PART II. PROGRAM DESCRIPTION AND RESULTS

FALL-RUN ADULT KING SALMON ENUMERATION

For 15 years prior to completion of the Oroville Dam Project the number of king salmon that spawned in the Feather River was estimated by carcass recovery. Our contract states that the number of spawning salmon will be estimated each year of our study in essentially the same manner (Appendix I, Figure 2). At the end of the study these population estimates will then serve as a primary index of satisfactory maintenance of the salmon run.

Methods

The carcass recovery method or technique (Creamer Count) was used every fall to estimate salmon abundance from approximately the second week in October to early December. Each survey consisted of eight or more trips down the river (Table 1). Each trip included that reach of the river from the Fish Barrier Dam near Oroville to Honcut Creek, some 21 miles. On these trips the salmon carcasses were enumerated (cut-in-two), sexed, examined for marks, and an estimate made of degree of successful spawning. In addition, water clarity, flow, and weather conditions were recorded so that a correction might be made for the number of salmon missed during the trip.

The river was divided into three sections or statistical areas (Plates 1-5). Normally each section would take one or two days to complete a trip. The uppermost section, or low flow reach of the river, extends seven miles from the Fish Barrier Dam at Oroville to the Thermalito Afterbay River Outlet. The middle section extends from the Afterbay Outlet to the highway bridge crossing the river near Gridley. Finally, the lower section covers a distance of six miles from the Gridley Bridge to the mouth of Honcut Creek.

A season population estimate consists of solving a ratio equation where known and unknown parameters from the year in question are compared to known statistics from the previous year. Thus:

$$\frac{\text{Unknown population } (P_1)}{\text{Previous year population } (P_2)} = \frac{\text{No. present year carcasses } (C_1)}{\text{No. previous year carcasses } (C_2)}$$

Correction factors are applied to the simple equation above for:

a. Differences in number of trips (T_n).

b. Changes in recovery conditions, e.g., water clarity, flow, etc. (R_n).

The final equation is:

$$\frac{P_1}{P_2} = \frac{C_1}{C_2 \left(\frac{T_1}{T_2}\right)\left(\frac{R_1}{R_2}\right)}$$

$$P_1 = \frac{P_2 C_1}{C_2 \left(\frac{T_1}{T_2}\right)\left(\frac{R_1}{R_2}\right)}$$

Results

Population levels estimated from carcass recovery surveys ranged from 18,144 fish in 1968 to 73,577 fish in 1973 (Table 1). To obtain these estimates we cut between 3,000 and 16,000 carcasses, usually between 20 and 35 percent of the total run for that year.

It is significant to note that over two-thirds of the carcasses recovered each year came from the upper river area. This reach of the river is a low flow area and always had a constant flow near 400 cfs throughout each spawning season (Table 2). Carcasses here were easy to find and not likely to be swept out of the area. In contrast, the middle and lower river sections had between 2,000 and 7,500 cfs flow each year. Recovery conditions were more difficult in the latter areas.

If the distribution of spawning salmon in the river is expressed as fractions of the total fish population, then about one-third of the run spawns in the upper area, approximately one-half use the middle section, less than one-tenth of the run utilized the lower area, and less than one-tenth enter the hatchery (Table 3). These fractions are reasonable for all but the lowest population levels (1968, Tables 1 and 3).

Comparison of Pre and Post King Salmon Populations

The mean king salmon population level during the seven years of our study was 53,600 fish. This compares favorably with the 15 year pre-Oroville Project mean population level of 39,100 fish (Table 4). These means are not significantly different, t = 1.33 ($t_{.05}$ = 2.09 with 20 d.f.).

The above comparison was made without reducing the yearly post-project fish totals by the hatchery count, or by the number of salmon contributed to the river by hatchery operations. When the hatchery counts for each year are removed from the river totals, the mean fish count for the seven year period after dam completion drops to 48,700 fish, even closer to the 39,100 fish 15 year pre-dam mean (Table 4). By inspection, no significance is assigned here since the first "t" test made above was so obviously nonsignificant.

To evaluate the hatchery contribution to the river is the next logical step. Unfortunately we do not know the inverse, what the river contribution is to the hatchery. In 1968, of course, all the hatchery count were "river fish". From 1969-1972 increasing numbers of returning hatchery releases made up greater proportions of the hatchery total count. From 1972 on we must assume that all fish that enter the hatchery are of hatchery origin. Accepting these assumptions, then the hatchery contribution to the river can be estimated by comparing ratios of marked and unmarked salmon from hatchery marking experiments to counterparts sampled and calculated present in the river. These data suggest that the hatchery contribution to the river will be about 160.0 percent of the total hatchery fish count (Tables 5 and 6). When these contributions, as well as the hatchery count itself, are removed from the total river salmon count each year, the seven year mean salmon population level becomes 44,300 fish (Table 4). Again, by inspection, no significant difference is assigned between pre- and post-dam population levels.

Evaluation of Carcass Recovery Estimates of King Salmon Abundance

We examined the early salmon population estimates to find possible effects of flow on salmon. We found that on those years when there were high population estimates there were low flows (Figure 1). Conversely, we found low fish population estimates whenever there were extraordinary high flows. However, there was no significant statistical correlation between flow and the number of salmon that spawned that same year ($r = 0.321$, Figure 2). Despite the lack of statistical evidence, we could not accept as a coincidence the almost mirror image relationship of the extreme high and low fish population estimates, and extreme low and high water flows. Our conclusion was that under some conditions a carcass recovery estimate might be suspect.

Since the population level estimate is so important, not only as an index of satisfactory maintenance of the salmon run, but also as the guide or tool used to determine the size of mitigation facilities, we felt that the validity of the carcass recovery estimate should be tested.

We then developed several ways to examine the carcass recovery technique:

a. In 1968, we tried to estimate the population from a mark and recapture study. We marked live salmon, released them, and recovered these marks during the carcass recovery survey.

b. In 1969 and 1970 we calculated the population levels from mark and recapture data from release of marked carcasses.

c. Finally, we installed an electronic fish counter in the low flow reach of the river to obtain an accurate fish count to compare with carcass recovery estimates.

Population Estimates Using Mark and Recovery Techniques with Marked Live Salmon

In 1968 we constructed a trap in the Feather River approximately one mile above the mouth of Honcut Creek. About 90 percent of the river was blocked off with wire mesh fencing and stop nets. This weir led to a "pot" that held salmon until they were examined to sex, measured, and dorsal fin clipped. The salmon were then released with the hope that these marked fish would be recovered during subsequent carcass recovery surveys.

We marked and released 409 salmon. The carcass survey team examined almost 3,500 carcass and reported only 14 of our marked fish among them (Table 7). This is a remarkably small return, especially when it is compared to the four marked returns out of 179 carcasses taken off our own weir.

Using the same computing formula as is used for carcass recovery, an estimate of 100,000 fish is obtained with the carcass recovery team data (absurd!) and an estimate of 17,500 fish from the weir caught carcass data. The carcass survey estimate for the river was 18,144 fish (Table 1).

For whatever reason the carcass survey crew did not find our marked salmon, we abandoned the technique of tagging or marking live fish in future population studies on the Feather River.

Population Estimates Using Mark and Recovery Techniques with Marked Carcasses

We made population estimates from marked and unmarked carcass recoveries in all three sections of the river in 1969 and 1970. In addition we conducted a mark and recovery program one more year in the low flow reach of the river in 1971.

These studies were conducted concurrent with the regular carcass recovery effort. Each of these years we marked carcasses that were considered in good condition, that is, were fresh dead fish. Every effort was made to release tagged fish in moving water so that they could drift downstream. Tags were put on the fish in the form of a hog ring attached around the lower jaw. A bright streamer (surveyors' tape) approximately four inches long was tied to the hog ring. Each week a different color streamer material was used, thus in succeeding weeks we could determine how old or how many weeks the marks had been out.

In 1971, in the upper reach of the river, we also recorded on the streamer the riffle upon which the carcass was released. Upon recovery, then, we could determine how far the carcass had drifted downstream.

Population Estimates

The population estimates were made using standard formula $N = \frac{nt}{s}$, where:

N = the population estimate for the year in question.

n = the number of carcasses found during the recovery period.

t = the number of tagged carcasses released.

s = the number of tagged fish recovered.

The population estimates for section one of the river were 19,850 fish in 1969, 17,925 fish in 1970, and 21,069 fish in 1971 (Table 8).

Estimates of numbers of king salmon in sections two and three, combined together here for later comparison with the carcass recovery estimates are 40,226 fish in 1969 and 42,313 fish in 1970 (Table 9).

Recovery Rates of Marked Fish

While the percent recovery of marked carcasses within the several river sections was remarkably constant from year to year, the differences between river sections was very large. In river section one we recovered 59.7 percent of the carcasses released in 1969, 62.3 percent in 1970, and 57.1 percent in 1971 (Table 10). In the two high flow river sections the data was combined, and again the results between the two years were very consistent. In 1969, 14 percent and in 1970, 14.7 percent of the marked fish were recovered (Table 10).

The differences between the high flow and low flow areas was expected. Carcasses were easier to find and collect in the low flow area than they were in the high flow areas.

The consistency of the recovery rates within areas, however, demonstrates that the carcass recovery method is predictable, i.e., that the method will duplicate recovery rates when year to year recovery conditions are similar.

