EXECUTIVE SUMMARY

We fished a rotary-screw trap in the Stanislaus River near Oakdale, California, to index the migration timing and abundance of down-migrating juvenile chinook during large manipulations of river flow. Our index of down-migrant abundance was the catch of juvenile chinook divided by the proportion of the river flow that passed through the trap. This index indicated that down migration peaked for at least one day, but no more than four days, when the Stanislaus River flow increased from 400 cfs to 1,400 cfs, one week after the trap was installed on April 21. The daily abundance of down migrants dropped back to pre pulse-flow levels within a few days of the flow increase, even though flows were sustained above 1,500 cfs.

The pattern in daily outmigrant abundance before, during, and after the sustained pulse flow events suggests that the stimulatory effect of flow on migration had two characteristics: (1) it lasted only a few days, and (2) it affected only a small portion of the population. There was no indication that the sustained high flows "flushed" juvenile chinook out of the river. Juvenile chinook continued to migrate in good numbers through the end of May, although pulse flows began in late April. We present sampling data which show similar responses of juvenile chinook migration to flow in the Sacramento River, the Rogue River, the Yakima River, and the Snake River.

The slow increase in mean lengths of down-migrating chinook throughout the season, coupled with their large size compared to rearing fish captured by seining, indicated there was a size-related threshold for migration. Other studies have shown that this size threshold is associated with physiological readiness to enter seawater. We deduce that only those chinook which were physiologically ready to migrate at the time the pulse flow began were stimulated to migrate.

We conducted a snorkel survey in July to determine abundance and relative distribution of juvenile chinook, and predator species remaining in the river. The survey confirmed that some juvenile chinook remained in the upper portion of the river where water temperatures were below 65/F. Squawfish were the most abundant predator seen, and were seen in all but the upper-most section of the river. Squawfish were most abundant in the Knights Ferry area, and we estimated that more than 50% of the squawfish seen were adults (> 20 cm).

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INTRODUCTION

Recent declines in the abundance of fall-run chinook salmon in the San Joaquin Basin have spurred a variety of actions, which eventually lead to the development in 1992 of "An Action Plan for the San Joaquin Fall-run Chinook Salmon Populations". The Action Plan, to be administered through the San Joaquin River Management Program, recommends several flow related measures intended to aid recovery of the salmon population. These flow related measures will require increased use of water from storage reservoirs in the basin. Therefore, Tri-Dam Project, which operates three reservoirs in the Stanislaus River Basin, and the two irrigation districts to which it supplies water, Oakdale and South San Joaquin Irrigation Districts (Joint Districts), sought to take a more informed and active role in the fisheries planning process of the San Joaquin River Management Program.

In the fall of 1992, Tri-Dam Project and the Joint Districts retained S.P. Cramer & Associates, fisheries consultants, to review available information on chinook salmon in the Stanislaus River and advise them on what action should be taken. Upon reviewing numerous reports and interviewing area fish biologists from California Department of Fish and Game (CDFG), we (S.P. Cramer & Associates) found that existing data were insufficient to confidently estimate the fishery benefits that could be derived from flow enhancement, and in particular, from pulsed flows.

A study recently completed by the U.S. Fish and Wildlife Service (USFWS) evaluated the relationship between instream flow and physical habitat availability for chinook salmon in the Stanislaus River (Aceituno 1993). Based on Instream Flow Incremental Methodology (IFIM) applied to the Stanislaus River between Goodwin Dam and the town of Riverbank, the study determined for chinook salmon that 1) habitat for spawning is greatest at 300 cfs, 2) habitat for egg incubation is greatest at 150 cfs, 3) habitat for fry rearing is limited and does not increase or decrease appreciably with stream flow, and 4) habitat for juvenile salmon is highest at 200 cfs. The USFWS (Aceituno 1993) further determined that 156,000 acre-feet would have to be set aside for fishery flows to provide maximum habitat availability within the study area.

However, the USFWS report (Aceituno 1993) recommends the delivery of additional water over and above the optimum estimated by IFIM, and this additional water has been provided for in an interim agreement between the US Bureau of Reclamation (USBR) and the CDFG. The USFWS report suggests the increased flows were necessary to investigate flow needs for 1) spring outmigration of juveniles, 2) water temperature control, 3) attraction for adult chinook in the fall, and 4) water quality maintenance.

