AN ASSESSMENT OF THE DOWNSTREAM MIGRATION OF
JUVENILE CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*)
IN THE LOWER MOKELUMNE RIVER, CALIFORNIA

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AN ASSESSMENT OF THE DOWNSTREAM MIGRATION OF
JUVENILE CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*)
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A Thesis

by

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Abstract

of

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Statement of Problem: A number of areas of needed research concerning the juvenile life stage of chinook salmon have been outlined in the literature. Important topics that remain unresearched include 1) determining what environmental cues stimulate emigration, 2) defining the variation in emigration patterns between years for river systems, and 3) defining when juveniles are rearing versus when they are emigrating.

Sources of Data: Juvenile chinook salmon were marked with acrylic paint and ink using a syringe to mark these fish subdermally at the fin bases, in order to assess movement patterns within the lower Mokelumne River. Juvenile chinook were marked in reaches III through VI of the lower Mokelumne River. Additionally, environmental variables were recorded daily on the Mokelumne River. These include temperature, rainfall, turbidity, and flow. These data were compiled from 1993 to 1998 and compared to the percent of emigrating juvenile chinook salmon and with the average fork length of emigrating juvenile chinook salmon.

Conclusions Reached: In 1997, a total of 1,196 juvenile chinook salmon were marked and 108 recaptured. Flow stability and temperature did not appear to affect movement. Longest residence time observed in 1997 was 35 days in reach III. Longest interval from mark to recapture was 51 days. In 1998, 2,332 fish were marked and 125 recaptured. Longest residence time observed in 1998 was 41 days in reach III. Longest interval from mark to recapture was 67 days.

Regression analysis of the effects of environmental variables on total emigration numbers from 1993 to 1998 showed no relationship. Daily emigration numbers also showed no relationship with daily environmental variables for the same period. Daily fork lengths showed varying levels of dependence on environmental variables, but these appear to be a function of operations of Camanche Dam rather than a biological phenomenon.

____________________________________, Committee Chair
Dr. Vanicek

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TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

INTRODUCTION

The Mokelumne River is a tributary to the Sacramento-San Joaquin Delta and the San Francisco Bay. This is the southernmost extent of the spawning population range of the chinook salmon, *Oncorhynchus tshawytscha*. Chinook salmon are anadromous and semelparous. Two races are recognized: stream-type and ocean-type. Stream-type chinook spend one or more years in freshwater before migrating out to sea. They perform extensive oceanic migrations, and then return to their natal streams in the spring, several months before spawning. Ocean-type chinook migrate to sea in their first year of life and spend most of their ocean existence in coastal waters and return to their natal river in the fall immediately before spawning (Healey 1991). The population on the Mokelumne River is classified as an ocean-type chinook and is also a fall-run i.e., adults enter the river in the fall, and spawn soon after entering fresh water.

The Mokelumne River forms the border between Calaveras and Amador Counties in central California and continues through San Joaquin County to the Sacramento-San Joaquin Delta. Like most California Central Valley river systems, it is regulated by a number of dams used for hydroelectric energy generation, drinking water impoundment, flood control, and fisheries and wildlife habitat. The upper Mokelumne River is controlled by a series of dams operated by the Pacific Gas and Electric Company. The lower Mokelumne River is controlled by the East Bay Municipal Utility District (EBMUD) (Lower Mokelumne River Project, Federal Energy Regulatory Commission ,FERC, License no. 2916), which operates two dams on the lower Mokelumne River. The upper dam impounds Pardee Reservoir, which serves as a drinking water supply for the east San Francisco Bay area. The lower dam, which impounds Camanche Reservoir, is a flood control reservoir that provides for downstream water rights, downstream fisheries flows, and hydroelectric power generation. Operation of these dams varies from year to year based on water year type, spring runoff, and precipitation. The river flows required in the lower river in wet, normal, dry, or critically dry years are different. These water year types are currently defined in the FERC Joint Settlement Agreement (JSA) (1999). In the past they have been defined by the Lower Mokelumne River Management Plan (LMRMP) (Biosystems 1992a), and by the Principle of Agreement (POA) documents. The POA was simply a precursor to the JSA, which outlined what agreements would be made in the JSA. Year type determination in the JSA is based on storage levels in Pardee and Camanche from October to March and on unimpaired runoff from April through September (Table 1). Minimum flow requirements for adult spawning, egg incubation, rearing and emigration also vary under these year types and EBMUD operates under the flows in the agreement. Any flow reductions made are subject to a ramping down rate of 100 cubic feet per second (cfs)/day broken into two 50 cfs reductions, usually at 0800 h and 1400 h per the JSA.