Carcass Recovery vs. Time

The summaries of release and recovery of marked carcasses in section one are listed in Tables 11, 12, and 13 for 1969, 1970, and 1971. The summary data for river sections two and three are listed in Table 14 for 1969 and Table 15 for 1970.

Virtually all marked fish recoveries occurred within two weeks after tagging. For river section one in 1969, 93.3 percent of our carcasses were recovered by the second week after release (Table 16). In 1970, 92.5 percent of recoveries were made through week two (Table 17). In 1971, 94.8 percent of recoveries were made through week two (Table 18).

In like fashion in the high-flow sections of the river, both in 1969 and 1970, between 91 and 95 percent of our recoveries of marked fish were by the second week after carcass release (Tables 19 and 20).

Although over 90 percent of our recoveries occurred by the second week in all river areas, the percentage of fish taken the first week differed greatly between the low and high flow sections. In the low flow area approximately 60 percent of the fish were taken the first week and 30 percent the second week

(Tables 16, 17, and 18). In the high flow areas, however, only 15 percent of the fish were recovered in week one and 75 to 80 percent of the recoveries were made during the second week (Tables 19 and 20).

The possible reasons for such differences in recoveries might be:

1. Section one has more shallows and fish were easier to find there. Many fish are taken in water three to five feet deep in this low flow area, few fish are found in such water in the high flow areas.
2. Fish may be swept out of the high flow areas while they are kept locally in the low flow reach. (More will be said about this later.)

What happened to the 40 percent of the marked fish we did not find in the low flow section, or the 85 percent of the marked carcasses we did not find in sections two and three? Perhaps these fish did not float but sank to the bottom of deep pools. Decay? We did not find instances of lost streamers, i.e., where we found hog rings in jaws of fish minus streamers. Neither did we find evidence of predators removing great numbers of carcasses from the river.

Carcass Drift

In 1971 we marked carcasses only in the upper river section, or low flow area. Besides changing tag color each week we wrote on the tag the riffle where the carcass was released. (A riffle area is defined as the entire river reach from the beginning of a fast water riffle, through the pool below, downstream to the beginning of the next fast water riffle.) Recovery of tagged fish enabled us to estimate how far each carcass traveled after tagging.

We found that 75 percent of our recoveries occurred on the riffle area where the fish were tagged (Table 21). Only 15 percent of the carcasses moved downstream a distance of one riffle.

Sex of the carcass had no effect on carcass drift. Of the female carcasses recovered, 75 percent were taken at the release riffle (Table 22). Likewise, 72 percent of the males recovered were taken on the riffle where they were tagged (Table 23). Finally, of the immature male salmon, 76.1 percent of the recoveries were from the release riffle (Table 24).

We did not expect that the sex of the carcass would affect drift distance. However, it was surprising that there was a difference in total recovery rates between sexes. That is, 67.1 percent of the females, 49.5 percent of the males, and only 29.2 percent of the immature males marked were recovered after tagging (Table 25)! Yet, 75 percent of these recovered fish, females, males and jacks alike, were taken in the riffle area where they were tagged. These data suggest that carcass recovery methods severely underestimate the number of jacks in the run.

King Salmon Population Estimates With Electronic Fish Counter:

For three spawning seasons, 1969-70-71, we installed an electronic fish counting system across the upper river area. A weir, made up of 4-foot-high by 10-foot-long wood framed wire fence sections, was constructed across the river. These sections were assembled into a vee shape with the apex of the vee pointing upstream.

The counter was of Irish manufacture, Cybertronic Model 404-Ic, Marine Electric, Killeybegs, Donegal, Ireland. It was a single tunnel system adjusted to count fish longer than 26 inches. Length discrimination was checked several times and the device was accurate to within one-eighth inch. The tunnel was of plywood, square in cross-section, and four feet long (18 x 18 x 48 inches). This tunnel was set into the apex of the vee-shaped fence. Counting error, checked with visual counts, found that the machine was more reliable than human eye (by eye an observer made errors estimating males that the counter counts, from precocious males that the counter does not register). Except for the first year of operation, machine error was limited to the occasions when two or more fish swam through the tunnel simultaneously.

Operations - 1969

This first year we installed the weir during the third week in August, and the counter on August 20. Troubles of several kinds beset us at once.

Batteries (12-volt automotive type) for the counter would not last more than six to eight hours. This meant that batteries had to be exchanged and charged several times each day, even if we used several batteries in series. We substituted aircraft type batteries to no avail.

The weir had to be cleaned at least once each day. During heavy leaf fall, cleaning was required twice every day. Twice during the season we lost several fence sections, and, of course the entire night's count, by leaf and debris buildup on the weir.

Another problem we encountered was failure of the wire fencing used in the weir sections. Salmon attacked the fence viciously, often tearing large holes through which an undetermined number of fish bypassed our counter. For the above reasons we did not get an accurate population estimate for 1969.

From this first year of electronic fish counting we concluded that the fence should be constructed very stoutly with a material heavier than the standard 2-by-2-inch field fencing that we used. Later, we replaced worn and unreparable fence sections with hurricane-type wire mesh.

We further surmised that a 110-volt a.c. power supply was needed. However, between seasons we discovered that we could increase battery life to two or three days by bypassing several of the safety devices in our counter. We eliminated the polarity protection device and also some of the panel lights thus cutting down on power consumption.

Results - 1969, 1970, 1971

Weekly fish counts for these years are listed in Tables 26, 27, and 28. All three years the run into the upper area peaked in October with the bulk of the run arriving throughout that month (Figure 3). As already described, the counts in 1969 were not accurate and the population estimate obtained was approximate at best.

In 1970 and 1971, however, the counter was very reliable. We estimated an adult salmon population of 15,218 in 1970, and 15,951 in 1971 (Table 29). Our error estimates for these two years were still somewhat higher than desired. We believe that we could eliminate all error due to equipment failure if the entire weir were constructed of heavier fencing.

Carcasses on the Weir

Besides acting as a guiding device for upstream migrant adult salmon, the weir also operated as a carcass trap to dead salmon floating downstream. Through the course of daily weir cleaning we kept records of the number of carcasses removed, their sex, and whether or not the carcass was marked. We examined 1,517 king salmon carcasses from the weir in 1969 (Table 30), 1,535 carcasses in 1970 (Table 31), and 1,586 carcasses in 1971 (Table 32).

In 1970 and 1971 we recovered enough marked* king salmon carcasses on the weir to interpret their abundance. The number of marked carcasses peaked in late November in 1970, but had apparently not peaked upon the week that we ceased carcass recovery operations in December of 1971 (Figures 4 and 5). However, both years the total number of carcasses on the weir was maximum near the first of November, almost one month earlier than the marked fish.

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*Marked carcasses were fin-clipped fish of hatchery origin. These were part of various marking experiments at the several hatcheries in the Sacramento River system.

This has interesting management implications. Why didn't the marked fish return to the river in the same distribution with respect to time as the unmarked fish? One reason could be that marking of fish at a young age somehow affects the time of migration when the fish return as adults. Another more probable explanation would be that fish used in the marking experiments came from the late portion of the run the year that they were marked. When we checked at the Feather River Hatchery to find out the early history of these fish we discovered that the latter was the case. In fact, these marked adults were the progeny of eggs taken during the late portion of run in 1968.

During the three years of weir operation and maintenance we found carcasses of fish other than king salmon. Sea lamprey, American shad, threadfin shad, chum salmon, silver salmon, red salmon, rainbow trout, brown trout, goldfish, carp, hardhead, blackfish, squawfish, sucker, white catfish, brown bullhead, striped bass, green sunfish, bluegill, smallmouth bass, largemouth bass, and tule perch were removed from the weir (Table 33). Only sea lamprey and American shad, however, were numerous enough so that summaries of their occurrence would be meaningful (Tables 30, 31, and 32).

Except for 1969, few American shad carcasses were found after the second week in November. This might also have been the case in 1969 but we have no data after November 16.

Sea lamprey carcasses were most numerous in August and September. During 1970 none were found after the first week in October, while in 1971, lamprey carcasses were found throughout October with few found after November 1. In 1969 too few lampreys were taken to be meaningful.

Discussion

COMPARISON OF KING SALMON POPULATION ESTIMATES

We have data from three different methods of measuring population levels. For 1969-70-71 carcass survey, mark and recovery, and electronic fish counting were used to estimate salmon abundance in the low flow area. Besides carcass survey recovery, only mark and recovery were used in the high flow area in 1969 and 1970.

It was difficult to decide which recovery method to use as a control. On the one hand we had a mark and recovery estimate that, at least in the low flow reach, resulted from a 60 percent tag recovery. These should be good estimates. On the other hand we had an electronic fish counter operating in the same low flow area that counted approximately 85 percent of the adult salmon that migrated past the weir. We decided not to select a common standard or control but compare the creamer estimates to each alternate method.

In the low flow area of the river the creamer survey always resulted in a greater estimate than did the mark and recovery technique. Conversely, in the high flow area carcass recovery gave smaller estimates than did marked carcass estimates. If the mark and recover method estimate is assumed the correct one, then in the low flow area the creamer survey overestimates the population level from 3.2 to 15.2 percent (Table 34). In the high flow area the creamer survey underestimates the assumed true population level from 1.5 to 6.4 percent.

Although we ran the electronic fish counter for three seasons in the low flow area, because of counter failure and gear breakdown, we must exclude the first year's information. During these two seasons the creamer survey estimates were smaller than the fish counter estimates. If the electronic counter is used as a control, then creamer chopping results in an underestimate of from 5.9 to 9.0 percent (Table 35).

