

## **What caused the Sacramento River fall Chinook stock collapse?**

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Pre-publication report to the Pacific Fishery Management Council

March 18, 2009

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# 1 Executive summary

2 In April 2008, in response to the sudden collapse of Sacramento River fall Chi-  
3 nook salmon (SRFC) and the poor status of many west coast coho salmon popula-  
4 tions, the Pacific Fishery Management Council (PFMC) adopted the most restric-  
5 tive salmon fisheries in the history of the west coast of the U.S. The regulations  
6 included a complete closure of commercial and recreational Chinook salmon fish-  
7 eries south of Cape Falcon, Oregon. Spawning escapement of SRFC in 2007 is es-  
8 timated to have been 88,000, well below the PFMC's escapement conservation goal  
9 of 122,000-180,000 for the first time since the early 1990s. The situation was even  
10 more dire in 2008, when 66,000 spawners are estimated to have returned to natural  
11 areas and hatcheries. For the SRFC stock, which is an aggregate of hatchery and  
12 natural production, many factors have been suggested as potential causes of the poor  
13 escapements, including freshwater withdrawals (including pumping of water from  
14 the Sacramento-San Joaquin delta), unusual hatchery events, pollution, elimination  
15 of net-pen acclimatization facilities coincident with one of the two failed brood  
16 years, and large-scale bridge construction during the smolt outmigration (CDFG,  
17 2008). In this report we review possible causes for the decline in SRFC for which  
18 reliable data were available.

19 Our investigation was guided by a conceptual model of the life history of fall  
20 Chinook salmon in the wild and in the hatchery. Our approach was to identify where  
21 and when in the life cycle abundance became anomalously low, and where and when  
22 poor environmental conditions occurred due to natural or human-induced causes.  
23 The likely cause of the SRFC collapse lies at the intersection of an unusually large  
24 drop in abundance and poor environmental conditions. Using this framework, all of  
25 the evidence that we could find points to ocean conditions as being the proximate  
26 cause of the poor performance of the 2004 and 2005 broods of SRFC. We recognize,  
27 however, that the rapid and likely temporary deterioration in ocean conditions is  
28 acting on top of a long-term, steady degradation of the freshwater and estuarine  
29 environment.

30 The evidence pointed to ocean conditions as the proximate cause because con-  
31 ditions in freshwater were not unusual, and a measure of abundance at the entrance  
32 to the estuary showed that, up until that point, these broods were at or near normal  
33 levels of abundance. At some time and place between this point and recruitment to  
34 the fishery at age two, unusually large fractions of these broods perished. A broad  
35 body of evidence suggests that anomalous conditions in the coastal ocean in 2005  
36 and 2006 resulted in unusually poor survival of the 2004 and 2005 broods of SRFC.  
37 Both broods entered the ocean during periods of weak upwelling, warm sea surface  
38 temperatures, and low densities of prey items. Individuals from the 2004 brood  
39 sampled in the Gulf of the Farallones were in poor physical condition, indicating  
40 that feeding conditions were poor in the spring of 2005 (unfortunately, comparable  
41 data do not exist for the 2005 brood). Pelagic seabirds in this region with diets sim-  
42 ilar to juvenile Chinook salmon also experienced very poor reproduction in these  
43 years. In addition, the cessation of net-pen acclimatization in the estuary in 2006  
44 may have contributed to the especially poor estuarine and marine survival of the

45 2005 brood.

46 Fishery management also played a role in the low escapement of 2007. The  
47 PFMC (2007) forecast an escapement of 265,000 SRFC adults in 2007 based on  
48 the escapement of 14,500 Central Valley Chinook salmon jacks in 2006. The real-  
49 ized escapement of SRFC adults was 87,900. The large discrepancy between the  
50 forecast and realized abundance was due to a bias in the forecast model that has  
51 since been corrected. Had the pre-season ocean abundance forecast been more ac-  
52 curate and fishing opportunity further constrained by management regulation, the  
53 SRFC escapement goal could have been met in 2007. Thus, fishery management,  
54 while not the cause of the 2004 brood weak year-class strength, contributed to the  
55 failure to achieve the SRFC escapement goal in 2007.

56 The long-standing and ongoing degradation of freshwater and estuarine habitats  
57 and the subsequent heavy reliance on hatchery production were also likely contrib-  
58 utors to the collapse of the stock. Degradation and simplification of freshwater  
59 and estuary habitats over a century and a half of development have changed the  
60 Central Valley Chinook salmon complex from a highly diverse collection of nu-  
61 merous wild populations to one dominated by fall Chinook salmon from four large  
62 hatcheries. Naturally-spawning populations of fall Chinook salmon are now ge-  
63 netically homogeneous in the Central Valley, and their population dynamics have  
64 been synchronous over the past few decades. In contrast, some remnant populations  
65 of late-fall, winter and spring Chinook salmon have not been as strongly affected  
66 by recent changes in ocean conditions, illustrating that life-history diversity can  
67 buffer environmental variation. The situation is analogous to managing a financial  
68 portfolio: a well-diversified portfolio will be buffeted less by fluctuating market  
69 conditions than one concentrated on just a few stocks; the SRFC seems to be quite  
70 concentrated indeed.

71 Climate variability plays an important role in the inter-annual variation in abun-  
72 dance of Pacific salmon, including SRFC. We have observed a trend of increasing  
73 variability over the past several decades in climate indices related to salmon sur-  
74 vival. This is a coast-wide pattern, but may be particularly important in California,  
75 where salmon are near the southern end of their range. These more extreme climate  
76 fluctuations put additional strain on salmon populations that are at low abundance  
77 and have little life-history or habitat diversity. If the trend of increasing climate  
78 variability continues, then we can expect to see more extreme variation in the abun-  
79 dance of SRFC and salmon stocks coast wide.

80 In conclusion, the development of the Sacramento-San Joaquin watershed has  
81 greatly simplified and truncated the once-diverse habitats that historically supported  
82 a highly diverse assemblage of populations. The life history diversity of this histor-  
83 ical assemblage would have buffered the overall abundance of Chinook salmon in  
84 the Central Valley under varying climate conditions. We are now left with a fish-  
85 ery that is supported largely by four hatcheries that produce mostly fall Chinook  
86 salmon. Because the survival of fall Chinook salmon hatchery release groups is  
87 highly correlated among nearby hatcheries, and highly variable among years, we  
88 can expect to see more booms and busts in this fishery in the future in response  
89 to variation in the ocean environment. Simply increasing the production of fall

90 Chinook salmon from hatcheries as they are currently operated may aggravate this  
91 situation by further concentrating production in time and space. Rather, the key to  
92 reducing variation in production is increasing the diversity of SRFC.

93 There are few direct actions available to the PFMC to improve this situation,  
94 but there are actions the PFMC can support that would lead to increased diversity  
95 of SRFC and increased stability. Mid-term solutions include continued advocacy  
96 for more fish-friendly water management and the examination of hatchery prac-  
97 tices to improve the survival of hatchery releases while reducing adverse interac-  
98 tions with natural fish. In the longer-term, increased habitat quantity, quality, and  
99 diversity, and modified hatchery practices could allow life history diversity to in-  
100 crease in SRFC. Increased diversity in SRFC life histories should lead to increased  
101 stability and resilience in a dynamic, changing environment. Using an ecosystem-  
102 based management and ecological risk assessment framework to engage the many  
103 agencies and stakeholder groups with interests in the ecosystems supporting SRFC  
104 would aid implementation of these solutions.

## 2 Introduction

In April 2008 the Pacific Fishery Management Council (PFMC) adopted the most restrictive salmon fisheries in the history of the west coast of the U.S., in response to the sudden collapse of Sacramento River fall Chinook (SRFC) salmon and the poor status of many west coast coho salmon populations. The PFMC adopted a complete closure of commercial and recreational Chinook fisheries south of Cape Falcon, Oregon, allowing only for a mark-selective hatchery coho recreational fishery of 9,000 fish from Cape Falcon, Oregon, to the Oregon/California border. Salmon fisheries off California and Oregon have historically been robust, with seasons spanning May through October and catches averaging over 800,000 Chinook per year from 2000 to 2005. The negative economic impact of the closure was so drastic that west coast Governors asked for \$290 million in disaster relief, and the U.S. Congress appropriated \$170 million.

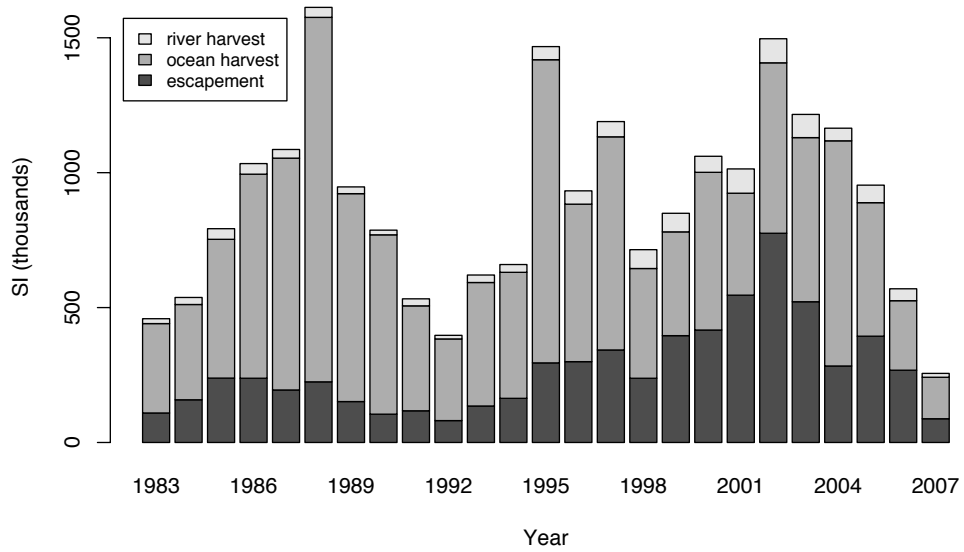
Escapement of several west coast Chinook and coho salmon stocks was lower than expected in 2007 (PFMC, 2009), and low jack escapement in 2007 for some stocks suggested that 2008 would be at least as bad (PFMC, 2008). The most prominent example is SRFC salmon, for which spawning escapement in 2007 is estimated to have been 88,000, well below the escapement conservation goal of the PFMC (122,000–180,000 fish) for the first time since the early 1990s (Fig. 1). While the 2007 escapement represents a continuing decline since the recent peak escapement of 725,000 spawners in 2002, average escapement since 1983 has been about 248,000. The previous record low escapement, observed in 1992, is believed to have been due to a combination of drought conditions, overfishing, and poor ocean conditions (SRFCRT, 1994). Although conditions have been wetter than average over the 2000-2005 period, the spawning escapement of jacks in 2007 was the lowest on record, significantly lower than the 2006 jack escapement (the second lowest on record), and the preseason projection of 2008 adult spawner escapement was only 59,000<sup>1</sup> despite the complete closure of coastal and freshwater Chinook fisheries.

Low escapement has also been documented for coastal coho salmon during this same time frame. For California, coho salmon escapement in 2007 averaged 27% of parent stock abundance in 2004, with a range from 0% (Redwood Creek) to 68% (Shasta River). In Oregon, spawner estimates for the Oregon Coast natural (OCN) coho salmon were 30% of parental spawner abundance. These returns are the lowest since 1999, and are near the low abundances of the 1990s. Columbia River coho and Chinook stocks experienced mixed escapement in 2007 and 2008.

For coho salmon in 2007 there was a clear north-south gradient, with escapement improving to the north. California and Oregon coastal escapement was down sharply, while Columbia River hatchery coho were down only slightly (PFMC, 2009). Washington coastal coho escapement was similar to 2006. Even within the OCN region, there was a clear north-south pattern, with the north coast region (predominantly Nehalem River and Tillamook Bay populations) returning at 46%

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<sup>1</sup>Preliminary postseason estimate for 2008 SRFC adult escapement is 66,000.



**Figure 1:** Sacramento River fall Chinook escapement, ocean harvest, and river harvest, 1983–2007. The sum of these components is the Sacramento Index (SI). From O’Farrell et al. (2009).



147 of parental abundance while the mid-south coast region (predominantly Coos and  
148 Coquille populations) returned at only 14% of parental abundance. The Rogue  
149 River population was only 21% of parental abundance. Low 2007 jack escapement  
150 for these three stocks in particular suggests a continued low abundance in 2008.  
151 In addition, Columbia River coho salmon jack escapement in 2007 was also near  
152 record lows.

153 There have been exceptions to these patterns of decline. Klamath River fall  
154 Chinook experienced a very strong 2004 brood, despite parent spawners being well  
155 below the estimated level necessary for maximum production. Columbia River  
156 spring Chinook production from the 2004 and 2005 broods will be at historically  
157 high levels, according to age-class escapement to date. The 2008 forecasts for  
158 Columbia River fall Chinook “tule” stocks are significantly more optimistic than  
159 for 2007. Curiously, Sacramento River late-fall Chinook escapement has declined  
160 only modestly since 2002, while the SRFC in the same river basin fell to record low  
161 levels.

162 What caused the observed general pattern of low salmon escapement? For the  
163 SRFC stock, which is an aggregate of hatchery and natural production (but prob-  
164 ably dominated by hatchery production (Barnett-Johnson et al., 2007)), freshwater  
165 withdrawals (including pumping of water from the Sacramento-San Joaquin Delta),  
166 unusual hatchery events, pollution, elimination of net-pen acclimatization facilities  
167 coincident with one of the two failed brood years, and large-scale bridge construc-  
168 tion during the smolt outmigration along with many other possibilities have been  
169 suggested as prime candidates causing the poor escapement (CDFG, 2008).

170 When investigating the possible causes for the decline of SRFC, we need to rec-  
171 ognize that salmon exhibit complex life histories, with potential influences on their  
172 survival at a variety of life stages in freshwater, estuarine and marine habitats. Thus,  
173 salmon typically have high variation in adult escapement, which may be explained  
174 by a variety of anthropogenic and natural environmental factors. Also, environ-  
175 mental change affects salmon in different ways at different time scales. In the short  
176 term, the dynamics of salmon populations reflect the effects of environmental vari-  
177 ation, e.g., high freshwater flows during the outmigration period might increase  
178 juvenile survival and enhance recruitment to the fishery. On longer time scales,  
179 the cumulative effects of habitat degradation constrain the diversity and capacity of  
180 habitats, extirpating some populations and reducing the diversity and productivity  
181 of surviving populations (Bottom et al., 2005b). This problem is especially acute in  
182 the Sacramento-San Joaquin basin, where the effects of land and water development  
183 have extirpated many populations of spring-, winter- and late-fall-run Chinook and  
184 reduced the diversity and productivity of fall Chinook populations (Myers et al.,  
185 1998; Good et al., 2005; Lindley et al., 2007).

186 Focusing on the recent variation in salmon escapement, the coherence of varia-  
187 tions in salmon productivity over broad geographic areas suggests that the patterns  
188 are caused by regional environmental variation. This could include such events  
189 as widespread drought or floods affecting hydrologic conditions (e.g., river flow  
190 and temperature), or regional variation in ocean conditions (e.g., temperature, up-  
191 welling, prey and predator abundance). Variations in ocean climate have been in-

192 creasingly recognized as an important cause of variability in the landings, abun-  
193 dant, and productivity of salmon (e.g, Hare and Francis (1995); Mantua et al.  
194 (1997); Beamish et al. (1999); Hobday and Boehlert (2001); Botsford and Lawrence  
195 (2002); Mueter et al. (2002); Pyper et al. (2002)). The Pacific Ocean has many  
196 modes of variation in sea surface temperature, mixed layer depth, and the strength  
197 and position of winds and currents, including the El Niño-Southern Oscillation, the  
198 Pacific Decadal Oscillation and the Northern Oscillation. The broad variation in  
199 physical conditions creates corresponding variation in the pelagic food webs upon  
200 which juvenile salmon depend, which in turn creates similar variation in the popula-  
201 tion dynamics of salmon across the north Pacific. Because ocean climate is strongly  
202 coupled to the atmosphere, ocean climate variation is also related to terrestrial cli-  
203 mate variation (especially precipitation). It can therefore be quite difficult to tease  
204 apart the roles of terrestrial and ocean climate in driving variation in the survival  
205 and productivity of salmon (Lawson et al., 2004).

206 In this report we review possible causes for the decline in SRFC, limiting our  
207 analysis to those potential causes for which there are reliable data to evaluate. First,  
208 we analyze the performance of the 2004, 2005 and 2006 broods of SRFC and look  
209 for corresponding conditions and events in their freshwater, estuarine and marine  
210 environments. Then we discuss the impact of long-term degradation in freshwater  
211 and estuarine habitats and the effects of hatchery practices on the biodiversity of  
212 Chinook in the Central Valley, and how reduced biodiversity may be making Chi-  
213 nook fisheries more susceptible to variations in ocean and terrestrial climate. We  
214 end the report with recommendations for future monitoring, research, and conser-  
215 vation actions. The appendix answers each of the more than 40 questions posed to  
216 the committee and provides summaries of most of the data used in the main report  
217 (CDFG, 2008).

## 218 **3 Analysis of recent broods**

### 219 **3.1 Review of the life history of SRFC**

220 Naturally spawning SRFC return to the spawning grounds in the fall and lay their  
221 eggs in the low elevation areas of the Sacramento River and its tributaries (Fig. 2).  
222 Eggs incubate for a month or more in the fall or winter, and fry emerge and rear  
223 throughout the rivers, tributaries and the Delta in the late winter and spring. In May  
224 or June, the juveniles are ready for life in the ocean, and migrate into the estuary  
225 (Suisun Bay to San Francisco Bay) and on to the Gulf of the Farallones. Emigra-  
226 tion from freshwater is complete by the end of June, and juveniles migrate rapidly  
227 through the estuary (MacFarlane and Norton, 2002). While information specific to  
228 the distribution of SRFC during early ocean residence is mostly lacking, fall Chi-  
229 nook in Oregon and Washington reside very near shore (even within the surf zone)  
230 and near their natal river for some time after ocean entry, before moving away  
231 from the natal river mouth and further from shore (Brodeur et al., 2004). SRFC  
232 are encountered in ocean salmon fisheries in coastal waters mainly between cen-

233 tral California and northern Oregon (O’Farrell et al., 2009; Weitkamp, In review),  
234 with highest abundances around San Francisco. Most SRFC return to freshwater to  
235 spawn after two or three years of feeding in the ocean.

236 A large portion of the SRFC contributing to ocean fisheries is raised in hatcheries  
237 (Barnett-Johnson et al., 2007), including Coleman National Fish Hatchery (CNFH)  
238 on Battle Creek, Feather River Hatchery (FRH), Nimbus Hatchery on the Amer-  
239 ican River, and the Mokelumne River Hatchery. Hatcheries collect fish that as-  
240 cend hatchery weirs, breed them, and raise progeny to the smolt stage. The state  
241 hatcheries transport >90% of their production to the estuary in trucks, where some  
242 smolts usually are acclimatized briefly in net pens and others released directly into  
243 the estuary; Coleman National Fish Hatchery (CNFH) usually releases its produc-  
244 tion directly into Battle Creek.

## 245 **3.2 Available data**

246 A large number of datasets are potentially relevant to the investigation at hand.  
247 These are summarized in Table 1.

## 248 **3.3 Conceptual approach**

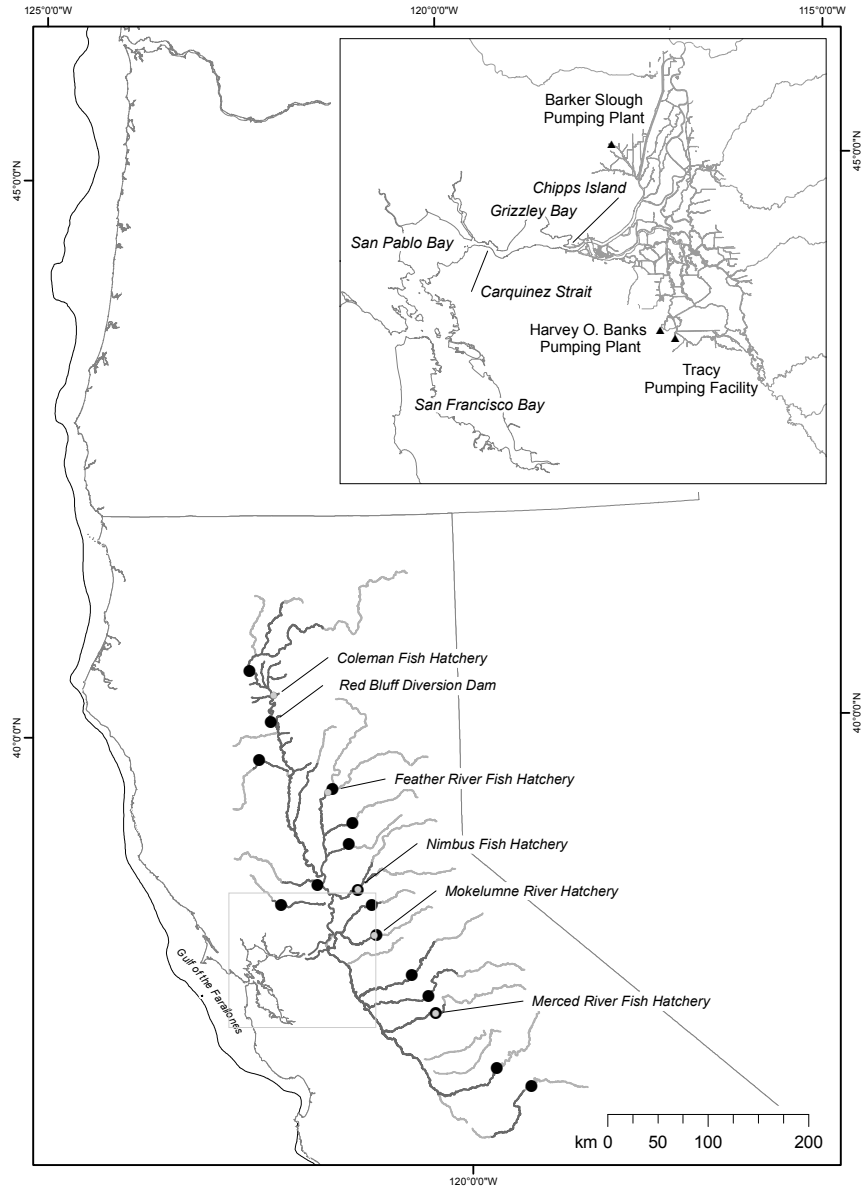
249 The poor landings and escapement of Chinook in 2007 and the record low escape-  
250 ment in 2008 suggests that something unusual happened to the SRFC 2004 and  
251 2005 broods, and more than forty possible causes for the decline were evaluated  
252 by the committee. Poor survival of a cohort can result from poor survival at one or  
253 more stages in the life cycle. Life cycle stages occur at certain times and places, and  
254 an examination of possible causes of poor survival should account for the temporal  
255 and spatial distribution of these life stages. It is helpful to consider a conceptual  
256 model of a cohort of fall-run Chinook that illustrates how various anthropogenic  
257 and natural factors affect the cohort (Fig. 3). The field of candidate causes can be  
258 narrowed by looking at where in the life cycle the abundance of the cohort became  
259 unusually low, and by looking at which of the causal factors were at unusual levels  
260 for these broods. The most likely causes of the decline will be those at unusual  
261 levels at a time and place consistent with the unusual change in abundance.

262 In this report, we trace through the life cycle of each cohort, starting with the  
263 parents of the cohort and ending with the return of the adults. Coverage of life stages  
264 and possible causes for the decline varies in depth, partly due to differences in the  
265 information available and partly to the committee’s belief in the likelihood that  
266 particular life stages and causal mechanisms are implicated in the collapse. Each  
267 potential factors identified by CDFG (2008) is, however, addressed individually in  
268 the Appendix. Before we delve into the details of each cohort, it is worthwhile to  
269 list some especially pertinent observations relative to the 2004 and 2005 broods:

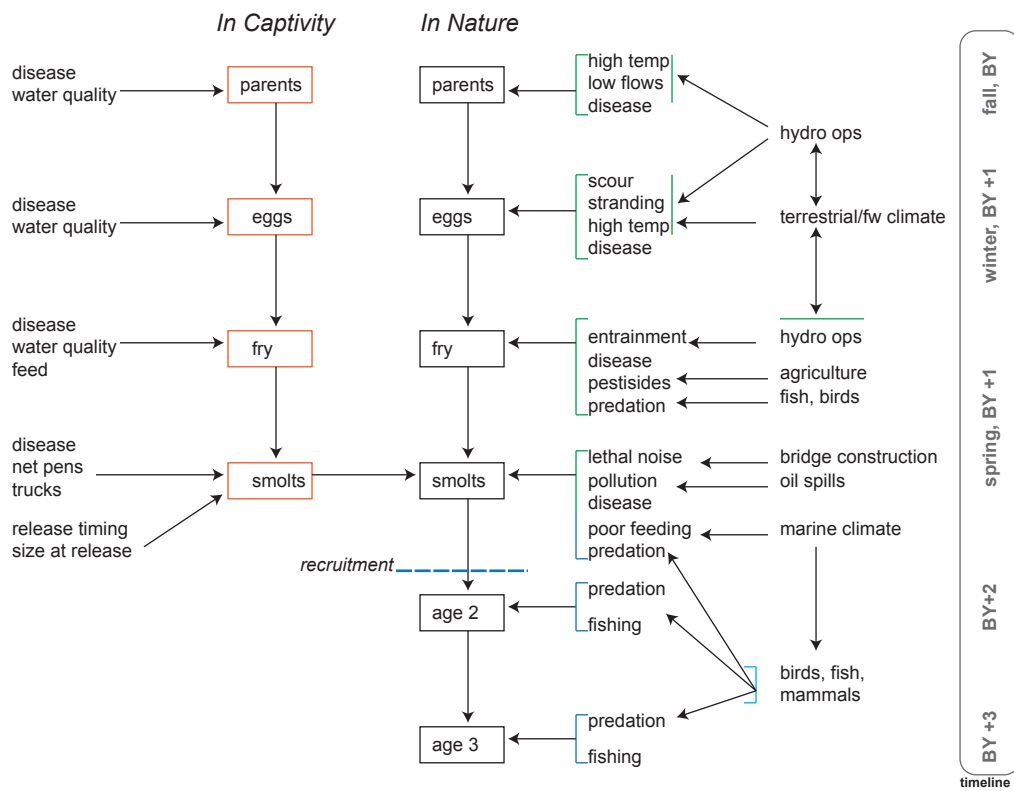
- 270 • Near-average numbers of fall Chinook juveniles were captured at Chipps Is-  
271 land

**Table 1:** Summary of data sources used in this report.

Data type	Period	Source
Time series of ocean harvest, river harvest and escapement	1983-2007	PFMC
Coded wire tag recoveries in fisheries and hatcheries	1983-2007	PSMFC
Fishing effort	1983-2007	PSMFC
Bycatch of Chinook in trawl fisheries	1994-2007	NMFS
Hatchery releases and operations	varies	CDFG, USFWS
Catches of juvenile salmon in survey trawls near Chipps Island	1977-2008	USFWS
Recovery of juvenile salmon in fish salvage operations at water export facilities	1997-2007	DWR
Time series of river conditions (discharge, temperature, turbidity) at various points in the basin	1990-2007	USGS, DWR
Time series of hydrosystem operations (diversions and exports)	1955-2007	DWR, USBR
Abundance of striped bass	1990-2007	CDFG
Abundance of pelagic fish in Delta	1993-2007	CDFG
Satellite-based observations of ocean conditions (sea surface temperature, winds, phytoplankton biomass)	various	NOAA, NASA
Observations of estuary conditions (salinity, temperature, Chl, dissolved O <sub>2</sub> )	1990-2007	USGS
Zoolankton abundance in the estuary	1990-2007	W. Kimmerer, SFSU
Ship-based observations of physical and biological conditions in the ocean (abundance of salmon prey items, mixed layer depth)	1983-2007	NOAA
Ocean winds and upwelling	1967-2008	NMFS
Abundance of marine mammals	varies	NMFS
Abundance of groundfish	1970-2005	NMFS
Abundance of salmon prey items	1983-2005	NMFS
Condition factor of juvenile Chinook in estuary and coastal ocean	1998-2005	NOAA
Seabird nesting success	1971-2005	PRBO



**Figure 2:** Map of the Sacramento River basin and adjacent coastal ocean. Inset shows the Delta and bays. Black dots denote the location of impassable dams; black triangle denote the location of major water export facilities in the Delta. The contour line indicates approximately the edge of the continental shelf.



**Figure 3:** Conceptual model of a cohort of fall-run Chinook and the factors affecting its survival. Orange boxes represent life stages in the hatchery, and black boxes represent life stages in the wild.

- 272 • Near-average numbers of SRFC smolts were released from state and federal  
273 hatcheries
- 274 • Hydrologic conditions in the river and estuary were not unusual during the  
275 juvenile rearing and outmigration periods (in particular, drought conditions  
276 were not in effect)
- 277 • Although water exports reaches record levels in 2005 and 2006, these lev-  
278 els were not reached until June and July, a period of time which followed  
279 outmigration of the vast majority of fall Chinook salmon smolts from the  
280 Sacramento system
- 281 • Survival of Feather River fall Chinook from release into the estuary to re-  
282 cruitment to fisheries at age two was extremely poor
- 283 • Physical and biological conditions in the ocean appeared to be unusually poor  
284 for juvenile Chinook in the spring of 2005 and 2006
- 285 • Returns of Chinook and coho salmon to many other basins in California,  
286 Oregon and Washington were also low in 2007 and 2008.

