trout suggest that the type of gradient used, i.e., vertical or horizontal, has a marked influence on the experimentally determined relation between acclimation temperature and selected temperature.

72. Johnson, Harlan E. and Richard F. Brice. 1953. Effects of Transportation on Green Eggs, and of Water Temperature During Incubation, on the Mortality of Chinook Salmon. Prog. Fish-Cult. 15: 104-108.

73. Johnson, W.E. and C. Groot. 1963. Observations on the Migration of Young Sockeye Salmon (Oncorhynchus nerka) Through a Large, Complex Lake System. J. Fish. Res. Bd. Canada. 20(4): 919-938.

The seaward migration of sockeye salmon smolts through the Babine Lake system to its outlet is examined by extensive tagging, direct observations and experimental orientation tests. The migration appears to be a well-oriented, non-random movement; it apparently commences from all lake regions at about the same time, suggesting a common triggering stimulus. When migrating, the smolts swim at a speed of 0.65 to 1.0 feet per second. The migration appears to take place primarily at near-surface depths; diurnally, most of the migration activity appears centered around the evening dusk period. There is a consistent increase in rate of travel as the season progresses; in large part this appears a result of increasing migration drive. Orientation

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tests with a view of only the sky show the smolts capable of time-compensated orientation in relation to celestial phenomena, and such tests at various points along the migration route show the preferred direction of smolts to correspond with the direction of most direct route to the outlet. Most smolts in the system show a constant preference for the northwesterly direction which would lead them rather directly to the outlet. However, one group which in the course of its migration to the outlet must make a 180° turn clockwise from southeast to northwest is found to have a corresponding shift in directional preference with time. Simple one-direction orientation, in one case shifting with time, is sufficient to account for ability to find the outlet. A positive relation is shown between rate of travel and tagged smolts and the hours of sunshine on days subsequent to their release.

74. Kerns, Orra E., Jr., and John R. Donaldson. 1968. Behavior and Distribution of Spawning Sockeye Salmon on Island Beaches in Iliama Lake, Alaska, 1965. J. Fish. Res. Bd. Canada. 25(3): 485-494.

In 1965, spawning was studied on the island beaches of the eastern part of Iliama Lake from a 5.5-m tower mounted on a 9.1-m boat and with the use of scuba. Over 3 million sockeye salmon (Oncorhynchus nerka) (Walbaum), utilized nearly 130 ha of the beaches surveyed during the period August 8-21. The total spawning population and utilized area of shoreline of all the islands in the lake were greater since each area was surveyed only once and possible multiple waves of spawners were not taken into account, and not all of the island shoreline was surveyed by the above methods. The salmon generally spawned in dense groups, over immovable rock, in exposed areas with no upwelling ground water, and with little display of territorial defense. Density ranged from less than 0.1 fish to more than 5 fish per 0.84 m^2 (1 $yard^2$). The latter density prevailed on reefs and outside points of the islands. Seventy-three percent of spawning took place over bottom with irregular rocks from 102 to 305 mm (4-12 inches) in diam. and over 90% at depths from 2 to 6 mm (6-20 ft.) on bottom with slopes from 15 to 25°. Commonly, in a group of fish, one or more of the females were seen with their vents down in rock interstices, emitting eggs, while the males in close proximity were observed releasing milt. Eggs on the beaches are probably aerated by wind-generated lake currents and seiches. Of 3553 eggs collected from several island beaches, 6.8% were infertile.

Several features of the spawning behavior and environment are favourable to the survival of eggs and fry. The bottom is not scoured. Most eggs are deposited between

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immovable rocks and are thus not disturbed by subsequent spawners. Fry emerging from the beaches have immediate access to the large food supply in the lake. Some hazards are predation on eggs by fishes, freezing, and ultraviolet radiation of eggs in shallow water, and smothering of eggs in areas with a high density of eggs or algal growth.

75. Lister, D.B. and C.E. Walker. 1966. The Effect of Flow Control on Freshwater Survival of Chum, Coho, and Chinook Salmon in the Big Qualicum River. Can. Fish-Cult. 37: 3-25.

76. Lister, D.B. and H.S. Genoe. 1970. Stream Habitat Utilization by Cohabiting Underyearlings of Chinook (O. tschawytscha) and Coho (O. kisutch) Salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Bd. Canada. 27: 1215-1224.

Habitat distributions of chinook and coho salmon underyearlings in the Big Qualicum River, Vancouver Island, B.C., under controlled folow conditions indicated that at similar sizes their habitat requirements during the first 3 months of stream life were similar. Just after emergence, fry of both species occupied marginal areas in association with bank cover. With increased size, the young fish moved into habitat of progressively higher velocity. However, differences between the species in time of emergence and size evidently resulted in a high degree of spatial segregation. Chinook fry emerged about a month earlier than coho, were larger upon emergence, and grew at a faster rate. Apparently, because of their larger size at a given time, chinook preferred higher velocity locations than coho.

77. Long, Clifford C. 1968. Diel Movement and Vertical Distribution of Juvenile Anadromous Fish in Turbine Intakes. Fish. Bull. 66(3): 599-609.

