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Managing Water to Protect Fish: A Review of California's Environmental Water Account, 2001–2005

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Abstract The Sacramento-San Joaquin Delta, the landward reach of the San Francisco Estuary, provides habitat for threatened delta smelt, endangered winter-run Chinook salmon, and other species of concern. It is also the location of huge freshwater diversion facilities that entrain large numbers of fish. Reducing the entrainment of listed fishes into these facilities has required curtailment of pumping, reducing the reliability of water deliveries. We reviewed the first 5 years (2001–2005) of the Environmental Water Account (EWA), a program instituted to resolve conflicts between protecting listed fishes and providing a reliable water supply. The EWA provided fishery agencies with control over 0.2–0.4 km^3 of water to be used for fish protection at no cost to users of exported water, and fish agencies guaranteed no disruption of water supply for fish protection. The EWA was successful in reducing uncertainty in water supply; however, its contribution to the recovery of listed fishes was unclear. We estimated the effectiveness of the EWA to be modest, increasing the survival of winter-run Chinook salmon by 0–6% (dependent on prescreen mortality), adult delta smelt by 0–1%, and juvenile delta smelt by 2–4%. Allocating EWA water for a single life stage of one species could provide larger gains in survival. An optimally allocated EWA of equal size to the median of the first 5 years could increase abundance of juvenile delta smelt up to 7% in the springs of dry years. If the EWA is to become a long-term program, estimates of efficacy should be refined. If the program is to be held accountable for quantitative increases in fish populations, it will be necessary to integrate scientific, possibly experimental, approaches.

Keywords Environmental water · Fish · Endangered species · California Delta · Management · Chinook salmon · Delta smelt · *Oncorhynchus tshawytscha* · *Hypomesus transpacificus*

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Introduction

As human populations grow, conflicts sharpen between human consumption and maintenance of natural resources (Costanza and others 1997; Sala and others 2000; Vitousek and others 1997). Meeting human needs for freshwater while maintaining or rehabilitating aquatic resources is one of the greatest challenges now facing water and resource managers around the world (Jackson and others 2001; Postel 1996, 2000). In the United States, implementation of the Clean Water Act in 1972 improved water quality in numerous water bodies, restoring many ecosystem services such as recreation and fish habitat. In the southwest in particular, implementation of the Endangered Species Act (ESA) and the Public Trust Doctrine has led to changes in federal, state, and local water project operations and water management to limit adverse effects and to aid in the recovery of fish and other aquatic species. Water resources have been formally reallocated to provide more water for maintenance or rehabilitation of aquatic resources (e.g., Mono Lake, CA; SWRCB 1994). Key examples of this reallocation in the San Francisco Estuary and watershed are the Central Valley Project Improvement Act of 1992 [CVPIA; see USBR 2006a for details], a recent agreement to restore river flows for salmon in the San Joaquin River below Friant Dam near Fresno while undertaking one of the West's largest river restoration efforts [see USBR 2006b for details], and a recent court decision to alter diversions from the Sacramento-San Joaquin Delta to protect delta smelt, *Hypomesus transpacificus* (Wanger 2007a, b).

Agricultural and urban development of the southwest United States depended on developing the region's water resources (Reisner 1986). The economy of California now relies on an extensive water storage and management system focused on the Sacramento-San Joaquin Delta, the landward reach of the San Francisco Estuary (Fig. 1). Concurrent with water development, ecological degradation of the river–estuarine ecosystem has led to declines of aquatic resources and listing of several Central Valley and San Francisco Estuary fish species under state and federal endangered species legislation (Table 1). Much of the concern over declining fish abundance has centered, rightly or wrongly, on the effects of exports of large quantities of freshwater from the southern delta.

Concerns over the ecological effects of water management are certainly not new or restricted to California. In the Columbia River Basin of the US Pacific Northwest, concern about depressed stocks of salmonids and the effects of existing and proposed hydroelectric projects led to legislation requiring a balance between a reliable hydropower system and enhancing fish and wildlife (McDonald and others 2007). Effects of power plant cooling-water diversions and discharges are a longstanding concern in many areas, including Chesapeake Bay (Richkus and McLean 2000) and the Hudson River (Barnthouse 2000; Barnthouse and others 1984). As in California, water extraction for human uses and subsequent effects on aquatic resources are an ongoing concern in arid and semiarid areas, including the Colorado River Basin (Brower and others 2001; Minckley and others 2003) in the southwestern United States and Australia (Arthington and Pusey 2003).

Conflicts over water management in central California reached a crisis in the 1990s, prompting formation of the CALFED Bay-Delta Program in 2000 (CALFED; CALFED 2000a). Among CALFED's goals were to rehabilitate the ecosystem for native species while improving the reliability of water supplies (CALFED 2000a). A key tool provided for CALFED was an Environmental Water Account (EWA), with the objective (CALFED 2000b) of providing water for the protection and recovery of fish in addition to water available through existing regulatory actions related to project operations (see the Background section). The EWA began as a 4-year trial program, but at the end of that period, a decision was made to continue the program while planning for a long-term EWA.

