Effects of screening diversions on fish populations in the Central Valley: What do we know?

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Peter B. Moyle and David White
University of California, Davis

Introduction

There are at least 3,356 diversions for taking water from the Sacramento and San Joaquin Rivers, their tributaries, and the Delta (Herren and Kawasaki 2001). 98.5% of these diversions are "either unscreened or screened insufficiently to prevent fish entrainment" (Herren and Kawasaki 2001, p. 343). Most of the diversions are small (diameters of intake pipes less than 40 inches) but many large diversions exist as well. In general, the larger the diversion, the more likely it is to be screened and diversions that take a significant percentage of river flow are almost always screened [Need verification and numbers here]. Small diversions on small streams can also take a significant percentage of the flow and are often subject to screening if the stream is regarded as important for spawning of anadromous fish.

Diversions are widely assumed to be killing large numbers of fish, especially salmon and steelhead. Thus, in the California Department of Fish and Game's (DFG) 1993 action plan for restoring Central Valley streams, 11 of the 32 top (A-1) priorities for protecting anadromous fish are screening or installing "fish protective devices" on diversions. Likewise, the CALFED Ecosystem Restoration Plan (1998) lists unscreened diversions as an important stressor on populations of salmon and other fishes and indicates elimination of unscreened diversions should be a high priority action. Not surprisingly, therefore, two suggested "performance indicators" for the CALFED ERP are the number of unscreened diversions and the proportion of water that flows through unscreened diversions (Pawley 2000).

In order to keep fish, especially juvenile salmonids, from being entrained in these diversions, the State of California has enacted fish screen requirements under three sections of the DFG code (Odenweller 1994). Diversions constructed or altered since 1972 must be screened by the diverter, if DFG thinks they will entrain salmon or steelhead. DFG must evaluate older and larger (more than 250 cfs) diversions to determine the impact of each diversion on fish. If screening is required, the cost is usually split between DFG and the diverter. DFG can also require screens on small pre-1972 diversions, but the agency has to bear the entire cost of screening. Requirements can be waived by DFG if the request is supported "by a report, prepared by the diverter, which includes data from onsite monitoring and a review of historical entrainment and diversion data (DFG, Statewide Fish Screening Policy, June 19, 2000)."

In addition, the National Marine Fisheries Service and USFWS often require screening to protect fish species listed as threatened or endangered under the Endangered Species Act, the Federal Power Act, and the Fish and Wildlife Coordination Act (see http://swr.ucsd.edu/hcd/fishscrn.htm). A major justification for screening under the ESA is that any removal of individuals of threatened or endangered species by a diversion constitutes "take" under the 4(d) rule and must be prevented, even if there is no demonstrable effect on the species at the population level.

The Anadromous Fish Restoration Program of USFWS has developed guidelines to prioritize screening projects of the Central Valley Project Improvement Act. Factors taken into account include location of the diversion in relation to areas used by anadromous fish for spawning and rearing, size of the diversion (or percent flow diverted in tributaries), season of diversion in relation to anadromous fish use of the stream or reach, and placement of the diversion (USFWS 1999, CVPIA Anadromous Fish Screen Program: Program Description). For the ERP program, the Fish Screen and Ladder Construction Panel uses the following criteria (as listed in the 2002 proposal solicitation package) to evaluate proposals:

- Diversions taking a greater proportion of flow;
- Location in terms of potential impact on fisheries;
- Implementability (minimal legal, regulatory, and technical obstacles);
- Partnerships/opportunities;
- Cost i.e., is the budget reasonable and adequate for the work proposed).

