A Summary of the

June 22 -23, 2005 Predation Workshop, Including the Expert Panel Final Report

by
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for
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Sponsored by
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and
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Preface

In this report we provide a summary and commentary on the June 22-23, 2005 workshop convened by the CALFED Science Program and the California Department of Water Resources (DWR) to examine questions associated with the losses of Chinook salmon, steelhead, delta smelt, and other fish at the southern Delta intakes to the State Water Project and the federal Central Valley Projects pumping plants. More than 60 people attended the workshop (see attachment 1) including an expert panel consisting of:

- James Cowan, PhD, Louisiana State University, Baton Rouge. LA
- Kyle Hartman, PhD, West Virginia University, Morgantown, West Virginia
- Ed Houde, PhD, Chesapeake Biological Laboratory, University of Maryland, Solomons, MD
- James Peterson, PhD, Biological Resources Division, USGS, Cook, WA
- Andy Sih, PhD, University of California, Davis, CA

An interagency workshop planning committee (attachment 2) helped organize the workshop with committee member Bruce Herbold (USEPA) moderating the workshop. The workshop format (attachment 3) provided considerable time for discussion, and for the expert panel to present and discuss their preliminary findings. We include the panel's final report as attachment 4. Finally, we also present our views of the reasonable next steps in predation related issues in the Delta.

Several terms used in this summary have specific local meaning and the following may help readers not familiar with the terminology:

- *Fish protection facility*. As used in this report the fish protection facilities include the trash racks, the fish screens, the bypass system that moves the fish from the screens to holding tanks, the holding (and counting) tanks, and the loading and trucking system used to move the fish from the screen area to the Delta. (See Brown et al. 1995 for a more detailed discussion of the salvage facilities and process including a schematic diagram.)
- *Salvage or expanded salvage*: Fish in the water to be exported are concentrated by primary and secondary louvers (screens) and move into holding tanks through the bypass system. Samples of the fish in the holding tanks are taken periodically (generally, 10 minutes of every 2 hours) and the fish are identified, measured, and counted. The sample counts are then expanded by dividing by the fraction of time sampled to arrive at an estimate of the total fish salvaged during the counting period. Periodically all fish in the holding tanks are transferred to tanker trucks for release back to the Delta.
- *Entrainment*. Fish that enter (are entrained into) the project intakes.
- *Impingement*. Fish that are impinged on the face of fish screens due to high through-screen velocities or poor swimming ability or both. Generally this is not a factor with the Delta louvers, which are behavioral barriers with screen openings large enough that fish are not generally impinged. Note that the new secondary in the SWP fish protection facility (constructed in the 1980s) is a positive barrier (holes smaller than the fish) where impingement is possible.)

- *Take or loss*: For listed species this is the number of fish estimated to have been killed at the facility. For salmon take is the total number of fish per day that either are lost to predators in the channels immediately in front of the facilities, pass through the louver screens, or are lost during handling and trucking. Delta smelt and steelhead numbers are not so expanded since there is no information on their losses to predators and screening efficiency. For these fish take is defined as salvage.
- *Direct losses* are losses of fish directly attributable to operation of the facilities, i.e., take for listed species as defined above.
- *Indirect losses* are losses of fish occurring remotely from the facilities, postulated to arise due altered Delta hydrodynamic conditions caused by water project operations. These effects could arise through alteration of cues for migration by anadromous fish – for example, if project operations and resultant flows were to cause salmon to enter the interior Delta where they take longer to move out of the Delta and into Suisun Bay (and thence the ocean) and can suffer increased predation.

Background

The workshop presentations and discussion focused on issues related to predation on fish species of concern in and near the water export facilities in the south Sacramento-San Joaquin Delta (Delta). The State Water Project Banks Pumping Plant and the federal Tracy Pumping Plant have a combined capacity to divert more that 15,000 cubic feet per second (cfs) to canals and pipelines that transport the water for use in the San Francisco Bay area, the San Joaquin Valley, the central coast and southern California. The intake canals to the pumps have fish protection facilities to separate many of the fish from the water being exported - the Skinner Fish Protective Facility and Tracy Fish Facility, respectively. The fish "salvaged" at these facilities are held in large tanks, and estimates are made of their numbers, before the fish are put into trucks and returned to the estuary.

The predation issue addressed at this workshop arises because the fish entrained are subject to predation by striped bass and other fish. This predation is exacerbated by the presence of physical structures and the configuration and operations of the facilities. Of particular interest are the losses of species listed as endangered (winter Chinook), threatened (delta smelt, spring Chinook, and steelhead), or otherwise of concern (for example Sacramento splittail). Since predation occurs before the salvaged fish are counted, it also complicates efforts to quantify losses of fish at the facilities because the predation losses of most fish are poorly known even for Chinook salmon and striped bass and unknown for other species.

The state and federal fish protection facilities are about one mile apart in the southern Delta near the town of Tracy and the village of Byron. They differ in their configuration: the federal facility takes its water from an adjacent channel, whereas the state facility draws water from a tidal impoundment, the Clifton Court Forebay (CCF). Radial gates at the southeast corner of the CCF are opened periodically to allow water from Delta channels to enter, usually near high tide. This intake configuration is believed to cause high predation losses at the state facility - mainly because fish entering the forebay have to transit it before encountering the fish screens. The estimated high predation losses at the SWP are supported by experimental results and predator abundance studies. The results, as discussed at the workshop, leave room for alternative interpretations. For purposes of calculating take, predators are assumed to remove 75% of the juvenile Chinook salmon entering the state facility, and 15% of those entering the federal facility. The state value is based on mark-recapture studies (Table 1, page 12) in which 63 to 99% of the juvenile Chinook salmon disappeared between the release point inside the forebay and the holding tanks, with the lost fish assumed to have been eaten.

The 75% was developed during 1986 negotiations leading the DWR-DFG Four Pumps Agreement (aka the 2-Agency Fish Agreement) and was the average of three most reliable estimated loss rates available at the time. The 15% loss rate for the federal facility was based on studies of predation at structures in water, not from studies conducted at the intake to the federal facility, and was considered a placeholder until biologists obtained an estimate based on actual loss data. The 15% is still a placeholder.

Workshop goal

With the help of an expert panel, determine if there are additional studies and or analyses needed to help managers agree on a course of action aimed at reducing predation losses at the water facility intakes.

Workshop objectives

- *Review the basis for current predation loss estimates for Chinook salmon at the fish facilities.*
- *Review new work and approaches for estimating losses of steelhead at the SWP intake and predation-related studies at the CVP intake.*
- *Develop an understanding of the hydrodynamic and operational system that leads to fish entrainment and losses.*
- *Develop an understanding of physical and operational changes being contemplated to reduce predation losses at the water facility intakes.*

Workshop products

The workshop results, conclusions and recommendations, are documented in this summary report submitted to the CALFED Lead Scientist, attendees, and agency managers for their consideration. The expert panel's complete report is appended to this summary (Attachment 4).

Report Organization

We start with the recommendations by the Expert Panel (extracted from their final report – attachment 4) followed by comments and recommendations by the authors of this report in their role of Calfed Science Program advisors. The workshop summary follows. Readers are urged to read the summary, the full panel report and to view the individual PowerPoint presentations found on the Science Program website and reach their own conclusions.

Recommendations of the Expert Panel

Recommendations on the need to quantify and model predation potential in CCF. The panel was unanimous in its conclusion that a more mechanistic understanding of the predation process and predator/prey interactions is required to address the problem.

1). ***The spatial overlap of predators and prey must be quantified at various temporal (seasonal, diel) and spatial (within the CCF and SWP facilities) scales***. Relationships between predator distribution and abundance and variables such as flow, temperature, depth, SAV coverage, etc. should be quantified, mapped and modeled statistically, along with similar relationships between prey abundance and patterns of delivery into the CCF. The panel was impressed with the progress being made along these lines by using ultrasonic tagging and other mark/recapture approaches and recommends that this type of work be expanded.

2). ***Size and time-specific diet data must be collected for predator populations in the CCF.*** Because the diets of predators are likely to change with respect to season and to predator size, monthly diet data across all species and size-classes of predators over multiple years will be necessary to adequately describe predator/prey interactions, and to inform bioenergetics modeling. It may also be possible to determine if predator swamping occurs, especially if swamping is attributable to alternative prey species such as American shad, thus reducing predation potential on the species of concern.

3). Size and growth rate data must be collected for both predators and prey to determine temporal and spatial variability in prey susceptibility to predators in the CCF and the SWP facility, and to inform bioenergetics models for predicting predation potential. ***Such data can be used to determine what fraction of the prey that enters the CCF is actually vulnerable to predation. These data also provide the basis for comparisons of predation potential in the CCF relative to other locations in the delta.***

*4**). The degree to which predators and especially prey are free to move into and out of the CCF must be evaluated, along with residence time of prey within the CCF.***

5). ***Although not related directly to this CCF issue, the degree to which predation occurs when salvaged fish are released must be quantified.*** Predation pressure could be reduced by alternative release procedures if predators have become conditioned to respond to releases at fixed locations

6). ***Begin to build integrated models, including bioenergetics models, that will combine data and information on the effects of systems hydraulics, predator and prey behavior as it affects species-specific vulnerability to predation, and predation potential.*** Once constructed, these modeling tools could be applied to evaluate management scenarios and hypotheses that reduce the risk of salmon smolts and steelhead to predation in the CCF.