The primary objectives of this article are to describe the EWA and evaluate its effectiveness in protecting fish during its first 5 years of implementation (2001–2005). Our focus is on the magnitude of the benefits provided to fish populations. Specifically, we estimate the improvements in survival of endangered winter-run Chinook salmon (*Oncorhychus tshawytscha*) and threatened delta smelt possible with EWA. We selected these two species for analysis because they are of great management interest and recent research has provided much new information on their biology (e.g., Sommer and others 2007).

Background

The San Francisco Estuary is the largest estuarine system on the west coast of North America, draining ~40% of the surface area of California. The estuary and its watershed have been highly altered by human activities with consequent changes in physical and ecological processes (Cloern and Nichols 1985; Conomos 1979; Hollibaugh 1996) and fish populations (Bennett and Moyle 1996; Moyle 2002; Sommer and others 2007). One consequence of these changes is that several native species of fish have been listed or considered for listing under state and federal endangered species legislation (Table 1).

The principal alterations to the freshwater portions of the system have been the extensive water projects of which the federal Central Valley Project (CVP) and State Water Project (SWP) are by far the largest. The CVP, operated by the US Bureau of Reclamation (USBR), and the SWP, operated by the California Department of Water Resources (DWR), include storage reservoirs on most of the major rivers in the Sacramento River and San Joaquin River basins and large export pumping facilities in the southern delta (Fig. 1). Although operations of the water projects are complicated, the basic idea is straightforward. During wet periods, runoff is captured in reservoirs. During the dry season, stored water is released from the reservoirs and flows through the rivers downstream to the delta. Some portion of the flow into the delta is then diverted by large export pumps in the southern delta (Fig. 1). Water demand south of the delta is met by a combination of export pumping from the delta and water released from San Luis Reservoir, an off-stream storage reservoir linked to both the state and federal aqueducts. Although export pumping historically has been high in most months, restrictions to protect fish in the delta have limited pumping rates, particularly from April to June.

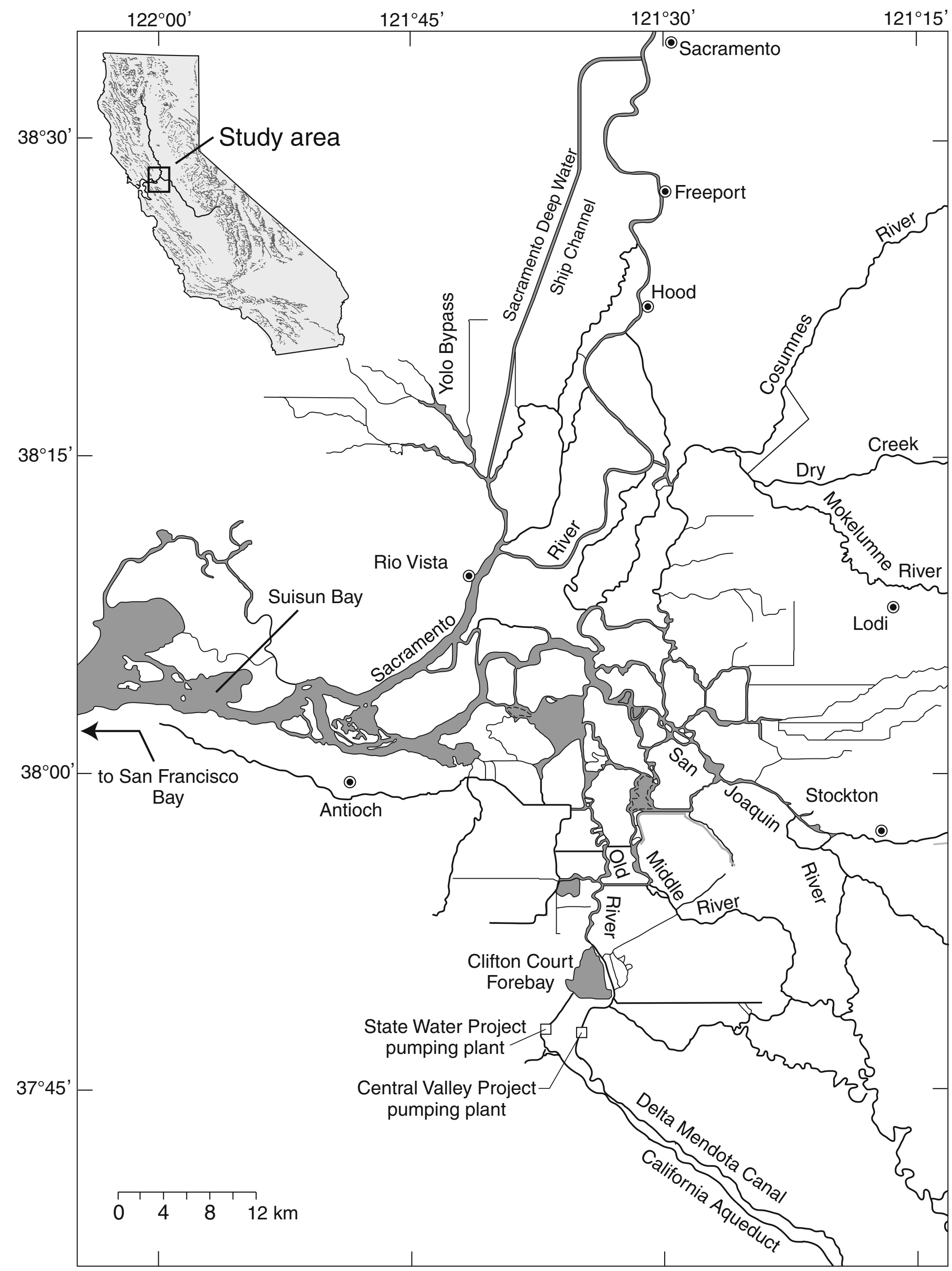

Fig. 1 Map of the upper San Francisco Estuary showing locations mentioned in the text

