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CALIFORNIA DEPARTMENT OF WATER RESOURCES

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF CALIFORNIA
FRESNO DIVISION

NATURAL RESOURCES DEFENSE COUNCIL, et al., Plaintiffs, v. **DIRK KEMPTHORNE, in his official capacity as Secretary of the Interior, et al.,** Defendants, **CALIFORNIA DEPARTMENT OF WATER RESOURCES,** Defendant-Intervener.	05 CV 01207 OWW-NEW **DECLARATION OF STEPHEN FORD IN SUPPORT OF INTERVENER DEPARTMENT OF WATER RESOURCES' REMEDY PROPOSAL** Hearing: August 21, 2007 Time: 9:00 am Courtroom: 3 Judge: Hon. Oliver W. Wanger

I, Stephen Ford, declare as follows:

1. I have been employed by the Department of Water Resources (DWR) since 1976 as an environmental scientist. I have worked on fish and water quality issues in the San Francisco Bay-Delta Estuary since 1990. As of September 2004, I have been Chief of the Office of Water Quality in the Division of Environmental Services. In that capacity, I am responsible for managing DWR's water quality, fish, and other aquatic monitoring and studies in the Sacramento-San Joaquin Delta and Suisun and San Pablo bays. DWR coordinates this work

DWR E

through the Interagency Ecological Program (IEP) with eight other state and federal agencies. Since July 2006, I have been DWR's Coordinator to the IEP. I have a Bachelor of Science in Biological Sciences with a focus in aquatic biology and a Master of Science in Ecology with a focus on water quality. Both of my degrees are from the University of California at Davis.

2. I make this declaration based on my own personal knowledge and could and would testify consistently with this declaration if called as a witness.

3. Between July 1, 2005 and January 31, 2006, I was assigned to temporarily act as the Deputy Director of Science for the California Bay Delta Authority (CBDA). The CBDA was established in 2003 to oversee the implementation of the CALFED Bay-Delta Program for the 25 state and federal agencies working cooperatively to improve the quality and reliability of California's water supplies while restoring the Bay-Delta ecosystem. As the Deputy Director of the CBDA's Science Program, I was responsible for integrating world-class science and peer review into every aspect of the Bay-Delta Program to assure the best scientific information possible was available to guide decisions and evaluate actions that are critical to its success.

4. I supervise and am responsible for the DWR biologists serving on the interagency team which manages the investigation to determine the causes and relative importance of factors responsible for the recent decline of the populations of delta smelt and other pelagic fishes in the Delta. This team is known as the Pelagic Organism Decline (POD) Management Team.

5. I also supervise DWR staff who serve on the U.S. Fish and Wildlife Service's (USFWS) Delta Smelt Working Group (DSWG) and the interagency Data Assessment Team. Both groups report results of delta smelt monitoring and make recommendations to DWR and the other state and federal agency managers on the CALFED Operations Group. These groups are identified in the USFWS 2005 delta smelt biological opinion, "Reinitiation of Formal and Early Section 7 Endangered Species Consultation on the Coordinated Operations of the Central Valley Project and State Water Project and the Operational Criteria and Plan to address Potential Critical Habitat Issues" (Feb. 16, 2005). (2005 BiOp at pp. 23-26.)

6. I have read and considered the statements made in the Declaration of Christina Swanson, Ph.D. in support of plaintiffs' proposed interim remedies, filed by plaintiffs on July 23,

2007 ("Swanson Declaration").

Delta Smelt Abundance Trends

7. I have reviewed the Swanson Declaration's delta smelt abundance trends contained in paragraph 4 of the declaration. The Swanson Declaration's conclusion that "[i]n 2005, abundance of delta smelt measured by the FMWT fell to its second consecutive record low and was just 2.4 percent of the abundance measured when the species was listed under the state and federal Endangered Species Act in 1993" does not fully reflect the historical data for the Fall Midwater Trawl Survey (FMWT). The Swanson Declaration's comparison of the 2005 FMWT index with the 1993 index does not disclose the historical variability of the index as displayed in Table 1 of the declaration. While the 1993 FMWT index was 1,078, the 1992 index was 156 and the 1994 index was only 102. Furthermore, the 1993 FMWT index was 10 times greater that the 1985 index. In the forty year period displayed in Table 1 of the Swanson Declaration, the FMWT index exceeded 1,000 in only six of the forty years. The Swanson Declaration's comparison of the current FMWT index with the 1993 index therefore does not provide an accurate account of the historical variability of smelt abundance as described by the FMWT data in Table 1 of the declaration.

8. I have reviewed the delta smelt abundance data derived from the 20 mm survey as set forth in Table I of the Swanson Declaration and declaration's discussion of the survey results. I have also reviewed the Department of Fish and Game (DFG) summary of the 20 mm survey catch for 2007. The declaration's conclusion that "results from the 20 mm survey indicated that the already low delta smelt population had again dropped by 90 percent" from the 2006 survey results does not fully reflect the recent variability of smelt abundance as set forth in the 20 mm survey. The 2006 survey catch results of 1084 were the highest smelt catch under this survey in the last seven years.

9. I have reviewed the results of the Summer Townet Survey for 2007 conducted by DFG. The results of the 2007 survey was a Summer Townet Survey index of 0.4, a result equaling the results of the 2006 survey.

Recent State Water Project Smelt Take

10. The recent take of the delta smelt by the State Water Project (SWP) may be explained by the operation of the Clifton Court Forebay, a component of the SWP.

11. The points of diversion from Old River in the southern Delta of the SWP and the Central Valley Project (CVP) are approximately one mile apart. However, the two projects divert from Old River in different ways. The CVP pumping facilities divert water directly from Old River at a relatively consistent rate through-out the day. In contrast, the SWP first diverts water into Clifton Court Forebay (CCF), a regulating reservoir, through radial diversion gates during the high tide period of the day. The SWP then pumps water from the CCF into the California Aqueduct. It is only after the SWP commences pumping from the CCF that smelt become entrained at the SWP's Skinner salvage facility. The SWP pumping normally occurs at night in order to minimize the energy costs of pumping.

12. In order to understand the recent take of delta smelt by the SWP it is necessary to compare the SWP smelt salvage with the CVP smelt salvage. The Table attached as Exhibit A to this declaration displays the daily salvage at the SWP and the CVP from May through July 25, 2007. This table shows that the CVP salvaged a relatively small number of smelt periodically through all of May. CVP salvage became more frequent between May 23rd and May 30th. However, the table shows that the SWP did not salvage any smelt until May 25th. Because the CVP diverts directly from Old River upstream of the SWP point of diversion at the CCF, the salvaged smelt at the CVP likely passed the CCF intake before reaching the CVP facilities. It is therefore likely that smelt were also being diverted into the CCF during the month of May.

13. The SWP did not pump from the CCF between June 1st and June 9th, and did not divert water from Old River into the CCF from June 1st through June 11th. During that period, the CVP continued diverting about 850 cubic feet per second (cfs) from Old River without salvaging any smelt. This lack of salvage was likely due to the fact that most, if not all, of the water diverted by the CVP from Old River originated from the San Joaquin River. The smelt are generally drawn into the south Delta when project pumping draws central Delta water from the north. This view is supported by the fact that CVP again began salvaging smelt on and after June 13th, when the CVP more than doubled its pumping rate and likely resumed drawing a substantial

portion of its water from the north.

14. The SWP resumed a low rate of pumping of about 90 cfs from the CCF on June 10th and June 11th, but did not divert any water into CCF from Old River. The SWP salvaged 36 smelt during these two days, all of which must have entered the CCF before June 1 and had resided in the CCF for more than 10 days. The SWP resumed its diversions from Old River into the CCF on June 12th. The SWP maintained minimal pumping from the CCF into the California Aqueduct until June 17th, when the SWP began ramping up pumping until it reached typical seasonal pumping levels starting on July 1st.

15. As Exhibit A shows, between June 17th and July 16th, the SWP was taking significantly more smelt than the CVP. During this 30 day period, the SWP took smelt in 27 of the 30 days. However, during the same period, the CVP only took smelt in 2 out of the 30 days. It is unlikely that such a significant disparity in smelt take between the two projects during this time can be fully explained by less efficient salvage at the CVP facilities. The low CVP salvage of smelt during this period, combined with the zero catch of smelt by the 20 mm survey at the south Delta stations, suggests that during this period, there were few smelt in Old River to be diverted into CCF. Given that the CVP and the SWP both divert water from Old River, it is therefore likely that a major portion of the smelt salvaged by the SWP during June and July had been diverted into the CCF in May and had resided in the CCF until they were salvaged in June and July.

16. In a separate declaration, Curtis Spencer, a DWR engineer, has reached a similar conclusion using a different analytical approach.

Plaintiffs' Remedy Proposal

17. The plaintiffs have proposed ten remedy actions. These actions are summarized in the Swanson Declaration and are more specifically described in Appendix 2 to the declaration. The first three actions require the continuation or addition of delta smelt monitoring in the Bay-Delta channels or at the SWP and CVP salvage facilities. The next six actions are designed to prevent entrainment at the SWP and the CVP facilities. Four of these actions require specified flows in Old and Middle rivers. Two of these actions prevent or delay the installation and operation of four barriers in the south Delta to provide more San Joaquin River flow into Old and Middle

rivers. These six actions are similar to those proposed by the U.S. Fish and Wildlife Service (USFWS) and DWR, but do not include the adaptive management elements contained in the USFWS' proposal that more narrowly tailor the actions to address variations in the distribution and abundance in the smelt population, hydrology, Delta hydrodynamics and other factors. The plaintiffs' tenth action would require additional Delta outflow in the fall to maintain low levels of salinity below the confluence of the Sacramento and San Joaquin rivers. This action is not included in the USFWS' proposal. The following will review each action individually.

Delta Smelt Monitoring Surveys

18. Action 1 would require the continuation of the existing DFG Delta smelt surveys. DWR and the U.S. Bureau of Reclamation (USBR) have contracted with DFG to fund the surveys, but DWR and USBR have no means to require DFG to continue to conduct the surveys.

19. Action 2 would require the USBR to increase the amount of time it samples and counts the number of fish entrained at the CVP facilities. DWR would have no objection to this action.

20. Action 3 would require the monitoring of delta smelt of less than <20 mm in length at the SWP and CVP facilities in the south Delta. There exist three reasons why this action should not be adopted. First, the ability to sample larval fish in the SWP is extremely difficult. DWR has attempted to sample larval fish at the CCF, but was forced to abort the sampling effort because the larval nets would not withstand the high water velocity due to project pumping and because of health and safety concerns regarding DWR personnel engaged in the sampling efforts. Second, the plaintiffs' Actions 5, 8, and 9 could be triggered by detection of larval smelt at the CVP or SWP facilities. The Kodiak survey and water temperature when spawning is likely to occur are more effective indicators of the risk of smelt entrainment. The DSWG has consistently used data from the Kodiak survey and water temperature to evaluate smelt entrainment risks during the spring period. Third, while monitoring <20 mm smelt at the CVP and the SWP facilities might improve information on delta smelt distribution during this life stage, the evaluation of this action should be left to the scientists currently conducting the Pelagic Organism Decline investigation. These scientists would be best able to determine the need for and the design of such localized larval sampling.