Pulse flows are currently recommended by CDFG due to the belief that these flows distribute fry and encourage smolt outmigration (CDFG 1992). There is a correlation between high returns of chinook to the Stanislaus River, and high flows during the year they were juveniles (Figure 1). Presently, many biologists are assuming, based on this correlation, that artificially created pulses in flow will substantially increase fish survival. Juvenile survival is believed to be improved by pulse flows due to reduced exposure to water diversion, reduced exposure to poor water quality, and reduced exposure to high temperatures.

Pulse flows were tested in 1988 and CDFG (1988) found that catches by seining in the upper river decreased, while catches in the trawl at Mossdale increased, when sampling was conducted after the pulse flows were completed. This is circumstantial evidence that the flows encouraged chinook to migrate out of the river. However, there was no control comparison to determine if the chinook would have migrated without the pulsed flow. A direct correlation of increases in natural chinook production to pulse flows has not been established.

Figure 1. Relationship of Stanislaus River fall-run chinook salmon escapements to mean daily flows from 1967 - 1988. From CDFG 1992.

There is strong evidence that juvenile chinook in the Stanislaus benefit from high flow years, but it has not been convincingly demonstrated that an artificial pulse in flow provides the same benefit as a natural high flow year. CDFG (1992) has shown that a rough correlation (r = 0.5) exists between the number of chinook returning to the Stanislaus River and the flow that those chinook experienced in the Stanislaus River during their year of juvenile rearing (Figure 1). Further, the USFWS (Kjelson 1992) has found a correlation of juvenile chinook survival in the lower San Joaquin River and flow at Stockton (Figure 2).

Figure 2. Relationship between juvenile chinook survival in the lower San Joaquin River and river flow at Stockton. From Kjelson 1992.

Recoveries of juvenile chinook marked with coded-wire tags (CWT) that were released into the Stanislaus River during 1986 and 1988 indicated that survival in the San Joaquin was similar between the two years (CDFG 1988), although flows at the time of peak outmigration in 1986 were 1,200 cfs compared to 900 cfs in 1988. Recoveries of CWT fish in both years indicated that there was roughly a 50% mortality between Knights Ferry and the lower Stanislaus River. Further, studies with CWT fish by the USFWS indicated that most mortality within the lower San Joaquin River was occurring between Stockton and the mouth of the Mokelumne River (Kjelson 1992). Thus, analysis by the fisheries agencies with the limited data that exist, do not demonstrate a relationship between flow and survival within the Stanislaus River, but do indicate that flow is related to survival in the San Joaquin River. It is possible that the rough correlation that exists between returns of chinook to the Stanislaus River and the flows they experienced as juveniles may reflect a flow effect on survival of the fish only during the portion of their migration through the Delta. This possibility is speculative and needs to be tested with further data on juvenile chinook survival in the Stanislaus River.

The following questions remain: 1) How high should the flow pulses be?, 2) How long should the pulses last?, and 3) are there limiting factors before or after the pulse that determine its benefit?

The purpose of the work reported here was to determine if the time and magnitude of juvenile chinook outmigration in the Stanislaus River was influenced by artificial pulses in flow during the spring of 1993. To accomplish this, we fished a rotary-screw trap in the river near Oakdale to monitor the daily abundance of down-migrant juvenile chinook in the river.

DESCRIPTION OF STUDY AREA

The headwaters of the Stanislaus River originate on the western slope of the Sierra Nevada Mountains. The Stanislaus River and its tributaries flow southwest, and the Stanislaus River enters the San Joaquin River on the floor of the Central Valley. The San Joaquin River flows north and joins the Sacramento River in the Sacramento-San Joaquin Delta. The Stanislaus River is dammed at several locations for the purpose of flood control, power generation, and water supply. Water uses include irrigation and municipal needs, as well as recreational activities and water quality control.

Goodwin Dam, at river mile (RM) 58 of the Stanislaus River, blocks the upstream migration of adult chinook. Almost all chinook spawning occurs upstream of the town of Riverbank (RM 34), and up to Goodwin Dam.