The placement and operations of Pardee and Camanche dams have decreased and altered available spawning and rearing habitat for fall run chinook. EBMUD, therefore, has responsibilities that include monitoring natural production of fish spawning in the river. EBMUD currently is working under the guidelines of the JSA. Parties to the agreement are EBMUD, United States Fish and Wildlife Service (USFWS), and California Department of Fish and Game (CDFG). The agreement is overseen by the Federal Energy Regulatory

Commission (FERC). In the LMRMP, fisheries research needs are outlined and include 1) monitoring juvenile salmon emigration, 2) monitoring survival of emigrants through Lake Lodi in normal and wet years, and 3) monitoring habitat use by fry and juvenile salmonids (LMRMP 6.3.2). Currently, as partial fulfillment of these guidelines, EBMUD Fisheries and Wildlife Division conducts biweekly fish community surveys in four reaches, reach III to VI, of the lower Mokelumne River, on a total of 37 river miles (Vogel and Marine 1997) (Figure 1).

There are a number of research questions that could be addressed utilizing data from these ongoing monitoring projects. At a workshop on Central Valley salmon (January 1993) several questions were posed (Cech et al. 1993). These included: 1) determining what environmental cues stimulate emigration. Flow rates and temperatures are listed as possible factors (Hanson 1993). 2) Determining the effects of hydrology on emigration rates. For example, are pulsed flows beneficial (Hanson 1993)? 3) Finding more information on variation in emigration characteristics between years for river systems (Hanson 1993). 4) Finding more information on rearing to help define rearing versus emigration (Vogel 1993). 5) Determining downstream dispersal patterns and the factors that influence these patterns (e.g., flow, velocity, turbidity, food availability) (Vogel 1993) and, 6) determining the effects of water temperature on growth, and on the timing, rate and pattern of downstream movements because these are also not well studied, according to Castleberry (1993).

The fish community surveys that have been conducted on the lower Mokelumne River since 1990 have provided a general view of habitat use by juvenile chinook (Hartwell 1990-1996; Merz and Workman 1998). Pulses in emigration of fry and smolts have been noted, and the condition of these fish has been monitored (Vogel and Marine 1994-1997). A pilot study was conducted by Biosystems (1992b) to study movement rates and survival of hatchery-reared smolts through Lake Lodi. However, data are lacking on movement patterns and residence times of naturally-produced Mokelumne River fish.

The objectives of this study were to 1) evaluate the use of acrylic paint injection as a marking method by assessing short-term survival and retention on Mokelumne River juvenile fall-run chinook salmon, 2) assess and compare the rate and pattern of downstream movements and residence times of juvenile chinook salmon in relation to flow patterns (fluctuating vs. stable flows) and temperature regimes for one year, 1998, and 3) describe and compare the annual emigration characteristics from 1993 to 1998, i.e., size and number of emigrants, and the timing of chinook salmon emigration in relation to flow, temperature, turbidity, rainfall, and prior-year adult escapement.

METHODS AND MATERIALS

Description of Study Area and Collection Sites

The lower Mokelumne River, from the base of Camanche Dam to its confluence with the Cosumnes River, is divided into six reaches (Figure 1). Reach delineation for the lower Mokelumne River is as follows. Reach I, from the confluence with the Cosumnes River to Woodbridge Irrigation District Dam (WIDD), is low gradient, heavily influenced by levees, has tidal influence, and secondary flow control from WIDD. Reach II, from WIDD to Highway 99, is a shallow, man-made reservoir 6 months out of the year and supports a warm-water fishery at that time. Within reach III, Highway 99 to Bruella Road and Reach IV, Bruella Road to Elliott Road, the river drops an average 0.1 ft/mile (0.02 m/km). Both of these reaches are made up of pools and glides with minimal salmonid spawning habitat. Reach V, from Elliott Road to Mackville Road, drops an average of 3.7 ft/mile (0.69 m/km) and exhibits a significant increase in salmonid spawning habitat. Reach VI, from Mackville Road to Camanche Dam drops an average of 4.8 ft/mile (0.89 m/km) and contains the greatest concentration of chinook spawning habitat (Merz 1997a).

During EBMUD fish community surveys, beach seining, and backpack and boat electroshocking techniques are used on 12 standardized seine sites in reaches III through VI. Fish collected in fish community surveys are weighed, measured, lifestage determined, and any anomalies noted (Merz and Workman 1998). For my study these 12 seine sites were used for collection and recapture of marked fish. Each collection site was determined to be a run, riffle, or pool, and the river mile location determined. Estimations were made from United States Geological Survey (USGS) topographical maps of the river mile location of each collection site used in this study (Table 2).