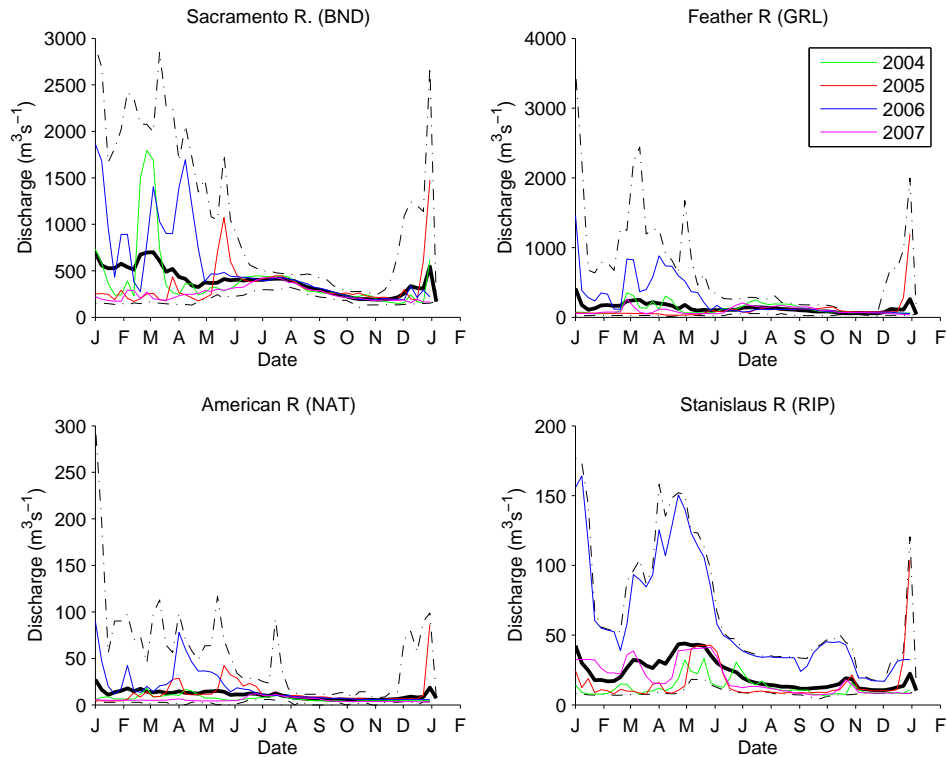
287 From these facts, we infer that unfavorable conditions during the early marine  
288 life of the 2004 and 2005 broods is likely the cause of the stock collapse. Fresh-  
289 water factors do not appear to be implicated directly because of the near average  
290 abundance of smolts at Chipps Island and because tagged fish released into the es-  
291 tuary had low survival to age two. Marine factors are further implicated by poor  
292 returns of coho and Chinook in other west coast river basins and numerous obser-  
293 vations of anomalous conditions in the California Current ecosystem, especially  
294 nesting failure of seabirds that have a diet and distribution similar to that of juvenile  
295 salmon.

296 In the remainder of this section, we follow each brood through its lifecycle,  
297 bringing relatively more detail to the assessment of ocean conditions during the  
298 early marine phase of the broods. While we are confident that ocean conditions are  
299 the proximate cause of the poor performance of the 2004 and 2005 broods, human  
300 activities in the freshwater environment have played an important role in creating a  
301 stock that is vulnerable to episodic crashes; we develop this argument in section 4.

## 302 **3.4 Brood year 2004**

### 303 **3.4.1 Parents**

304 The possible influences on the 2004 brood of fall-run Chinook began in 2004, with  
305 the maturation, upstream migration and spawning of the brood's parents. Most sig-  
306 nificantly, 203,000 adult fall Chinook returned to spawn in the Sacramento River  
307 and its tributaries in 2004, slightly more than the 1970-2007 mean of 195,000; es-  
308 capement to the Sacramento basin hatcheries totaled 80,000 adults (PFMC, 2009).  
309 In September and October of 2004, water temperatures were elevated by about



**Figure 4:** Discharge in regulated reaches of the Sacramento River, Feather River, American River and Stanislaus River in 2004-2007. Heavy black line is the weekly average discharge over the period of record for the stream gage (indicated in parentheses in the plot titles); dashed black lines indicate weekly maximum and minimum discharges. Data from the California Data Exchange Center, <http://cdec.water.ca.gov>.

310 1°C above average at Red Bluff, but remained below 15.5°C. Temperatures inhibit-  
 311 ing the migration of adult Chinook are significantly higher than this (McCullough,  
 312 1999). Flows were near normal through the fall and early winter (Fig. 4). Es-  
 313 capement to the hatcheries was near record highs, and no significant changes to  
 314 broodstock selection or spawning protocols occurred. Carcass surveys on the Sacra-  
 315 mento River showed very low levels of pre-spawning mortality in 2004 (D. Killam,  
 316 CDFG, unpublished data). It therefore appears that factors influencing the parents of  
 317 the 2004 brood were not the cause of the poor performance of that brood.

### 318 3.4.2 Eggs

319 The naturally-spawned portion of the 2004 brood spent the egg phase in the gravel  
 320 from October 2004 through March 2005 (Vogel and Marine, 1991). Water tempera-  
 321 tures at Red Bluff were within the optimal range for egg incubation for most of this  
 322 period, with the exception of early October. Flows were below average throughout  
 323 the incubation period, but mostly above the minimum flow levels observed for the  
 324 last 20 years or so. It is therefore unlikely that the eggs suffered scouring flows; we  
 325 have no information about redd dewatering, although flows below the major dams



326 are regulated to prevent significant redd dewatering.

327 In the hatcheries, no unusual events were noted during the incubation of the  
328 eggs of the 2004 brood. Chemical treatments of the eggs were not changed for the  
329 2004 brood.

### 330 **3.4.3 Fry, parr and smolts**

331 As noted above, flows in early 2005 were relatively low until May, when conditions  
332 turned wet and flows rose to above-normal levels (Fig. 4). Higher spring flows  
333 are associated with higher survival of juvenile salmon (Newman and Rice, 2002).  
334 Water temperature at Red Bluff was above the 1990-2007 average for much of the  
335 winter and spring, but below temperatures associated with lower survival of juvenile  
336 life stages (McCullough, 1999). In 2005, the volume of water pumped from the  
337 Delta reached record levels in January before falling to near-average levels in the  
338 spring, then rising again to near-record levels in the summer and fall (Fig. 5,top), but  
339 only after the migration of fall Chinook smolts was nearly complete (Fig. 8). Water  
340 diversions, in terms of the export:inflow ratio (E/I), fluctuated around the average  
341 throughout the winter and spring (Fig. 5,bottom). Statistical analysis of coded-  
342 wire-tagged releases of Chinook to the Delta have shown that survival declines  
343 with increasing exports and increasing E/I at time of release (Kjelson and Brandes,  
344 1989; Newman and Rice, 2002).

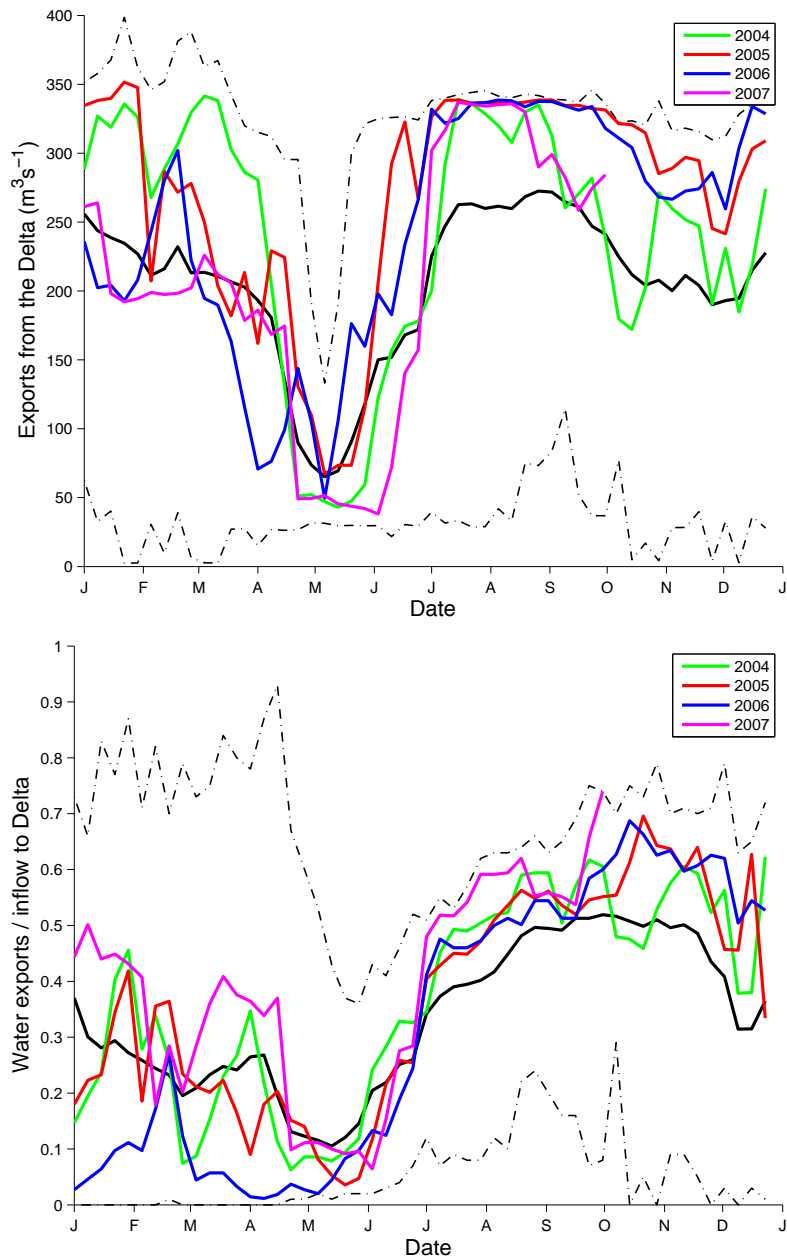
345 Releases of Chinook smolts were at typical levels for the 2004 brood, with a  
346 high proportion released into the bay, and of these, a not-unusual portion acclima-  
347 tized in net pens prior to release (Fig. 6). No significant disease outbreaks or other  
348 problems with the releases were noted.

349 Systematic trawl sampling near Chipps Island provides an especially useful  
350 dataset for assessing the strength of a brood as it enters the estuary<sup>2</sup>. The US-  
351 FWS typically conducts twenty-minute mid-water trawls, 10 times per day, 5 days  
352 a week. An index of abundance can be formed by dividing the total catch per day by  
353 the total volume swept by the trawl gear. Fig. 7 shows the mean annual CPUE from  
354 1976 to 2007; CPUE in 2005 was slightly above average. The timing of catches  
355 of juvenile fall Chinook at Chipps Island was not unusual in 2005 (Fig. 8). Had  
356 the survival of the 2004 brood been unusually poor in freshwater, catches at Chipps  
357 Island should have been much lower than average, since by reaching that location,  
358 fish have survived almost all of the freshwater phase of their juvenile life.

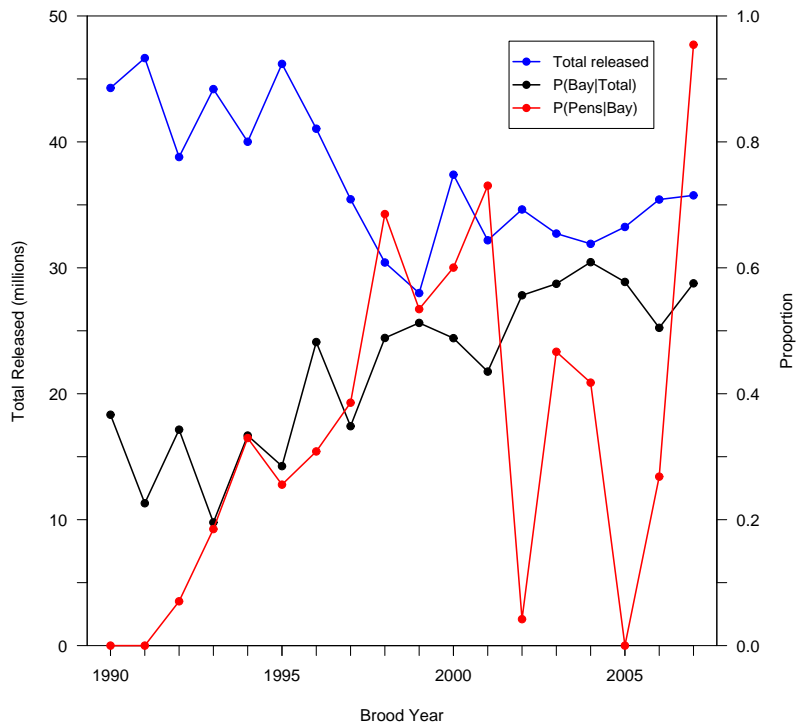
359 There are two reasons, however, that apparently normal catches at Chipps Island  
360 could mask negative impacts that occurred in freshwater. One possibility is that  
361 catches were normal because the capture efficiency of the trawl was much higher  
362 than usual. The capture efficiency of the trawl, as estimated by the recovery rate  
363 of coded-wire-tagged Chinook, is variable among years, but the recovery rate of  
364 Chinook released at Ryde in 2005 was about average (P. Brandes, USFWS, un-  
365 published data). This suggests that the actual abundance of fall Chinook passing

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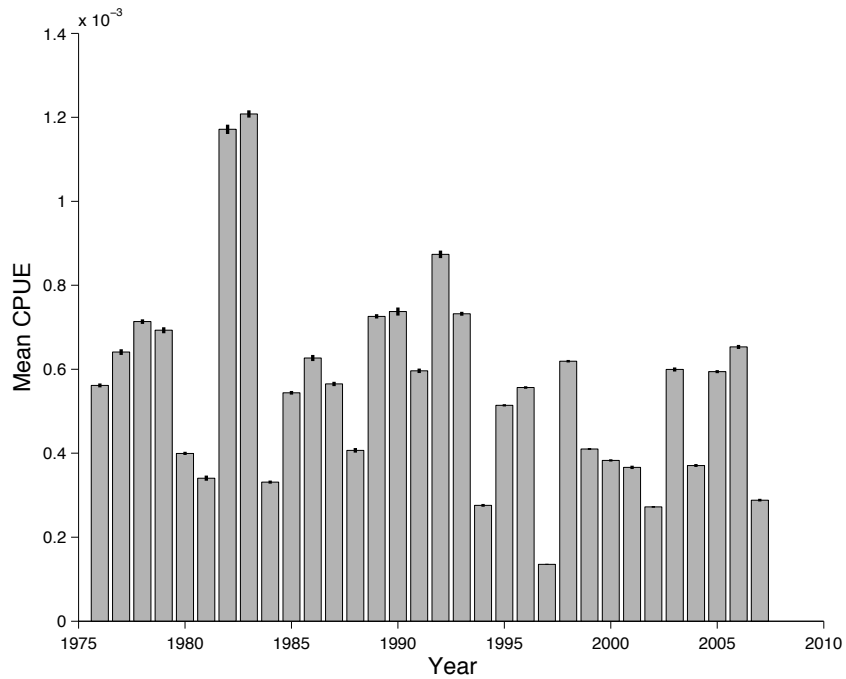
<sup>2</sup>Catches at Chipps Island include naturally-produced fish and CNFH hatchery fish released at Battle Creek; almost all fish from the state hatcheries are released downstream of Chipps Island.



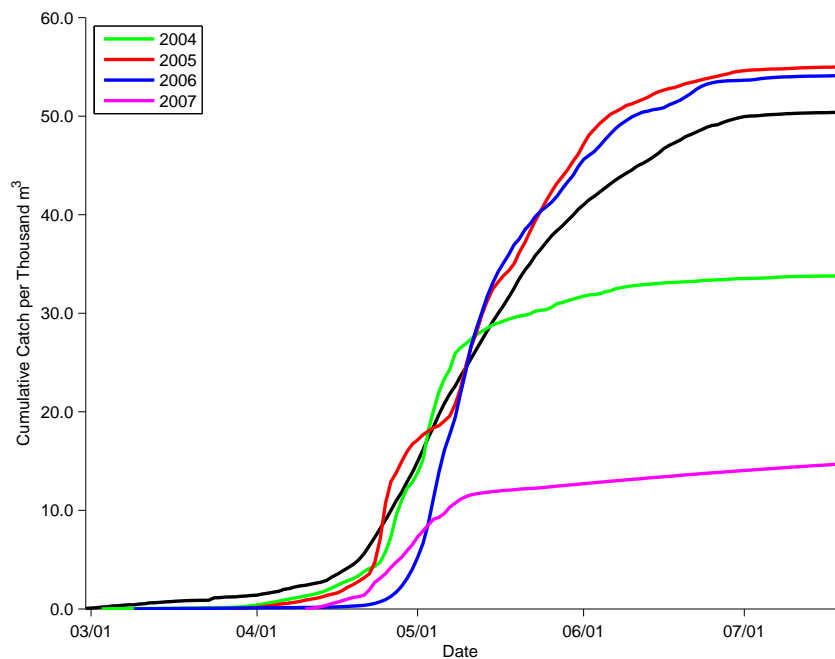
**Figure 5:** Weekly average export of freshwater from the Delta (upper panel) and the ratio of exports to inflows (bottom panel). Heavy black line is the weekly average discharge over the 1955-2007 period; dashed black lines indicate maximum and minimum weekly average discharges. Exports, as both rate and proportion, were higher than average in all years in the summer and fall, but near average during the spring, when fall Chinook are migrating through the Delta. Flow estimates from the DAYFLOW model (<http://www.iep.ca.gov/dayflow/>).



**Figure 6:** Total releases of hatchery fall Chinook, proportion of releases made to the bay, and the proportion of bay releases acclimatized in net pens. Unpublished data of CDFG and USFWS.



**Figure 7:** Mean annual catch-per-unit effort of fall Chinook juveniles at Chipps Island by USFWS trawl sampling conducted between January 1 and July 18. Error bars indicate the standard error of the mean. USFWS, unpublished data.



**Figure 8:** Cumulative daily catch per unit effort (CPUE) of fall Chinook juveniles at Chipps Island by USFWS trawl sampling. Black line shows the mean cumulative CPUE for 1976-2007.

366 Chipps Island was not low. The other explanation is that the effects of freshwa-  
367 ter stressors result in delayed mortality that manifests itself after fish pass Chipps  
368 Island. Delayed mortality from cumulative stress events has been hypothesized to  
369 explain the relatively poor survival to adulthood of fish that successfully pass more  
370 hydropower dams on the Columbia River (Budy et al., 2002). However, there is no  
371 *direct* evidence, to date, for delayed mortality in Chinook from the Columbia River  
372 (ISAB, 2007), and its causes remain a mystery. In any case, we do not have the data  
373 to test this hypothesis for SRFC.

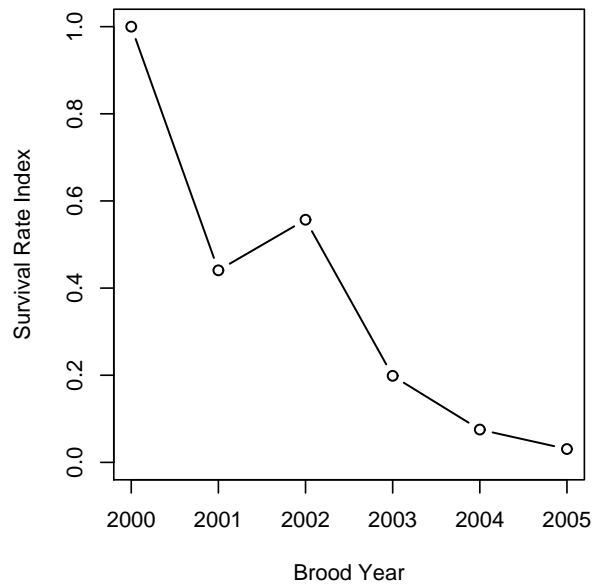
#### 374 **3.4.4 Early ocean**

375 Taken together, two lines of evidence suggest that something unusual befell the  
376 2004 brood of fall Chinook in either the bay or the coastal ocean. First, near-  
377 average numbers of juveniles were observed at Chipps Island (Fig. 8), and the state  
378 hatcheries released normal numbers of smolts into the bay. Second, survival of FRH  
379 smolts to age two was very low for the 2004 brood, only 8% that of the 2000 brood  
380 (Fig. 9; see the appendix for the rationale and details behind the survival rate index  
381 calculations), and the escapement of jacks from the 2004 brood was also very low in  
382 2006 (Fig. 10). The Sacramento Index of for 2007 was quite close to that expected  
383 by the escapement of jacks in 2006 (see appendix), indicating that the unusual mor-  
384 tality occurred after passing Chipps Island and prior to recruitment to the fishery at  
385 age two. Environmental conditions in the bay were not unusual in 2005 (see ap-  
386 pendix), suggesting that the cause of the collapse was likely in the ocean. Before  
387 reviewing conditions in the ocean, it is helpful to consider a conceptual model of  
388 physical and biological processes that characterize upwelling ecosystems, of which  
389 the California Current is an example.

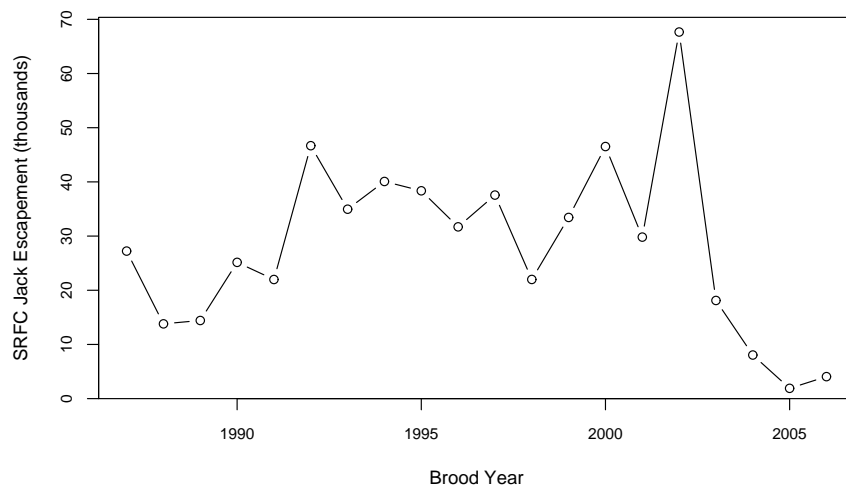
390 Rykaczewski and Checkley (2008) provides such a model (Fig. 11). Several  
391 factors, operating at different scales, influence the magnitude and distribution of  
392 primary and secondary productivity<sup>3</sup> occurring in the box. At the largest scale, the  
393 winds that drive upwelling ecosystems are generated by high-pressure systems cen-  
394 tered far offshore that generate equator-ward winds along the eastern edge of the  
395 ocean basin (Barber and Smith, 1981). The strength and position of pressure sys-  
396 tems over the globe change over time, which is reflected in various climate indices  
397 such as the Southern Oscillation Index and the Northern Oscillation index (Schwing  
398 et al., 2002), and these large-scale phenomena have local effects on the California  
399 Current. One effect is determining the source of the water entering the northern  
400 side of the box in Fig. 11. This source water can come from subtropical waters  
401 (warmer and saltier, with subtropical zooplankton species that are not particularly  
402 rich in lipids) or from subarctic waters (colder and fresher, with subarctic zooplank-  
403 ton species that are rich in lipids) (Hooff and Peterson, 2006). Where the source  
404 water comes from is determined by physical processes acting at the Pacific Ocean  
405 basin scale. The productivity of the source water entering the box is also influenced  
406 by coastal upwelling occurring in areas to the north.

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<sup>3</sup>Primary production is the creation of organic material by phytoplankton; secondary production is the creation of animal biomass by zooplankton.



**Figure 9:** Index of FRH fall Chinook survival rate between release in San Francisco Bay and age two based on coded-wire tag recoveries in the San Francisco major port area recreational fishery; brood years 2000-2005. The survival rate index is recoveries of coded-wire tags expanded for sampling divided by the product of fishing effort and the number of coded-wire tags released, relative to the maximum value observed (brood year 2000).



**Figure 10:** Escapement of SRFC jacks. Escapements in 2006 (brood year 2004) and 2007 (brood year 2005) were record lows at the time. Escapement estimate for 2008 (brood year 2006) is preliminary.

407 Within the box, productivity also depends on the magnitude, direction, spatial  
408 and temporal distribution of the winds (e.g., Wilkerson et al., 2006). Northwest  
409 winds drive surface waters away from the shore by a process called Ekman flow,  
410 and are replaced from below by colder, nutrient-rich waters near shore through the  
411 process of coastal upwelling. Northwest winds typically become stronger as one  
412 moves away from shore, a pattern called positive windstress curl, which causes  
413 offshore upwelling through a processes called Ekman pumping. The vertical ve-  
414 locities of curl-driven upwelling are generally much smaller than those of coastal  
415 upwelling, so nutrients are supplied to the surface waters at a lower rate by Ekman  
416 pumping (although potentially over a much larger area). Calculations by Dever et al.  
417 (2006) indicate that along central California, coastal upwelling supplies about twice  
418 the nutrients to surface waters as curl-driven upwelling. The absolute magnitude of  
419 the wind stress also affects mixing of the surface ocean; wind-driven mixing brings  
420 nutrients into the surface mixed layer but deepens the mixed layer, potentially lim-  
421 iting primary production by decreasing the average amount of light experienced by  
422 phytoplankton.

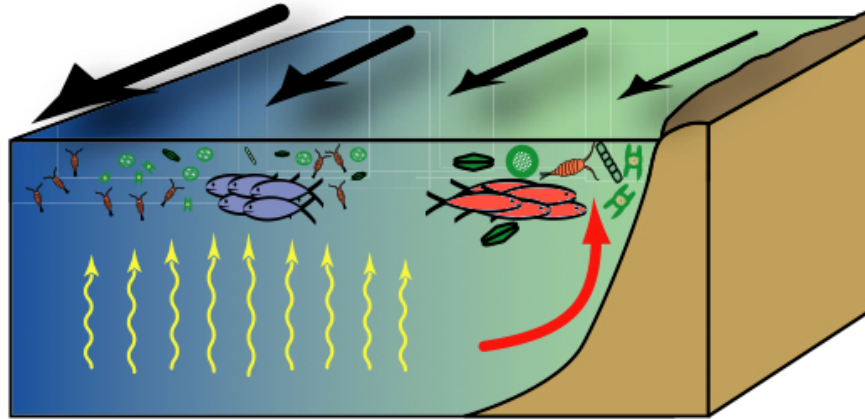
423 Yet another factor influencing productivity is the degree of stratification<sup>4</sup> in the  
424 upper ocean. This is partly determined by the source waters– warmer waters in-  
425 crease the stratification, which impedes the effectiveness of wind-driven upwelling  
426 and mixing. The balance of all of these processes determines the character of the  
427 pelagic food web, and when everything is “just right”, highly productive and short  
428 food chains can form and support productive fish populations that are characteristic  
429 of coastal upwelling ecosystems (Ryther, 1969; Wilkerson et al., 2006).

430 It is also helpful to consider how Chinook use the ocean. Juvenile SRFC typ-  
431 ically enter the ocean in the springtime, and are thought to reside in near shore  
432 waters, in the vicinity of their natal river, for the first few months of their lives in  
433 the sea (Fisher et al., 2007). As they grow, they migrate along the coast, remaining  
434 over the continental shelf mainly between central California and southern Wash-  
435 ington (Weitkamp, In review). Fisheries biologists believe that the time of ocean  
436 entry is especially critical to the survival of juvenile salmon, as they are small and  
437 thus vulnerable to many predators (Percy, 1992). If feeding conditions are good,  
438 growth will be high and starvation or the effects of size-dependent predation may  
439 be lower. Thus, we expect conditions at the time of ocean entry and near the point  
440 of ocean entry to be especially important in determining the survival of juvenile fall  
441 Chinook.

442 The timing of the onset of upwelling is critical for juvenile salmon that migrate  
443 to sea in the spring. If upwelling and the pelagic food web it supports is well-  
444 developed when young salmon enter the sea, they can grow rapidly and tend to  
445 survive well. If upwelling is not well-developed or if its springtime onset is delayed,  
446 growth and survival may be poor. As shown next, most physical and biological  
447 measures were quite unusual in the northeast Pacific, and especially in the Gulf of  
448 the Farallones, in the spring of 2005, when the 2004 brood of fall Chinook entered  
449 the ocean.

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<sup>4</sup>Stratification is the layering of water of different density.



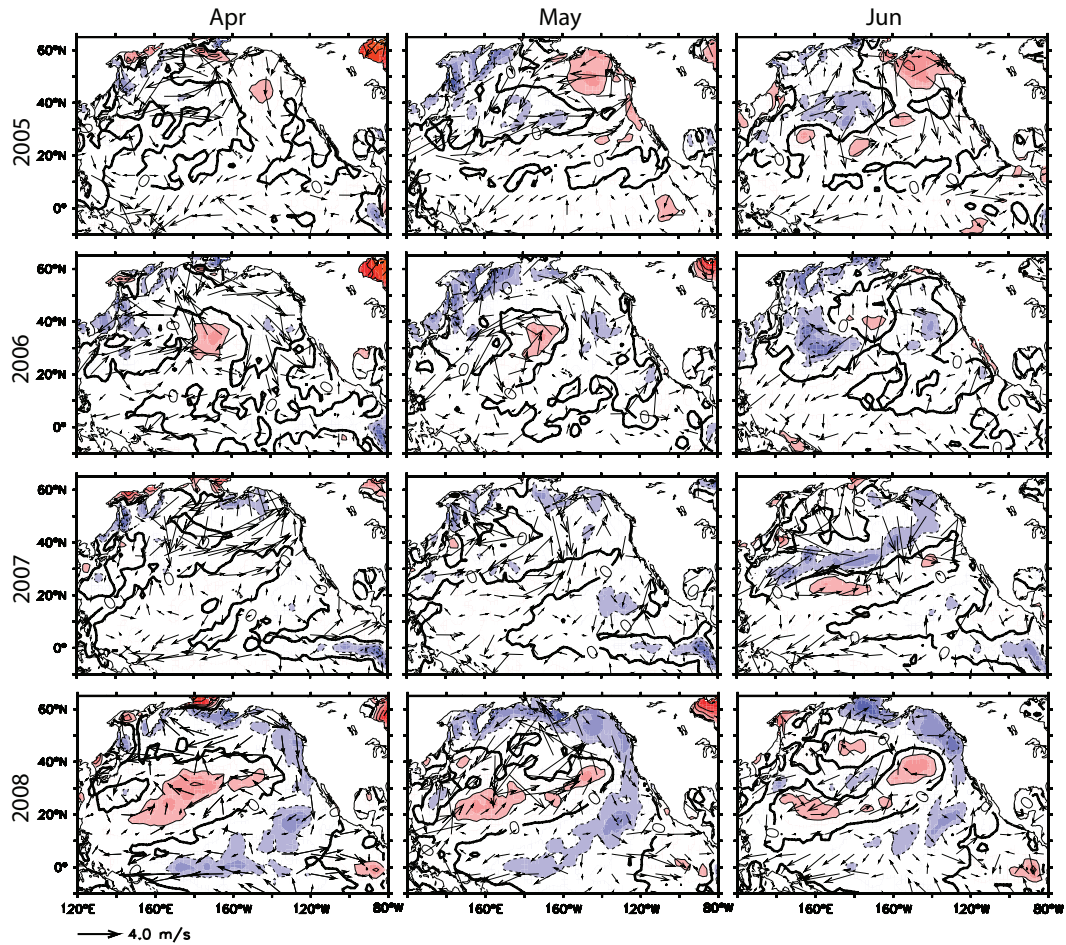
**Figure 11:** Conceptual diagram displaying the hypothesized relationship between wind-forced upwelling and the pelagic ecosystem. Alongshore, equatorward wind stress results in coastal upwelling (red arrow), supporting production of large phytoplankters and zooplankters. Between the coast and the wind-stress maximums, cyclonic wind-stress curl results in curl-driven upwelling (yellow arrows) and production of smaller plankters. Black arrows represent winds at the ocean surface, and their widths are representative of wind magnitude. Young juvenile salmon, like anchovy (red fish symbols), depend on the food chain supported by large phytoplankters, whereas sardine (blue fish symbols) specialize on small plankters. Growth and survival of juvenile salmon will be highest when coastal upwelling is strong. Redrawn from Rykaczewski and Checkley (2008).