Neglecting delta smelt in the recommendations above is not an oversight. Rather, because delta smelt rarely survive the salvage process and are unlikely to be able to exit the CCF when the gates are open, the panel infers that once delta smelt enter the CCF, mortality may be a foregone conclusion, whether they are consumed by a predator or die during salvage. **As such,**

the panel believes that the best course of action is first to determine the magnitude of losses of all life stages of delta smelt attributable to operations of the SWP, including delivery to the CCF, and impingement, entrainment and predation in the CCF and SWP facility. If these losses are deemed to be significant at the population level, the panel believes that options to limit losses of delta smelt to pumping are more limited than those possible for salmon smolts and steelhead, and should emphasize those factors that will limit smelt delivery to the CCF and, later, to the pumps.

7). ***The efficiency of the louvers in screening delta smelt > 20 mm from entering the SWP must be evaluated.*** Even small changes in louver efficiency could have dramatic effects on losses of adults to the pumps, particularly in winter months prior to spawning when shallow waters near the SWP warm more quickly than elsewhere in the delta.

8). ***All operational options that have the potential to reduce the delivery of delta smelt (of any life stage) into CCF must be evaluated***. The panel was impressed by results presented by Cathy Ruhl, who showed with particle tracking experiments that prey delivery into the CCF possibly could be managed by varying when and how the CCF was filled, and believes this type of work should be expanded. Short of reducing pumping rate, flexibility in modifying the engineering of the system must be explored as it effects delivery of water containing delta smelt into the CCF, including such options as filling the CCF more slowly, and/or on ebbing tides, etc. This approach also should be informed by any aspect of smelt behavior that can be used in conjunction with SWP operations to reduce prey delivery.

Comments and recommendations by the Advisors to the CALFED Lead Scientist

Our general comment is that readers should carefully consider the expert panel report and recommendations. If the IEP, DWR or the Calfed Science Program decides to pursue any of the recommendations, they should probably engage one or more panel members to help plan, or even conduct, studies or analyses as part of any rethinking of intake design or changes in operations to reduce predator impacts.

We also have the following specific comments and recommendations:

1. Before beginning any extensive new data collection the agencies should evaluate:
    - The relative population level impacts of estimated losses to predators on winter and spring Chinook populations. Additional work would only begin when there was strong evidence that these losses were major factors in controlling population abundance. The same general comment applies to delta smelt even though it is not now possible to calculate predation losses at the intakes.
    - Where the agencies are going with CVP and SWP facilities in the Delta. Will the intake to the SWP be modified? Will DWR increase maximum export flow to 8,500 cfs? What will the USBR do about modifying (fixing) their existing fish protection facilities? How will the new “Delta Vision” affect the way the facilities are designed and operated?
2. Until the above has been done we recommend that:
    - The agencies continue to use the 75% predation loss factor for Chinook. This is based in part on the panel’s conclusion that the current predation levels are not

well supported technically. It is also based on a limited sensitivity analysis using the average of all predation studies (about 87% loss rate) and USFWS estimates of indirect losses due to project impacts. For winter Chinook these rough calculations indicate that direct and indirect losses are higher than the postulated actual population. We recommend that this sort of sensitivity analysis be conducted in a more quantitative fashion.

- For steelhead, continue the interesting work Hanson described at the workshop. Some of his findings may be applicable to Chinook, although steelhead test fish are much larger than the Chinook appropriate for this type of study.
- Continue to assume that all delta smelt entering the CCF are lost either to predation, through the screens or during the salvage process. Salvage estimates for delta smelt have unquantified and potentially large uncertainties and may not be useful for estimating the number of fish entering the CCF. Current analyses that are part of the IEP's Pelagic Organism Decline studies may yield more insight into the role of losses at the intakes to controlling population levels.

3. Two additional workshops on predation issues have been suggested:
    - We recommend that the IEP coordinators and DWR's Delta office appoint a small group to discuss predation throughout the Delta, particularly as affected by water project operations and focusing on Chinook and steelhead. The outcome could be a recommendation to hold an additional workshop on this topic, sponsored by the Calfed Science Program.
    - The time is not quite ripe to hold a workshop on losses of fish to predators at the end of the salvage release discharge pipes. The current IEP collection, handling, and release studies will provide the data and information that would be discussed at such a workshop. Only the program staff and managers will know when they have enough information for a workshop. The Calfed Science Program could be asked to help sponsor this workshop to provide an independent review of study findings, conclusions, and implications.

Workshop Summary

Note that in the following summary we have extracted what we consider to be the major points from the individual presentations and have not included the figures. The PowerPoint presentations are posted on the Calfed website along with this summary and readers are urged to review them for more details. We take full responsibility for the contents.

Introduction, Randy Brown, CALFED

Randy set the scope of the workshop, emphasizing that it was to cover direct effects at the facilities only, and not effects occurring further out in the Delta. Randy also laid out the goals and objectives and workshop procedures. This workshop is considered to be the first in a possible series of workshops dealing with predation in the Delta. A second workshop would cover predation losses away from the project intakes – that is, the indirect losses due to project operation. A third workshop would deal with losses of the transported fish to predator populations in the vicinity of the points where the salvaged fish are released. (The fish from the transport trucks are released into permanent pipes several miles from the intakes with their outlets below the water surface.) Current Collection, Handling and Transport and Release studies (CHTR) are expected to have specific results about predation at the end of the release pipe in a couple of years.

Randy also pointed out that existing agency and CALFED planning programs could result in increased Delta exports and operational and facilities changes. DWR's South Delta Improvement Program and CALFED's Delta Improvement Package are considering physical and operational changes that are intended to minimize losses of listed and other sensitive fish species at the project intakes. Information from this workshop will feed into those planning processes.

An overview of the fish salvage process at the state and federal water project intakes – Darryl Hayes, CH2M Hill and CALFED

Darryl described the fish facilities including their location, operations, and history, focusing mainly on the state facility. The principal difference between the two facilities is that, since the State facility takes water from CCF, it is less affected by changing tidal stage than the federal facility which must pump water continuously at whatever water level exists. The state facility also has more than twice the pumping capacity and often uses this capacity to pump during off-peak hours to minimize energy costs. This pumping strategy, and the use of the intake gates to CCF, can result in large quantities of water quickly entering the forebay when the gates are opened at or near high tide. Not pumping during the on-peak hours can also result in entrained fish remaining in the forebay longer (making them more subject to predation) than if pumping were around the clock.

The federal Tracy fish facility was built in the 1950s, and the state Skinner facility in the late 1960s (and extensively modified in the 1980s), both principally to protect striped bass and Chinook salmon. Fish are separated from incoming water by two sets of louvers (primary and secondary) with openings along the faces of the primary louvers (like slanted Venetian blinds) of 26mm, which means that these fish screens operate behaviorally – i.e., fish that could physically go through the screens are deterred from doing so by the turbulence generated along the louver face. Small, weakly swimming fish, such as juvenile delta smelt, go through the louver openings and down the canals to the pumps and thence to the Delta Mendota Canal and the California Aqueduct for the state and federal facilities respectively. Most of the bigger fish (fish larger than about 20-25 mm) move down the faces of the primary louvers to a bypass pipe and thence to the secondary louvers where they are further concentrated. (The remodeling completed by the state in the 1980s included a new positive barrier, flat plate screen secondary. This screen has 3/32 inch openings.) Fish screened by the secondary system enter another bypass and then the holding tanks. At intervals depending on fish density in the holding tanks and other conditions (but no longer than 8 hours), fish are lifted into a tanker truck for transfer and release at one of four sites in the Delta (two for each facility).

Darryl discussed the timing of operation of the radial gates at Clifton Court Forebay. The purpose of the forebay is to allow flexibility in pumping and to reduce water level impacts in the south Delta. However, at high pumping rates the gates may be open most of the day. Gate operations schedules are available on the DWR Operations web site.

Darryl described the calculations of fish loss (take) at the SWP intake, which it is useful to report here. These calculations were part of the DFG-DWR agreement (the Four Pumps agreement – also called the 2-Agency Fish Agreement)) signed in 1986 and are used to calculate the losses of striped bass, Chinook salmon and steelhead for purposes of defining DWR's mitigation obligation. The overall equation for determining loss is:

$$Loss = N_0 - N_R = \frac{C_{\exp}}{(1-L_P)E} - C_{\exp}(1-L_{HT}) \qquad (1)$$

where N_0 is the number of fish of a certain species entering Clifton Court Forebay in a day, N_R the number successfully released back to the estuary, C_{exp} the fish count expanded by dividing by the fraction of time sampled, L_P the fractional loss to predation, E the louver efficiency (i.e., the fraction of fish arriving at the louvers that enter the holding tanks), and L_{HT} the fractional loss to handling and trucking. Based on a series of experiments with marked fish (mainly salmon), the predation loss term L_P is assumed always to be 75%, although the mean of the experiments was 85% and values ranged from 63 to 99% (Table 1, page 12). Handling and trucking loss terms together amount to 4%. Louver efficiency E is

$$E = 0.586 + 0.0579*V \qquad (2)$$

where V is velocity of the water leading to the screens. Other than that, all terms are fixed, although Darryl stated that predation losses may depend on pumping rate and temperature, and probably vary among species. No account is taken of fish consumed by predators upon release, although anecdotal evidence and typical behavior of predatory fish suggest that they would respond quickly and voraciously to the release of a large number of small fish at a single site. As mentioned earlier, this predation loss may be the subject of another workshop.