Marking Techniques

Literature was reviewed to determine which marking methodology would be the most appropriate to achieve the objectives of this study relating to movement. There were a number of studies in the literature using injected marking techniques. Thedinga and Johnson (1995) injected juvenile coho salmon (*O. kisutch*), and sockeye salmon (*O. nerka*) using Alcian blue dye, india ink, and fluorescent acrylic paint. Batches of fish were marked using a commercial jet injection procedure. According to this study, all of these colors were suitable for short-term studies (<6 weeks) and the fluorescent orange and yellow were recommended for longer retention (>6 weeks). Fay and Pardue (1985) assessed the retention rates of red and blue latex injections on hatchery-reared rainbow trout. Retention rates for blue and red were 91.6% and 75.4%, respectively, for a 13.5-week period. Marking entailed syringe injection on the mandible using a 26 gauge needle and a 3-cc syringe. Biosystems (1992b) used a jet injection system to mark smolts during a pilot study in the Mokelumne River in 1991 to assess smolt mortality in Lake Lodi. Fish were marked with Alcian blue dye and different mark locations were used to distinguish release locations.

Fish for this study were marked combining methods outlined in Thedinga and Johnson (1995), Fay and Pardue (1985), and Biosystems (1992b). Liquitex brand fluorescent acrylic paints and Higgins brand non-waterproof india ink were injected with a 26-gauge needle and a 3-cc syringe using different mark locations and colors to distinguish groups by reach and by date of marking.

Mark Retention and Mortality

Evaluations of survival and mark retention were conducted at the Mokelumne River Fish Installation (MRFI) in 1997 and 1998. To assess marking mortality, two groups of chinook salmon fry were held in the Mokelumne River Fish Installation (MRFI) for a 48-h period in March, 1997. These fish had been produced from eggs collected as part of hatchery operations, and were collected from the rearing troughs at the MRFI. One group of 30 fish was marked using fluorescent orange, yellow, and green acrylic paint and Higgins non waterproof India Ink, and a second group of 30 was held as a control. Mark locations were at the bases of the caudal, anal, pelvic and pectoral fins on the right and left sides of the body. These fish were kept alive in three 25 liter live cars that were 30 cm in diameter, 40 cm long with soft nylon 2 mm Delta mesh covered ends. The live cars were then placed in an 11ft (3.3 m) diameter circular tank equipped with packed column aerators with an inflow of approximately 15 cfs (0.42 m^3/sec), at the MRFI.

Downstream Movements

In 1997, juvenile salmon were marked in conjunction with biweekly fish community surveys for the period of 12 March 1997 to 18 June 1997. Salmon >32 mm were marked where captured in all reaches. The fish were weighed (nearest 0.1 g) and measured (nearest mm) and then marked by injecting Liquitex acrylic paint (flourescent orange, green, yellow, purple or blue) or black Higgins non-waterproof India ink subdermally, with a Becton Dickinson and Co., 3-cc Sub-Q (25G/8) syringe. When sample sizes were greater than 50 per site, only the first 50 were weighed and measured to determine length-frequency distributions. All recaptured marked fish were weighed and measured. Marks were made at the base of the pectoral, pelvic, and caudal fins. Marking was designated for reach and week of capture. Each reach was represented by a different color and each week was represented by a different mark location. Chinook in reach VI, were marked on alternate weeks from chinook in reach III, IV and V. These fish were recaptured in subsequent seining and electroshocking surveys, and in rotary screw traps, and upper and lower ladder incline plane traps at Woodbridge Irrigation District Diversion Dam (WIDD). In 1997 salmon in reaches IV and V were given the same mark. Because this method deviates from the proposal, the fish collected in these reaches and recaptured in these reaches or lower are not included in the results of this study.

In 1998, I used three techniques to collect samples for marking: 1) seine sampling with a 50 ft. X 6 ft., 1/8 inch mesh (15.25 m X 1.8 m, 0.16cm) beach seine following methods described by Merz (1997b); 2) backpack electroshocker; and 3) operation of a riffle-type fyke trap placed at the AIS site in reach VI, which is below some of the most active spawning areas. In 1998, fish in reaches V and VI were marked on alternate weeks from fish in reaches III and IV.

The fyke trap was operated in a side channel riffle in reach VI from dusk until dawn to optimize catch-per-unit-effort (CPUE), since downstream movements of juvenile chinook salmon occur mainly at night (Healey 1991). It was operated on alternate weeks of seining surveys to provide a temporal separation of mark groups for the upper reach. The fyke was operated from January to April, at which time capture rates became too low to be useful. After April, juvenile chinook were captured by seine on alternate weeks of regular seining surveys to augment numbers of marked fish.

Seine sampling to recapture marked fish, and to mark additional fish, throughout reaches III through VI, was conducted in conjunction with biweekly fish community surveys, monthly electroshocking surveys, and trap operations at Woodbridge Dam. Three sites that are accessible by car were seined each week in addition to the biweekly surveys of 12 seine sites. These additional sites were Highway 99 (reach III), Mackville Road (reach V), and the Mokelumne Day Use Area (MDUA)(reach VI) (Figure 1). These additional seining efforts were included to decrease time between sampling efforts. All recaptured marked fish were weighed and measured. The fyke trap was monitored daily when in operation.