Protection of Pre-Spawning Adults

21. The plaintiffs' Action 4 includes two sub-actions that are similar in nature and purpose to the USFWS' Actions 1 and 2. These actions limit the amount of upstream flow in Old and Middle rivers to prevent or minimize the movement of pre-spawning adult smelt toward the SWP and the CVP's pumping facilities.

22. There are significant differences in the plaintiffs' Action 4 and the USFWS' actions in terms of the action triggers and the extent of the actions. The first sub-action of Action 4 would be triggered by (1) an increase of Sacramento River flow at Freeport to 25,000 cfs; or (2) a greater than 10 % increase in San Joaquin River flow over three days. The Swanson declaration cites to the DSWG notes of 10/10/06 and 12/11/06 and the Pelagic Fish Action Plan in support of these triggers. However, the DSWG notes do not support the triggers used by the plaintiffs. The 12/11/06 DSWG notes document the DSWG's final recommendation and state that the action would be triggered after Freeport flows exceeded 25,000 cfs "for at least three days." (Swanson Declaration, Exhibit S (Doc. 421-6) at p. 3.) The Pelagic Fish Action Plan also adopts the three day measuring period. (Swanson Declaration, Exhibit Q (Doc. 421-5) at p. 44.) By not including the three days of Freeport flows identified in the DSWG notes and the Pelagic Fish Action Plan, the plaintiffs' trigger is more sensitive and would at times require curtailments of SWP and CVP exports earlier than recommended by the DSWG without any apparent benefit to the smelt. Moreover, the plaintiffs Action 4 includes a trigger based upon San Joaquin River flow that is not included in either the DSWG notes or in the Pelagic Fish Action Plan and the rationale for the trigger is not explained or justified.

23. In addition, a second difference between the plaintiffs and the USFWS' action triggers is that the plaintiffs' triggers are based on flow while the USFWS has shifted from a flow-based trigger to a turbidity-based trigger for USFWS' Action 1. Significant pulses of river inflows during the winter are turbid, causing Delta inflow and turbidity within the Delta waters to be highly correlated. The use of the turbidity criterion rather than flow criterion enables the USFWS to factor the combined effects on the delta smelt of the Sacramento River, the San Joaquin River, and other Delta tributaries into a single trigger.

24. There are significant differences between the actions that plaintiffs and the USFWS have proposed to respond to and to follow up on a pulse flow event. First, upon detection of the first pulse flow, the plaintiffs' Action 4 would restrict CVP and SWP exports to prevent a 5-day average negative flow in Old and Middle rivers for a minimum of 10 days. Second, Old and Middle rivers flows would not exceed negative 3,500 cfs after the end of the first pulse flow action, if monitoring found smelt in the Delta, or after January 15th. This negative 3,500 cfs limit would continue until the onset of spawning. The USFWS' Action 1 would prohibit upstream Old and Middle river flows from exceeding negative 2,000 cfs over a 10 day period upon the detection of the turbidity resulting from a high pulse flow event. The USFWS' Action 2 would prevent upstream Old and Middle river flows from exceeding negative 4,500 cfs after Action 1 was completed or after January 15th.

25. The plaintiffs' Action 4 points to the DSWG notes of 10/10/06 and 12/11/06 as an explanation for the flows identified in this action. While Action 4 points out that the upstream Old and Middle river flow of negative 3,500 cfs is the lower value of the negative 3,500 to 5,000 cfs range of flows recommended by the DSWG, the Swanson declaration does not explain the rationale for requiring no upstream flow rather than the negative 3,500 cfs recommended by the DSWG in response to a pulse flow event. Nor does the declaration explain why negative 3,500 cfs was selected as the proper value within the negative 3,500 to 5,000 cfs range recommended by the DSWG. (Swanson Declaration, Exhibit S (Doc. 421-6) at p. 2.) Moreover, this aspect of Action 4 is also inconsistent with the suggested possible actions described in the Pelagic Fish Action Plan. (Swanson Declaration, Exhibit Q (Doc. 421-5) at p. 44.)

26. In support of Action 4, the Swanson declaration relies upon a regression analysis prepared by Pete Smith of the U.S. Geological Survey. This analysis is set forth in Figure 8 of the Swanson declaration. One concern about this analysis is that it calculated and displayed the relationship as though positive Old and Middle river flows which occurred in 1997 and 1998 were of zero value. The alteration of these data points causes the regression line to pass through zero when such a result does not accurately reflect the data. This approach is not appropriate for the purpose of determining the relationship between Old and Middle river flows and project

salvage.

27. The July 9, 2007 Jerry Johns declaration and Exhibits B and C of his declaration contain an update and refined analysis by DWR of actual adult salvage and Old and Middle river flow data from 1993 through 2006. (Jerry Johns Declaration (Doc. 399) at ¶ 34, pp. 12-13.) According to this analysis, the January regression was the strongest, showing Old and Middle river flow could account for nearly 90 % of the variability in the salvage of adult smelt. The February regression could account for 30 % of that variability. The weaker February relationship suggests that other factors have a greater effect on adult salvage than the average Old and Middle river flows. The strong January relationship suggests that the benefit of limiting negative Old and Middle river flow for the protection of adult smelt falls off rapidly as negative flow drops below about 6,000 cfs.

28. The updated DWR analysis of Old and Middle river flows and salvage suggests that the plaintiffs' Action 4 might not provide much more protection for adult smelt than the DSWG recommendation or the USFWS' proposal.

29. The USFWS' Action 1 would restrict CVP and SWP exports to prevent average negative flow in Old and Middle rivers from exceeding negative 2,000 cfs for a minimum of 10 days after a pulse flow event. This recommendation is intermediate between the 0 proposed by Swanson and the negative 3,500 cfs proposed by the DSWG.

30. The USFWS' Action 2 would restrict CVP and SWP exports to prevent the 14-day average negative flow in Old and Middle rivers from exceeding negative 4,500 cfs. This recommendation is greater than negative 3,500 cfs proposed by the plaintiffs and within the range of negative 3,500 to 5,000 cfs proposed by the DSWG. As noted in Jerry Johns' declaration and the attached exhibits, the flows in USFWS' Action 1 and Action 2 should be sufficient to protect adult smelt during this period.

Protection of Adults, Larvae and Juveniles

31. When taken together, the plaintiffs' Actions 5, 6 and 7 are similar to the USFWS' Action 3. These actions would limit the amount of upstream flow in Old and Middle rivers to avoid or minimize the entrainment of larval and juvenile delta smelt. They would also minimize

the entrainment of adult smelt. All of these actions would be initiated at the onset of smelt spawning, which is to be determined by the fish surveys, salvage, and water temperatures.

32. The plaintiffs' Action 5 would start with the onset of smelt spawning and end with the initiation of the Vernalis Adaptive Management Program (VAMP). Action 5 would therefore cover a period from late February to mid to late April. Action 6 is the VAMP, which usually starts in mid to late April and ends in mid to late May. Action 7 is essentially the same as Action 5, except that it covers the period between the end of VAMP and June 15th or the last detection of smelt, whichever is later. Like the plaintiffs' proposals, the USFWS' Action 3 starts with the onset of spawning. Action 3 then continues through the VAMP period covered by plaintiffs' Action 6 and into the post-VAMP period covered by the plaintiffs' Action 7. However, the USFWS' Action 3 ends when the entrainment risk is abated or by June 1st, whichever occurs first, rather than continuing on to June 15th as does the plaintiffs' Action 7. The USFWS' Action 4 would evaluate real-time delta smelt data and identify actions to protect juvenile smelt through June. Unlike the plaintiffs, the USFWS did not include VAMP as an action because VAMP is already part of the CVP/SWP baseline operations upon which a remedy would overlay.

33. The plaintiffs' Actions 5 and 7 would restrict CVP and SWP exports to prevent negative flow in Old and Middle rivers from exceeding negative 1,500 cfs. The USFWS has structured its Action 3 to be less prescriptive than plaintiffs' Actions 5 and 7 to allow the actions to be more narrowly tailored to protect delta smelt based upon the actual conditions in the watershed next winter and spring. Unlike the plaintiffs' actions, the USFWS action would not be required if fish and Delta flow and monitoring show smelt are unlikely to be entrained. The lack of smelt south or east of Franks Tract or the inflow of flood flows from the Yolo Bypass into the Delta are specific criterion which would be used to determine the need for action.

34. When triggered, the USFWS' Action 3 restricts upstream flow in Old and Middle rivers to between 0 and negative 4,000 cfs. The initial value would be determined and then readjusted through the spring based on the analysis of the potential CVP and SWP effects on the real-time distribution and abundance of smelt. The Particle Tracking Model would be relied upon for these analyses to predict the susceptibility of the smelt to entrainment at the CVP and

the SWP facilities. The range of 0 to negative 4,000 cfs upstream Old and Middle river flows included in USFWS' Action 3 could result in more restrictive flow limits than the plaintiffs' negative 1,500 cfs flow limit. At times when the USFWS determines that smelt have a high risk of entrainment based upon real-time data, Action 3 would allow for more aggressive protective actions than the plaintiffs' proposal.

Protection of Larval and Juveniles

35. The plaintiffs' Actions 8 and 9 are similar to USFWS' Action 5. These actions are designed to minimize the entrainment of larval and juvenile smelt by minimizing the negative flow in Old and Middle rivers. The plaintiffs' Actions 8 and 9 would prevent the installation of the Head of Old River Barrier and three agricultural barriers until June 15th or the last detection of smelt, whichever is later. The USFWS' Action 5 would prohibit the installation of the Head of Old River Barrier, but would allow the installation of agricultural barriers as long as the barrier flap gates remained opened. USFWS' Action 5 would end at the termination of VAMP.

36. The plaintiffs contend that their Action 8 prohibition on the installation of the agricultural barriers is "nearly identical to that identified by CDWR in the Pelagic Fish Action Plan and recommended by the DSWG in 2007." However both the Pelagic Fish Action Plan and the DSWG notes allow for the installation of these barriers after June 1st, not June 15th or later as provided in the plaintiffs' Action 8. (Swanson Declaration, Exhibit Q (Doc. 421-5) at p. 44.)