Regardless of which control is used, it is reasonable to assume that the creamer estimates will result in a minimum error of five to ten percent. This error, under the excellent collection conditions that we experienced during the course of our studies, is undoubtedly well within the inherent experimental error of either control method. However, suppositiion of more difficult recovery conditions (changes in trips or river conditions, flow, etc.) might result in creamer estimate errors of greater magnitude.

Some Inherent Problems With Carcass Recovery

Besides the problems of correcting for differences in trips and recovery conditions, there are other things that cause difficulty in creamer survey work. Perhaps the most obvious are year-to-year changes in personnel conducting the river surveys. It is easy to imagine consistant data collection if the same people conduct the survey each year. However, whenever crew changes occur, no matter how explicit the directions are for conducting recovery work, there will be some subtle changes in direction or application of effort that might easily affect population estimates. This is especially so if new personnel involved are expected to derive the correction factors used in calculation of population levels.

Another factor that affects survey efficiency is the size of the salmon run. It is our experience that without considerable mental effort we do a less thorough job of carcass recovery when there are a great number of carcasses present. We have difficulty concentrating on things like clipped fins and marks. Only by severely flagging the fish with hog rings and bright streamers were we assured of recognizing our own marked fish. When there are many carcasses in sight, the chopper gets lost in the seemingly endless cutting task. He forgets to look for marks in the hacking frenzy. We did find that, in the low flow area where the density of carcasses was high, by totaling carcasses on a master chart at the end of each riffle we were subtly and constantly reminded to look for marks. This problem did not manifest itself in the higher flow river area. Here the chopper was not "pressured" by the cutting task.

Still another problem that affects year to year comparison of carcasses obtained in creamer surveys is the amount of boat retrieval used during survey trips. We have noticed that some crews elsewhere hardly use a motor all day. They drift through riffles under oar power and only use the motor to boat through long pool areas. Our own crews criss-crossed pool areas retrieving all fish they could find on the pool bottoms. The amount of boat retrieval work, then, might give very different estimates of population levels.

Conclusions

1. From creamer count surveys and hatchery fish totals, the fall-run king salmon population levels were 18,144 in 1968, 60,588 in 1969, 61,525 in 1970, 47,041 in 1971, 46,865 in 1972, 73,577 in 1973, and 65,946 in 1974.
2. For the above estimates we cut between 3,000 and 16,000 carcasses each year, usually between 20 and 35 percent of the total run.
3. On the average, about 1/10 of the fall run enters the hatchery, 1/3 spawn in the low flow area, 1/2 use the middle section of the river and less than 1/10 utilize the lower river area.
4. There has been no significant difference between pre- and post-Dam adult king salmon population levels.
5. The pre-project 15 year mean population level was 39,100 fall-run king salmon. The post-project seven year mean population level, after accounting for the hatchery count and the hatchery contribution to the river was 42,800. There has not been a decrease in adult king salmon abundance due to Project Operation.

Assumes all hatchery fish are marked

6. The hatchery contribution to the river is approximately 160.0 percent of the hatchery count.

7. Mark and recovery techniques with marked carcasses in the low flow area resulted in population estimates of 19,850 fish in 1969, 17,925 in 1970, and 21,069 fish in 1971.

8. High flow river area population estimates, using mark and recovery methods, resulted in levels of 40,226 fish in 1969 and 42,313 fish in 1970.

9. The percent recovery of marked carcasses within river sections was constant from year to year. In the low flow reach the recovery rate averaged 60 percent for three years (range 57.1 - 62.3). In the high flow areas the rate was 14 percent for two years (range 14 - 14.7).

10. The consistence of recovery rates within areas demonstrates that carcass recovery of creamer count survey is predictable, i.e., the method will duplicate recovery when year to year recovery conditions are similar.

11. Virtually all marked fish recoveries occur within two weeks after tagging. Over 90 percent of all our recovered marked carcasses were taken within two weeks after release.

12. Approximately 75 percent of the recoveries occurred on the same riffle area where the carcass was set adrift. Of the fish recovered, by sex, 75 percent of the females, 72 percent of the males, and 76.1 percent of the jacks were taken on the release riffle.

13. Creamer survey methods severely underestimate jacks in the run. There was a significant difference in the total recovery rate between sexes. Of the carcasses released, 67.1 percent of the females, 49.5 percent of the males, and 29.2 percent of the jacks were subsequently recaptured.

14. Using an electronic fish counter in the low flow section of the river, we estimated an adult population of 15,218 salmon in 1970 and 15,951 fish in 1971.

15. The number of marked carcasses found on the counting weir peaked almost one month later than did ordinary salmon carcasses. These marked adults were progeny of eggs taken during the late portion of the fall fun in 1968.

16. The correction factors used in the formula for computation of population levels for the creamer survey provide some margin of error.

17. Reasonable discretion should be used when correcting data for trips. Indeed, when trip differences are small, especially if the missed trip is at the start or finish of the season, it is better to not correct at all.

18. When compared with mark and recovery methods, creamer surveys overestimated the population of salmon in the low flow area from 3.2 to 15.2 percent. In the high flow area creamer survey underestimated the mark and recover estimate by 1.5 to 6.4 percent.

19. Creamer count estimates were smaller than electronic fish count estimates by 5.9 to 9.0 percent.

20. In years when correction factors are minimal, i.e., when collection conditions are similar to previous years, the creamer survey method is a reliable estimator of king salmon abundance.

AVAILABLE GRAVEL STUDY

One of the several projects scheduled for completion early in the contract period was the available gravel study (Appendix I, Figure 2). We were unable to complete the investigation when scheduled because of water supply problems. Most of the work was conducted during June of 1969 and all field work was finished in early July 1969.

Studies that the Department of Fish and Game made prior to completion of the Oroville Dam (Keir, 1964) indicated that serious losses of available gravel for salmon spawning occur below 1,700 cfs (Figure 6). Unfortunately these studies were interrupted by flood flows and when concluded were based on information from only one riffle.

To check on the validity of the earlier recommendation we chose three riffle areas for our evaluation. These areas were at approximate river miles 46.0, 51.0, and 55.5. On each riffle, Fish and Game personnel, assisted by Department of Water Resources employees, established transects at 100-foot intervals across the river. At 5-foot intervals along each transect a total water depth and a single water velocity measurement, 0.2 foot off bottom, were taken. Notice was made of river gravel type. For our purposes here gravel type was either acceptable or not acceptable. These measurements and observations were made at river flows of 1000, 1500, 2000, and 2500 cfs.

Contour maps showing water depth, water velocity and acceptable gravel were made of each riffle at each of the river flows (Figures 7 to 18). A planimeter was used to determine the area on each contour map where water depth was between 0.8 and 4.0 feet, where water velocity ranged between 1.0 and 3.5 fps, and where gravel was acceptable. Areas at each flow at each riffle could then be compared.

The optimum water-flow available-gravel relationship exists near 2,000 cfs (Figure 19). No change in recommendation from the 1,700 cfs minimum flow release is indicated at this time.

The lowest riffle did not fit the similar patterns of the upper two riffles (Figure 15). The result in the lower section was a loss in available gravel over the increasing increments of flow tested. This was expected because this lower reach of the spawning area has sand and silt along most of the shoreline. Thus, increased flows do not inundate "new" suitable spawning gravels. Instead, there is a net loss of gravel to the fish at any higher flow because water depth or water velocity begin to exceed desired limits.

In 1974 we planned to conduct another survey (Appendix I, Figure 2). We attempted twice to schedule this study but were unable to do so. An unusually high runoff in spring did not allow controlled flow that season. Likewise, high flows occurred in the fall because of an extraordinary drawdown of Lake Oroville for repair and maintenance of the penstock intake structures. No survey was made.

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GRAVEL QUALITY STUDIES

Prior to the Oroville Project, Feather River spawning gravels were considered excellent. While many precautions were taken during project construction to protect the riverbed from siltation, there was some concern that gravel quality was reduced by dam construction operations.

Methods and Results

In 1968, to measure gravel quality we selected four riffles for study that represented the approximate 50 riffles available for salmon spawning (Plates 1, 2, 3, and 5). These riffles are located at river miles 64.5, 56.5, 54.5, and 46.0. They were named Hatchery, Hour, Goose, and Herringer Riffles.

Gravel samples were taken from these riffles for mechanical analysis. We removed the bottom from an empty 50 gallon drum and attached handles to the drum sides. Using this drum as a kind of caisson we scooped gravels from selected sites by hand, soup ladle, and dust pan. Gravels were removed to a depth of 12 - 15 inches, placed in canvas bags, labeled, and sent to the Department of Water Resources for sediment size analysis.

Results of these analyses showed that there was a gradual deterioration of gravel quality from the upper, or Oroville end of the spawning area toward the lower Live Oak area (Table 36). Rated on a Fish and Game scale of either good, fair, or poor (Table 37), the gravel quality ranged from good to fair (Table 38).

Standpipe devices, similar to those used by Gangmark and Bakkala (1958) (Figure 20) were buried in the same locations where the gravel samples were taken. These standpipes were essentially a plastic pipe with a valve at the bottom that was used to admit or exclude intergravel water. We measured dissolved oxygen and temperature of water circulating through the gravels. By adding a concentrated salt solution to the water in the standpipe and carefully measuring the dilution of this salt by changes in water conductivity we also were able to estimate the rate of flow through the gravel (gravel permeability).