For the mark-recapture portion of this study, movement (1997) and residence times (1997 and 1998) were analyzed. I assumed that there was no significant upstream movement from the point of marking. Movement was determined to have occurred when a marked fish from the study reaches was recovered in a lower reach than initially marked, or recovered at the WIDD trapping site. Residence times were recorded using recapture data for the reach of initial marking. Residence times were recorded as number of days from initial marking to the date of subsequent recaptures in that reach. In any group with multiple recaptures at a single location, each separate recapture was recorded as a separate residence time.

Movement of marked fish in 1997 was assessed by comparing movement versus no movement for 1) fluctuating vs. stable flows, and 2) temperature (>13^{o}C versus <13^{o}C) using chi square analysis (Zar 1984). Flow fluctuations were any change in flow greater than *50 cfs*, and over more than 1 day. Temperature criteria were based on optimal rearing temperatures for chinook salmon outlined in Allen and Hassler (1986). In 1998, there were very few recaptures in new locations, i.e., movement, so residence times were analyzed rather than movement patterns.

In 1998, additional data were collected during Kodiak trawl sampling in the Sacramento-San Joaquin Delta. The Vernalis Adaptive Monitioring Program (VAMP) conducts daily kodiak trawl surveys in the lower San Joaquin River just off of Jersey Island in an area known as Jersey Point (Chuck Hanson, Hanson Environmental Services, Inc., pers. comm.).

Environmental Factors

Historical data on flow, annual estimates of the number of emigrating juvenile salmon, size of emigrants, rainfall, temperature, and turbidity were available for analysis for 1993 through 1998. The parameters of estimated number of emigrants (from rotary screw trap captures), average fork length of emigrants, surface temperature at WIDD, turbidity at WIDD measured as secchi depth in centimeters, and precipitation at WIDD and Camanche Dam were collected and compiled by Vogel Environmental Services (1994, 1996), and Natural Resource Scientists (1997 unpublished raw data) under contract by EBMUD. These data were collected at the WIDD site, with the exception of the rainfall data, which were collected at two National Weather Service stations, one below WIDD and one at Camanche Dam. Daily release rates (in cfs) from Camanche Dam were also available from the EBMUD Water Supply Section (unpublished raw data). Several of these variables are a result of operations at Camanche Dam, and therefore, are controlled to a certain degree. The amount of flow, and the variation in flow patterns are directly controlled by operations at Camanche Dam. The temperature can also be a function of operations. That is, the EBMUD Water Operations Division can release water from the top of the reservoir or the bottom of the reservoir, or a mixture of both. This, along with natural weather patterns, affect water temperature. Turbidity can be affected by operations and by natural storm events. Because some of these variables are at least partially controlled in the Mokelumne River, it is important to evaluate how differences in these variables, based on water year type, may affect the characteristics of the downstream movement of juvenile fall chinook salmon. The third objective of this study deals with the possible effects of these variables on fish movement.

Analysis of the historical (1993-1998) daily environmental data with the daily emigration data was accomplished using linear regression analysis of number of emigrants (represented as a % of the total annual emigration number) by date as the dependent variable and the environmental factors as distinct independent variables. Average fork length by date was also related to the environmental factors. Correlation analysis was also performed to correlate both number and size to the environmental factors, and to determine if any cross correlation of independent variables existed (Zar 1984).

Annual emigration characteristics were analyzed using linear regression of total emigration with previous year escapement, number of redds, annual average flows, flow variability (represented as the coefficient of variation of flow), average water temperature, average turbidity, and average rainfall. Correlation analysis was again used to determine cross correlation relationships between independent variables.

RESULTS

Mark Retention and Mortality

Of the 60 fish marked and held in March 1997 to assess marking-related mortality, none died after a 48-h holding period. I found that fluorescent yellow and green were hard to distinguish from each other and anal and pelvic marks were hard to distinguish. Consequently, anal marks were excluded from the study, and yellow was not used as a mark color.

Downstream Movements

1997 Movement and Residence Times

From 12 March to 10 June 1997 a total of 1196 juvenile chinook salmon were marked in reaches III and VI (Table 3). Of the 108 recaptures (representing a 9% recapture rate), 23 were collected in boat electrofishing surveys, 20 were collected at the trapping operations at WIDD, and 65 were collected during seining surveys. Marked fish ranged from 32 mm FL to 116.5 mm FL, and recaptured fish ranged from 38 mm FL to 107 mm FL. All movement was recorded from fish recaptured at WIDD, no movement between the other sample sites was recorded. The longest interval from marking to recapture was 51 days. This fish was marked on 2 April 1997 in reach VI and recaptured at WIDD on 22 May 1997. The shortest measured migrations downstream to WIDD were 9 days from reach III, and 11 days from reach VI. The last fish recaptured was recorded at WIDD on 27 June 1997. This was from a group marked on 28 May 1997 in reach VI. All 20 fish recovered at WIDD were released from reach VI. Average time, in days, from marking to recapture at WIDD from reach VI was 32 days (range: 19-51) (Table 4). The distances traveled from the bottom of each reach to WIDD are: 20 miles from reach VI, and 4 miles from reach III.