450 Figure 12 shows temperature and wind anomalies for the north Pacific in the  
 451 April-June period of 2005-2008. There were southwesterly anomalies in wind  
 452 speed throughout the California Current in May of 2005, and sea surface tempera-  
 453 ture (SST) in the California Current was warmer than normal. This indicates that  
 454 upwelling-inducing winds were abnormally weak in May 2005. By June of 2005,  
 455 conditions off of California were more normal, with stronger than usual northwesterly  
 456 winds along the coast.

457 Because Fig. 12 indicates that conditions were unusual in the spring of 2005  
 458 throughout the California Current and also the Gulf of Alaska, we should expect  
 459 to see wide-spread responses by salmon populations inhabiting these waters at this  
 460 time. This was indeed the case. Fall Chinook in the Columbia River from brood  
 461 year 2004 had their lowest escapement since 1990, and coastal fall Chinook from  
 462 Oregon from brood year 2004 had their lowest escapement since either 1990 or the  
 463 1960s, depending on the stock. Coho salmon that entered the ocean in the spring of  
 464 2005 also had poor escapement.

465 Conditions off north-central California further support the hypothesis that ocean  
 466 conditions were a significant reason for the poor survival of the 2004 brood of fall  
 467 Chinook salmon. The upper two panels of Fig. 13 show a cumulative upwelling  
 468 index (CUI; Schwing et al. (2006)), an estimate of the integrated amount of up-  
 469 welling for the growing season, for the nearshore ocean area where fall Chinook  
 470 juveniles initially reside (39°N) and the coastal region to the north, or “upstream”





**Figure 12:** Sea surface temperature (colors) and wind (vectors) anomalies for the north Pacific for April-June in 2005-2008. Red indicates warmer than average SST; blue is cooler than average. Note the southwesterly wind anomalies (upwelling-suppressing) in May 2005 and 2006 off of California, and the large area of warmer-than-normal water off of California in May 2005. Winds and surface temperatures returned to near-normal in 2007, and become cooler than normal in spring 2008 along the west coast of North America.

471 (42°N). Typically, upwelling-favorable winds are in place by mid-March, as shown  
472 by the start dates of the CUI. In 2005, upwelling-favorable winds were unseason-  
473 ably weak in early spring, and did not become firmly established until late May and  
474 June further delayed to the north. The resulting deficit in the CUI (Fig. 13, lower  
475 two panels) is thought to have resulted in a delayed spring bloom, reduced biologi-  
476 cal productivity, and a much smaller forage base for Chinook smolts. The low and  
477 delayed upwelling was also expressed as unusually warm sea-surface temperatures  
478 in the spring of 2005 (Fig. 14).

479 The anomalous spring conditions in 2005 and 2006 were also evident in surface  
480 trajectories predicted from the OSCURS current simulations model<sup>5</sup>. The model  
481 computes the daily movement of water particles in the North Pacific Ocean surface  
482 layer from daily sea level pressures (Ingraham and Miyahara, 1988). Lengths and  
483 directions of trajectories of particles released near the coast are an indication of  
484 the strength of offshore surface movement and upwelling. Fig. 15 shows particle  
485 trajectories released from three locations March 1 and tracked to May 1 for 2004,  
486 2005, 2006 and 2007. In 2005 and 2006 trajectories released south of 42°N stayed  
487 near coast; a situation suggesting little upwelling over the spring.

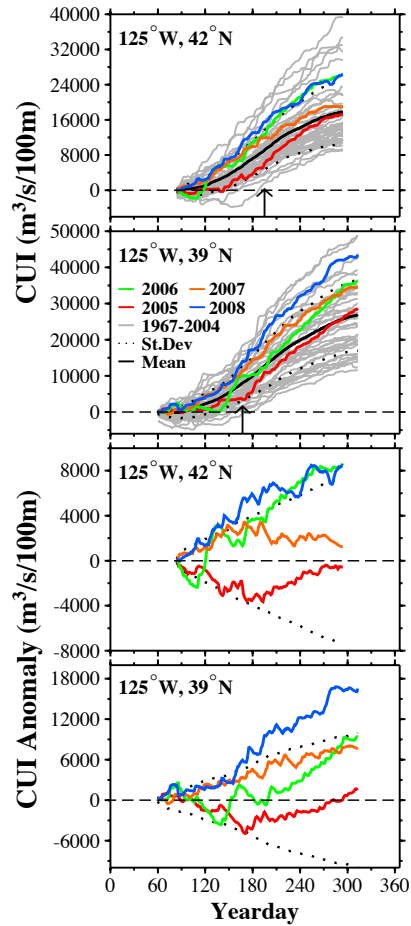
488 The delay in 2005 upwelling to the north of the coastal ocean habitat for these  
489 smolts is particularly important, because water initially upwelled off northern Cali-  
490 fornia and Oregon advected south, providing the source of primary production that  
491 supports the smolts prey base. Transport in spring 2005 (Fig. 15b) supports the con-  
492 tention that the water encountered by smolts emigrating out of SF Bay originated  
493 from off northern California, where weak early spring upwelling was particularly  
494 notable.

495 Some of the strongest evidence for the collapse of the pelagic food chain comes  
496 from observations of seabird nesting success on the Farallon Islands. Nearly all  
497 Cassin's auklets, which have a diet very similar to that of juvenile Chinook, aban-  
498 doned their nests in 2005 because of poor feeding conditions (Sydeman et al., 2006;  
499 Wolf et al., 2009). Other notable observations of the pelagic foodweb in 2005 in-  
500 clude: emaciated gray whales (Newell and Cowles, 2006); sea lions foraging far  
501 from shore rather than their usual pattern of foraging near shore (Weise et al., 2006);  
502 various fishes at record low abundance, including common salmon prey items such  
503 as juvenile rockfish and anchovy (Brodeur et al., 2006); and dinoflagellates be-  
504 coming the dominant phytoplankton group in Monterey Bay, rather than diatoms  
505 (MBARI, 2006). While the overall abundance of anchovies was low, they were  
506 captured in an unusually large fraction of trawls, indicating that they were more  
507 evenly distributed than normal (NMFS unpublished data). The overall abundance  
508 of krill observed in trawls in the Gulf of the Farallones was not especially low, but  
509 krill were concentrated along the shelf break and sparse inshore.

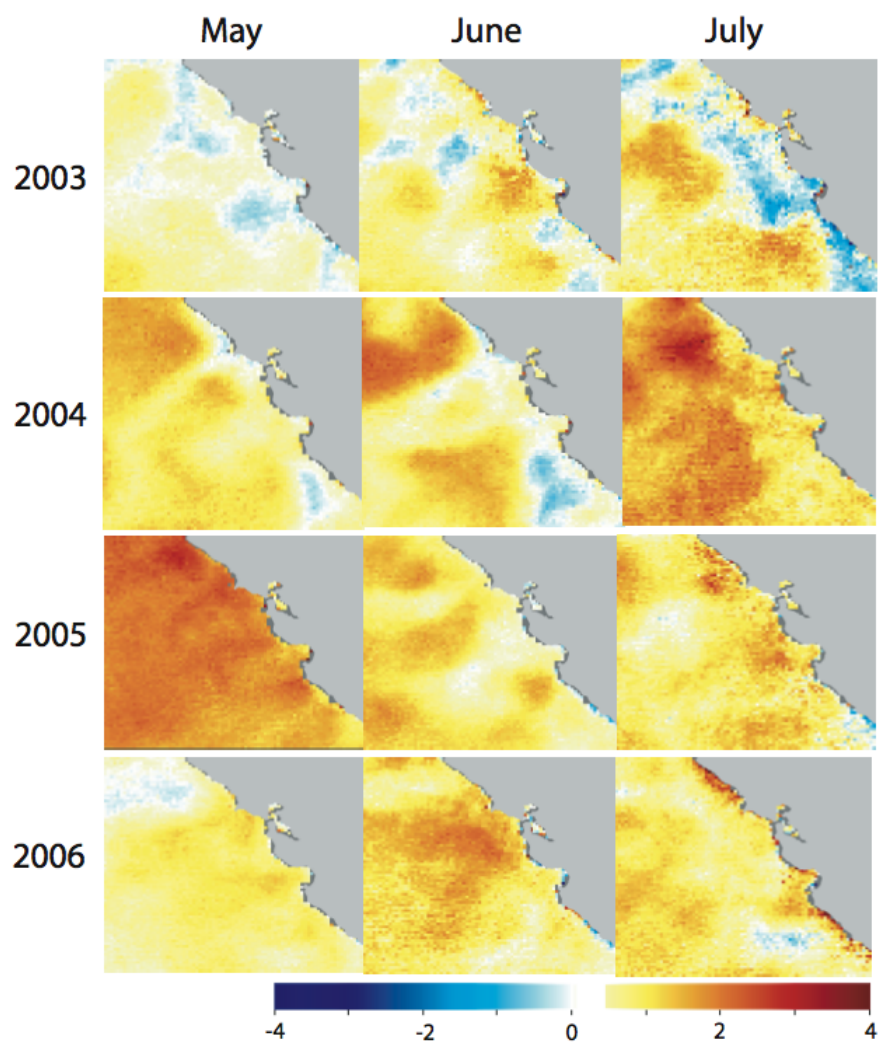
510 Observations of size, condition factor (K, a measure of weight per length) and  
511 total energy content (kilojoules (kJ) per fish, from protein and lipid contents) of  
512 juvenile salmon offer direct support for the hypothesis that feeding conditions in

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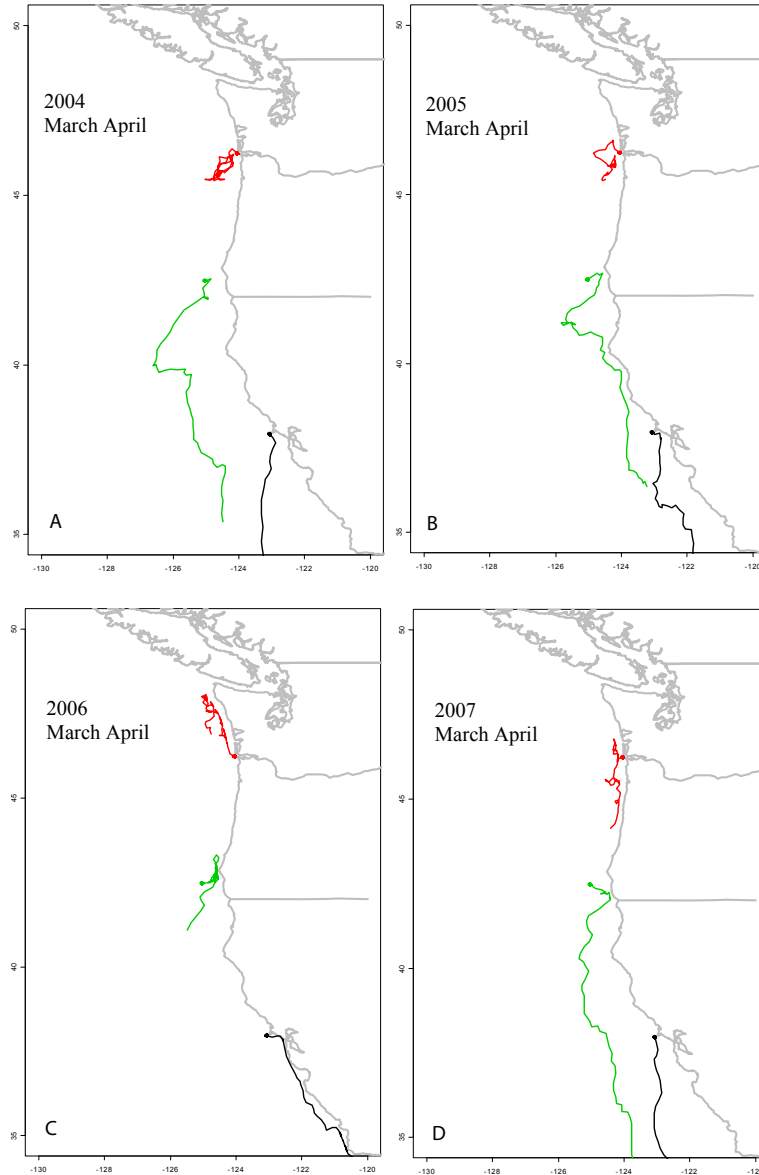
<sup>5</sup>Live access to OSCURS model, Pacific Fisheries Environmental Laboratory. Available at [www.pfeg.noaa.gov/products/las.html](http://www.pfeg.noaa.gov/products/las.html). Accessed 26 December 2007.



**Figure 13:** Cumulative upwelling index (CUI) and anomalies of the CUI at  $42^\circ\text{N}$  (near Brookings, Oregon) and  $39^\circ\text{N}$  (near Pt. Arena, California). Gray lines in the upper two panels are the individual years from 1967-2004. Black line is the average, dashed lines show the standard deviation. Arrow indicates the average time of maximum upwelling rate. The onset of upwelling was delayed in 2005 and remained weak through the summer; in 2006, the onset of upwelling was again delayed but became quite strong in the summer. Upwelling in 2007 and 2008 was stronger than average.



**Figure 14:** Sea surface temperature anomalies off central California in May-July of 2003-2006.



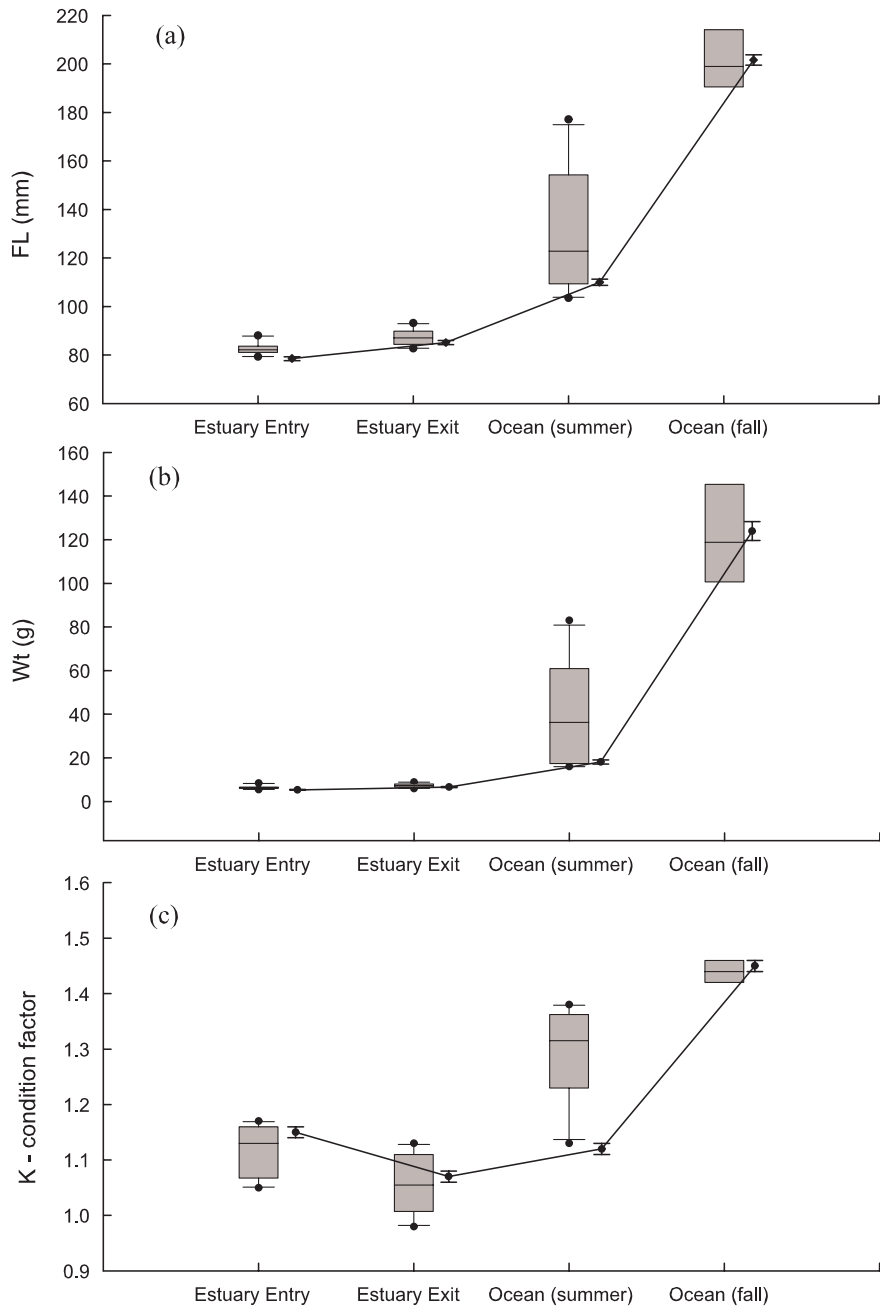
**Figure 15:** Surface particle trajectories predicted from the OSCURS current model. Particles released at 38°N, 43°N and 46°N (dots) were tracked from March 1 through May 1 (lines) for 2004-2007.

513 the Gulf of the Farallones were poor for juvenile salmon in the summer of 2005.  
514 Variation in feeding conditions for early life stages of marine fishes has been linked  
515 to subsequent recruitment variation in previous studies, and it is hypothesized that  
516 poor growth leads to low survival (Houde, 1975). In 2005, length, weight, K, and  
517 total energy content of juvenile Chinook exiting the estuary during May and June,  
518 when the vast majority of fall-run smolts enter the ocean, was similar to other ob-  
519 servations made over the 1998-2005 period (Fig. 16). However, size, K, and total  
520 energy content in the summer of 2005, after fish had spent approximately one month  
521 in the ocean, were all significantly lower than the mean of the 8-year period. These  
522 data show that growth and energy accumulation, processes critical to survival dur-  
523 ing the early ocean phase of juvenile salmon, were impaired in the summer, but  
524 recovered to typical values in the fall. A plausible explanation is that poor feeding  
525 conditions and depletion of energy reserves in the summer produced low growth  
526 and energy content, resulting in higher mortality of juveniles at the lower end of the  
527 distribution. By the fall, however, ocean conditions and forage improved and size,  
528 K, and total energy content had recovered to typical levels in survivors.

529 Taken together, these observations of the physical and biological state of the  
530 coastal ocean offer a plausible explanation for the poor survival of the 2004 brood.  
531 Due to unusual atmospheric and oceanic conditions, especially delayed coastal up-  
532 welling, the surface waters off of the central California coast were relatively warm  
533 and stratified in the spring, with a shallow mixed layer. Such conditions do not  
534 favor the large, colonial diatoms that are normally the base of short, highly produc-  
535 tive food chains, but instead support greatly increased abundance of dinoflagellates  
536 (MBARI, 2006; Rykaczewski and Checkley, 2008). The dinoflagellate-based food  
537 chain was likely longer and therefore less efficient in transferring energy to juve-  
538 nile salmon, juvenile rockfish and seabirds, which all experienced poor feeding  
539 conditions in the spring of 2005. This may have resulted in outright starvation of  
540 young salmon, or may have made them unusually vulnerable to predators. What-  
541 ever the mechanism, it appears that relatively few of the 2004 brood survived to  
542 age two. These patterns and conditions are consistent with Gargett's (1997) "opti-  
543 mal stability window" hypothesis, which posits that salmon stocks do poorly when  
544 water column stability is too high (as was the case for the 2004 and 2005 broods)  
545 or too low, and with Rykaczewski and Checkley's (2008) explanation of the role  
546 of offshore, curl-driven upwelling in structuring the pelagic ecosystem of the Cal-  
547 ifornia Current. Strong stratification in the Bering Sea was implicated in the poor  
548 escapement of sockeye, chum and Chinook populations in southwestern Alaska in  
549 1996-97 (Kruse, 1998).

### 550 **3.4.5 Later ocean**

551 In the previous section we presented information correlating unusual conditions  
552 in the Gulf of the Farallones, driven by unusual conditions throughout the north  
553 Pacific in the spring of 2005, that caused poor feeding conditions for juvenile fall  
554 Chinook. It is possible that conditions in the ocean at a later time, such as the spring  
555 of 2006, may have also contributed to or even caused the poor performance of the



**Figure 16:** Changes in (a) fork length, (b) weight, and (c) condition (K) of juvenile Chinook salmon during estuarine and early ocean phases of their life cycle. Boxes and whiskers represent the mean, standard deviation and 90% central interval for fish collected in San Francisco Estuary (entry = Suisun Bay, exit = Golden Gate) during May and June and coastal ocean between 1998-2004; points connected by the solid line represent the means ( $\pm 1$  SE) of fish collected in the same areas in 2005. Unpublished data of B. MacFarlane.

556 2004 brood. This is because fall Chinook spend at least years at sea before returning  
557 to freshwater, and thus low jack escapement could arise due to mortality or delayed  
558 maturation caused by conditions during the second year of ocean life. While it  
559 is generally believed that conditions during early ocean residency are especially  
560 important (Pearcy, 1992), work by Kope and Botsford (1990) and Wells et al. (2008)  
561 suggests that ocean conditions can affect all ages of Chinook. As discussed below  
562 in section 3.5.4, ocean conditions in 2006 were also unusually poor. It is therefore  
563 plausible that mortality of sub-adults in their second year in the ocean may have  
564 contributed to the poor escapement of SRFC in 2007.

565 Fishing is another source of mortality to Chinook that could cause unusually  
566 low escapement (discussed in more detail in the appendix). The PFMC (2007)  
567 forecasted an escapement of 265,000 SRFC adults in 2007 based on the escape-  
568 ment of 14,500 Central Valley Chinook jacks in 2006. The realized escapement of  
569 SRFC adults was 87,900. The error was due mainly to the over-optimistic forecast  
570 of the pre-season ocean abundance of SRFC. Had the pre-season ocean abundance  
571 forecast been accurate and fishing opportunity further constrained by management  
572 regulation in response, so that the resulting ocean harvest rate was reduced by half,  
573 the SRFC escapement goal would have been met in 2007. Thus, fishery manage-  
574 ment, while not the cause of the 2004 brood weak year-class strength, contributed  
575 to the failure to achieved the SRFC escapement goal in 2007.

### 576 **3.4.6 Spawners**

577 Jack returns and survival of FRH fall Chinook to age two indicates that the 2004  
578 brood was already at very low abundance before they began to migrate back to  
579 freshwater in the fall 2007. Water temperature at Red Bluff was within roughly  
580 1°C of normal in the fall, and flows were substantially below normal in the last 5  
581 weeks of the year. We do not believe that these conditions would have prevented  
582 fall Chinook from migrating to the spawning grounds, and there is no evidence  
583 of significant mortalities of fall Chinook in the river downstream of the spawning  
584 grounds.

### 585 **3.4.7 Conclusions for the 2004 brood**

586 All of the evidence that we could find points to ocean conditions as being the proxi-  
587 mate cause of the poor performance of the 2004 brood of fall Chinook. In particular,  
588 delayed coastal upwelling in the spring of 2005 meant that animals that time their  
589 reproduction so that their offspring can take advantage of normally bountiful food  
590 resources in the spring, found famine rather than feast. Similarly, marine mammals  
591 and birds (and juvenile salmon) which migrate to the coastal waters of northern  
592 California in spring and summer, expecting to find high numbers of energetically-  
593 rich zooplankton and small pelagic fish upon which to feed, were also impacted.  
594 Another factor in the reproductive failure and poor survival of fishes and seabirds  
595 may have been that 2005 marked the third year of chronic warm conditions in the  
596 northern California Current, a situation which could have led to a general reduction



597 in health of fish and birds, rendering them less tolerant of adverse ocean conditions.

## 598 **3.5 Brood year 2005**

### 599 **3.5.1 Parents**

600 In 2005, 211,000 adult fall Chinook returned to spawn in the Sacramento River  
601 and its tributaries to give rise to the 2005 brood, almost exactly equal to the 1970-  
602 2007 mean (Fig. 1). Pre-spawning mortality in the Sacramento River was about  
603 1% of the run (D. Killam, CDFG, unpublished data). River flows were near normal  
604 through the fall, but rose significantly in the last weeks of the year. Escapement to  
605 Sacramento basin hatcheries was near record highs, but this did not result in any  
606 significant problems in handling the broodstock.

### 607 **3.5.2 Eggs**

608 Flows in the winter of 2005-2006 were higher than usual, with peak flows around  
609 the new year and into the early spring on regulated reaches throughout the basin.  
610 Flows generally did not reach levels unprecedented in the last two decades (Fig. 4;  
611 see appendix for more details), but may have resulted in stream bed movement  
612 and subsequent mortality of a portion of the fall Chinook eggs and pre-emergent  
613 fry. Water temperature at Red Bluff in the spring was substantially lower than  
614 normal, probably prolonging the egg incubation phase, but not so low as to cause  
615 egg mortality (McCullough, 1999).

### 616 **3.5.3 Fry, parr and smolts**

617 The spring of 2006 was unusually wet, due to late-season rains associated with a  
618 cut-off low off the coast of California and a ridge of high pressure running over  
619 north America from the southwest to the northeast. This weather pattern gener-  
620 ated high flows in March and April 2006 (Fig. 4) and a very low ratio of water  
621 exports to inflows to the Delta (Fig. 5). Water temperatures in San Francisco Bay  
622 were unusually low, and freshwater outflow to the bay was unusually high (see ap-  
623 pendix). These conditions, while anomalous, are not expected to cause low survival  
624 of smolts migrating through the bay to the ocean. It is conceivable that the wet  
625 spring conditions had a delayed and indirect negative effect on the 2005 brood. For  
626 example, surface runoff could have carried high amounts of contaminants (pesti-  
627 cide residues, metals, hydrocarbons) into the rivers or bay, and these contaminants  
628 could have caused health problems for the brood that resulted in death after they  
629 passed Chipps Island. However, since both the winter and spring had high flows  
630 the concentrations of pollutants would likely have been at low levels if present. We  
631 found no evidence for or against this hypothesis.

632 Total water exports at the state and federal pumping facilities in the south Delta  
633 were near average in the winter and spring, but the ratio of water exports to inflow to  
634 the Delta (E/I) was lower than average for most of the winter and spring, only rising

635 to above-average levels in June. Total exports were near record levels throughout  
636 the summer and fall of 2006, after the fall Chinook emigration period.

637 Catch-per-unit-effort of juvenile fall Chinook in the Chipps Island trawl sam-  
638 pling was slightly higher than average in 2006, and the timing of catches was very  
639 similar to the average pattern, with perhaps a slight delay (roughly one week) in  
640 migration timing.

641 Releases from the state hatcheries were at typical levels, although in a poten-  
642 tially significant change in procedure, fish were released directly into Carquinez  
643 Strait and San Pablo Bay without the usual brief period of acclimatization in net  
644 pens at the release site. This change in procedure was made due to budget con-  
645 straints at CDFG. Acclimatization in net pens has been found to increase survival  
646 of release groups by a factor of 2.6, (CDFG, unpublished data) so this change may  
647 have had a significant impact on the survival of the state hatchery releases. CNFH  
648 released near-average numbers of smolts into the upper river, with no unusual prob-  
649 lems noted.

650 Conditions in the estuary and bays were cooler and wetter in the spring of 2006  
651 than is typical. Such conditions are unlikely to be detrimental to the survival of  
652 juvenile fall Chinook.

#### 653 **3.5.4 Early ocean**

654 Overall, conditions in the ocean in 2006 were similar to those in 2005. At the  
655 north Pacific scale, northwesterly winds were stronger than usual far offshore in the  
656 northeast Pacific during the spring, but weaker than normal near shore (Fig. 12).  
657 The seasonal onset of upwelling was again delayed in 2006, but this anomaly was  
658 more distinct off central California (Fig. 13). Unlike 2005, however, nearshore  
659 transport in 2006 was especially weak (Fig. 15b). In contrast to 2005, conditions  
660 unfavorable for juvenile salmon were restricted to central California, rather than be-  
661 ing a coast-wide phenomenon (illustrated in Fig. 13, where upwelling was delayed  
662 later at 39°N than 42°N). Consequently, we should expect to see corresponding  
663 latitudinal variation in biological responses in 2006.

664 These relatively poor conditions, following on the extremely poor conditions  
665 in 2005, had a dramatic effect on the food base for juvenile salmon off central  
666 CA. Once again, Cassin's auklets on the Farallon Islands experienced near-total  
667 reproductive failure. Krill, which were fairly abundant but distributed offshore near  
668 the continental shelf break in 2005, were quite sparse off central California in 2006  
669 (see appendix). Juvenile rockfish were at very low abundance off central California,  
670 according to the NMFS trawl surveys (see appendix). These observations indicate  
671 feeding conditions for juvenile salmon in the spring of 2006 off central California  
672 were as bad as or worse than in 2005.

673 Consistent with the alongshore differences in upwelling and SST anomalies, and  
674 with better conditions off of Oregon and Washington, abundance of juvenile spring  
675 Chinook, fall Chinook and coho were four to five times higher in 2006 than in 2005  
676 off of Oregon and Washington (W. Peterson, NMFS, unpublished data from trawl  
677 surveys). Catches of juvenile spring Chinook and coho salmon in June 2005 were

678 the lowest of the 11 year time series; catches of fall Chinook were the third lowest.  
679 Similarly, escapement of adult fall Chinook to the Columbia River in 2007 for the  
680 fish that entered the sea in 2005 was the lowest since 1993 but escapement in 2008  
681 was twice as high as in 2007. A similar pattern was seen for Columbia River spring  
682 Chinook. Cassin's auklets on Triangle Island, British Columbia, which suffered  
683 reproductive failure in 2005, fared well in 2006 (Wolf et al., 2009).