Standpipe gravel quality measurements taken at several times during the year revealed that gravel conditions were good (Table 39). Mean dissolved oxygen measurements ranged from 7.7 to 11.5 ppm and never approached levels considered critical for salmon egg development. Mean water temperature beneath the gravel ranged from 11.7°C to 22.1°C and were usually the same or slightly higher than surface water temperatures. Apparent water velocity through the gravel was high in all gravels where the standpipe functioned in normal fashion.

Discussion and Conclusions

We were disappointed with the standpipes. They were difficult to install and each installation was time consuming. After a few test runs many of the pipes became clogged with sand, grit, etc. and were essentially worthless. Most discouraging was the fact that in "excellent" gravels there were few standpipe failures, while in the "poorer" gravels, those where gravel quality information was more important, most of our standpipe failures took place.

Nevertheless, we obtained enough information to conclude:

1. Construction of Oroville Dam did not deteriorate gravel quality conditions in the Feather River.
2. Present gravel conditions are good for the natural propagation of king salmon.

KING SALMON EGG SURVIVAL

The original contract schedule called for these studies three times during the investigation period (Appendix I, Figure 1).

We increased our emphasis on egg survival work, however, after gravel quality investigations resulted in limited data due to equipment malfunction. Since the cost to conduct an adequate gravel study, both in equipment and in manpower, was prohibitive we decided to use egg survival as an indicator of gravel condition. Presumably if egg survival was good then gravel quality was also. Instead of the infrequent schedule indicated in our original contract, a yearly sampling program began in 1969 (Appendix I, Figure 2).

Methods and Results

We studied egg survival in two ways, (1) by counting live versus dead eggs from portions of natural redds; and (2) by observing survival of eggs in small screen sacks buried in various gravels in the river.

1. Natural Mortality Observation. The general procedure was to dig out eggs from two square feet of an identifiable salmon redd. The location selected from each redd was the forward slope of the redd spill (Figure 21). A McNeil egg sampler (McNeil, 1964), a kind of jet pump, was worked into the gravel some 10 to 14 inches by circular motions, much like routing a hole. The eggs, lifted from the gravel by air bubbles, were caught in a special net placed over the redd (Figure 22). If no eggs were taken at a sample site we moved to another redd. Thus, only two square feet of redd surface area was examined from each selected salmon nest.

Three reaches of the river were designated as sample areas. The upper area extended from the Fish Barrier Dam at Oroville to the Thermalito Afterbay River Outlet, a distance of approximately seven miles. The second section, or middle reach of the river was some eight miles of river between the Thermalito Afterbay

C-067048

River Outlet and a highway bridge crossing the Feather River near the town of Gridley. The third section, or lower river area, extended from the Gridley Bridge to the mouth of Honcut Creek. Data from redds sampled from several riffles within each area were grouped together and totaled to provide a gross survival figure for that area.

The number of redds sampled from year to year (Table 40) depended on availability and our own ability to distinguish one redd from another. Indeed, some years spawning was so intense in the Upper Area that we could not identify single redds. Redds were contiguous or obviously superimposed on one another. Conversely, during 1971 in the lower area, we could not find redds with eggs in them.

Egg survival varied greatly both within and between years and areas (Tables 40 and 41). In the Lower and Middle River Sections there was no apparent relationship between number of spawning salmon (Table 42) and subsequent egg survival (Figures 23 and 24). Survival was high in these areas throughout every year of the study period and fluctuated around the 86 percent range expected in natural population (Briggs, 1953).

However, there was a significant relationship between numbers of adult salmon and gross egg survival in the Upper River Section, r = -0.833 (Figure 25). Survival was inversely proportional to the number of adult fish present. Apparently, this reach of the river is saturated with fish at about 10,000 spawners. Any additional salmon above this population level results in a substantial reduction in egg survival.

2. Buried Bags of Eggs. In 1968 and 1970 we observed survival of eggs buried in plastic screen bags. This technique was used to compare with survival estimates from natural redds. In both years we buried 100 eggs in 6 x 10-inch screen bags. Each bag received 100 eggs and a handful of "pea-gravel". Eggs were taken from several female salmon and were kept separate, so that each screen sack could be identified to origin of eggs. Several bags were then

C-067049

buried in river gravel in lots, with each bag in a lot containing eggs from a different female salmon. At intervals during egg development a lot was dug up and survival noted.

a. 1968. The purpose of burying eggs this year was to compare survival from poor, fair, and good gravels. We chose Goose Riffle as the test site (River Mile 53.3), and by eye, chose our gravel locations. Eggs from three female salmon were used in these tests, therefore each lot of eggs contained three bags of eggs. Results were as expected, except the "fair" gravel survival was not as high as we had hoped (Table 43). Poor gravels had an egg survival of 4.5 percent, fair gravels 19, and good gravels 83 percent. The rather mediocre survival in the fair gravel lots might be explained by the fact that a natural redd was dug immediately upstream of this lot burial site and placed 6 to 12 inches of additional gravel on top of the buried screen bags.

The 83 percent survival from good gravels agrees quite well with the 86.9 percent survival we noted from our natural redd sampling in this same Middle Section of the Feather River.

b. 1970. This season we wanted to compare screen-bag egg survival in the same three reaches of the river that we sampled with egg survival from natural redds. Bags of eggs from two female salmon were buried in lots in Hatchery Riffle (Upper Section), Big Riffle (Middle Section), and Herringer Riffle (Lower Section). Survival could only be compared at age four weeks because of loss of egg bags at one of the burial sites (Table 44). Survival of eggs in bags at all sites was within the expected range of natural redds but was somewhat lower than survival from the natural redds we sampled (Table 41).

Egg Survival in the Low Flow Area

As reported above, egg survival rates are very low in the 400 cfs reach of the river. We can assess the problem as being a combination of two causes.

First, an extraordinary number of salmon are returning to the low flow river section. Our salmon enumeration studies show that more than 16,500 fish (16,500 to 25,500) have spawned here each year since 1969 (Page 18 and Table 1, this report). A major portion of these fish are of hatchery origin (Page 19 this report) and represent an unexpected burden upon the river.

Second, the reduction in flow down this reach of the river, due to operation of the Oroville Project, has decreased the amount of gravel available for spawning. Although we did not conduct available gravel studies in this section (because of a "constant" cfs flow) we believe that the closest riffle examined from the high flow area approximates what will happen here. From studies at the flow riffle at river-mile 55.5 we conclude that only 55 percent of the gravel is available for spawning at 400 cfs (Figure 26). As shown, with our present fish population levels, we can expect about a 40-50 percent egg survival at this river flow.

Although the problem might be solved by encouraging the hatchery strays to return to the hatchery, a more practical solution is to provide more gravel area for salmon spawning. The Department of Fish and Game has already taken steps to do just this. During May and June of 1974 a 1,100 foot long by 40 foot wide channel designed for 140 cfs flow was constructed along side the river at Oroville. This channel will provide spawning habitat for some 200 pairs of salmon.

Spawning channels can help to alleviate the crowding of spawning fish, however, the number of sites adaptable for such construction are limited. Additional flow is needed to "create" the habitat salmon require from the river itself. Our estimates from the available gravel study are that 1,000 cfs are necessary to provide the needed gravel area (Figure 26). This flow would be required from October 15 through January 31 each year.

To demonstrate the effect of a flow increase on king salmon egg survival the Department of Fish and Game requested a total of 800 cfs during the 1974-75 spawning season. We anticipated an increase in egg survival of about 20 percent. This would raise over all survival to between 60 and 70 percent. The estimated spawning salmon in the area was over 20,000 adults (Table 1). This population level was within the spawning saturation range where redd crowding and other spawning difficulties arise. Survival was 52.4 percent in Auditorium Riffle, 65.5 percent in Bedrock Riffle, and 67.4 percent survival in Matthews Riffle. Gross survival (combined data for all riffles) was 62 percent (Table 41). This increase in egg survival may result in a 37.6 percent increase in adult salmon produced per female from this low flow reach of the river (Table 45).

We do not submit this 37.6 percent increase as a long term equilibrium figure. What will happen is that the large number of returning adults from this experiment plus the constant hatchery contribution to the river will again saturate the spawning area. Once again the crowding conditions will be created that lower egg survival rates. If the river flow is increased to 1,000 cfs each year a new population equilibrium figure will be formed. This level, of course, will be higher than the old one at 400 cfs and lower than a predicted one-time 37.6 percent increase.

By somewhat tortuous logic that compares available gravel at various flows with sustained population levels of those flows we determined that a net gain of 4,000 salmon can be expected from a flow of 1,000 cfs. This logic is as follows:

1. The average population level in the lower flow area has been 19,000 salmon and the average return to the hatchery has been 5,000 salmon over the past seven years.

2. At a ratio of 1.6 to 1 (page 19, this report) the hatchery contributes an average of 8,000 fish to the river (5,000 x 1.6 = 8,000) each year.

3. Therefore, the average river yield at 400 cfs is actually 11,000 per year (19,000 - 8,000 = 11,000).

4. From our available gravel studies we determined that 1,700 cfs will maintain the salmon population in the high flow area (Page 34, this report). We opine that this population is 50,000 salmon.

5. From the same available gravel study above, we determined that about 90 percent of the gravel is available at 1,000 cfs. We assume that 90 percent of the salmon, or 45,000 fish can be supported by this 90 percent available gravel.

6. The low flow reach of the river is about one-third the size of the high flow area. Therefore one-third of the high-flow salmon population level (45,000/3) or 15,000 fish is the expected equilibrium population level at 1,000 cfs in the lower flow reach of the river.