Protection of Juveniles and Sub-Adults

37. The plaintiffs' Action 10 requires the CVP and the SWP to maintain Delta outflow of 7,500 cfs or a salinity of 2 parts per thousand below the confluence of the Sacramento and San Joaquin rivers. I have reviewed the declaration of John Leahigh and have considered Mr. Leahigh's conclusion that, depending upon water year type, compliance with the plaintiffs' Action 10 may result in the reduction of upstream storage in 2008 by between 20,000 to 310,000 acre-feet of water. If water year conditions result in reduced storage at the amounts equivalent to the high range of this estimate, then the projects may be unable to meet temperature related water quality requirements on the Sacramento River necessary to protect salmon species listed under the federal and state Endangered Species Act. For similar reasons, the Pelagic Fish Action Plan

did not recommend the maintenance of a fall salinity requirement in below normal or drier water years. (Swanson Declaration, Exhibit Q (Doc. 421-5) at pp. 44 and 51.)

38. I have reviewed the Feyrer, Nobriga, and Sommer paper referenced by the plaintiffs in their proposed Action 10, and have attached a true and correct copy of said paper to this declaration as Exhibit B. The paper suggests that fall salinity is a factor in determining the delta smelt's summer abundance index from 1987 - 2004. Table 2 of the of the paper shows 40% of the variation in the summer abundance index can be accounted for by the smelt's abundance index from the previous fall. A total of about 60% of the summer index can be accounted by the previous fall's smelt abundance, salinity, and water turbidity.

39. I have reviewed Figure 4 of the Swanson Declaration, which presents the Guerin et al. (2006) analysis of the relationship between the fall salinity in the western Delta and the abundance index of juvenile smelt the following summer between 1988 and 2005. The plaintiffs' have used this analysis as the second basis for their proposed Action 10. I have included the original Figure 4 at the top of Exhibit C attached to this declaration. Below the original Figure 4, I have included the results of the same analysis updated to include 2006 and 2007 data. When the last two years of data are added, the relationship between the smelt's summer abundance and the salinity in the previous fall is no longer significant. Also note that the 2005-2007 data all fall well below the regression line shown in the original Figure 4. The recent data suggest that the relationship shown in Figure 4 of the Swanson Declaration no longer provides a statistically significant justification for the plaintiffs' Action 10.

Population Estimates

40. Estimating delta smelt populations requires making numerous assumptions about the effectiveness of various nets used to sample various life stages of the smelt, how those life stages distribute themselves in the water column, and other factors. DWR is currently working through the Interagency Ecological Program with a USFWS statistician to develop a more statistically refined estimate of smelt population. This estimate may be available within the next two months. I have reviewed the population estimate set forth in the declaration of Charles Hanson. The overall approach used by Dr. Hanson is generally consistent with the approach being considered

by the Interagency Ecological Program.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

DATED:
August 2, 2007

Stephen Ford

STEPHEN FORD

EXHIBIT A

To

FORD DECLARATION

Exhibit A

	SWP				CVP					
DATE	Clifton Court Intake (cfs)	Banks Pumping (cfs)	Skinner Delta Smelt Salvage	Salvage Density (smelt/taf)	Tracy Pumping (cfs)	Tracy Delta Smelt Salvage	Salvage Density (smelt/taf)	San Joaquin Flow (cfs)	Estimated San Joaquin Flow Diverted down Old River (cfs)	Head of Old River Barrier Status
01-May-07	618	531	0	0.0	849	12	7.13	3478	1878	Closed: With 3 Culverts Open/ 3 Closed
02-May-07	989	872	0	0.0	580	0	0.00	3398	1798	Closed: With 3 Culverts Open/ 3 Closed
03-May-07	695	677	0	0.0	848	0	0.00	3263	1605	Closed: With 3 Culverts Open/ 3 Closed
04-May-07	692	676	0	0.0	846	0	0.00	2847	1180	Closed: With 3 Culverts Open/ 3 Closed
05-May-07	682	675	0	0.0	844	0	0.00	2901	1132	Closed: With 3 Culverts Open/ 3 Closed
06-May-07	691	673	0	0.0	855	0	0.00	2970	1169	Closed: With 3 Culverts Open/ 3 Closed
07-May-07	693	679	0	0.0	846	0	0.00	3012	1181	Closed: With 3 Culverts Open/ 3 Closed
08-May-07	692	578	0	0.0	852	0	0.00	3053	1281	Closed: With 3 Culverts Open/ 3 Closed
09-May-07	696	652	0	0.0	853	0	0.00	3100	1301	Closed: With 3 Culverts Open/ 3 Closed
10-May-07	680	532	0	0.0	853	12	7.09	3080	1276	Closed: With 3 Culverts Open/ 3 Closed
11-May-07	695	536	0	0.0	849	48	28.50	3122	1331	Closed: With 3 Culverts Open/ 3 Closed
12-May-07	699	530	0	0.0	849	0	0.00	3159	1375	Closed: With 3 Culverts Open/ 3 Closed
13-May-07	685	787	0	0.0	850	12	7.12	3196	1378	Closed: With 3 Culverts Open/ 3 Closed
14-May-07	697	681	0	0.0	844	0	0.00	3225	1360	Closed: With 3 Culverts Open/ 3 Closed
15-May-07	685	521	0	0.0	853	0	0.00	3160	1328	Closed: With 3 Culverts Open/ 3 Closed
16-May-07	346	303	0	0.0	852	0	0.00	3184	1398	All 6 culverts Open
17-May-07	342	275	0	0.0	855	0	0.00	3380	1661	All 6 culverts Open
18-May-07	347	317	0	0.0	852	0	0.00	3405	1660	All 6 culverts Open
19-May-07	345	273	0	0.0	855	0	0.00	3352	1601	All 6 culverts Open
20-May-07	344	272	0	0.0	850	0	0.00	3342	1630	All 6 culverts Open
21-May-07	345	271	0	0.0	856	0	0.00	3302	1495	Breached
22-May-07	341	273	0	0.0	852	0	0.00	3118	1636	Fully Breached
23-May-07	397	798	0	0.0	848	24	14.27	2997	1973	Fully Breached
24-May-07	395	359	0	0.0	849	24	14.25	2853	2074	Fully Breached
25-May-07	394	358	2	2.8	851	0	0.00	2731	2015	Fully Breached
26-May-07	396	358	22	30.9	845	24	14.32	2641	1971	Fully Breached
27-May-07	395	260	24	46.5	849	24	14.25	2606	1930	Fully Breached
28-May-07	393	321	20	31.4	853	0	0.00	2631	1948	Fully Breached
29-May-07	397	315	58	92.9	853	12	7.09	2537	1931	Fully Breached
30-May-07	390	316	46	73.7	854	24	14.17	2532	1852	Fully Breached
31-May-07	392	261	40	77.4	856	0	0.00	2463	1792	Fully Breached
01-Jun-07	0	0	0	0.0	852	0	0.00	2486	1820	Fully Breached
02-Jun-07	0	0	0	0.0	853	0	0.00	2537	1847	Fully Breached
03-Jun-07	0	0	0	0.0	854	0	0.00	2502	1786	Fully Breached
04-Jun-07	0	0	0	0.0	858	0	0.00	2367	1693	Fully Breached
05-Jun-07	0	0	0	0.0	851	0	0.00	2254	1639	Fully Breached
06-Jun-07	0	0	0	0.0	850	0	0.00	2196	1566	Fully Breached
07-Jun-07	0	0	0	0.0	847	0	0.00	2140	1577	Fully Breached
08-Jun-07	0	0	0	0.0	845	0	0.00	2145	1643	Fully Breached
09-Jun-07	0	0	0	0.0	849	0	0.00	2080	1580	Fully Breached
10-Jun-07	0	90	27	151.7	845	0	0.00	1947	1496	Fully Breached
11-Jun-07	0	90	9	50.3	846	0	0.00	2084	1578	Fully Breached
12-Jun-07	390	89	30	170.5	853	0	0.00	2223	1723	Fully Breached
13-Jun-07	391	89	9	50.8	2009	48	12.05	2294	1780	Fully Breached
14-Jun-07	391	90	9	50.6	2526	0	0.00	2006	1570	Fully Breached
15-Jun-07	397	96	18	94.2	2575	0	0.00	1858	1448	Fully Breached
16-Jun-07	396	97	9	46.9	2575	0	0.00	1854	1366	Fully Breached
17-Jun-07	989	495	168	171.3	2697	12	2.24	1935	1366	Fully Breached
18-Jun-07	997	400	90	113.5	2689	0	0.00	1960	1429	Fully Breached
19-Jun-07	996	840	90	54.0	3363	0	0.00	1812	1289	Fully Breached
20-Jun-07	739	717	9	6.3	3754	0	0.00	1668	1178	Fully Breached
21-Jun-07	997	932	30	16.2	3525	0	0.00	1625	1218	Fully Breached
22-Jun-07	994	934	57	30.8	4017	0	0.00	1600	1314	Fully Breached
23-Jun-07	985	945	15	8.0	4278	0	0.00	1368	1134	Fully Breached
24-Jun-07	334	587	24	20.6	4211	0	0.00	1354	1126	Fully Breached
25-Jun-07	487	192	0	0.0	4279	0	0.00	1385	1145	Fully Breached
26-Jun-07	746	324	30	46.7	4288	0	0.00	1297	1117	Fully Breached
27-Jun-07	491	848	327	194.5	4254	0	0.00	1326	1136	Fully Breached
28-Jun-07	994	856	30	17.7	4270	0	0.00	1316	1104	Fully Breached
29-Jun-07	996	878	78	44.8	4277	0	0.00	1260	1058	Fully Breached
30-Jun-07	997	1360	390	144.6	4431	0	0.00	1224	1008	Fully Breached
01-Jul-07	6668	5301	246	23.4	3926	12	1.54	1288	1162	Fully Breached
02-Jul-07	6382	6032	311	26.0	4452	0	0.00	1297	1207	Fully Breached
03-Jul-07	5339	5485	13	1.2	4442	0	0.00	987	906	Fully Breached
04-Jul-07	5593	5833	18	1.6	4385	0	0.00	980	900	Fully Breached
05-Jul-07	5611	5301	21	2.0	4440	0	0.00	983	945	Fully Breached
06-Jul-07	5830	5755	9	0.8	4358	0	0.00	989	971	Fully Breached
07-Jul-07	5025	5582	12	1.1	4346	0	0.00	929	831	Fully Breached
08-Jul-07	5780	5459	6	0.6	4344	0	0.00	948	854	Fully Breached
09-Jul-07	5990	5807	6	0.5	4354	0	0.00	1045	988	Fully Breached
10-Jul-07	5990	5824	6	0.5	4406	0	0.00	929	856	Fully Breached
11-Jul-07	6661	6200	0	0.0	4385	0	0.00	992	896	Fully Breached
12-Jul-07	6456	6256	6	0.5	4386	0	0.00	1013	907	Fully Breached
13-Jul-07	5946	6424	0	0.0	4391	0	0.00	1011	954	Fully Breached
14-Jul-07	6927	6985	6	0.4	4365	0	0.00	1053	1070	Fully Breached
15-Jul-07	7156	7986	6	0.4	4354	0	0.00	1069	1062	Fully Breached
16-Jul-07	7147	6441	24	1.9	4353	0	0.00	1102	1074	Fully Breached
17-Jul-07	7163	6878	6	0.4	4376	0	0.00	997	973	Fully Breached
18-Jul-07	7167	7055	3	0.2	4382	0	0.00	946	924	Fully Breached
19-Jul-07	6960	7317	0	0.0	4367	0	0.00	988	1010	Fully Breached
20-Jul-07	7178	6930	0	0.0	4363	0	0.00	963	991	Fully Breached
21-Jul-07	6274	6993	0	0.0	4391	0	0.00	941	940	Fully Breached
22-Jul-07	7160	6693	0	0.0	4379	0	0.00	1030	952	Fully Breached
23-Jul-07	7175	6681	0	0.0	4385	0	0.00	1036	938	Fully Breached
24-Jul-07	7170	6895	0	0.0	4418	0	0.00	990	925	Fully Breached
25-Jul-07	6584	4799	0	0.0	4458	0	0.00	988	928	Fully Breached

