EMIGRATION OF YOUNG CHINOOK SALMON
FROM THE TEHAMA-COLUSA FISH FACILTIES

by

Stephani A. Spaar

A Thesis
Presented to
The Faculty of Humboldt State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

October, 1987

EMIGRATION OF YOUNG CHINOOK SALMON

FROM THE TEHAMA-COLUSA FISH FACILITIES

by

Stephani A. Spaar

Approved by the Master's Thesis Committee

11-11-87

Thomas J. Hassler, Chairman — Date

11·XI·87

Gary L. Hendrickson — Date

11/12/87

Roger A. Barnhart — Date

12 Nov 87

Director, Natural Resources Graduate Program — Date

87/FI-101/11/13

Natural Resources Graduate Program Number — Date

Approved by the Dean of Graduate Studies

Nov. 1987

Alba M. Gillespie — Date

ABSTRACT

The effects of water temperature, turbidity, precipitation, lunar phase, date, time of day, and artificial illumination at night on intensity and timing of downstream movements of fall-run chinook salmon (*Oncorhynchus tshawytscha*) sac fry and fry were studied at Tehama-Colusa Fish Facilities, Red Bluff, California. A sampling program and sampling gear were developed to estimate numbers and sizes of young chinook salmon as they left the single-purpose spawning channels. Catch data and environmental data were collected twice daily from January through March 1984 and January and February 1985. Young chinook salmon were collected with a fyke net and catch was expressed as the number of fish caught per hour (CPUE). Multiple regression analysis showed that turbidity, time of day, and date accounted for 32% of the variability in CPUE for 1984, in that order of importance. In 1985, time of day, turbidity, date, and lunar phase accounted for 71% of the variation in CPUE. Under conditions of low turbidity in 1985, artificial illumination and time of day accounted for 66% of the variability. The fork length of young chinook salmon that migrated at day and night did not differ significantly in 1984, but fish that migrated at night in 1985 were significantly shorter than fish that migrated during daylight.

ACKNOWLEDGMENTS

This project was possible only through the committment and help of others. I thank Dr. Thomas Hassler for his invaluable guidance and help with this project and through my time in graduate school, and the other members of my graduate committee, Dr. Roger Barnhart and Dr. Gary Hendrickson, for their comments and suggestions. The people of the U.S. Fish and Wildlife Service at the Tehama-Colusa Fish Facilities and the Fisheries Assistance Office in Red Bluff, California were wonderful to work with and I greatly appreciate all of their help. A special thanks to John Hanson, Dave Vogel, and Jim Smith. Financial support was provided by the U.S. Fish and Wildlife Service and by the Tyee Foundation of San Francisco. I am very grateful to Delores Neher for her efforts in pulling various reports together in finished form, and making sure I had a paycheck every month.

Finally, I thank my best friends who saw me through my darkest moments. Lisa for her emotional support and good coffee, and Chessie, a silent friend but never too arrogant to listen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The development of water resources in northern California by the U.S. Bureau of Reclamation (USBOR) has had a significant impact on the chinook salmon (Oncorhynchus tshawytscha) stocks of the Sacramento River. The loss of spawning and nursery habitat due to water development has contributed to the decline of salmonid stocks (Kjelson et al. 1982). The U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Game (CFG), USBOR, and others are currently developing methods to enhance the depressed stocks. The USFWS's Tehama-Colusa Fish Facilities (TCFF) near Red Bluff, California, are designed to mitigate the loss of habitat due to construction of the Red Bluff Diversion Dam. The USFWS is currently conducting an intensive evaluation of the operations at TCFF under the Tehama-Colusa Canal Fish Problems Study (USBOR 1985). A portion of the USFWS evaluation is concerned with obtaining an accurate assessment of TCFF's salmon production.

A knowledge of stock production is important to the proper management of a fishery resource. Measures of stock production can be made in a number of ways depending on the species and life history stage being studied. In Pacific salmon stocks, year class production is often estimated through enumeration of young fish during their seaward migration. Various sampling methods have been employed in an attempt to estimate abundance of downstream migrants. The most common method involves use of a net or trapping device operated from a fixed structure, bridge, or weir. Many studies have successfully used traps usually in association with weirs (Wolf 1951; McLain and Manion 1967; Mason 1975). Fyke nets and other netting devices have also been used for enumeration and migratory behavior studies (Acara and Smith 1971; Smith 1974; Tyler 1979; Davis 1980).

Young fall-run chinook salmon migrate seaward during their first year of life; with the bulk of this movement in early spring soon after fish emerge from the gravel (Bjornn 1978). Usually this period of emigration occurs 3-4 months after the spawning period when the fish are less than 50 mm fork length (FL) (Bjornn 1971; Bell 1973). Downstream movement of chinook salmon is governed by both environmental and behavioral factors. Water flow, water temperature, turbidity, time of day, and precipitation appear to influence migration timing and intensity (MacKinnon and Hoar 1953; Hoar et al. 1957; Ali 1959; Mains and Smith 1964; Thomas et al. 1969; Thomas 1975). The movement of young fish may also be governed by the lunar cycle (Clarke and Smith 1972; Mason 1975). Other studies indicate that aggression and habitat rearing capacity, among other factors, also play a role in the downstream movement of salmon (Hoar 1951; 1958; Chapman 1962; Mason and Chapman 1965; McCart 1967).

Operators of the Tehama-Colusa Fish Facilities have encountered a number of problems in the enumeration of outmigrant juvenile salmon. The escape of numerous young chinook salmon passing over and through the terminal drum screens was of primary concern. Monitoring salmon produced at the facilities began in 1972 with the use of electronic counting tubes from January 31 to June 15 (USFWS 1972). Estimates of the escapement of young chinook salmon with a fyke net at the drum screens also began in 1972. A live box was added to the fyke net in

1973 and tests were conducted to determine the rate of catch based on the recovery of marked fish released upstream (USFWS 1973). An inclined screen migrant trap replaced the fyke net and was operated below the terminal screen structure from December 19, 1973 to March 20, 1974 (USFWS 1974). This trap screened all of the flow and removed the migrants to a holding box. A fyke net replaced the inclined migrant trap in 1977 and operated up to the time of this study (USFWS 1977). A second set of drum screens were added to the terminal screen complex in 1980 to replace the flat screens (USFWS 1980). Attempts to measure fish losses have been continually hindered by excessive amounts of algae and debris clogging the sampling gear, operational problems, and loss of sampling efficiency. This loss of fish is not a threat to the fish produced at TCFF, but it does present a serious problem in accurately assessing the production at the facilities.

The objective of this study was to develop a sampling program to estimate the number and sizes of fall-run chinook salmon sac fry and fry leaving TCFF's single-purpose spawning channels (SPC). Only an estimated 5-15% of the salmon leaving the SPC pass through the electronic counting station at the channel's downstream end. The remaining young "roll over" the rotating drum type fish screens and are not counted. In order to obtain an accurate estimate of TCFF's salmon production, the number of fish escaping from the facilities by roll over was estimated by fyke net catch. The catch of young salmon was investigated in relation to water flow, water temperature, turbidity, precipitation, lunar phase, and diurnal activity. The effect of night lighting over the drum screens was also determined.

STUDY AREA

The TCFF are located adjacent to the Sacramento River near Red Bluff, California (Figure 1). The facilities have approximately 8.2 km of salmon spawning channels and are an integral part of the USBOR's Red Bluff Diversion Dam (RBDD) and Tehama-Colusa Irrigation Canal. The TCFF were constructed to mitigate the loss of spawning habitat for 3,000 fall-run chinook salmon spawners displaced by Lake Red Bluff and RBDD, and as an enhancement facility to provide spawning habitat for an additional 27,000 chinook spawners (USFWS 1963).

The facilities include a 5.1 km dual-purpose channel (DPC), two 1.6 km single-purpose channels (SPC), and a 1.5 km fish conveyence channel to Coyote Creek. The DPC was designed for irrigation flows and to provide spawning habitat for up to 26,000 salmon (Vogel 1982). The SPC is used only for salmon production with spawning habitat for 4,000 salmon (USFWS 1981).

Fall-run chinook salmon spawners migrate into the SPC from October through November (USFWS 1981). The majority of the young migrate out of the facilities prior to April. The young are released from the SPC through the terminal fish counting facilities and into the fish conveyance channel for release into Coyote Creek and on to the Sacramento River. Chinook salmon produced at TCFF are considered to be wild or naturally produced fish. The estimated mean annual contribution from the facilities to the ocean fisheries was 11,489 chinook salmon (range 2,367-29,593) and to the spawning escapement 4,575 fish (range 963-11,913) for 1973-1977 (USBOR 1985).

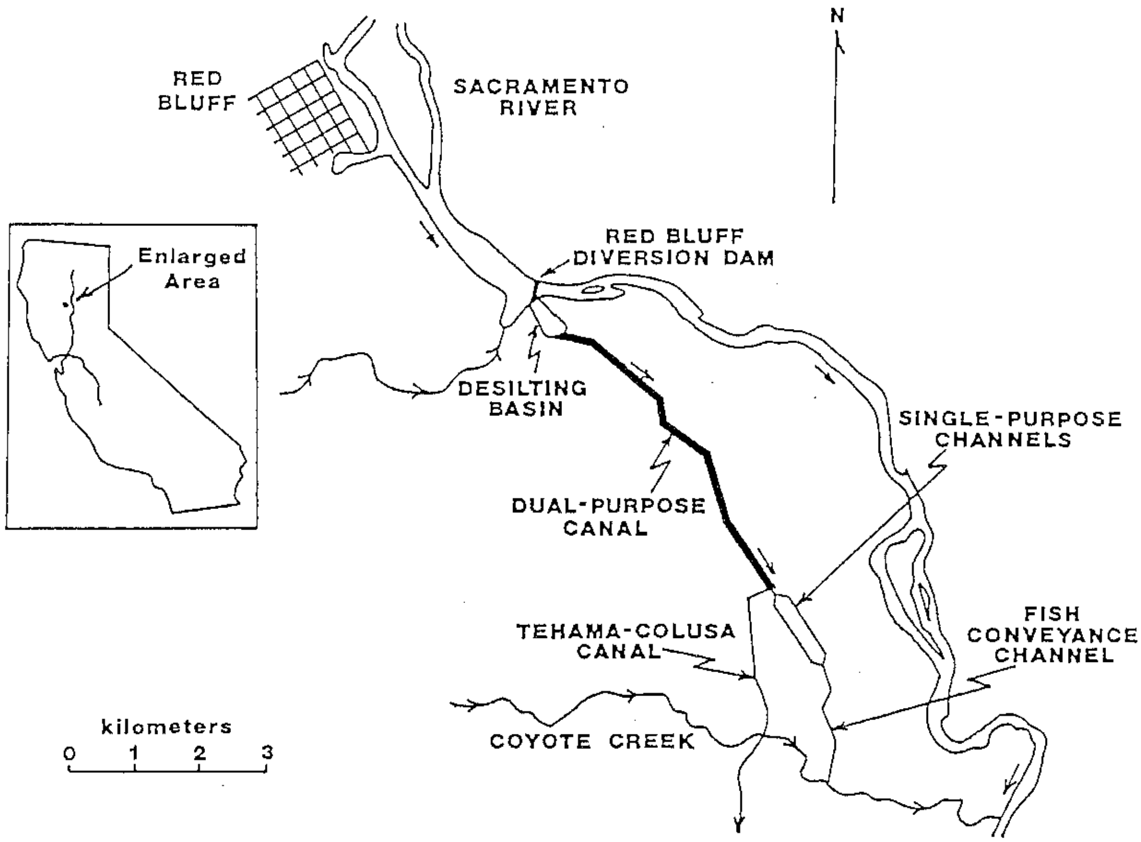

Figure 1. Tehama-Colusa Fish Facilities, Red Bluff, California.