The above applies to salmon and striped bass only, since the corresponding terms for other fish, including steelhead, are unknown.

Note: A sample calculation for both the state and federal facilities may help clarify the calculation process and show more clearly the effects of the predation loss component. Darryl did not present these calculations but there seemed to some confusion among the attendees about the calculations. A subsequent email from one of the attendees requested that more information be provided on the loss calculations. We apply equation 1 above using the following parameters:

State facility:

- Expanded salvage C_{exp}= 100 winter Chinook salmon
- Screen efficiency E = 90%
- Fraction lost to predation L_P = 0.75
- Fraction lost to handling and trucking = 0.04 (typical at winter temperatures)
- Number of fish entering the forebay = N_0 = 444 fish.
- Number of fish successfully salvaged = N_R = 96 fish
- Loss is the difference or **348** fish.

Federal facility

All parameters are the same except predation loss

- Fraction lost to predation F_P = 0.15
- Number of fish entering the forebay = N_0 = 131 fish.
- Number of fish successfully salvaged = N_R = 96 fish
- Loss is the difference or **35** fish.

The combined winter run loss for that day would be 348 plus 35 or **383**. The daily losses are accumulated and the accumulated loss is used for regulatory purposes (e.g., to compare with established NOAA Fisheries and DFG take restrictions for juvenile winter Chinook).

A major problem both operationally and in terms of estimating salvage is that debris (mostly from aquatic plants) piles up on the trash racks in front of the fish screens and on the screens themselves, often impeding flow significantly. This has become worse in recent years because of the spread of the introduced waterweed *Egeria densa*. However, the above calculations are done exactly the same whether the louvers are clean or clogged. Typically DFG requests the Bureau or DWR to temporally cease pumping when sensitive fish are present and the screen panels need to be lifted for cleaning..

Discussion: The facilities are not limited by their capacity to hold or move fish; when fish accumulate, the transport trucks make more trips. Debris tends to shut the system down more than the fish overwhelm it. Sometimes the operators have reduced pumping when large numbers of species of concern were being salvaged. At the SWP, the pumps are occasionally turned off to chemically treat aquatic weeds in CCF. Striped bass spawning in the San Joaquin River may be especially affected by losses at the export facilities, and before combined pumping increased when the SWP came on line in 1967 they were more abundant in the San Joaquin than the Sacramento.

Salvage at SWP and CVP intakes – Randy Brown, CALFED:

Randy described the general patterns of salvage reported by the two export facilities. Although the salvage data have limitations, they do provide useful information on abundance trends. The general data limitations are that the louvers do not effectively screen fish smaller than ~20mm, thus most delta smelt and other small fish are probably entrained before they reach that size. The salvage counts are also subject to substantial but mostly undefined errors, including identification errors. The historic data base is available through DFG but only data from years after 1979 are considered reliable. For delta smelt, the data are even more restricted with only data after about 1990 being most useful.

Species composition of salvage in 2003 (the latest year for which Randy had extensive data) was dominated by two introduced species – threadfin shad and striped bass. For the last several years threadfin shad has made up 25-80% of the salvage at the two facilities, whereas in earlier years striped bass dominated the salvage . Salvage of threadfin shad, striped bass, delta smelt, and several other species has declined in the last 1-3 years, as have catches in the trawl surveys in the Delta. Interannual patterns generally reflect abundance patterns in the Delta, although differences between the two facilities can be substantial .

Focusing on data from 2003 revealed seasonal patterns of salvage that differed by species. Delta smelt were salvaged mostly in January-June (peak in May), consistent with their summer-fall movement into brackish water. Striped bass were salvaged year-round but were most common in salvage, particularly at the SWP, in June and July. Chinook salmon were salvaged mainly in April-May, although winter-run fish (identified by size) were salvaged mostly in February-March. Steelhead juveniles were also most common in the salvage records in January-March of 2003.

Chinook salmon salvage at the two facilities is of particular importance since the numbers of winter Chinook salmon that can be taken (killed) is limited by the 2004 (and previous) NOAA Fisheries Biological Opinions. There is no specific take limit for spring Chinook, but releases of late fall Chinook from Coleman National Fish Hatchery are used as spring run surrogates. Brown showed salmon salvage data by race, with race determined by the length of the fish at a specific date. The size criteria are reasonably accurate for winter Chinook (as identified by genetic analysis) but even with this race only about one-half the fish identified as winter run base on size were genetic winter run. (As Brown reported to NOAA Fisheries in a series of memos during the mid 1990s.) The size criteria do not work for spring Chinook and the other races (for example many fall Chinook are misidentified as spring run) but genetic techniques are now available to sort all the races. Better run identification is needed estimate the salmon run components in the salvage (and take) at the project intakes.

Discussion: The discussion focused on two questions. First, what is the value of this data set given problems in the past with incorrect identification, and past and present problems with fouling of the trashrack and louvers and other technical difficulties affecting salvage? This did not elicit an answer but a lot of discussion centered on whether it was a good idea to use data with some unknown and possibly large biases (in addition to the known bias arising from the position of the facilities relative to those of the fish populations).

Second, what is the influence of the changing composition of the water going to the facilities? In the past, the Tracy facility took mostly San Joaquin water and the State facility mostly Sacramento water. Now with higher pumping rates requiring greater flows from the Sacramento River, and with the south Delta barriers in place, the water is often well mixed and both facilities can get more or less the same water.

The technical basis for calculating fish losses to predators at the intake to the State Water Project - Marty Gingras, California Department of Fish and Game

Fish losses to predators at the intake to the State Water Project (i.e., pre-screen loss) have been assessed in a series of mark-recapture studies and studies of predatory fish, particularly striped bass and white catfish, in the forebay.

Ten mark-recapture studies were run in 1976-1993 to estimate pre-screen loss to fishes entrained into the forebay (Gingras 1997). Salmon or striped bass were marked with dye and 7000-22000 were released at the radial gates and recovered in the fish facility. Various adjustments were made to account for salvage efficiency, tag retention, and handling mortality. Calculated loss rates ranged from 63%-99%, averaging about 86% (Table 1). Gingras (1997) discussed various errors and biases in the approach, and reported that the pre-screen loss rate decreased as export flow increased. *[Note: using the data in Table 1, we found that arcsine-*

transformed percent loss for Chinook salmon was not significantly related to flow reported in the table (p ~ 0.2, 6 df) or to export flow on the day of release (p ~ 0.5).]

Table 1 - Dates, operational and experimental variables, and results of pre-screen loss studies at Clifton Court Forebay (from Gingras 1997, compiled by D. Odenweller). In most cases fish were released at the radial gates and the trash boom, and the pre-screen loss was determined as the ratio of the fraction of fish salvaged from the group released at the radial gates the corresponding fraction for fish released at the trash boom. Salvage in most cases was expanded based on time sampled, and to account for size-dependent louver efficiency. Release sites were: G, radial gates, T, trashboom, O, outlet channel. Flows were through radial gates at the time of release except for the 1992 and April 1993 releases, when flows were export flow.

DATE	SPECIES	PRE-SCREEN LOSS (%)	MEAN FORK LENGTH (mm)	MEAN WATER TEMP (F)	FLOW (cfs)	MARK TYPE	RELEASE SITE	RELEASE AT RADIAL GATES	RELEASE AT TRASH BOOM
1976OCT	SALMON	97	114	69	252	DYE	G	6825	N/A
1978OCT	SALMON	88	87	60	4476	DYE	G/O/T	10510	1907
1984APR	SALMON	63	79	61	6000	DYE	G/T	13493	5853
1984JUL	S. BASS	94	52	N/A	4000	DYE	G/T	13710	8550
1985APR	SALMON	75	44	62	6825	DYE	G/T	11606	5915
1985AUG	S. BASS	70	55	N/A	7622	DYE	G/T	18486	8943
1992MAY	SALMON	99	77	75	306	DYE	G/T	21894	3199
1992DEC	SALMON	78	121	47	3390	DYE	G/T	10729	1782
1993APR	SALMON	95	66	63	3390	DYE	G/T	10332	2518
1993NOV	SALMON	99	117	53	6780	DYE /CLIP	G/T	4246	469
								1509	468
								4260	233

G = RADIAL GATES; O = OUTLET CHANNEL; T = TRASH BOOM

In the early 1970s, DFG staff conducted a creel survey at CCF where only bank fishing is allowed. In a 1980 report of these studies Lee Mecum (DFG) reported a catch rate of 1-2 fish/hour in all areas of the forebay and estimated anglers spent about 14,000 hours fishing there during the course of the one-year study. White catfish were the most-caught fish, followed by bluegill, crappie, and striped bass. The implication was that potential predators were abundant in the forebay.

In the early 1980s, DFG staff examined the abundance of predator fish in the forebay. Kano (1990) reported capturing about 20,000 white catfish, 6,000 striped bass, and 900 predatory fish of other species during the year-long study. Using the study data, Kano developed Petersen population estimates of 100,000 white catfish and about 80,000 striped bass in the forebay. He also reported seasonally-fluctuating length frequencies and catch-per-unit-effort, and movement of tagged striped bass from the forebay. The implication was that predation could be substantial and that the predator population may be freely exchanging with the open Delta

A study of radio-tagged striped bass indicated that striped bass used all areas of the Forebay but showed a seasonal preference for areas in the vicinity of the radial gates and inlet channel (Bolster 1986). The implication was that predation, and therefore predation control, might be more efficient at the radial gates and inlet channel than elsewhere.