78. MacKinnon, D. 1960. A Successful Transplant of Salmon Eggs in the Robertson Creek Spawning Channel. Can. Fish. Cult. No. 27, pp. 1-7.

A relatively large-scale eyed egg transplant of pink salmon into a newly-constructed spawning channel produced a fry output of 95% (91% of the number of eggs taken from fish). This extremely high survival is credited to near optimum conditions in the channel.

79. MacKinnon, D. and J.R. Brett. 1955. Some Observations on the Movement of Pacific Salmon Fry Through a Small Impounded Water Basin. J. Fish. Res. Bd. Canada. 12(3): 362-368.

79. Cont'd.

A small-scale field experiment was conducted to investigate the migration of Pacific salmon fry through an impounded water basin, 2.4 acres in area. Pink, chum, coho, spring and sockeye fry were released at the upstream end. During nine days of operating a trap placed below the outlet dam, only pink and chum fry appeared. One-quarter of the total of these latter species moved through the impoundment and were recaptured. The migration of the fry was mainly confined to a period 1 1/2 hours after sunset to 1 1/2 hours before sunrise. The rate of migration of fry through the impoundment differed significantly from the movement of floats also released above the basin.

80. MacKinnon, Dixon and William S. Hoar. 1953. Responses of Coho and Chum Salmon Fry to Current. J. Fish. Res. Bd. Canada. <u>10</u>(8): 523-538.

Chum and coho salmon fry respond positively to changes in water flow by swimming against the current. The magnitude of the response varies with the intensity of the current. Currents eliciting optimum response differ for the two species. Both species respond to the stronger of the two parallel laminar currents but, after a time, coho fail to discriminate between small differences while the chums move continuously into the greater flow. No evidence of adaptation is apparent in a two-hour period with rapid complex turbulences. In turbulent water coho fry make a sharper initial response than chum fry but do not seem to maintain the peak response over as wide a range of turbulences.

81. Maher, F.P. and P.A. Larkin. 1954. Life History of the Steelhead Trout of the Chilliwack River, British Columbia. Trans. Amer. Fish. Soc. <u>84</u>: 27-38.

Nearly 800 scale samples submitted by anglers were used to investigate features of the life history of steelhead trout (<u>Salmo gairdneri gairdneri</u>) from the Chilliwack River, a tributary of the Fraser River near Vancouver, British Columbia. After criteria for scale reading were established, data on age, fork length, sex, month and year of capture, previous spawning history and lengths at previous ages were treated statistically. Age groups are so designated as to indicate the amount of time spent in the river and in the ocean; thus 2/3 refers to fish that were 2 years in the stream and 3 in the ocean. Age composition of adult runs of steelhead trout tended to be uniform from year to year. The four major types of life history were: fish spending 2 or 3 years in fresh water and 2 or 3 years in salt water. No correlation existed between the numbers of years spent in fresh water and in salt water. Length at maturity was

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determined by the number of years in salt water. There was no tendency for fish of any particular age, length, or sex to return to fresh water at any particular time of year. Sixty percent of young steelhead trout migrate to salt water in the spring months as age 2 at an average length of 16.49 centimeters. Thirty-five percent go seaward as age 3 at an average length of 19.95 centimeters. A few smolts remain in fresh water until late summer. These and other findings are related to management of steelhead trout for sport fishing.

82. Mains, J.E. and J.M. Smith. 1956. Determination of the Normal Stream Distribution, Size, Time, and Current Preferences of Downstream Migrating Salmon and Steelhead Trout in the Columbia and Smake Rivers. In: Progress Report on Fisheries Engineering Research Program, North Pacific Division Corps Engineers, U.S. Army. pp. 14-27.

83. Mason, J.C. and D.W. Chapman. 1965. Significance of Early Emergence, Environmental Rearing Capacity, and Behavioral Ecology of Juvenile Coho Salmon in Stream Channels. J. Fish. Res. Bd. Canada. 22(1): 173-190.

Coho behavior was examined in two glass-walled stream channels containing riffle-pool series. The apparatus permitted volitional residence. Experimental groups of coho in each channel were permitted to emerge from a simulated redd environment and subsequently studied for 5 months.

Aggressive behavior in these coho fry was initiated within 1 week of emergence from the gravel. Within 10 days of emergence, coho occupied and defended feeding territories well-distributed in riffles. Initial aggression was nipping and chasing but within 2 weeks of emergence, aggression also involved threat.

Pools appear to constitute principal security features of coho environment. A behavioral pattern termed "fright huddle" was observed and described. Individual fish developed habitual living patterns in the channels, and smaller fish tended to occupy downstream areas.

Earliest-emerging coho enjoyed ecological advantages over later-emerging fish. The former were larger at a given time and had a greater tendency to remain in the stream channels, suggesting that they have "settler's rights" to available environment and/or better feeding opportunity. The results are discussed with reference to environmental rearing capacity and volitional residence.

84. Mattson, Chester R. 1948. Spawning Ground Studies of Willamette River Spring Chinook Salmon. Oregon Fish. Comm., Res. Briefs, 1(2): 21-32.