The study site was located at the downstream end of the SPC (Figure 2). Four rotating drum screens (1.52 m diameter x 3.66 m long) and an electronic fish counting station are part of the terminal fish counting facilities. The sampling station was located directly downstream of the drum screens in the fish conveyance channel. The channel is 8.7 m wide at the top and 3.7 m wide at the bottom. The maximum water depth is 1.2 m at a flow of 6.51 m^3/s. Seasonal flow requirements for the SPC vary with the time of year (Table 1). Past sampling of young chinook salmon loss from TCFF has not been adequate to develop reliable estimates. Annual estimates of this loss have ranged from 2 to 65% of the total juvenile chinook salmon released from TCFF each year since 1972 (USBOR 1985). Young salmon captured at the station are primarily fish produced in the SPC. However, since any fish leaving TCFF must pass this point, fish produced in the DPC and those which leak in through the headworks at the Sacramento River may also be sampled. Future operations at TCFF include provisions to keep the groups of fish separated to allow for enumeration.

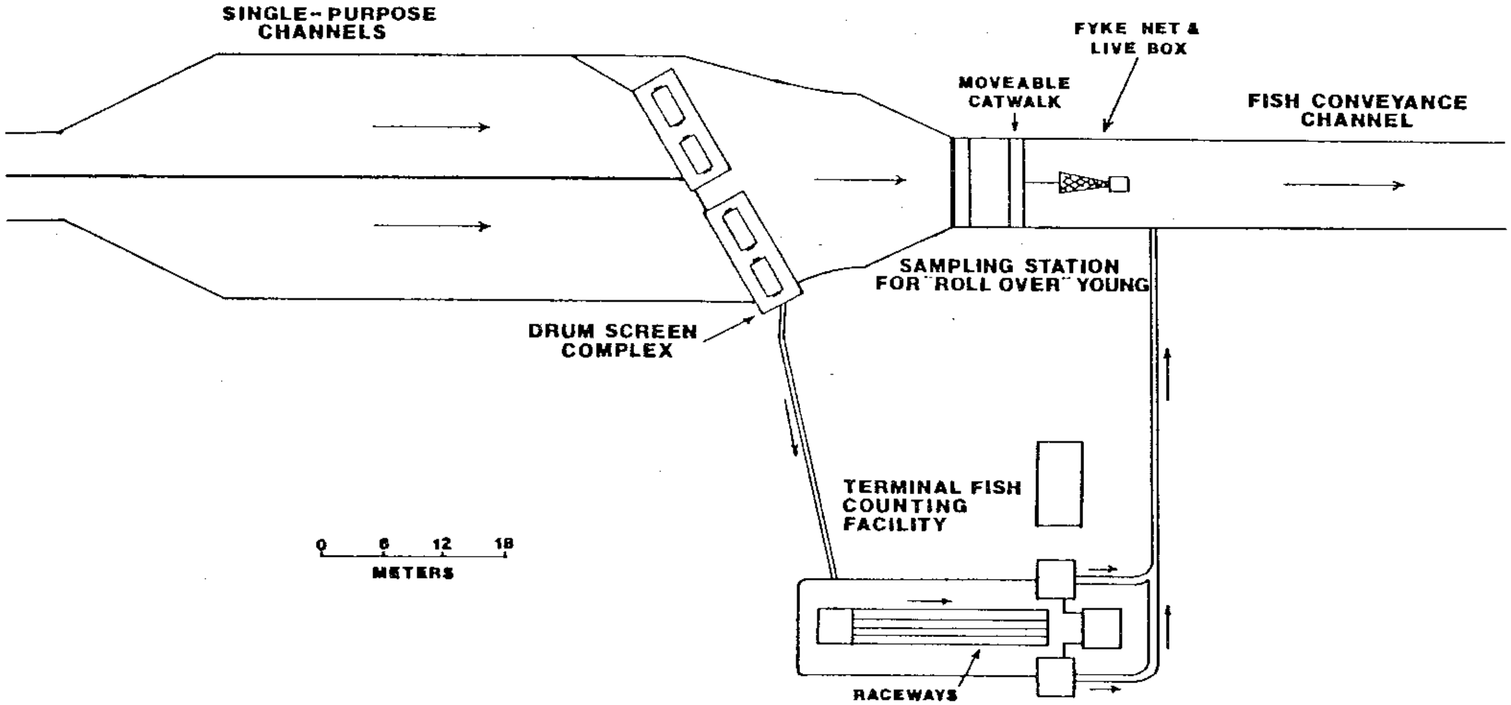

Figure 2. Fish Sampling Station Tehama-Colusa Fish Facilities, Red Bluff, California.

Table 1. Recommended Flows for the Tehama-Colusa Irrigation Canal and Tehama-Colusa Fish Facilities (From U.S. Bureau of Reclamation 1985).

	Flow (m^3/s)			
	Oct. 1 - Dec. 15 Salmon Spawning	Dec. 16 - Feb. 28 Incubation, Rearing and Outmigration	Mar. 1 - June 30 Rearing and Outmigration	July 1 - Aug. 15 Gravel Cleaning
Minimum flow in DPC[a]	33.42	16.98	14.44	40.49
Minimum flow out of:				
SPC into Coyote Creek[b]	6.51	2.26	2.83	1.42
Coyote Creek turnout	13.31	11.04	5.95	1.42
Thomas Creek turnout	1.42	0	0	0
Stony Creek turnout	5.10	0	7.83	5.66
Other irrigation turnouts	7.08	3.68	2.83	31.99

[a] Dual purpose canal. Minimum flows are subject to change per periodic negotiation between FWS and BOR.

[b] SPC = Single purpose canal.

MATERIALS AND METHODS

Young fall-run chinook salmon leaving the SPC by "rolling over" the drum screens were sampled with a fyke net and live box combination located downstream of the drum screens in the fish conveyance channel. The fyke net was 2.06 m long narrowing from a mouth of 58 x 43 cm to the cod-end of 30 cm square. The net was 3.22 mm stretch mesh of the Delta type and attached to a metal pipe frame 71 x 58 cm. A wire harness, floats, and digital flowmeter were attached to the frame. The cod-end was attached to a live box with a separate harness connected to a hand winch and pulley system. The system was located on a movable catwalk spanning the fish conveyance channel. The net fished approximately the upper 50 cm of flow at the center of the channel.

Sampling was conducted continuously from January 18 to March 25, 1984 and January 15 to February 20, 1985. Filamentous algae in channel flows persistently clogged the net and live box by the end of February reducing sampling efficiency and increasing gear maintenance. The net and live box were pulled and cleaned of debris and algae and reset twice daily at early morning and late afternoon. During periods of high turbidity and debris, the net was pulled more often. The number of chinook salmon captured per net lift were counted and the fork lengths (FL in mm) of up to 50 fish were measured. The catch per set was expressed as: CPUE = C/T, where C = number of fish captured per lift and T = hours that the net was fished per set. The volume of water passing through the net was estimated for each set.

Sampling efficiency, retention of captured fish in the live box, and distribution of fish in the channel profile were measured. A known number of marked fish were placed in the live box and checked after 2-4 hours of fishing. The number of young remaining in the live box was used to determine holding efficiency. The distribution of fish in the channel profile was monitored with a fyke net 30 cm square at the mouth. A digital flowmeter was attached to the mouth of the net to measure flow. The channel was divided into three equal size sampling sections and fished for 0.25 hour at the surface and bottom of each section.

The number of young salmon escaping downstream were estimated per net set in proportion to the fraction of total flow sampled by the net as follows:

$$N = \frac{\frac{C}{R}}{\frac{V_N}{V}}$$

where N = total estimated number of downstream migrants, C = actual number caught, R = average retention of captured fish, V_N = flow (cfs) sampled, and V = total flow (cfs) in channel. Seasonal totals were obtained by summing the daily estimates.

A multiple regression program from the Biomedical Computer Programs (Dixon 1985) was used to analyze relative importance of time of day, turbidity, water temperature, precipitation, lunar phase, and night lighting of the screens on emigration intensity (Table 2). The Student-Newman-Keuls Test (Sokal and Rohlf 1969) was used to compare length of fish caught at day and night. Linear regression was used to analyze the relationship between water flow and catch in determining

Table 2. Independent Variables Used in the Regressional Analysis.

Variable	Description
Date	Progression of days through each study period beginning at 1 for January 15 and ending at 71 for March 25
Time	Day or night
Turbidity	Turbidity (NTU) during sampling period (NTU-Nephelometric Turbidity Unit)
Precipitation	Rainfall (cm) during sampling period
Temperature	Temperature (^{o}C) during sampling period
Moonphase	Lunar phase beginning with new moon
Lights	Lighting over drum screens on or off, only used in 1985

distribution of salmon in the channel profile. Fish catch per hour was transformed by log(x+1) where x = catch per hour.

Environmental conditions were measured at the end of each sampling period on the upstream side of the drum screen complex. Turbidity was measured with at Hach Turbidimeter Model 2100A. Water temperature was measured with a hand thermometer. Data on precipitation was obtained from the National Weather Service Office in Red Bluff, California. Water flow in the SPC was obtained from the USBOR and the USFWS. Information on lunar phase was found in the Old Farmer's Almanac (Thomas 1984; 1985).

RESULTS

Water temperature in the channels fluctuated slightly in both years with an upward trend toward the end of the study period (Figures 3 and 4). In 1984, temperature ranged from 6°C in January to 12°C in March (mean 9°C). In 1985, temperature ranged from 6°C in January to 11°C in late February (mean 8°C).

Turbidity in both years remained relatively low except for periods of high rainfall. In 1984, turbidities ranged from 4 to 52 NTU (mean 10 NTU). In 1985, turbidity ranged from 2 to 40 NTU (mean 5 NTU).

Precipitation during the study occurred in the form of rainfall. In 1984, it ranged from 0.025 to 1.270 cm per sampling period (mean 0.397 cm). In 1985, it ranged from 0.025 to 2.083 cm per sampling period (mean 0.065 cm). Water flow in the fish conveyance channel was held constant at 2.605 cms in 1984 and 3.501 cms in 1985.