EXHIBIT B

To

FORD DECLARATION

Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA

Frederick Feyrer, Matthew L. Nobriga, and Ted R. Sommer

Abstract: We examined a 36-year record of concurrent midwater trawl and water quality sampling conducted during fall to evaluate habitat trends for three declining fish species in the San Francisco Estuary, California, USA: delta smelt (*Hypomesus transpacificus*), striped bass (*Morone saxatilis*), and threadfin shad (*Dorosoma petenense*). Generalized additive modeling revealed that Secchi depth and specific conductance were important predictors of occurrence for delta smelt and striped bass, while specific conductance and water temperature were important for threadfin shad. Habitat suitability derived from model predictions exhibited significant long-term declines for each species; the southeastern and western regions of the estuary exhibited the most dramatic changes. Declines in habitat suitability were associated with anthropogenic modifications to the ecosystem. For delta smelt, an imperiled annual species endemic to the estuary, the combined effects of fall stock abundance and water quality predicted recruit abundance during recent years of chronically low food supply. Our results are consistent with existing evidence of a long-term decline in carrying capacity for delta smelt and striped bass and demonstrate the utility of long-term data sets for evaluating relationships between fish and their habitat.

Résumé : Nous avons examiné des données concomitantes d'échantillonnage au chalut en pleine eau et d'échantillonnage de la qualité de l'eau faites à chaque automne pendant 36 années dans l'estuaire de San Francisco, Californie, É.-U., afin d'évaluer les tendances de l'habitat chez trois espèces de poissons en déclin, soit l'éperlan du delta (*Hypomesus transpacificus*), le bar rayé (*Morone saxatilis*) et l'alose fil (*Dorosoma petenense*). Un modèle additif généralisé montre que la profondeur de Secchi et la conductance spécifique sont d'importantes variables explicatives de la présence de l'éperlan du delta et du bar rayé, alors que la conductance spécifique et la température de l'eau le sont pour l'alose fil. Les prédictions du modèle indiquent une diminution significative à long terme de la qualité de l'habitat pour chaque espèce; les régions du sud-est et de l'ouest de l'estuaire montrent les changements les plus spectaculaires. Le déclin de la qualité de l'habitat est associé à des modifications anthropiques de l'écosystème. Chez l'éperlan du delta, une espèce annuelle, menacée et endémique à l'estuaire, les effets combinés de l'abondance des stocks à l'automne et de la qualité de l'eau expliquent l'abondance du recrutement durant les années récentes de sources de nourriture chroniquement limitées. Nos résultats confirment les indications existantes d'un déclin à long terme du stock limite de l'éperlan du delta et du bar rayé; ils démontrent l'utilité des banques de données couvrant de grandes périodes pour l'évaluation des relations entre les poissons et leur habitat.

[Traduit par la Rédaction]

Introduction

There have been worldwide declines in production and yield of many estuarine-dependent fishes resulting from overfishing, pollution, and habitat alterations (Houde and Rutherford 1993). These trends have coincided with substantial long-term changes in fish species composition and abundance in developed North American estuaries (Matern et al. 2002; Hurst et al. 2004). Declining yields and changing fish communities suggest that current understanding of fish population dynamics is insufficient to ensure proper management.

The processes underlying fish population dynamics are complex because multiple interacting factors contribute to interannual variation in recruitment and abundance. A fundamental component in the study of population dynamics is the interaction between fish and their habitat. In the broadest sense, habitat can be characterized as the abiotic and biotic factors that are required to support healthy fish populations (Hayes et al. 1996). The abiotic components of habitat often strongly influence the biotic components, particularly in estuaries where freshwater inputs and associated salinity effects are important community-structuring mechanisms (e.g., Bulger et al. 1993; Jassby et al. 1995). Quantifying

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fish–habitat relationships and long-term trends in habitat suitability is critical because abiotic habitat components can affect the population dynamics of fishes in most habitat types (e.g., Cardinale and Arrhenius 2000; Claramunt and Wahl 2000; Rose 2000). Here, we use the term environmental quality (EQ; Rose 2000) to describe abiotic habitat variables that may affect fish population dynamics.

Long-term data sets are essential for the development and evaluation of fish–EQ relationships and time trends (Bray 1996; Rose 2000). Long-term data sets that include a wide range of environmental conditions are particularly useful because they allow researchers to more effectively model the linkages between EQ and fish occurrence (Rose 2000). Moreover, analyses of long-term data sets are needed to understand the effects of management actions. If rehabilitation is desired, then management actions aimed at improving EQ to a pre-existing state can often be determined from existing data. One limitation of empirical data, however, is that it frequently focuses on a particular life stage or time period when sampling was conducted. Thus, it is important to understand the temporal relevance of the sample collections in subsequent model development (Levin and Stunz 2005).

In this study, we quantified fish–EQ relationships in San Francisco Estuary (Fig. 1) using a long-term record (1967–2004) of fish and water quality data concurrently collected during fall (September–December). Our objectives were to (1) develop models relating fish occurrence to EQ, (2) examine temporal and spatial trends in EQ, and (3) determine whether the water quality variables that define EQ can also be linked to fish abundance. Understanding fish–EQ linkages is a principal goal in fisheries science and is of great practical interest in San Francisco Estuary. The estuary is well known for anthropogenic modifications that have highly altered most natural elements of the system, and there have been long-standing concerns about the effect of these modifications on fish populations (Nichols et al. 1986; Bennett and Moyle 1996). Indeed, many fish species have exhibited declines in abundance since long-term monitoring began in the 1950s (e.g., Stevens et al. 1985; Moyle et al. 1992). In recent years, there has also been an apparent step-decline in the abundance of three pelagic species — delta smelt (*Hypomesus transpacificus*), striped bass (*Morone saxatilis*), and threadfin shad (*Dorosoma petenense*) (Fig. 2). These species are the focus of our study. Concern is perhaps greatest for delta smelt, a rare and delicate endemic species listed as threatened under both the California and US Endangered Species Acts; a petition is currently being considered to downgrade delta smelt status to endangered. Water management actions in the estuary are closely tied to protecting delta smelt, even on a daily basis during some portions of the year. Management actions in the estuary receive great attention throughout the state because water diversions from the estuary supply drinking water to over 22 million people in California, in addition to supporting a multibillion dollar agricultural industry. Striped bass and threadfin shad are both introduced species; because they comprise a substantial portion of fish biomass in the ecosystem and support valuable recreational fisheries, their declines are also cause for concern.

Materials and methods

Study area

San Francisco Bay (Fig. 1) forms the largest estuary on the Pacific coast of the United States. The estuary is a drowned river valley separated into different basins by complex bathymetry. Water enters the estuary primarily from California's two largest rivers — Sacramento (from the north) and San Joaquin (from the south) — which drain a 100 000 km^2 watershed encompassing 40% of California's surface area. The rivers converge in the upper estuary to form the Sacramento – San Joaquin Delta, a 3000 km^2 network of tidal freshwater channels. From the delta, water flows west into Suisun Bay, through the Carquinez Strait, and enters San Pablo Bay before reaching San Francisco Bay and ultimately the Pacific Ocean. Owing to the Mediterranean climate, freshwater flow entering the estuary varies seasonally, occurring mainly in late winter through spring. The estuary is also subject to extreme interannual variation in freshwater flows, with periodic droughts and floods.

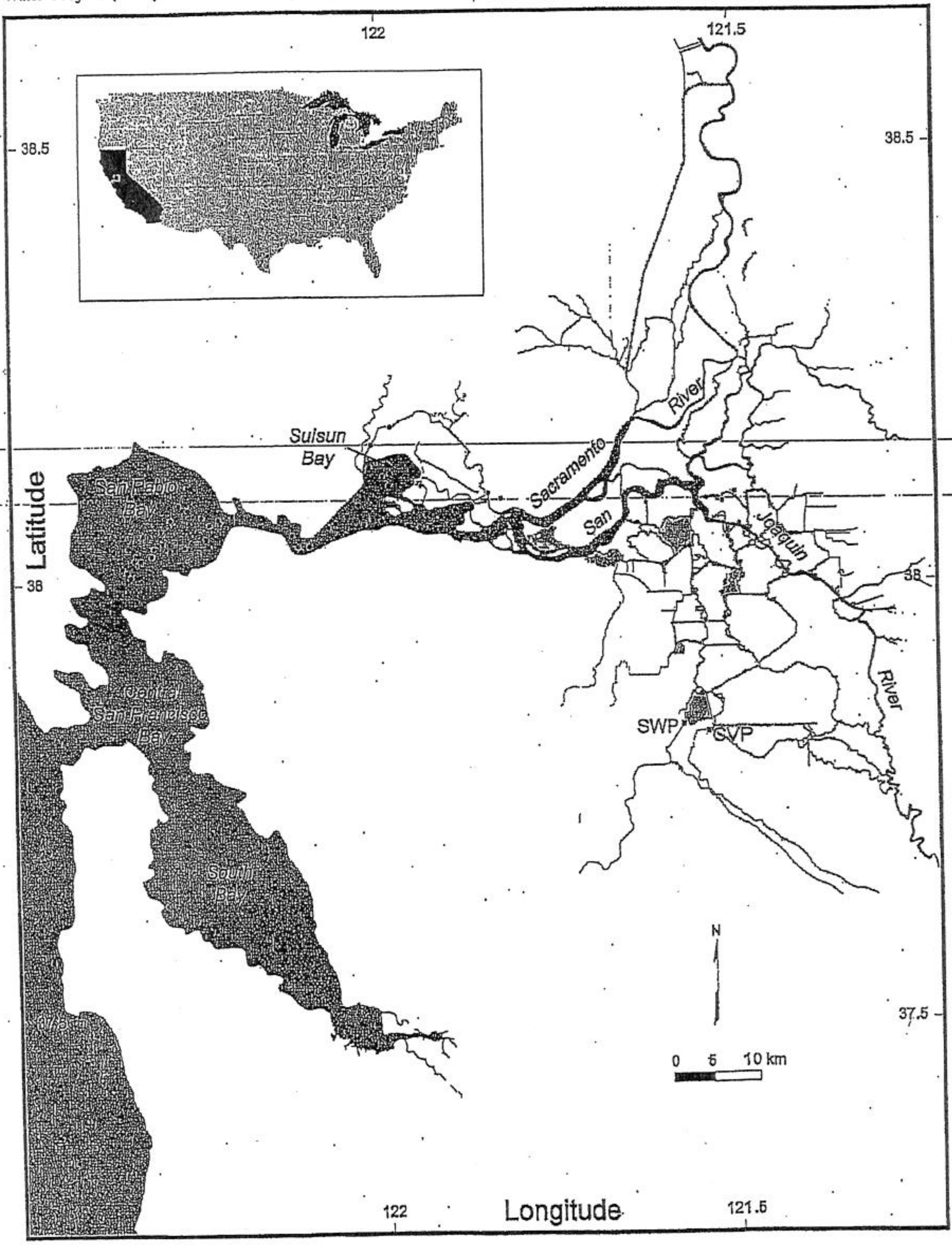
Anthropogenic modifications in this highly altered estuary include the loss of wetlands via draining and diking for agriculture, channel modifications for flood control and navigation, and a variety of water reclamation activities, including storage, conveyance, and large-scale water diversion from the southern delta (Nichols et al. 1986). Major dams located on the Sacramento and San Joaquin rivers, including most of their major tributaries, control flows entering the estuary. One result of these modifications is that water movement through the estuary is highly managed. Through the many large upstream dams; smaller, within-estuary flow control structures; and large water diversion operations in the southern delta, managers have an unparalleled ability to control water movement in the system. One of the ways in which flows are managed in this estuary is to benefit fishes and other organisms by manipulating the position of the estuarine salinity gradient.