684 Estimated survival from release to age two for the 2005 brood of FRH fall Chi-  
685 nook was 60% lower than the 2004 brood, only 3% of that observed for the 2000  
686 brood (Fig. 9). We note that the failure to acclimatize the bay releases in net pens  
687 may explain the difference in survival of the 2004 and 2005 Feather River releases,  
688 but would not have affected survival of naturally produced or CNFH smolts. Jack  
689 escapement from the 2005 brood in 2007 was extremely low. Unfortunately, lipid  
690 and condition factor sampling of juvenile Chinook in the estuary, bays and Gulf  
691 of the Farallones was not conducted in 2006 due to budgetary and ship-time con-  
692 straints.

### 693 **3.5.5 Later ocean**

694 Ocean conditions improved in 2007 and 2008, with some cooling in the spring in  
695 the California Current in 2007, and substantial cooling in 2008. Data are not yet  
696 available on the distribution and abundance of salmon prey items, but it is likely  
697 that feeding conditions improved for salmon maturing in 2008. However, improved  
698 feeding conditions appear to have had minimal benefit to survival after recruitment  
699 to the fishery, because the escapement of 66,000 adults in 2008 was very close to  
700 the predicted escapement (59,000) based on jack returns in 2007. Fisheries were  
701 not a factor in 2008 (they were closed).

### 702 **3.5.6 Spawners**

703 As mentioned above, about 66,000 SRFC adults returned to natural areas and hatcheries  
704 in 2008. Although detailed data have not yet been assembled on freshwater and  
705 estuarine conditions for the fall of 2008, the Sacramento Valley has been experi-  
706 encing severe drought conditions, and river temperatures were higher than normal  
707 and flows have been lower than normal. Neither of these conditions are beneficial  
708 to fall Chinook and may have impacted the reproductive success of the survivors of  
709 the 2005 brood.

### 710 **3.5.7 Conclusions for the 2005 brood**

711 For the 2005 brood, the evidence suggests again that ocean conditions were the  
712 proximate cause of the poor performance of that brood. In particular, the cessation  
713 of coastal upwelling in May of 2006 was likely a serious problem for juvenile fall  
714 Chinook entering the ocean in the spring. In contrast to 2005, anomalously poor  
715 ocean conditions were restricted to central California. The poorer performance of

716 the 2005 brood relative to the 2004 brood may be partly due to the cessation of  
717 net-pen acclimatization of fish from the state hatcheries.

### 718 **3.6 Prospects for brood year 2006**

719 In this section, we briefly comment on some early indicators of the possible per-  
720 formance of the 2006 brood. The abundance of adult fall Chinook escaping to the  
721 Sacramento River, its tributaries and hatcheries in 2006 had dropped to 168,000, a  
722 level still above the minimum escapement goal of 122,000. Water year 2007 (which  
723 started in October 2006) was categorized as “critical”<sup>6</sup>, meaning that drought con-  
724 ditions were in effect during the freshwater phase of the 2006 brood. While the  
725 levels of water exports from the Delta were near normal, inflows were below nor-  
726 mal, and for much of the winter, early spring, summer and fall of 2007, the E/I ratio  
727 was above average. During the late spring, when fall Chinook are expected to be  
728 migrating through the Delta, the E/I ratio was near average. Ominously, catches of  
729 fall Chinook juveniles in the Chipps Island trawl survey in 2007 were about half  
730 that observed in 2005 and 2006. A tagging study conducted by NMFS and UC  
731 Davis found that survival of late-fall Chinook from release in Battle Creek (upper  
732 Sacramento River near CNFH) to the Golden Gate was roughly 3% in 2007; such  
733 survival rates are much lower than have been observed in similar studies in the  
734 Columbia River (Williams et al., 2001; Welch et al., 2008).

735 Ocean conditions began to improve somewhat in 2007, with some cooling evi-  
736 dent in the Gulf of Alaska and the eastern equatorial Pacific. The California Current  
737 was roughly 1°C cooler than normal in April and May, but then warmed to above-  
738 normal levels in June-August 2007. The preliminary estimate of SRFC jack escape-  
739 ment was 4,060 (Fig. 10, PFMC (2009)), double that of the 2005 brood, but still the  
740 second lowest on record and a level that predicts an adult escapement in 2009 at the  
741 low end of the escapement goal absent any fishing in 2009. A survival rate estimate  
742 from release to age two is not possible for this brood due to the absence of a fishery  
743 in 2008, but jack returns will provide some indication of the survival of this brood<sup>7</sup>.

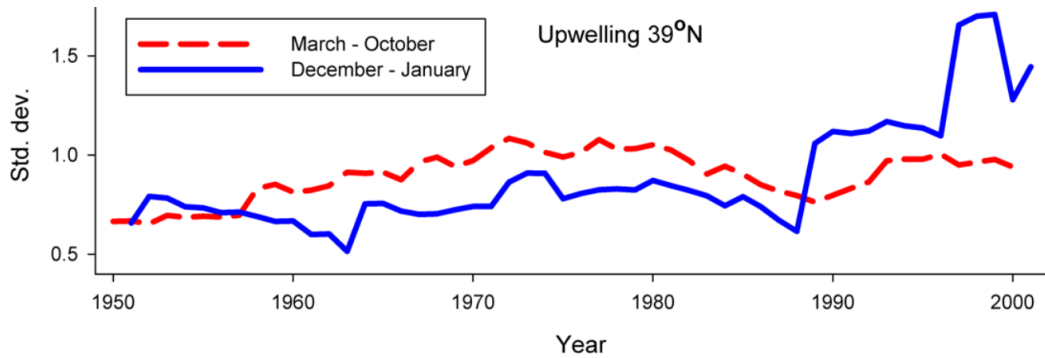
### 744 **3.7 Is climate change a factor?**

745 An open question is whether the recent unusual conditions in the coastal ocean are  
746 the result of normal variation or caused in some part by climate change. We tend  
747 to think of the effects of climate change as a trajectory of slow, steady warming.  
748 Another potential effect is an increased intensity and frequency of many types of  
749 rare events (Christensen et al., 2007). Along with a general upward trend in sea  
750 surface temperatures, the variability of ocean conditions as indexed by the Pacific  
751 Decadal Oscillation, the North Pacific Gyre Oscillation, and the NINO34 index  
752 appears to be increasing (N. Mantua, U. Washington, unpublished data).

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<sup>6</sup>California Department of Water Resources water year hydrological classification indices,  
<http://cdec.water.ca.gov/cgi-progs/iodir2/WSIHIST>

<sup>7</sup>Proper cohort reconstructions are hindered because of inadequate sampling of tagged fish in the hatchery and on the spawning grounds, and high rates of straying.



**Figure 17:** Changes in interannual variation in summer and winter upwelling at 39°N latitude, 1946 - 2007. Summer upwelling shows a possible decadal-scale oscillation. Winter upwelling (downwelling) shows a sharp increase starting in the late 1980s. The graph shows 11-year moving average standard deviations of standardized time series.

753 Winter upwelling at 39°N, off the California coast, took a jump upward in the  
 754 late 1980s (Fig. 17). Whether there is a direct causative relationship between this  
 755 pattern and recent volatility in SRFC escapement is a matter for further investi-  
 756 gation, but there is a similar pattern of variability in environmental indices and  
 757 salmon catch and escapement coast wide. While not evident in all stocks (Sacra-  
 758 mento River winter Chinook escapement variability is going down, for example)  
 759 the general trend for salmon stocks from California to Alaska is one of increasing  
 760 variability (Lawson and Mantua, unpublished data). The well-recognized relation-  
 761 ship between salmon survival and ocean conditions suggests that the variability in  
 762 SRFC escapement is at least partly linked to the variability in ocean environment.

763 In the Sacramento River system there are other factors leading to increased vari-  
 764 ability in salmon escapements, including variation in harvest rates, freshwater habi-  
 765 tat simplification, and reduced life history diversity in salmon stocks (discussed in  
 766 detail in the section 4). In addition, freshwater temperature and flow patterns are  
 767 subject to the same forces that drive variability in the ocean environment (Lawson  
 768 et al., 2004), although they are modified significantly in the Central Valley by the  
 769 water projects. These factors, in combination with swings in ocean survival, would  
 770 tend to increase the likelihood of extreme events such as the unusually high escape-  
 771 ments of the early 2000s and the recent low escapements that are the subject of this  
 772 report.

### 773 3.8 Summary

774 A broad body of evidence suggests that anomalous conditions in the coastal ocean  
 775 in 2005 and 2006 resulted in unusually poor survival of the 2004 and 2005 broods  
 776 of SRFC. Both broods entered the ocean during periods of weak upwelling, warm  
 777 sea surface temperatures, and low densities of prey items. Pelagic seabirds with  
 778 diets similar to juvenile Chinook also experienced very poor reproduction in these  
 779 years. A dominant role for freshwater factors as proximate causes of poor survival  
 780 for the 2004 and 2005 broods were ruled out by observations of near-normal fresh-

781 water conditions during the period of freshwater residency, near-normal numbers of  
782 juvenile fall-run Chinook entering the estuary, and typical numbers of juvenile fall  
783 Chinook released from hatcheries. However, as Lawson (1993) reasoned, long-term  
784 declines in the condition of freshwater habitats are expected to result in increasingly  
785 severe downturns in abundance during episodes of poor ocean survival (Fig. 18). In  
786 the following section, we explain how human activities may be making the Central  
787 Valley Chinook salmon stock complex more susceptible to natural stressors.

## 788 **4 The role of anthropogenic impacts**

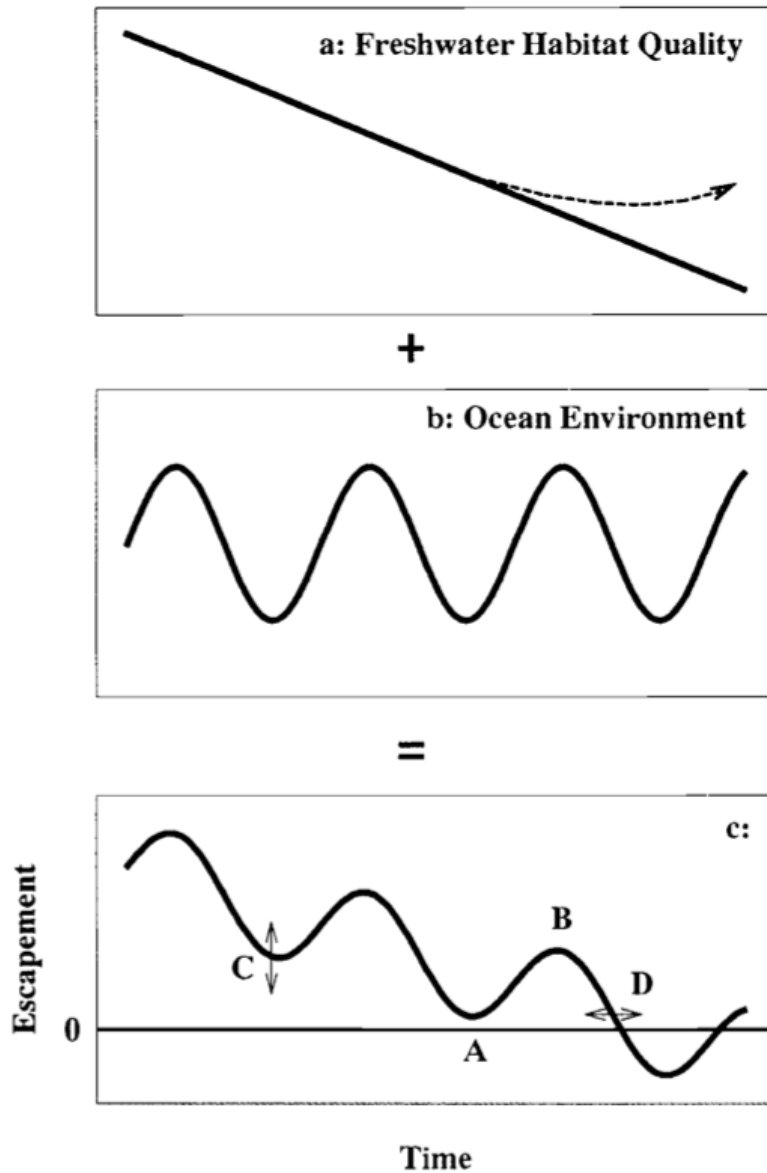
789 So far, we have restricted our analysis to the question of whether there were un-  
790 usual conditions affecting Sacramento River fall-run Chinook from the 2004 and  
791 2005 broods that could explain their poor performance, reaching the conclusion  
792 that unfavorable ocean conditions were the proximate cause. But what about the  
793 ultimate causes?

### 794 **4.1 Sacramento River fall Chinook**

795 With regard to SRFC, anthropogenic effects are likely to have played a signifi-  
796 cant role in making this stock susceptible to collapse during periods of unfavorable  
797 ocean conditions. Historical modifications have eliminated salmon spawning and  
798 rearing habitat, decreased total salmon abundance, and simplified salmon biodi-  
799 versity (McEvoy, 1986; Yoshiyama et al., 1998, 2001; Williams, 2006a). To the  
800 extent that these changes have concentrated fish production and reduced the ca-  
801 pacity of populations to spread mortality risks in time and space, we hypothesize  
802 that the Central Valley salmon ecosystem has become more vulnerable to recurring  
803 stresses, including but not limited to periodic shifts in the ocean environment.

804 Modifications in the Sacramento River basin since early in the nineteenth cen-  
805 tury have reduced the quantity, quality, and spatial distribution of freshwater habitat  
806 for Chinook. Large dams have blocked access to spawning habitat upriver and  
807 disrupted geomorphic processes that maintain spawning and rearing habitats down-  
808 stream. Levees have disconnected flood plains, and bank armoring and dewatering  
809 of some river reaches have eliminated salmon access to shallow, peripheral habitats.  
810 By one estimate at least 1700 km or 48% of the stream lengths available to salmon  
811 for spawning, holding, and migration (not including the Delta) have been lost from  
812 the 3500 km formerly available in the Central Valley (Yoshiyama et al., 2001).

813 One of the most obvious alterations to fall Chinook habitat has been the loss  
814 of shallow-water rearing habitat in the Delta. Mid-nineteenth century land surveys  
815 suggest that levee construction and agricultural conversion have removed all but  
816 about 5% of the 1,300 km<sup>2</sup> of Delta tidal wetlands (Williams, 2006a). Because  
817 growth rates in shallow-water habitats can be very high in the Central Valley (Som-  
818 mer et al., 2001; Jeffres et al., 2008), access to shallow wetlands, floodplains and  
819 stream channel habitats could increase the productive capacity of the system. From  
820 this perspective, the biggest problem with the state and federal water projects is not



**Figure 18:** Conceptual model of effects of declining habitat quality and cyclic changes in ocean productivity on the abundance of salmon. a: trajectory over time of habitat quality. Dotted line represents possible effects of habitat restoration projects. b: generalized time series of ocean productivity. c: sum of top two panels where letters represent the following: A = current situation, B = situation in the future, C = change in escapement from increasing or decreasing harvest, and D = change in time of extinction from increasing or decreasing harvest. Copied from Lawson (1993).

821 that they kill fish at the pumping facilities, but that by engineering the whole system  
822 to deliver water from the north of the state to the south while preventing flooding,  
823 salmon habitat has been greatly simplified.

824 Although historical habitat losses undoubtedly have reduced salmon production  
825 in the Central Valley ecosystem, other than commercial harvest records, quantita-  
826 tive abundance estimates did not become available until the 1940s, nearly a century  
827 after hydraulic gold mining, dam construction, and other changes had drastically  
828 modified the habitat landscape. Harvest records indicate that high volumes of fish  
829 were harvested by nineteenth-century commercial river fisheries. From the 1870s  
830 through early 1900s, annual in-river harvest in the Central Valley often totaled four  
831 to ten million pounds of Chinook, approaching or exceeding the total annual harvest  
832 by statewide ocean fisheries in recent decades (Yoshiyama et al., 1998). Maximum  
833 annual stock size (including harvest) of Central Valley Chinook salmon before the  
834 twentieth century has been estimated conservatively at 1-2 million spawners with  
835 fall-run salmon totals perhaps reaching 900,000 fish (Yoshiyama et al., 1998). In re-  
836 cent decades, annual escapement of SRFC, which typically accounts for more than  
837 90% of all fall Chinook production in the Central Valley, has remained relatively  
838 stable, totaling between 100,000 and 350,000 adults in most years from the 1960s  
839 through the 1990s. However, escapement began to fluctuate more erratically in the  
840 present decade, climbing to a peak of 775,000 in 2002 but then falling rapidly to  
841 near-record lows thereafter (Fig. 1).

842 Beyond the effects of human activities on production of SRFC are the less obvi-  
843 ous influences on biodiversity. The diversity of life histories in Chinook (variations  
844 in size and age at migration, duration of freshwater and estuarine residency, time  
845 of ocean entry, etc.) has been described as a strategy for spreading mortality risks  
846 in uncertain environments (Healey, 1991). Diverse habitat types allow the expres-  
847 sion of diverse salmon rearing and migration behaviors (Bottom et al., 2005b), and  
848 life history diversity within salmon stocks allows the stock aggregate to be more  
849 resilient to environmental changes (Hilborn et al., 2003).

850 Juvenile SRFC have adopted a variety of rearing strategies that maximize use  
851 of the diverse habitat types throughout the basin, including: (1) fry (< 50 mm fork  
852 length) migrants that leave soon after emergence to rear in the Delta or in the es-  
853 tuarine bays; (2) fingerling migrants that remain near freshwater spawning areas  
854 for several months, leaving at larger sizes (> 60 mm fork length) in the spring but  
855 passing quickly through the Delta; and (3) later migrants, including some juveniles  
856 that reside in natal streams through the summer or even stay through the winter  
857 to migrate as yearlings (Williams, 2006a). Today most SRFC exhibit fry-migrant  
858 strategies, while the few yearling migrants occur in areas where reservoir releases  
859 maintain unusually low water temperatures. Historical changes reduced or elim-  
860 inated habitats that supported diverse salmon life histories throughout the basin.  
861 Passage barriers blocked access to cool upper basin tributaries, and irrigation di-  
862 versions reduced flows and increased water temperatures, eliminating cool-water  
863 refugia necessary to support juveniles with stream-rearing life histories (Williams,  
864 2006a). The loss of floodplain and tidal wetlands in the Delta eliminated a con-  
865 siderable amount of habitat for fry migrants, a life history strategy that is not very



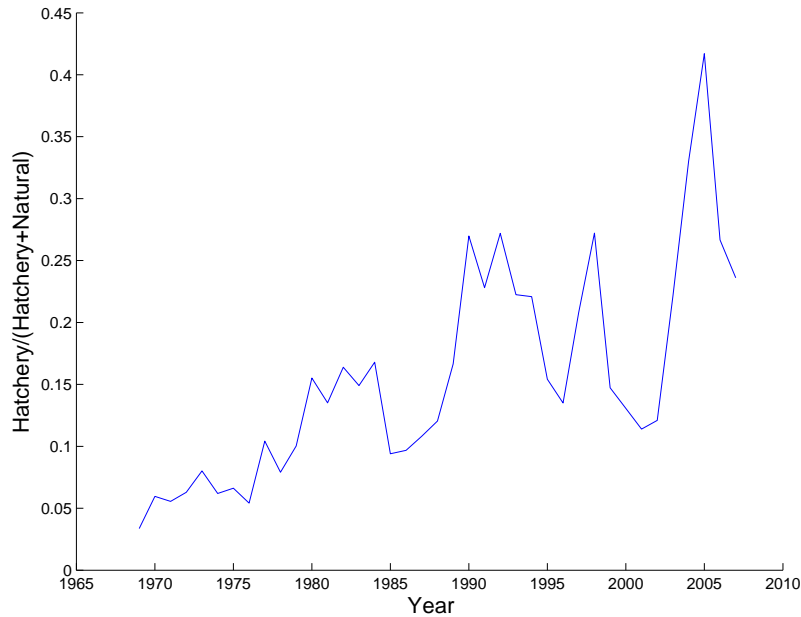
866 effective in the absence of shallow-water habitats downstream of spawning areas.  
867 Similar fresh water and estuarine habitat losses have been implicated in the simplifi-  
868 cation of Chinook life histories in the Salmon (Bottom et al., 2005a) and Columbia  
869 River basins (Bottom et al., 2005b; Williams, 2006b). In Oregon's Salmon River,  
870 an extensive estuarine wetland restoration program has increased rearing opportu-  
871 nities for fry migrants, expanding life history diversity in the Chinook population,  
872 including the range of times and sizes that juveniles now enter the ocean (Bottom  
873 et al., 2005a). Re-establishing access to shallow wetland and floodplain habitats in  
874 the Sacramento River and Delta similarly could extend the time period over which  
875 SRFC reach sufficient sizes to enter the ocean, strengthening population resilience  
876 to a variable ocean environment.

877 Hatchery fish are a large and increasing proportion of SRFC (Barnett-Johnson  
878 et al., 2007), and a rising fraction of the population is spawning in hatcheries  
879 (Fig. 19). The Central Valley salmon hatcheries were built and operated to miti-  
880 gate the loss of habitat blocked by dams, but may have inadvertently contributed to  
881 the erosion of biodiversity within fall Chinook. In particular, the release of hatchery  
882 fish into the estuary greatly increases the straying of hatchery fish to natural spawn-  
883 ing areas (CDFG and NMFS, 2001). Central Valley fall Chinook are almost unique<sup>8</sup>  
884 among Chinook ESUs in having little or no detectable geographically-structured ge-  
885 netic variation (Williamson and May, 2005). There are two plausible explanations  
886 for this. One is that Central Valley fall Chinook never had significant geographical  
887 structuring because of frequent migration among populations in response to highly  
888 variable hydrologic conditions (on a microevolutionary time scale). The other ex-  
889 planation is that straying from hatcheries to natural spawning areas has genetically  
890 homogenized the ESU. One implication of the latter explanation is that populations  
891 of SRFC may have lost adaptations to their local environments. It is also likely that  
892 hatchery practices cause unintentional evolutionary change in populations (Reisen-  
893 bichler and Rubin, 1999; Bisson et al., 2002), and high levels of gene flow from  
894 hatchery to wild populations can overcome natural selection, reducing the genetic  
895 diversity and fitness of wild populations.

896 Another consequence of the hatchery mitigation program was the subsequent  
897 harvest strategy, which until the 1990s was focused on exploiting the aggregate  
898 stock, with little regard for the effects on naturally produced stocks. For many  
899 years, Central Valley Chinook stocks were exploited at rates averaging more than  
900 60 percent in ocean and freshwater fisheries (Myers et al., 1998). Such levels may  
901 not be sustainable for natural stocks, and could result in loss of genetic diversity,  
902 contributing to the homogeneity of Central Valley fall Chinook stocks. Harvest  
903 drives rapid changes in the life history and morphological phenotypes of many or-  
904 ganisms, with Pacific salmon showing some of the largest changes (Darimont et al.,  
905 2009). An evolutionary response to the directional selection of high ocean harvest  
906 is expected, including reproduction at an earlier age and smaller size and spawn-  
907 ing earlier in the season (reviewed by Hard et al. (2008)). A truncated age structure

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<sup>8</sup>The exception to this rule is Sacramento River winter-run Chinook, which now spawn only in the mainstem Sacramento River below Keswick Reservoir.



**Figure 19:** The fraction of total escapement of SRFC that returns to spawn in hatcheries.

908 may also increase variation in population abundance (Huusko and Hyvärinen, 2005;  
 909 Anderson et al., 2008).

910 Hatchery practices also may cause the aggregate abundance of hatchery and nat-  
 911 ural fish to fluctuate more widely. Increased variability arises in two ways. First,  
 912 high levels of straying from hatcheries to natural spawning areas can synchronize  
 913 the dynamics of the hatchery and natural populations. Second, hatcheries typically  
 914 strive to standardize all aspects of their operations, releasing fish of a similar size  
 915 at a particular time and place, which hatchery managers believe will yield high  
 916 returns to the fishery on average. Such strategies can have strong effects on age  
 917 at maturation through effects on early growth (Hankin, 1990), reducing variation  
 918 in age at maturity. A likely product of this approach is that the high variation in  
 919 survival among years and high covariation in survival and maturation among hatch-  
 920 ery releases within years may create boom and bust fluctuations in salmon returns,  
 921 as hatchery operations align, or fail to align, with favorable conditions in stream,  
 922 estuarine or ocean environments.

923 Hankin and Logan's (2008) analysis of survival rates from release to ocean  
 924 age 2 of fall-run Chinook released from Iron Gate, Trinity River and Cole Rivers  
 925 hatcheries provides an example. Survival of 20+ brood years of fingerling releases  
 926 ranged from 0.0002 to 0.046, and yearling releases ranged from 0.0032 to 0.26, a  
 927 230-fold and 80-fold variation in survival, respectively. Hankin and Logan (2008)  
 928 found that survival covaried among release groups, with the highest covariation  
 929 between groups released from the same hatchery at nearly the same time, although  
 930 covariation among releases from different hatcheries made at similar times was sub-  
 931 stantial. Because Central Valley fall Chinook are dominated by hatchery produc-  
 932 tion, and Central Valley hatcheries release most of their production at similar times,

933 this finding is significant: very high variation in ocean abundance and escapement  
934 *should be expected* from the system as currently operated.

935 A similar mechanism has been proposed to explain the collapse of coho salmon  
936 fisheries along the Oregon coast following the 1976 ocean regime shift. Cumulative  
937 habitat loss, overharvest, and the gradual replacement of diverse wild populations  
938 and life histories with a few hatchery stocks left coho salmon vulnerable to col-  
939 lapse when ocean conditions suddenly changed (Lawson, 1993; Lichatowich, 1999;  
940 Williams, 2006b)). The situation is analogous to managing a financial portfolio: a  
941 well-diversified portfolio will be buffeted less by fluctuating market conditions than  
942 one concentrated on just a few stocks; the SRFC seems to be quite concentrated in-  
943 deed.

## 944 **4.2 Other Chinook stocks in the Central Valley**

945 Sacramento River fall Chinook have been the most abundant stock of Chinook  
946 salmon off of central California in recent decades, but this has not always been  
947 the case. Sacramento River winter Chinook, late-fall Chinook and especially spring  
948 Chinook once dominated the production of Chinook from the Central Valley (Fisher,  
949 1994), but over the decades have dwindled to a few remnant populations mostly  
950 now under the protection of the Endangered Species Act (Lindley et al., 2004). The  
951 causes for these declines are the same as those that have affected fall Chinook, but  
952 because these other stocks spend some portion of their life in freshwater during  
953 the summer, they have been more strongly impacted by impassable dams that limit  
954 access to cold-water habitats.

955 Spring-run Chinook were once the most abundant of the Central Valley runs,  
956 with large populations in snow-melt and spring-fed streams in the Sierra Nevada  
957 and southern Cascades, respectively (Fisher, 1994). Spring-run Chinook have been  
958 reduced from perhaps 18 major populations spawning in four distinct ecoregions  
959 within the Central Valley to three remnant populations inhabiting a single ecoregion  
960 (Lindley et al., 2007). Winter-run Chinook were less abundant than spring Chinook,  
961 spawning in summer months in a few spring-fed tributaries to the upper Sacramento  
962 River. Perhaps four distinct populations of winter Chinook have been extirpated  
963 from their historical spawning grounds, with survivors founding a population in the  
964 tailwaters of Shasta Dam (Lindley et al., 2004). The historical distribution of late-  
965 fall-run Chinook is less clear, but their life history requires cool water in summer,  
966 and thus their distribution has probably also been seriously truncated by impassable  
967 dams at low elevations in the larger tributaries.

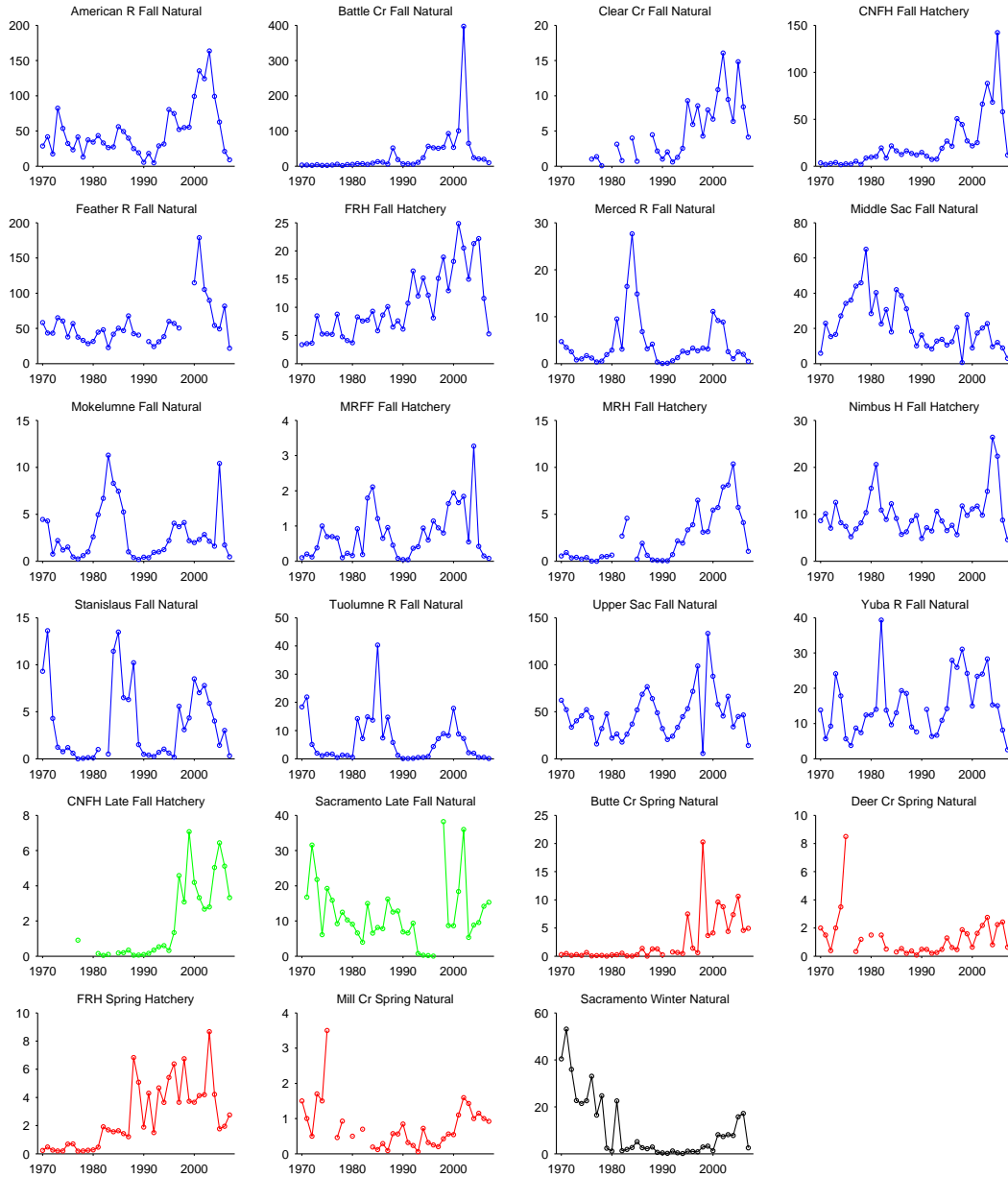
968 An examination of the population dynamics of extant Central Valley Chinook  
969 populations illustrates that if spring, winter and late-fall Chinook contributed sig-  
970 nificantly to the fishery, the aggregate abundance of Chinook in central California  
971 waters would be less variable. Populations of Central Valley fall-run Chinook ex-  
972 hibited remarkably similar dynamics over the past two decades, while other runs  
973 of Central Valley Chinook did not (Fig. 20 and 21). Almost all fall Chinook popu-  
974 lations reached peak abundances around 2002, and have all been declining rapidly  
975 since then. In contrast, late-fall, winter and naturally-spawning spring Chinook

976 populations have been increasing in abundance over the past decade, although es-  
977 capement in 2007 was down in some of them and the growth of these populations  
978 through the 1990s and 2000s has to some extent been driven by habitat restoration  
979 efforts. This begs the question of why have these other stocks responded differently  
980 to recent environmental variation.