Downstream movement in relation to flow and temperature was evaluated. A chi-square contingency analysis comparing numbers of marked salmon that moved 1) during periods of fluctuating and non-fluctuating water levels, and 2) during periods of high and low water temperatures did not result in significant X^2 values (Table 5). Thus, fluctuations in flow and water temperature did not have a significant effect on downstream movement of marked fish.

Residence times were determined from recapture data, and recorded as number of days in a reach. The number of days from marking to the date of recapture in one reach was recorded as residence time for a particular mark group. In any group with multiple recaptures in the same reach, each separate recapture was recorded as a separate residence time. Reach III was sampled 10 times during the study period. Of these 10 efforts, four produced recaptures. Maximum observed time in reach III was 35 days from 1 April 1997 to 6 May 1997. Reach VI was sampled nine times in 1997. Four of these efforts produced recaptures. Maximum observed time in reach VI was 28 days from 13 May 1997 to 10 June 1997 (Table 6).

1998 Residence Times

In 1998, sampling was increased from two times per month, in 1997, to weekly in 1998, in an attempt to increase recapture rates. In 1998 a total of 2,332 fish were marked and 125 recaptured (Table 7). Marked fish ranged in size from 25 mm to 187 mm FL. Of the 125 recaptures only two were recorded at WIDD, and eight at Jersey Point. All other recaptures were collected in seining and boat electroshocking surveys. The two captured at WIDD were captured on 18 January 1998 and 7 February 1998. The fish recaptured on 18 January had been marked in reach VI only two days prior. Thus, this fish traveled the approximately 27 river miles to WIDD in only 2 days. The fish recaptured on 7 February took 18 days to travel the same distance.

<u>Residence times</u> for 1998 were also investigated. Reach VI was sampled 26 times. Eleven of these efforts produced recaptures. Longest observed time in reach VI was 40 days from 18 March 1998 to 27 April 1998 (Table 8). Reach V was sampled 14 times during the study period. Of these 14 sampling efforts, three produced recaptures. The longest interval from marking to recapture was 15 days from 20 January 1998 to 4 February 1998. Reach IV was sampled eight times. One sampling effort produced recaptures (Table 9). Reach III was sampled 14 times, and six of these times resulted in recaptures. Longest observed residence time in reach III was 41 days from 20 March 1998 to 30 April 1998 (Table 10).

Some fish in 1998 stayed in the same location through numerous flow changes. Fish marked on 20 March 1998 in reach III stayed in reach III for a maximum of 41 recorded days during which three flow changes occurred from 3000 cfs (84.9 m^3/s)to 1100 cfs (31.1 m^3/s). Likewise, fish marked on 18 March 1998 stayed in the same reach for 40 days through three flow changes.

VAMP Data

In 1998 additional recaptures were made in Kodiak trawls at Jersey Point, downstream in the San Joaquin River (Chuck Hanson, pers. comm.). From 13 May to 24 May, a total of eight fish marked with fluorescent orange on the caudal fin were recovered during sampling efforts at Jersey Point. No description of right or left caudal was given, but because very few fish were marked left caudal orange (n=16), these fish were more likely right caudal orange marks (n=195). The latter group was marked on March 18 in reach VI of the Mokelumne River. Sixty-seven days elapsed from the time of marking in the uppermost rearing reach in the Mokelumne River to the observations at Jersey Point.

Emigration in Relation to Environmental Factors

Annual Emigration

The number of fish that moved past WIDD during an entire emigration was compared with the total prior year escapement number (number of adult salmon immigrating past WIDD), the number of redds built in the river, average flow for the year, the flow variation for the year, and average temperature, turbidity and rainfall. Correlation analysis for data from

1993-1998 determined that the independent variables were highly correlated. Thus, multiple regression analysis of these data was invalid, necessitating separate linear regression of each independent variable. Number of redds and escapement numbers were predictive of total emigration numbers for the period of 1993 through 1998 (R^2 = 0.67. and 0.66, respectively). Flow quantity, flow variation, temperature, turbidity, and rainfall were all not predictive of total emigration numbers (Table 11).

Daily Emigration

Because flow, temperature, turbidity, and precipitation were highly correlated with one another, multiple regression could not be used to assess the relationship of these variables with the number and size of emigrating chinook salmon. Instead, linear regressions were run for each variable separately. Environmental factors did not appear to have any predictive value for percent of total emigrants on a daily basis. In all years temperatures were highly predictive of average fork length of emigrants. Precipitation was not predictive of fork length of emigrants. Flow and turbidity showed varying levels of predictive value in different years (Table 12) (Figure 2).