METHODS

MONITORING OF JUVENILE CHINOOK DOWN-MIGRATING

Capture Methods

We fished a rotary-screw trap in the mainstem of the Stanislaus River near the Oakdale Recreation Area, approximately 3 miles west of the town of Oakdale, California, for the purpose of capturing juvenile chinook as they migrate downstream (Figure 3). The trap site was chosen because it was the farthest downstream that we could find adequate water velocities to operate the trap. This site (RM 40) was downstream from the majority of chinook spawning and juvenile rearing.

The trap, manufactured by E.G. Solutions in Eugene, Oregon, consisted of a funnel shaped core suspended between two pontoons (Figure 4). The trap was positioned in the current so that water entered the 8 ft wide funnel mouth. Water entering the funnel struck the internal screw core causing the funnel to rotate. The rotating funnel trapped fish in pockets of water that were forced rearward into a livebox, where the fish could hold until retrieved. The trap was held in a static position in the main current by cables anchored on opposite river banks (Figure 5).

The trap fished at night from 8 p.m. to 8 a.m. during April 21 to June 29 and throughout the day during most of our sampling as well. We did not always operate the trap during daytime, in order to reduce the time needed to check and clean the trap. The high water velocity and debris load in the location we were fishing caused substantial wear on the trap. Juvenile chinook migrate downstream principally at night, and trap efficiency is greatest during darkness (Cramer 1992).

Figure 3. Map showing location of Stanislaus River.

Figure 4. Photographs of rotary screw trap.

The upper photo shows the trap being hoisted into position at the start of the study.
The lower photo shows the trap fishing near the Oakdale Recreation Area.

Figure 5. Photographs looking upstream from the rotary screw trap showing flow pattern entering the trap.

The trap fished from 4 to 7 nights per week. To stop the trap from fishing, we hoisted the funnel out of the water. At times of high flow, it was necessary to check the trap during the day to clear away debris that accumulated against the trap. Each morning we removed the contents of the livebox and counted, measured and recorded all fish captured (Figure 6). Juvenile chinook were then released back into the river unharmed. At times of low flow the trap could be reached by walking through knee deep water. At higher river flows a raft or boat was used to reach the trap.

Experimental Release Groups

Our original plan was to obtain fish from the Merced Hatchery to test the efficiency of the screw trap. Due to a shortage of fish, it was not possible. At the beginning of June, we began saving fish captured in the screw trap for mark-recapture tests. Because naturally spawned fish are difficult to rear for more than a few weeks, we were unable to accumulate enough fish to conduct multiple releases. We released two groups of marked fish the evening of June 13 to determine trapping efficiency.

CDFG provided us with a holding cage to keep the fish we captured from the screw trap. The cage contained three cells of about 1 m^3, made of perforated aluminum plating. The cage was placed in the river near the trap, where the fish were held and fed daily.

Juvenile chinook were marked with fin clips. The top and bottom caudal fins were clipped with sharp finger-nail clippers, and only the very tip of the fin was cut to ensure that the swimming ability of the fish was not impaired. Before marking, fish were anesthetized with Finquel (Sigma Chemical Company, St. Louis, Missouri). After marking, fish were retained in the holding cage for 24 hrs before release, to allow the fish time to recover from the stress of being marked.

Figure 6. Photographs of juvenile chinook captured in the rotary screw trap.
The upper photo shows juvenile chinook after they were scooped from the livebox.
The lower photo is of anesthetized chinook. Fish were anesthetized to facilitate measuring.

The fish were transported in 20 gallon insulated coolers from the live cage to the release site, approximately 450m upstream from the trap. The release site was upstream and around a riverbend from two areas of river constriction, which we assume caused fish to mix in the water column in a manner representative of naturally migrating fish. The coolers containing marked fish were immersed in the river near the bank, and the fish were allowed to swim away at their own will. The two groups were released about 5 minutes apart, beginning about 8 p.m.