7. The net gain, then, is 4,000 fish (15,000-11,000). The net economic gain from 4,000 "extra" salmon each year is at a minimum $120,000.00/year. That is, at an escapement ratio of 1:3, 12,000 salmon will be taken in the commercial and sport catch. At 10 pounds per salmon and $1.00/pound, $120,000.00 will be "earned" from these fish.

Conclusions

1. Egg survival has been good in the high flow area of the river. There, the survival rate has fluctuated between 65 and 85 percent range.
2. We infer from the good survival rates that gravel quality in the high flow area is also good.
3. Egg survival in the low flow area is very low.
4. Gravel quality is still excellent in the low flow area.
5. Redd super-imposition and crowding into "poorer" gravel areas are deemed responsible for the low egg survival rates.
6. More water is required in the low flow channel to increase the available gravel supply. A flow of 1,000 cfs from October 15 through January 31 is recommended.

YOUNG SALMON OUTMIGRATION STUDY

To what extent do the amount and timing of river discharge affect the outmigration of young salmonids in the Feather River? Some years one or both of these flow parameters are under the control of the Department of Water Resources. The objectives of this investigation then, are:

1. Determine if Oroville Project operations have any effect on the downstream migration of salmon.
2. If the effect of operations is detrimental, then, we are to make recommendations that will assure satisfactory outmigration conditions.

Methods

Because we were just organizing our studies and sampling gear and field personnel were not available, the investigation of the outmigration by the 1967 year class did not begin until March of 1968. No meaningful estimates of population size, timing of migration or fish size at time of outmigration could be made for this year class (Figure 27).

Since 1968, however, we have such information. Each year we conducted a mark and recovery program to enumerate the number of outmigrants. These studies consisted of releasing approximately 1,000 marked fry daily into the Feather River. Below the spawning area, fyke-nets were used to capture marked and unmarked wild outmigrants. Our fyke-nets consisted of a pipe frame that provided a three by five foot throat opening for the net material. The net was 16 feet long and had meshes that varied from 2 to 1/2 inches (Figure 28). A wire-mesh-covered-live-box was attached to the cod-end of the net. The nets were anchored in riffle areas when water flows were low and were floated with styrofoam logs and cabled to tree limbs during high river discharge.

Fyke netting commenced as early as mid-December (Table 46). From 1968 through the 1972 year classes of salmon all through the January - March intense migration period we sampled with one to four nets seven days per week. These nets were kept in the water 24 hours/day. Enough nets were used to recapture some of the marked-released fry. During the remainder of the year we sampled at least one night each week.

Fish for marking were obtained both from a wild source, usually the low-flow river section, and from the Feather River Fish Hatchery. In one year both wild and hatchery fish were used but since 1970 all marked fry have been of hatchery origin (Table 46). Hatchery fry were held 24 hours after marking to determine gross handling and marking mortality. Fry loss was minimal (Table 46).

Size of Outmigrant Populations

The formula used to estimate the number of outmigrants is:

$$N = \frac{nt}{s}$$

Where: N = Estimate of number of outmigrants

n = Number marked fish released

t = Number wild fry subsequently sampled

s = Number marks recovered

Population estimates of fry ranged from 10.9 million in 1968 to 40.9 million in 1970 (Table 47).

Time of Outmigration

The time of peak outmigration was related to water flow (Figures 29-34). In high river discharge years, the peak outmigration occurred in mid-January. The duration of this peak was usually short, with typically a spiked mode. Examples of high flow type years are 1969 (Figure 29) and 1970 (Figure 30). In contrast, during low flow years the outmigration peaked one month later than it did in high flow years. The duration of this peak was long, extending over several weeks. Examples of low river discharge conditions are 1971, 1972, 1973 and 1974 (Figures 31, 32, 33 and 34).

The week that peak outmigration occurred can also be identified as the point of inflection on cumulative catch curve. This point occurs between weeks two and three for wet years (1968, 1969) and at week seven for dry years (1970, 1971)(Figure 35).

The cumulative catch curve can also be used to identify that time during the outmigration when the run was essentially over, i.e., where the cumulative curve becomes asymatotic to an unidentifiable but approaching total seasonal catch. This "end week" was at week four during the wet years of 1968 and 1969, and was near week 11 for the dry years of 1970 and 1971 (Figure 35).

Length of Fish and Time of Outmigration

During the peak of downstream migration the average length of the fry varied between 35 and 40 mm (Figure 36-42). Some years there were only one or two mm difference in mean fish length for almost three months (Figures 38, 39, 40, and 41).

Although the mean fish length was nearly the same, the range in fish lengths was wider during wet years than it was during dry years. We speculate that during wet years the nursery capacity of the river is reduced. Some of the larger fry that decide to hold up and take temporary residence in the river are displaced downstream during periods of high flow. Thus, a wide range in fry lengths are recorded. In dry years, by definition, the high flows are reduced. Because of lower flows larger fry are not encouraged to move downstream. We further speculate that once the "nursery capacity" of the river is reached all succeeding newly emergent fry can find no free nursery area. These fry are forced immediately downstream. Thus, a long period with a narrow range of fish lengths occurs.

Flow During Fry-Fingerling Outmigration and Adult Returns

Correlation coefficients were computed between mean monthly flow and adult king salmon returns three and four years later. Data used was from 1949 to 1973 with r values computed for each month from October through June.

Only December flows were positively correlated with adult returns four years later (Table 48). Flows during March and May were almost significantly correlated with returns three years later. The rest of the r values were far from being significant.

We would like to conclude that high late spring flows during outmigration ensure good adult returns from a year class of salmon. The Q-Mar. and Q-May r values point toward this, but why do we have a vary puny r value of 0.171 for April between these correlations? And, if late spring flows bring good adult returns three years later, why don't they likewise affect four year returns the same way? There were no significant four year return correlations with late spring flows.

Some error in our correlation computations are obvious. Because no age analysis of adult returnees was made during any of the 15 years of adult salmon returns we could not accurately assign correct proportions of each year's return into three or four year categories. Thus, in the correlation analyses above, the strength or weakness of any year class in a three or four year cycle may be confused by the overlay of adjacent year classes. We submit that although our correlations were weak, a real relationship might still be present.

Conclusion

1. Time of peak outmigration is related to water flow. During high-water years the peak occurs in mid-January. In low-water (flow) years the peak is in mid-February.
2. The duration of the outmigration period is related to water flow. Both during high water and low water years outmigration began in late December or early January. In wet years, most of the outmigrants are gone by the end of January. In dry years, however, the outmigration of the great majority of year class was not over until the first week in March.

3. The average length of fry varied from 35 to 40 mm through most of the outmigration season.
4. Correlation coefficients between flow during outmigration and adult population levels three and four years later were not very good. Four year returns were correlated significantly with December flows.
5. Because of inconsistencies between the correlations above our interpretation of the results are conservative. We make no firm recommendations about changes in Project Operations but do urge the Department of Water Resources to investigate procedures, operations, flow prediction improvements, etc. that will ensure good spring flows in the Feather River.

SPRING-RUN KING SALMON SURVIVAL

Adult spring-run king salmon migrate in the Feather River during April, May, and June. In pre-project years they migrated past the present damsite into the several forks of the river where there was shelter and suitable cool water temperatures. Now, these fish are blocked from the upstream areas and must spend the summer months in pools below the Fish Barrier Dam at Oroville.

We know that spring-run salmon "hold" or survive the summer months to spawn successfully in the fall when summer water temperatures are between 60° and 65°. Water warmer than this can harm the yet unspawned eggs.

The Feather River Hatchery is designed to handle all the spawn from the entire spring salmon run. Although these fish arrive in the spring months, because of holding problems in the hatchery, the salmon are not allowed to enter the hatchery until late August or early September. During, the two or three days immediately after the ladder is opened there is a large influx of salmon into the hatchery (Table 49). Then, there are a few days before any significant number of salmon migrate up the ladder. We believe that this initial influx of fish is the spring-run salmon population.

Our goal is to maintain the spring salmon run at least as high as pre-project population levels. For practical purposes this population size is assumed to be 2,000 adults (Table 50). The spring-run king salmon study described below was designed to estimate summer mortality and determine if this race of fish can survive under post-Oroville project water temperature and shelter conditions.

Methods

River Holding Mortality

Range and means of water temperature were taken from a constant recording thermometer at the Feather River Hatchery. Daily ranges of temperature and monthly means were supplied by computer from the Department of Water Resources.

To determine mortality of salmon over the summer we conducted a carcass recovery program through a short reach of the river. We looked for carcasses from the Fish Barrier Dam downstream some two miles (foot of Montgomery Street). This is the area where we believe all of the spring-run rest. The survey techniques were the same as those used in the fall-run king salmon enumeration study.

We examined this reach of the river once each week. Carcass recovery started in mid-June and terminated one week after the date when the hatchery opened its ladder in September. The number of weekly trips varied from eight to eleven over the several years of the investigation (Table 51).

Hatchery Evaluation

Hatchery personnel made a study in 1968 to determine the feasibility of holding spring-run salmon in the hatchery. A portion of the spring-run salmon were allowed to enter the hatchery complex. Sixty-seven fish were held within three different areas. These areas were the fish ladder, circular tanks, and spawning channel.

Results

River Holding Mortality

We did not find many salmon carcasses in any year (Table 51). In 1974 a high of eight carcasses were found while in 1968 and 1970 only one carcass was recovered each year.