Fish salvage facilities associated with the export plants in the delta recover huge numbers of fish of a variety of species (Brown and others 1996). At the facilities, louvers guide fish into holding tanks to be trucked for release in the estuary far from the influence of the pumps. The salvage facilities also take a substantial subsample of the fish and identify, measure, and count them for estimates of daily *salvage* (i.e., the total number by species and length that was handled by each facility). However, the salvage process is inefficient and large numbers of fish are lost through the louvers and to predation near the facilities (Brown and others 1996).

Current concerns over export effects on fish focus on species listed under state or federal endangered species legislation, specifically winter-run and spring-run Chinook salmon, steelhead rainbow trout (*Oncorhynchus mykiss*), and delta smelt. In addition, concern over the probable vulnerability of juvenile San Joaquin River fall-run Chinook salmon to export effects has led to protective measures in the delta, some of which are discussed below. Juvenile salmonids might be present in the delta at any time but are most abundant in spring (Table 2). Most juvenile winter-run Chinook salmon migrate to the ocean from January through March (Moyle 2002). Delta smelt are

Table 1 Species of concern in the Sacramento-San Joaquin Delta listed or proposed for listing under state and federal endangered species acts

Common name	Scientific name	Federal status[a]	State status[b]
Chinook salmon	*Oncorhynchus tshawytscha*		
Winter run		E	E
Spring run		T	T
Fall and late fall run		C	–
Steelhead rainbow trout	*Oncorhynchus mykiss*[c]	T	–
Delta smelt	*Hypomesus transpacificus*	T[d]	T[d]
Sacramento splittail	*Pogonichthys macrolepidotus*	DL	SSC
Green sturgeon	*Acipenser medirostris*	T	–
Longfin smelt	*Spirinchus thaleichthys*	PL	PL
Pacific lamprey	*Lampetra tridentata*	NW	–
River lamprey	*Lampetra ayersii*	NW	–

[a] E, endangered; T, threatened; PL, proposed for listing, C, candidate; NW, species was proposed for listing but listing was found to be not warranted; DL, delisted

[b] E, endangered; T, threatened; PL, proposed for listing; C, candidate; SSC, species of special concern; –, no special status

[c] Central Valley ESU

[d] Delta smelt is currently being considered for status as endangered

Source: Data from USFWS (2006), NOAA (2006), and Moyle (2002)

Table 2 Months when vulnerable life stages[a] of species of concern might be present in the Sacramento-San Joaquin Delta

Common name	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Chinook salmon												
Winter run	S	S	S									
Spring run[b]	S, F	S, F	S, F									
Fall and late fall run	F	F	F	S	S	S						
Late fall run												
Steelhead rainbow trout	S	S	S	S	S							S
Delta smelt	A	A	A, J	A, J	A, J	J	J					A
Sacramento splittail				J	J	J	J	J				

[a] F, fry; S, smolt; J, juvenile; A, adult

[b] These time periods are approximate for all fishes, but the life cycle of spring-run Chinook salmon is particularly complex. Smolts represent yearling fish emigrating as smolts. Fry represent young-of-year fish emigrating the same year of adult spawning

Source: Data from Brown and Kimmerer (2001) and Moyle (2002)

present as adults in late winter and as larvae and juveniles in spring (Table 2).

Studies have associated export pumping with changes in hydrodynamic conditions and losses of primary and secondary production in the delta (Arthur and others 1996; Brown and others 1996; Jassby and others 2002). However, recent studies have suggested that population-level effects of entrainment might be small for the introduced striped bass *Morone saxatilis* (Kimmerer and others 2000, 2001) and the native delta smelt (Bennett 2005). Declines in abundance of fish species probably have multiple causes, so it seems unrealistic to single out the effects of entrainment (Bennett and Moyle 1996). Nevertheless, it is broadly believed that export effects contribute significantly to declines of fish populations in the delta (Bennett 2005; Kjelson and Brandes 1989; Sommer and others 2007; Stevens and others 1985).

The Environmental Water Account was designed to reduce conflicts between fish protection and the reliability of water supplies. It provides fish management agencies with a tool to reduce the impacts of export pumping on fish populations without resorting to the alternative—draconian and unplanned cuts in pumping that disrupt water supplies. The fundamental assumption behind this use of the EWA is that relatively small but carefully targeted reductions in export flow can offset harmful effects of export pumping.

To be successful, the EWA must meet the following objectives (EWA Agencies 2004): (1) protect at-risk species affected by SWP/CVP operations and facilities; (2) contribute to the recovery of these species; (3) allow timely water management responses to changing environmental conditions and changing needs for fish protection; (4) provide reliable water supplies to water users in SWP/CVP export areas; and (5) cause no uncompensated water loss to users.