Similar to most estuaries, many of the ecosystem components and functions of the San Francisco Estuary exhibit measurable responses to flow (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002). In particular, the abundance or survival of many fishes and invertebrates exhibits a strong relationship with flow entering the estuary, as indexed by the position of the 2‰ isohaline (Jassby et al. 1995; Kimmerer 2002). This index, termed X_2, is defined as the distance (km) from the Golden Gate Bridge to the location in the estuary where mean bottom salinity is 2‰ (Jassby et al. 1995; Kimmerer 2002). The position of X_2 is seasonally variable based primarily on river flow variation. However, its position can be manipulated and is closely managed to be located in certain regions during specific times of the year to benefit aquatic species.

Data sources and analytical methods

We analyzed long-term data collected from a fall midwater trawl survey (FMWT) conducted by the California Department of Fish and Game (Stevens and Miller 1983). The survey has been conducted each year since 1967, except that no sampling was done in 1974 and 1979. The FMWT collects a sample (10- to 12-minute tow) at 100 sites four

Fig. 1. Map of the San Francisco Estuary (California, USA) showing fall midwater trawl survey sampling stations. The location of the State Water Project (SWP) and Central Valley Project (CVP) export pumping facilities are also shown.



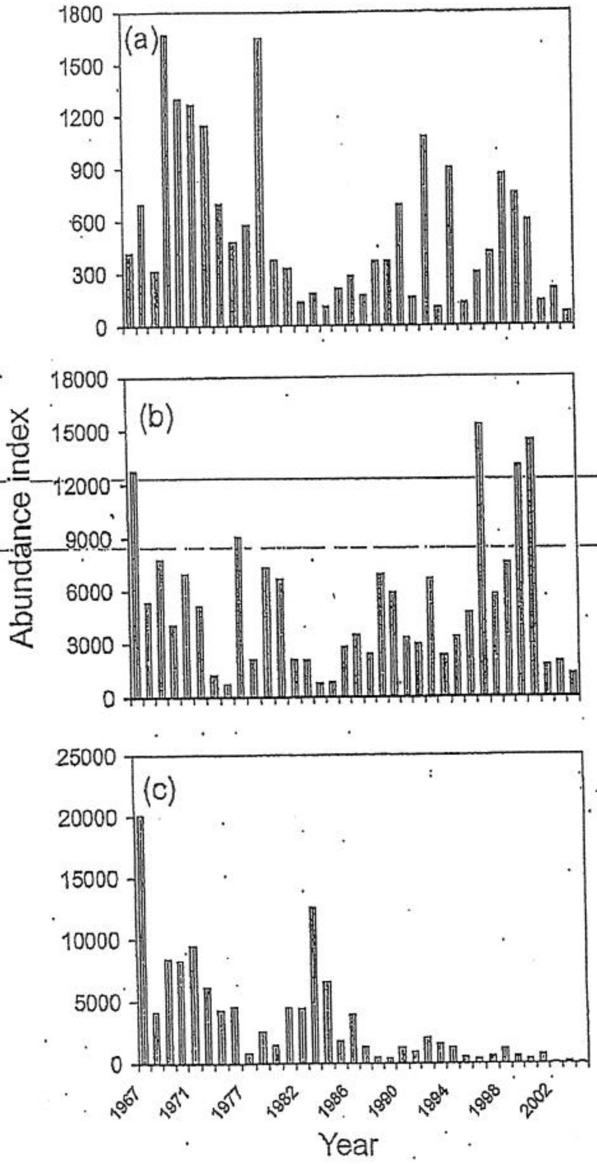


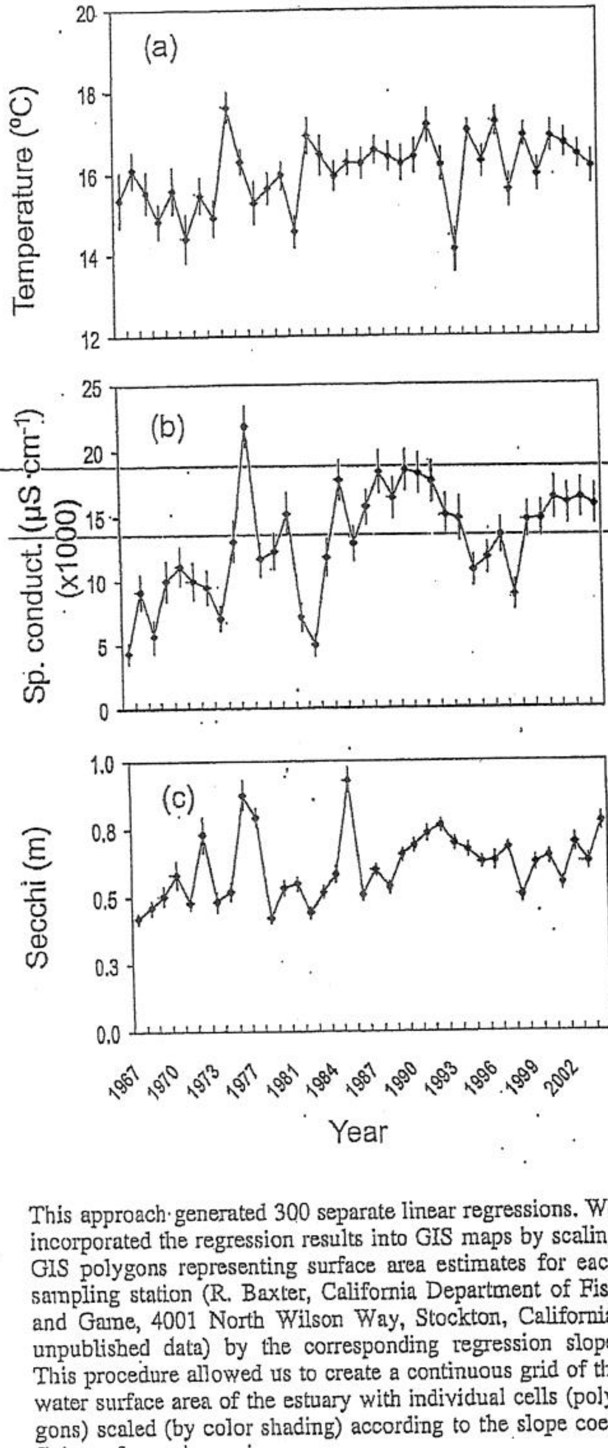
Fig. 2. Time series of abundance indices for (*a*) delta smelt (*Hypomesus transpacificus*), (*b*) threadfin shad (*Dorosoma petenense*), and (*c*) striped bass (*Morone saxatilis*) for the fall midwater trawl survey.

times per year — each month from September to December throughout the freshwater to mesohaline portions of the upper estuary (Fig. 1). The FMWT was originally designed to index the abundance of age-0 striped bass, which is reflected in the dimensions of the net: 17.6 m long with a mouth opening of 3.7 m^2 and nine tapered panels of stretch mesh from 14.7 to 1.3 cm in the cod end (Stevens and Miller 1983). The FMWT data have been used extensively in analyses of striped bass and delta smelt population dynamics (Turner and Chadwick 1972; Stevens et al. 1985; Moyle et al. 1992). Our analysis focused on age-0 striped bass, delta smelt, and threadfin shad, for which the FMWT is most efficient at capturing. The FMWT stations encompass the distribution of these species and life stages in the estuary. Delta smelt have been observed at 85% of the stations, while striped bass and threadfin shad have been observed at every station. Similar to many river-dominated estuaries, inflow to the system varies substantially from year to year. Thus, while the position of the sampling sites remains consistent, water quality varies interannually, which shifts the center of distribution of the fishes (Dege and Brown 2004). Three water quality variables — temperature (°C), Secchi depth (m), and specific conductance ($\mu S \cdot cm^{-1}$) — were measured concurrent with each tow, providing a 36-year time series (12 109 samples) of fish and environmental data (Fig. 3).

The FMWT data set provided a uniquely long time series to quantify fish occurrences in relation to water quality. For study objective 1, we used generalized additive models (GAMs) to describe these relationships (Norcross et al. 1997; Stoner et al. 2001). GAMs are semiparametric extensions of generalized linear models that are effective for describing nonlinear relationships between predictor and response variables (Guisan et al. 2002). GAM techniques are data-driven; they do not presuppose a particular relationship between predictor(s) and response variables. Rather, they employ smoothers to characterize the empirical relationships between predictor and response variables (Guisan et al. 2002). Link functions are used to establish relationships between the response variable and a smoothed function of the predictor variables; we used the cubic spline as our smoothing technique in the S-Plus language (Venables and Ripley 1997). Similar to previous studies (Maravelias 1999; Stoner et al. 2001), we used a binomial GAM with logit link function to relate fish occurrence to log-transformed environmental variables. A binary response (fish presence or absence, i.e., occurrence) was used instead of fish abundance to minimize the influence of outliers (i.e., extremely anomalous abundance values) and bias associated with previously reported abundance declines through time. We assumed that habitat preference was constant and that fish would continue to be present under preferred habitat quality conditions, albeit possibly in increasingly lower numbers. We modeled each species separately. Based on our knowledge of the range of each species and laboratory physiology studies (Swanson et al. 2000), we expected that each species would exhibit a unimodal occurrence probability to salinity and temperature and a declining occurrence probability to increasing Secchi depth. We assessed the statistical significance of the GAM results with a χ^2 approximation that tests the ability of each explanatory variable to reduce the null deviance in the model (Venables and Ripley 1997).