DISCUSSION

Mark Retention and Mortality

In this study, only short-term mark retention and mortality were assessed. Fish available for this study were hatchery grown and reared, and retention and mortality were assessed within the hatchery. During the 48-h holding period, marking did not result in any mortality in the experimental groups. Hatchery conditions did not mimic natural conditions sufficiently to warrant a long-term mark retention study. Field studies to assess mortality and retention under natural conditions would be useful to assess long-term retention of syringe injected acrylic paint and ink in juvenile chinook salmon.

Fay and Pardue (1985) used syringe injected latex to mark the mandibles of rainbow trout (*O. mykiss*) in both a hatchery situation and in a river situation. To assess mark retention under natural conditions they conducted creel surveys along the river where they had released marked fish. The movement portion of this study allowed similar inference. I recaptured marked fish in a river situation, and could assess how long some fish retained their mark. This does not, however, give accurate percent retentions under natural conditions. Holland-Bartels et al. (1989) used mesh net pens to assess mortality and retention of pressure applications of fluorescent pigment on centrarchids (Centrarchidae) and minnows (Cyprinidae) along the Mississippi River. This technique could be used on the Mokelumne River with juvenile chinook.

Thedinga and Johnson (1995) used a jet injection system to mark coho and sockeye salmon with Alcian blue dye, black india ink, and Liquitex brand acrylic paint in fluorescent yellow and orange. This study was conducted under laboratory conditions and noted that retention rates were greater when the paint entered the fin ray rather than strictly dermal tissue. I used black india ink and various colors of Liquitex acrylic paint following the methods of Thedinga and Johnson (1995). I chose to mark at the base of the fin rays based on retention rates being higher for fin rays rather than dermal tissue. With the syringe injection technique though, most if not all of the mark remained in the main body of the fish, and did not project into the fin rays. Thedinga and Johnson (1995) found that all marks were suitable for short-term marking (<6 weeks). In the fish I marked to assess downstream movement, marked fish were recovered up to 51 days after initial marking in 1997 and up to 67 days in 1998. One thing I noticed in the field is that as the fish grows, the marks tend to migrate away from the initial marking location, and so care must be taken in reading older marks. This type of short-term mark seems very useful in marking juvenile fall run chinook salmon, because of their short freshwater residency period. Several of the fish I marked in the Mokelumne River were recaptured in the Sacramento- San Joaquin Delta two months after marking.

Downstream Movement

In 1997 I got a 9% recovery rate of marked fish, and in 1998 I got a 5.4% recovery of marked fish. Fraley and Clancey (1988) obtained a recapture rate of 1.2% when monitoring downstream migration of over 65,000 stained kokanee fry in the Flathead River. The number of fish marked in the Mokelumne was much lower. In 1997 I marked 1,196 fish out of an estimated 459,010 that emigrated that year. In 1998 I marked 2,332 fish out of an estimated 1,848,539 emigrants. Although this marking technique had retentions that were appropriate for this study, future studies should focus on increasing initial sample size. Biosystems (1992b) had recovery rates as high as 23% during their pilot studies to determine movement of chinook salmon smolts through Lake Lodi, but this study was much more intensive over a shorter distance and duration than my study.

The movement portion of this study was conducted in conjunction with fish community surveys conducted by EBMUD staff and with data collected at WIDD by independent contractors. The effects of these factors on this study are twofold. 1) First, the primary effect is that sampling periodicity was not standardized so conclusions made about residence times cannot be tested statistically and are only observational. Mundie and Traber (1983) recaptured stained coho fry at 3-day intervals while tracking their movement. 2) Second, mark recognition at WIDD for this study was lower than could be expected. In 1997, 20 marked fish were recaptured at WIDD throughout the emigration period. In 1998, only two marked fish were recaptured, and these were before mid February. This could be due to the large emigration numbers or inadequate training of WIDD staff in mark recognition.

I found no significant difference in movement patterns between stable and fluctuating flows. Irvine (1986) investigated the effect of varying flow discharge on the downstream movement of chinook salmon in experimental channels, and found that varying discharge appeared to increase the number of fry moving downstream. In my study there was no significant difference in movement patterns with flow stability in 1997, and in 1998 mark groups were observed in the same location through as many as three flow changes. The Mokelumne River was operated under high water conditions in 1998. Even through multiple flow changes there may have still been sufficient rearing habitat due to unusually high flows caused by El Nino precipitation. Although 1997 and 1998 were both classified as normal and above average water years, they were very different flow years based on operations of Camanche Dam (Figure 3). In 1997 flows started out high initially and continued to drop all year. In 1998, flows started out low and contained two peaks during the emigration period. Flow fluctuations for 1998 were a combination of increases and decreases. In 1997, all fluctuations were decreases in flow.

Environmental Variables

Annual Emigration

Temperature, turbidity, and rainfall were not predictive of total emigration numbers based on the results of this study. Average flow and flow variability did not explain a significant amount of the variation in emigration numbers for the period of 1993 through 1998.