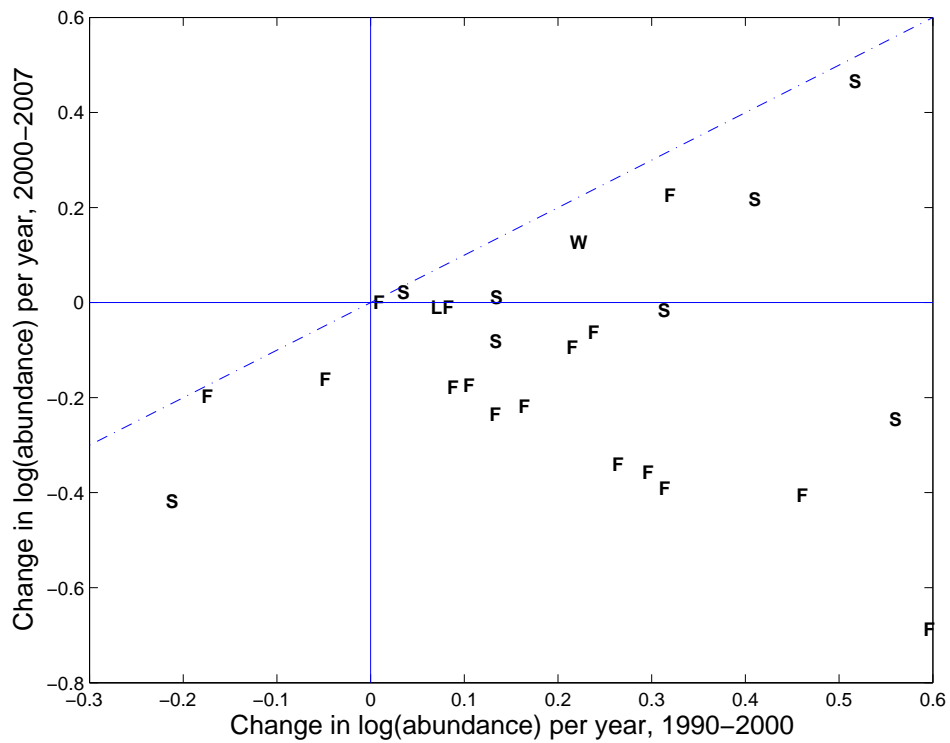
981 The answer may have two parts. One part has to do with hatcheries. As dis-  
982 cussed above, hatcheries may be increasing the covariation of fall Chinook popu-  
983 lations by erasing genetic differences among populations that might have caused  
984 the populations to respond differently to environmental variation. They may be fur-  
985 ther synchronizing the demographics of the naturally-spawning populations through  
986 straying of hatchery fish into natural spawning areas, a problem exacerbated by out-  
987 planting fish to the Delta and bays. Finally, hatchery practices minimize variation  
988 in size, condition and migration timing, which should tend to increase variation in  
989 survival rates because “bet hedging” is minimized.

990 The other part of the answer may lie in the observation that the other runs of  
991 Chinook have life history tactics that differ in important ways from fall Chinook.  
992 While named according to the time of year that adults enter freshwater, each run  
993 type of Central Valley Chinook has a characteristic pattern of habitat use across  
994 space and time that leads to differences in the time and size of ocean entry. For  
995 example, spring-run Chinook juveniles enter the ocean at a broader range of ages  
996 (with a portion of some populations migrating as yearlings) than fall Chinook, due  
997 to their use of higher elevations and colder waters. Winter run Chinook spawn in  
998 summer, and the juveniles enter the ocean at a larger size than fall Chinook, due  
999 to their earlier emergence and longer period of freshwater residency. Late-fall-run  
1000 Chinook enter freshwater in the early winter, and spawn immediately, but juveniles  
1001 migrate as yearlings the following winter. Thus, if ocean conditions at the time  
1002 of ocean entry are critical to the survival of juvenile salmon, we should expect  
1003 that populations from different runs should respond differently to changing ocean  
1004 conditions because they enter the ocean at different times and at different sizes.

1005 In conclusion, the development of the Sacramento-San Joaquin watershed has  
1006 greatly simplified and truncated the once-diverse habitats that historically supported  
1007 a highly diverse assemblage of populations. The life history diversity of this histor-  
1008 ical assemblage would have buffered the overall abundance of Chinook salmon in  
1009 the Central Valley under varying climate conditions. We are now left with a fish-  
1010 ery that is supported largely by four hatcheries that produce mostly fall Chinook  
1011 salmon. Because the survival of fall Chinook salmon hatchery release groups is  
1012 highly correlated among nearby hatcheries, and highly variable among years, we  
1013 can expect to see more booms and busts in this fishery in the future in response  
1014 to variation in the ocean environment. Simply increasing the production of fall  
1015 Chinook salmon from hatcheries as they are currently operated may aggravate this  
1016 situation by further concentrating production in time and space. Rather, the key to  
1017 reducing variation in production is increasing the diversity of SRFC. In the follow-  
1018 ing section, we make some recommendations towards this goal.



**Figure 20:** Escapement trends in selected populations of Chinook since 1970. Plots are color-coded according to run timing. Y-axis is thousands of fish; X-axis is year. CNFH = Coleman National Fish Hatchery; FRH = Feather River Hatchery; MRFF = Merced River Fish Facility; MRH = Mokelumne River Hatchery.



**Figure 21:** Escapement trends in the 1990s and 2000s of various populations of Chinook. F = fall Chinook, S = spring Chinook, LF= late fall Chinook, W= winter Chinook. If populations maintained constant growth rates over the 1990-2007 period, they would fall along the dashed diagonal line. All populations fall below the diagonal line, showing that growth rates are lower in the 2000s than in the 1990s, and fall Chinook populations have tended to decline the fastest in the 2000s.

## 1019 **5 Recommendations**

1020 In this section, we offer recommendations in three areas. First, we identify major  
1021 information gaps that hindered our analysis of the 2004 and 2005 broods. Filling  
1022 these gaps should lead to a better understanding of the linkages between survival  
1023 and environmental conditions. Second, we offer some suggestions on how to im-  
1024 prove the resilience of SRFC and the Central Valley Chinook stock complex. While  
1025 changes in harvest opportunities are unavoidable given the expected fluctuations in  
1026 environmental conditions, it is the panel's opinion that reducing the volatility of  
1027 abundance, even at the expense of somewhat lower average catches, would benefit  
1028 the fishing industry and make fishery disasters less likely. Finally, we point out that  
1029 an ecosystem-based management and ecological risk assessment framework could  
1030 improve management of Central Valley Chinook stocks by placing harvest man-  
1031 agement in the broader context of the Central Valley salmon ecosystem, which is  
1032 strongly influenced by hatchery operations and management of different ecosystem  
1033 components, including water, habitat and other species.

### 1034 **5.1 Knowledge Gaps**

1035 We are confident in our conclusion that unusual conditions in the coastal ocean in  
1036 2005 and 2006 caused the poor performance of the 2004 and 2005 broods. Our  
1037 case could have been strengthened further, however, with certain kinds of informa-  
1038 tion that are not currently available. Chief among these is the need for constant  
1039 fractional marking and tagging of hatchery production, and adequate sampling of  
1040 fish on the natural spawning grounds. Such information would better identify the  
1041 contribution of hatcheries to the ocean fishery and natural spawning escapement,  
1042 survival rates of different hatchery release groups, and the likely degree to which  
1043 hatchery populations are impacting naturally-spawning populations. Central Valley  
1044 hatcheries have recently started a constant-fractional marking program for fall Chi-  
1045 nook, and CDFG is currently planning how to improve in-river sampling for mark  
1046 and tag recovery. These efforts are critical to improved assessment of SRFC in the  
1047 future.

1048 CDFG has also recently begun to determine the age of returns to the river, which  
1049 will allow stock assessment scientists to produce cohort reconstructions of the nat-  
1050 ural stocks in addition to hatchery stocks. Cohort reconstructions provide better  
1051 survival estimates than the method used in this report (releases of tagged juvenile  
1052 and recovery of tagged fish at age-two in recreational fisheries) because they are  
1053 based on many more tag recoveries and provide estimates of fishery mortality and  
1054 maturation rates.

1055 In the case of the 2004 and 2005 broods, freshwater factors did not appear to be  
1056 the direct cause of the collapse, but future collapses may have multiple contribut-  
1057 ing causes of similar importance. In such cases, it would be extremely valuable to  
1058 have reach-specific survival rates like those routinely available for several salmonid  
1059 species in the Columbia River and recently available for late-fall Chinook and steel-  
1060 head in the Sacramento River. This would provide powerful and direct information

1061 about when and where exceptional mortality occurs.

1062 Observations of growth and energetic condition of Chinook in the estuary and  
1063 ocean provided valuable evidence for the 2004 brood, but were unavailable for the  
1064 2005 and later broods, due to funding limitations.

## 1065 **5.2 Improving resilience**

1066 It appears that the abundance of SRFC is becoming increasingly variable (Fig. 17).  
1067 Exceptionally high abundance of SRFC may not seem like a serious problem (al-  
1068 though it does create some problems), but exceptionally low abundances are treated  
1069 as a crisis. The panel is concerned that such crises are to be expected at a frequency  
1070 much higher than is acceptable, and that this frequency may be increasing with  
1071 time due to changes in the freshwater environment, the ocean environment, and the  
1072 SRFC stock itself. The main hope of reducing this volatility is increasing the diver-  
1073 sity within and among the populations of fall Chinook in the Central Valley. There  
1074 are a number of ways to increase diversity.

1075 Perhaps the most tractable area for increasing diversity is in changing hatchery  
1076 operations. We recommend that a hatchery science review panel, be formed to  
1077 review hatchery practices in the Central Valley. The panel should address a number  
1078 of questions, including the following:

- 1079 1. assess impacts of outplanting and broodstock transfers among hatcheries on  
1080 straying and population structure and evaluate alternative release strategies
- 1081 2. evaluate alternative rearing strategies to increase variation in timing of out-  
1082 migration and age at maturity
- 1083 3. assess whether production levels are appropriate and if they could be adjusted  
1084 according to expected ocean conditions

1085 Ongoing efforts to recover listed Chinook ESUs and increase natural production  
1086 of anadromous fish in the Central Valley (e.g., the fisheries programs of the Central  
1087 Valley Project Improvement Act) are also relevant to the problem and should be  
1088 supported. In particular, efforts to increase the quantity and diversity of spawning  
1089 and rearing habitats for fall Chinook are likely to be effective in increasing the  
1090 diversity of life history tactics in that stock.

1091 The PFMC should consider creating specific conservation objectives for natural  
1092 populations of SRFC. Especially in coordination with revised hatchery operations  
1093 and habitat restoration, managing for natural production could increase diversity  
1094 within Central Valley fall Chinook. Because conditions for reproduction and juve-  
1095 nile growth are more variable within and among streams than hatcheries, natural  
1096 production can be expected to generate a broader range of outmigration and age-at-  
1097 maturity timings. If straying from hatcheries to natural areas is greatly reduced, the  
1098 population dynamics of natural populations would be less similar to the dynamics of  
1099 the hatchery populations, which would smooth the variation of the stock aggregate.



### 1100 **5.3 Synthesis**

1101 Addressing hatcheries, habitat and harvest independently would provide benefits  
1102 to Central Valley Chinook, but addressing them together within a holistic frame-  
1103 work is likely to be much more successful. The fisheries management community  
1104 is increasingly recognizing the need to move towards an ecosystem based manage-  
1105 ment approach. While there is still much uncertainty about what this should en-  
1106 tail, the ecosystem-based management and ecological risk assessment (EBM/ERA)  
1107 approach used by the south Florida restoration program (e.g., Harwell et al., 1996;  
1108 Gentile et al., 2001) is readily applicable to management of Central Valley Chinook.  
1109 That approach could lead stakeholders to a common view of the different problems  
1110 afflicting Central Valley Chinook, identify and organize the information needed  
1111 to effectively manage the ecosystem, better connect this information to decision-  
1112 making, and reduce the uncertainty surrounding our decisions.

1113 At the core of the EBM/ERA approach are conceptual models of how the sys-  
1114 tem works. The current fishery management regime for SRFC has some features  
1115 of adaptive management, in that there are clearly stated goals and objectives for  
1116 the fisheries, monitoring and evaluation programs, and an analytic framework for  
1117 connecting the data to decisions about operation of the fishery. If one were to make  
1118 explicit the conceptual model underlying SRFC harvest management, it would in-  
1119 clude hatcheries that maintain a roughly constant output of fish coupled with ocean  
1120 and in-river fisheries operating on aggregate stock abundance. The goal is to max-  
1121 imize harvest opportunities in the current year within constraints posed by vari-  
1122 ous weak stocks, which do not include naturally-spawning populations of SRFC.  
1123 The panel feels that it would be useful to expand this conceptual model to include  
1124 naturally-spawning populations, revised hatchery operations, habitat effects, ocean  
1125 effects, and climate change. Also, resource managers might consider changing the  
1126 goal of management from maximizing harvest opportunity for the current year to  
1127 reducing fluctuations in opportunity from year to year and maintaining the stability  
1128 of the system for the long term. Both of these goals require viable and productive  
1129 populations of wild salmon. Not all of the factors in the revised system would be  
1130 subject to control by fisheries managers, but including them in the model would  
1131 at least make clear the contribution of these factors to the problem of effectively  
1132 managing Chinook salmon fisheries.

1133 The panel is well aware that the resource management institutions are not well-  
1134 equipped to pursue this approach, and that many of the actions that could improve  
1135 the status and resilience of Central Valley Chinook are beyond the authority of the  
1136 PFMC or any other single agency or entity. Nonetheless, significantly improv-  
1137 ing the resilience of Central Valley Chinook and the sustainability of California's  
1138 Chinook salmon fishery will require resource managers and stakeholders to work  
1139 together, and EBM/ERA offers a framework for facilitating such cooperation.

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# **Appendix A: Assessment of factors relative to the status of the 2004 and 2005 broods of Sacramento River fall Chinook**

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Appendix to the pre-publication report to the Pacific Fishery Management Council

March 18, 2009

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# 1 **Purpose of the appendix**

2 In this appendix, we attempt to answer the specific questions posed by the Pa-  
3 cific Fishery Management Council regarding potential causes for the SRFC decline  
4 (McIsaac, 2008). Some closely-related questions have been combined. In addition  
5 and for completeness, we also address the question of whether ocean salmon fish-  
6 eries and fishery management contributed to the low escapement of SRFC in 2007  
7 and 2008.

## 8 **2 Freshwater Biological Focus**

### 9 *2.1 Was the level of parent spawners too low, for natural or hatchery populations?*

10 The abundance of naturally-spawning SRFC adults in 2004 and 2005 was 203,000  
11 and 211,000, respectively (PFMC, 2009). This level of escapement is near the  
12 1970-2007 mean of 195,000 spawners. It therefore does not appear that the level  
13 of parent spawners was too low. SRFC adult returns to the hatcheries in 2004 and  
14 2005 were some of the highest on record, well in excess of that needed for egg take,  
15 so the level of parent spawners in the hatchery could not have been responsible for  
16 the poor adult returns observed in 2007 and 2008.

### 17 *2.2 Was the level of parent spawners too high, for natural or hatchery popula- 18 tions?*

19 While the level of parent spawners for the 2004 and 2005 broods was higher than  
20 average, these levels of abundance are not unusual over the 1970-2007 period, and  
21 other broods from similar-sized returns are not associated with particularly low sur-  
22 vival. It therefore does not appear that the level of parent spawners was too high  
23 on the spawning grounds. Returns to the hatcheries were near record highs, but  
24 hatchery managers control the matings of hatchery fish, so it is unlikely that the  
25 high level of hatchery returns had a negative impact on hatchery operations.

### 26 *2.3 Was there a disease event in the hatchery or natural spawning areas? Was 27 there a disease event in the egg incubation, fry emergence, rearing, or down- 28 stream migration phases? Was there any disease event during the return phase 29 of the 2 year old jacks?*

30 There were no known disease events affecting naturally-produced brood-year 2004  
31 and 2005 fall-run Chinook in the Sacramento River or tributaries, although there  
32 is no routine fish health sampling program for naturally produced fish the Sacra-  
33 mento River system. In the Feather River Hatchery, brood-year 2004 and 2005  
34 Chinook were treated an average of five to six times a year, primarily for bacte-  
35 rial infection. The typical treatment was copper sulfate flushes. This incidence of  
36 disease was not unusually high compared to other recent years. In the Mokelumne  
37 River Hatchery, brood-year 2004 and 2005 Chinook experienced minimal losses

38 from coagulated yolks. At the Nimbus Hatchery, there were no significant disease  
39 events affecting brood-year 2004 Chinook. Brood-year 2005 fall-run Chinook ex-  
40 perience an outbreak of infectious hematopoietic necrosis (IHN). Losses began to  
41 spike in mid-April and continued through May before declining. Losses incurred  
42 represented 44% of the fish on hand at the time of the outbreak. However, the hatch-  
43 ery planted 3,002,600 brood-year 2005 fish, approximately 75% of the mitigation  
44 goal of 4 million fish. There were no significant disease outbreaks at the Coleman  
45 National Fish hatchery for the 2004 and 2005 broods. We therefore conclude that  
46 disease events during the freshwater lifestages are an unlikely explanation for the  
47 poor performance of the 2004 and 2005 broods.

48 *2.4 Were there mortalities at the time of trucking and release of hatchery fish?*

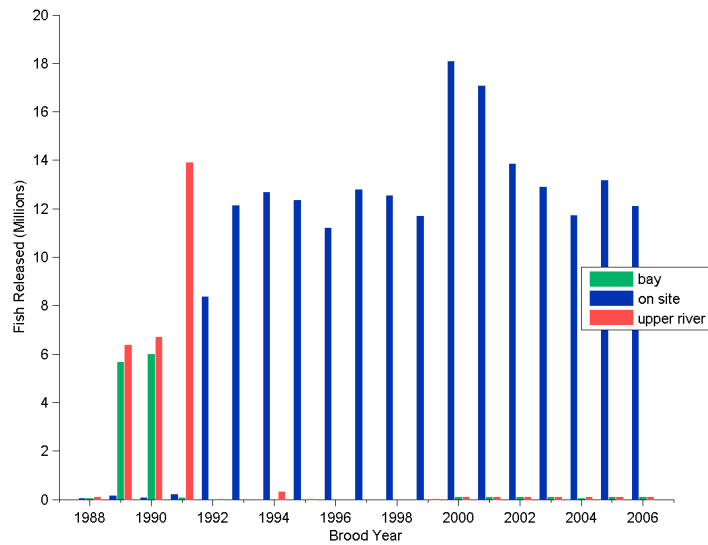
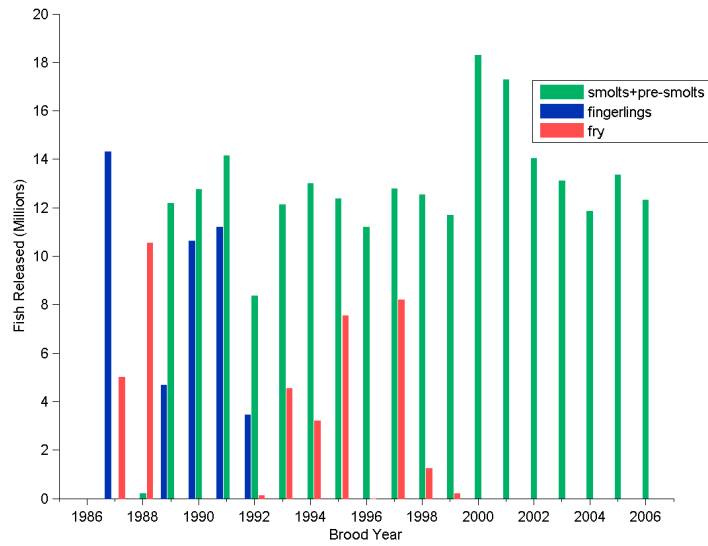
49 No unusual mortality events were noted for these broods.

50 *2.5 Was there a change in the pattern of on-site release of hatchery fingerlings*  
51 *compared to trucked downstream release? Was there a change in recovery,*  
52 *spawning and/or release strategies during hatchery operations?*

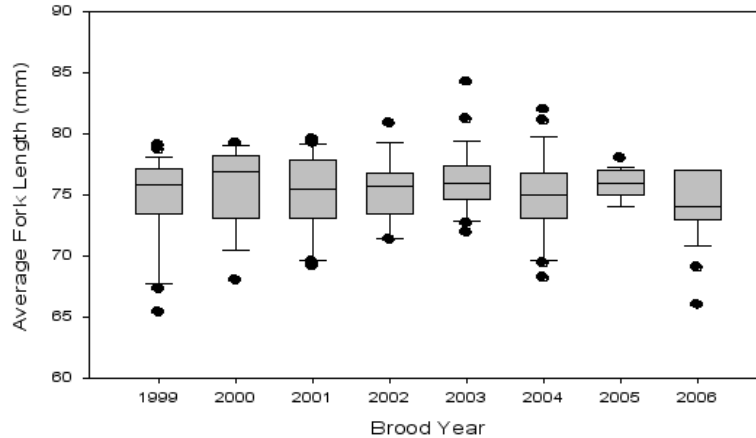
53 Hatchery practices, particularly the numbers and life stages of fish released, have  
54 been stable over the last decade. Coleman National Fish Hatchery has been releas-  
55 ing only smolts or pre-smolts since 2000, and releases from brood-year 2004 and  
56 2005 were at typical levels (Fig. 1). The vast majority of fall-run smolts and pre-  
57 smolts have been released at or very near the hatchery, within two weeks of April  
58 15 of each release year. Individual fish size also has remained very steady with the  
59 average size at release varying only 2 mm around an average of 75 mm (Fig. 2).

60 There were no significant changes in broodstock collection or spawning proto-  
61 cols for brood-year 2004 and 2005 fall-run Chinook at state-operated hatcheries  
62 in the Sacramento River Basin. Feather River, Mokelumne River, and Nimbus  
63 Hatcheries are operated by California Department of Fish and Game (CDFG) ac-  
64 cording to Operational Plans (Production Goals and Constraints). These plans have  
65 not been significantly modified in recent years. Fish ladders at each of the facilities  
66 are operated seasonally to allow fall-run to volitionally enter the hatchery. Eggs  
67 are taken from fall-run fish to represent the entire spectrum of the run. Some or  
68 all of each pooled lot of eggs are retained for rearing according to a predetermined  
69 schedule of weekly egg take needs. Sacramento River fall-run Chinook reared for  
70 mitigation purposes are released at smolt size (7.5 g or greater), and those reared for  
71 enhancement purposes are released at post-smolt size (10 g). Most are transported  
72 by truck to the Carquinez Straits-San Pablo Bay area for release from April through  
73 July while a small portion may be released in-stream.

74 The production levels of fall-run Chinook released from each of the Sacramento  
75 River Basin state hatchery facilities into anadromous waters from 1990 through  
76 2006 is shown in Fig. 3. From 1990 to 1998, and in 2001, the total production  
77 shown includes some releases of fry-sized fish. Production levels for brood-year



**Figure 1:** Top: Releases of fall-run Chinook from Coleman National Fish Hatchery. Bottom: number of smolts and pre-smolts released to the bay, upper river and on site (Battle Creek).



**Figure 2:** Size of fall Chinook released from Coleman National Fish Hatchery. Horizontal lines indicate mean size, boxes delineate the inner-quartile range, and whiskers delineate the 95% central interval.

78 2004 and 2005 fall-run Chinook (21.4 million and 19.3 million fish, respectively)  
 79 were not significantly different from other recent years.

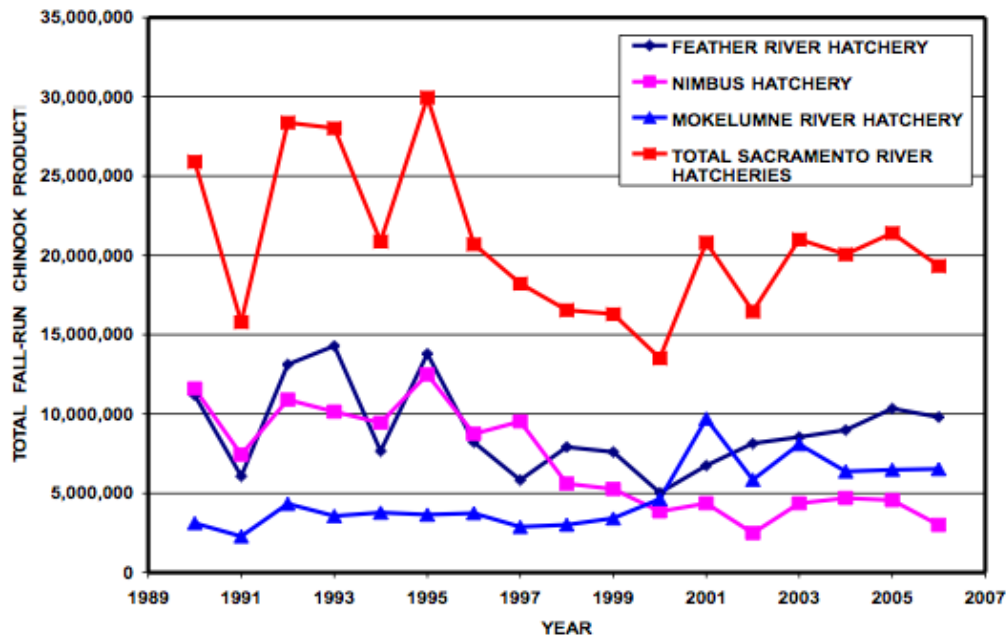
80 Most of the state hatchery production of Sacramento River fall-run Chinook has  
 81 been transported to the San Pablo Bay and Carquinez Straits area for release since  
 82 the 1980s (average of 93% over last decade). Coded-wire tagging studies indicate  
 83 that transporting salmon smolts or yearlings to San Pablo Bay and Carquinez Straits  
 84 planting sites significantly increases their survival to adults (unpublished data of  
 85 CDFG).

86 Table 1 shows the release locations of fall-run Chinook from each of the Sacra-  
 87 mento River Basin state hatchery facilities, 1990 to 2006. Instream releases include  
 88 releases into the stream of origin, the mainstem Sacramento River, or within the  
 89 Delta. Bay releases include fish transported for release in the San Pablo Bay/Carquinez  
 90 Straits/San Francisco Bay area or to ocean net pens.

91 For brood-years 2004 and 2005 (release-years 2005 and 2006), release locations  
 92 were not changed significantly from other recent years. As in other recent years,  
 93 more than 95% were transported for release in the San Pablo Bay/Carquinez Straits  
 94 area.

95 *2.6 Did thermal marking occur for any hatchery releases? What were the effects*  
 96 *of this or other studies (e.g. genetic stock identification of parental brood-*  
 97 *stock)?*

98 At Feather River Hatchery, a pilot program of otolith thermal marking was con-  
 99 ducted on the 2004 brood of fall-run Chinook. The entire 2005 brood was thermally  
 100 marked. Fish were marked after hatching. There has been an increase in the inci-  
 101 dence of cold water disease at the hatchery in recent years, but there is no evidence  
 102 that the otolith thermal marking study contributed to this increase. The literature on  
 103 otolith thermal marking reports no adverse effects on survival (Volk et al., 1994).