85. Meehan, William R. and Donald B. Simiff. 1962. A Study of the Downstream Migration of Anadromous Fishes in the Taku River, Alaska. Trans. Amer. Fish. Soc. 91: 399-407.

A modified scoop trap was designed and constructed to sample downstream-migrant juvenile salmon in the Taku River, a turbid river in southeastern Alaska. A sampling program was designed to determine the behavior of these migrants with respect to their seasonal and daily timing, the size and age composition of the various species, and the correlation between certain of these biological measurements and the physical characteristics of the environment. The length-weight relationships and condition factors of chinook, coho, and sockeye smolts were determined; differences in these relationships by week and by time of day are discussed.

86. Monan, Gerald E., Robert J. McConnell, John R. Pugh, and Jim R. Smith. 1969. Distribution of Debris and Downstream-Migrating Salmon in the Snake River Above Brownlee Reservoir. Trans. Amer. Fish. Soc. 98: 239-244.

The distribution of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon migrating downstream and the weight and vertical distribution of various types of debris were studied above Brownlee Reservoir in the Snake River during the spring and early summer of 1964. Electrified fyke nets were used in the fish sampling.

Salmon and debris were present simultaneously and were distributed throughout the cross-section of the river. Most of the salmon were in the upper 2.4 m of water, although appreciable numbers migrated at all depths; more migrants were in each of the two outer thirds of the river than in the middle third. Large quantities of debris, which represented a wide range of materials from algae to parts of buildings, were distributed throughout the river.

To effectively collect most of the salmon migrating downstream, the entire water mass will need to be strained by some method which has the capacity to cope with large quantities of debris.

87. Mundie, J.H. 1968. Ecological Implications of the Diet of Juvenile Coho in Streams. (Publ.) Fish. Res. Bd. Canada, Biological Station, Nanaimo, British Columbia. pp. 135-152.

88. McCauley, R.W. and W.L. Pond. 1971. Temperature Selection of Rainbow Trout (Salmo gairdneri) Fingerlings in Vertical and Horizontal Gradients. J. Fish. Res. Bd. Canada. 28: 1801-1804.

Preferred temperatures of underyearling rainbow trout (Salmo gairdneri) were determined in both vertical and horizontal temperature gradients. No statistically significant difference was found between the preferred temperatures by the two different methods. This suggests that the nature of the gradient plays a lesser role than generally believed in laboratory investigations of temperature preference.

89. McColley, C. 1933. The Spawning Migration of Rainbow Trout. Trans. Amer. Fish. Soc. 63: 80-84.

90. McDonald, J.E., ed. 1978. Salmonid Enhancement Program 1977. Fish. Mar. Serv. Ann. Rep.

91. McDonald, J.G. 1960. The Behavior of Pacific Salmon Fry During Their Downstream Migration to Freshwater and Saltwater Nursery Areas. J. Fish. Res. Bd. Canada. 17(5): 655-676.

The downstream migration of sockeye, coho, pink and chum salmon fry is initially nocturnal and appears to be regulated quite precisely by changes in light intensity. Downstream movement is seen to arise from a displacement by the current when firm visual contact with fixed objects in the stream is lost. Once the migration is under way the distribution of the fry varies. The lateral distribution of pink and sockeye, but not chum and coho, was closely and positively related to current speed, above a threshold of 1.3 ft/sec (0.4 m/sec). Pink fry were found to be distributed throughout the total depth of water but greatest catches were made at intermediate depths. The negative response of fry to light appears to change after exposure to it, and pink and chum fry were found to extend their movements into and throughout the daylight hours where the migration route was lengthy. Feeding and schooling activity is probably associated with this change in response to light. Both pink and chum fry were observed to school only near the end of their seaward movement. Pink fry were found to feed to some extent in the natal areas but to a greater extent as the sea was approached.

92. McDonald, J.G. 1969. Distribution, Growth, and Survival of Sockeye Fry (Oncorhynchus nerka) Produced in Natural and Artificial Stream Environments. J. Fish. Res. Bd. Canada. 26: 229-267.

A comparative study was made at Babine Lake, British Columbia, of the distribution, growth, and survival of sockeye salmon fry resulting from the same parental stock but reared

92. Cont'd.

in natural and artificial streams. Fry produced from natural spawning in the Fulton River and from eyed eggs planted in an adjacent artificial spawning channel were marked distinctively, released, and later recovered in the lake nursery area and at the lake outlet at time of seaward migration. Both groups dispersed rapidly and widely into the main lake basin and apparently mixed extensively with sockeye produced from other main lake tributaries. Lake distribution of marked fish, and the underyearling population as a whole, was not uniform nor static and the fish were concentrated in different lake areas at different times of their first growing season. River and channel fry were comparable in mean length at time of release but subsequently channel fish were smaller. Their smaller size appeared to result from late lake entry and a slower rate of growth for a short period thereafter. Over most of the growing period (June 25 - October 25) rates of growth in length were similar (instantaneous daily rates of 0.00687 and 0.00737). No significant difference in survival rates of the two groups could be detected for the first 5 months of lake residence. Production of age I seaward migrants was less for river fish than for channel fish but no significance was attached to the small difference observed. These findings are discussed with respect to a fish-cultural scheme which is aimed at increasing adult production by making fuller use of the lake's capacity to rear young sockeye.