In principle, the EWA is straightforward. The EWA is given an annual monetary budget for the purchase of water from willing sellers (Table 3). Several operational tools can be used to obtain additional water for EWA (CBDA 2004); for example, environmental standards on project operations might be relaxed during seasons that the management agencies (US Fish and Wildlife Service, National Marine Fisheries Service, and California Department of Fish and Game) deem safe, allowing for increased export flow, with the additional water stored in San Luis Reservoir to support later export curtailments for EWA. The management agencies use monitoring data, scientific understanding, and professional judgment to select "fish actions" that they believe will help to protect fish. The project agencies (USBR and DWR) then implement those actions using EWA water. Because the water has been purchased from willing sellers or obtained by the use of

Table 3 Volume of total annual delta inflow, total SWP/CVP exports from the Delta, and EWA water acquired (in km^3)

	2001	2002	2003	2004	2005
Delta inflow[a]	16.02	19.33	26.30	27.19	27.63
SWP/CVP exports[a]	6.13	6.67	7.58	7.35	7.78
EWA water acquired					
Water purchases					
Sources upstream of delta	0.13	0.17	0.09	0.15	0.01
Sources in export area	0.29	0.12	0.18	0.04	0.12
Total purchases	0.41	0.30	0.27	0.19	0.13
Operational water	0.06	0.10	0.11	0	0.19
Exchanges	0	0	0	0	0.06
Losses[b]	−0.02	−0.06	−0.02	−0.04	0
Total net water acquired	0.45	0.33	0.36	0.15	0.38
Water carried over from previous year	0	0.09	0.07	0	−0.02
Total water available	0.45	0.43	0.43	0.15	0.35
EWA asset costs ($)					
State	54.4	17.8	30.5	19.6	17.9
Federal	10.0[c]	11.5	0	0	0
Total cost	64.4	29.3	30.5	19.6	17.9
EWA water use					
SWP/CVP pumping reductions for fish actions					
Chinook salmon and steelhead	0.11	0	0	0	0.01
Salmonids and delta smelt	0.17	0.08	0.15	0	0.21
VAMP	0.05	0.05	0.04	0.02	0.17
Post-VAMP period: delta smelt and Chinook salmon	0.03	0.17	0.24	0.13	0.04
Total SWP/CVP pumping reductions for fish actions	0.36	0.31	0.43	0.15	0.42
Pumping reductions converting EWA water to project water in San Luis Reservoir[d]	0	0.05	0	<0.01	0
Upstream use for salmon/steelhead	0	0.01	0	0.02	<0.01
Total EWA asset use	0.36	0.36	0.43	0.15	0.42

Note: Cost is in millions of dollars and use of EWA water for fish is in cubic kilometers in water years 2001–2005

[a] Calculated from output from the Dayflow Program (http://www.iep.ca.gov/dayflow/index.html)

[b] Includes carriage water losses associated with EWA transfers through the delta, conveyance loss to delta from San Joaquin River tributary sources, and water lost when spilled from a storage facility due to relatively low priority for EWA water

[c] Amount paid for water by the US Bureau of Reclamation for CVP purposes and subsequently provided to EWA

[d] This is an operational tool by which EWA water stored in San Luis Reservoir is transferred to the water projects in exchange for pumping reductions

Source: Adapted from DWR (2006)

operational tools, there has been no uncompensated loss to water users. Furthermore, the agreements underlying the CALFED Record of Decision ensure compliance with endangered species regulations, so there is little prospect that water supplies will be disrupted by unanticipated hazards to fish. See CALFED (2000a) and EWA Agencies (2004) for detailed descriptions of EWA.

A common use of the EWA has been to support or complement the Vernalis Adaptive Management Plan (VAMP) (SJRGA 2005). VAMP was developed to protect juvenile Chinook salmon emigrating from the San Joaquin River through the delta while experimentally determining how survival of juvenile Chinook salmon responds to San Joaquin River flow and export flow (SJRGA 2006). In the context of the EWA, the most relevant action taken by VAMP is to increase San Joaquin River flow and reduce export flow for 1 month, generally around 15 April to 15 May. Although VAMP is usually operated with water from other environmental programs, the EWA might contribute to export curtailments for VAMP or extend export curtailments before or after the VAMP period.

The total water available to the EWA was relatively constant for the first 3 years at about 0.4 km^3, but was less in 2004 and 2005 (Table 3). The amount of water available for the EWA each year was relatively small compared to total annual inflow and total annual SWP/CVP exports (Table 3). Costs of obtaining water also varied among years. The operational tools never produced as much water as expected. During the first 5 years of the EWA, actions evolved in response to experience and perceived benefits. Several actions were taken specifically for salmon in 2001 (Table 3). In subsequent years, actions were intended to benefit both delta smelt and Chinook salmon (Table 3). In the final 4 years, most (all in 2004) EWA water was expended in association with VAMP (Table 3), particularly for 2 weeks after VAMP, when delta smelt larvae are moving toward rearing areas to the north and west, and it was assumed that these fish would be entrained in large numbers if export pumping increased (Poage 2004).