The main factors influencing CPUE in 1984 were turbidity, time, and date, in that order of importance (Table 3). In 1984, these factors accounted for 32% of the variability in CPUE and had the following relation: CPUE = -0.047+0.006 Turbidity+0.041 Time-0.001 Date. In 1985, time, turbidity, date and moon phase were the main factors influencing CPUE (Table 3). The factors accounted for 71% of the variation in CPUE in 1985 and had the following relation: CPUE = 0.136+0.366 Time+0.027 Turbidity-0.015 Date-0.007 Moon Phase.

The effect of night lighting over the screens was examined from January 15 to February 9, 1985. The lighting appeared to decrease

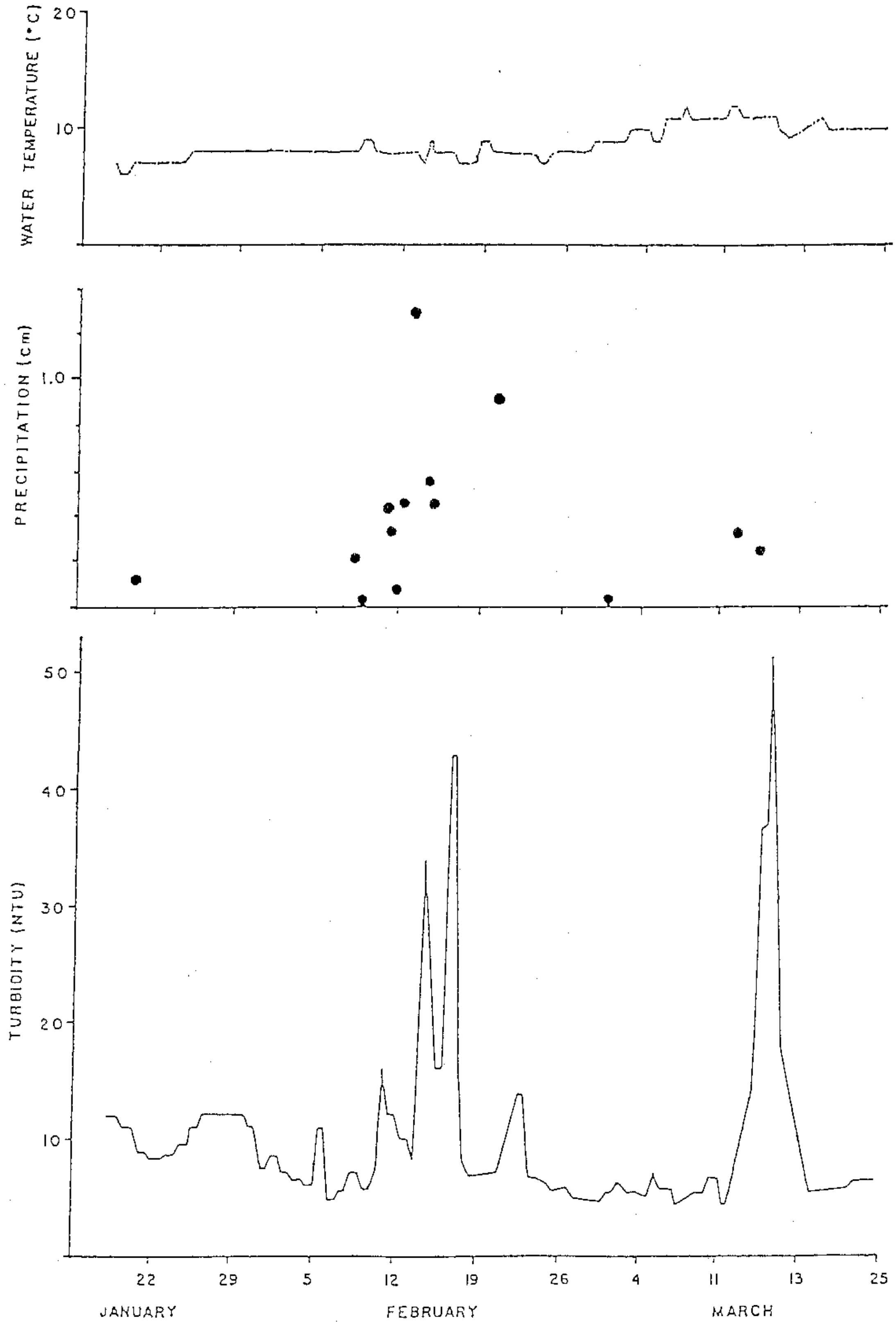

Figure 3. Environmental Data at Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-March 1984.

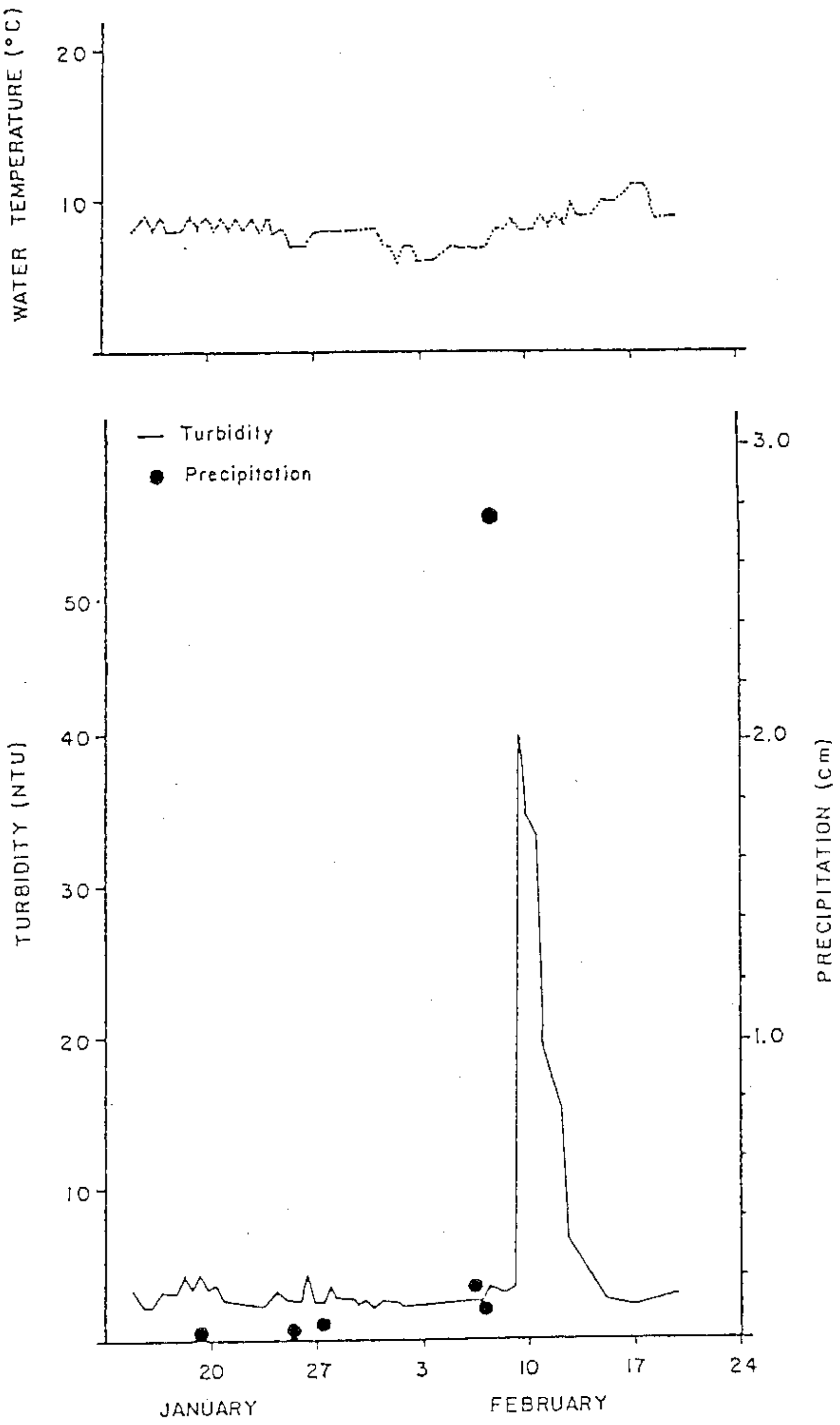

Figure 4. Environmental Data at Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-March 1985.

Table 3. Summary of Regression Analysis of Environmental Factors and Catch of Chinook Salmon Fry at Tehama-Colusa Fish Facilities Fish Conveyance Channel, January 18 to Marcy 25, 1984 and January 15 to February 20, 1985.

Year	Variable	Regression Coefficient	Multiple R	Multiple R^2	Partial Regression Coefficients F	Partial Regression Coefficients Significance	Overall Regression F	Overall Regression Significance
1984	Turbidity (X_1)	0.006	0.498	0.248	37.78	0.001	39.63	0.001
	Time (X_2)	0.041	0.542	0.293	7.93	0.001	24.69	0.001
	Date (X_3)	-0.001	0.563	0.317	4.00	0.005	18.26	0.001
	Precipitation (X_4)	0.120	0.569	0.324	1.18	0.50	14.01	0.001
	Temperature	0.011			1.50	0.25		
	Moon Phase	-0.0002			0.07	0.75		
	Constant =	-0.047						
	Standard Error =	0.081						
1985	Time (X_1)	0.366	0.514	0.264	58.22	0.001	23.70	0.001
	Turbidity (X_2)	0.027	0.676	0.458	66.22	0.001	27.41	0.001
	Date (X_3)	-0.015	0.818	0.670	36.11	0.001	43.22	0.001
	Moon Phase (X_4)	-0.007	0.841	0.706	7.86	0.001	37.90	0.001
	Precipitation (X_5)	-0.257	0.844	0.712	1.12	0.50	30.60	0.001
	Temperature	-0.055			5.49	0.001		
	Lights	-0.023			0.19	0.75		
	Constant =	0.136						
	Standard Error =	0.195						

migration (CPUE), but seemed to be overshadowed by the effects of high turbidity (Figures 4, 5). The main factors influencing CPUE when night lighting was used were time, lights, precipitation, and turbidity (Table 4). These factors accounted for 71% of the variation in CPUE and had the following relation: CPUE = -0.073+0.473 Time-0.163 Lights-0.541 Precipitation+0.045 Turbidity.

Daily estimates of the loss of young salmon from the drum screens during 1984 and 1985 are presented in Figures 5 and 6. Weekly estimates of losses are given in Tables 5 and 6. In 1984, an estimated 8,734 chinook juveniles escaped from the facilities during the sampling period, and in 1985 the estimated escapement was 82,720 fish. The roll over escapement represented 12% of the facilities' production in 1984 and 20% in 1985. It was assumed that the net sampled fish in direct proportion to the percentage of total flow filtered by the net, and that fry were uniformly distributed with the current in the area fished. This appeared to be true based on tests for the distribution of fry in the current. The center of the channel where the net was set had the highest flows (CMS) and fish catch (Table 7). However, no significant difference was found between channel area sampled and fish catch ($r = 0.253$, $P = 0.05$).

Tests on the retention of captured fish by the sampling gear indicated that some losses occurred. Escape of fish from the live box averaged 30%. Escape from the metal live box used during March of 1984 was 55%.