93. McNeil, William J. 1967. Randomness in Distribution of Pink Salmon Redds. J. Fish. Res. Bd. Canada. 24(7): 1629-1633.

94. McNeil, William J. 1968. Migration and Distribution of Pink Salmon Spawners in Sashin Creek 1965, and Survival of their Progeny. Fish. Bull. 66(3): 575-586.

95. Neave, Ferris. 1955. Notes on the Seaward Migration of Pink and Chum Salmon Fry. J. Fish. Res. Bd. Canada. 12(3): 369-374.

The seaward migration of pink and chum salmon fry takes place at night. Strong light is avoided. In pink salmon negative rheotaxis (swimming with a current) is strongly developed and migration is not primarily effected by random swimming and passive displacement. Downstream movement is mainly at or close to the surface. In slack water vertical distribution is more uniform. In the shortest streams examined, each night's migrants appeared to reach the sea before daybreak. In a longer stream, fry were seen to bury themselves at the onset of daylight. After being held in fresh water for an undetermined period, fry

95. Cont'd.

show positive rheotaxis and schooling behavior and no longer avoid light. Behavior of fry after reaching the sea also differs from that shown during actual migration. Changes in behavior may coincide with commencement of feeding.

96. Neave, F., J.G. Hunter and W.P. Wickett. 1953. The 1952-54 Pink Salmon Cycle in the Queen Charlotte Islands. Fish. Res. Bd. Canada, Prog. Rep. No. 96, Pacific Coast Stations, pp. 22-24.

97. Neave, F. and W.P. Wickett. 1955. Transplantation of Pink Salmon into the Fraser Valley in Barren Years. Fish. Res. Bd. Canada, Prog. Rep. No. 103, Pacific Coast Stations, pp. 14-15.

98. Needham, Paul R., Osgood R. Smith, and Harry A. Hanson. 1940. Salmon Salvage Problems in Relation to Shasta Dam, California, and Notes on the Biology of the Sacramento River Salmon. Trans. Amer. Fish. Soc. 70: 55-69.

Studies on the chinook salmon runs which will be blocked by Shasta Dam on the Sacramento River, California, indicate that a total annual run of about 27,000 fish will be blocked sometime in 1942. There are two relatively distinct spawning runs, one in the spring and one in the fall. The number of eggs per female is calculated to be nearly 7,000. There are also two distinct downstream migrations, one in the spring and one in the fall. Most of the young salmon go to sea during their first spring.

It is not considered practicable to install fish ladders over Shasta Dam because of the height of the structure and because young downstream migrants could not pass it safely. Therefore, consideration is being given to salvage plans similar to those used for the salmon runs blocked by Grand Coulee Dam in the upper Columbia River. All tributaries of the Sacramento River below Shasta Dam have been examined as to their suitability for transfer of the run now passing Redding. Of 17 drainages examined, 9 are dry in their lower reaches part of the year and 7 have dry stretches during periods of salmon migration. Only 2 streams, Battle and Deer Creeks, were found below Shasta Dam which have salvage possibilities.

Not a single effective fish screen was found in the 19 drainages investigated and most fish ladders seen were inoperable because of lack of water.

Copper pollution in the Sacramento River above Redding from abandoned mines may become lethal to trout and salmon unless corrective measures are undertaken.

98. Cont'd.

In the salvage plan recommended by the Board of Consultants it is proposed that three rack barriers be constructed across the Sacramento River between Redding and the mouth of Battle Creek. After river temperatures had dropped below 60°F in the fall, salmon would be stopped on the expectation that they would spawn naturally between the racks. Because of high water temperatures in the main Sacramento, the spring run and the early part of the fall run would be transferred by trucks to Battle and to Deer Creeks. A hatchery having a capacity of about sixty million eggs is proposed for construction on Battle Creek in connection with this plan. A fish collecting system, including traps and lifts will have to be provided at one of the barriers. Tank trucks will be required for transfer of the fish to Battle and Deer Creeks.

99. Northcote, T.G. 1969. Lakeward Migration of Young Rainbow Trout (Salmo gairdneri) in the Upper Lardeau River, British Columbia. J. Fish. Res. Bd. Canada. 26(1): 33-45.

Lakeward migration of rainbow trout fry was studied in the upper Lardeau River, where the young emerge from a spawning area immediately below the outlet of Trout Lake utilized by large trout from Kootenay Lake, about 56 km downstream. Most fry move downstream towards Kootenay Lake, shortly after emergence; however, some, particularly later in the emergence period, move upstream into Trout Lake. Field observations and experiments suggest that water temperature may be important in inducing different responses to water current in these fish, but may not play such a predominant role or operate at the same levels as proposed earlier for control of young trout migration in the Loon Lake system.

100. Northcote, T.G. 1974. Salmonids as Elements in the Ecology of British Columbia Streams. A Contribution to the Symposium on Stream Ecology, Continuing Education for Foresters, Parksville, B.C. November 26-27.