The GAM analyses generated predicted occurrence probabilities for each species in each sample. We used these capture probabilities as an indicator of habitat suitability through time, which we defined as EQ (study objective 2). We visually evaluated long-term spatial variation in annual trends throughout the estuary using maps created with ArcMap geographic information system (GIS) software (ESRI, Redlands, California). Employing ordinary least squares, we linearly regressed the EQ data for the three fish species at each of the 100 stations against year and used the magnitudes of the slopes to examine long-term EQ trends among sampling stations and across regions of the estuary.

Fig. 3. Time series of (*a*) water temperature, (*b*) specific conductance, and (*c*) Secchi depth for the fall midwater trawl survey. The average and variation based on two standard errors are shown for each variable.



This approach generated 300 separate linear regressions. We incorporated the regression results into GIS maps by scaling GIS polygons representing surface area estimates for each sampling station (R. Baxter, California Department of Fish and Game, 4001 North Wilson Way, Stockton, California, unpublished data) by the corresponding regression slope. This procedure allowed us to create a continuous grid of the water surface area of the estuary with individual cells (polygons) scaled (by color shading) according to the slope coefficients for each species.

Lastly, we tested the ability of the water quality variables that composed EQ to predict delta smelt abundance (study objective 3). We limited this analysis to delta smelt because it is an annual species. The longevity of striped bass and threadfin shad makes modeling the effects of abiotic factors on abundance markedly more complex and beyond the scope of this paper (e.g., Kimmerer et al. 2001). Further, recent stock–recruit modeling supports the possibility of density dependence for delta smelt (Bennett 2005). In that study, Bennett (2005) hypothesized that a shrinking volume of physically suitable habitat combined with a high density of competing planktivorous fishes were the primary factors contributing to the decreasing carrying capacity for delta smelt. Our analysis was designed to test the hypothesis that the combined effects of fall stock abundance and fall water quality affect recruit abundance the following summer. We compared eight simple stock–recruit models to evaluate this hypothesis. Comparing the relative fit of models with differing conceptual interpretations is generally superior to simply examining the fit of any single model (Hilborn and Mangel 1997). The abundance indices we used for these models were derived by the California Department of Fish and Game and are available at www.delta.dfg.ca.gov/. Similar to previous studies (Moyle et al. 1992; Bennett 2005), we used the FMWT abundance index as an estimate of fall stock abundance and the Summer Townet abundance index as an estimate of summer recruit abundance. The basic model was a simple linear regression of adult stock versus recruit abundance. The other models included fall stock abundance and various combinations of mean annual fall Secchi depth or specific conductance in multiple regressions.

We separated the time series into two segments for this analysis: 1968–1986 and 1987–2004. This separation delineates a major ecological change in the food web of the estuary stemming from the invasion of the clam *Corbula amurensis* (Kimmerer 2002). Intense filtering of the water column by large populations of this clam essentially eliminated phytoplankton blooms in the lower estuary and caused major declines in the abundance of most planktonic invertebrates, including copepods, which are the primary prey of delta smelt (Kimmerer and Orsi 1996; Moyle 2002). Separation of the two time periods allowed us to examine the role of water quality when food was relatively abundant versus when it was not.

We compared the models in each time series by traditional means (level of statistical significance and comparison of r^2 values), but also evaluated the relative fit of each model with an information-theoretic approach based upon Akaike's information criterion (AIC; Burnham and Anderson 1998). This technique allows for a comparison of models with varying numbers of parameters and is based upon a strength-of-evidence context rather than traditional statistical tests of null hypotheses. Candidate models were evaluated based upon AIC, Δ_i, and w_i (Burnham and Anderson 1998): Δ_i (AIC differences) provides a level of empirical support for each model and is evaluated in relative rather than in absolute terms (values of 0–2 provide substantial support for a given model (0 being best), 4–7 considerably less support, and >10 virtually no support); w_i provides a relative weight of evidence in support of a given model with the largest value being best. We further evaluated the fit of the regression models by visually examining residual plots for homogeneity of variance and used the Anderson–Darling test to determine if the residuals were normally distributed.

Table 1. Generalized additive modeling results.

Model	Species Delta smelt (*Hypomesus transpacificus*)	 Striped bass (*Morone saxatilis*)	 Threadfin shad (*Dorosoma petenense*)
Temperature (T)	11 805 (0.1)	16 542 (0.4)	14 285 (4.4)
Secchi depth (S)	10 295 (12.9)	14 356 (13.6)	14 748 (1.3)
Specific conductance (C)	9 620 (18.6)	14 928 (10.1)	13 066 (12.5)
T + S	10 250 (13.3)	14 290 (14.0)	14 125 (5.4)
T + C	9 537 (19.3)	14 893 (10.3)	12 608 (15.6)
S + C	8 856 (25.1)	13 549 (18.4)	12 874 (13.8)
T + S + C	8 780 (25.7)	13 460 (19.0)	12 387 (17.1)

Note: Residual deviance and percentage of total deviance explained (in parentheses) are given for each model. Null deviance is 11 822 for delta smelt, 16 608 for striped bass, and 14 935 for threadfin shad. The variables in each model were all statistically significant ($P < 0.0001$) based on approximate χ^2 tests.

Results

GAMs

For each species, we found that all three environmental variables were statistically significant predictors of fish occurrence (Table 1). The global model, which included all three water quality variables, accounted for 25.7%, 19.0%, and 17.1% of total deviance in the models for delta smelt, striped bass, and threadfin shad, respectively (Table 1). Relationships between predicted occurrence (based on the global model) and individual water quality variables generally matched our expectations for Secchi depth and specific conductance, but not for water temperature (Fig. 4). Predicted occurrence of each species decreased as Secchi depth increased. Predicted occurrence of striped bass and delta smelt peaked at relatively low values along the specific conductance gradient, whereas for threadfin shad it exhibited a gradual negative relationship. There was no clear trend in the predicted occurrence of striped bass with temperature. For delta smelt, predicted occurrence was highest at the lowest temperature, and for threadfin shad it was highest at the lowest and highest temperatures. The addition of temperature to the GAMs for striped bass and delta smelt did not appreciably improve the amount of the deviance explained (0.4% for striped bass and 0.1% for delta smelt; Table 1). Hence, we concluded that a GAM including Secchi depth and specific conductance was the most appropriate for generating annual BQ trends for further analysis for these species. For threadfin shad, Secchi depth accounted for only 1.3% of the deviance; thus we selected temperature and specific conductance as a final model for threadfin shad.

Trends in EQ

Overall, EQ values were highest for striped bass, intermediate for threadfin shad, and lowest for delta smelt, reflecting both their relative abundance and distributional range in the estuary (Fig. 5). There was an overall negative trend in EQ for each species, with delta smelt and striped bass exhibiting the most apparent declines. The declines in EQ appeared to be most apparent following the mid 1980s. Long-term spatial patterns in EQ (Fig. 6) were generally similar across species in that a high percentage of stations exhibited statistically significant ($P < 0.05$) declines: threadfin shad (64% of stations), delta smelt (63% of stations), and striped bass (65% of stations). There was only one instance of a station exhibiting a statistically significant increase in EQ; it was near the confluence of the Sacramento and San Joaquin rivers for delta smelt. The western and southeastern regions of the estuary exhibited the most substantial long-term declines in EQ for striped bass and delta smelt, as indicated by consistently steeper negative slopes and statistically significant regressions. The lower Sacramento River exhibited virtually no significant EQ changes for any species. For delta smelt, there were also some nonsignificant regressions for stations in the lower San Joaquin River. The southeastern region of the system exhibited few EQ changes for threadfin shad.

Water quality – delta smelt abundance linkages

The results of the regression modeling support the hypothesis that water quality was an important predictor of delta smelt abundance during the 1987–2004 post-*Corbula* period (Table 2). None of the 1968–1986 pre-*Corbula* regression models were statistically significant ($P > 0.05$). However, all 1987–2004 post-*Corbula* models were statistically significant ($P < 0.02$). The residuals from these significant models were normally distributed (Anderson–Darling P values ≥ 0.05) and exhibited no apparent trend with the fitted values, suggesting the models adequately fit the data. A comparison of the r^2 values suggested that the stock + specific conductance model and the stock + specific conductance + Secchi depth model produced similar results (~60% of variance explained) and were superior in that they accounted for ~30% more variance than the other models. The AIC results also suggested that these two models provided similar fits to the data set and were superior to the other models (Table 2).

Discussion

Understanding fish–habitat relationships is a fundamental step in characterizing EQ, as well as the effects of habitat manipulations on EQ, and ultimately, fish populations. In this study, we used statistical and graphical techniques to establish and evaluate EQ for selected fishes in the San Francisco Estuary. Our ultimate goal was to determine if changes in the water quality variables that defined EQ could have contributed to declines in fish abundance. Our approach was relatively novel in that most similar studies have been of much shorter duration and have been used merely to identify, not further analyze, fish–EQ relationships (Norcross et

Fig. 4. Generalized additive model (GAM) predictions of fish occurrence (based on all three water quality variables) versus the observed individual water quality parameters ((*a*) water temperature, (*b*) Secchi depth, (*c*) specific conductance) for threadfin shad (*Dorosoma petenense*) (black triangles), delta smelt (*Hypomesus transpacificus*) (black circles), and striped bass (*Morone saxatilis*) (gray circles).