Methods

To evaluate the effectiveness of the EWA, we focus on the uses of EWA water from 2001 to 2005 to reduce export losses of winter-run Chinook salmon smolts, adult delta smelt, and juvenile delta smelt. The actual reductions in water volume exported were rather modest in relation to total monthly export volumes (Fig. 2). Most of the export reductions were concentrated in April–May, although early in the program, EWA water was used in January–April (Fig. 2). Also notable in Fig. 2 is the large reduction in export pumping under VAMP and the additional export curtailment before and after VAMP using EWA water. On an annual basis, EWA volume was less than one-tenth of SWP/CVP exports (Table 3).

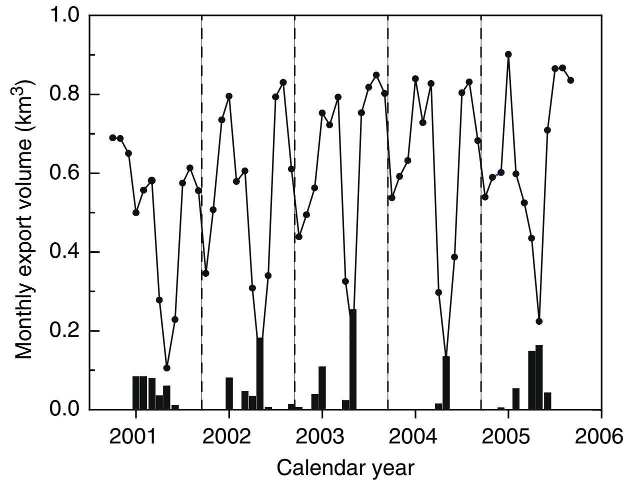

Fig. 2 Monthly export volumes during the EWA period (*line*) and reduction in export volumes attributable to EWA (*bars*). *Vertical lines* indicate water year (October 1 of previous year through September 30)

We examined the effects of the EWA on fish populations based on calculations of proportional losses (i.e., mortality) of fish at the export facilities for winter-run Chinook salmon smolts, adult delta smelt, and juvenile delta smelt. Kimmerer (2008) presented the details of the calculations, listed assumptions of the calculations, and considered various sources of uncertainty. Because these calculations are central to the estimates of EWA effects, the methods to calculate proportional losses are briefly summarized here. We consider only "direct" losses, which by local convention include losses during the salvage process, including fish passing through the louvers, mortality during the salvage and release process, and predation in or near the salvage facilities (together termed "presalvage mortality"). The operation of the salvage facilities did not change over the course of the EWA. The general approach was to estimate losses as a fraction of population size and accumulate these losses over the periods of exposure.

Winter-run Chinook salmon smolts are exposed to export losses during migration through the delta, which we take as a one-time mortality risk. The fraction of smolts salvaged was calculated simply as the total number salvaged divided by the total number estimated to have left the delta toward the ocean, calculated from the catch in an intensive trawl survey at the western margin of the delta. The fraction of smolts lost differs from the fraction salvaged and can be substantially higher if presalvage mortality is high. Therefore, this essentially unknown factor introduces large uncertainty into estimates of the fraction of salmon smolts lost.

Adult delta smelt are entrained at the fish salvage facilities from mid-December through May. Daily fractional losses were calculated as the ratio of estimated daily loss divided by the estimated population size from a spring Kodiak trawl survey. Both of these have unknown scaling factors that can be combined into a single factor. This factor was estimated by a linear model linking the abundance per volume of adult delta smelt in the water flowing to the export pumps with the catch per volume in the Kodiak trawl at stations near the export facilities. The daily fractional loss was then accumulated through the period of exposure as a mortality.

Calculations for juvenile delta smelt were conceptually similar but practically more complicated. No scaling factor was required, because the daily loss term was determined from catch in a spring trawl survey as the product of catch per volume near the export pumps and flow of water toward the export pumps, whereas population size was estimated as catch per volume times habitat volume for all sampling stations. Corrections were made for inefficient sampling of smaller larvae. The ratio of export loss to population size, or the daily fractional loss, was accumulated through spring as a mortality, as for adult delta smelt, except that natural mortality was also taken into account.

The EWA effects are presented here as the difference in percent of the population lost to export pumping with and without the EWA. The principal additional assumption underlying the calculations for the EWA is that a reduction in the proportion of fish lost to export pumping is equivalent to the same proportional increase in population size.

Here we consider two scenarios of water use applied separately for each species and life stage: (1) application of EWA water according to the historical pattern and (2) application of a range of hypothetical volumes of EWA water for a particular species/life stage. For the first scenario, we compared estimated losses of fish to export pumping using the actual export data (Fig. 2) with estimated losses using export flows that would have existed in the absence of the EWA (i.e., no export curtailments).

For the second scenario we developed estimates of fish export losses for a hypothetical period of export flow equal to the highest flow observed during the study period, which was 347 m^3/s. The volume of EWA water was set at the median volume for the first 5 years of the program. Available EWA water was applied by reducing export flows by a constant amount during a 60-day period, which was selected to encompass the period of maximum vulnerability for each species/life stage. We then developed estimates of percent of the population lost for various alternative magnitudes of EWA up to 1.2 km^3 at various levels of San Joaquin River flow (<169, 200, 300, and >411 m^3/s). Although changing export flow must be accompanied by changes in either outflow from or inflow to the delta [generally the latter; see Kimmerer (2004)], most of the variability in outflow and inflow is driven by seasonal and interannual variability in runoff. We therefore did not consider the possible effects of changes of either inflow or outflow on the fish.