101. Olson, P.A. and R.F. Foster. 1955. Temperature Tolerance of Eggs and Young of Columbia River Chinook Salmon. Trans. Amer. Fish. Soc. 85: 203-207.

A study was made on the temperature tolerance of eggs and young of chinook salmon which spawn in the mainstem of the Columbia River. The control temperature followed a seasonal trend typical for the locality. It started at 57°F, reached a minimum of 36°F, and increased to 47°F at the end of the test. Other experimental lots averaged about 4°F colder and 2°F, 4°F, and 8°F warmer than the control throughout the greater part of the test.

101. Cont'd.

Significant mortality above that of the control occurred only in the warmest lot. Although about 90 percent of the eggs in this group hatched successfully, the fry and early fingerlings suffered heavy mortalities even though the mean temperature of this lot was well below 50°F during the fingerling stage.

The results of this single experiment indicated that the eggs could begin incubation at temperatures as high as 61°F without significant loss.

102. Orcutt, Donald R., Ben R. Pulliam, and Arthur Arp. 1968. Characteristics of Steelhead Trout Redds in Two Idaho Streams. Trans. Amer. Fish. Soc. 97: 42-45.

Steelhead spawning behavior and redd construction were studied in 1958 and 1959 in the Clearwater and Salmon River watersheds in Idaho. Steelhead began spawning in early April; spawning peaked between 20 April and 10 May at water temperatures of 36 to 47°F, and was over by 15 June. Minimum water depth over a redd was 0.7 feet; maximum water depth exceeded 5 feet. Water velocity 0.4 feet above streambed averaged 2.3 to 2.5 ft/sec. Steelhead favoured spawning gravels 0.5 to 4.0 inches in diameter; however, they readily accepted areas with smaller and somewhat larger gravels if 6-inch stones were not abundant. Steelhead tolerated crowding without antagonism; pairs spawned within 4 feet of one another. The average redd occupied 6.5 square yards of gravel, and ranged from 2.9 to 13.4 square yards.

103. Peck, James W. 1970. Staying the Production of Coho Salmon (Oncorhynchus kisutch) Planted in a Lake Superior Tributary. Trans. Amer. Fish. Soc. 99: 591-595.

104. Pitney, W.E. 1969. Determination of Stream Flows for Fish Life. Western Proc. 48th Annual Conference of the Western Association of the State Game Commission, Reno, Nevada. pp. 498-501.

105. Platts, William S. 1974. Chinook Salmon Runs, Fish Standing Crop and Species Composition in the South Fork Salmon River, Idaho. (Publ.) U.S. Forest Service, Progress Report V: 1-48.

106. Pritchard, A.L. 1944. Physical Characteristics and Behavior of Pink Salmon Fry at McClinton Creek, B.C. J. Fish. Res. Bd. Canada. 6 (3): 217-227.

High temperatures appear to shorten and low temperatures lengthen the incubation period of pink salmon (Oncorhynchus gorbuscha) eggs. The fry migrate to sea during spring when the yolk sac is almost completely absorbed.

106. Cont'd.

There is no significant difference from year to year in qualitative description or in certain countable physical characters. Migration is usually swift and vigorous. The effect of light is demonstrated by the fact that movement is limited to the hours of darkness and slowed by direct moonlight. Rainfall does not initiate migration but causes fry already in motion to proceed more rapidly. Small temperature variations have little effect. Oxygen content and pH of the water vary coincidentally with rainfall.

107. Raleigh. Robert F. 1967. Genetic Control in the Lakeward Migrations of Sockeye Salmon (Oncorhynchus nerka) Fry. J. Fish. Res. Bd. Canada. 24(12): 2613-2622.

Eggs of sockeye salmon taken from tributary, outlet, and beach spawners at Karluk, Alaska, were treated identically from time of egg fertilization through time of testing as fry in a laboratory. Test lots were released during the day and at night in a central release pool from which the fry could migrate either upstream or downstream through simulated stream channels. Oxygen-saturated water at 50°F (10°C) was pumped through the 40-ft (12.2-m) gravel-bottomed simulated stream at about 0.3 ft/sec (9.1 cm/sec).

Test results showed that directions (upstream or downstream) and times (day or night) of migration differed substantially between fry from the tributary and those from the outlet. Fry from beach spawning reacted in a manner similar to that of the tributary fry. These differences were concluded to be of genetic origin. The possible interaction of innate behavior and environment in controlling the migratory movements of salmonid fry is discussed along with the significance of choosing a donor stock with appropriate innate responses to make best use of a new environment.

108. Raymond, Howard L. 1968. Migration Rates of Yearling Chinook Salmon in Relation to Flows and Impoundments in the Columbia and Snake Rivers. Trans. Amer. Fish. Soc. 97: 356-359.

Migration rates of yearling chinook salmon (Oncorhynchus tshawytscha) through free-flowing and impounded stretches of the Snake and Columbia Rivers were compared during periods of low and moderate river discharge. Generally, the rate of migration was directly related to the water flows; it was 21 km/day at the low river discharge (Columbia - 4,248 m^3/sec; Snake - 1,416 m^3/sec), and 37 km/day during moderate river discharge (Columbia - 8,495 m^3/sec; Snake - 2,265 m^3/sec). Migration rates through most free-flowing and impounded stretches of the Snake and Columbia

108. Cont'd.

Rivers were similar with the one exception that in McNary Reservoir (Columbia River) fish moved only about one-third as fast as elsewhere.