In the early 1990s, DFG staff conducted various predator-related studies. A predator-translocation effort yielded about 27,000 striped bass in 80 days of sampling. Catch-per-unit-effort (CPUE) sampling showed seasonally-fluctuating length frequencies and rapid, substantial shifts in CPUE. Gut contents of 1900 striped bass included 1,092 unidentifiable fish, 106 threadfin shad, 60 striped bass, one Chinook salmon, and fewer than 100 fish of 11 other species. Gut contents of 581 catfish included 23 unidentifiable fish, 7 threadfin shad, and 2 striped bass. Attempts to estimate abundance using mark-recapture techniques were generally unsuccessful; although about 12,300 striped bass were tagged and 2,800 were subsequently caught, just 199 tagged fish were recaptured. Radio telemetry showed that striped bass used the entire CCF, moved rapidly across the forebay, and came and went repeatedly from the forebay. The implications from studies in the early 1990s were that predatory fish, especially striped bass, are seasonally abundant and use the entire forebay, but it would be difficult to reduce their abundance and to determine predation impacts on Chinook salmon from striped bass stomach contents.

Discussion: The discussion centered on the movement of the predatory fish in and out of the forebay, which confounds efforts to assess feeding or abundance, as well as any control efforts. Anecdotally: striped bass are often seen in large numbers vigorously feeding at the surface. Questions also focused on methods of assessing predation. At least some of the mark-recapture studies appear to have allowed for the possibility of small fish residing in the forebay for some time before moving toward the pumps. The open design, in which fish not accounted for are assumed to have been eaten, was a concern to some participants. The diet study was generally considered unsatisfactory because of the low proportion of fish that could be identified, and ideas for better ways to do that were mentioned (e.g., identifying characteristic bones in partially-digested fish).

2005 Pilot-Scale Investigation of Predation on Steelhead within Clifton Court Forebay - Roger Churchwell, DWR, and Charles Hanson, Hanson Environmental

Chuck and Roger reported on the first attempt to determine the potential effects of predation on juvenile steelhead (*Oncorhynchus mykiss*) within the forebay. Since pre-screening losses within CCF are included in the incidental take calculations for salvage losses of Chinook salmon, the National Marine Fisheries Service (NMFS) OCAP biological opinion (NMFS 2004) required investigations to quantify predation losses on juvenile steelhead within CCF (pre-screen losses), and identify potential management actions to reduce predation mortality on juvenile steelhead. The steelhead predation investigation is a pre-condition to increasing SWP water export rates to 8,500 cfs.

A series of pilot-scale investigations using juvenile hatchery steelhead was conducted during spring 2005 to develop insight into the movement of juvenile steelhead through the forebay, identify potential areas of increased vulnerability to predation mortality, identify movement patterns of predatory-size striped bass, and provide information for developing the experimental design for a mark-recapture steelhead survival study. The intent was that the pilot study would be expanded in 2006 based on the 2005 results.

Thirty yearling steelhead from the Mokelumne River Fish Hatchery (221 to 275 mm TL) were surgically implanted with ultrasonic tags and released into the forebay intake channel immediately upstream of the radial gates. In addition, 16 adult striped bass, ranging in length from 625 to 940 mm TL, were captured using hook and line from the forebay, externally tagged using ultrasonic tags, and released into the forebay. Movement and fate of the juvenile steelhead and adult striped bass were monitored using mobile sensors and with continuously recording fixed-position acoustic receivers within the forebay, in the SWP holding tanks, adjacent to the radial gates, and within Old River.

Preliminary results showed that of the 30 steelhead released, four were subsequently detected in the salvage holding tanks, four were detected emigrating through the radial gates into Old River, and 22 of the tagged fish appeared to have been lost as a result of predation mortality or other factors within the forebay. Seventeen of the 30 steelhead were detected entering the intake canal, of which 13 were detected in the general vicinity of the trash rack. Although the results had not been analyzed at the time of the workshop, they suggested much longer residence in the forebay than expected, up to 30 days, which would increase their exposure to predation (but also would confound estimates of predation losses based on mark-recapture techniques). The low recovery in the holding tanks was probably due mostly to predation.

Although adult striped bass moved throughout the forebay, the fish tended to concentrate in the area immediately adjacent to the radial gates and within the intake canal. Adult striped bass were also observed to emigrate from the forebay during periods when the radial gates were open. These results appeared consistent with earlier results of Bolster (1986).

Results of the 2005 pilot study demonstrated the feasibility and utility of the general approach, and provided useful information for the design of the 2006 mark-recapture survival studies. For example, the 2006 studies will need to account for emigration of a portion of the marked steelhead population from the forebay. An experimental design and protocol for conducting the steelhead survival investigations in 2006, specifically designed to estimate losses of juvenile steelhead within the forebay, is being developed and will be available for peer review and comment in August 2005. The 2006 study will use ultrasonic and passive integrated transponder (PIT) tags.

Discussion: There was a lot of support by workshop participants for this approach, although probably everybody forgot immediately that it was billed as a pilot study. An appropriate model for the fish movements is quasi-steady-state allowing for residence in the forebay (perhaps with reduced risk of predation). How do the movements of the fish correspond with that of the water? Is the placement of sensors the best to determine movements of the fish? How can the apparent movements of the ultrasonic tags be used to determine whether fish have been consumed by a predator or not? In mark-recapture studies like those reported by Marty Gingras, only one of the possible fates of the fish is quantified: i.e., salvaged fish are counted but those eaten by predators, that died of other causes, or are still at large somewhere in the system are all counted as eaten. Hanson's study offers a way of quantifying those different fates. It might be a good idea to use a variety of different tags, since they all give different (presumably complementary) information.

Using bioenergetics models to estimate predation rates - Kyle Hartman, West Virginia University Wildlife & Fisheries Resources Program

Bioenergetics can be used to calculate consumption by predators. Consumption is easier to calculate from the energy balance than to measure directly. The fundamental equation is based on the First Law of thermodynamics:

Growth = Consumption - R -SDA - EX -EG

Where R is respiration, SDA is specific dynamic action (i.e., energy used in consuming and processing the food eaten), EX is excretion, and EG is egestion. Using the Wisconsin model makes this calculation relatively easy since the equations and many of the parameters are available. Growth can be estimated using otoliths or scales. The remaining terms in the model are fairly well constrained so that estimates of growth by this method are reasonable. Energy content of predator and prey must be determined but these too are relatively constrained.

Kyle presented a case study on the influence of increasing striped bass populations in Maryland on menhaden populations. This study involved estimating the increase in predatory demand by striped bass, then examining the seasonal patterns to determine the part of that demand likely to have been supplied by menhaden. The resulting estimate was that striped bass consumed up to 57% of the annual harvest of menhaden.

Energetic approaches have several benefits, e.g., the overall approach and parameters have been largely worked out. In addition, it is easy to combine bioenergetic approaches with more complex models. However, as with any models these are only as good as the input data, and in some applications of bioenergetics a closed system is assumed.

Discussion: Centered mainly on how and whether we could use this approach to help solve our problems. A related approach that might be useful is to combine biomass estimates (based on acoustics) with bioenergetics in an individual-based model, as Steve Brandt has done for the Great Lakes and the Chesapeake. There was some concern about the magnitude of active metabolism, but that seems relatively well constrained. The degree to which feeding by fish is saturated also received some discussion – however, if fish are saturated the bioenergetic calculations should still work.

Discussion at end of Day 1: We need alternative, complementary approaches, including better information on predation rates. Hanson's finding that some steelhead stay in the forebay for many days indicates that the earlier mark-recapture studies cannot be interpreted quite so straightforwardly (although the Chinook used in the earlier studies were much smaller than Hanson's steelhead, implying less capability to avoid predation or move out of the forebay). Thus we need an ecological context for predation in the forebay, a way to determine independently how much of the apparent loss was actually due to predation, and estimates of species-specific predation rates.

We need information on predation on delta smelt – at the moment we have none (and it is unlikely that such information would come from studies of gut contents because of the low relative abundance of delta smelt).

Summary (Randy Brown): In general, can we do a better job of quantifying predation? If so, what do we gain by doing this? Is it sufficient to know that predation at the project intakes is a major issue, or would improving our estimates of its magnitude increase our ability to manage the system?

DAY 2

Flow Fields in the South Delta as Influenced by Water Project Facilities and Operations, Cathy Ruhl, US Geological Survey, Sacramento, CA

Cathy gave an overview of hydrodynamic conditions in the south Delta, particularly as they might affect fish movement and predation. Even in the vicinity of the export facilities the flows in the south Delta are strongly tidal. The net flows superimposed on the tidal flows move water to the pumps, but both need to be taken into account when considering how water movement affects fish. There may be opportunities to take advantage of these strong forcing mechanisms and reduce the likelihood of fish entrainment and predation. Bends in the channels have spiraling secondary circulation patterns, whereby flow near the surface moves toward the outside of the bend and that near the bottom toward the inside. Areas of recirculation also occur where velocities are reversed from those in the main channel. Junctions can produce inertial effects such as jets, and a good example of this is the flow entering the forebay through the radial gates. All of these flow features could be used by predators, which often hold in low-velocity areas where higher-velocity flows bring food toward them. For example, previous talks showed that predators tend to congregate near the entrance to the forebay when the radial gates are open. Opportunities for minimizing fish loss in the South Delta may exist by operating the radial gates in synchrony with the tides and preferentially drawing water from one region of the Delta over another.