**Figure 3:** Releases of fall-run Chinook from state hatcheries.

**Table 1:** Releases of Chinook from state hatcheries.

Release Year	Brood Year	Feather River		Nimbus		Mokelumne	
		Instream	Bay	Instream	Bay	Instream	Bay
1990	1991	3,368,726	7,815,311	6,995,625	438,140	295,150	1,983,400
1991	1992	0	6,078,920	9,963,840	939,652	858,836	3,476,310
1992	1993	3,439,465	9,691,616	9,540,285	602,705	563,414	3,011,600
1993	1994	8,676,431	5,624,222	8,795,300	638,000	1,396,390	2,384,180
1994	1995	0	7,659,432	8,578,437	3,915,870	1,886,084	1,772,800
1995	1996	7,381,185	6,417,755	5,733,951	3,009,840	0	3,740,998
1996	1997	825,785	7,395,468	0	9,520,696	0	2,873,750
1997	1998	854,593	4,978,070	1,253,570	4,348,210	0	3,023,782
1998	1999	1,755,126	6,170,994	0	5,270,678	0	3,422,180
1999	2000	1,834,947	5,769,640	0	3,851,700	0	4,629,559
2000	2001	848,622	4,188,000	101,856	4,273,950	0	9,697,358
2001	2002	997,723	5,746,188	0	2,314,800	0	5,846,743
2002	2003	1,321,727	6,815,718	0	4,361,300	106,506	7,991,961
2003	2004	699,688	7,850,188	115,066	4,578,400	102,121	6,273,839
2004	2005	673,401	8,323,279	0	4,570,000	0	6,485,914
2005	2006	786,557	9,560,592	0	3,002,600	0	6,539,112
2006	2007	1,616,657	10,252,718	0	5,045,900	3,712,240	2,480,391
2007	2008	2,273,413	10,550,968	0	4,899,350	468,736	4,660,707

104 2.7 *Was there a change in the methodology or operations of the San Francisco*  
105 *Bay net pen acclimation program for trucked hatchery fish?*

106 Coleman National Fish Hatchery production is not acclimated in net pens.

107 CDFG initiated a net pen acclimation program for hatchery-reared fall-run Chi-  
108 nook in 1993. When fish are transported for release into the Carquinez Straits-San  
109 Pablo Bay area, they may experience immediate and delayed mortality associated  
110 with the transfer to seawater. Instantaneous temperature and salinity changes are  
111 potential sources of direct mortality as well as indirect mortality due to predation  
112 on disoriented fish and stress-induced susceptibility to disease. Temporary transfer  
113 of salmon yearlings to net pens has been shown to reduce loss of fish due to preda-  
114 tion at the time of their planting and greatly increase survival. A three-year study  
115 by the California Department of Fish and Game (unpublished) found that holding  
116 smolts in net pens for two hours increased the recovery rate by a factor of 2.2 to 3.0  
117 compared to smolts released directly into the bay.

118 The Fishery Foundation of California has been contracted to operate the project  
119 since 1993. Fish are offloaded from CDFG hatchery trucks into the mobile pens in  
120 San Pablo Bay at the Wickland Oil Company pier facility in Selby (between Rodeo  
121 and Crockett) in Contra Costa County from May through July. Upon receiving the  
122 fish, the net pens are towed into San Pablo Bay. The pens are allowed to float with  
123 the current and the fish are held for up to two hours until they become acclimated  
124 to their surroundings. The net pens are then dropped and the fish released in San  
125 Pablo Bay.

126 Methods used for net pen acclimation were not significantly changed from 1993  
127 through 2007, although the number of hatchery fish acclimated in the pens has  
128 varied over the years. Significantly, no hatchery releases from the 2005 brood were  
129 acclimated in net pens before release. The following table shows the total number  
130 of Chinook acclimated in the Carquinez Straits net pens and released from 1993  
131 through 2006.

132 Similar numbers of brood-year 2004 fish were acclimated in the net pens com-  
133 pared to other recent years. For this brood year, there is no evidence that lack of  
134 acclimation contributed to poor escapement in 2007. However, the net pen project  
135 was not operated in the spring of 2006 due to insufficient funds, a change in oper-  
136 ations that may have had a significant impact on the survival of the portion of the  
137 2005 brood produced by state hatcheries.

138 2.8 *Were there any problems with fish food or chemicals used at hatcheries?*

139 Coleman National Fish Hatchery had no issues or problems with fish food or chem-  
140 icals used at the hatchery for the release years 2004-06 that would have caused any  
141 significant post-release mortality (pers. comm., Scott Hamelberg, USFWS).

142 All chemical treatments at the state hatcheries were used under the guidelines  
143 set by the CDFG Fish Health Lab. There were no significant changes in chemical  
144 use or feeds over the 1990-2007 period. Some Bio-Oregon/Skretting salmon feeds  
145 were recalled in 2007 due to contamination with melamine, but this is not believed

**Table 2:** Releases of Chinook after acclimatization in Carquinez Straits net pens. Data for release years 1993 through 1995 obtained from 2004 net pen project proposal (Fishery Foundation of California). Data for release years 1996 through 2006 obtained from hatchery records (Nimbus, Mokelumne, and Feather River Hatcheries).

Brood Year	Release Year	Number Acclimatized	% Acclimatized
1992	1993	935,900	7
1993	1994	1,600,000	19
1994	1995	4,400,000	33
1995	1996	3,366,596	26
1996	1997	6,102,250	31
1997	1998	4,765,050	39
1998	1999	10,186,340	69
1999	2000	7,667,860	54
2000	2001	10,962,400	60
2001	2002	10,232,429	74
2002	2003	808,900	4
2003	2004	8,773,788	47
2004	2005	8,114,122	42
2005	2006	0	0
2006	2007	4,797,212	27
2007	2008	19,632,289	86

146 to be an issue for the 2004 or 2005 broods, which in any case, exhibited normal  
 147 patterns of growth and survival while in the hatchery.

### 148 **3 Freshwater Habitat Areas Focus**

149 *3.1 Were there drought or flood conditions during the spawning, incubation, or*  
 150 *rearing phases?*

151 The 2005 water year (when the 2004 brood was spawned, reared and migrated  
 152 to sea) had above normal precipitation, and the 2006 water year was wet (based  
 153 on runoff, California Department of Water Resources classifies each water year  
 154 as either critical, dry, below normal, above normal or wet). In 2005, flows were  
 155 typical through the winter, but rose to quite high levels in the spring (Table 3). In  
 156 2006, flows were above average in all months, especially so in the spring. High  
 157 flows during the egg incubation period can result in egg mortality from scour, but  
 158 high flows during the spring are usually associated with higher survival of juvenile  
 159 salmon.

160 *3.2 Was there any pollution event where juveniles were present?*

161 The possibility has been raised that exposure of outmigrating juvenile salmon to  
 162 toxic chemical contaminants may be a factor in the reduced adult return rates. No-

**Table 3:** Combined monthly runoff (in millions of acre-feet) of eight rivers in the Sacramento-San Joaquin basin. Data from the California Department of Water Resources (<http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST>). The hi-lighted rows correspond to the spawning, rearing and outmigration periods of the 2004 and 2005 broods.

Water Year	Month					
	Dec	Jan	Feb	Mar	Apr	May
1990	0.45	1.27	0.88	1.84	1.80	1.77
1991	0.34	0.37	0.45	2.64	1.95	2.40
1992	0.47	0.58	2.41	1.99	2.17	1.33
1993	1.25	4.06	3.13	5.70	4.33	5.23
1994	0.78	0.78	1.23	1.49	1.57	1.79
1995	1.06	8.11	3.12	10.19	5.61	7.18
1996	1.72	2.47	6.25	4.25	3.97	5.50
1997	6.84	12.15	2.74	2.45	2.70	2.96
1998	1.18	5.19	7.44	5.11	4.53	5.53
1999	1.88	2.60	4.59	3.67	3.26	4.27
2000	0.65	2.55	5.49	4.08	3.55	3.62
2001	0.67	0.87	1.50	2.39	2.03	2.49
2002	2.50	2.70	1.74	2.31	2.82	2.60
2003	3.24	3.40	1.66	2.52	3.27	4.82
2004	2.14	1.90	3.98	3.47	2.64	2.29
2005	1.56	2.49	2.01	3.75	3.18	7.23
2006	5.82	5.21	3.44	5.30	8.52	6.80
2007	1.31	0.85	2.14	2.06	1.73	1.66
min	0.34	0.37	0.45	1.49	1.57	1.33
mean	1.88	3.20	3.01	3.62	3.31	3.86
max	6.84	12.15	7.44	10.19	8.52	7.23

163 tably, NMFS has recently issued a biological opinion in response to the EPA’s pro-  
164 posed re-registration and labeling of three pesticides commonly used in the region.  
165 These pesticides are chlorpyrifos, diazinon, and malathion. In the opinion, NMFS  
166 states ‘After considering the status of the listed resources, the environmental base-  
167 line, and the direct, indirect, and cumulative effects of EPA’s proposed action on  
168 listed species, NMFS concludes that the proposed action is likely to jeopardize the  
169 continued existence of 27 listed Pacific salmonids as described in the attached Opin-  
170 ion’. However, because so many of the outmigrating salmon which are the subject  
171 of this current analysis are transported around the river system and released into the  
172 bay/delta, it is not likely that chemical contaminants in the river (e.g. urban runoff,  
173 current use pesticides, sewage treatment plant effluents) are the primary driver be-  
174 hind the reduced adult return rates. It is possible that contaminants in the bay/delta  
175 proper may be contributing to a reduced resilience of SR salmon runs overall, but  
176 there are very little empirical data by which to evaluate this hypothesis. Rather,  
177 that possibility is derived from work being done in Puget Sound and the lower  
178 Columbia River, where contaminant exposure in the river and estuary portion of  
179 juvenile salmon outmigration is shown to reduce fitness, with inferred consequence  
180 for reduced early ocean survival.



181 3.3 *Was there anything unusual about the flow conditions below dams during the*  
182 *spawning, incubation, or rearing phases?*

183 Flows below dams in 2004, 2005 and 2006 were consistent with the hydrologic  
184 conditions discussed above (Fig. 4). For the 2004 brood on the Sacramento and  
185 American rivers, flows were near normal during the spawning period, and lower  
186 than normal during the juvenile rearing and migration period. Flows on the Feather  
187 and Stanislaus rivers were substantially below normal during the juvenile rearing  
188 and migration phase for this brood.

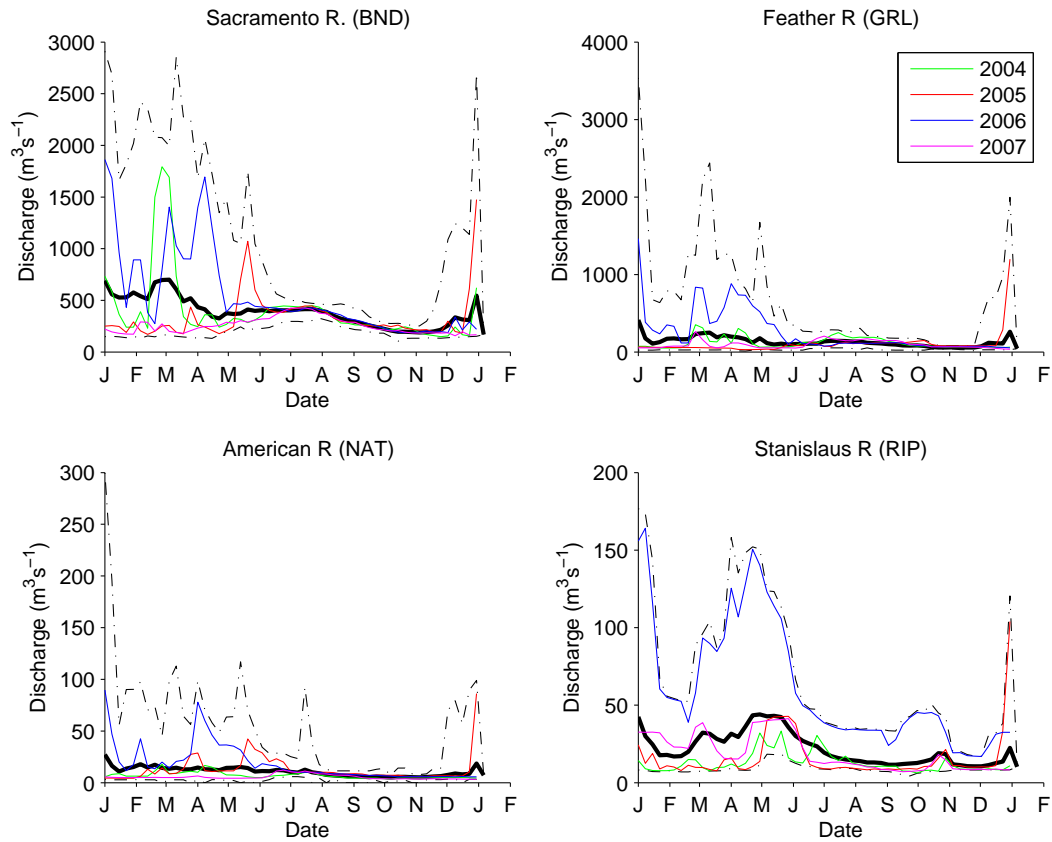
189 A different pattern was observed for the 2005 brood, which experienced high  
190 flows late in the year when eggs would be incubating, and generally higher than  
191 normal flows throughout the rearing and migration period in 2006. Flows on the  
192 Stanislaus River were near or at the highest observed from all of 2006. It is likely  
193 that flows were high enough in early January to cause bed load movement and  
194 possibly redd scour in some river reaches. It is difficult to determine the extent of  
195 the scour and loss of eggs but it did come at a time after all of the fall run had  
196 completed spawning and were beginning to emerge. Only 20-30% of the fall run  
197 fry should have emerged by early January in time to avoid the high flows, so loss  
198 could have been significant. These types of flows are generally infrequent but do  
199 occur in years when reservoir carry-over storage is relatively high and rainfall is  
200 high in December and January.

201 3.4 *Were there any in-water construction events (bridge building, etc.) when this*  
202 *brood was present in freshwater or estuarine areas?*

203 According to D. Woodbury (Fishery Biologist with the National Marine Fisheries  
204 Service, Southwest Region, Santa Rosa, California; pers. comm.), the main con-  
205 struction events were pile driving for the Benecia-Martinez Bridge, the Richmond-  
206 San Rafael Bridge, and the Golden Gate Bridge. Pile driving for the Benecia-  
207 Martinez Bridge was completed in 2003. Pile driving for the Richmond-San Rafael  
208 Bridge was conducted between 2002 and 2004. Pile driving for the Golden Gate  
209 Bridge is ongoing, but the largest diameter piles were installed before 2005. At-  
210 tempts are made to limit pile installation to summer months when salmonids are  
211 minimally abundant in the estuary. If piles are installed during salmonid migration,  
212 attenuation systems are used that substantially reduce the level of underwater sound.  
213 Based on the construction schedule for the large bridges (2002-2004), underwater  
214 sound from the installation of large diameter steel piles should not have limited  
215 salmonid returns in 2007. There is no evidence these activities had a significant  
216 impact on production of the 2004 or 2005 broods.

217 3.5 *Was there anything unusual about the water withdrawals in the rivers or es-*  
218 *tuary areas when this brood was present?*

219 Statistical analysis of coded-wire-tagged releases of Chinook have shown that sur-  
220 vival declines when the proportion of Sacramento River flow entering the interior



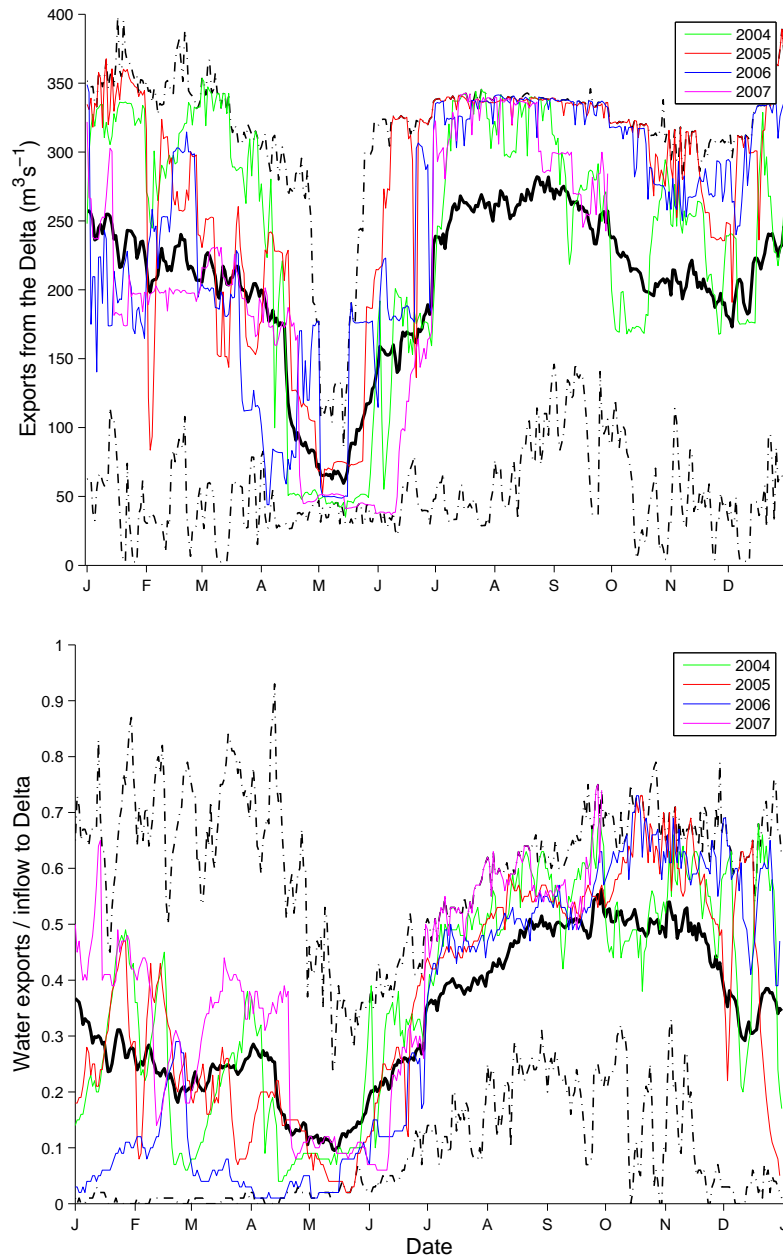
**Figure 4:** Weekly mean discharge at selected stations on the Sacramento, Feather, American and Stanislaus rivers. Heavy black line is the weekly mean flow over the period of record at each station (BND=1993-2007; GRL=1993-2007, NAT=1990-2007, RIP=1999-2007); dashed black lines are the maximum and minimum flows. Colored lines are average weekly flows for 2004 (green), 2005 (red) and 2006 (blue). Data from the California Data Exchange Center (<http://cdec.water.ca.gov/>).

**Table 4:** Estimated loss of fall- and spring-run Chinook fry and smolts at Delta water export facilities. Water year corresponds to outmigration year. Unpublished data of California Department of Water Resources.

Water Year	Non-clipped Loss	Adclipped Loss
1997	78,786	4,017
1998	124,799	5,282
1999	262,758	42,864
2000	210,180	17,030
2001	114,058	3,614
2002	19,166	6,545
2003	51,802	2,854
2004	38,938	703
2005	59,148	9,860
2006	56,227	1,935
2007	8,045	81

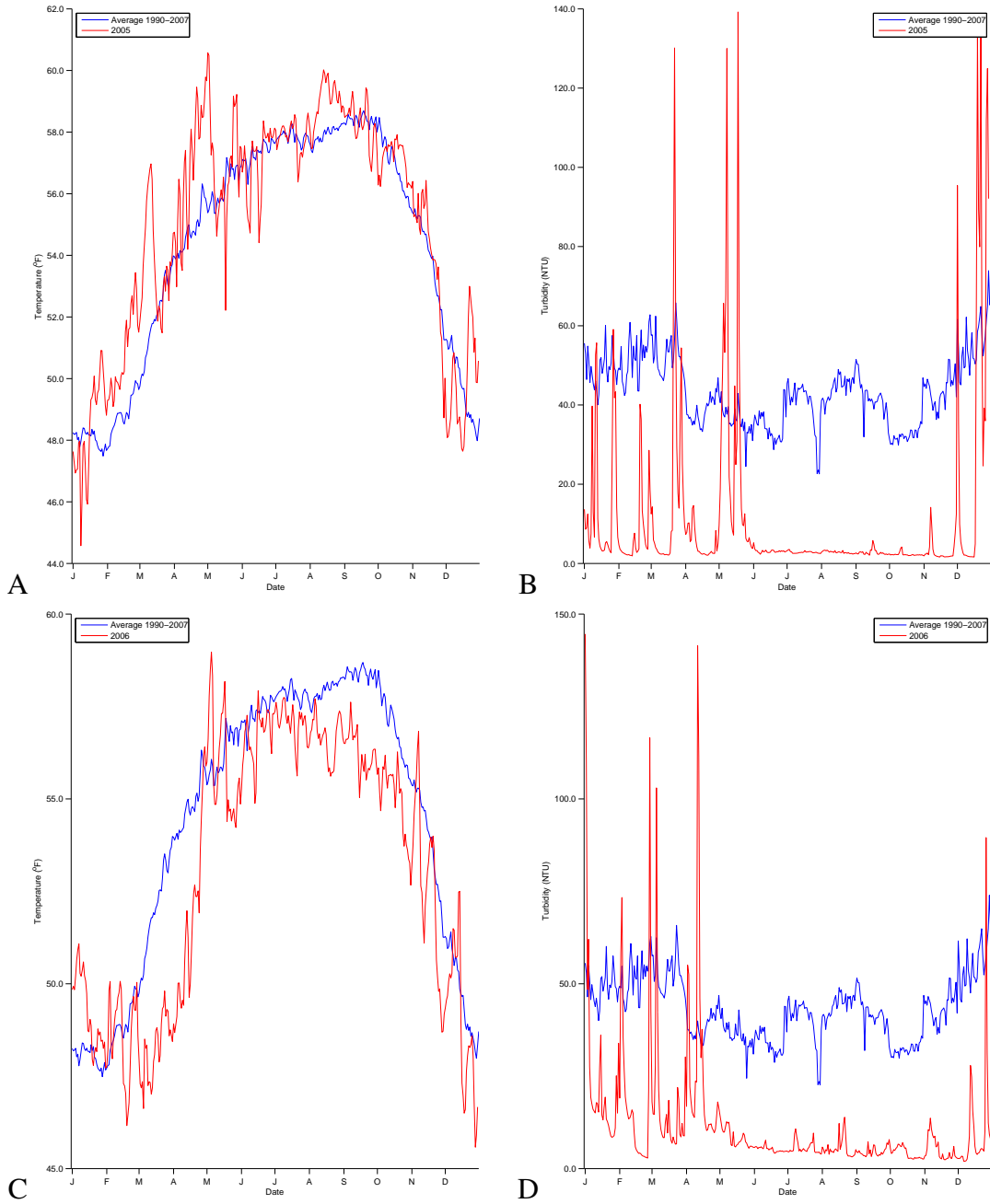
221 Delta rises (Kjelson and Brandes, 1989) and that there is a weak negative rela-  
 222 tionship between survival and the ratio of water exported from the Delta to water  
 223 entering the Delta (the E/I ratio) (Newman and Rice, 2002). In January 2005, wa-  
 224 ter diversion rates, in terms of volume of water diverted, reached record levels in  
 225 January before falling to near-average levels in the spring, then rising again to near-  
 226 record levels in the summer and fall, presumably after the migration of fall Chinook  
 227 smolts. Water diversions, in terms of the E/I ratio, fluctuated around the average  
 228 throughout the winter and spring (Fig. 5). In 2006, total water exports at the state  
 229 and federal pumping facilities in the south delta were near average in the winter and  
 230 spring, but the ratio of water exports to inflow to the Delta (E/I) was lower than av-  
 231 erage for most of the winter and spring, only rising to above-average levels in June.  
 232 Total exports were near record levels throughout the summer and fall of 2006, after  
 233 the fall Chinook emigration period (Fig. 6).

234 At the time the majority of fall-run Chinook are emigrating through the Delta,  
 235 the Delta Cross Channel (DCC) gates are closed. The 1995 Water Quality Control  
 236 Plan requires the gates to be closed from February 1 through May. Therefore, for  
 237 the majority of period that fall-run Chinook are emigrating through the lower Sacra-  
 238 mento River, they are vulnerable to diversion into the interior Delta only through  
 239 Georgianna Slough, not the through the DCC. Loss of Chinook fry and smolts at the  
 240 Delta export facilities in 2005 and 2006 were lower than the average for the 1997-  
 241 2007 period (Table 4). Because of the timing of water withdrawals, it seems unlikely  
 242 that the high absolute export rates in the summer months had a strong effect on the  
 243 2004 and 2005 broods of SRFC.

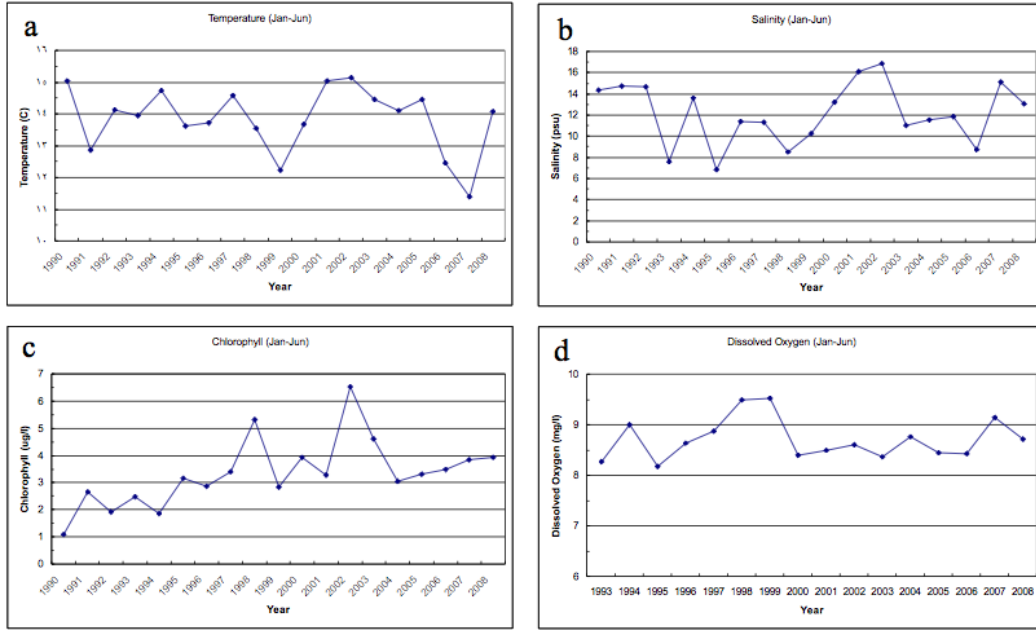


**Figure 5:** Daily export of freshwater from the delta (upper panel) and the ratio of exports to inflows (bottom panel). Heavy black line is the daily average discharge over the 1955-2007 period; dashed black lines indicate daily maximum and minimum discharges. Flow estimates from the DAYFLOW model (<http://www.iep.ca.gov/dayflow/>).





**Figure 7:** Temperature (A and C) and turbidity (B and D) in 2005 and 2006 at Red Bluff.



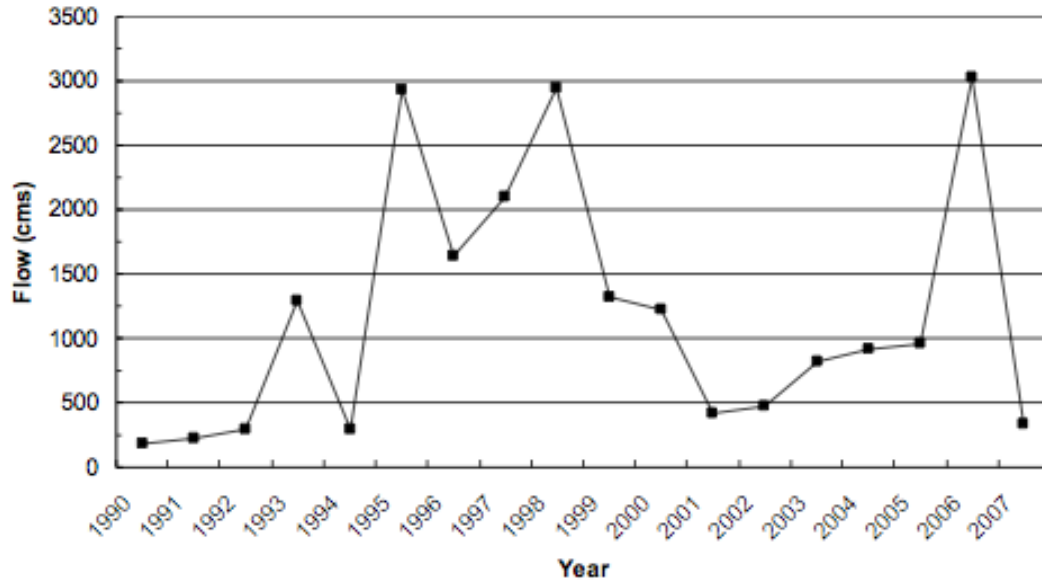
**Figure 8:** Mean annual values near the surface between January and June for a) water temperature, b) salinity, c) chlorophyll, and d) dissolved oxygen for San Francisco Estuary between Chipps Island and the Golden Gate. (Source: USGS Water Quality of San Francisco Bay: <http://sfbay.wr.usgs.gov/water/>.)

269 times on the tidal cycle. Mean salinity for the 19 years was  $12.1 \pm 2.9$  (Fig. 8b).

270 Mean chlorophyll concentrations, an indicator of primary productivity, were  
 271 similar to the long-term mean of  $3.3 \pm 1.2$  mg/l (Fig. 8c). The mean chlorophyll  
 272 concentrations for 2005 and 2006 were 3.3 and  $3.5 \hat{1}_4$  g/l, respectively, indicating  
 273 neither an oligotrophic or eutrophic system. The long-term trend, however, does  
 274 suggest an increasing amount of phytoplankton in the estuary.

275 As with the other hydrologic variables, dissolved oxygen concentrations were  
 276 within the span typical of the estuary and do not reveal hypoxia as a contributor to  
 277 the salmon decline (Fig. 8d). Mean  $O_2$  levels were 8.4 mg/l for both years, which  
 278 is the same as the long-term average of  $8.7 \pm 0.4$  mg/l.

279 Freshwater outflow has been highly variable in the period 1990 to 2007 (Fig-  
 280 ure 9). During the outmigrating season, mean flows were 963 and 3,033  $m^3s^{-1}$  for  
 281 2005 and 2006, respectively. The long-term mean for January to June is  $1,190 \pm 978$   
 282  $m^3s^{-1}$ , thus 2005 was a relatively dry year and 2006 a relatively wet year. In fact,  
 283 2006 had the greatest mean outflow of any year in the past 18. High flows through  
 284 the estuary are considered beneficial for juvenile salmonids, thus 2006 was favor-  
 285 able. Although 2005 had lower flows, it was situated in the middle of the range:  
 286 nine years had lower flows, eight had higher. Since 2001 and 2005 had similar val-  
 287 ues, and since fall Chinook returns were high and low respectively in those years, it  
 288 would seem that flow does not appear to be a factor contributing to the poor survival  
 289 of the 2004 and 2005 broods.



**Figure 9:** Mean annual freshwater outflow through San Francisco Estuary between January and June. (Source: <http://iep.water.ca.gov/dayflow/>).