FLOW MEASUREMENT

Daily flow of the Stanislaus River was obtained from the California Data Exchange Center (CDEC). All river flows cited throughout this report are those measured at the Orange Blossom Bridge (RM 48.8), approximately 8 miles upstream from where the trap was fishing. We also monitored water velocity flowing into our trap with a Global Flow Probe, manufactured by Global Water (Fair Oaks, CA). Water velocity at the trap mouth was recorded each time the trap was monitored.

SNORKEL SURVEY

We conducted a snorkel survey on July 7 and 8, near the end of our juvenile down migrant trapping period, to determine if juvenile chinook still remained in the river above the trap site, and determine their relative distribution. We also wanted to obtain information on predator species composition, abundance and distribution throughout the Stanislaus River.

We snorkeled at 5 sites over two consecutive days. The farthest upstream location we snorkeled was near Tullock Road (RM 57) on July 7. We sampled this area to familiarize the crew with the methods we would use the following day, when we would snorkel 4 sites considerable distances apart.

On June 8, we snorkeled 4 sites, beginning at 1030 hrs at RM 22. We selected sites at evenly spaced intervals between RM 22 and 54, to determine relative distribution of both juvenile chinook, and predator species. Two snorkelers counted and recorded fish at each survey site by drifting downstream. The snorkelers were responsible for counting fish on opposite sides of the river. We classified salmon and trout as "0" and "1+". Fish smaller than 6 in. were classified as age "0", and fish over 6 in. were classified as "1+". Survey distance varied at each site depending on time constraints and site characteristics.

RESULTS

STANISLAUS RIVER FLOW AND TEMPERATURE

Daily flow in the Stanislaus River during 1993 was highest in late January at 2,850 cfs, about three months before we began monitoring juvenile chinook outmigration (Figure 7). During our sampling period the river flow ranged from 243 cfs on June 13 to 1,620 cfs on May 22. Pulse flows of about 1,500 cfs, intended to benefit fish, were released during April 27 - May 13 and May 21 - June 2. Between these two pulses, flow was ramped down to 455 cfs on May 18, and then back to over 1,500 cfs by May 21. Temperature of the Stanislaus River at Oakdale dropped about 5° F coincident with the pulse flows, and quickly increased 5° - 6° F during the short drop in flow between pulses (Figure 7). The range of mean daily temperatures in the river jumped about 10° F in early June when flows dropped from the 1,500 cfs pulse down to 200 cfs by June 11 (Figure 7).

Figure 7. Daily flow and temperature of the Stanislaus River at Orange Blossom Bridge (RM 48.8) near Oakdale.

JUVENILE CHINOOK OUTMIGRATION TIMING

We installed the rotary screw trap April 21, and began retrieving catches the morning of April 22. Monitoring continued until the trap was removed on June 29. Daily catches of juvenile chinook ranged from 0 to 52. All fish were captured at night. We periodically fished the trap through the daytime, but caught no chinook during daylight during about 15 days of fishing. Overnight catches were highest during the five days following installation of the trap, when the Stanislaus River flow was increasing from 400 cfs to almost 1,500 cfs (Figure 8).

Figure 8. Daily catch of juvenile chinook in the rotary screw trap and Stanislaus River flow.

Size of Outmigrants

The mean lengths of chinook captured in the screw trap increased slowly from about 85 mm in late April to about 100 mm in early June and then declined to about 90 mm in mid June (Figure 9). Individual lengths measured daily ranged over 25 to 50 mm.

Figure 9. Daily mean and range of lengths of chinook captured in the rotary screw trap.

Trap Efficiency

The screw trap captured an average 23% of two marked groups (22% and 31%) of chinook released upstream on June 13 (Table 1). The trap was monitored hourly beginning one hour after the fish were released, from 9 p.m. to midnight. The trap was again monitored hourly from 5 a.m. to 8 a.m. on June 14. River flow and water velocity at the trap entrance remained relatively constant over the release period (Figure 10). The capture of marked fish peaked within two hours of the time released, and no marked fish were captured later than four hours after release (Figure 11). Catch of naturally migrating fish continued through the night.