In contrast, both prior-year escapement numbers and number of redds in the river accounted for a significant amount of variability in total emigration numbers (R^2=0.67, and R^2=0.66, respectively). Escapement for the Mokelumne River from 1993 to 1998 peaked in 1997 at 10,163 adults and the number of redds also peaked during this same year at 1,312. Consequently emigration peaked at 1.8 million fish in 1998. It appears from these data that the Mokelumne River fall run chinook salmon population has not reached a level where egg losses due to redd superimposition has resulted in a reduction in number of emigrants, i.e., the river is able to support a run of at least 10,000 adult chinook without an apparent negative density-dependent response in egg/fry survival.

Daily Emigration

None of the daily environmental factors tested had a significant effect on the number of fish passing through Woodbridge Dam, as determined by regression analysis. In contrast, when daily environmental factors were regressed against average fork length of emigrants, the results varied from year to year. Rainfall was always insignificant, accounting for very little variation in size at emigration. In contrast, temperature was always a significant predictor with R^2 values ranging from 0.51 to 0.82. The fry portion of the emigrating population generally leaves before April, when temperatures are cooler. Also, temperature is a factor that contributes to fish growth, so the fish that stay in the river longer are subjected to warmer temperatures and have more time to grow.

When flow was analyzed as the independent variable, the results varied from year to year. In some years there was a highly positive relationship, e.g., 1993. In contrast, some years there was a highly negative relationship, such as 1997, and in some years, such as 1998, no relationship was apparent. Thus, the observed relationship is actually a byproduct of operations rather than a biological phenomenon. In 1993 (a dry to wet/normal year type), flow started low when fish were younger and naturally smaller and peaked later when fish were older and hence bigger. In 1997, an above average water year, the opposite was true. In January, river flow was 5000 cfs (141.6 m^3/s) and reduced to 300 cfs (8.49 m^3/s) by June. In 1998, another above average water year, flow was high all year (Figure 3).

When I first began to look at these data I was interested to see if there were certain flow levels that allowed fish to stay and rear longer and leave at a larger size and if extremely high flows might push out young fry while they were still small. That did not appear to be the case judging from these data.

The last factor tested, turbidity, was actually a measure of water clarity in secchi depth. This factor also had a variable relationship with average fork length of emigrants. Turbidity on the Mokelumne fluctuates throughout the year from rainfall and its associated runoff, pulses in releases from Camanche Reservoir, and can also be related to algal growth in Camanche Reservoir and Lake Lodi (VES 1996, NRS 1997). Because there was no general trend over the six-year period studied, turbidity was not a good predictor of size at emigration.

According to Healey (1991) the factors that determine whether fry hold and rear in the river, or move downstream to rear in the estuary are generally unknown. Factors that have been associated with downstream migration of chinook salmon include developmental stage of the fish, intraspecific interactions, interspecific interactions, rainfall, turbidity, high and variable flows, and genetic factors. Thomas et al. (1969) hypothesized that reduced swimming ability at time of yolk absorption was the cause of downstream migration. Thus, fry are displaced rather than actively moving downstream. Intraspecific interactions where dominant fish displaced subordinate fish have been observed in experimental tanks (Reimers 1968) and in natural populations (Lister and Walker 1966). Interspecific interactions in systems with both Chinook and Coho salmon (*O. kisutch*) have been observed (Stein et al 1972). Other factors that have been linked to downstream migration are rainfall (Mains and Smith 1964) and genetic factors (Taylor and Larkin 1986).

In the Sacramento San Joaquin delta it has been speculated that flow surges and high discharges have influenced the number of fish that migrate as fry. Kjelson et al.(1981) and Healey (1980) related high flows to downstream migration. Irvine (1986) investigated the downstream movement of salmon fry subjected to varying rates of discharge in experimental channels. He found that fluctuating flows appeared to increase the rate of downstream movement. Snider and Titus (1995) found that increases in turbidity coincided with early peaks in fry emigration on the American River in 1994, but found no association between flow and temperature with emigration for the same period. In my study of 6 years of emigration data and the corresponding environmental data, there was no overall trend observed to conclude that these environmental variables were important determinants of when the fish leave the river.

In recent studies, the CDFG has consistently observed that most fall-run chinook salmon in the Sacramento River system leave their natal stream area soon after emergence; that is, as fry and very young parr (Snider and Titus 1995, 1998; Snider et al. 1998; W.M. Snider and R.G. Titus, CDFG, unpublished data). This pattern has been observed historically (USFWS and CDFG 1953) and contemporaneously at several locations and under a variety of environmental conditions. Snider and Titus recognize the linkage between this behavior and use of the lowermost river and delta/estuary for rearing to the smolt stage as characteristic of the ocean-type chinook life history (R.G. Titus, pers. Comm.). More work needs to be done to determine where, when, and how young salmon use the lower system for rearing.