Marked yearling chinook salmon from the Salmon River took 32 days to travel the 669 km to Bonneville Dam during the low river discharge in 1966. New impoundments may more than double the travel time now required during low river flows.

109. Rees, William H. 1956. Determination of the Vertical and Horizontal Distribution of Seaward Migrants, Baker Dam. In: Progress Report on Fisheries Engineering Research Program, North Pacific Division Corps of Engineers, U.S. Army. pp. 154-161.

110. Reimers, Paul E. 1968. Social Behavior Among Juvenile Fall Chinook Salmon. J. Fish. Res. Bd. Canada. 25(9): 2005-2008.

111. Reimers, Paul E. 1973. The Length of Residence of Juvenile Fall Chinook Salmon in Sixes River, Oregon. Fish. Comm. Oregon, Res. Report 4(2): 1-43.

This study was designed to provide life history information about juvenile fall chinook salmon, Oncorhynchus tshawytscha (Walbaum), in Sixes River, a small coastal river of Oregon, by 1) documenting the length of residence of the juveniles throughout the river, 2) exploring several factors possibly influencing their length of residence, and 3) assessing the relative importance of fresh-water and estuarine rearing areas for producing returning spawners. The juveniles were followed from their emergence in the spawning streams to their entry into the ocean. Most information on the length of residence of the juveniles was obtained by seining and trapping at various times and locations in the river.

Spawning occurred mostly in the tributary streams, primarily in Dry Creek. Most fish spawned from November to January. Fry emerged from the gravel from March to May. Newly emerged fry moved downstream from the spawning areas in large numbers at night. Based on experimental studies of juvenile behavior, this movement apparently resulted from emergence at night and lack of visual orientation of the fry during darkness. Downstream movement was reduced during increased light levels (daylight or moonlight). This initial movement of fry is thought to assure rapid dispersal of juveniles throughout the river without extensive energy costs of dispersal by a social mechanism.

111. Cont'd.

Many juveniles remained in fresh water until early summer. Most then entered the estuary, possibly because of high temperature in the main river. A small number of fish continued to reside in the cool spawning tributaries. Detailed studies in 1969 showed that juveniles began entering the estuary in spring, but large increases in the population did not occur until June. During the period of increasing abundance, many juveniles were also captured in the ocean surf. The population level in the estuary peaked at about 145,000 fish during July and August and then declined to a low level in autumn. The rate of growth of the juveniles was reduced for 3 months during the period of high population abundance. Population density is hypothesized as a major cause of the depressed rate of growth of the juveniles. After the population declined in late summer, growth of juveniles again improved. Following the autumn freshets, most fall chinook salmon remaining in the estuary and those in the cool spawning streams entered the ocean. A few fish from the tributary populations remained in fresh water through the winter and migrated to the ocean as yearlings the following spring.

Based on variation in the length of residence of juveniles in fresh water and the estuary, five types of life histories were defined. Scale patterns from these types were distinguished and returning spawners from the 1965 brood sorted into the various types. The type-3 fish, those remaining in fresh water until early summer and then remaining for a period of improved growth in the estuary, represented about 90% of the returning spawners. Based on the return of these type-3 fish, fresh water and estuarine rearing were concluded to be about equally important to fall chinook salmon in Sixes River.

112. Reimers, Paul E. and Robert E. Loeffel. 1967. The Length of Residence of Juvenile Fall Chinook Salmon in Selected Columbia River Tributaries. Fish. Comm. Oregon Res. Briefs. 13(1): 5-19.

113. Reingold, Melvin. 1968. Water Temperature Affects the Ripening of Adult Fall Chinook Salmon and Steelhead. Prog. Fish-Cult. 30(1): 41-42.

114. Robertson, J.G. 1949. Sockeye Fry Production in a Small British Columbia Coastal Watershed. F. Res. Bd. Canada, Prog. Rep. No. 80, Pac. Coast Stations, pp. 55-57.

115. Shapovalov, Leo and William Berrain. 1939. An Experiment in Hatching Silver Salmon (Oncorhynchus kisutch) Eggs in Gravel. Trans. Amer. Fish. Soc. 69: 135-140.

The eggs from five adult sea-run silver salmon (Oncorhynchus kisutch) were divided into two lots: 8,239 eggs were buried in gravel in a standard hatchery trough and 7,500 placed in a standard hatching basket as a control. Natural conditions were simulated as closely as possible with the gravel eggs. The eggs required 772.3 temperature units (t.u.) to maximum hatch (control), 1,084.3 t.u. to earliest emergence from the gravel, and 1,155.6 t.u. to maximum emergence from the gravel. Initial to final emergence required at least thirty-eight days. Of the eggs buried, 10.2 percent emerged from the gravel. In the control, 65.9 percent of the eggs hatched and 48.2 percent survived to the time that the experimental fish had finished emerging from the gravel. Examination of the gravel and the dead eggs in it at the conclusion of the experiment and observations made during previous experiments support the view that silt carried by unusually severe floods smothered many of the eggs in the gravel. This fact seems to account in large part for the small percentage of salmon emerging from the gravel. Fifty-six days after initial emergence from the gravel, the experimental fish averaged 23.8 fish per ounce (1.19 grams each, live weight) while the control lot average 27.6 fish per ounce (1.13 grams each). During these fifty-six days only forty-eight of the experimental fish died, whereas the mortality in the control lot for the same period totalled 905. In the final two weeks, however, the average daily mortality in the control was only one fish.