Outmigration Index

Our trapping efficiency varied as flow varied, so we converted our raw trap catches to an index of total outmigrants by dividing the catch by the proportion of flow entering the trap. The volume of flow entering the screw trap during the release period varied from 31 to 39% of the total river volume, and averaged 35%. Thus, we captured fish almost in proportion to the volume of flow sampled. Therefore, we assumed, that our trapping efficiency for capturing juvenile chinook was approximated by the proportion of river flow that entered our trap. When river flow decreases, our trap samples a larger proportion of the river, and as a result catches a larger percentage of the fish that migrate past it. The outmigrant index we calculated should not be used as an accurate estimate of chinook abundance, but rather as an index for comparing the relative abundance of outmigrants between days.

Table 1. Mark-recapture data for June 13 trap efficiency test. TC = top caudal clip and BC = bottom caudal clip.

Mark	# Released	# Recaptured	% Recaptured	Mean Length (mm) Released	Mean Length (mm) Recaptured
TC	69	15	21.7	96.4	94.7
BC	13	4	30.8	94.9	94.5
Total	82	19	23.2		

Figure 10. Hourly Stanislaus River flow, and water velocity at trap entrance during the June 13 mark-recapture test.

Figure 11. Time of capture of natural migrating and marked chinook during the June 13 mark-recapture test. Catches at 0500 represented fish entering the trap since 2400.

The spike in abundance of outmigrants lasted only one day that we sampled, April 27, and may have lasted at most four days (we were not sampling on April 26, 28 and 29) (Table 2). After April 27, the abundance of outmigrants dropped back to the level that existed before the flow began increasing (Figure 12). Outmigrant abundance increased again for a few days to about half of that during the initial spike during mid May and again in late May (Figure 12).

Outmigrant abundance dropped to low levels in early June and remained so until the conclusion of sampling in late June.

Table 2. Daily screw trap data, Stanislaus River flow, and expanded chinook outmigrant index. The outmigrant index is the trap catch divided by the proportion of the flow sampled.

Figure 12. Daily chinook outmigration index and Stanislaus River flow. The outmigrant index is the trap catch divided by the proportion of the flow sampled.

SNORKEL SURVEY

On June 8, we snorkeled 4 sites ranging from RM 22 to RM 54. On June 7, we snorkeled one site at RM 57. Some juvenile chinook were still present in the river at the time of the survey (Table 3). We saw more juvenile chinook at Knights Ferry than any other survey site. Squawfish were the most abundant predator seen, and were present in all but the upper-most section of the river. We estimated that over 50% of the squawfish we counted were adults. This is a higher percentage of adults than we witnessed on previous snorkel surveys in the Yuba and Sacramento rivers. We saw relatively few predators of other species throughout the river. Rainbow trout were abundant in the upper reach of the river (RM 57) but this is above most chinook spawning.

Table 3. The species, abundance and distribution of fish seen snorkeling on July 7 and 8, 1993.

DISCUSSION

PULSE FLOW EFFECTS

The only change in daily outmigrant index that stood out as an obvious consequence of the pulse flows in 1993 was the spike in outmigrant abundance on April 27 as flows first increased. Following that spike in outmigration, the abundance of outmigrants dropped back to nominal levels for over one week (see Figure 12). Studies on streams elsewhere on the West Coast have demonstrated that outmigration of juvenile chinook is stimulated temporarily by increases in flow, not simply by the magnitude of flow. We cite here examples from the Sacramento River, the Yakima River in Washington, the Rogue River in Oregon, and the Snake River in Idaho.

The outmigration of juvenile chinook from the upper Sacramento River has been indexed by catches in rotary screw traps at several locations in recent years. Catches in these traps during 1993 and 1994 show effects of increases in flow at various times of year. In 1993, Cramer et al. (1993) fished a rotary screw trap in the Sacramento River near Wilkins Slough from late April through mid July, and observed substantial peaks in outmigration during late April and again in the first week in June. The peak outmigration in late April was composed predominantly of hatchery fish that had just been released from Coleman Hatchery, but the peak on June 1 and 2, which was atypical for the Sacramento River, coincided with an unseasonal flow event (Figure 13). The sharp increase in flow in June clearly stimulated some fish to migrate for about two days, although flows remained elevated for over two weeks. During 1994, CDFG fished a rotary-screw trap in the Sacramento River near Hamilton City through the winter, spring and summer. Spikes in catch of juvenile chinook show a close correspondence with spikes in flow (Figure 14). The largest spike in catch during late April was not stimulated by a flow increase, but corresponds to the passage of 12 million juvenile chinook released from Coleman Hatchery on April 14. As was true for the Stanislaus River, events of increasing flow stimulated migration for only a few days, and many fish remained upstream to migrate at a later date. However, these examples from the Sacramento River in 1994 do not provide an opportunity to see the effects of a sustained high flow.