Discussion centered on the details of flow patterns in the vicinity of the facilities and alternative ways the radial gates could be operated to reduce predatory losses while minimizing adverse impacts on the ability to pump or the cost of pumping (which increases as level in the forebay goes down).

Predators and predation at the intake to the Central Valley Project – preliminary study findings - Brent Bridges, USBR

By contrast to the SWP, the CVP export facility has no forebay and takes water directly from an adjacent Delta channel. Otherwise the physical structure has similar features to that of the SWP, with a trash rack, primary and secondary louvers, and holding tanks for fish. Brent showed photographs of the facility during construction, which showed clearly the physical complexity of the structure. He then showed telemetry data documenting the position and movement patterns of predatory fish (striped bass) in the facility. Some of these fish moved freely up and down the pipes leading between the primary and secondary louvers. Fish tended to hold in low-velocity areas where they could forage in the higher-velocity stream. Fish may enter the facility while trash racks are removed for cleaning, or they may enter when they are small and grow larger within the facility.

The species composition of diets of predatory fish was similar to that seen in the salvage facilities. Most of the food was shad, with bay goby making up a substantial proportion of the overall diets. Removing predators from the system was fairly fruitless, as the area was repopulated within days.

Discussion mostly centered on the details of predatory fish in the facilities. It may be ecologically more interesting to see the variability among locations and between facilities - can we learn something about both predator and prey from this comparison? Louver efficiencies vary with fish size, species, and water depth (tide).

The environmental context of predation losses in the South Delta - Wim Kimmerer, San Francisco State University

Although the focus of the workshop was predation in and near the fish facilities, it is always a good idea to take a step back and look at the problem from a broader perspective. For example, we need to convince ourselves that losses in the export facilities are an important problem from a biological (or management) standpoint in order to decide whether the predation issue, nested within the loss issue, is worth attention.

Several approaches are available for making this assessment (Table 2). An obvious one is to compare salvage losses with total population size, under some assumptions as to tolerable losses, but this compares two estimates with very different sampling methods and underlying assumptions and is therefore not recommended. The second method is to divide the flux of fish in the south Delta, determined as the product of fish per unit volume times flow, by the total population size. Since both estimates include the same biases in net efficiency, these estimates should be valid. Third, statistical analyses of the potential influence of export flow or other measures of export impact on population trajectories, survival, or other responses can be used to determine whether the effect of export pumping is detectable.

Closer to the purpose of the workshop, the effect of predation can be estimated either by comparing abundance at the facilities with net samples in nearby waterways (subject to the difference in efficiencies), or by comparing abundance or size between the two facilities. In the latter case it is assumed that predation losses in the state facility greatly exceed those in the federal facility, as has been assumed for management purposes.

Analyses have been done along the lines of Table 2 for various studies that were presented as examples. Export losses of delta smelt, calculated by method 2, amount to several percent per day (see Discussion below, and Bennett 2005). Losses of brackish-water zooplankton did not appear to be an important part of population dynamics (Kimmerer unpublished). Losses of freshwater phytoplankton were considerable but were not the major loss term in the mass balance of chlorophyll (Jassby et al. 2002).

Table 2. Summary of measurements to assess importance of various elements of the predation problem in the export facilities.

Number	Objective of Measurement	Metric	Issues
1	Magnitude of Salvage	Salvage at Fish Facilities / Population Size	Apples and Oranges
2	Magnitude of Loss	Abundance per volume in South Delta * Export flow / Population Size	Assumes all are lost
3	Effect of Export Activities	Slope of Abundance or Survival vs. Export Flow (X2 effect?)	Power may be low
4	Predator Losses (or Louver / Net Efficiency	Abundance per unit volume at fish facilities / Same in net samples	Different Efficiencies
5	Predator Losses (or Louver Efficiency)	Comparison of lengths of salvaged fish between the two facilities	Interpretation, source populations
6	Predator Losses (or Louver Efficiency)	Comparison of total salvage between the two facilities	Source populations

Applying method 3 from Table 2, Kimmerer et al. (2001) concluded that export flow was not a major factor in the population dynamics and decline of striped bass, although associated modeling studies (Rose et al. in prep.) showed that export losses were a contributing factor to low recruitment. Winter-run salmon survival through the Delta appears to be somewhat affected by export flow (data from P. Brandes, USFWS), but a model of winter run cohort replacement rate did not show a statistical association with export flow or three other measures of conditions in the Delta. Nevertheless, particle tracking model results suggest that particles and possibly fish entering the Delta from the San Joaquin River would be very vulnerable to entrainment by the export facilities, particularly when river flow is low and export flow is high.

Striped bass data were also analyzed with method 4 (Kimmerer unpublished), with a result that was inconsistent with a higher predatory impact at the state than at the federal facilities (Table 3).

Median size (method 5) and abundance (method 6) results were generally similar between the two facilities but differed for some species. For example, median length of striped bass and threadfin shad was sometimes lower in the state than the federal facility, whereas that of other fish including Chinook salmon and delta smelt were about the same. Abundance (fish per unit volume) was generally somewhat lower at the state facility but not for all species: American shad, striped bass, delta smelt, and splittail were about equally abundant.

Table 3. Comparison of abundance at salvage facilities with data from net samples taken close to the facilities during the same month. Data presented are geometric mean ratios of the salvage abundance estimates to those taken in the net samples with 95% confidence limits (CL). Asterisks denote mean log ratios significantly different from zero at $p<0.05$ (*) or $p<0.01$ (**) (t-test, 85 df for townet and 70 df for midwater trawl data).

Survey Data	CWP Fish Facility	SWP Fish Facility
Summer Townet	0.47 (0.34 to 0.65)**	1.2 (0.9 to 1.7)
Fall Midwater Trawl	1.3 (1.0 to 1.8)*	1.3 (0.8 to 2.2)

Discussion: The calculation of losses of delta smelt to the export facilities using method 2 may overestimate these losses. The reason is that the fractional loss is high early in the season when smelt are not very abundant especially in the central Delta. It would be useful to revisit this analysis including the potential for a protracted period of reproduction.

Have you done these analyses for other species? No, these analyses take a lot of time and were done for specific purposes. It might be worth doing them for other species, and updating some of the older analyses.

Predation studies and management in the Columbia River Basin – Jim Petersen, Columbia River Research Laboratory, USGS

Dams and predators, especially northern pikeminnow, are major sources of mortality to emigrating salmon in the Columbia River system. Predation rates were estimated by examining gut contents of predators and using gut turnover time. Predation losses were highest in dam forebays and tailraces, and lowest in reservoirs. A predator management program using bounties was estimated to reduce predation on salmon by 25%, but this fails to account for potential density dependence, and variability may be too high to rely on such estimates. Petersen showed that per capita predation rates declined significantly as the number of predators increased.

Considerable effort has gone into designing fish passage systems that minimize the influence of predators. These include the carnival ride the fish go through when passing the John Day dam, designed to keep velocities low during the descent and to minimize exit velocities.

Smallmouth bass are also important predators, especially in impoundments compared to free-flowing streams. Bioenergetics models illustrated the importance of predation by smallmouth bass in impoundments.

American shad were introduced from the east coast to the Sacramento River and spread up and down the west coast. They are now much more abundant upstream in the Columbia system than before the dams were built, apparently because they found it possible to ascend the fish ladders where before they encountered impassable barriers. Juvenile shad are abundant in fall, the opposite of salmon, but could have an influence on salmon by supplementing the growth of pikeminnow.

Discussion: Is predator control worth it? It costs a lot but is difficult to evaluate the relative benefits of alternative strategies, particularly in a constantly changing system. The elaborate design of facilities to release fish into the river after they have bypassed the dams suggested the need to reconsider the current system of release of salvaged fish in our system. Although it is difficult to determine the fate of these fish, the combination of hydrodynamic conditions, disorientation of prey at the discharge, and attraction of predators may be lethal to many of the small fish released from the trucks.

Proposed changes in Delta facilities and suggestions to reduce predation impacts – Ron Ott, CALFED.

Ron described efforts to solve some of the problems in the fish facilities. These included studies of collection, handling, trucking, and release (CHTR), improvements to the South Delta Fish Facilities to increase survival, and predation research at the Tracy Fish Facility. However, most of his talk focused on alternative engineering solutions that would alter the configuration of CCF with the goal being to reduce predation losses. These include screening at the entrance to the forebay, moving the inlet to a location more suited to screening, constructing multiple inlets to provide flexibility in operations, and installing "fish-friendly" lift pumps.

Discussion: What about delta smelt? The idea is to use the Environmental Water Account instead of facilities to reduce impacts on delta smelt. Alternative pumping strategies could achieve the same goals, although as the average pumping rate goes up, the flexibility in the system decreases. There was some discussion about whether all of these engineering solutions really addressed the predator problem.

Initial statement of the review panel – Jim Cowan, Panel Chair

The Panel chose to limit discussion to predation in the forebay, leaving out broader ecological questions. In general, predation is a result of the interaction of susceptibility and encounter rate, which is a function of many factors such as predator and prey density, temporal and spatial patterns, behavior, water conditions, and abundance of alternative prey. Susceptibility is a function of attack rate (a function of predator: prey size ratio, turbulence, and turbidity.). and capture rate (e.g., functional response, handling time, hunger, risk of predation on predator). The quantity consumed depends on the above factors plus the bioenergetic characteristics of the predator, which limits how much it eats. The question is whether the various influences on predation rate are being measured at the appropriate scales.