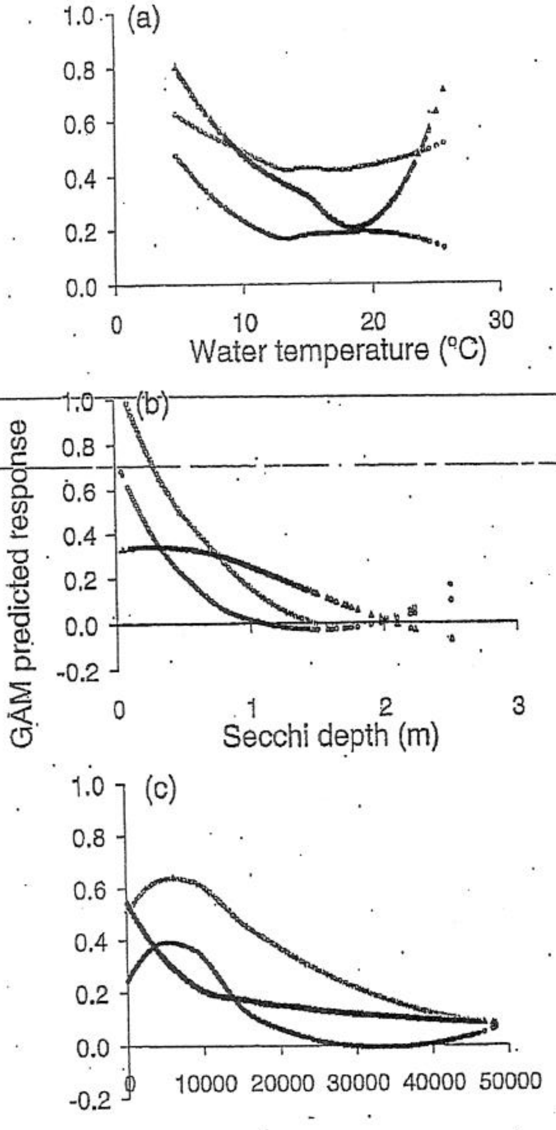
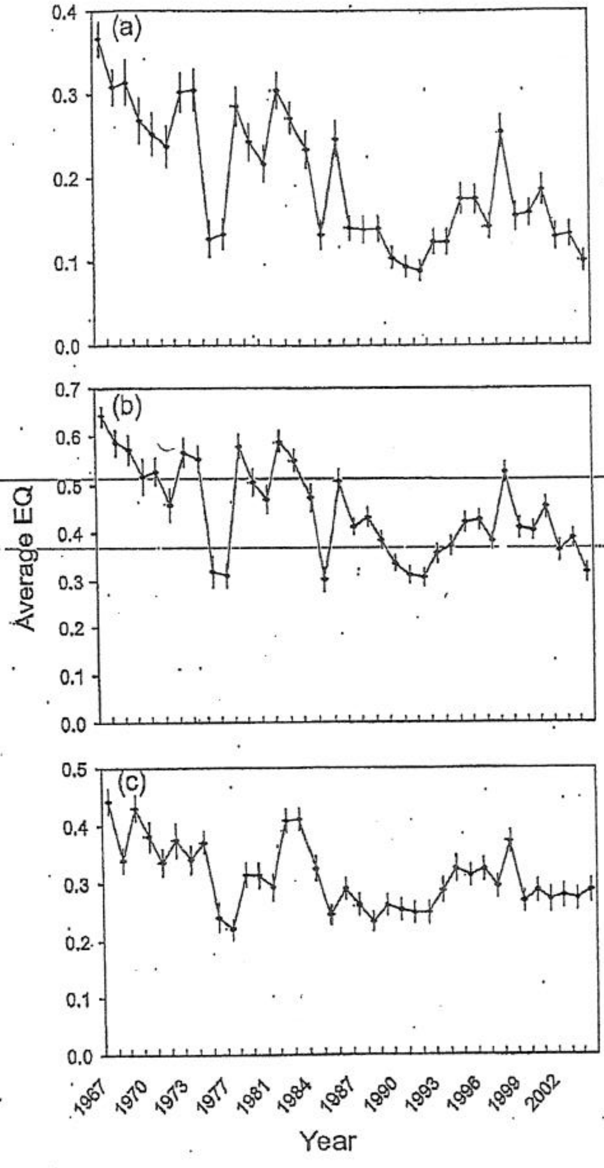


Fig. 5. Environmental quality (EQ) time series for threadfin shad (*Dorosoma petenense*), delta smelt (*Hypomesus transpacificus*), and striped bass (*Morone saxatilis*). The average and variation based on two standard errors are shown for each species.



al. 1997; Stoner et al. 2001). Whereas these previous studies sometimes used GAM results to make inferences about the likelihood of fish occurrence at new or unsampled locations, the extensive temporal (36 years) and spatial (100 stations) coverage of the FMWT survey afforded us an unusual opportunity to examine multidecadal trends throughout the estuary and in multiple geographic locations.

The first objective in our study was to relate fish occurrence to water quality variables to establish EQ for the three investigated species. We found that Secchi depth and specific conductance were important factors explaining the occurrence of delta smelt and striped bass, while specific conductance and water temperature were important for threadfin shad. Our GAMs using all three variables reduced null deviance between 17% and 26%, levels comparable with other studies (Maravelias 1999; Stoner et al. 2001). The GAM analysis results are consistent with information about the life history of each species. Delta smelt and age-0 striped bass are low-salinity zone specialists (Turner and Chadwick 1972; Moyle et al. 1992), and threadfin shad are mostly confined to freshwater zones, so it is reasonable to expect specific conductance to affect their occurrence. For delta smelt,

Fig. 6. Spatial distribution of long-term trends in annual environmental quality (EQ) for (*a*) delta smelt (*Hypomesus transpacificus*), (*b*) threadfin shad (*Dorosoma petenense*), (*c*) striped bass (*Morone saxatilis*) in San Francisco Estuary shown for the region bordered downstream at Carquinez Strait. Color shading represents the coefficient for the year term for individual linear regressions of EQ versus year for each station. Lighter shading represents a more negative slope. Open circles and solid circles represent stations with nonsignificant ($P \geq 0.05$) or significant regressions ($P < 0.05$), respectively.

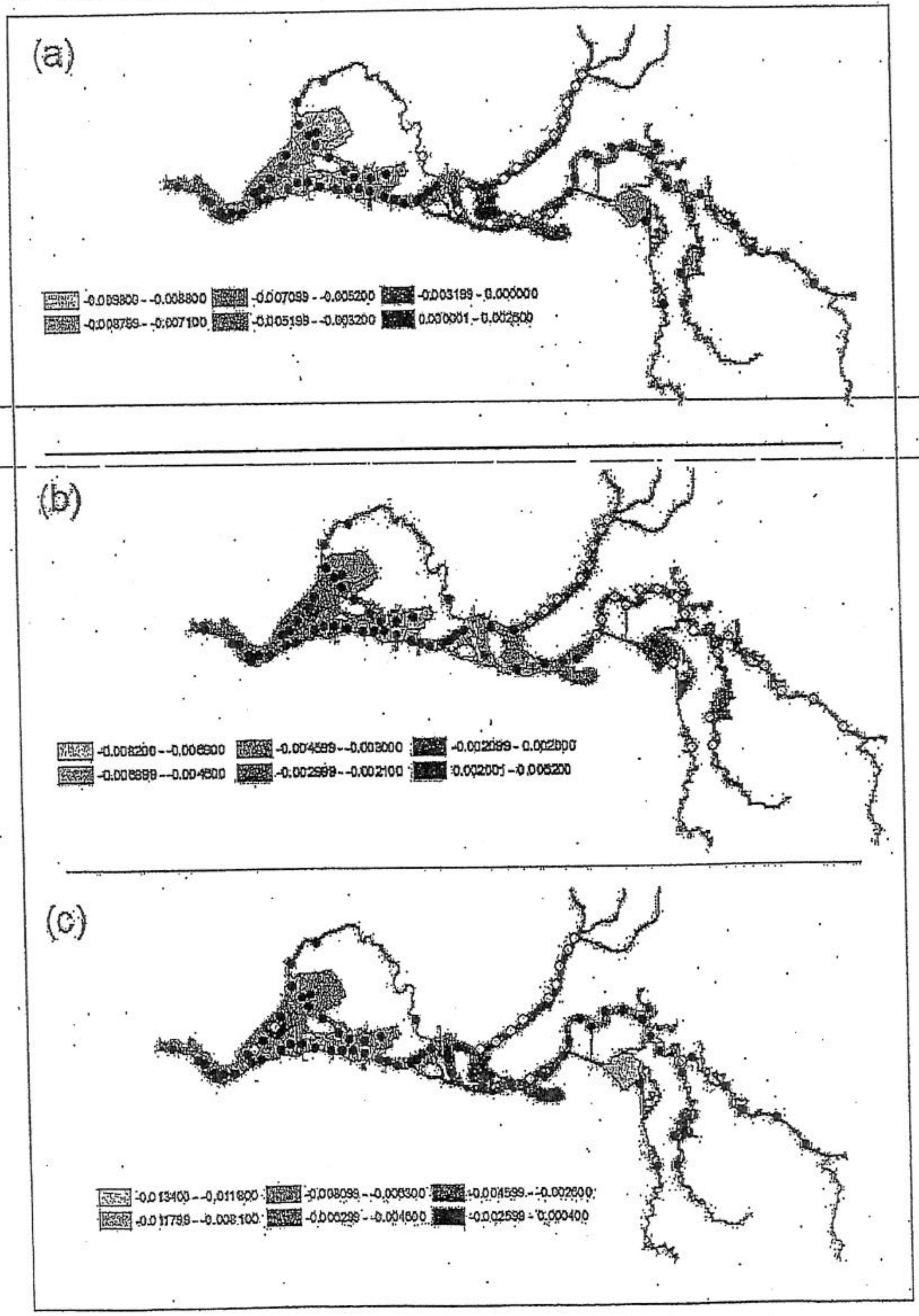


Table 2. Regression statistics for various stock–recruit models for delta smelt (*Hypomesus transpacificus*) for the 1987–2004 post-*Corbula* time period.

Fall stock	Specific conductance	Secchi	Constant	df	P	r^2	AIC	Δ_i	w_i
0.0078	—	—	1.5	16	0.005	39.5	96.08	6.0	0.003
0.0067	−0.00068	—	12.3	15	0.001	59.6	90.08	0.0	0.06
0.0076	—	−7.9	6.7	15	0.018	41.6	97.4	7.3	0.002
0.0068	−0.00069	1.6	11.5	14	0.0004	59.6	92.8	2.7	0.02

Note: The same models were developed for the 1968–1986 pre-*Corbula* time period but are not shown because none were statistically significant ($P > 0.05$). The dependent variable for all regression models was the delta smelt recruit abundance index, as measured by the Summer Townet Survey. Candidate models were developed based on the possible combinations of the fall stock abundance index, with average fall values of specific conductance and Secchi depth as independent variables. Akaike's information criterion (AIC), AIC differences (Δ_i), and AIC weights (w_i) are also shown.

our results are consistent with laboratory studies on their physiological tolerances to salinity (Swanson et al. 2000). Because delta smelt require turbidity for successful feeding (Baskerville-Bridges et al. 2004) and because predation is mediated by turbidity, it is possible that long-term increases in Secchi depth may have affected feeding success and predation pressures.

Factors affecting fish distribution often interact along spatial and temporal gradients (Jackson et al. 2001). Thus, it is critical to understand their spatiotemporal trends (study objective 2). The long-term EQ trends showed similar declines for each species across a broad geographical range. However, the steepest declines and highest levels of statistical significance occurred in the western, eastern, and southern regions. These results suggest that the lower Sacramento River has exhibited the least long-term habitat alteration as compared with the rest of the estuary, at least with respect to the evaluated abiotic factors. For delta smelt, there was some evidence that EQ had not declined as substantially in the lower San Joaquin River, suggesting that EQ in the region just upstream of the confluence of the Sacramento and San Joaquin rivers has remained relatively stable for delta smelt.