Figure 13. Daily catches in a rotary-screw trap fished in the Sacramento River near Wilkins Slough in 1993. Catch data from Cramer et al (1993). Flow data from USGS gauge at Wilkins Slough.

Figure 14. Daily catches in a rotary-screw trap fished in the Sacramento River near Hamilton City in 1994. Catch data from personal communication, Paul Ward, CDFG, Redding. Flow data from the USGS gauge at Vina.

The outmigration of juvenile chinook was studied extensively in the Yakima River for nine years, 1982 through 1990, and in the final report of that study (Fast et al. 1991), the following conclusions were offered:

> *"Flow-induced stimulation of passage is especially pronounced when it occurs on the heels of a number of days of declining flows. Interestingly, the peak of the migratory response to increased flows usually occurs before the discharge peak."*

> *"Inspection of daily passage and flow data has revealed that consecutive days of declining, or even stable, flows are usually associated with declining outmigration rates. It should be noted that descending flows stall passage, even when absolute discharge during the decline remains relatively high. During such periods, smolts accumulate somewhere between Sunnyside and Prosser dams, and are subject to longer periods of vulnerability to predators."*

> *"Stalled migrations are stimulated by rapid increases in flow. The increase need not be especially large, but should be abrupt; gradual increases do not evoke a sharp response in passage. An analysis of natural flow pulses gauged below Sunnyside Dam indicates the "minimal stimulated pulse" should be about 20% of the pre-pulse "base flow," and that the pulse should occur over no more that two days."*

Similarly, studies in the Rogue River, where the peak outmigration of juvenile chinook is typically during mid summer, showed that a sharp increase in flow during the period of juvenile outmigration, stimulated a sharp, but short-lived, increase in the number of outmigrant chinook (Cramer et al. 1985). Cramer et al. (1985) found that a unique event during the 10 year study occurred in 1976 when a record setting freshet caused a sharp increase in flow during early August (Figure 15). Immediately following the increase in flows, the number of outmigrants passing Savage Rapids Dam (RM 173) increased dramatically (Figure 16). However, the peak in outmigration lasted less than one week (outmigration for the season was only about 50% complete), while the river flows remained at double the summer base flow for more than three weeks (Figures 15 and 16). Cramer et al. (1985) did not observe similar spikes in outmigration (or flow during the summer) during any other year of the study.

Figure 15. Average weekly flow in the Rogue River at Grants Pass (km 166) during the summers of 1975 and 1976. USGS data.

Figure 16. Weekly catch/trap hour of juvenile chinook salmon at Savage Rapids in 1974, 1975, and 1976. From Cramer and Martin (1978).

Perhaps the most directly applicable example of pulsed flow effects on subyearling chinook migration comes from the Snake River during 1994. There, a dramatic pulse of high flow was mandated to last most of July (Figure 17) in order to benefit outmigration of the endangered Snake River fall chinook. A spike in outmigration of juvenile chinook, lasting about three days, immediately followed the sharp increase in flow, but the abundance of outmigrants dropped back to nominal levels for the last half of July, while flows remained high (Figure 17). Shortly after flows dropped in early August, a small increase in flow was associated with another pulse of outmigrants that lasted several days. Thus, even the radical high flow measures implemented in the Snake River during 1994 did not flush juvenile chinook from the river, and the migration stimulus was effective for only a few days.

Figure 17. Timing of subyearling chinook passage at Lower Granite Dam on the Snake River during 1994, compared to river flow. Data from Fish Passage Center, Columbia Basin Agencies and Tribes, Portland, Oregon.