The estimated "roll over" loss of young salmon at the drum screens in 1984 and 1985 indicated a preference for young to emigrate at night and during periods of high turbidity. Sac fry were caught

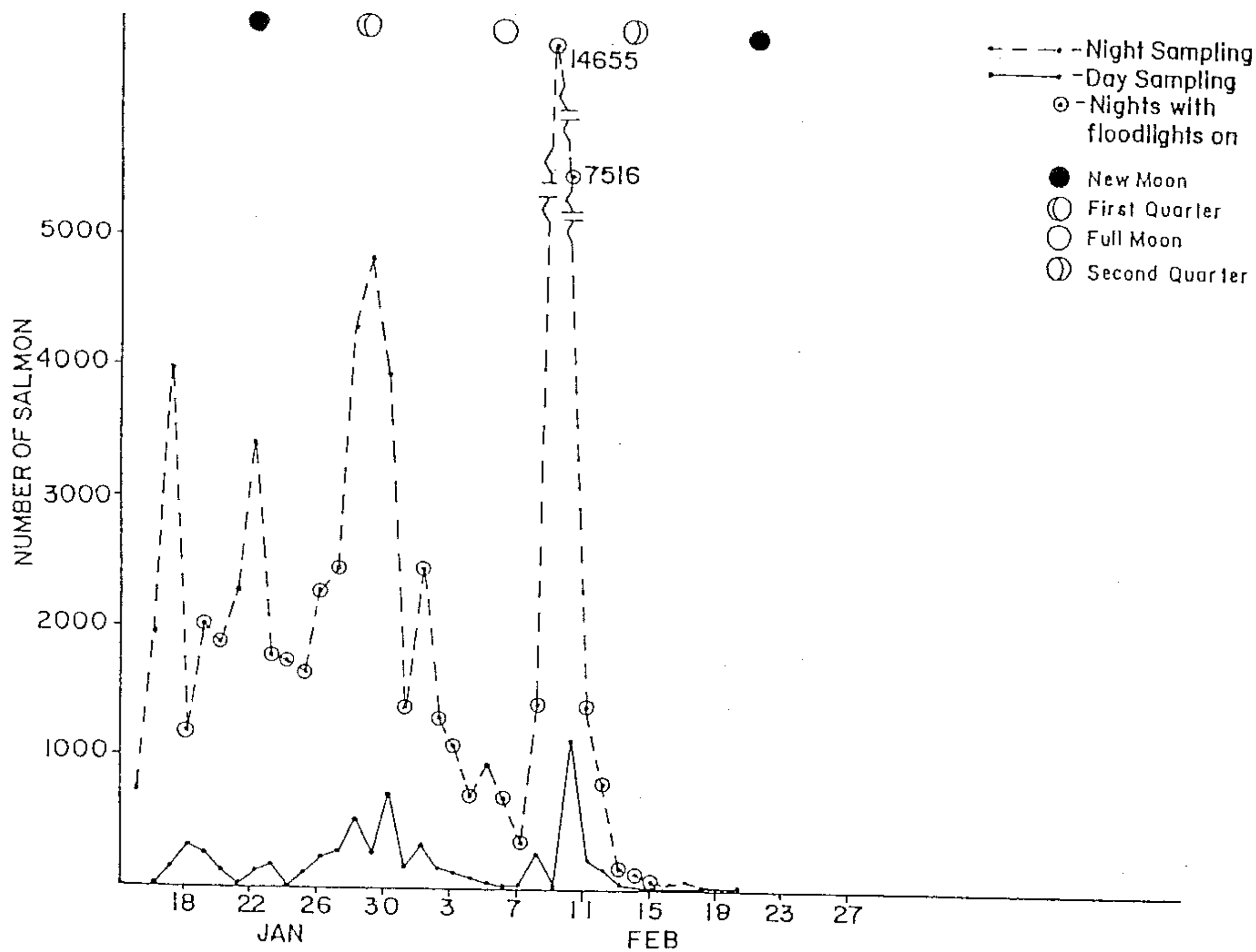

Figure 5. Estimated Numbers of Chinook Salmon Fry Escaping Daily Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-February 1985.

Table 4. Summary of Regression Analysis of Environmental Factors and Catch of Chinook Salmon Fry When Night Lighting Was Used at Tehama-Colusa Fish Facilities Fish Conveyance Channel, January 15 to February 9, 1985.

Year	Variable	Regression Coefficient	Multiple		Partial Regression Coefficients		Overall Regression	
			R	R^2	F	Significance	F	Significance
1985	Time (X_1)	0.473	0.762	0.581	91.15	0.001	66.51	0.001
	Lights (X_2)	-0.163	0.812	0.659	10.41	0.001	45.39	0.001
	Precipitation (X_3)	-0.541	0.836	0.699	6.46	0.001	35.53	0.001
	Turbidity (X_4)	0.045	0.842	0.708	1.39	0.25	27.22	0.001
	Date	0.004			1.04	0.50		
	Temperature	-0.038			1.07	0.50		
	Moon Phase	-0.004			1.67	0.25		
	Constant =	-0.073						
	Standard Error =	0.169						

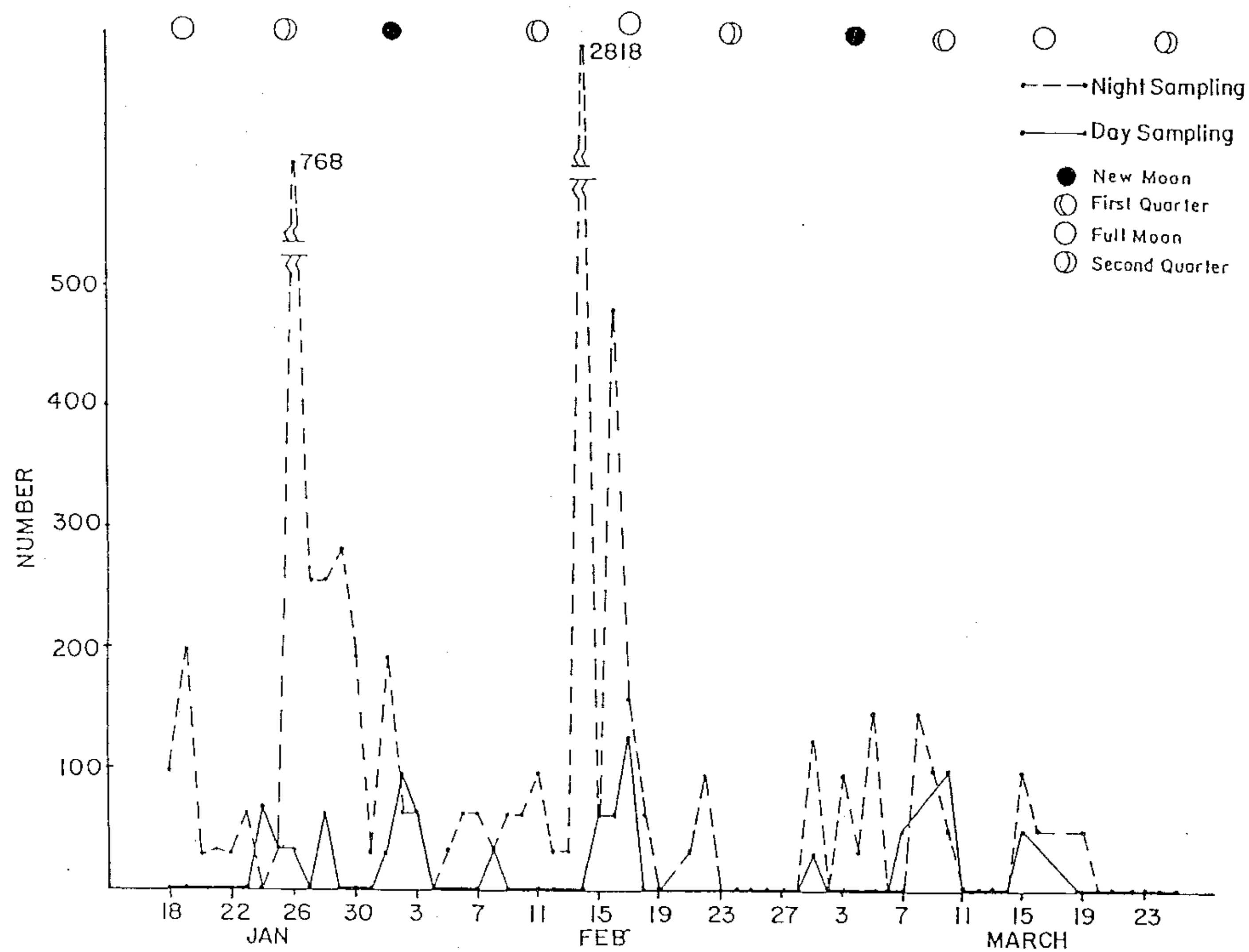

Figure 6. Estimated Numbers of Chinook Salmon Fry Escaping From Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-March 1984.

Table 5. Estimated Numbers of Chinook Salmon Fry Escaping Weekly From Tehama-Colusa Fish Facilities Single Purpose Spawning Channels, January - March 1984.

Week	Night	Day	Total	Cumulative Total	Sac Fry in Catch (%)	Mean Fork Length (mm)	Mean Turbidity (NTU)	Flow Sampled (%)
1-18 to 1-22	390	0	390	390	a	34	13	4.77
1-23 to 1-29	1,659	334	1,993	2,383	a	34	10	4.56
1-30 to 2- 5	576	192	768	3,151	29	34	8	4.69
2- 6 to 2-12	416	32	448	3,599	7	36	8	4.67
2-13 to 2-19	3,618	256	3,874	7,473	6	36	19	4.67
2-20 to 2-26	128	0	128	7,601	0	37	9	4.67
2-27 to 3- 4	253	32	285	7,886	22	34	5	4.67
3- 5 to 3-11	448	150	598	8,484	8	41	5	4.67
3-12 to 3-18	150	50	200	8,684	0	42	18	4.67
3-19 to 3-18	50	0	50	8,734	0	45	5	4.67

[a]Not counted.

Table 6. Estimated Numbers of Chinook Salmon Fry Escaping Weekly From Tehama-Colusa Fish Facilities Single Purpose Spawning Channels, January - February 1985.

Week	Night	Day	Total	Cumulative Total	Sac Fry in Catch (%)	Mean Fork Length (mm)	Mean Turbidity (NTU)	Flow Sampled (%)
1-15 to 1-20	11,792	860	12,652	12,652	37	34	3	5.61
1-21 to 1-27	15,543	943	16,486	29,138	19	34	3	5.60
1-28 to 2- 3	19,422	2,344	21,766	50,904	5	36	3	5.60
2- 4 to 2-10	26,373	1,670	28,043	78,947	5	36	11	5.60
2-11 to 2-17	2,803	889	3,692	82,639	7	37	8	5.60
2-18 to 2-20	54	27	81	82,720	a	35	2	5.60

Table 7. Mean Numbers of Young Chinook Salmon Caught in Fyke Net Per 0.25 Hour at the Fish Conveyance Channel. Surface = S, Bottom = B.