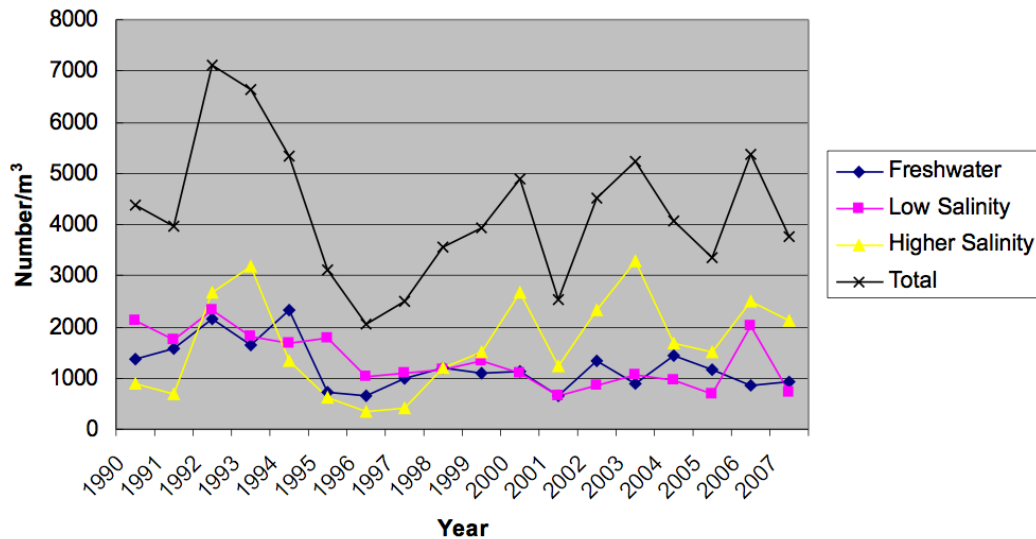
290 3.8 *Were there any unusual population dynamics of typical food or prey species*  
 291 *used by juvenile Chinook in the relevant freshwater and estuarine areas?*

292 Juvenile Chinook feed on a wide variety of organisms during freshwater and estuarine phases of their life cycle (MacFarlane and Norton 2002). Stomach contents of fish sampled at the west end of the Delta, at Chipps Island, had decapods, mysids, amphipods and insects as the primary prey. In particular, the gammaridean amphipod *Corophium* is a dominant food item. In Suisun Bay, larval aquatic and terrestrial insects form a major part of juvenile Chinook diets, but mysids, amphipods, small fish, and calanoid copepods are also important food items. In San Pablo Bay, cumaceans make up a large fraction of stomach contents, but insects remain important. In the central San Francisco Bay, small fish greatly dominate the stomach contents, but cumaceans and amphipods are often present. These species are not sampled regularly, or at all, in the salmon outmigrating corridor, except for calanoid copepods, which are monitored by the Interagency Ecological Program (IEP) at stations in the Delta, Suisun and San Pablo Bays. Although calanoid copepods are not a major food item to juvenile salmon, they represent an important component of aquatic food webs and offer a view of the zooplankton community and will be used here as a surrogate for the juvenile prey community.

308 The IEP zooplankton survey categorizes copepod samples into salinity zones: less than 0.5, 0.5–6, and greater than 6. Fluctuations in the annual copepod abundance can be large, ranging from 2,000 to over 7,000 copepods  $m^{-3}$  (Fig. 10). The annual mean abundance since 1990 is  $4,238 \pm 322$  (SE) copepods/ $m^3$  for the combined total of the samples from the three salinity bands. In 2005 the mean abundance of copepods was  $3,300 m^{-3}$ . This value is 21% below the longer term



### Calanoid Copepod Abundance



**Figure 10:** Mean annual abundance of calanoid copepods in the Delta, Suisun Bay and San Pablo Bay from 1990 and 2007 (Sources: Wim Kimmerer, Romberg Tiburon Center for Environmental Studies, San Francisco State University, Tiburon, California; <http://www.delta.dfg.ca.gov/baydelta/monitoring/>). Freshwater is <0.5, low salinity is 0.5-6, and higher salinity is > 6.

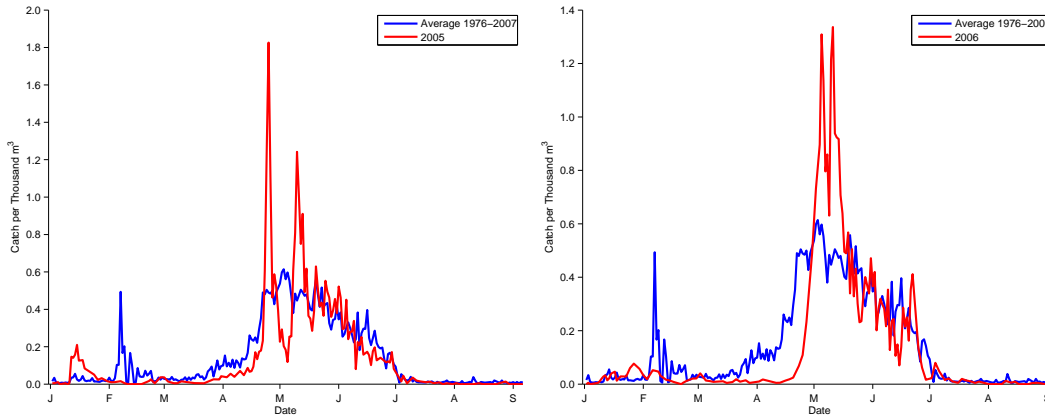
314 average, but is not the lowest during the time interval. The years 1995-1997 and  
 315 2001 were all lower. Further, the copepod concentrations that largely drive the in-  
 316 terannual fluctuations are those found in salinities above 6, which are typically in  
 317 lower Suisun Bay and San Pablo Bay where other food items dominate. In 2006,  
 318 zooplankton abundance was higher than 2005, except in the freshwater zone. Taken  
 319 together, there is no compelling evidence that zooplankton abundance, or other prey  
 320 for juvenile salmon, in freshwater and estuarine life phases played a role in the poor  
 321 survival of the 2004 and 2005 broods of SRFC.

322 *3.9 Was there anything unusual, in the same context as above for juvenile rearing*  
 323 *and outmigration phases, about habitat factors during the return of the 2 year*  
 324 *olds from this brood?*

325 No unusual habitat conditions were noted.

326 *3.10 Were there any deleterious effects caused by miscellaneous human activities*  
 327 *(e.g., construction, waterfront industries, pollution) within the delta and San*  
 328 *Francisco bay areas?*

329 The construction of the Benicia Bridge is discussed in question 4 above, and the  
 330 Cosco Busan oil spill is discussed in question 6. No other unusual activities or  
 331 events were noted for these broods.



**Figure 11:** Daily catches of juvenile fall-run Chinook at Chipps Island in 2005 (left) and 2006 (right), in red, compared to average daily catches (in blue) for 1976-2007.

332 *3.11 Was there a change in the recovery of juvenile outmigrants observed in*  
 333 *the USFWS mid-water trawl surveys and other monitoring programs in the*  
 334 *Delta.*

335 Patterns of juvenile recoveries by midwater trawling near Chipps Island in 2005  
 336 and 2006 were similar in 2005 and 2006 compared to the pattern observed in  
 337 other recent years (Fig. 11). In 2005, total catch and the timing of catches was quite  
 338 near the average for the 1976-2007 period of record. In 2006, total catches were a  
 339 bit higher than average, with typical timing.

#### 340 **4 Freshwater Species Interactions Focus**

341 *4.1 Was there any unusual predation by bird species when this brood was in fresh-*  
 342 *water or estuarine areas?*

343 None was noted.

344 *4.2 Was there any unusual sea lion abundance or behavior when this brood was*  
 345 *in freshwater or estuarine areas?*

346 None was noted.

347 *4.3 Was there any unusual striped bass population dynamics or behavior when*  
 348 *this brood was in freshwater or estuarine areas?*

349 Annual abundance estimates for adult striped bass in the Sacramento-San Joaquin  
 350 Estuary from 1990 through 2005 are shown in Table 5. Estimates represent the  
 351 number of adult fish in the estuary in the spring of the reporting year. The estimate  
 352 for 2005 is preliminary and subject to change based on additional data. There is no  
 353 estimate for 2006 because tagging was not conducted in that year.

**Table 5:** Striped bass abundance. NA indicates estimate unavailable. Unpublished data of CDFG.

Year	Abundance
1990	830,742
1991	1,045,975
1992	1,071,805
1993	838,386
1994	908,480
1995	NA
1996	1,391,745
1997	NA
1998	1,658,379
1999	NA
2000	2,133,043
2001	NA
2002	1,296,930
2003	1,179,656
2004	1,904,623
2005	1,373,886
2006	NA

354 Brood-year 2004 and 2005 fall-run Chinook emigrated through the estuary, and  
355 were vulnerable to predation by adult striped bass, in the spring of 2005 and 2006.  
356 In 2005, the preliminary estimate of adult striped bass abundance was not signifi-  
357 cantly higher than in previous years. In 2000, the striped bass population was the  
358 highest among recent years, when the brood-year 1999 fall-run Chinook were em-  
359 igrating through the estuary. This year class returned to spawn in 2002 at record  
360 high levels.

361 There is no apparent correlation between the estimated abundance of the adult  
362 striped bass population in the estuary and the subsequent success of Sacramento  
363 River Basin fall-run Chinook year classes. Predation in freshwater may be a signif-  
364 icant factor affecting survival of fall-run Chinook emigrating through the system,  
365 but there is no indication that increased predation in the spring of 2005 or 2006  
366 contributed significantly to the decline observed in the subsequent escapement of  
367 Sacramento River fall-run Chinook.

368 *4.4 Were northern pike present in any freshwater or estuarine areas where this*  
369 *brood was present?*

370 Northern pike have not been noted in these areas to date.

371 4.5 *Is there a relationship between declining Delta smelt, longfin smelt, and threadfin*  
372 *shad populations in the Delta and Central Valley Chinook survival?*

373 Indices of abundance for Delta smelt (*Hypomesus transpacificus*), longfin smelt  
374 (*Spirinchus thaleichthys*), and threadfin shad (*Dorosoma petenense*) from the Cali-  
375 fornia Department of Fish and Game's Fall Mid-water Trawl Surveys in the Delta,  
376 Suisun Bay, and San Pablo between 1993 and 2007 reveal a pattern of substantial  
377 variation in abundance (Fig. 12). From 1993 to 1998, Delta smelt and longfin smelt  
378 abundances vary similarly among years; Threadfin Shad dynamics were somewhat  
379 out of phase with the smelt species. However, longfin smelt abundances declined  
380 greatly from 1998 to 2002, about one year prior to Delta smelt declines. By 2002,  
381 all three species were in low numbers in the study area and have remained low  
382 since. Juvenile salmon abundance between April and June at Chipps Island was  
383 somewhat reflective of threadfin shad abundance until 2002, but then departed from  
384 the shad trend (Fig. 12). Since 2002, juvenile salmon abundance appears to be  
385 increasing, in general, but there are relatively wide variations among years. In par-  
386 ticular, juvenile fall-run abundance appeared to be relatively high in 2004. In 2005,  
387 the abundance index value was greater than in 2002 and 2003, but below estimates  
388 for 2006 and 2007. Correlation analysis found no significant relationships ( $P > 0.05$ )  
389 between population fluctuations of the smelt and shad species with juvenile fall-run  
390 Chinook catch at Chipps Island. Differences in abundance patterns between juve-  
391 nile salmon at Chipps Island and the three other species, which are all species of  
392 concern in the Pelagic Organism Decline (POD) in the Delta, indicate that whatever  
393 is affecting the POD species is not a major influence on juvenile salmon production  
394 in the Central Valley.

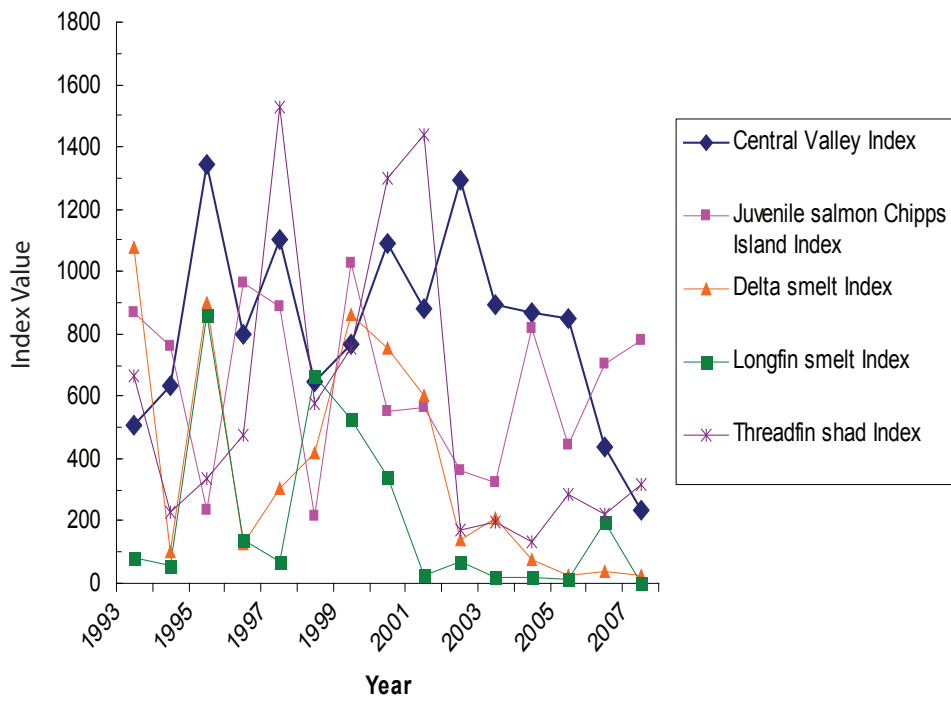
395 4.6 *Was there additional inriver competition or predation with increased hatchery*  
396 *steelhead production?*

397 Releases of steelhead from state and federal hatcheries have been fairly constant  
398 over the decade, suggesting that predation by steelhead is an unlikely cause of the  
399 poor survival of the 2004 and 2005 broods of fall-run Chinook.

## 400 **5 Marine Biological Focus**

401 5.1 *Was there anything unusual about the ocean migration pattern of the 2004*  
402 *and 2005 broods? Was there anything unusual about the recovery of tagged*  
403 *fish groups from the 2004 and 2005 broods the ocean salmon fisheries?*

404 Unfortunately, in contrast to previous years, little of the 2004 and 2005 broods  
405 were coded-wired tagged at the basin hatcheries. As a consequence the informa-  
406 tion available for addressing these questions is limited to Feather River Hatchery  
407 (FRH) fall Chinook coded-wire tag recoveries. The analysis was further restricted  
408 to recreational fishery age-2 recoveries for the following reasons. First, it is gen-  
409 erally accepted that SRFC brood recruitment strength is established prior to ocean

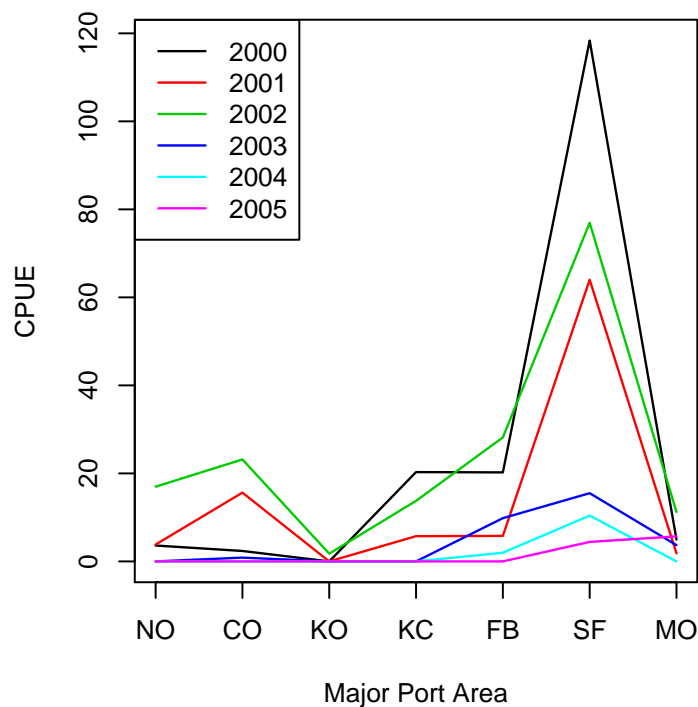


**Figure 12:** Abundance indices for Delta smelt, longfin smelt, and threadfin shad from California Department of Fish and Game Mid-water Trawl Surveys between 1993 and 2007 in the Delta, Suisun Bay, and San Pablo Bay (Source: <http://www.delta.dfg.ca.gov>)

410 age-2. Thus, age-2 recoveries provide the least disturbed signal of brood strength  
411 and distribution prior to the confounding effects of fishery mortality. Second, many  
412 more age-2 fish are landed by the recreational fishery than by the commercial fish-  
413 ery, in part because of differences in the minimum size limits for the two fisheries.  
414 Effort in the recreational fishery is also generally more evenly distributed along the  
415 coast and more consistent across years than in the commercial fishery.

416 Ocean salmon recreational fishery coded-wire tag recoveries of age-2 FRH fall  
417 Chinook, brood years 2000-2005, were expanded for sampling and summed across  
418 months by major port area for each brood year. Catch per unit of effort (CPUE)  
419 was derived by dividing the expanded recoveries by the corresponding fishing ef-  
420 fort. For any given recovery year, assuming catchability is the same for each port  
421 area, the pattern of CPUE across the port areas reflects the ocean distribution of the  
422 cohort (Fig. 13). The coherent pattern across brood years suggests that the ocean  
423 distribution of age-2 fish was similar for all of these broods, and concentrated in the  
424 San Francisco major port area.

425 Within a port area, assuming catchability is the same each year, differences  
426 in CPUE across brood years reflect differences in the age-2 abundance of these  
427 broods. Clearly, the 2004 and 2005 (and 2003) brood age-2 cohorts were at very low  
428 abundance relative to the 2000-2002 broods (Fig. 13). Was this because there were  
429 fewer numbers of coded-wire tagged FRH fall Chinook released in those years,  
430 or was it the result of poor survival following release? The number of released  
431 fish was very similar in each of these brood years (Table 6), except for brood-year  
432 2003 which was about half that of the other years. An index of the survival rate  
433 from release to ocean age-2 was derived by dividing the San Francisco major port  
434 area CPUE by the respective number of fish released (Table 6, Figure 14). The  
435 San Francisco CPUE time series is the most robust available for this purpose given  
436 that the number of recoveries it is based are significantly greater than those for the  
437 other ports (stock concentration and fishing effort is highest here). This index is  
438 proportional to the actual survival rate to the degree that the fraction of the age-2  
439 ocean-wide cohort abundance and catchability in the San Francisco major port area  
440 remains constant across years, both of which are supported by the coherence of the  
441 CPUE pattern across all areas and years (Fig. 13). The survival rate index shows  
442 a near monotonic decline over the 2000-2005 brood-year period (Table 6, Fig. 14).  
443 In particular, the survival rate index for 2004 and 2005 broods was very low: less  
444 than 10% of that observed for the 2000 brood (Table 6, Fig. 14). The survival rate  
445 index in turn is fairly well-correlated with the SRFC jack escapement for the 2000-  
446 2005 broods (correlation = 0.78, Fig. 15 ). Taken together, this indicates that the  
447 survival rate was unusually low for the 2004 and 2005 broods between release in  
448 San Francisco Bay and ocean age-2, prior to fishery recruitment, and that brood  
449 year strength was established by ocean age-2. Genetic stock identification methods  
450 applied to catches in the Monterey Bay salmon sport fishery showed relatively low  
451 abundance of Central Valley fall Chinook in the 2007 landings (Fig. 16). We also  
452 note that the survival rate for the 2003 brood was also considerably lower than for  
453 previous broods in this decade.



**Figure 13:** Recreational fishery CPUE of age-2 FRH fall Chinook by major port area; brood-years 2000-2005. CPUE was calculated as Recoveries / Effort, where “Recoveries” is coded-wire tag recoveries expanded for sampling; “Effort” is fishing angler days  $\times 10^{-4}$ . Major port areas shown from north to south: “NO” is northern Oregon; “CO” is central Oregon; “KO” is the Klamath Management Zone, Oregon portion; “KC” is the Klamath Management Zone, California portion; “FB” is Fort Bragg, California; “SF” is San Francisco, California; “MO” is Monterey, California.

454 *5.2 Has the bycatch in non-salmonid fisheries (e.g., whiting, groundfish) increased?*

455 Bycatch of Chinook in trawl fisheries off of California has been variable over the  
 456 last two decades (Fig. 17). The magnitude of bycatch by trawl fisheries is quite  
 457 small compared to combined landings by the commercial and recreational salmon  
 458 fisheries (1.4 metric tons (t) and 686 t respectively, in 2007), so it is unlikely that  
 459 variations in bycatch in non-salmonid fisheries are an important cause of variation  
 460 in the abundance of Chinook.

461 **6 Marine Habitat Areas Focus**

462 *6.1 Were there periods of reduced upwelling or other oceanographic physical*  
 463 *conditions during the period of smolt entry into the marine environment, or*  
 464 *during the period of marine residence up to the return to freshwater of the*  
 465 *jacks?*

466 Conditions in the coastal ocean in the spring of 2005 were unusual. Most notably,  
 467 the onset of upwelling was delayed significantly compared to the climatological  
 468 average (Schwing et al., 2006); Fig. 18) due to weaker than normal northerly winds

**Table 6:** Recreational fishery coded-wire tag recoveries of age-2 FRH fall Chinook in the San Francisco major port area, brood-years 2000-2005. “Released” is number released  $\times 10^{-5}$ ; “Effort” is fishing angler days  $\times 10^{-4}$ ; “Recoveries” is coded-wire tag recoveries expanded for sampling; “Survival Rate Index” is Recoveries/(Effort  $\times$  Released) relative to the maximum value observed (brood-year 2000).

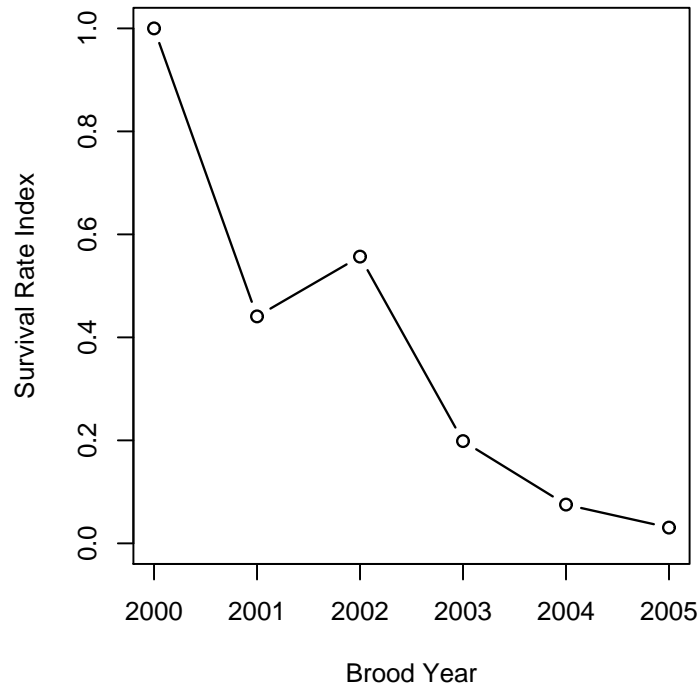
	Brood Year					
	2000	2001	2002	2003	2004	2005
Released	11.23	13.78	13.11	7.41	13.13	13.71
Effort	9.88	6.71	10.10	8.00	7.45	4.30
Recoveries	1169	429	777	124	78	19
Survival Rate Index	1.00	0.44	0.56	0.20	0.08	0.03

469 (Fig. 19). Off central California ( $36^{\circ}\text{N}$ ), there was a only a brief period of upwelling  
 470 in the early spring before sustained upwelling began around mid May. Moving  
 471 northward along the coast, sustained upwelling began later: late May off Pt. Arena,  
 472 early June near the California-Oregon border, and not until July in central Oregon  
 473 (Fig. 18, see also Kosro et al. (2006)). In the north ( $> 42^{\circ}\text{N}$ ) a delay in the advent of  
 474 upwelling led to a lag in cumulative upwelling, which was made up for in the latter  
 475 part of the year, leading to an average annual total. In the south, upwelling was  
 476 lower than average all year, leading to a low annual total. The delay in upwelling  
 477 in the north was associated with a southward shift of the jet stream, which led to  
 478 anomalous winter-storm-like conditions (i.e., downwelling) (Sydeman et al., 2006;  
 479 Barth et al., 2007). The delay in upwelling was not unprecedented, having occurred  
 480 also in '83, '86, '88, '93 and '97.

481 Sea surface temperatures along the coast of central California were anomalously  
 482 warm in May (Fig. 20), before becoming cooler than normal in the summer, coinci-  
 483 dent with strong, upwelling-inducing northwesterly winds. The mixed layer depth  
 484 in the Gulf of the Farallones was shallower than normal in May and June in both  
 485 2005 and 2006 (Fig. 21). Warm sea surface temperatures, strong stratification, and  
 486 low upwelling have been associated with poor survival of salmon during their first  
 487 year in the ocean in previous studies (Pearcy, 1992).

488 A number of researchers observed anomalies in components of the Califor-  
 489 nia Current food web in 2005 consistent with poor feeding conditions for juvenile  
 490 salmon. For example, gray whales appeared emaciated (Newell and Cowles, 2006);  
 491 sea lions foraged far from shore rather than their usual pattern of foraging near  
 492 shore (Weise et al., 2006); various fishes were at low abundance, including common  
 493 salmon prey items such as juvenile rockfish and anchovy (Brodeur et al., 2006);  
 494 Cassin’s auklets on the Farallon Islands abandoned 100% of their nests (Sydeman  
 495 et al., 2006); and dinoflagellates became the dominant phytoplankton group, rather  
 496 than diatoms (MBARI, 2006). While the overall abundance of anchovies was low,  
 497 they were captured in an unusually large fraction of trawls, indicating that they  
 498 were more evenly distributed than normal. The anomalous negative effect on the  
 499 nekton was also compiled from a variety of sampling programs (Brodeur et al.,  
 500 2006) indicating some geographic displacement and reduced productivity of early



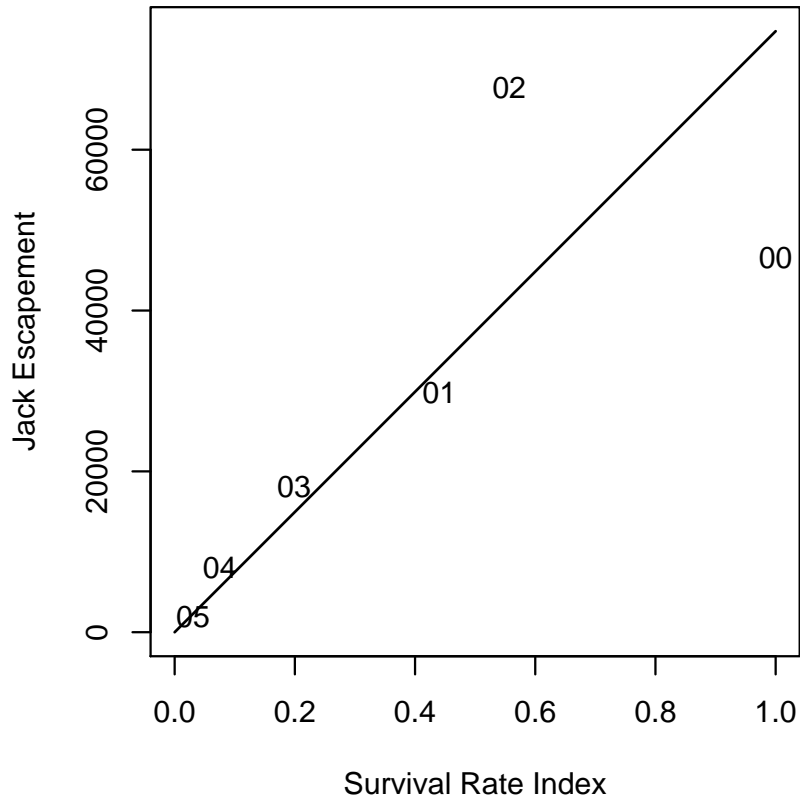


**Figure 14:** Index of FRH fall Chinook survival rate between release in San Francisco Bay and ocean age-2 based on coded-wire tag recoveries in the San Francisco major port area recreational fishery; brood-years 2000-2005. Survival rate index was derived as described in Table 6.

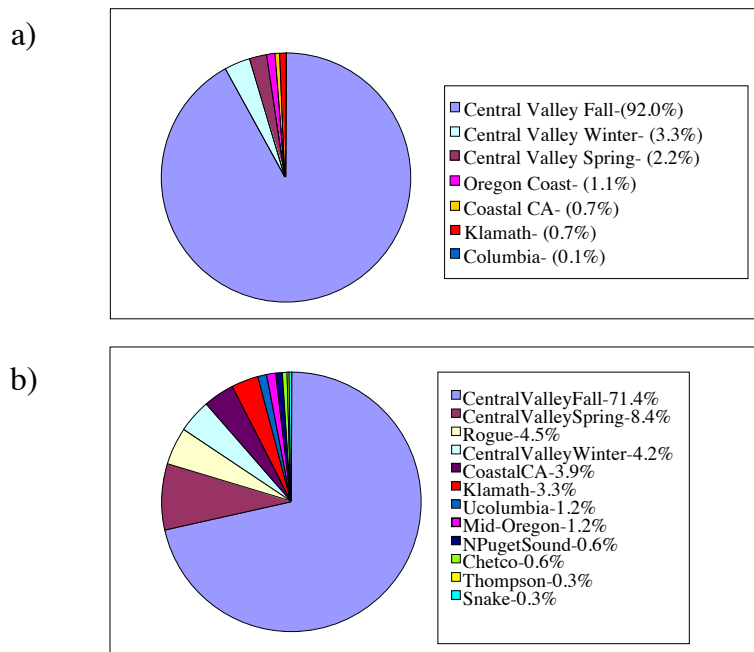
501 life stages. In central California, the abundance of young-of-the-year rockfishes  
 502 was the lowest seen in the previous 22 years, even lower than the recent El Niño of  
 503 1998. Brodeur et al. (2006) noted that (1) “these changes are likely to affect juve-  
 504 nile stages and recruitment of many species (rockfishes, salmon, sardine) that are  
 505 dependent on strong upwelling-based production,” and (2) the presence of unusual  
 506 species not quantitatively sampled such as blue sharks, thresher sharks and alba-  
 507 core which “likely became important predators on juvenile rockfishes, salmon, and  
 508 other forage fish species.” The latter adds the possibility of a top down influence  
 509 of this event on nektonic species. To this list of potential predators might be added  
 510 jumbo squid, which since 2003 have become increasingly common in the California  
 511 Current (discussed in detail below).