The spatial and temporal trends in EQ can largely be explained by an interaction of climate variability and anthropogenic factors. The increase in Secchi depth during the study period is primarily a function of a decline in total suspended solids, one of the long-term effects of upstream dam construction (Jassby et al. 2002). Wright and Schoellhamer (2004) documented that sediment transport to the estuary from the Sacramento River has declined by 50% since 1957. Nobriga et al. (2005) hypothesized that this change in sediment dynamics and corresponding changes in hydrodynamics have had dramatic effects on fish assemblages and the proliferation of alien fishes in the system. In addition, Nobriga et al. (2005) observed that submerged aquatic vegetation, especially the invasive Brazilian waterweed (*Egeria densa*), became increasingly abundant in the system during the past 20 years. This macrophyte increases water clarity by trapping suspended sediments and also has had measurable effects on the fish community. The increase in specific conductance during the study period is likely a function of decreasing river flow entering the estuary during the fall. There has been no significant long-term trend in runoff entering the watershed of the estuary during September–December (Dettinger and Cayan 1995). Thus, the positive specific conductance trend appears to be the result of water operations; the change could be a consequence of less water released from upstream dams into the system during this time of the year, or more water exported from the south delta, or a combination of both effects.

The third objective of our study was to determine if changes in water quality could explain the observed declines in the abundance of delta smelt, an annual fish species. The simple statistical models evaluated for delta smelt suggest that water quality may indeed be an important factor, at least during the past two decades, when food availability was severely reduced by the invasion of *Corbula*. This finding is consistent with previous analyses on population dynamics of delta smelt and striped bass, which revealed long-term declines in carrying capacity (Kimmerer et al. 2000; Bennett 2005). A decline in suitable physical habitat and decreases in prey availability are two of the likely mechanisms for the changes in carrying capacity. Studies on the physiological tolerances of delta smelt suggest that they can survive in salinities higher than those at which they have been found in the wild (Swanson et al. 2000). This suggests that recent patterns of fish recruitment and abundance are probably controlled by multiple interacting factors. Current efforts in parameratizing life cycle models for delta smelt and striped bass are likely to better quantify the relative importance of water quality on their population dynamics.

Although we believe that our results are robust given the substantial amount of data, we acknowledge that our analysis did not include all potential water quality, physical, or biological factors that affect fish occurrence and habitat. With respect to water quality, dissolved oxygen is perhaps the most important variable that we could not evaluate because of a lack of suitable data. Dissolved oxygen requirements for delta smelt are poorly understood; however, both striped bass and threadfin shad are sensitive to low levels of dissolved oxygen (Moyle 2002). In general, dissolved oxygen levels are not a major problem in most regions of the San Francisco Estuary. Problem areas include the extreme upstream limits of the south Delta during summer and fall (Lehman et al. 2004) and in the sloughs of Suisun Marsh during fall drainage of reclaimed marshlands (P. Moyle, University of California – Davis, Wildlife, Fish and Conservation Biology, Davis, California 95616, USA, personal communication). Both of these regions are outside of the sampling area covered by the FMWT.

Physical habitat features such as substrate type (e.g., sand, mud, detritus, etc.), depth (e.g., shoals versus channels), and cover (e.g., woody debris or submerged aquatic vegetation). can also be important variables for fish habitat. Although data of this type are relatively scarce for fishes in San Francisco Estuary, we have no reason to believe that there have been major changes in these variables except for vegetative cover. As noted previously, there have been substantial increases in the amount of submerged aquatic vegetation during the past 20 years (Nobriga et al. 2005). We evaluated the increase in Secchi depth, one of the potential effects of this invasion, but were not able to analyze the effects of the increase in physical structure in the estuary.

Biotic variables, most notably competition, predation, and food availability, could have also played a major role in controlling the distribution of the three fishes (Hayes et al. 1996). Including competition in explanatory models would be extremely difficult in a practical sense because it is complicated to measure and is affected by many other variables. There have been some limited diet studies of piscivorous fishes in the estuary (e.g., Turner and Kelly 1966; Feyrer et al. 2003; Nobriga et al. 2006); however, the bioenergetics of predation within the estuary have remained largely unmeasured or modeled (but see Lindley and Mohr 2003 for a paper modeling striped bass predation on winter-run Chinook salmon (*Oncorhynchus tshawytscha*)).

Perhaps the greatest opportunity for improving our analyses of EQ distributions and trends lies with additional studies on the effects of food availability. Food availability has been successfully incorporated into similar GAMs (Maravelias 1999; Stoner et al. 2001). Moreover, some work in San Francisco Estuary suggests that prey availability can affect fish populations, especially striped bass (Kimmerer et al. 2000, 2001; Feyrer et al. 2003) and delta smelt (Bennett 2005). Although we did not include a direct measure of food availability in our models because there were no comparable invertebrate data at the spatial and temporal resolution of the FMWT data, our comparison of stock–recruit models for delta smelt suggests that food availability plays an important role.

We also acknowledge that our study is focused on conditions during a single season of the year, but it represents 1/3 of a year. Conditions during other seasons undoubtedly play a role in the population dynamics of the fish species we examined, but the changing physical habitat conditions during fall are likely important for several reasons. For age-0 striped bass, conditions during their first autumn play a role in the density-dependent survival exhibited by this species from age-0 to age-3 (Kimmerer et al. 2000). This is especially true given that food web changes have affected diet composition (Feyrer et al. 2003). Fall conditions may be even more important for delta smelt and threadfin shad, since these fish represent prespawning adults. In general, less suitable habitat constricts the range of these fishes, which combined with an altered food web, may affect their health and survival.

Overall, our study illustrates that ecological knowledge gained from long-term monitoring data can be a valuable tool to understand changes in aquatic ecosystems. First, they highlight the utility of long-term data sets to describe fish–EQ relationships, derive EQ, and track EQ trends for a variety of species. The long-term declining EQ trends and the apparent link to delta smelt abundance detected in this study corroborate previous hypotheses that the area of suitable physical and chemical habitat has played a role in the decline in fish abundance. However, the degree to which EQ could be used for management purposes remains unclear. Flow standards in San Francisco Estuary are based largely on a surrogate for salinity (X_2), particularly during winter and spring. While X_2 is a valuable generalized variable that is relatively easy to measure and is correlated with long-term abundance trends of multiple species (Jassby et al. 1995; Kimmerer 2002), the recent step change in the abundance of pelagic fishes suggests that salinity alone may not be sufficient to explain long-term trends in estuarine management. Our analyses of EQ showed that water transparency might also be an important consideration. For example, the combined effects of specific conductance and Secchi depth improved the stock–recruitment relationship for delta smelt, a species that has proven difficult to model using a variety of environmental data (Bennett 2005). Nonetheless, it is questionable whether there are simple ways to use variables such as Secchi depth for species management, at least during the fall period that we studied. Moreover, for the water quality data to be most effective for species management, additional information is needed to better define the mechanisms for the effects of water quality variables on aquatic organisms.

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To: Cliff Lee <Cliff.Lee@doj.ca.gov>, Deborah Wordham <Deborah.Wordham@doj.ca.gov>, "Crothers, Cathy" <crothers@water.ca.gov>, "Johns, Jerry" <jjohns@water.ca.gov>
Date: 6/27/2007 4:43:40 PM
Subject: Smelt Habitat Qualty Index Paper- CONFIDENTIAL ATTORNEY - CLIENT-COMMON INTEREST RULE

Attached is the Feyrer et al paper on smelt habitat quality. It more complicated than this, but basically, they found that historically the presence or absence of smelt was significantly correlated with water temp and salinity in the fall. These two factors can be used to calculate an index of habitat quality. During the POD years this index declined, primarily due to an upstream movement of the salinity....which was due to reduced outflow which correlates well with the position of X2. If I understand this correctly, as X2 moves upstream from Collinsville (80rk) the area of good smelt habitat declines as it moves into the more constrained channels of the Delta. The argument for a fall X2 action is now largely based on this paper. I've heard that only about 1/3 of the reduced fall outflow (since POD?) is due to CVP/SWP exports......while the other 2/3 is due to reduced inflows to the Delta due to several non-project factors....or something like that.

EXHIBIT C

To

FORD DECLARATION

Swanson Figure 4
(Page 9)

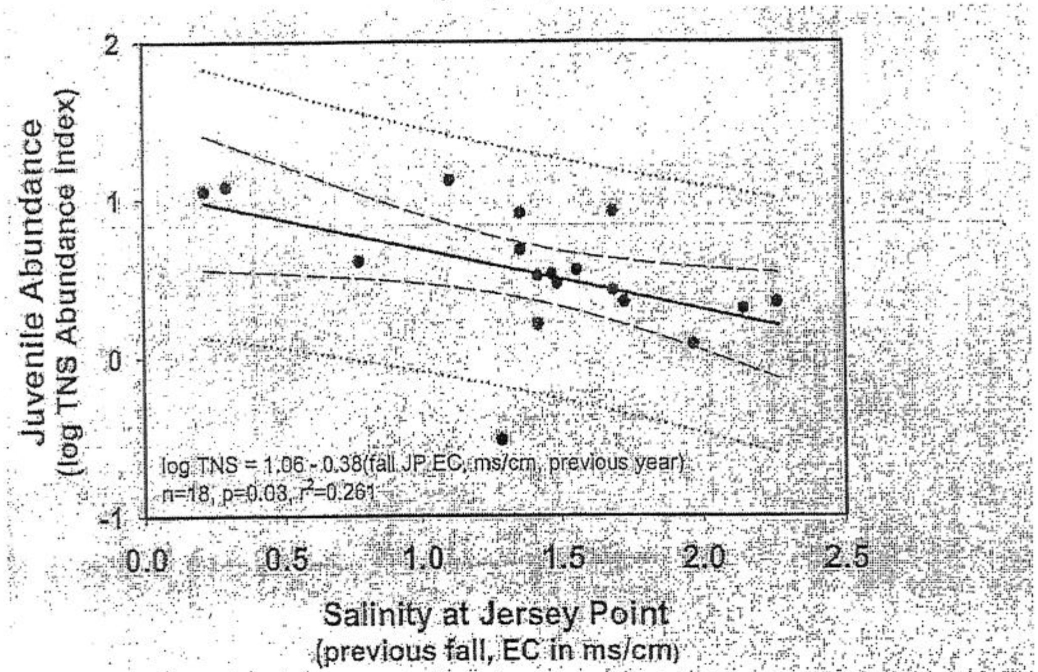

Figure 4. The relationship between fall salinity in the western Delta (Jersey Point EC [ms/cm], October-December) and abundance of juvenile delta smelt measured the following year (log TNS Abundance Index). Data are for 1988-2005. Regression equation and associated statistics, 95 percent confidence limits and the prediction limits are shown with the graph. Data sources: California Department of Fish and Game, Contra Costa Water District.

Swanson Figure 4
(All data points from 1988 through 2007)