	Channel Area					
	Side 1		Center		Side 2	
	S	B	S	B	S	B
Flow (cms)	0.02	0.02	0.06	0.06	0.03	0.03
Mean Catch	0	0.6	0.8	1.0	0.4	0.2
Standard Deviations(±)	--	0.9	1.8	1.4	0.5	0.4

during January and through mid-February, and during periods of high turbidity, such as in mid-February the number of sac fry escaping increased (Figures 7 and 8). Although a few appeared to be diseased, most sac fry were in healthy condition and many still had large yolk sacs.

Estimates of young salmon "roll over" at the drum screens showed two peaks, one in late January and the other in mid-February (Figures 5 and 6). This pattern of downstream migration has been followed since TCFF has been in operation. Usually peak migration was concurrent with storms and increased turbidity, but the January 1985 peak occurred without these influences. In 1985, lights over the screen complex were turned on during some nights (Figure 5). It appears that the lights had a dampening effect on emigration of fry. However, when turbidity was high, as on February 9 and 19, 1985, lights had little or no effect on discouraging downstream movement of fry. Overall, the loss of young fish over the drum screens decreased in February and into March with a third, smaller peak in March. By this time, however, fry have reached a size where they no longer tend to "roll over" drum screens.

In 1984, the fork length (FL) of chinook salmon fry escaping from the facilities increased during the sampling season (Figure 9). In 1985, FL of escaped fry did not increase as much due to the shortened sampling season. The mean FL of captured fish decreased in late-February both years, concurrent with an increase in migration intensity (Tables 5, 6).

In general, "roll over" fry were less than 40 mm FL and none were over 50 mm (Figures 10 and 11). All fry over 40 mm FL in 1984

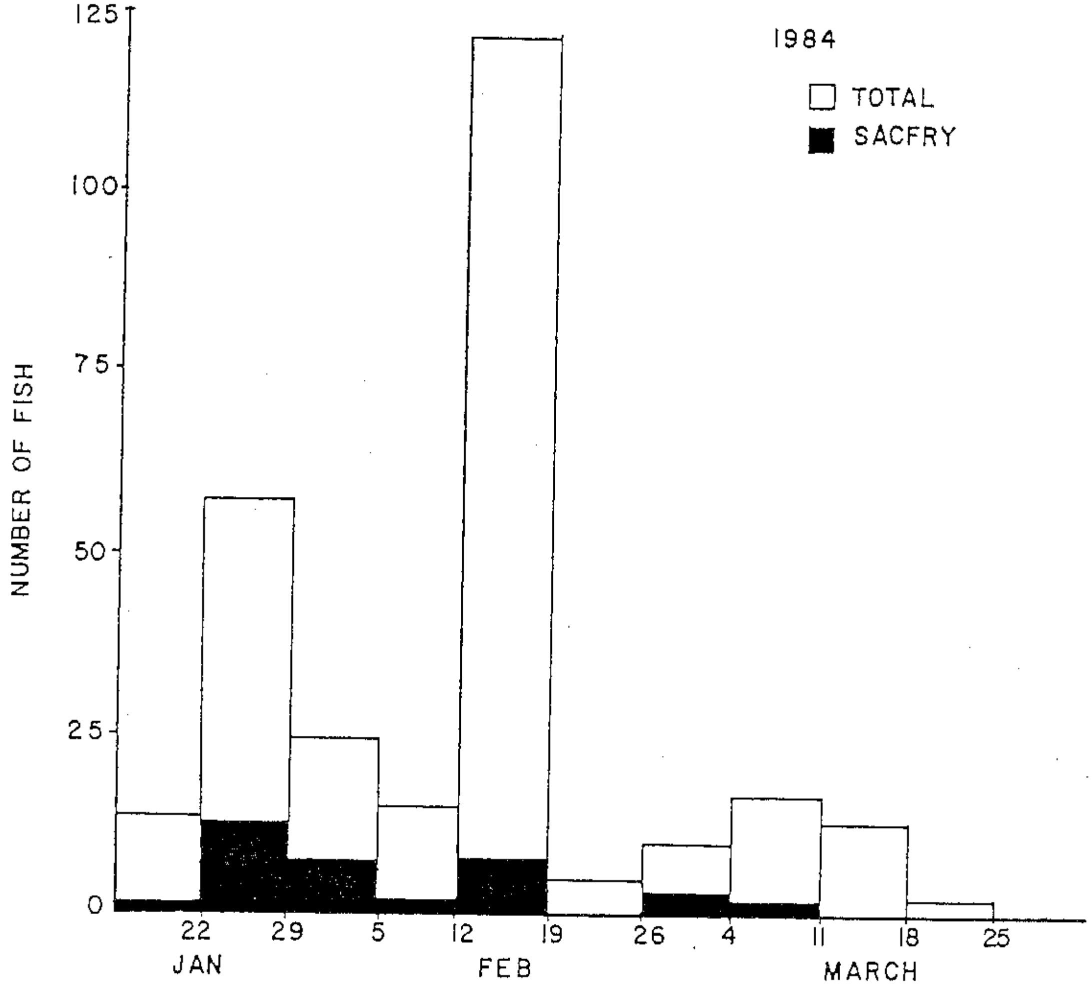

Figure 7. Estimated Numbers of Chinook Salmon Sac Fry and Fry Escaping From Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-March 1984.

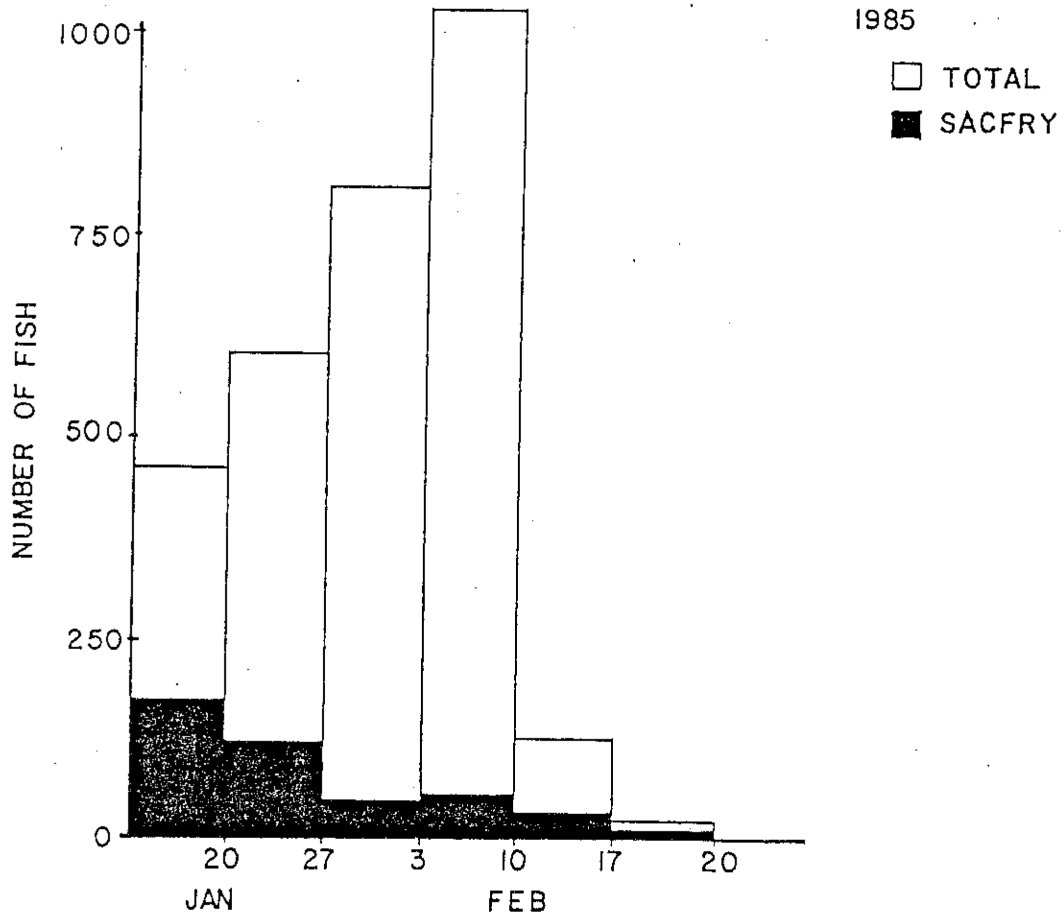

Figure 8. Estimated Numbers of Chinook Salmon Sac Fry and Fry Escaping From Tehama-Colusa Fish Facilities Single Purpose Spawning Channel, January-February 1985.

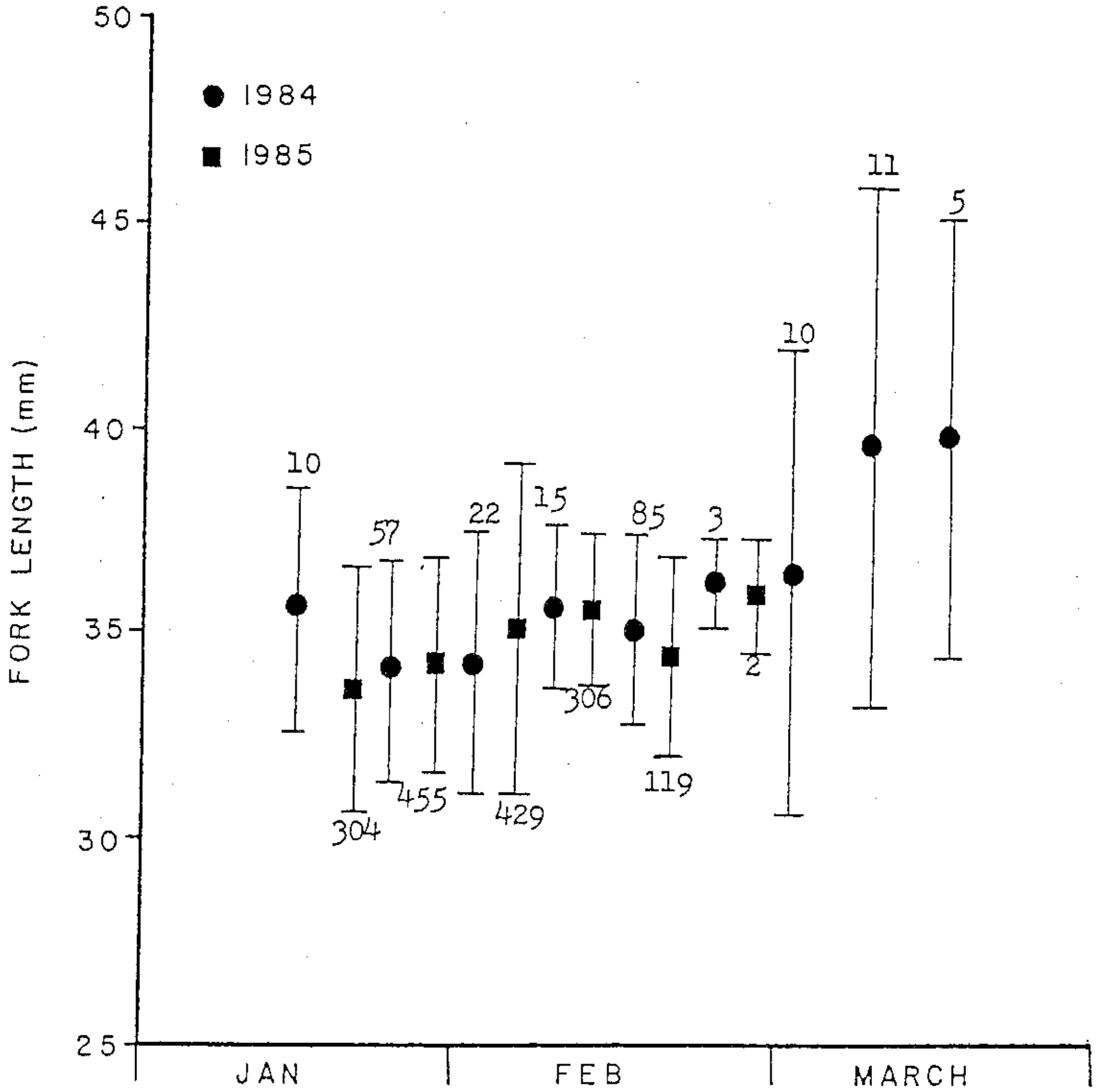

Figure 9. Mean Lengths ± 1 Standard Deviation and Sample Size of Chinook Salmon Fry Caught in Trap Net at Tehama-Colusa Fish Facilities Fish Conveyance Channel, 1984 and 1985.