Water Year Types and Flow Variability

In the years included in this study for analysis, there were a number of water year types seen. The years 1993-1996 were classified by the LMRMP and these were 1993 as a dry to wet/normal year; 1994 as a wet to normal year; 1995 as a normal to wet year; and 1996 as a wet year. The water year type for 1997 was defined using the criteria in the POA as a normal/above average year. The water year type for 1998 was defined using the criteria in the JSA as a normal and above year. (Stein, R., EBMUD, pers. comm.)

Flow variability during the study period ranged from a coefficient of variation (%) of 25 in 1994 to 102 in 1997 (this figure was over 100 due to rounding error). Average flows for the years studied ranged from 279 cfs (7.9 m^3/s) in 1994 to 2459 cfs (69.6 m^3/s) in 1995. Even with these differences in flow variability, there appeared to be no significant correlation between emigration characteristics and flow variability or average flow rate.

Data Collection and Variability

There are a few caveats about the data used in these analyses. One is that monitoring of the 1993 emigration was significantly different than that carried out in the following years. In 1993, two sites were fished with one screw trap each (Elliott road at RM 53, and WIDD at RM39). In 1993, a fyke trap was used at the WIDD site in the fish ladder from 19 January to 31 March then a screw trap from 1 April to 29 July (VES 1994). In all other years two screw traps were operated at the WIDD site.

Another caveat is that monitoring start and end dates have been variable in the past 6 years. As noted in 1993, monitoring began on 19 January. In 1993/1994, the two screw traps were fished from 21 October 1993 to 20 June 1994 and a box trap was placed in the low stage fishway pool #9a, and an incline plane trap was installed in the high stage fishway pool #15 from 20 June to 31 July. This was due to the fact that flows had been reduced and most of the river flow passed the dam through the ladder. When flows are higher they spill over the boards of Woodbridge Dam (VES 1996). In 1995, two screw traps were operated from 25 January to 28 July at WIDD. In 1996, two screw traps were operated from 17 January to 25 July. In 1997 the two screw traps were operated from 3 February to 16 July. The incline plane trap and ladder traps were operated in 1997 in conjunction with the screw traps. In 1998 two screw traps were operating from 1 January to 31 July, and the incline plane and bypass traps were never installed due to high flow conditions (NRS unpublished data). The same variability exists for the redd survey data. For the years 1992/93 through 1995/96 spawning surveys were all begun on different weeks, but all began with zero counts of redds in the river which would imply that the true beginning of redd construction was encompassed by these surveys. In the 1996/97 season, however, 34 redds were found on the first day of sampling in various stages of construction in the river. The spawning surveys ended in zero counts of new redds, except in the 1996/97 and 1997/98 spawning seasons, surveys were ended earlier than previous surveys due to high flows which made it impossible to find new redds.

There was also some variability in the way the environmental data were collected. The EBMUD database for temperatures for Camanche Dam only goes back to 1994, so those data are not available for 1993.

Freshwater Rearing

Tidal influence on the Mokelumne is considered to be felt as far upstream as a gauge called "Frandy", in river mile 29. According to Dennis Haugan, EBMUD Hydrologist, this gauge was established by the USGS in 1926 and its maintenance was assumed by EBMUD in 1933. In a May 1991 elevation survey, shot with a level and a rod, the indication was that a 1-ft (0.3 m) gauge height would level approximately 0.75 mile (0.23 m) upstream of the gauge station and a 2-ft (0.6 m) gauge height would be 1.25 mile (2.0 m) upstream at the 30-mile mark. High tides are in the 2-3 ft (0.6-0.9 m) range which would put tidal influence upstream, at the 30-mile mark, not the Frandy gauge. Large emigrations of chinook salmon fry are common for the Mokelumne River, but the last monitoring site on the Mokelumne River, and for this study is at WIDD. Juvenile Chinook can utilize seven more miles below WIDD for rearing in freshwater, and it is unknown how many fish utilize this area and for how long this stretch of river is utilized. According to Snider and Titus (1995), salmon that remain in the natal stream for a long period of time after emergence are more likely to approach the smolt stage there before emigrating, but that salmon that did so represented a very small proportion of the emigrating population. Future studies of juvenile rearing and survival below WIDD will be helpful in determining where and for how long these fish are rearing in the lower river and Delta.

Flow regulation from Camanche Dam has potentially altered flow patterns, temperature regimes and the frequency of turbidity events. This study considered the effects of these elements, along with rainfall patterns, on the river residence and emigration of juvenile chinook salmon. Other factors may be attributable to timing of, and size at, emigration for juvenile chinook salmon and on residence times in specific reaches. These factors include habitat and food availability, length of egg incubation, timing of emergence, and interspecific and intraspecific fish interactions (Snider et al. 1998). These factors should be considered for future study.

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