116. Shelton, Jack M. 1955. The Hatching of Chinook Salmon Eggs Under Simulated Stream Conditions. Prog. Fish-Cult. 17: 20-35.

117. Shelton, J.M., and R.D. Pollock. 1966. Siltation and Egg Survival in Incubation Channels. Trans. Amer. Fish. Soc. 95: 183-187.

Fall chinook salmon eggs in Abernathy incubation channel suffered as much as 85% mortality when 15 to 30% of the voids in the gravel beds were filled with sediment. With one 70-foot section of the channel used as a silt-settling basin, the mortality was reduced to 10% or less. We believe that a siltation control system consisting of a flushable sand trap and settling basin constitute the most economical means of reducing the amount of sediment entering this and similar channels.

118. Shelbourn, J.E., J.R. Brett, and S. Shirahata. 1973. Effect of Temperature and Feeding Regime on the Specific Growth Rate of Sockeye Salmon Fry (Oncorhynchus nerka), With a Consideration of Size Effect. J. Fish. Res. Bd. Canada. 30: 1191-1194.

Specific growth rates were obtained for sockeye fry (Oncorhynchus nerka) acclimated to four temperatures and fed excess ration over a 36-day period, starting at an initial weight of 0.4 g. The rates were 2.2 (5°C), 5.1 (10°C), 6.5 (15°C), and 6.1 (20°C)% wet weight/day. Continuous feeding for 15 hr/day at 20°C produced a significantly greater growth rate than feeding to satiation three times daily ($P < 0.05$). The growth rates are compared to those obtained for larger sockeye, determined in earlier experiments.

119. Slater, Daniel W. 1963. Winter Run Chinook Salmon in the Sacramento River, California, with Notes on Water Temperature Requirements During Spawning. Special Scientific Report - Fisheries No. 461, Washington, D.C., pp. 1-9.

120. Smith, Allan K. 1973. Development and Application of Spawning Velocity and Depth Criteria for Oregon Salmonids. Trans. Amer. Fish. Soc. 102: 312-316.

Water velocity and depth criteria were developed to formulate recommended stream flows for spawning of Oregon salmonids. Criteria have additional application in the design of artificial spawning channels. About 1,170 redd measurements of 10 species and races were made during a 10-year period. Mean redd velocities ranged between 0.11 and 0.73 m/sec and depths between 0.22 and 0.43 m for all species. A velocity range and minimum depth were found for each species which included 80% of the measurements with 95% confidence. The resulting criteria were compared with data and recommendations from Oregon and elsewhere.

121. Stauffer, Thomas M. 1972. Age, Growth, and Downstream Migration of Juvenile Rainbow Trout in a Lake Michigan Tributary. Trans. Amer. Fish. Soc. 101: 18-28.

Juvenile rainbow trout were examined during 1951-59 while in stream nursery areas and when migrating downstream. The body-scale relationship was: total length (mm) = 4.06 + 2.10 scale radius (mm x 107) and relationship between length (mm) and weight (g) was $W = 0.00001384L^{3.0420}$. Age composition of trout during autumn in the nursery areas averaged 68% age 0, 29% age I and 3% age II; trout in the downstream migration averaged 64% age I, 34% age II and 2% age III. Most downstream migration occurred between 21 May and 30 June, at night, on subsiding water levels and at water

121. Cont'd.

temperatures of 9-17°C. There was an association between numbers of juveniles in the nursery areas and numbers of subsequent downstream migrants.

Trout grew about 76 mm per year; growth was similar to that in other Great Lakes tributaries and to growth in Pacific Ocean tributaries. Most downstream migrants in Great Lakes tributaries were age II or less, while in Pacific Ocean tributaries, most were age II and III. Time of migration was about the same in Great Lakes tributaries as in Pacific Ocean tributaries.

122. Stein, R.A., P.E. Reimers, and J.D. Hall. 1972. Social Interaction Between Juvenile Coho (Oncorhynchus kisutch) and Fall Chinook Salmon (O. tshawytscha) in Sixes River, Oregon. J. Fish. Res. Bd. Canada. 29: 1737-1748.

Spawning and emergence of coho and fall chinook salmon overlapped in timing and location in Sixes River, Oregon. In early spring both species were distributed throughout most of the river system. Underwater observations during this period indicated that both species occupied the same habitat. As temperatures increased, coho disappeared from the main river, but continued to occupy cool tributaries. Fall chinook were found primarily in the main river until early summer, when they moved to the estuary.