There is no question that screening diversions, especially large diversions, is an important component of fish conservation programs for the Central Valley and the Delta. However, for a variety of reasons, many diversions have remained unscreened or have poorly functioning screens. The establishment of the CALFED Ecosystem Restoration Program made money available for new and improved screens and, as of 2000, around $20 million in ERP funds (12.5% of the total dollars spent by ERP) had been allocated to screening projects. In 2002, there were 17 applications for ERP funds related to fish screens, totaling over $55.6 million. Because applications for the use of ERP funds for screening are frequent and large and because fish screens need continuous maintenance, repair, and replacement, a serious evaluation of their overall effectiveness in increasing or maintaining populations of anadromous and resident fishes, especially endangered species, is needed. Basic questions that need to be answered include:

1. In the absence of screens, how many fish, and what kinds, are entrained by the remaining unscreened diversions?
2. Given expected losses in the absence of screens, what are the likely population consequences of screening the remaining diversions, particularly for listed or declining species?
3. What is the relationship between fish entrained in unscreened diversions and amount of water diverted?
4. Is it more beneficial to screen some diversions than others, based on size, location, and mode of operation?
5. Are there alternatives to fish screens for many diversions?
6. Are there detrimental effects of screening, including changes in fluvial and riparian processes or enhancement of predation on species of concern?
7. Given the above considerations, how do additional screens compare with other potential restoration actions in a cost:benefit analysis?

The purpose of this paper is to review the literature to determine if studies already exist that might answer the questions posed above. The review focuses mainly on studies in the Central Valley and Delta, with most attention being paid to the Sacramento and San Joaquin rivers.

Methods

The literature review was conducted in March-June, 2001. The first step was a cross-database search of the California Digital Library (CDL) for publications containing any of the title words "California Fish Screens." The CDL is a collection of 47 digital databases that has a search function "SearchLight" that enables a coarse but rapid search of chosen databases. Searchlight identified 19 databases that contained at least one article with California fish screens in the title. It was found that searching by "any title words" rather than by the subject yielded far more results. Once these 19 databases had been identified, each was searched separately using its own search function, if available, or by the CDL's search function if not. The articles were then segregated into categories according to what topic of California fish screens they addressed. Because we were interested specifically in the effects of screening projects on fish, additional searches were conducted by examining the bibliographies of articles located in the computer search as well as through personal contacts. We recognize that our search, based on a few key words and mainly scanning of titles, is incomplete, although this was necessary to complete the project in a short period of time. Nevertheless, the ability of the search to find large numbers of reports in the gray literature suggests that it caught most major studies relating to the Central Valley and at least a representative sample of other studies. For the purposes of analysis, we divided the studies into the following categories:

1. *General Reviews*— This category includes reports and documents of the broadest scope. Typical are descriptions of current screening programs, the history of fish screens in California, screening policy and compliance, surveys of fish conservation devices on waterways and reviews of the many different types of fish screens.
2. *Facility Reports*— This category includes all articles concerned with the design, construction, operation and maintenance of fish protection facilities on the Delta and the Sacramento and San Joaquin Rivers, including feasibility and environmental impact reports, environmental assessment reports, physical model studies, technical design documents, studies of value engineering, and construction progress reports, design and technical details of existing facility operations and maintenance, reports on invasive species at water diversion facilities, fisheries evaluations, testing of different screen types in an operating facility, hydroacoustic and hydraulic studies, water velocity studies in an operating facility, and debris and sedimentation studies.
3. *Fish Losses*— This category includes all field surveys and estimates of Delta, Sacramento and San Joaquin River fish losses due to water diversions. This literature includes facility collection numbers, evaluation program pilot studies, evaluation program summary reports, egg and larvae entrainment reports, juvenile entrainment studies, mark and recapture experiments to determine pre-screening

predation losses, predator control studies, and several estimates of fish entrainment losses associated with the SWP and CVP facilities in the South Delta.

4. *Literature Reviews*— The only paper in this category is a 1959 review of the literature on fish screens.
5. *Economic Costs of Fish Screens*— This category included an estimate of the magnitude of screening costs for water diversions on the Delta and the Sacramento and San Joaquin Rivers, and a report on economic costs to the state water project of environmental protection and mitigation measures.
6. *New Technology*— Includes technical design documents and evaluation reports on acoustical fish barriers, screen designs, aquatic filter barriers, bypass systems, sand and gravel filters, attraction flow alternatives, and Archimedes and helical lifts that are being tested as potential new fish passage, fish barrier and alternative flow technologies.
7. *Laboratory Studies*— Includes all studies related to fish screens that were performed in a laboratory environment. Typical articles in this category were studies of the behavioral or physiological response of fish near fish screens, swimming stamina studies, or studies of physical parameters near specific types of fish screens such as water velocity.