We also examined how several factors affected percent losses for each species/life stage. For winter-run Chinook salmon smolts, a key factor is the rate of presalvage mortality at the fish facilities. A series of experiments at the SWP fish facility estimated prescreen mortality (mainly predation) as ranging from 63% to 99%, with a mean of 85% (Gingras 1997). No such estimate has been made for the CVP fish facility. The values used for regulatory purposes are 75 and 15%, respectively (NMFS 2004); that is, at the SWP facility, it is assumed that 75% of the smolts that might have been salvaged are not, primarily because of predation. This means that the loss of fish is three times greater than the observed number salvaged. This poorly constrained value is extremely important in determining the magnitude of losses (i.e., mortality) as a function of salvage (i.e., the estimated number of fish that arrived alive at the fish facilities). We examined the effect of presalvage losses ranging from 20% to 90%.

For adult and juvenile delta smelt, salvage occurs primarily when net (i.e., tidally averaged) flows in the Old and Middle rivers (Fig. 1) are negative (i.e., toward the pumps rather than toward the ocean). This occurs when export pumping is large compared to San Joaquin River flows. We examined this factor by calculating percent losses as a function of EWA volume at selected San Joaquin River flows for adult and juvenile delta smelt.

Results

Winter-Run Chinook Salmon

Reductions in estimated salvage as a fraction of total winter-run Chinook salmon smolts leaving the delta ranged from 0 to 1% for actual EWA expenditures of water during January–March (Fig. 2, Table 4). The reduction in fractional losses was as high as 6%, with presalvage mortality at 90% (Table 4).

We estimated that about 6% of the winter-run Chinook salmon migrating through the delta would be salvaged at the maximum export flow of 347 m^3/s. Projected improvements in survival through the delta due to hypothetical volumes of the EWA increased with the volume of water and with presalvage mortality (Fig. 3). With the EWA close to its historical magnitude of 0.37 km^3 and assuming 90% presalvage mortality, the EWA would be

Table 4 Calculated effect of historical EWA (in km^3) on winter-run Chinook salmon outmigration with historical export flows (in km^3)

Year	EWA	Export flow	Percent salvage			Percent losses for presalvage mortality rate			
			No EWA	EWA	Difference	20%	50%	75%	90%
2002	0.08	1.38	3.0	2.2	0.8	0.2	0.9	2.2	4.5
2003	0.11	1.48	3.8	2.8	1.0	0.3	1.0	2.6	5.6
2004	0	1.57	3.3	3.3	0	0.0	0.0	0.0	0.0
2005	0.05	1.51	3.8	3.5	0.3	0.1	0.3	0.8	2.0

Note: The table is a summary of salvage and losses as a percentage of total numbers of fish leaving the delta, with losses calculated using different assumed values of presalvage mortality

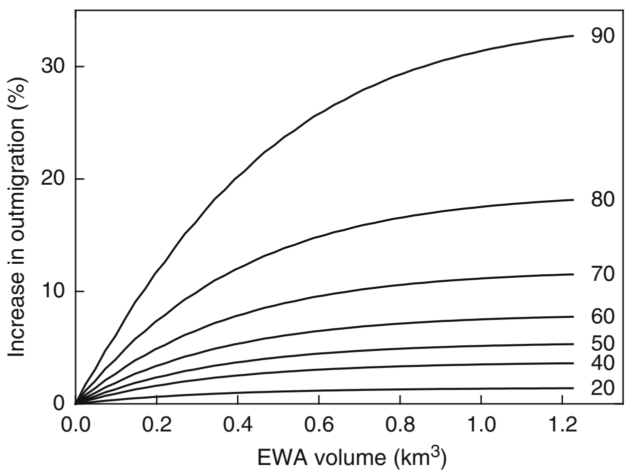

Fig. 3 Percentage increase in outmigration (assumed equal to percentage reduction in losses) of winter-run Chinook salmon smolts due to the application of hypothetical EWA volumes over a 60-day period encompassing the entire outmigration period. Numbers within the graph indicate percent presalvage mortality in the south delta. Curves are based on a model developed by Kimmerer (2008)

capable of increasing the fraction of winter-run Chinook salmon surviving passage through the delta by about 20% if applied over 60 days encompassing the entire outmigration period. These results highlight the key role of presalvage mortality in altering the estimated losses of salmon at the export facilities and, therefore, the effectiveness of the EWA. This topic seems an important one for further research if the EWA is to be continued.