OUTMIGRATION TIMING

The pattern in daily outmigrant abundance before, during, and after the sustained pulse flow events suggests that the stimulatory effect of flow on migration had two characteristics: (1) it lasted only a few days, and (2) it affected only a small portion of the population. The fact that juvenile chinook continued to outmigrate in good numbers through the end of May indicates that juvenile chinook were not "flushed" out of the river by the pulse flows that began in late April. The annual seining efforts by CDFG at standard stations in the Stanislaus indicate that the abundance of juvenile chinook generally peaks in March and April (CDFG 1991). Catches by CDFG during biweekly seining in 1993 at seven sites in the Stanislaus River showed that catches on April 23 (prior to the first flow pulse) had already declined from catches in March and early April (Figure 18). Catches during standardized trawling by CDFG in the San Joaquin estuary at Mossdale during 1987-1992 indicate that few chinook typically outmigrate after mid May (Figure 19). Thus, the true 1993 peak in outmigration may have occurred before our sampling began, and the protracted outmigration through May indicates that many chinook were not stimulated to migrate by the sustained high flows.

The protraction of outmigration through May, considered in the light of data on the effects of seasonal high flows on outmigration timing in other rivers, suggests that sustained high flows may have caused juvenile chinook to remain longer in the Stanislaus River than usual. It has been well documented that juvenile chinook outmigrating as subyearlings tend to rear longer in freshwater in years of higher streamflow. Jones & Stokes Associates, Inc. (1992) found that the date of 50% outmigration of juvenile chinook from the Yuba River was highly correlated ($R^2 = 0.80$) to the mean river flow during April and May over an 11 year period. In the Yuba River, the date of 50% outmigration averaged one month later (about June

1) in years of high flow than in years of low flow (about May 1). Similarly, Cramer et al (1985) found with 10 years of data that the percentage of subyearling chinook outmigrating from the upper Rogue River by July 31 was highly correlated ($R^2 = 0.91$) to river temperature during April-May; fewer fish outmigrated by July 31 in years of lower temperature. Lower temperatures were correlated with higher flows.

Figure 18. Number of chinook captured seining in the Stanislaus River during 1993 by CDFG. The number of stations sampled varied some between dates. Data are

presented in Appendix 1. Data from personal communication, John Kleinfelter, CDFG, Fresno.

Figure 19. Mean daily catch of subyearling chinook per 10 minute tow of the Kodiak trawl at Mossdale, in the San Joaquin River estuary 1987-1991 (from CDFG 1992).

The limited distribution of juvenile chinook that we found in the Stanislaus River during snorkel surveys in July was probably a response to water temperatures. Water temperatures were sufficiently cool to provide suitable rearing conditions in the Knights Ferry area (<65° F) and above, but fish rearing downstream of there may have been stimulated to migrate out of the river in response to increasing water temperatures. Water temperatures near Oakdale (RM 48.8) averaged 65-70°F daily throughout June (see Figure 7). Findings from the temperature model for the Stanislaus River recently completed by the USBR indicate that river temperatures at Riverbank and downstream will rise to 65°F and higher by mid to late May under most flow conditions (Rowell 1993).

The presence of juvenile chinook during our snorkel survey, combined with continued trap catches through June, confirmed that at least some fish remained in the river after the pulsed flows. Some juveniles may remain through the summer in the upper portion of the Stanislaus River, and migrate out in fall or winter as yearlings. This is consistent with previous snorkel observations by CDFG (1988).

CHINOOK READINESS TO MIGRATE

The relatively slow change in the mean lengths of chinook we captured is consistent with the widely observed phenomena that juvenile chinook are stimulated to migrate as they reach a threshold size (see Figure 9). Smolting generally occurs when juvenile chinook are 80 to 100 mm long. The outmigration of fish when they reach this size range continuously removes the largest fish in the population and causes the mean length of the population to increase slower than the actual growth rate.

This was illustrated in our sampling data during 1993 in that mean lengths of juvenile chinook captured by CDFG during seining surveys (Figure 20) (these would represent rearing fish) were at the lowest range of fish sizes captured in the screw trap on similar dates (see Figure 9).

Figure 20. Mean lengths of fish seined by CDFG during 1993. Data from personal communication, John Kleinfelter, CDFG, Fresno.