Recorded also during the carcass survey was the number of live salmon observed on each trip. It is interesting to note that more live fish were seen during those years when the total salmon population level was low (Table 51). For instance, in 1968 we saw 23 live salmon when the total estimated population was 161 fish. While in 1971, the total run was 481 fish but we saw only two live salmon.

Since Oroville Project completion, river water temperatures near Oroville have ranged from 51° to 67° during the critical time when spring-run salmon are resting in the river (Table 52). At no time did the mean temperature exceed the 65° parameter for desirable holding temperature.

Hatchery Evaluation

Losses among the 67 spring-run salmon allowed to enter the hatchery occurred in all three holding areas. The highest mortality was among those fish held in the fish ladder and the least among those kept in circular ponds (Table 53). It should be noted that the fish in the circular ponds were treated frequently for fungus infections while the salmon in the fish ladder and spawning channel were not.

Conclusions

1. We conclude from the low mortality of spring-run salmon that holding conditions in the river are excellent, at least for population levels as high as those we have seen during our observation period.
2. We cannot speculate why we saw more live salmon during low population level years than we saw when many more salmon were present in the river.
3. The Department of Water Resources has fulfilled its water temperature commitment to the hatchery in the low flow reach of the river.
4. No change in water temperature regime is recommended for the protection of spring-run salmon.
5. Spring-run salmon should not be held in the hatchery through the summer season.

AMERICAN SHAD STUDIES

Our contract charged the study to determine the population size of adult shad. We carefully considered this and concluded that we did not have the resources available to complete such a project. We thought it possible to pool all our "shad monies" for the entire several years of the study period and obtain a population estimate for one year. We questioned whether one estimate would be meaningful. Would that estimate be the highest one in the past twenty years or the worst run in history?

Therefore, we abandoned a direct assault on the adult population question and turned our efforts toward a better understanding of the effect of Oroville Project operations upon the eggs and larvae of American shad. This might be an indirect measure of adult shad abundance if we assume that an index of egg and/or larvae abundance was related to the size of the adult spawning population.

We also initiated a fyke-net and beach-seine program to monitor the outmigration of any young shad that remained in the river beyond the larvae stage. Finally, each year we conducted a creel census to demonstrate trends in angler success for adult shad.

Methods and Results

Egg Pump Collections

In 1968, 1969, and 1970 the method used to index egg and larvae was an egg-pump collection system. During these years, we used a variety of pump sites (Table 54).

Our basic system consisted of a pump with an inclined screen collection box (Figure 43). In addition, in 1968 we used the water discharge from a continuously recording turbidimeter at the DWR Gridley Bridge recording station.

C-067062

We did not collect many eggs from any of the stations, and only rarely did we capture larvae (Tables 55, 56 and 57). The only consistent egg collections were at the Boyd's Pump site.

Our conclusion was that when the pumps collected eggs, these samples only represented the spawning that occurred immediately above each pump. For instance, at the Gridley site we knew that many thousands of adult shad were above this location, yet only on rare occasions did we capture eggs there. Either eggs from fish spawning miles upstream did not reach the Gridley sample site, or the amount of water sampled was too small to capture enough eggs to give an indication of spawning intensity.

Tow Net Surveys

The sampling program was changed to a tow-net survey in 1971. We retained measures of egg abundance as indicators of peaks of spawning intensity and egg survival. However, emphasis was switched to larvae abundance as basis for a population index. We assumed that larvae abundance was a better estimator of seasonal spawning effort. The logic here was that larvae originating anywhere above our net sites were free to migrate past our nets while apparently only eggs of local origin did so.

Night tows of one-half hour duration were made with a fine mesh nylon net from an anchored boat. The net had a 0.7 meter diameter mouth opening leading to a three meter long mesh cone. The mesh openings were eight to the centimeter. Usually, two tows were made simultaneously. A water velocity measurement was taken at the start of each tow by placing a Gurley-Meter in the throat of each net. Time of sampling and water temperature were also recorded.

We added or removed stations from year to year because of manpower or other program irregularities. The only common station for all years was at Yuba City - Marysville (Table 58).

Results - Tow Net Surveys

American shad spawning began with water temperatures as low as 13.4°C (56°F) and continued through temperatures as high as 24.5°C (76°F). Each year the bulk of the spawning took place between 16.6°-22.2°C (62°-72°F).

1971 - Spawning Intensity

In 1971 cool water temperatures dominated the spring and early summer. At Yuba City - Marysville water temperatures were in the preferred spawning temperature range of 15.5°-21.1°C almost the entire period from mid-May to early August (Figure 44). There were no real modes of water temperature during the spawning season but there were two important temperature "breaks"; one centered around May 31 and the other June 17-21.

There were two modes of spawning intensity. These modes were obviously separated by the mid-June temperature break (Figure 44).

The water temperature at our Verona site followed the Yuba City - Marysville pattern in 1971 but was usually several degrees warmer on any given day. Here there was only one mode of spawning. This took place between the two temperature breaks (Figure 45).

1972 - Spawning Intensity

This year we occupied three stations on the Feather River and one inside the Yuba River. Three modes of water temperature occurred at the Feather River stations. Each mode was closely associated with a mode of shad spawning (Figures 46, 47, and 48).

Yuba River water temperatures were similar to those in the Feather but too few eggs were taken to be sure of a temperature - shad spawning intensity relationship (Figure 49).

1973 - Spawning Intensity

The Yuba City - Marysville and Yuba River stations were the only ones used this year. Two easily identified modes of temperature occurred before mid-June. One was centered about mid-May and the other about the first week in June. Again each of these temperature modes had a matching mode of egg abundance (Figure 50). After mid-June the water temperature-egg relationship was variable.

In 1973, as was the case in 1972, not enough shad eggs were captured in the Yuba River to determine any water temperature-spawning intensity relationship (Figure 51).

1974 - Spawning Intensity

Only one station in the Feather River, at Yuba City - Marysville, and one in the Yuba River station were used this year. We sampled two nights on; one off from May 6 through July 10.

At Yuba City - Marysville two obvious modes of egg abundance were measured; one near May 9 and another centered about June 2. These modes are coincident with the first and second of three modes of Feather River temperature (Figure 52). Again, the first mode or "wave" of spawning took place at the first rise of water temperature through the 15.5°C (60°F) threshold. The second and largest wave of spawning encompassed the entire 15.5°C-21.1°C (60°-70°F) range. The highest temperatures recorded during this wave was 22.2°C (72°F).

In the Yuba River spawning began with a water temperature of 14.5°C (58°F) on May 10. There were three waves of spawning. The first was centered about May 22, another about June 3, and another about June 14 (Figure 53). In contrast with the Feather River spawning this year, there were no real modes or breaks in temperature associated with waves of spawning.

Results - Egg Survival Studies

Egg survival from each tow-net sample was recorded. An egg was designated dead if the nucleous was broken up or if the yolk was cloudy.

In 1972, 1973, and 1974 egg survival in all the samples from all the collection sites was highest at the beginning of the spawning period (Figures 54 to 60). The duration of this high survival varied both between years and between tow-net sites. Usually, this initial high survival was coincident with the first occurrence of the 15.5°-21.1°C (60°-70°F) water temperature interval. The duration of excellent survival sometimes terminated with a sudden water temperature decline (Figure 55), or an increase in water temperature above 21.1°C (70°F) (Figures 54, 57 and 59). Return of water temperature to the preferred spawning temperature range, however, did not increase survival (Figures 54, 57 and 59). This latter relationship, or lack of it, casts doubt on any survival-water temperature correlation.

Except that Oroville Project operations determine the time of initial occurrence of the 15.5°-21.1°C (60°-70°F) temperature range, we could not discover any effects of Oroville Project operations on shad egg survival.

Results - Larvae Studies

Shad larvae were collected in the same samples taken for egg abundance. Our early efforts at larvae collection were not successful. Few larvae were ever taken, either in pump samples or from net tows made in conjunction with daylight maintenance of egg pump stations (Tables 55, 56 and 57). When evening net-tows were started, however, it was obvious that shad larvae as well as shad eggs were most abundant during darkness. In June of 1971 we conducted a diurnal sampling study that verified the increase of abundance of larvae in surface waters during nighttime hours (Figure 61). After this diurnal sampling we took all our eggs and larvae collections between 2100 and 0300 hours.

Each year the peak or mode of larvae abundance occurred sometime between late May through the month of June (Figures 62-66). As expected, modes of larvae were coincident with or follow modes of egg abundance (Figures 67-70).

Larvae Sampling - 1971

We sampled at Yuba City - Marysville and Verona in 1971. At both locations the peak in larvae abundance occurred during the last half of June (Figure 62). There was little time lag between peaks of abundance even though these stations are approximately 28 miles apart.

Larvae Sampling - 1972

A peak in larvae abundance occurred during the first half of June at both Yuba City - Marysville and Verona (Figure 63). There was a one week difference between the occurrence of a spiked peak (Maximum) in abundance. We are unable to explain why the mode in abundance at Verona (the downstream station) was so much earlier than was the upstream Yuba City - Marysville mode.

We also sampled at Star Bend, between our Yuba City and Verona sites, and in the Yuba River about one-half mile from its confluence with the Feather River. Larvae abundance at these stations also was highest in early June (Figure 64). The Star Bend peak coincided with that of the Verona peak in larvae abundance while the Yuba River peak closely paralleled that of the Yuba City - Marysville maximum.