Adult Delta Smelt

Reductions in export flow equivalent to the historical EWA resulted in calculated improvements in survival up to 2% (Table 5). A hypothetical EWA of similar volume to historical (0.37 km^3) could improve survival by up to about 4% if applied during the period of highest export loss (Fig. 4). Large confidence limits on this calculation are due to uncertainty in the calibration between the salvage catch per volume at the export facilities and that in the Kodiak trawl survey used to estimate the density of fish in the local

Table 5 Increase in percent survival (±95% confidence intervals) of adult delta smelt for historical EWA (in km^3)

Year	EWA	Percent increase
2001	0.17	2.0 ± 1.4
2002	0.08	0.9 ± 0.6
2003	0.11	1.2 ± 0.8
2004	0	0
2005	0.05	0.7 ± 0.5

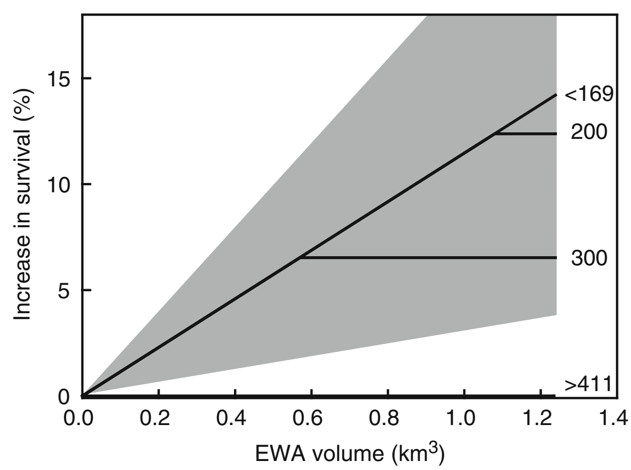

Fig. 4 Projected increase in survival of adult delta smelt with increasing EWA volume up to the 5-year median EWA volume at various levels of San Joaquin River flow (m^3/s, numbers inside the graph). The *shaded band* gives 90% confidence limits around the values for the lowest San Joaquin River flows modeled (<169 m^3/s), which provides the greatest increases in survival

area of the export pumps [see Kimmerer (2008) for details]. At San Joaquin River flow less than 169 m^3/s, changes in percent losses were linearly related to EWA volumes because flow in the Old and Middle rivers was always southward (toward the export pumps). At progressively higher San Joaquin River flow, the EWA was effective only up to the point at which the Old and Middle rivers' flow became northward. The Old and Middle rivers' flow was always northward once San Joaquin River flow exceeded 411 m^3/s. These two flows (169 and 411 m^3/s) are the 62nd and 88th percentiles, respectively, of all flows during January–February of 1995–2006, the only years during which the Old and Middle rivers' flows have been measured.

Juvenile Delta Smelt

The historical EWA resulted in calculated improvements in survival up to 4% (Table 6). A hypothetical EWA of a volume similar to the historical (about 0.37 km^3) could improve survival by up to about 7% (Fig. 5). Confidence limits around this estimate are smaller than for adults because of better sampling statistics for the more numerous juvenile smelt. Otherwise, the pattern was similar to that for adult delta smelt except that the San Joaquin River flow below which the survival relationship was linear was higher at 236 m^3/s and the flow at which the Old and Middle rivers' flow was always positive was slightly higher at 434 m^3/s. These two flows are the 58th and 80th percentiles, respectively, of all flows during March–May of 1995–2006.

Table 6 Increase in percent survival of juvenile delta smelt for historical EWA (in km^3)

Year	EWA	Percent increase
2001	0.18	2.2 ± 0.6
2002	0.27	3.3 ± 1.0
2003	0.28	3.5 ± 1.0
2004	0.15	1.9 ± 0.6
2005	0.32	4.0 ± 1.2

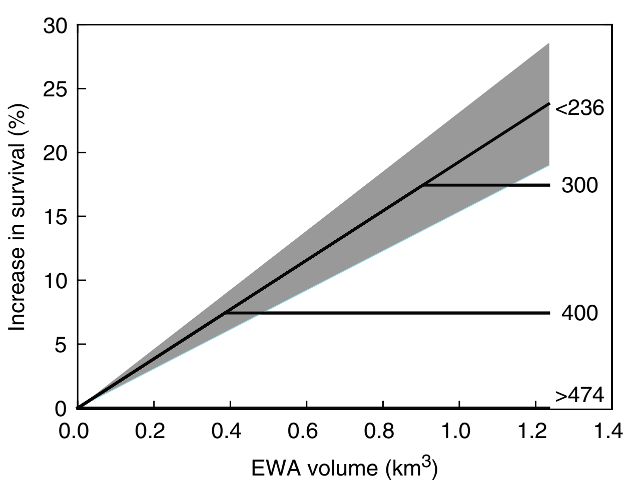

Fig. 5 Projected increase in survival of young delta smelt with increasing EWA volume up to the 5-year median EWA volume at various levels of San Joaquin River flow (m^3/s, numbers inside the graph). The *shaded band* gives 90% confidence limits around the values for the lowest San Joaquin River flows modeled (<236 m^3/s), which provides the greatest increases in survival

Discussion

The EWA is an innovative program from several perspectives. It involves the purchase of water on the open market by a government agency. It allows for the use of that water for environmental purposes. It also provides flexibility in the application of environmental regulations (i.e., flow requirements). Although not discussed in detail in this article, the management and project agencies have developed an unprecedented level of cooperation in the implementation of this program and have been responsive to new information regarding the best use of water for fish protection. The program also includes a substantial degree of review and scrutiny, most notably by a panel of independent scientists (EWA Review Panel 2001, 2002, 2003, 2004). As an experiment in management and organization, the EWA has demonstrated that a rather complex consortium of agencies can work together to effect change in a dynamic, ever-changing system.