Once we had the literature sorted in the above categories, we further refined the search to screens on certain kinds of diversions. Broadly speaking, there are five basic classes of diversions in the Central Valley

1. The large pumping plants in the South Delta by the State Water Project and the Central Valley Project.
2. Other large Delta diversions (power plants, etc.)
3. Small (mostly < 40 cfs) diversions within the Delta
4. Large diversions (>250 cfs) on the main rivers and tributaries that mainly serve large irrigation districts.
5. Small diversions along the rivers and their tributaries.

The "screens" on the pumping plants of the South Delta and other large diversions are large and specialized facilities with their own particular problems, so will not be discussed here. The hundreds of small diversions in the Delta are the subject of a review paper by Marianne Kirkland of DWR (under preparation, personal communication) so will be treated here only briefly. Therefore this analysis will deal mainly with the latter two categories of screened diversions.

Results

General results

255 articles related to California fish screens were identified. Most of the reports (153, 60%) discussed some aspect of the operation and design of facilities. Thirty-six (14%) of the articles dealt with some aspect of evaluating losses of fish in diversions in relation to screening, while 34 (13%) dealt with alternatives to fish screens (new technology). Other categories were general reviews of screening and fish passage problems and

technology (21), laboratory studies of fish impingement on screens, etc. (4), economic evaluations of screening (2), and a single literature review.

Of the 36 reports on fish losses, only 15 were related at least vaguely to effects of fish screens on fish populations in rivers and streams, the category of most interest here (see bibliography). Six were studies of small diversions in the Delta and Suisun Marsh. The rest (15) dealt with losses at the state and federal pumping plants in the South Delta.

For comparison with our results, we examined the bibliography maintained by the Delta Fish Facilities Study Program (http://iep.water.ca.gov/cvffrt/references.htm), which lists 75 reports spanning the years 1959-1986 (only). 13 of the reports (17%) dealt with some aspect of loss of fish to diversions in rivers and to small diversions in the Delta. Five of the 13 were not included in our bibliography because they were essentially interoffice memoranda or draft reports.

Riverine diversions.

Of the 15 reports on riverine diversions, 9 dealt with the largest diversions on the rivers, mostly (7) Red Bluff Diversion Dam on the Sacramento River, the largest of the diversions with very special problems related to its size. Two dealt with the Hallwood-Cordua diversion on the Yuba River (Hall 1979; Kano 1987). Two dealt with studies of predation losses in relation to fish screens because of indications that some screens increased predation rates on juvenile salmon by providing holding areas for predatory fish. Both were inconclusive. With the exception of three of the recent experimental Red Bluff studies, estimates of the numbers of fish lost to diversions or saved by screening large diversions are lacking.

Hallock and Van Woert (1959) was the only publication that attempted a fairly broad evaluation of fish losses in unscreened diversions. This paper is not particularly rigorous in its analysis (no statistics, limited data summaries), but it did attempt to evaluate losses of salmon for both mainstem Sacramento and San Joaquin rivers over a three year period, mainly by using fyke nets to sample water being diverted or by sampling irrigation canals. A variety of diversions were sampled, but most of the effort focused on the larger ones. Their findings, based on data presented in their tables, include: (1) more fish were lost to large diversions than small ones, although no relationship between size and numbers lost was developed; (2) total numbers of salmon lost in the diversions was surprisingly small and was attributed to low overlap with irrigation season and the main periods of salmon outmigration; (3) numbers of fish lost to individual diversions was highly variable among diversions and through time, but was often quite low; (4) many species were entrained but most abundant were chinook salmon, common carp, Sacramento suckers, white catfish, and small centrarchids. Hallock and Van Woert (1959) concluded "…appreciable losses of salmon in irrigation diversions now occur at few places on the [Sacramento] river itself above Meridian . Individually, most of the small irrigation diversions do not destroy many young salmon and steelhead. Collectively, however, they do take considerable numbers (p. 245)." "The 1955 studies on the San Joaquin River show that all of the large diversions sampled…are destroying appreciable numbers of salmon fry. This is not surprising, since between 20 and 40 percent of the entire river flow is pumped into irrigation canals during the period when salmon are migrating downstream… (p. 252)" "Appreciable numbers," in the latter case, meant an estimated 1.5- 12 juvenile salmon/ hour of diversion or approximately 31,000 fish for the entire season in three large diversions. Along the Sacramento River, about 9000 total hours of fyke netting in 23 diversion canals yielded about 1600 juvenile salmon, with a total estimated loss of less than 4,000 salmon for the season. Catches for common carp and Sacramento suckers were appreciably higher.