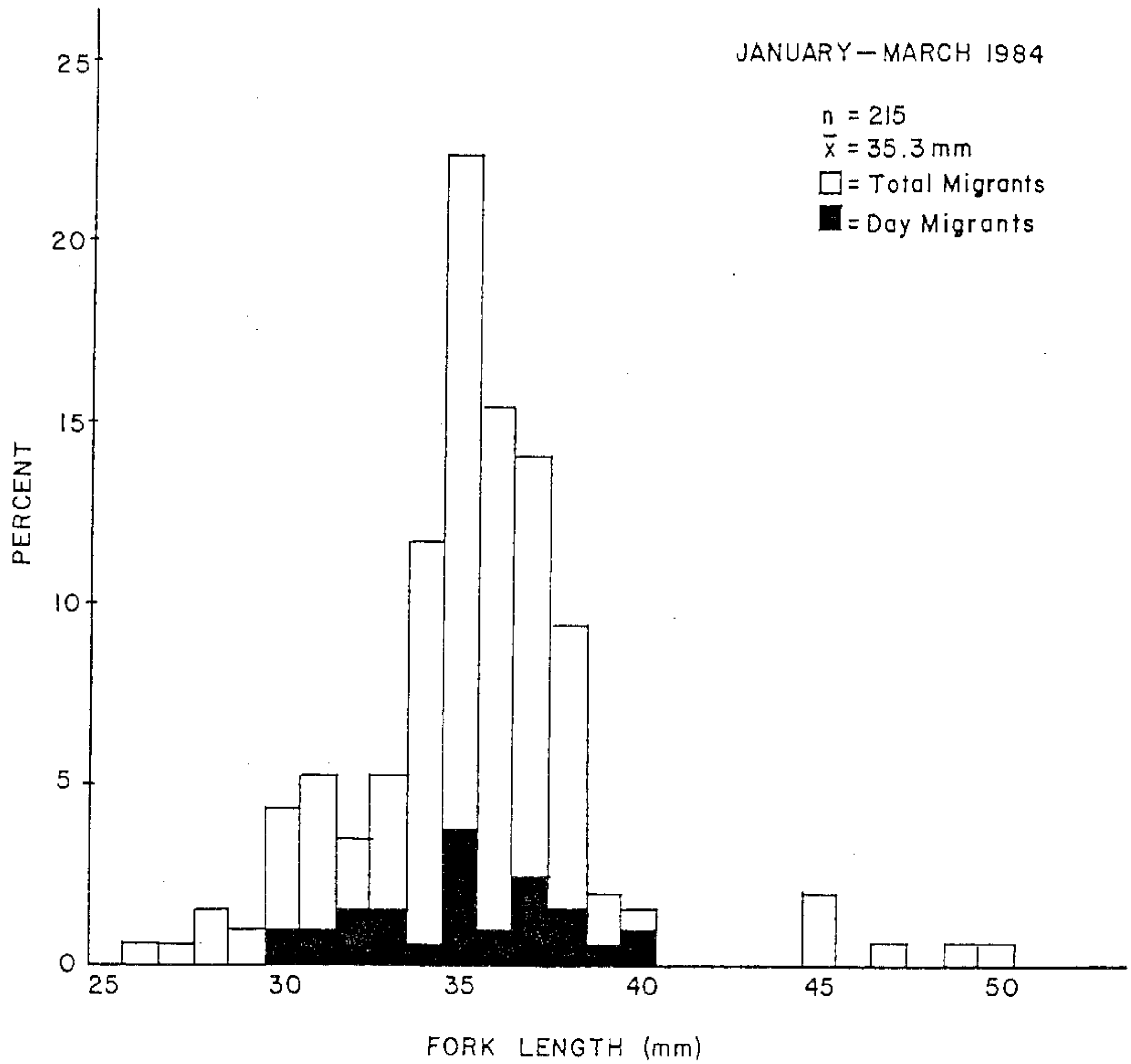

Figure 10. Length Frequencies of Chinook Salmon Fry Caught at Tehama-Colusa Fish Facilities Fish Conveyance Channel, January-March 1984.

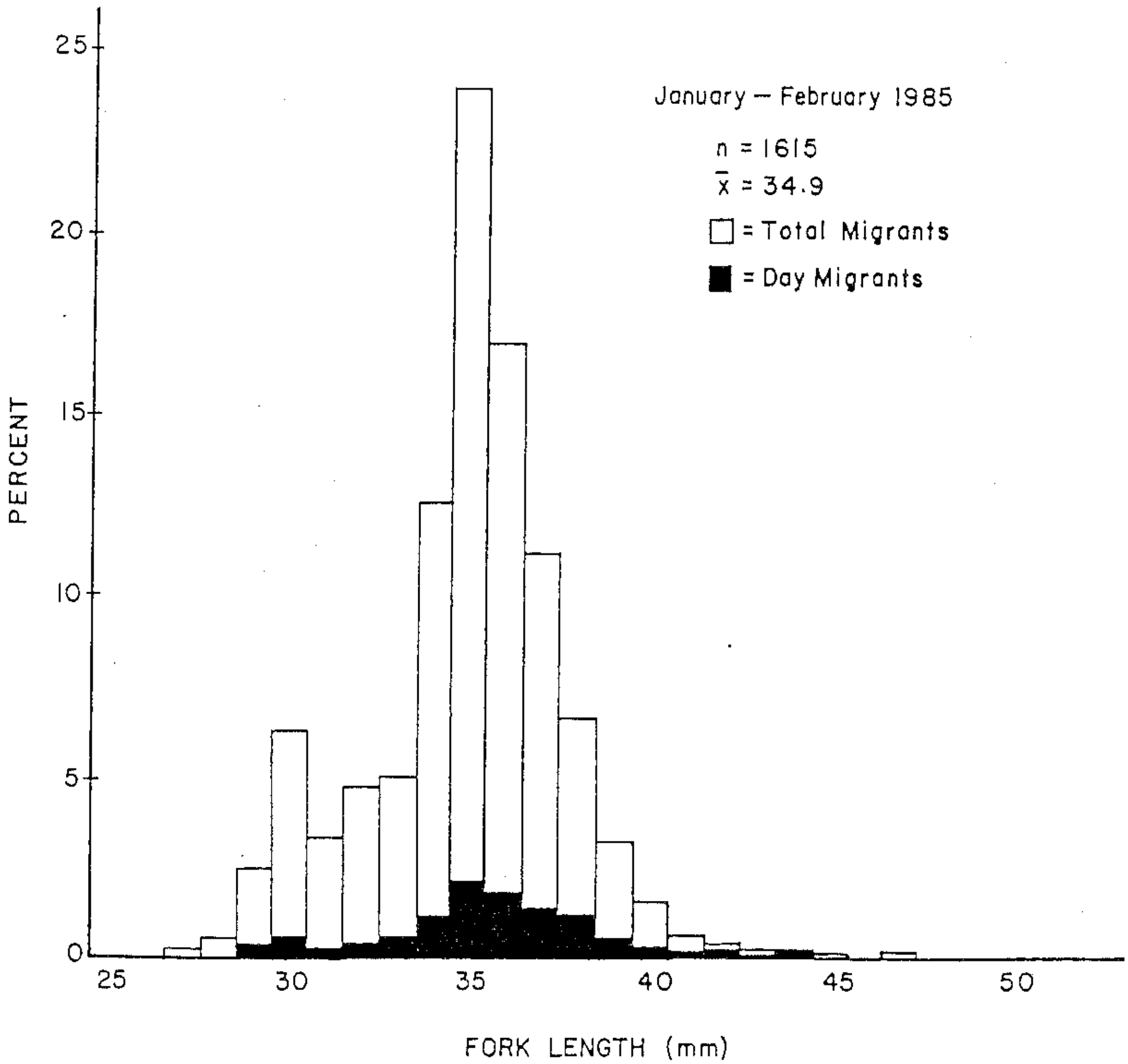

Figure 11. Length Frequencies of Chinook Salmon Fry Caught at Tehama-Colusa Fish Facilities Fish Conveyance Channel, January-February 1985.

were captured during March, and in 1985 fry over 40 mm were consistently captured in low numbers after January. Fry averaged 35.27 mm FL in 1984 and 34.89 mm in 1985. Many 1984 and 1985 outmigrants were still sac fry, but most were button up and larger fry (Figures 7 and 8). Larger fry may have been fish that "rolled over" at a smaller size, but which remained in the pool area below the drum screens and migrated at a later date. There was no significant ($P>0.05$) difference between the FL of fish that migrated during the day and those that migrated at night in 1984. The FL of fish that migrated at night (mean 34.79, n=1437) in 1985 were significantly ($P\leq 0.05$) shorter than those migrating during daylight (mean 35.62, n=178).

DISCUSSION

Mechanisms influencing the downstream migration of chinook salmon fry involve density-dependent factors and environmental stimuli. Young salmon emerge from the gravel as newly hatched sac fry and as fry with the yolk sac almost totally absorbed. Some fry may migrate downstream as sac fry shortly after emergence or as fry 3 to 4 months after the spawning period (Bell 1973). Downstream migration, or passive drift, of salmon fry from spawning to feeding areas appears to be partially density-dependent. The immediate problems of obtaining food and living space in areas of excessive fish densities are adjusted through emigration (Chapman 1966; Edmundson et al. 1968). The fry of coho salmon (Oncorhynchus kisutch) adjust their population to the rearing capacity through space-related aggressive behavior (Chapman 1962). Aggressive behavior may also be responsible for the large, variable downstream movement of fall chinook salmon fry early in the migratory period in comparison with the small, constant output of later migrants (Lister and Walker 1966; Reimers 1968). In incubation channels, however, one of the principal factors causing outmigration appears to be reduced swimming ability shortly before complete yolk sac absorption, and the inability of fish to cope with the current (Thomas et al. 1969). Density-dependent factors may also be responsible for displacement or movement of fry into high velocity areas resulting in passive drift.