Larvae Sampling - 1973

Only the Yuba City - Marysville and Yuba River stations were used this year. Larvae collected at both stations had obvious tri-modal distributions of larvae abundance (Figure 65). The principal mode in each case was in the first half of June.

Larvae Sampling - 1974

This year the Yuba City - Marysville and Yuba River stations were used. On the Feather River, shad larvae abundance was greatest the last week in May through the first week in June. However, peak abundance on the Yuba River did not occur until the last week of June, almost one month later than on the Feather River (Figure 66).

Larvae Index of Abundance

We established 1971 as the base year for a larvae index. This index was computed by dividing the total number of larvae caught during a season by the acre-feet of water sampled and multiplying this by the total acre-feet flow during the sampling season. The four index values, years 1971 to 1974, are listed in Table 59. The index was highest in 1974 with a value of 1.46.

Most significant is the high correlation of the larvae index with angler catch rates for adult shad. With only four pairs of data to work with the correlation was significant ($r = .9929$, $r_{.05} = 0.9500$ with 2 d.f., Figure 71). This high correlation suggests that our larvae index and angler catch rates are reasonable indices of adult shad abundance.

Young Fish Abundance

We sampled young shad (23 mm to 98 mm) with fyke-nets described earlier (Figure 28) and with beach seines. The seines were of two sizes. A 50' x 6' x 3/8" mesh seine was used early in the year when shad were quite small (less than 20 mm) and a 20' x 6' x 1/2" mesh seine was used the remainder of each season. Sampling locations and frequency of sampling varied from year to year as manpower and other program irregularities varied. Fish lengths were recorded from each catch, and the water temperature noted.

Results - Fyke Net Catches

We sampled every year at the Live Oak site. One or two other locations were also visited each season (Table 60).

At Live Oak most of the young shad were taken when river temperatures were greater than 21.1°C (70°F) (Figure 72). By the time water temperature reached 15.5°C (60°F) usually in September, few shad were sampled.

During 1972, 1973 and 1974 we maintained a sampling station at Shanghai Bend. Like shad catches at the Live Oak site, young shad were more abundant when river temperatures were in excess of 21.1°C (70°F) (Figure 73). Also a few shad were sampled after September and/or 15.5°C (60°F) water temperatures.

We sampled shad at Verona from 1970 through 1972. Here, shad abundance varied from year to year with respect to river temperature (Figure 74). Most shad were captured from water temperatures greater than 18.3°C (65°F).

Results - Beach Seine Catches

Until 1973 we sampled infrequently with beach seines. In 1973 and 1974 a systematic sampling program was followed (Table 61).

1973

We began seining July 12, 1973 at Shanghai Bend. Four to six seine hauls were made on one evening each week. Because day catches during seine collections in other seasons were not very successful, we began seining about 2030 hours and finished just before total darkness.

The average catch of shad per seine haul increased rapidly during July. The peak catch occurred on August 1 and then fell off rapidly. This rise and fall in average catch closely resembles the fyke-net catches made immediately off-shore at this site (Figure 75). The average seine catch after the first week in August until the first week in October fluctuated between zero and ten fish per haul. Again, as did the fyke-net catches for the same period, this represents a low fish population level (Figure 76).

Beach Seine - 1974

We seined only at Shanghai Bend this year. Sampling started the evening of July 1, and on one evening each week from July 11 through September 26. We made four to six seine hauls each night. The average catch per seine haul was highest on August 7. The period of principal migration was from July 31 through August 21 (Figure 77).

From angler fishing success we assumed there was a large population of adult shad this year. For this reason we expected a much larger outmigration. Instead, the catch rate in our seines was 10 to 20 times smaller than last year (Figures 76 and 77).

Angler Census

From the beginning of our shad investigations angler, or creel, census was given a "time available" priority. Accordingly, during some years our census was more intensive than others (Table 62).

Direct angler interviews were not used. Angler success and fisherman density was high enough to determine catch rates by direct observation. It was not uncommon to have 10 to 20 anglers in sight at one time on one riffle or pool. Census takers would spend 15 to 30 minutes at any fishing site and record the number of fishermen present, the number of fish caught, and the length of time of observation.

Angler success was greatest in 1967-68 when the catch rate was 1.5 fish/angler hour (Table 63). In 1974 the catch rate was again almost 1.5. Between these years the average catch rate was 0.78 fish/angler hour.

Discussion

Water Temperature vs. Spawning Intensity

So many instances of coincident modes of water temperature and spawning intensity occurred during our studies that further analysis was undertaken.

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We carefully examined changes in egg abundance with respect to increments of temperature change. When day to day water temperature changes were greater than ± 1.7°C (± 3°F), spawning intensity increased or decreased in the direction of the temperature change (Table 64). The management possibilities of this phenomenon are still unclear. It may be possible to control the duration as well as the beginning of the spawning period if unusual river conditions are anticipated during May and June of any year.

Young Fish Abundance

Water temperatures near 15.5°C (60°F) were expected to trigger the outmigration of young shad. Research on east coast shad concludes that the largest number of shad moved downstream when the temperature dropped below 15.5°C (60°F) for a period of several days (Sykes and Lehman, 1957; Walburg and Nichols (1967); Leggett and Whitney, 1972). Our work does not support these east coast observations. Indeed, our young fish have virtually all left the area a month or more before the river ever reaches 15.5°C (60°F) (Figures 76 and 77). If water temperature is one of the factors that helps initiate the outmigration then it appears a falling temperature regime from the low-twenties (70°-75°F) affects shad in the Feather River. However, we do not have enough evidence to fully endorse temperature as a trigger mechanism.

Affect of Oroville Project on American Shad

We have already discussed how water temperature affects American shad spawning. Egg survival, seasonal peaks in spawning intensity, day-to-day fluctuations in egg abundance, and when spawning begins are all related to water temperature. How has Oroville Project Operations affected water temperature?

One of the expressed purposes of the Thermalito Afterbay is to warm water for irrigation purposes. This it has done (Figure 78). These pre- and post-Oroville Project seasonal river temperatures are significantly different from each other (Table 65). Analysis of covariance reveals that the average temperature gain over time is not the same (hypothesis of a common regression line) for pre- and post-project data. Likewise, pre- and post-project temperature are not affected at the same rate with respect to time throughout the season (hypothesis of a common slope). Finally, the relationship between river temperature and time is significant (hypothesis Beta = 0).

The occurrence of water temperatures acceptable to spawning is much earlier now than before dam construction. The date when 15.5°C (60°F) water first occurs can be expected from one week to three months earlier than before dam construction (Figure 79). Expressed as averages, temperatures during prime spawning time are also in the preferred range almost one month earlier now than they were before Oroville Dam (Figure 80). We speculate that the period of highest egg survival, during the initial water temperature rise from 15.5°C (60°F), occurs before the bulk of shad have arrived in the upper river area.

Of more concern to the shad fishermen is how his catch success is affected by Project operation. The correlation of catch rate and mean river discharge is not significant ($r = -0.011$, Figure 81). The correlation of catch rates and mean May temperatures is almost significant ($r = -0.722$, where $r_{.05}$ with 5 d.f. = 0.754). There appears to be some contradiction here because the correlation of river discharge and river temperature ($r = -0.872$) is significant at the five percent level. Why should there be a positive relationship between catch and water temperature and no relationship between catch and flow when both flow and temperature are related? It may be that angler catch is not always a good way to estimate fish abundance and in this case too much water lowers fishing success even though many fish are present.

Conclusions

1. Survival of shad eggs is highest early in the spawning period (typically early May).

2. Seasonal peaks in spawning are related to water temperature.

3. The earliest peak in spawning closely follows the first occurrence of the 15.5 to 21.1°C (60°-70°F) temperature.

4. Later peaks in egg abundance follow or are coincident with water temperature peaks.

5. Day to day fluctuations in egg abundance were also related to water temperature.

6. Water temperature changes of more than three degrees caused the intensity of spawning to increase or decrease directly with the direction of temperature change.

7. Shad larvae were most abundant during June.

8. Peaks in larvae numbers follow peaks of high egg survival or peaks in egg abundance.

9. Numbers of young shad caught in our fyke-nets and beach seine hauls were most numerous in late July and early August.

10. Almost all large catches of young shad outmigrants were made when river temperatures were greater than 21.1°C (70°F).

11. Outmigration of young-of-the-year shad was virtually over by early October.

12. Angler success for American shad has decreased almost 50 percent during this investigation. From a high of 1.5 fish per angler hour in 1968 the catch rate has dropped to an average of 0.8 fish per hour until 1974 when the rate was again 1.5 fish per hour.

STRIPED BASS STUDIES

Introduction

Information concerning striped bass was obtained using the same methods, techniques, and equipment as outlined in the American shad investigations. The same sampling schedules and locations already described apply as well to striped bass as they do to shad studies.

Results

Egg and Larvae Sampling

Only one striped bass egg was collected during three seasons of use of egg pump samplers. This egg was taken in 1968 (Table 55). No striped bass eggs were sampled in 1969 or 1970 (Tables 56 and 57).

During the several years of sampling with tow nets few striped bass eggs were taken (Table 66). Only in 1974 were enough eggs sampled to interpret their abundance (Figure 82). From the 25th of May through the 4th of June eggs were sampled at the Yuba City site on the Feather River. Spawning began at 19.5°C (67°F) and peaked near 21.7°C (71°F). No striped bass larvae were caught in these samples, or at any other time during all of our studies.