Overall, Hallock and Van Woert (1959) indicated that despite the mixed results from the surveys all diversions should be screened because of cumulative effects. The authors also indicated that they thought (without documentation) diversion losses were probably much higher in tributaries and results from the main rivers were therefore not representative of the problem.

In a study published after our literature search, Hanson (2001) reported experimental salmon losses at a diversion on the Sacramento River that diverted about 1% of the river's flow. When he released large numbers of marked, hatchery-reared chinook juveniles above the diversion, only 0.05% of the fish released were entrained, a result similar to an earlier study on another diversion. As Hanson (2001) points out, his use of hatchery fish, his release methods, and the particular configuration of the diversion limit the generality of his results.

In an unpublished study made available to us after the literature analysis was completed, DeLeon (1993) used methods similar to those of Hallock and Van Woert to evaluate a single 20 cfs diversion along the lower San Joaquin River, May-June 1993. She found it entrained only small numbers of non-native species (21 fish, 9 species, captured in 12 days with one-hour samples), about 0.08 fish/acre foot diverted. The extremely limited nature of this study restricts its value but it appears to one of the few such evaluations attempted.

Delta diversions

Diversions in the Delta and estuary have been studied more intensively than those in the rivers, mainly by DWR, because of potential effects on striped bass, salmon, and other species. Allen (1975), in a brief study, concluded that lost of striped bass eggs and larvae through small diversions was proportional to the number of fish in the river and the amount of water being diverted. Brown (1982), using minimal data, estimated that as many as 5-8% of striped bass larvae in the Delta were lost to small in-Delta diversions. He also estimated that, in 1976, over 71,000 juvenile salmon were lost, a number he thought was probably a severe underestimate of losses. Pickard et al. (1982) studied one diversion in Suisun Marsh. They netted the diversion for an unspecified number of hours on 12 days over a six-month period, and captured over 14,000 fish of 27 species. Most abundant species were Delta smelt, longfin smelt, threespine stickleback, and chinook salmon. No attempt was made to extrapolate to total number of fish lost. Losses of all species continued after the diversion was screened (due to holes in the screen, which were later repaired) but at much lower numbers.

Spaar (1994) evaluated four diversions in a "pilot" study and found that larvae were entrained at roughly their densities in the associated sloughs, with species captured more or less in proportion to their numbers in the sloughs as well. Screening one diversion significantly reduced numbers of fish being diverted. Most abundant fish in her study were shimofuri goby, threadfin shad, bluegill, western mosquitofish, white catfish, and centrarchids, all non-native fishes. Most fish were captured as eggs and larvae although small numbers of juveniles were captured as well. Although the three diversions studied were estimated to entrain over 3 million eggs and larvae in a season, over 85% were those of shimofuri goby (invading explosively at the time, 1992) and threadfin shad (an abundant planktivore). In a study comparing the take of fish in a diversion with a screen in place with take with the screen removed, Wadsworth (appendix in Cook and Buffaloe 1998) found screening reduced take of larval fish by a factor of 5-10. In a three-year follow-up study, Cook and Buffaloe (1998) concluded they could not develop quantitative estimates from their study because of sampling problems. They nevertheless noted (p. 13) “The results of this study… suggest that small-scale diversions …can entrain a large diversity of fish species … The actual number of entrained fish can be large.” They noted that benthic fishes were more likely to be entrained than pelagic fishes, although threadfin shad and striped bass were commonly captured. Only a few individuals of delta smelt, splittail, and chinook salmon were captured; most fishes taken were non-native warm-water fishes. Cook and Buffaloe concluded (p. 14):

“It is not presently possible to identify the proportional effect of…agricultural diversions… on resident and migratory Delta fish. This is due mainly to our inability to quantify populations sizes and demographics in an open and highly variable system…Because we lack this information, we cannot relate data from fish captured in diversions to population level effects on species in the system. Futhermore, because environmental variables … change over time and because fish behaviors are complex and variable, the ability to predict future impacts does not exist.”