Some initial recommendations

1. Think outside the box - need better mechanistic understanding
    Focus on delta smelt, although the approach would be applicable for any species
        (Salmon concerns do not seem as critical as they once did)

Focus on when and where predation occurs

2. Need new data

   Diets for major predators, growth rates

   Ultrasonic tagging, alternative estimates of consumption

3. Magnitude of predation near and within facilities, louver efficiency.
4. Scenarios that Cathy Ruhl suggested

   System has considerable operational flexibility

   Consider experimenting with the system to influence predation rates.

Discussion: All of this needs to be put in an ecological context. Considering delta smelt, what if we solved the predation problem, would there be any population-level consequences? It seems unlikely because delta smelt are not salvaged to any great success, and the current management scenario does not call for expansion of delta smelt salvage to estimate losses. Why haven't we discussed delta smelt much in this workshop? We are still basing all our beliefs and assumptions on measurements made with and for salmon and striped bass. We really need mechanistic models to help us understand how to assess population level impacts of predation near the project intakes.

References

Bennett, W. 2005. Critical assessment of the delta smelt population in Sacramento-San Joaquin estuary. Volume 2, Issue 2, on-line journal, San Francisco Estuary and Watershed Science.

Brown, R, S. Greene, P. Coulston, and S. Barrow. 1996. An evaluation of the effectiveness of fish salvage operations at the intake to the California Aqueduct. In San Francisco Bay - the Ecosystem. JT Hollibaugh editor. 497-518, Calif. Acad. Sci. San Francisco.

Bolster, B. 1986. Movement patterns of striped bass (Morone saxatilis) in Clifton Court Forebay, California. Master of Science Thesis, California State University, Sacramento.

Gingras, M. 1997. Mark/recapture experiments at Clifton Court Forebay to estimate pre-screening losses to juvenile fishes:1976-1983. IEP Technical Report 55. DWR, Sacreamento, CA.

Jassby, A. D., J. E. Cloern, and B. E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal estuary. Limnol. Oceanogr. 47: 698-712.

Kano, R. 1990. Occurrence and abundance of or predator fish in Clifton Court Foreaby. IEP Technical Report 24, DWR, Sacramento, CA

Kimmerer, W., J. Cowan, L. Miller, and K. Rose. 2001. Analysis of an estuarine striped bass population: Effects of environmental conditions during early lifed. Estuaries 24:556:574 California.

Mecum, L. 1980. Clifton Court Forebay Fishery. Bay-Delta Fishery Project, DFG, Stockton, CA.

NOAA Fisheries. 2004. Biological Opinion on the Long-Term Operation of Central Valley Project and State Water Project Operations Criteria and Plan NMFS, Southwest Region.

Attachment 1 – Predation Workshop Summary

Attendance List
Predation Workshop
June 22-23, 2005

Adams, Gary
Adams, Bridget - MWD
Baker, Peter - Stillwater Science
Bellmer, Russ - USFWS
Birk, Serge - CVPWA
Bridges, Brent - USBR
Brown, Randall - CALFED
Burr, Kari - DeltaKeeper
Castillo, Gonzalo - USFWS
Cech, Joe - UCD
Churchwell, Roger - DWR
Clark, Kevin - DWR
Conrad, Louise
Cotter, Rhett
Coulston, Pat - DFG
Cowan, Jim* - LSU
Davy, Paul – Vallecitos Water District
Demko, Doug – Steve Cramer Associates
Durand, John - SFSU
Ellrot, Brian - SWRI
Feyrer, Fred - DWR
Fujimura, Bob - DFG
Gingras, Marty - DFG
Hanson, Chuck – Hanson Environmental
Harlow, David - USFWS
Hartman, Kyle*
Hayes, Darryl – CH2MHill
Herbold, Bruce - USEPA
Hindman, Nick - USFWS
Hinojosa, Tracy - DWR
Hobbs, Jim - UCD
Houde, Ed* U. Maryland
Karkonen, Kristel
Kimmerer, Wim - SFSU
Kurosaka, Don - DWR
Lentz, Ken - USBR
Lucas, Rhonda - Farm Bureau
Malasian, David - DWR

Mayr, Shawn - DWR
McReynolds, Tracy - DFG
Miller, BJ - SLDMWA
Miyamoto, Joe - EBMUD
Nobriga, Matt - DWR
Odenweller, Dan - USBR
Odum, Jim - DWR
Ott, Ron - CALFED
Peterson, Jim *
Portz, Don - UCD
Raasch, Jerry - DWR
Attachment 1 continued

Ruhl, Cathy - USGS
Sandhu, Amrit - DWR
Sharpe, Laura -
Sih, Andrew* - UCD
Smith, Pete - USGS
Stein, Derek
Swenson, Ramona
Taplin, Justin
Thome, Darrin
Totzke,Kane - KCWA
Ward, Paul - DFG
White, Jim - DFG
Witalis, Shirley – NOAA Fisheries

Attachment 2 – Predation Workshop Summary Report
Workshop planning committee

Darryl Hayes (CH2MHill)
Matt Nobriga (DWR)
Marty Gingras (DFG)
Dan Odenweller (DFG and NOAA Fishereis, retired)
Wim Kimmerer, (SFSU)
Roger Churchwell (DWR),
Mike Chotkowski (USBR)
Bruce Herbold (USEPA)
Bruce Oppenheim (NOAA Fisheries)
Randy Brown (CALFED Science Program).

Attachment 3 – Predation Workshop- Summary Report
Workshop Agenda

Predation Workshop
June 22-23, 2005
Romberg Tiburon Center

Workshop objectives
- Review basis for current direct project related predations loss estimates for Chinook salmon.
- Review new work and approach relating to estimating losses of steelhead at the SWP intake and predation related studies at the CVP intake.
- Develop an understanding of the hydrodynamic and operational system that leads to fish entrainment and losses.
- Develop an understanding of physical and operational changes being contemplated at the project intakes to reduce predation losses at the intakes.

Goal

With the help of an expert panel, determine if there are additional studies and or analyses that are needed to help managers agree on a course of action aimed at reducing predation losses at the project intakes. The workshop results, conclusions and recommendations will be documented in a report to be submitted to CALFED and agency managers for their consideration.

Agenda

Note that this is a workshop and the timing of the presentations will depend in part on the questions and discussion resulting from each presentation. Bruce Herbold will moderate the workshop and help keep us on track.

June 22

0930 – Introduction, Importance, Goals, Format – Randy Brown, CALFED

0945 - 1010 – An overview of the fish salvage process at the state and federal water project intakes – Darryl Hayes, CALFED

1010-1040 Discussion and Q&A

1040 *Break*

1100 – 1135 Annual and inter-annual variation in fish salvage at state and federal water project intakes – Randy Brown, CALFED

1135 – 1210 Discussion and Q&A

1210 *Lunch on site*

1310 - 1335 The technical basis for calculating fish losses to predators a the intake to the State Water Project – Marty Gingras, DFG

1335 - 1430 Discussion and Q&A

1430 – 1455 Preliminary results of pilot studies to evaluate potential losses of juvenile steelhead to predators in Clifton Court Forebay, Chuck Hanson, Hanson Environmental

1455 – 1530 Discussion and Q&A

1530 *Break*

1600 - 1625 Use of bioenergetic models in helping understand predator/prey dynamics – Kyle Hartman, UWV

1625 – 1700 Discussion and Q&A

1700 *Adjourn*

1730 *Reception and BBQ on site*

June 23

0900 – 0925 Flow fields in the south Delta as influenced by water project facilities and operations – Cathy Ruhl, USGS

0925 – 1000 Discussion and Q&A

1000 – 1020 *Break*

1020 – 1045 Predators and predation at the intake to the Central Valley Project intake – preliminary study findings – Brent Bridges, USBR

1045 – 1115 Discussion and Q&A

1115 – 1140 Stepping back – losses to predators at the South Delta intakes to the water projects in the context of the larger riverine/estuarine system – Wim Kimmerer, San Francisco State University

1140 – 1210 Discussion and Q&A

1210 *Lunch on site*

1300 – 1325 Predation studies on the middle reach of the Columbia River system – Jim Petersen, USGS

1325 – 1345 Discussion and Q&A

1345 – 1410 Proposed changes in Delta facilities and operations, including structural and operational suggestions to reduce predator impacts – Ron Ott, CALFED

1410 – 1500 Discussion and Q&A

1500 *Break*

1520 – Where to next? – Darryl Hayes leads discussion
- Expert Panel – Preliminary comments/reactions/suggestions
- Speakers and other attendees
- Specific plans – Ron Ott representing the Fish Facilities Forum

1700 *Adjourn*

Attachment 4 – Summary of Predation Workshop Expert Panel Final Report

Predation in Clifton Court Forebay

Summary and Evaluation of Results of the June 22-23, 2005 Workshop

James H. Cowan, Jr.
Louisiana State University

Kyle Hartman
West Virginia University

Edward Houde
University of Maryland

James Petersen
United States Geological Survey

Andy Sih
University of California, Davis

March 2006

Predation in Clifton Court Forebay

Clifton Court Forebay (CCF) is a water intake facility of the State Water Project (SWP) operated by the California Department of Water Resources (DWR). The CCF is located near Byron, Contra Costa, CA and diverts water from Old River into the CCF, which serves as a storage reservoir just upstream of the SWP pumps. Water and fish are entrained into the 742 ha impoundment through intake gates whose operations are scheduled and depend on the tidal differential between the CCF and Old River. It is generally accepted that small fish entering the CCF are vulnerable to predation by larger fish while resident in the CCF, and as they traverse toward a fish screen upstream of the SWP pumps. The rates of predation within CCF are uncertain, but they are essential to calculate entrainment losses at the SWP. In recent years, the rate of predation within CCF has become a major concern because of presumed losses of winter run Chinook salmon (*Oncorhynchus tshawytscha*) and delta smelt (*Hypomesus transpacificus*), both of which are federally protected by the Endangered Species Act.