These findings indicate that the response of juvenile chinook to pulses in flow is modulated by their own physiological readiness to migrate. The physiological process of smolting in juvenile chinook peaks at a consistent time of year for the population as a whole, but there can be several months of variation between individuals in the time that they reach physiological readiness to migrate. We conclude that individual fish which are physiologically ready to migrate will respond to the stimulus of a sharp increase in flow, while the remainder of the population will not. This being the case, periodic pulses in flow, perhaps two weeks apart, which allowed time between flow pulses for additional fish to reach physiological readiness to migrate, should be more effective at stimulating outmigration than a constant high flow. However, it remains to be determined what level of increased survival of smolts would be achieved by such a scenario.

MIGRATION RATE

Data we obtained in 1993 does not enable estimation of migration rates, but it has been asked, "Once fish have been stimulated by a change in flow to migrate, how long will they take to migrate through the Delta?" Data assembled by the US Fish and Wildlife Service (USFWS) on recoveries of marked chinook provide some insight to this question. The USFWS (1992) reports, *"Migration time to Chipps Island of CWT fish released into the San Joaquin River at Dos Reis Park was longer in the dry years of 1985, 1987, 1989, and 1990 (about 8 to 13 days) than it was in 1986 (about 4 days) when inflows were high (7000 cfs at Vernalis)."* This conclusion is tenuous, because it is based on data from only one year of high flow. In contrast, USFWS (1987) reports the following from mark-recapture studies in the Sacramento Delta, "*We found no relationship between smolt migration rate and the* *magnitude of flow in either the Sacramento Delta or the Bay. Even during the spring of 1982 and 1983 when river flows were very high, migration rates remained similar to that of the other dryer years."* They further conclude, *"fall-run smolts pass through the entire Delta and Bay in about two weeks."* It appears from the USFWS data that chinook will require one to two weeks to move through the San Joaquin Delta and Bay if the fish have not been stimulated by high flows to migrate, and they may require as little as 4 days when they have been stimulated by high flows to migrate. These conclusions are highly tenuous, because the tests were not completed with fish that initiated migration in response to a rapid change in flow.

POTENTIAL PREDATION BY SQUAWFISH

The reason for the high concentration of squawfish in the Knights Ferry survey area is unknown. Releases of chinook in the Stanislaus River that were marked with CWT's in 1986 and 1988 indicated that roughly half of the smolts died between Knights Ferry and the mouth of the river (CDFG 1992). Predation by the abundant squawfish may have been an important factor in this mortality.

CONCLUSIONS

1. The rapid increase in flow from 399 cfs to almost 1,400 cfs during April 24 to April 27 stimulated the outmigration of some juvenile chinook for at least one day, but no more than four days. Sampling of outmigrating chinook in other streams also indicates that

the migratory stimulus provided by an increase in flow generally lasts no more than a few days.

2. Sustained flows of 1,500 cfs did not "flush" juvenile chinook from the river and many remained in the river through May. Sampling of outmigrating chinook in other streams also indicates that an increase in flow only stimulates a portion of the population to migrate.

3. The mean lengths of outmigrating chinook increased slowly during April through early June, and we believe this indicates that juveniles migrate out of the river when they reach a size-related physiological threshold for smolting.

4. Most juvenile chinook had emigrated from the Stanislaus River by mid June, but some juvenile chinook remained in the river above Knights Ferry in July, and probably rear there through summer.

5. Adult squawfish that may prey on juvenile chinook were abundant in the Stanislaus River in early July, particularly in the vicinity of Knights Ferry.

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APPENDICES

Appendix 1. Number and mean lengths of chinook seined by CDFG in the Stanislaus River during 1993.

Appendix 2. Fish species captured in the rotary screw trap sampling in the Stanislaus River near Oakdale, from April 22 through June 29,1993.

Appendix 3. Species and number of fish captured in the rotary screw trap during 1993.

Appendix 4. River flow, water velocity at trap mouth and percent of flow sampled during mark-recapture test.

Appendix 5. Individual lengths and time of capture for marked and natural fish captured on June 13-14, during the mark-recapture sampling.