Conclusions

It is fairly clear that the effectiveness of screening diversions in the Central Valley, especially those on streams, has not been well evaluated. Not only are pre-screening studies few, but published studies to demonstrate how well existing screens are working are even fewer. Existing reports are primarily in-house documents by agency staff that have gone through little or no outside peer review. The few evaluations available focus on large diversions, the pumping plants in the South Delta, and small Delta diversions. Not surprisingly, there are at best only limited answers to the questions posed in the introduction.

In the absence of screens, how many fish, and what kinds, are entrained by the remaining unscreened diversions? There is no doubt that at times large numbers of juvenile salmonids and various other species of concern are entrained by diversions, especially by large diversions or small diversions on spawning tributaries. Yet the quantification of this is very poor. The few studies that exist tend to find that alien species or abundant natives (e.g., Sacramento sucker) are the principal species diverted, especially in small (<40 cfs) diversions. Diversions that have been perceived to be major problems (mainly large riverine diversions) appear to have been screened, so the remaining unscreened diversions are mainly small ones. The existing data suggests that such diversions, especially on main stem rivers, have low or no impact on fish populations although little definitive can be said about this issue until studies are undertaken to evaluate both individual and cumulative impacts.

Given expected losses in the absence of screens, what are the likely population consequences of screening the remaining diversions, particularly for listed or declining *species?* As indicated, answers to this question cannot be given based on existing data. Answers that *are* given are perhaps reflected in the list of benefits of screening diversions on small streams given by J. Bybee of NMFS in a memorandum to the ISB prepared by the Central Valley Fish Facilities Coordination Team (June 20, 2001):

"First, installed fish screens remove the potential legal burden of taking an ESA listed fish. Second a screen compliments habitat restoration in particular watersheds and is a vote of confidence that increased fish production in a small stream is not in vain. Third, fish screens will probably be identified as an action in Recovery Plans. Fourth, steelhead occur in these small streams, often year round, being subjected to entrainment continuously during the diversion season. Fifth, fish screens are probably also effective in keeping more than listed fish in the streams; certain other species of fish and macroinvertebrates of importance to the ecosystem are also saved."

Implicit in this answer is the importance of saving fish and invertebrates at the individual level, regardless of population consequences, for largely social and legal reasons. Also implicit is application of the *precautionary approach* to fisheries management (Dayton 1998) that diversions should be assumed to harm fish populations unless it can be proven otherwise. The latter is perhaps the best reason for screening but it still does not remove the need for evaluation studies.

What is the relationship between fish entrained in unscreened diversions and amount of water diverted? Surprisingly, this seems to be poorly understood, at least in the Central Valley. It is obviously a complex relationship, with high seasonal and year-to-year variation, yet it would seem amenable to modeling, provided adequate experimental data existed. Developing this relationship would seem worth pursuing as a way to get a handle on cumulative effects of diversions.

Is it more beneficial to screen some diversions than others, based on size, location, and mode of operation? At a gross scale, the answer to this question is a fairly obvious " yes." However, once the clear problem diversions are identified and screened (which they have mostly been), there are still several thousand left. While the ERP Fish Screen and Ladder Construction Technical Panel includes these criteria in their evaluation of projects for funding, it is not clear that adequate data actually exists to make the decisions based on studies rather than just intuition and experience.

Are there alternatives to fish screens for many diversions? For the most part, it appears that fish screen proposals are to screen or not to screen, with alternatives not considered seriously, such as changing the timing of water diversion or adjusting the volume in relation to the presence or absence of fish of concern.