However, the central question about the effectiveness of the EWA is whether it contributes to the recovery of at-risk species. Presumably this means that the EWA should contribute materially and substantially; if so, our calculations show that the EWA has a mixed record of achieving this objective. We showed that EWA actions to protect winter-run Chinook salmon probably had rather small effects. To put these effects in perspective, the cohort replacement rate of winter-run Chinook salmon for 1996–2005 was about 148% (Kimmerer and Brown unpublished data). The additional increment to the cohort replacement rate due to the EWA depends strongly on the presalvage mortality (Fig. 3), but in any case, it is probably small. It is unwise to make further projections about the actual magnitude of the effectiveness of EWA for winter-run Chinook salmon without better estimates of presalvage mortality.

The EWA actions to protect delta smelt have occurred in every month from January to June (Poage 2005). The effectiveness of the EWA for both adult and juvenile delta smelt has been modest. The apparent improvement in survival of juvenile smelt is about twofold higher than that for adults at any level of EWA within the linear portions of Figs. 4 and 5, but this difference is lost within the confidence limits around the two lines. The confidence limits around the line for adults could be reduced with additional data, particularly from dry years, although currently low levels of abundance might limit the catch of the trawl surveys needed to refine these estimates (Sommer and others 2007).

Under the most favorable conditions, the EWA could have substantial population-level effects on juvenile delta smelt in the spring, moderate effects on adult delta smelt in late winter, and possibly large effects on winter-run Chinook salmon (Tables 4–6). The effects on delta smelt would accrue only during dry periods when flow in the Old and Middle rivers was southward. Furthermore, highly variable survival (>10-fold among years) between summer and fall would likely obscure any EWA benefits accrued in the spring (Kimmerer 2008). Whether realized gains in abundance of any of the species or life stages are a sufficient contribution to recovery to justify the expenditure for EWA is beyond our scope.

Questions about the effectiveness of management actions in correcting human-caused declines in aquatic resources are common. In the Columbia River Basin, $3.7 billion was expended on fish and wildlife restoration from 1981 to 2006; however, populations have not recovered to target levels (McDonald and others 2007). In the Chesapeake Bay, Hudson River, and elsewhere, work on entrainment and impingement of fishes by power-plant cooling systems has documented the magnitude of effects and how to avoid them, but the overall benefit of reducing such losses must be assessed in the context of all other human activities (e.g., fishing) affecting the resources of interest (Barnthouse 2000; Richkus and McLean 2000). Difficulties also occur when the desired benefit of management actions, such as recovery of a fish population or community, is difficult to model or anticipate in advance (Growns 2008).

Even given the difficulties, managers must do their best to manage resources but acknowledge that, given the large uncertainties involved, the outcomes will be difficult to predict. Brower and others (2001) presented a cautionary example from the upper Colorado River Basin. A consensus-based management process was initiated, which successfully initiated research on the rare and poorly known native fishes, facilitated development of scarce water resources, avoided litigation of water resource development, and included all relevant stakeholders. However, the fish species of interest did not recover. Similar to our observations regarding the success of EWA, Brower and others (2001) emphasized that the success of a recovery program should focus on the recovery of the desired resource rather than successful implementation of a program.

A call for adaptive management has become a common response to managing with uncertainty. We suggest that the operation of the EWA from 2001 to 2005 is an example of managing adaptively, meaning that management is flexible in the face of variability and new information. Adaptive management, as defined by Holling (1978) and Walters (1986) and discussed in an extensive literature, is a very different approach in which all actions are seen as scientific experiments. It would be difficult to operate the EWA as an active adaptive management program because the export manipulations are small compared with other flows and the immediate responses have low signal-to-noise ratios. The greatest impediment, though, may be the difficulty of experimenting with the system. This difficulty arises from the need for the agencies to remain within the expected level of "take" (essentially, estimated losses of fish due to water facility operations) required by the Endangered Species Act. Experiments that increased take in even one year are unlikely to be approved even if the results might suggest new management strategies that would reduce take in all subsequent years.

The CALFED Record of Decision called for an annual scientific review of the EWA (CALFED 2000b) but was otherwise silent on the role of science, and no money was allocated for scientific activities within the EWA program. During the first 4 years, the topics of the annual review varied widely, but in later years the determination of benefits of EWA to fish populations was emphasized (EWA Review Panel 2001, 2002, 2003, 2004). (There was no review in 2005.) The review panel was especially helpful in identifying scientific weaknesses in the EWA, thereby stimulating EWA scientists to focus on the highest-priority issues to improve the scientific underpinnings and ultimately the performance of the EWA.

Are there advantages to the EWA in incorporating adaptive management and science more fully? That depends on the development of any long-term version of EWA. If it is clearly designed only to reduce entrainment at the export facilities, then the program in place during our study is sufficient, although additional investigations of entrainment could better define the magnitude of reductions achieved. If the EWA is actually meant to be held accountable for quantifiable improvements in fish populations, then the EWA must incorporate science, including the necessary monitoring, fully throughout the program. Subsequent to the initial drafts of this article, many of the management actions, such as the EWA, intended to protect and restore delta smelt were deemed insufficient and were supplanted by court ordered actions, including actions resulting in decreased exports (Wanger 2007a, b). It is unclear whether the EWA or an EWA-like program will be included in any future management plans for delta smelt or the delta as a whole.

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