Workshop goals and objectives

The CALFED Bay-Delta program convened a workshop on 22-23 June, 2005 to determine what additional studies or analyses, if any, are needed to help managers agree on a course of action aimed on reducing predation losses at the SWP intakes. Participants included an expert panel, consisting of Drs. James Cowan (Louisiana State University), Kyle Hartman (West Virginia University), Edward Houde (University of Maryland), James Petersen (USGS), and Andy Sih (University of California, Davis), that was tasked to address the following objectives:

1). Review the basis for current direct SWP related predation losses for Chinook salmon;
2). Review new work and approaches to estimate losses of steelhead at the SWP intake, and predation related studies at the Central Valley Project intake;
3). Develop an understanding of the hydrodynamics and operational systems that lead to fish entrainment and losses; and,
4). Develop an understanding of physical and operational changes being contemplated at the SWP intakes to reduce predation losses at the intakes.

Summary of results

The panel heard numerous presentations that addressed the listed objectives. Having heard the presentations, it was clear to the panel that data to support estimation of predation losses in the CCF are weak for Chinook salmon (based upon limited evidence of presence of salmon smolts in the diets of predators (e.g., for striped bass, 1 juvenile salmon found in 1,990 stomachs as reported by Edwards 1997) and on limited tag-recapture releases of smolts at locations within the CCF (Table 1, provided upon request by Randy Brown – extracted from Gingras 1997) (these studies did not evaluate the possibility of smolt out-flux and/or long-term residence within the CCF). Similar data do not exist for delta smelt. **As such, the panel concludes that the overall basis for current estimates of direct predation losses in the CCF must be improved for Chinook salmon, and remains to be developed for delta smelt.** The following report elements outline the panel's understanding of the problem and provide an outline of a course of action for future studies.

Table 1. Summary of Chinook salmon predation loss rates from experiments in CCF.

Study	Release Date	Forebay Loss Rate
Schaffter 1978	10/12/76	97%
Hall 1980	9/10/78	88%
Kano 1984	4/25 84	63%
Kano 1985	4/02/85	75%
Bull 1992	5/04/92	98%
Tillman 1993a	12/13/92	78%
Tillman 1993b	4/7/93	95%
Bull 1994	11/21/93	99%

General methods used in salmon predation studies in CCF

- DFG used fall and late fall run hatchery fish, from DWR's Feather River Hatchery, the Coleman National Fish Hatchery (late fall) and Mokelumne River Hatchery.
- The first two tests were done in the fall using fish that had been held over in the hatchery to be released as yearlings thus they were larger. The last three studies used advanced fingerlings/presmolts.
- The fish were spray dyed with fluorescent dye at the hatchery and held for a couple days at the hatchery before being transported by truck to the Delta. Probably around 4 hours transit time. They were checked for delayed mortality and tag retention before release.
- Numbers of fish dyed varied from a few thousand for releases near the trashracks just upstream of the louvers to several thousand for releases at the radial gates.
- Some fish were held to check for mark retention, to measure length and weight to estimate numbers of fish released. In the first test, 10 % of the fish died in transit apparently from a fungus infection.
- The fish were released directly from the trucks into the CCF.
- One release site was always near the radial gates. Other release sites were near the trashracks or at the head of the channel leading from CCF to the fish screen.
- Sampling was commenced in the salvage shortly after the closest fish releases (fish could arrive from the radial gate release within 4 hours of the release.)
- UV lights were used to detect the dye – with one dye particle being considered a positive count.
- Sampling for the dyed fish continued for several days – typically at least a few days after the last marked fish had been recovered. In most instances the bulk of the returns came in the first few days after the releases.

What we know

We recognize intuitively that predation must occur in CCF because predators and prey co-occur there. However, information about the rates of predation and the magnitude of population-level impacts is lacking, especially for delta smelt. Together, the scarcity of knowledge begs the questions: Can predation mortality in the CCF be estimated? And, if so, and is it significant, and can it be managed?

Can predation be estimated?

To answer the first question, we must examine factors that determine numbers and types of prey eaten by predators in the CCF. However, predation mortality rates, even in small, well-defined water bodies such as CCF, are difficult to estimate. It is no coincidence that this is a sticking point in many fisheries studies, including population assessments. Unfortunately, data on early-life-stage-specific rates of decline, and the sources of mortality contributing to the decline, are among the most difficult data to obtain *in situ*. At a minimum, determining rates of loss requires successive, unbiased estimates of abundance of a cohort through time, a difficult task at any temporal and spatial scale. To address this problem many studies begin by focusing on prey abundances and changes in abundance *in situ* and in predator stomachs; this is evident in the CCF release-recapture experiments of marked salmon smolts, predator diet studies, etc. But, in some cases, where the problem is well defined and spatially explicit as in CCF, it may be more beneficial to focus on the predators and their capacity to consume prey. Simply put, one can address whether predators in a system are likely to consume prey of the types and size ranges of interest, at rates that are significant to reduce prey abundances. Although usually highly mobile, predators generally are larger and their numbers may be estimated with higher reliability than their prey. Predator selection and consumption can be estimated by performing diet studies. This approach does require accurate estimation of types of prey consumed and inference with respect to significance of consumption relative to vulnerable prey populations. However, for some predators such as striped bass we do have limited knowledge of prey sizes and types preferred, and like information for foraging and bioenergetics models. We don't have predator numbers or growth rates, which are needed to estimate predation rates.

Which prey gets eaten?

This simple question is not so easy to answer, at least in a quantitative sense. Predation consists of a complex series of discrete events driven by factors related to the spatial and temporal overlap of predators and prey; in other words, the spatial setting that affects rate of encounter and capture success. Following an encounter, ingestion is based upon a suite of size-based interactions that are specific to the species involved, which determines susceptibility. The product of encounter (E) and susceptibility (S) is termed vulnerability (V):

$$V=S * E$$

Relevant to the discussion of CCF, variables that contribute to encounter rate include densities and sizes of predators and prey, their rates of movement, their seasonal and spatial co-occurrence, diel shifts in distributions, water clarity as its affects the ability of predators to see prey and vice versa, and flow and turbulence. Because of the potential for variation in any or all of these, both encounter and hence predation rates can be very patchy in space and time, adding to the difficulty in estimating the later. Susceptibility is also a complex variable and can be expressed as the product of the probability of attack (A) and capture success (C):

$$S = A * C$$

Again, relative to CCF, the hunger level of the predator, the predator's assumed risk of being eaten by a larger predator, the rate of prey delivery and prey handling time, and the predator's functional response, determine the probability of attack once a prey is encountered. The implications of variability in handling time and its effect on functional response are particularly important because if prey is encountered at rates exceeding the time a predator requires to ingest a single prey item, theory predicts that the predator will be unable to attack all prey it encounters. This is in part why prey fish are believed to have evolved schooling behavior. Moreover, estimating the components of predation can show if predation rates may decline if a predator is "swamped" by large numbers of prey whereby it becomes satiated and thus can no longer consume prey even if they are available. Capture success is only slightly less complex and is dependent upon size-based interactions (relative prey size to predator size ratios), and the relative growth rates of predators and prey. In other words, it is possible for prey to outgrow a predator such that the predator can no longer capture the prey. The ratio of prey size to predator size and its effects on capture success in the CCF may be more important than in natural settings because predators in an arena (artificial environment), where prey delivery and residence times are more predictable, can become conditioned to attack preferred prey types almost independently of their relative abundance to alternative prey.

Determining the significance of predation losses of Chinook salmon and Delta smelt in CCF will require thinking 'outside of the box'---understanding predation in CCF is far more complex than just determining number of predators present and what they eat---what is needed is a better mechanistic understanding of predation at the process level. The panel suggests utilization of existing data and initiation of new studies to generate information in the following areas:

1). Identification and estimates of abundance of predators on Chinook salmon **and especially** delta smelt in the CCF;

2). Estimation of when and where predation occurs in the CCF, or in the SWP facility itself;

3). Estimation of predator population sizes in the CCF (or SWP), temporal variability in their abundances, their size distributions, and their growth rates;

4). Determination of temporal patterns of prey delivery into the CCF, conditions under which prey are delivered, and estimates of prey abundances and size distributions; and,

5). Determination of whether local production of delta smelt is possible or significant within the CCF.

How much prey gets eaten?