Are there detrimental effects of screening, including changes in fluvial and riparian processes or enhancement of predation on species of concern? Responses to this question by members of the CVFFCT in their June 20, 2001 memorandum the ISB suggest that these problems are of small concern either because the problems exist mainly around existing large diversion structures or because they can be handled by proper design of new screening facilities. We suspect the responses are correct but hard information to support the conclusions seems to be lacking.

Given the above considerations, how do additional screens compare with other potential restoration actions in a cost:benefit analysis? This should be an important consideration for the ERP because of the costs of screening and the costs of other ecosystem restoration actions are both high and funds are limited. We suggest that each screening project should have a high, well-defined benefit to fish populations as demonstrated by careful studies. Benefits that are largely in terms of limiting "take" of individuals under the ESA, seem inappropriate for ERP funding.

Most screening projects today are built to keep diverters from killing endangered species (mainly spring run and winter run chinook salmon and steelhead), although the desire to protect fisheries is also an important rationale. But we simply do not know if screening *every* diversion or *any* particular diversion makes a difference to fish populations, even those of listed species. Some screens may even be detrimental because of increases in predation rates on juvenile salmon and other fish. Screening diversions has no doubt slowed population declines or even prevented extinctions of local populations of salmon and other fishes but the cumulative contribution of this screening to survival has not been evaluated since Hallock and Van Woert (1959), a study whose results are equivocal. Costs of constructing new screens and replacing and maintaining old ones are high and funds for ERP projects are limited, so evaluations of new projects in terms of both local and cumulative impacts on fish populations is in order.

It is important to recognize that this report is **not** saying that diversions, even small ones, are unimportant as sources of mortality for juvenile salmon and other fishes, including endangered species. Given their large number and volume of water diverted, they clearly can divert large numbers of fish and potentially impact fish populations. Fish screening and/or operating diversions to minimize loss of fish can be important conservation tools. What is lacking is the means to prioritize screening projects, aside from size and location, or to find alternatives to them. There should be a prioritization scheme based at least in part on the contribution of the diversion to the cumulative loss of fishes to the system and the impact of this contribution on fish populations, especially those of declining species. Such an evaluation could help determine priorities for spending limited funds available for fish conservation.

As a final note, it is worth pointing out that the lack of information on the effectiveness of fish screens is not just a local problem. Fisheries agencies have historically not bothered to evaluate overall effectiveness of fish screens because screening has seemed so obviously beneficial to fish. Leitritz (1952), in a review of fish screens in California doesn't mention a need to evaluate their effectiveness, except in terms of screen design. Odenweller (1994) in a popular article on fish screens in a DFG magazine answers the question "Why are they necessary?" only with "Fish screens are necessary to prevent loss of fishery resources at water diversion sites." The implication is that without screens, fisheries will be lost. This attitude is reflected in the book *Inland Fisheries Management in North America* (C. C. Kohler and W. A. Hubert, eds., 1999), published as a review of fisheries management by the American Fisheries Society. In this book, fish screens are mentioned just twice in single sentences, e.g. "Fish screens are used to keep fishes out of particular reaches of streams or to keep game fishes or endangered species from entering irrigation diversion canals …(p. 424)”. Considering the millions of dollars spent on fish screens nationwide, but especially in California and the West, the lack of systematic analyses of their effectiveness by fisheries biologists is curious.

Recommendations

Until the basic questions posed above are answered, it does not seem appropriate for the CALFED Ecosystem Restoration Program to be funding fish screening projects that do not have a strong evaluation component to them, including intensive before and after studies. Under an adaptive management framework, the “before” study should be evaluated by independent experts to see if clear population benefits are demonstrated. If they are not, the project should not be built with CALFED ERP funds. We appreciate that the regulatory agencies generally work on the philosophy that diversions should be assumed to be doing harm to fish populations unless it can be proven otherwise. While we agree with this philosophy, the fact remains that funds for conservation projects are limited. We think it *is* appropriate for ERP funds to pay for a study on the population benefits of screening small diversions, including a cumulative effects analysis of existing screens. We also think that ERP should develop a clear policy towards funding fish screen projects (beyond the policy developed in the latest ERP RFP).

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