Environmental stimuli, such as light, temperature, or current, also have an important influence on the intensity and timing of salmon migration. Environmental cues may alter fish orientation acting as a "director" of migration, or they may serve as a "regulator" of migration and trigger movement or alter its intensity (Northcote 1984). Whatever the impact of density-dependent factors on migration, the daily periodicity and intensity of migration is also influenced by environmental stimuli.

Daily fluctuation of emigration intensity at TCFF was attributed largely to the diel pattern of downstream movement common in the young of river-spawning fishes. This movement is mainly nocturnal and also occurs in young pink (O. gorbuscha), chum (O. keta), coho, and sockeye (O. nerka) salmon populations (McDonald 1960). Smith (1974) observed that 92% of the outmigrating chinook salmon from the Snake River were caught at night.

Nocturnal migrations of salmon fry are due to various factors. When the yolk sac is almost absorbed, sac fry still in the gravel begin to exhibit positive rheotaxis (Dill 1968). After yolk absorption is complete, chinook salmon fry usually emerge from the gravel after dark as free-swimming fry. Since rheotaxis as a "station-keeping" behavior is dependent on visual stimuli, this stimulus is reduced or lost at night. Salmon fry are positively phototactic, and their eyes can adapt to decreases in light intensity (Hoar 1951; 1954; Hoar et al. 1957). However, in nature, light decreases at sunset and into the night more rapidly than their eyes can adapt resulting in a state of partial night blindness (Ali 1959).

The ability of newly emerged fry to maintain their position in the stream is reduced due to the loss of visual reference points and movement towards the water surface (Hoar 1976). This results in their displacement downstream by the current rather than active downstream swimming. As soon as fry can attain visual orientation their drift downstream is slowed. However, sac fry and some small fry cannot resist the current and may drift all day and night (Manteifel et al. 1978). This passive drift is typical of salmon fry as they emerge from the gravel. Thus, the daytime migrants at TCFF are most likely accounted for by this type of drift.

Intensity of diurnal and noctural activity increases dramatically with increased turbidity in TCFF channels. Thomas (1975) found a similar increase in the number of downstream migrant chinook salmon associated with increasing turbidity at the Abernathy Salmon Cultural Development Center, Longview, Washington. Increases in the rate of fish entering and leaving the DPC at TCFF has also been correlated with increased turbidity (Vogel 1982). Increased migration of salmon fry associated with high turbidity is due either to the silt itself or to a decrease in light penetration, which simulates darkness (Meehan and Siniff 1962; Clarke and Smith 1972). Increased abundance of sac fry and an overall decrease in the mean length of fish caught during turbid conditions indicated that turbidity was associated with emergence and emigration of fall-run chinook salmon from TCFF.

The seasonal timing of emigration of young chinook salmon from the spawning channels was also an important factor influencing migration intensity over a long period of time. However, over a shorter period of time as in 1985, seasonal timing was not such an importance influence. Most out migration occurred prior to April 1, with peaks in January and February. This pattern was supported by a similar occurrence in the upper Sacramento River where 90% of the young chinook emigrate from mid-January to mid-March (Beauchamp et al. 1983). Photoperiod plays a role in the seasonal changes in downstream migration but only at the start and end of the migratory season (Northcote 1984). Also, as the migration season progresses there is a shorter time period each night for migration.

The role of the lunar cycle as an influence on animal movements and activities has been extensively studied. The lunar rhythm referred to here approximates a synodic lunar month of 29.5 days (Gibson 1978). Migration of fry from TCFF appeared to be influenced by this cycle, but its effects seemed to be masked by the effects of high turbidity. Seaward movement of coho salmon fry has been found to be influenced by the lunar cycle. Peaks in outmigration were associated with the new moon and migration declined through the lunar cycle (Mason 1975).

The lunar cycle may influence fish migration by the amount of moonlight and by mediating hormone levels in fish. A sharp reduction in the level of downstream movement of young redside shiner (Richardsonius balteatus) was associated with clear moonlit nights (Lindsey and Northcote 1963). Brannon (et al. 1981) observed that newly emerged sockeye fry had a weak directional orientation, but orientation was highly enhanced by moonlight. Thyroid hormones are important in the preparation and orientation of migration in fish (Godin et al. 1974; Hoar 1976; Folmar and Dickhoff 1979; Scholz 1980). The lunar cycle may partially influence the timing of thyroid activity (Grau 1982).

In this study, the influences of precipitation, water temperature and night lighting on migration intensity were small. Thomas (1975) observed that the numbers of migrating chinook fry were positively correlated with rainfall however, heavy sediment loads were also present. Thomas also compared fry migration from troughs of filtered and unfiltered water, and found increased migration from both troughs after periods of heavy rains. At TCFF, it is most likely that the physical changes after heavy rainfall (turbidity) and not rainfall itself influence migration as the flow in the channel does not change. During periods of rainfall with no subsequent increase in turbidity, no noticeable change in migration was observed.

Water temperature may act as a stimulus to trigger downstream movement or as a regulator of migration periodicity (Fried et al. 1978). Fry migration stimulated by rising temperatures and increasing turbidity has been observed for pink salmon and chinook salmon (Coburn and McCart 1967; Thomas 1975). Although temperature varied daily with a general increase through the study periods, it appeared to have little or no influence on migration intensity and timing of migration for chinook salmon at TCFF. Temperature did not account for enough of the variability in the migration data to make it a reliable predictor variable.

Light may regulate the intensity of migration as reduced fish movement has been associated with bright illumination (daylight). Lighting the drum screens did not significantly contribute to a reduction in emigration at TCFF over the sampling season. However, over a short time period of average turbidity in 1985, lighting did significantly reduce emigration intensity, but when turbidity increased so did emigration. Perhaps with higher intensity lighting, migration could have been significantly affected. The use of artificial illumination over a stream area at night greatly decreased the intensity of downstream migrations of rainbow trout (Salmo gairdneri) and catostomid fry (Northcote 1962; Geen et al. 1966). Downstream migrating salmon were repelled in both clear and turbid waters from a 300 watt light bulb (Fields et al. 1958). Whether the night lighting repels the fry or just enables them to maintain stream position and visual contact with their surroundings was not known.

Fall-run chinook salmon fry emigrating from TCFF over the drum screens were generally less than 40 mm FL and all were less than 50 mm. Downstream chinook migrants from the Sacramento River have been caught in the Sacramento-San Joaquin Estuary when they were 41 mm long and may have entered the Sacramento-San Joaquin Delta when they were only 35 mm long (Beauchamp et al. 1983). Young chinook salmon caught in midwater trawls in Carquinez Strait, California averaged 39 mm FL in February (California Department of Fish and Game 1962). Some chinook fry migrate seaward within the first month after emergence when about 30 mm long (Beauchamp et al. 1983). The abundance of sac fry and the small size of emigrants from TCFF also appear to be a common occurrence for fall-run chinook salmon in the Sacramento River.

In 1985, the night-time migrants were a smaller average size than those migrating during daylight. This may be attributed to the large differences in sample sizes. Another possible explanation is that smaller fry emigrated at night due to their emergence from the gravel at night, and their inability to maintain stream position due to the loss of visual stimuli and lack of swimming ability. According to Manteifel et al. (1978) fry of fish species that exhibit passive drift, such as salmon, were able to orient themselves at lower light intensities against the flow in darkness once they reached a defined size. The larger fry migrated later at night and at lower light intensities. This resulted in a reduced time period in which drifting migration was possible, and fewer large fish would be expected to be captured. As fry grow, the threshold value of light intensity becomes lower for the visual mechanism of rheotaxis. Similarly, the tactile mechanism of rheotaxis begins to function and may account for the sudden decrease in mass emigration by passive drift in late February and early March at TCFF.

The downstream migration of fall-run chinook salmon fry is influenced by environmental stimuli and density-dependent factors. However, this does not explain why fry "roll over" the rotating drum screens at TCFF. The "roll over" of fry appeared to be associated with screen design and operation, velocity of water in the channel, and developmental stage of the young. An inherent weakness in the design and operation of drum screens is that the screens cannot be efficiently operated without providing an "escalator" effect that transports fish up the screens (Clay 1961). Under proper operating conditions, a drum screen is submerged at a depth of 67% to 75% of its diameter. The drum screen carries debris on its surface as it rotates. When the drums are submerged at operating depth, the screen surface where it leaves the water is at a small enough angle to the horizontal that sac fry and fry tend to lie against the screen and are carried on the screen surface into the fish conveyance channel, bypassing the fish counting facility.

The developmental stage of young salmon affects its swimming ability which is crucial to avoiding impingement on the screens. As chinook salmon develop there is a period of reduced swimming ability that occurs when the yolk sac is nearly absorbed to a point at or shortly after total absorption (Thomas et al. 1969). Prior to this period, swimming ability increases as the fish becomes more fusiform. At the Abernathy Cultural Center incubation channel there was a close correlation between the period of reduced swimming ability and outmigration (Thomas et al. 1969). Chinook fry in the Abernathy Cultural Center channel did not regain their original level of swimming performance until 22 days after total yolk absorption. At that point, 95% of the migrants had already left the channel. The fry maintained their swimming performance through the time of yolk sac absorption at a maximum water velocity of 18.3 cm/s. Fisher (1981) evaluated swimming performance of juvenile chinook salmon for 6 hour periods at velocities of 6.1-30.5 cm/s. He found that juveniles were impinged at 18.3 cm/s and concluded that juveniles should not be exposed for long periods to velocities greater than 12.2 cm/s. Sasaki et al. (1972) found that swimming performance of juveniles 36-38 mm FL decreased as velocity exceeded 12.2 cm/s. The criterion used at TCFF was a maximum water velocity of 24.4 cm/s (Pollock 1969). Greenland and Thomas (1972) recommended that screening facilities for the Tehama-Colusa Canal be designed to provide water velocities for fall-run chinook fry with a swimming speed of 18.3 cm/s when the fry were 33.0-34.9 mm FL. Thus the "roll over" fry at TCFF were mostly fry which had nearly absorbed their yolk sacs and averaged 35 mm.

I recommend the following for the operation of the TCFF: (1) That sampling young chinook salmon in the fish conveyance channel with a fyke net be discontinued for the season when the algae in channel flows persistantly clog the net. This occurs by the end of February and at that time most of the fry remaining in the channel are too large to "roll over" the drum screens. The loss of sampling efficiency and high maintenance due to the filamentous algae justify this recommendation. (2) The live box be modified to reduce fish loss. A smaller version of the live box used at the DPC velocity barrier would probably work well. (3) The net should be cleaned at least once a day and preferably twice. A jet of water from a hose works well to remove debris and algae. (4) The drum screens be modified to reduce "roll over". (5) The water velocity in the SPC be reduced to a maximum of 18 cm/s with consideration for 12-13 cm/s.