Well-established methodology to estimate predator population consumption rates is available and potentially applicable in the CCF/SWP situation. The modeling of bioenergetics describes in quantitative terms, the balance of energy gained through feeding and the costs of capturing and digesting the food consumed. Kyle Hartman described methodological details of this approach at the workshop, and they are summarized briefly here. The following difference form of the bioenergetics equation describes the energy budget of an individual predator:

$$W_t = W_{t-1}\, C_{max} * (p) * A - R_{tot}\, \Delta t;$$

Where W_t = predator weight at time t; W_{t-1} = predator weight at time t-1; C_{max} = the maximum potential consumption rate of the predator and is a function pf predator weight and temperature; p = realized fraction of C_{max}; A = assimilation efficiency and is prey-specific; R_{tot} = predator respiration rate and is dependent on predator weight and temperature; and, Δt = the time step, often daily. C_{max} and R_{tot} can be estimated in laboratory experiments. Because it is now possible to accurately determine the rate of growth of most fish predators by increment analysis in otoliths, the bioenergetics equation (model) can be applied in conjunction with diet studies to answer the question: "How many prey, particularly what biomass, must be consumed to generate observed growth rates?" The answer to this question is, of course, size- and species-specific and requires the following data and information:

1). Diet data of major predator species and predator growth rates;
2). Estimation of numbers and size distributions of predators through time—these data may be less difficult to obtain than numbers of prey, and can be related to hydrodynamics and SWP operations, and to diel and seasonal patterns of predator behavior;
3). Water temperature within the CCF collected at the same temporal resolution at which bioenergetics modeling is to occur; and,
4). Determination of the temporal variability in caloric density (calories/gram) of predators and prey, as energy content is the "currency" used in bioenergetics models.

Once the numbers, sizes, and growth rates of predators have been estimated, bioenergetics modeling will allow simulation and estimation of population-level consumption rates and potential by the predator populations in the CCF based upon well-established methodologies.

Why is a mechanistic understanding important?

The predation process is complex. In preceding paragraphs, we have described the types of data that will be necessary to adequately quantify predation rates in CCF. Perhaps more importantly, decomposing the process into a series of discrete events permits discussion of whether predation rates in the CCF can be managed if they are found to be significant to the health and sustainability of endangered prey (Chinook salmon and delta smelt) populations.

When considered in this light, the panel infers that among the most important parameters for management considerations is the rate of encounter between predators and prey. The panel believes that it is important to explore how the flexibility inherent in the engineering of the CCF/SWP can be utilized to minimize encounter between predators and prey, i.e., to experiment with varying time and space applications of pumping strategies to minimize prey delivery into the CCF and their co-occurrence with predators. Interesting and possibly important results presented at workshop concerning predator movements in response to opening of the radial gates to fill the CCF, and on residence time and flux of prey into and out of CCF, support the panel's view that temporal and spatial manipulation of flow into the CCF could modify predation potential. It is probable that such manipulations could help to interpret results of past smolt release experiments, and may provide some insights into how changes in SWP operations could modify prey delivery. Simply put, if fewer prey are delivered into the CCF, predation losses will decline. Exploration of such possibilities may be especially important to delta smelt, not only to reduce predation in the CCF, but also to reduce entrainment losses in the SWP, given that delta smelt rarely survive the salvage process. If predation and entrainment losses combined are found to be critical to the future survival of the delta smelt population, substantial engineering measures such as moving the location of radial gates and intakes to a location farther north on the Old River, away from reaches of the delta that historically supported large numbers of smelt, should be considered.

Another possible means of reducing potential encounter between predators and prey in CCF is predator removal. While difficult, this task is not impossible in a relatively small system such as CCF, and could be accomplished through intensive netting and/or electroshocking removal of predators. This approach could be useful to reduce predation losses of salmon smolts and steelhead, but would have to be repeated at regular and perhaps frequent time intervals to prevent re-colonization. Clearly, the costs of intensive predator control vs. engineering approaches to reduce overlap and reduce encounter of predator and prey would have to be determined. Since the species of concern are endangered or threatened, costs might not be as critical as otherwise, but if both alternatives could be successful, then the economics need to be considered.

The panel saw compelling evidence from the CVP that predator abundances in that facility were high, and that predators were free to move widely within the facility. As such, the panel recognizes the need to evaluate the magnitude of predation on salmon smolts and steelhead at the entrance and within the SWP facilities, and the degree to which entrainment is an issue for delta smelt. For example, improvements in louver efficiency may be warranted if entrainment rates of delta smelt adults, particularly during winter months, put the population in jeopardy.

Below, we provide specific advice and recommendations that represent the consensus of the panel.

Recommendations on the necessity to quantify and model predation potential in CCF. The panel was unanimous in its conclusion that a more mechanistic understanding of the predation process and predator/prey interactions is required to address the problem.

1). The spatial overlap of predators and prey must be quantified at various temporal (seasonal, diel) and spatial (within the CCF and SWP facilities) scales. Relationships between predator distribution and abundance and variables such as flow, temperature, depth, SAV coverage, etc. should be quantified, mapped and modeled statistically, along with similar relationships between prey abundance and patterns of delivery into the CCF. The panel was impressed with the progress being made along these lines by using ultrasonic tagging and other mark/recapture approaches and recommends that this type of work be expanded.

2). **Size and time-specific diet data must be collected for predator populations in the CCF.** Because the diets of predators are likely to change with respect to season and to predator size, monthly diet data across all species and size-classes of predators over multiple years will be necessary to adequately describe predator/prey interactions, and to inform bioenergetics modeling. It may also be possible to determine if predator swamping occurs, especially if swamping is attributable to alternative prey species such as American shad, thus reducing predation potential on the species of concern.

3). *Size and growth rate data must be collected for both predators and prey to determine temporal and spatial variability in prey susceptibility to predators in the CCF and the SWP facility, and to inform bioenergetics models for predicting predation potential.* ***Such data can be used to determine what fraction of the prey that enters the CCF is actually vulnerable to predation. These data also provide the basis for comparisons of predation potential in the CCF relative to other locations in the delta.***

4). The degree to which predators and especially prey are free to move into and out of the CCF must be evaluated, along with residence time of prey within the CCF.

5). **Although not related directly to this CCF issue, the degree to which predation occurs when salvaged fish are released must be quantified.** Predation pressure could be reduced by alternative release procedures if predators have become conditioned to respond to releases at fixed locations

6). **Begin to build integrated models, including bioenergetics models, that will combine data and information on the effects of systems hydraulics, predator and prey behavior as it affects species-specific vulnerability to predation, and predation potential.** Once constructed, these modeling tools could be applied to evaluate management scenarios and hypotheses that reduce the risk of salmon smolts and steelhead to predation in the CCF.

Neglecting delta smelt in the recommendations above is not an oversight. Rather, because delta smelt rarely survive the salvage process and are unlikely to be able to exit the CCF when the gates are open, the panel infers that once delta smelt enter the CCF, mortality may be a foregone conclusion, whether they are consumed by a predator or die during salvage. **As such, the panel believes that the best course of action is first to determine the magnitude of losses of all life stages of delta smelt attributable to operations of the SWP, including delivery to the CCF, and impingement, entrainment and predation in the CCF and SWP facility.** If these losses are deemed to be significant at the population level, the panel believes that options to limit losses of delta smelt to pumping are more limited than those possible for salmon smolts and steelhead, and should emphasize those factors that will limit smelt delivery to the CCF and, later, to the pumps.

7). **The efficiency of the louvers in screening delta smelt > 20 mm from entering the SWP must be evaluated.** Even small changes in louver efficiency could have dramatic effects on losses of adults to the pumps, particularly in winter months prior to spawning when shallow waters near the SWP warm more quickly than elsewhere in the delta.

8). **All operational options that have the potential to reduce the delivery of delta smelt (of any life stage) into CCF must be evaluated**. The panel was impressed by results presented by Cathy Ruhl, who showed with particle tracking experiments that prey delivery into the CCF possibly could be managed by varying when and how the CCF was filled, and believes this type of work should be expanded. Short of reducing pumping rate, flexibility in modifying the engineering of the system must be explored as it effects delivery of water containing delta smelt into the CCF, including such options as filling the CCF more slowly, and/or on ebbing tides, etc. This approach also should be informed by any aspect of smelt behavior that can be used in conjunction with SWP operations to reduce prey delivery.

References

Bull, J. 1992. 1992 Clifton Court Forebay evaluation of predation losses of juvenile Chinook salmon DFG Memo Report, Stockton.

Bull, J 1994. November 1993 Clifton Court Forebay evaluation of predation losses to juvenile Chinook salmon. DFG Memo Report, Stockton

Edwards, G. 1997. Food habits of striped bass, white and channel catfish at Clifton Court Forebay during 1983-84 and 1993-1995. DFG Report.

Gingras, M. 1997. Mark/recapture experiments at Clifton Court Forebay to estimate pre-screening losses to juvenile fishes 1976-1993. IEP Technical Report 55

Hall, F.A.1980. Evaluation of downstream migrant Chinook salmon, *Oncorhynchus tshawytscha*, losses in Clifton Court Forebay, Contra Costa County, California. DFG Administrative Report 80-4.

Kano, R. 1985. 1985. Clifton Court Forebay evaluations of predation losses to juvenile Chinook salmon. DFG Memorandum Report, Stockton CA.

Kano, R. 1984. 1984. Clifton Court Forebay evaluations of predation losses to juvenile Chinook salmon. DFG Memorandum Report, Stockton CA.

Schaffter, R.G. 1978. An evaluation of juvenile king salmon (*Oncorhynchus tshawytscha*) loss in Clifton Court Forebay. DFG Anadromous Fisheries Administrative Report 78-21.

Tillman, T. 1993a. December 1992 estimates of pre-screen mortality of juvenile Chinook salmon at Clifton Court Forebay: State Water Project, Byron, CA. DFG Memo Report, Stockton.

Tillman, T. 1993b. April 1993 Estimates of pre-screen mortality of juvenile Chinook salmon at Clifton Court Forebay, State Water Project, Byron, CA. DFG Memo Report, Stockton.