Creel Census

We interviewed anglers in our creel census for adult bass every year of our study except 1970. The catch rate was not very high any year (Table 67). The highest rate was 0.063 in 1974 and the lowest 0.028 in 1968 and 1972.

The river was divided into statistical areas and the data collected was stored and analyzed. Thus:.

River Section 1. Fish diversion dam at Oroville to Thermalito River Outlet.

River Section 2. Thermalito River Outlet to Gridley Bridge.

River Section 3. Live Oak to Star Bend.

River Section 4. Nicholas to Verona.

The catch per hour of striped bass was skewed toward section four. Five of the seven years of our study the catch rate was highest in this section (Table 67). Only in 1973 did Section 2 have a higher catch rate, and only in 1974 was Section 3 higher.

Correspondingly, every year except 1970 over 50 percent of the adult striped bass seen in the creel census were observed in section four. In 1972 over 90 percent of the bass were caught here.

Correlations were computed to show the relationship between river flow, temperature and catch rates. April and May were chosen as the index months. The correlation coefficients are given in Table 68 (Figures 83 and 84). All were relatively high. The only significant correlations in the mid-river section were for catch and April river flow, and for catch and April river temperatures. In the lower river section catch rates and May river flow were significant, $r = 0.926$ ($r_{.95}$ with 3 d.f. equals 0.878). In general low catch rates were associated with flow below 3,000 cfs.

Conclusions

During the course of our studies the Feather River has not been an important waterway for striped bass spawning. Only in 1974 were significant numbers of eggs taken. No larvae were ever sampled.

Our angler survey and striped bass catch rates derived from this data reveal that:

1. Angler success varied from 0.063 in 1974 to 0.028 fish per angler hour in 1968 and 1972.
2. In most years over 50 percent of the adult striped bass are taken in the lower river section. Most of these are caught within one or two miles of the river mouth at Verona.

3. A significant positive correlation in the mid-river area (Yuba City - Marysville) was found between catch rates and April river flow, and a significant negative correlation between catch rate and April river temperature.

4. From regression lines generated from these correlations we conclude that if water storage in April and May suppresses outflow below 3,000 cfs from the Thermalito Complex, catch rates in the middle reach of the Feather River will be low (presumably few striped bass will be attracted up the Feather River).

RESIDENT FISH

Introduction

The Feather River contains a variety of resident fish, none of which are unique to this river system. Resident fish are those that remain in freshwater throughout their life, without undergoing migration to the ocean. Individual fish may spend their entire lives within a given area of the river leaving it only during high winter river flows or for spawning purposes. Normally considered migratory, striped bass, and steelhead trout can be found in the Feather River at any month of the year, and therefore are considered resident fish for this report.

It was thought post-project conditions would be satisfactory for warmwater game fish (smallmouth and largemouth bass, bluegill, black crappie, white and channel catfish, and striped bass), but it was possible that conditions would be better for nongame fish, such as carp, squawfish, hardhead, hitch, suckers, and sculpins.

Our objectives were to determine:

1. Species composition in the Feather River, and any changes in that composition as a result of the Oroville Project.
2. The importance and frequency of these species in the angler's creel.

Methods

SPECIES COMPOSITION

During 1968 resident fish were collected with a Smith Root Type V Electrofisher mounted on a 16-foot Jon boat. We collected again during 1974 to determine if any change occurred.

The sample area was located from the Fish Barrier Dam at Oroville to the Live Oak Launch Ramp. The fish shocked were identified and counted. The length of time the electroshocker was activated while sampling was recorded.

We also collected from 1969 through 1974 with a floating fyke net (Figure 28). The fyke net was fished at Live Oak for at least one 24 hour period each week. All fish caught were measured.

Creel Census

Prior to 1970 our creel census was confined to the times of the year when American shad, striped bass, and king salmon were present. However, at the recommendation of the Board of Fisheries Consultants we expanded our creel census in 1970 to cover the months of the year we were not sampling (Appendix I; I-B and Figures 1, 2). The creel census then became a year-round project, with a census conducted on one day each week and two weekend days each month when possible.

The census was conducted by automobile to the various access sites, or by boat, which probably canvassed the anglers more thoroughly. The river was divided into three areas and later into four when in 1973 the river from the Thermalito Afterbay River Outlet to Oroville opened to fishing. The other three areas were Thermalito Afterbay River Outlet to just downstream from Live Oak, Marysville to Bear River, and Nicolaus to Verona. The Nicolaus to Verona area was only censused during the striped bass run, and only occasionally during the king salmon run for the years 1970, 1971 and 1972.

Results

SPECIES COMPOSITION

We found no change in the number of fish species encountered during the course of our studies from 1969 through 1974. Thirty-six (36) different species were collected and identified. Twenty-five (25) are considered true resident (i.e., non anadromous) fish while an additional two were given resident fish status since they can be found in the Feather River all year (Table 69).

A chi square test indicates no difference between years 1968 and 1974 for the catch rates of eight fish species sampled using the electro-shocker ($X^2 = 1.73$, where $X^2_{.05} = 14.07$ at 7 D.F.) (Table 70). However, a student's t-test comparing catch rates of individual fish between years indicate significant differences for two fish species. They are the Sacramento western sucker (*Catostomus occidentalis occidentalis*) and hitch (*Lavinia exilicauda*) ($t = 2.966$ and $t = 2.317$ respectively; where $t_{.05} = 2.20$ with 11 D.F.) (Table 70). We believe these results indicate actual population increases for the two fish species.

The catch rates for the riffle sculpin (*Cottus gulosus*) and carp (*Cyprinus carpio*) indicate a large magnitude of change between 1969 and 1974, however, the catch data for these two years overlaps to the extent that the increase is not significant. No significant decrease was found for any species.

From fyke net catches seven species of fish were found to occur in sufficient numbers to warrant mention (Table 71). These were the thread-fin shad, blue gill, squawfish, carp, Sacramento sucker, smallmouth and largemouth bass (Figure 85, 86). Nearly all fish caught were smaller than 150 millimeters in fork length and with few exceptions were judged to be immature or juvenile individuals at time of examination.

The small mouth and largemouth bass exhibited weak increasing trends over the 1969 to 1974 period, while the thread-fin shad and bluegill exhibit decreasing trends.

Creel Census

We found that few anglers fished for resident fish. During 1970-71 we interviewed only 92 anglers for resident fish, compared to 232 salmon anglers. The total estimated annual catch ranged from 392 fish during the 1970-71 season to 1,256 fish for the 1972-73 season (Table 72). Virtually all fishing occurred upstream from Bear River. Combining all fish caught, the catch per angler hour varied between 0.115 and 0.239 (Table 73). This is compared to a range of 0.028 to 0.056 for striped bass, and 0.018 to 0.053 for king salmon, which are species that attract considerably more anglers. Over 70 percent of the catch of resident fish was white catfish for each season except 1970-71 and 1974-75. Largemouth bass and smallmouth bass made the largest contribution to the angler's catch during 1970-71. Striped bass made the largest contribution during 1974-75 (Table 73).

The estimated seasonal values in Table 74 were derived as follows: Total Estimated Fish Caught = (Mean Number Fisherman per Day Censused) x (Days in Sample Season) x (4 hours per Angler-Day) x (Observed Season Total Catch per Angler-Hour).

Discussion

Species Composition

The changes in water flow and water temperature in the Feather River since completion of the Oroville Project have not altered the number of fish species present since 1968.

Of the 36 species collected, 19, or over 50 percent, are not native to California; the remaining 17 are indigenous to the Sacramento River drainage system. The only native centrarchid to the Sacramento River system, the Sacramento perch (*Archoplites interruptus*), was never seen during the course of this project.

Of all the fish found we least expected to find the introduced logperch (*Percina caprodes*). This is a range extension for this species in California. Moyle, Fisher, and Li (1974) report recent records of logperch in the Sacramento-San Joaquin River system, but none are from the Feather River. This is unusual since the original introduction of the logperch was in the Yuba River drainage, a tributary of the Feather. It probably reflects the fact that ichthyologists have not collected from the Feather in recent years.

The Sacramento sucker and hitch, the only species shown to have increased from 1968 to 1974, can be found the entire length of the Feather River and its drainage system. We can not attribute these increases to the changes in water flow and temperature created by the Oroville Project since the increase in population probably is a result of emigration from Lake Oroville. Our studies found large concentrations of suckers and hitch only in that portion of the river adjacent to and just downstream of the Feather River Hatchery to Bedrock Park in Oroville.

We are not surprised that our fyke net catches only sampled the smaller fish since fyke nets are known to be highly size selective. Because of wide variability in survival of year classes of juvenile fish, even when adult numbers remain stable, it is not relevant to use their abundance an an indication of population change.

These seven species of resident fish found in the fyke net catches can be found in the Oroville Lake, Forebay and Afterbay Complex in substantial numbers. We believe these net catches are a direct result of emigrations from these areas.

Creel Census

Anglers who fish for resident fish are not as numerous as those who fish for striped bass, American shad, king salmon, and steelhead. Most fishing occurs during the late spring and summer months when there is little or no fishing for anadromous species.

Conclusions

1. The changes in water flow and water temperature in the Feather River since completion of the Oroville Project have not altered the number of fish species present since 1968.
2. We conclude that except for the Sacramento sucker and hitch, pre- and post-project population levels of resident fish are not significantly different.
3. The fishery for resident fish is an excellent fishery at present, with white catfish dominating the catch.