REFERENCES CITED

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.

Ali, M.A. 1959. The ocular retinomotor and photobehavioral responses of juvenile Pacific salmon. Canadian J. Zool. 37:965-996.

Beauchamp, D.A., M.F. Shepard, and G.B. Pauley. 1983. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) -- Chinook salmon. U.S. Fish Wildl. Serv. FWS/OBS-82/11.6. U.S. Army Corps of Engineers, TR EL-82-4. 15 pp.

Bell, M.C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fisheries Engineering Research Program, Corps of Engineers, North Pacific Division; Portland, OR. 500 pp.

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.

Bjornn, T.C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Idaho Dept. Fish Game, Bull. No. 27. 72 pp.

Brannon, E.L., T.P. Quinn, G.T. Zucchette, and B.D. Ross. 1981. Compass orientation of sockeye salmon from a complex river system. Canadian J. Zool. 59:1548-1553.

California Department of Fish and Game. 1962. Cruise Reports. Calif. Dept. Fish Game Marine Resources Branch.

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. J. Fish. Res. Bd. Canada 19:1047-1080.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. Americ. Nat. 100:345-357.

Clarke, W.C., and H.D. Smith. 1972. Observations on the migration of sockeye salmon fry (Oncorhynchus nerka) in the lower Babine River. J. Fish. Res. Bd. Canada 29:151-159.

Clay, C.H. 1961. Design of fishways and other fish facilities. Dept. Fisheries of Canada, Ottawa. 301 pp.

Coburn, A., and P. McCart. 1967. A hatchery release tank for pink salmon fry with notes on behaviour of the fry in the tank after release. J. Fish. Res. Bd. Canada 24:77-85.

Davis, S.K. 1980. Modified fyke net for the capture and retention of salmon smolts in large rivers. Prog. Fish-Cult. 42:235-237.

Dill, L.M. 1968. The subgravel behavior of Pacific salmon larvae. Pages 89-100 In T.G. Northcote, ed. Salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver, B.C., Canada.

Dixon, W.J., editor. 1985. BMDP statistical software. Univ. of California Press, Berkeley, CA. 733 pp.

Edmundson, F.H., F.H. Everest and D.W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish. Res. Bd.Can. 25:1453-1464.

Fields, P.E., A.K. Murray, D.E. Johnson, and G.L. Finger. 1958. Guiding migrant salmon by light repulsion and attraction in fast and turbid water. Univ. of Wash., College of Fisheries, Tech. Report 36. Seattle, WA.

Fisher, F.W. 1981. Long term swimming performance of juvenile American shad, Alosa sapidissima, and chinook salmon, Oncorhynchus tshawytscha. Calif. Dept. Fish Game, Anad. Fish. Br. Admin. Rept. 81-2. 19 pp.

Folmar, L.C. and W.W. Dickhoff. 1979. Plasma thryoxine and gill Na^+-K^+ ATPase changes during sea water acclimation of coho salmon, Oncorhynchus kisutch. Comp. Biochem. Physiol. 63A:329-332.

Fried, S.M., J.D. McCleave, and G.W. LaBar. 1978. Seaward migration of hatchery reared Atlantic salmon, Salmo salar, smolts in the Penobscot River Estuary: Riverine movements. J. Fish. Res. Bd. Canada 35:76-87.

Geen, G.H., T.G. Northcote, G.F. Hartman, and C.C. Lindsey. 1966. Life histories of two species of catostomic fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Bd. Canada 23:1761-1788.

Gibson, R.N. 1978. Lunar and tidal rhythms in fish. Pages 201-213 In J.E. Thorpe, ed. Rhythmic activity of fishes. Academic Press, New York, N.Y. 312 pp.

Godin, J.G., P.A. Dill, and D.E. Drury. 1974. Effects of thyroid hormones on behavior of yearling Atlantic salmon (Salmo salar). J. Fish. Res. Bd.Canada 31:1787-1790.

Grau, E.G. 1982. Is the lunar cycle a factor timing the onset of salmon migration? Pages 184-189 In E.L. Brannon and E.O. Salmo, eds. Salmon and trout migratory behavior. Univ. of Wash. College of Fisheries, Seattle, WA.

Greenland, D.C. and A.E. Thomas. 1972. Swimming speed of fall chinook salmon (Oncorhynchus tshawytscha) fry. Trans. Amer. Fish. Soc. 101:696-700.

Hoar, W.S. 1951. The behavior of chum, pink and coho salmon in relation to seaward migration. J. Fish. Res. Bd.Canada 8:241-263.

Hoar, W.S. 1954. Control and timing of fish migration. Biol. Rev. 28:437-452.

Hoar, W.S. 1958. The evolution of migratory behavior among juvenile salmon of the genus Oncorhynchus. J. Fish. Res. Bd. Canada 15:391-428.

Hoar, W.S. 1976. Smolt transofrmation: Evolution, behavior, and physiology. J. Fish. Res. Bd. Canada 33:1234-1252.

Hoar, W.S., M.H.A. Keenleyside, and R.C. Goodall. 1957. Reactions of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada 14:815-830.

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1982. Life history of fall-run juvenile chinook salmon, Oncorhynchus tshawytscha, in the Sacramento-San Joaquin Estuary, California. Pages 393-411 In V.S. Kennedy, ed. Estuarine Comparisons. Academic Press, New York. 709 pp.

Lindsey, C.C., and T.G. Northcote. 1963. Life history of redside shiners, Richardsonius balteatus with particular reference to movements in and out of Sixteenmile Lake streams. J. Fish. Res. Bd. Canada 20:1001-1030.

Lister, D.B., and C.E. Walker. 1966. The effect of low control on freshwater survival of chum, coho, and chinook salmon in the Big Qualicum River. Canadian Fish Culturist 37:3-25.

MacKinnon, D., and W.S. Hoar. 1953. Responses of coho and chum salmon fry to current. J. Fish. Res. Bd. Canada 10:523-538.

Mains, E.M., and J.R. Smith. 1964. The distribution, size, time and current preferences of seaward migrating chinook salmon in the Columbia and Snake Rivers. Washington State Department of Fisheries, Fisheries Research Paper 2:5-43.

Manteifel, B.P., I.I. Girsa, and D.S. Pavlov. 1978. On rhythms of fish behaviour. Pages 215-224 In J.E. Thorpe, ed. Rhythmic activity of fishes. Academic Press, New York, N.Y. 312 pp.

Mason, J.C. 1975. Seaward movement of juvenile fishes, including lunar periodicity in the movement of coho salmon (Oncorhynchus kisutch) fry. J. Fish. Res. Bd. Canada 32:2542-2547.

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 22:173-190.

McCart, P. 1967. Behavior and ecology of sockeye salmon fry in the Babine River. J. Fish. Res. Bd. Canada 24:375-428.

McDonald, J. 1960. The behaviour of Pacific salmon fry during their downstream migration to fresh water and salt water nursery areas. J. Fish. Res. Bd. Canada 17:655-676.

McLain, A.L., and P.J. Manion. 1967. An all-season trap for downstream-migrating fish and other aquatic organisms. Prog. Fish-Cult. 29:114-117.

Meehan, W.R., and D.B. Siniff. 1962. A study of the downstream migrations of anadromous fishes in the Taku River, Alaska. Trans. Amer. Fish. Soc. 91:399-407.

Northcote, T.G. 1962. Migratory behaviour of juvenile rainbow trout, Salmo gairdneri, in outlet and inlet streams of Loon Lake, British Columbia. J. Fish. Res. Bd. Canada 19:201-270.

Northcote, T.G. 1984. Mechanisms of fish migration in rivers. Pages 317-355. In J.D. McCleave, G.P. Arnold, J.J. Dodson, and W.H. Neill, eds. Mechanisms of migration in fishes. Plenum Press, N.Y. 574 pp.

Pollock, R.D. 1969. Tehama-Colusa Canal to serve as spawning channel. Prog. Fish-Cult. 31: 123-130.

Reimers, P.E. 1968. Social behavior among juvenile fall chinook salmon. J. Fish. Res. Bd. Canada 25:2005-2008.

Sasaki, M., W. Heubach, and J.E. Skinner. 1972. Some preliminary results on the swimming ability and impingement tolerances of young-of-the-year steelhead trout, king salmon, and striped bass. Final Report for Anad. Fish. Act. Project Calif. AFS-13. 31 pp.

Scholz, A.T. 1980. Hormonal regulation of smolt transformation and olfactory imprinting in coho salmon. Unpublished Ph.D. Thesis, Univ. Madison, WI. 363 pp.

Smith, J.R. 1974. Distribution of seaward-migrating chinook salmon and steelhead trout in the Snake River above Lower Monumental Dam. Marine Fisheries Review 36(8):42-45.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco, CA. 776 pp.

Thomas, A.E. 1975. Migration of chinook salmon fry from simulated incubation channels in relation to water temperature, flow, and turbidity. Prog. Fish-Cult. 37:219-223.

Thomas, A.E., J.L. Banks, and D.C. Greenland. 1969. Effect of yolk sac absorption on the swimming ability of fall chinook salmon. Trans. Amer. Fish. Soc. 98:406-410.

Thomas, R.E. 1984. The old farmer's almanac. Yankee, Inc., Dublin, N.H. 218 pp.

Thomas, R.E. 1985. The old farmer's almanac. Yankee, Inc., Dublin, N.H. 224 pp.

Tyler, R.W. 1979. Method of sampling seaward mdigrations of juvenile salmon. Prog. Fish-Cult. 41:78-81.

U.S. Bureau of Reclamation. 1985. Central Valley fish and wildlife management study -- fishery problems at Red Bluff Diversion Dam and Tehama-Colusa Canal Fish Facilities. Special report: Mid-Pacific Region, Sacramento, CA. 112 pp.

U.S. Fish and Wildlife Service. 1963. Special interim report of July 19, 1963. Portland, Or. 13 pp.

U.S. Fish and Wildlife Service. 1972. Tehama-Colusa Fish Facilities Spawning Channel production reports. 48 pp.

U.S. Fish and Wildlife Service. 1973. Tehama-Colusa Fish Facilities Spawning Channel production reports. 44 pp.

U.S. Fish and Wildlife Service. 1974. Tehama-Colusa Fish Facilities Spawning Channel production reports. 41 pp.

U.S. Fish and Wildlife Service. 1977. Tehama-Colusa Fish Facilities Spawning Channel production reports. 40 pp.

U.S. Fish and Wildlife Service. 1980. Tehama-Colusa Fish Facilities annual reports. 22 pp.

U.S. Fish and Wildlife Service. 1981. Tehama-Colusa Fish Facilities annual reports. 22 pp.

Vogel, D.A. 1982. Evaluation of the 1981-82 operation of the Tehama-Colusa Fish Facilities. U.S. Fish and Wildl. Serv. 24 pp.

Wolf, P.A. 1951. A trap for the capture of fish and other organisms moving downstream. Trans. Amer. Fish. Soc. 80:41-45.