In flowing-water observation troughs coho assumed social dominance and defended space near the source of incoming food. In allopatry in the troughs, both grew at similar rates, but coho maintained lower population densities than did chinook. In sympatry in the troughs or in cool tributary streams, coho grew faster than chinook. Coho had brighter fin and body colors, greater fin development, deeper bodies, and were heavier than fall chinook of the same length.

Our study suggests that the population of fall chinook salmon in Sixes River might be adversely affected by an increase in numbers of coho. Our evidence suggests that ecology of native fishes should be examined closely before widespread manipulation of fish stocks is encouraged.

123. Summer, Francis H. 1952. Migrations of Salmonids in Sand Creek, Oregon. Trans. Amer. Fish. Soc. 82: 139-150.

A picket barrier with upstream and downstream fish traps was maintained on Sand Creek, a small Oregon Coast stream, during 4 upstream and 3 downstream fish runs (1946-

123. Cont'd.

1949), and a smaller trap was operated on a tributary during part of 1947. Two species of trout, coast cutthroat, Salmo clarki clarki Richardson, and steelhead, Salmo gairdneri gairdneri Richardson, and two species of Pacific salmon, the coho salmon, Oncorhynchus kisutch (Walbaum), and the chum salmon, Oncorhynchus keta (Walbaum), made spawning runs during the fall and winter. Downstream migrations of fry and fingerlings, and of spent adult trout, occurred in the spring.

Physical data on Sand Creek included water temperatures and information on occurrence and magnitude of freshets. Records of fish trapped included the numbers of salmonids in each migration, lengths, weights, sex ratios in upstream runs, loss in weight after spawning, and survival rates.

The results of this experiment indicate the need for a careful study of environmental and ecological conditions in order that a trapping structure may be adapted to extremes of water levels and to the habits of all species of migratory fishes found in the stream.

124. Wagner, Harry H. 1968. Effect of Stocking Time on Survival of Steelhead Trout, Salmo gairdneri, in Oregon. Trans. Amer. Fish. Soc. 97: 374-379.

Marked juvenile steelhead trout were stocked from 1961 through 1965 in the North Fork of the Alsea River on the Oregon coast to determine the importance of release time, within the spring migratory period, on adult returns.

Fish stocks in April survived better than fish stocked in February and March. The migration pattern for fish leaving a raceway voluntarily was similar to that of wild smolts in the stream. Similar numbers of fish returned from both the voluntary and mid-April liberation groups.

Mid-April appeared to be the most favourable time for stocking hatchery-reared steelhead on the Alsea River. A voluntary release method did not significantly increase survival.

125. Wales, J.H. and Millard Coots. 1954. Efficiency of Chinook Salmon Spawning in Fall Creek, California. Trans. Amer. Fish. Soc. 84: 137-149.

The spawning efficiency of chinook salmon (Oncorhynchus tshawytscha) in Fall Creek, a tributary of the Klamath River in northern California, was measured during four runs, 1950-1954, inclusive. In these years the following numbers of pairs of spawners were allowed to enter the stream: 750, 500, 300, and 300, respectively. Estimates

125. Cont'd.

of the total egg production of these fish were based on sampling. The numbers of downstream migrant fingerlings resulting from each of these spawning runs were computed by trapping the migrants in a known fraction of the stream flow. The percentages of potential eggs resulting in migrants leaving Fall Creek in the years sampled were 7, 10, 9, and 32, respectively. There appears to be an inverse correlation between the size of floods during incubation and the efficiency of spawning.

126. Walker, C.E. and D.B. Lister. 1971. Results for Three Generations From Transfers of Pink Salmon (Oncorhynchus gorbuscha) Spawn to the Qualicum River in 1963 and 1964. J. Fish. Res. Bd. Canada. 28: 647-654.

Transfers of pink salmon (Oncorhynchus gorbuscha) eggs were made to the Qualicum River in two years, utilizing 5.79 million eggs from Cheakamus River stock in 1963 and 6.85 million eggs from Bear River stock in 1964. Adult returns to the Qualicum River were 100 spawners in 1965, 1967, and 1969; 11,940 in 1966; 3000 in 1968; and 300 in 1970. Differences between the odd- and even-year plants were noted in times of egg-take (equivalent to time of spawning of donor stock), incubation, and fry emigration, lengths of emigrating fry, possibility of losses through predation by herring on estuarine fry, and direction of orientation to the recipient (Qualicum River) stream. Pronounced differences between donor stock in rate of return are thought to be primarily related to differences in spawning times and stream temperature. The decrease in numbers of adults in the even-year generation may have been due to lower freshwater survival during incubation as a result of suspected superimposition of chum salmon on the earlier deposited pink salmon eggs; the loss was estimated to be in the order of 46%.

127. Westwater: Notes on Water Research in Western Canada. No. 7. 1974. The Fraser River: A Thoroughfare for Migrant Fish. (Publ.) Westwater, Westwater Research Center, Univ. of British Columbia, Vancouver, B.C. V6T 1W5, Canada.

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downstream from Portland

July-October → Daphnia + other zoop.
Spring & fall → insects

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hold a specific area throughout summer → mostly, yes

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