512 Conditions in the coastal ocean were also unusual in the spring of 2006. Off  
 513 central California (36°N), upwelling started in the winter, but slowed or stopped  
 514 in March and April, before resuming in May. At 39°N, little upwelling occurred  
 515 until the middle of April, but then it closely followed the average pattern. At 42°N,  
 516 the start of sustained upwelling was delayed by about one month, but by the end  
 517 of the upwelling season, more than the usual amount of water had been upwelled.  
 518 At 45°N, the timing of upwelling was normal, but the intensity of both upwelling  
 519 and downwelling winds was on average greater than normal. In late May and early  
 520 June, upwelling slowed or ceased at each of the three northern stations.

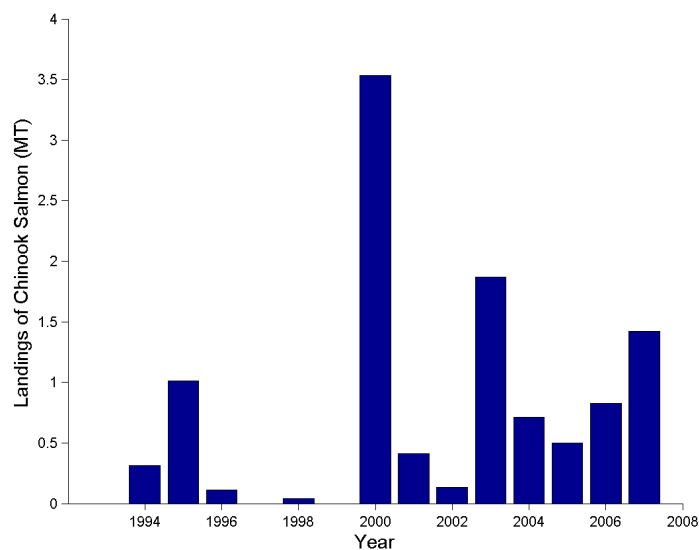
521 In the Gulf of the Farallones region, northwest winds were stronger offshore



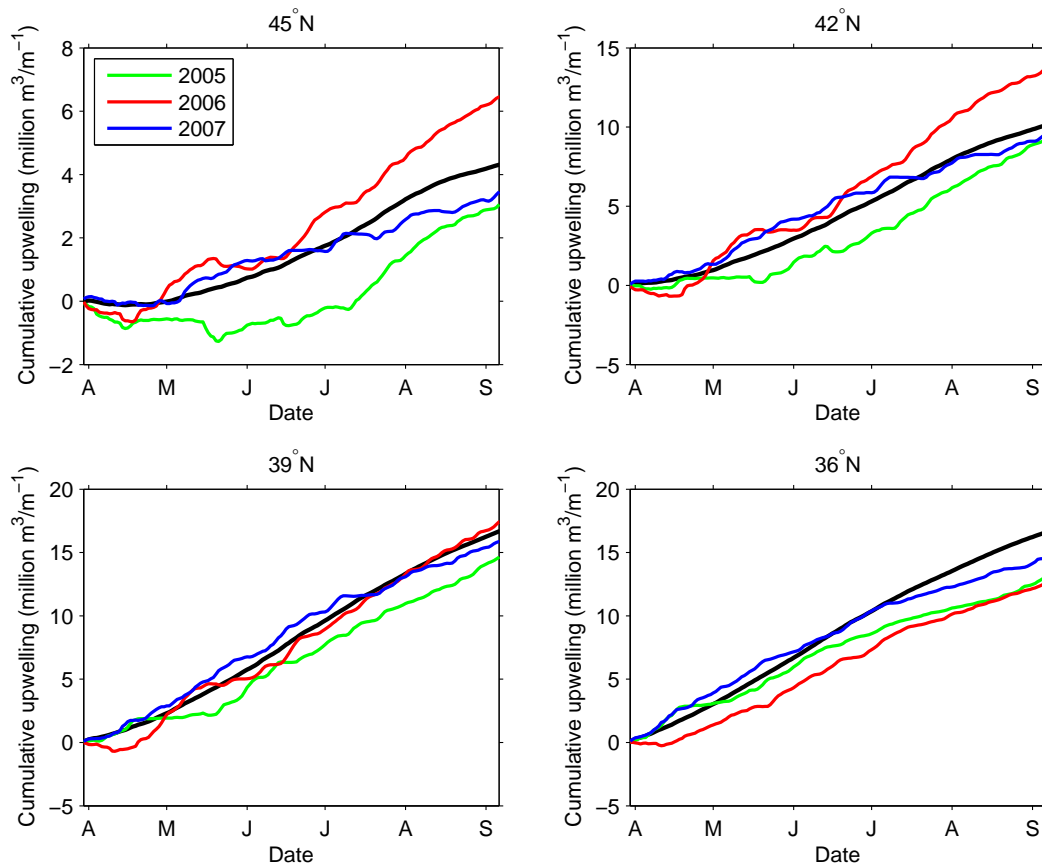
**Figure 15:** SRFC jack spawning escapement versus FRH fall Chinook survival rate index. Line is ratio estimate. Numbers in plot are last two digits of brood year; e.g., “05” denotes brood-year 2005 (jack return-year 2007). Line denotes ratio estimator fit to the data (through the origin with slope equal to average jack escapement/average survival rate index).



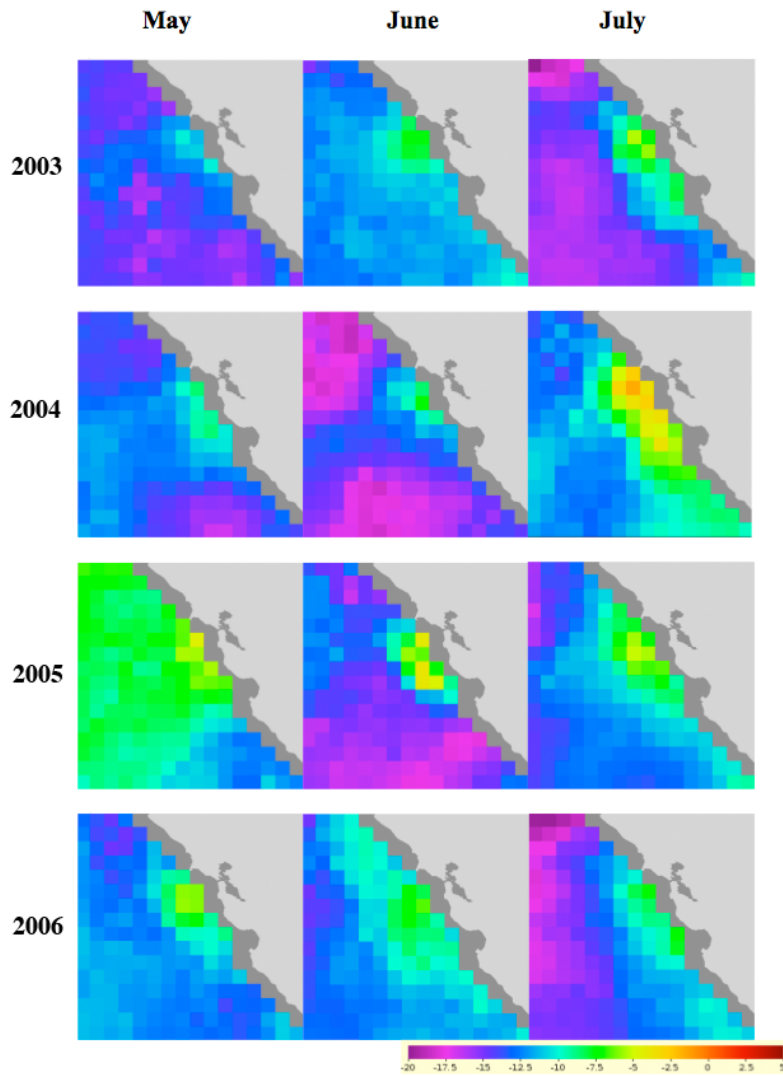
**Figure 16:** Composition of the Monterey Bay sport fishery landings as determined by genetic stock identification. Based on samples of 735 fish in 2006 and 340 fish in 2007. NMFS unpublished data.



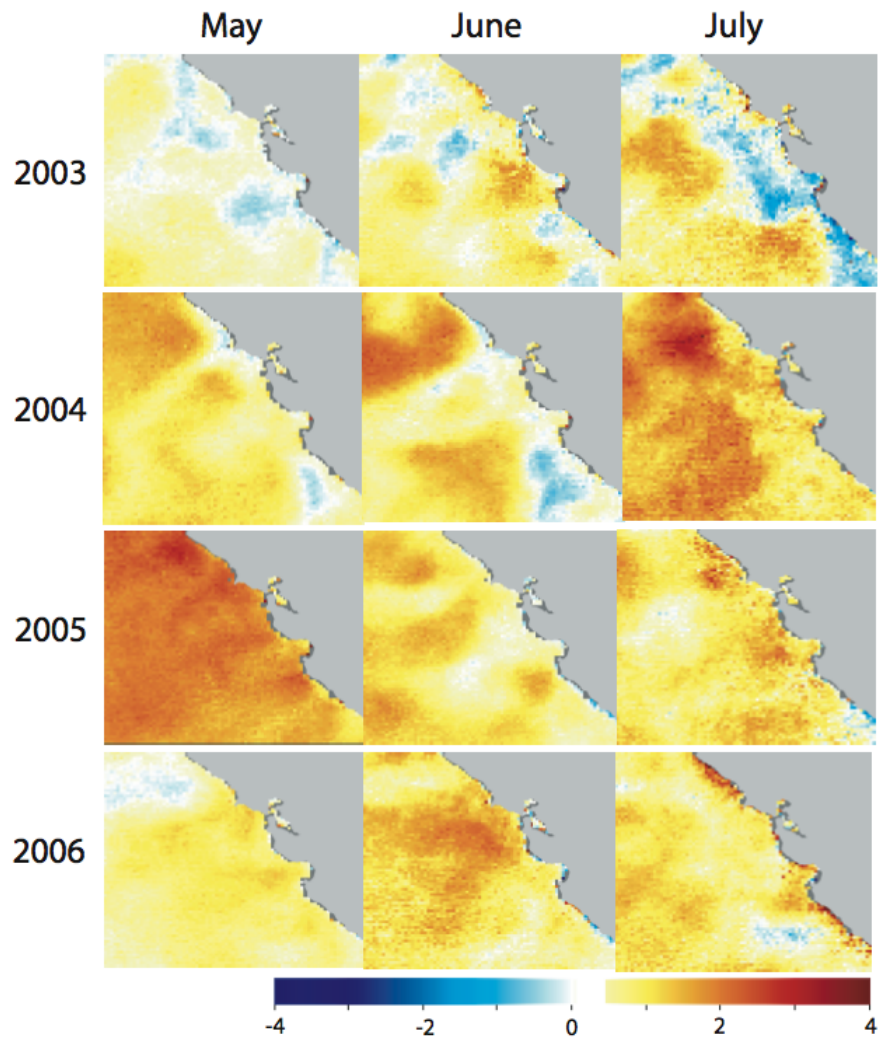
**Figure 17:** Landings of Chinook taken in trawl fisheries and landed at California ports. Data from the CALCOM database (D. Pearson, SWFSC, pers. comm.).



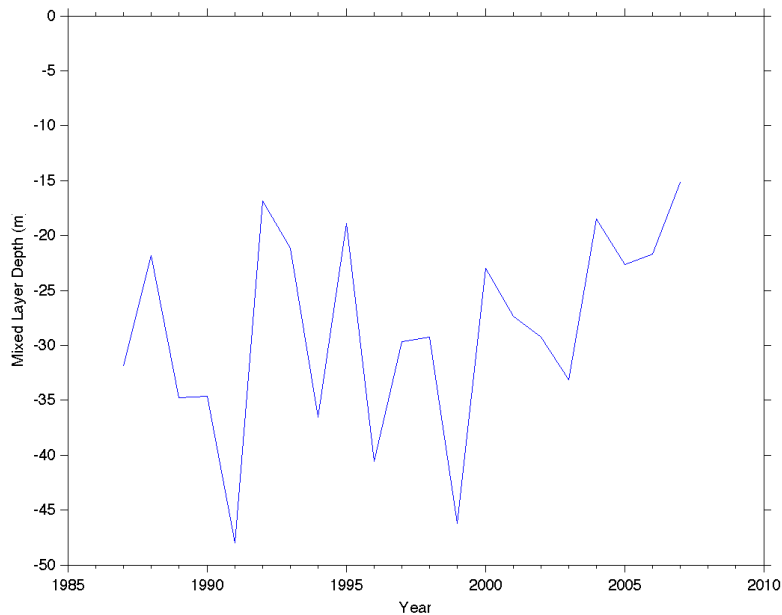
**Figure 18:** Cumulative upwelling at four locations along the California and Oregon coast; 45°N is near Lincoln City, Oregon; 42°N is near Brooking, Oregon, 39°N is near Pt. Arena, and 36°N is near Santa Cruz, California. Units are in millions of cubic meters per meter of shoreline. The black line represents the average cumulative upwelling at each location for the 1967-2008 period. Upwelling is indicated by increasing values of the upwelling index.



**Figure 19:** Strength of meridional winds (negative from the north) along the central California coast in 2003-2006. Note weak winds near the coast and in the Gulf of the Farallones in 2005 and 2006.



**Figure 20:** Sea surface temperature anomalies off central California in May (left), June (center) and July (right). Note especially warm temperatures in the Gulf of Farallones in May 2005 and June 2006, and warm temperatures along the coast in 2006. Data obtained from CoastWatch (<http://coastwatch.noaa.gov/>).



**Figure 21:** Average depth of the thermocline during May and June in the Gulf of the Farallones. NMFS unpublished data.

522 in 2006 than 2005, but were relatively weak near the coast between Pt. Reyes  
 523 and Monterey Bay. At NMFS trawl survey stations in the Gulf of the Farallones,  
 524 the mixed layer depth in May was the shallowest on record since 1987. Cassin's  
 525 auklets again abandoned all their nests in 2006 (J. Thayer, PRBO, unpublished  
 526 data), juvenile rockfish abundance was very low in the NMFS trawl survey, and  
 527 anchovies were again encountered in a high fraction of trawls, even though overall  
 528 abundance was low (NMFS unpublished data). While conditions in the spring of  
 529 2006 might not have been as unusual as 2005, it is important to realize that the  
 530 pelagic ecosystem of the California Current is not created from scratch each year,  
 531 but the animals in the middle and upper trophic levels (where salmon feed) have  
 532 life spans longer than one year. This means that the food web will reflect past  
 533 conditions for some time. Overall, it appears that the continuation of relatively  
 534 poor feeding conditions in the spring of 2006, following on the poor conditions in  
 535 2005, contributed significantly to the poor survival of Sacramento River fall-run  
 536 Chinook in their first year in the ocean

537 *6.2 Were there any effects to these fish from the "dead zones" reported off Oregon*  
 538 *and Washington in recent years?*

539 Hypoxia in inner-shelf waters can extend from the bottom to within 12 m of the sur-  
 540 face at certain times and places (Chan et al., 2008), but juvenile salmon are usually  
 541 found in the upper 10 m of the water column and are capable of rapid movement, so  
 542 are not expected to be directly impacted by hypoxic events. Furthermore, hypoxia

543 has not been observed on the inner shelf in California waters, where juvenile Chi-  
544 nook from the Central Valley are thought to rear. It is conceivable that outbreaks  
545 of hypoxia alter the distribution of Chinook, their prey, and their predators, but this  
546 seems an unlikely explanation for the poor performance of brood-year 2004 and  
547 2005 Sacramento River fall-run Chinook.

548 *6.3 Were plankton levels depressed off California, especially during the smolt en-*  
549 *try periods?*

550 Phytoplankton levels, based in remotely sensed observations of chlorophyll-a con-  
551 centrations in the surface waters, were not obviously different in the spring and early  
552 summer of 2005 and 2006 compared to 2003 and 2004 (Fig. 22). Zooplankton are  
553 discussed in the answer to the first question in section 7.

554 *6.4 Was there a relationship to an increase in krill fishing worldwide?*

555 To date, there have been no commercial fisheries for krill in US waters; kill fishing  
556 in other parts of the world is unlikely to impact SRFC.

557 *6.5 Oceanography: temperature, salinity, upwelling, currents, red tide, etc.*

558 These issues are addressed in the response to question 1 in this section above, with  
559 the exception of red tides. Red tides are frequently caused by dinoflagellates (but  
560 can also be formed by certain diatom species). MBARI (2006; Fig. 23) reported  
561 that dinoflagellates in Monterey Bay have become relatively abundant since 2004,  
562 concurrent with increased water column stratification, reduced mixed layer depth  
563 and increased nitrate concentrations at 60 m depth. Increased stratification favors  
564 motile dinoflagellates over large diatoms which lack flagella, and thus diatoms are  
565 prone to sinking out of the photic zone when the upper ocean is not well-mixed.

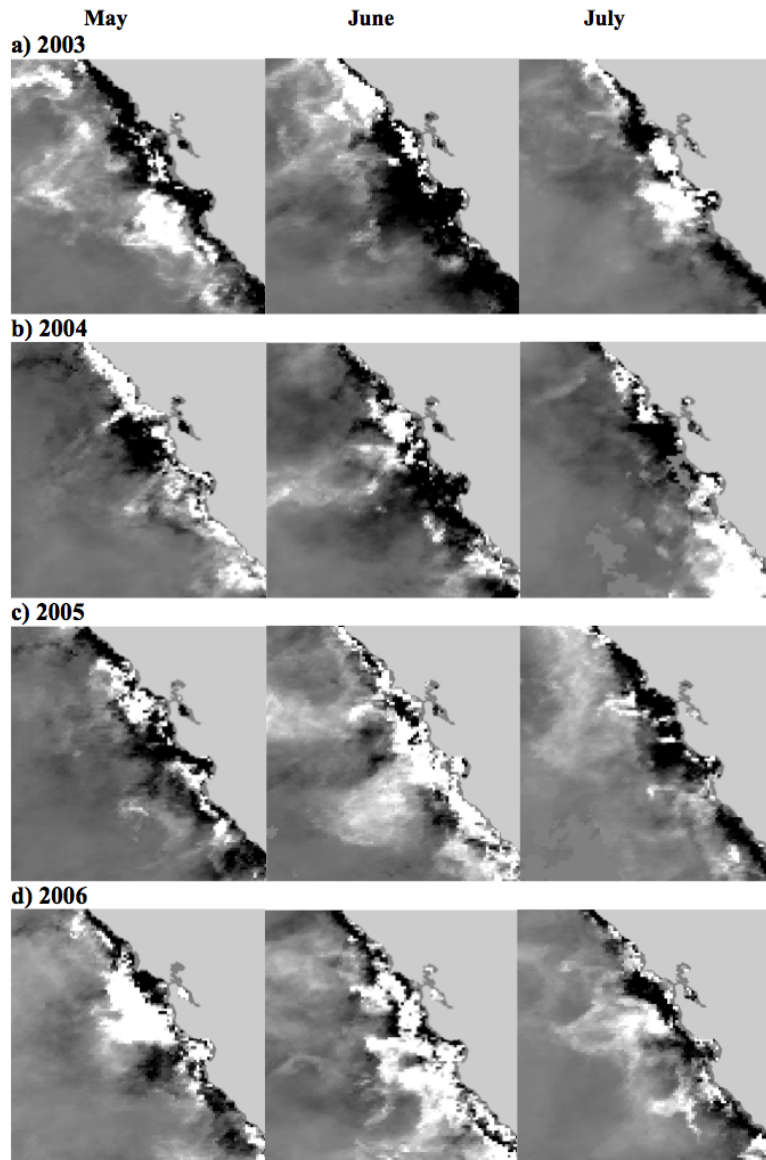
566 *6.6 Were there any oil spills or other pollution events during the period of ocean*  
567 *residence?*

568 As discussed in the answer to question 6 of the section “Freshwater habitat area  
569 focus”, the cargo ship *Cosco Busan* spilled 58,000 gallons of bunker fuel into San  
570 Francisco Bay on 7 November 2007, and some of this fuel dispersed from the bay  
571 into the coastal ocean, eventually fouling beaches in San Francisco and Marin coun-  
572 ties. This would have had the most impact on brood-year 2006 Chinook, some of  
573 which would have been in nearshore areas of the Gulf of the Farallones at that time.  
574 The actual effects of this spill on fish in the coastal ocean are unknown.

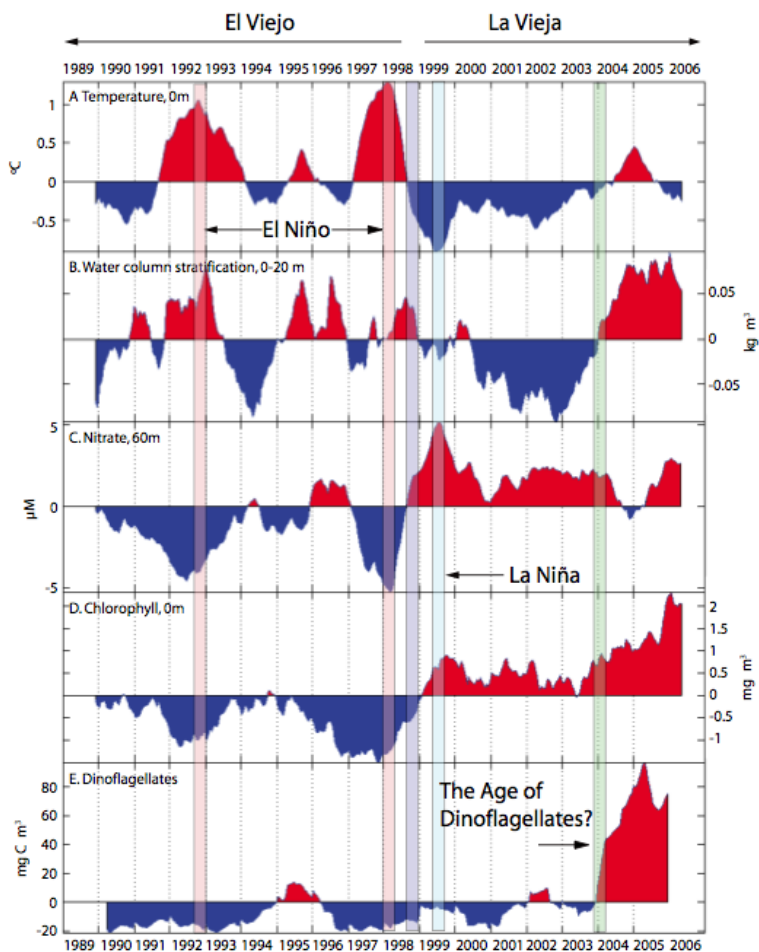
575 *6.7 Was there any aquaculture occurring in the ocean residence area?*

576 Aquaculture in California is generally restricted to onshore facilities or estuaries  
577 (e.g., Tomales Bay) where it is unlikely to impact salmonids from the Central Val-  
578 ley; we are unaware of any offshore aquaculture in California.





**Figure 22:** Chlorophyll-a (Chl-a) anomalies obtained from MODIS (CoastWatch) during May, June, and July. Black indicates low values and white high values. Anomalies represent monthly Chl-a concentrations minus mean Chl-a concentration values at the pixel resolution for the 1998-2007 period. From Wells et al. (2008).



**Figure 23:** Time series of temperature, water column stratification, nitrate, chlorophyll and dinoflagellates observed in Monterey Bay. “El Viejo” refers to the warm-water regime lasting from 1976-1998, and “La Vieja” refers to the present regime. El Niño and La Niña events are indicated by the colored vertical bars spanning the subplots. Figure from MBARI (2006).

579 6.8 *Was there any offshore construction in the area of ocean residence, for wave*  
580 *energy or other purposes?*

581 A review of NMFS Endangered Species Act consultations indicate no significant  
582 offshore construction projects occurred during the time period of interest.

## 583 **7 Marine Species Interactions Focus**

584 7.1 *Were there any unusual population dynamics of typical food or prey species*  
585 *used by juvenile Chinook in marine areas? (plankton, krill, juvenile anchovy*  
586 *or sardines, etc.)*

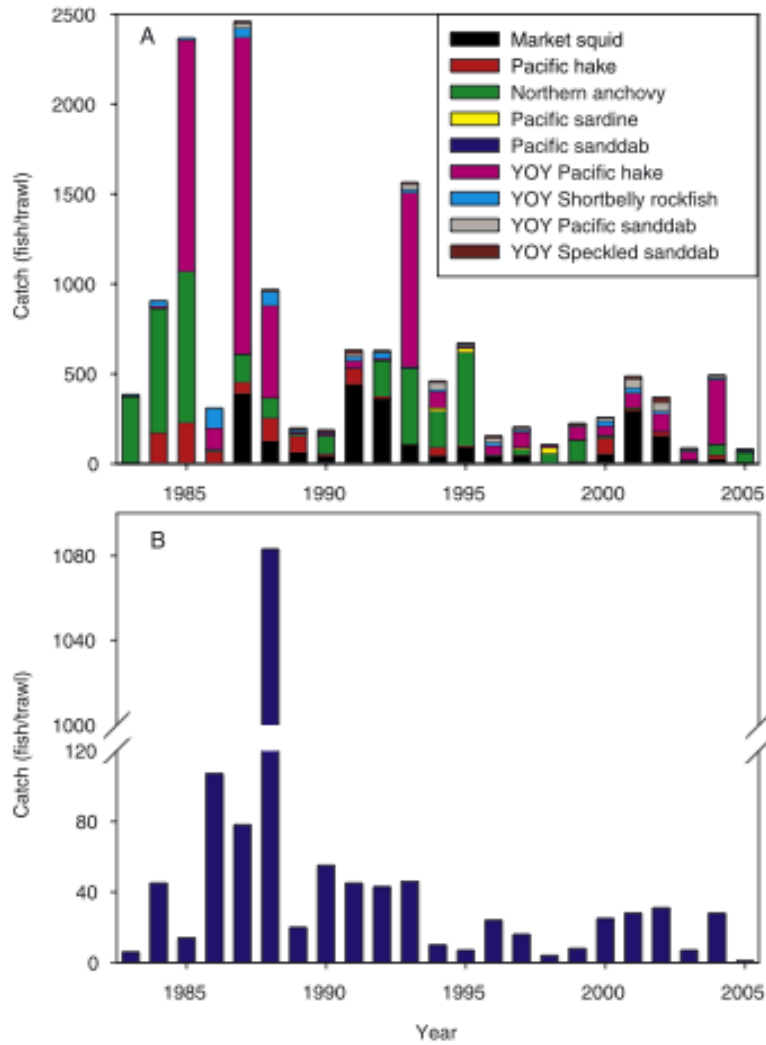
587 Prey items of juvenile salmon, especially juvenile rockfish, were at very low abun-  
588 dance in 2005 (Brodeur et al. (2006), Fig. 24) and 2006. Catches of adult anchovies  
589 in midwater trawls conducted by NMFS exhibited an unusual pattern: the average  
590 catch in the Gulf of the Farallones was moderately low, but the frequency of en-  
591 counter (fraction of trawls with at least some anchovy) was higher than normal,  
592 indicating that the distribution of anchovy was less clustered than normal (Fig. 25).  
593 Sardines have been increasing since 2003, possibly indicating a shift in the Califor-  
594 nia Current to a state more favorable to warm-water species and less favorable to  
595 cold-water species such as salmon and anchovy.

596 Data are limited for krill, but it appears that krill abundance was fairly normal  
597 in the spring of 2005 (Fig 26a and b), but krill were distributed more evenly than in  
598 2002-2004, which may have made it harder for salmon to find high concentrations  
599 of krill upon which to feed. In spring 2006, krill abundance was very low in the  
600 Gulf of the Farallones (Fig. 26c).

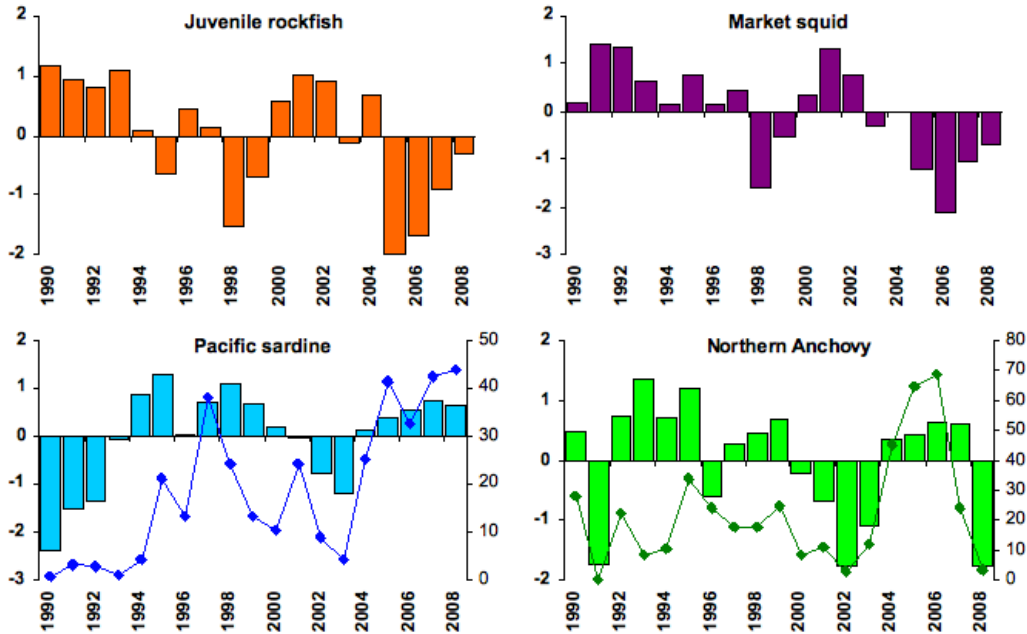
601 7.2 *Was there an increase in bird predation on juvenile salmonids caused by a*  
602 *reduction in the availability of other forage food?*

603 Among the more abundant species of seabirds, common murre (*Uria aalge*) and  
604 rhinoceros auklets *Cerorhinca monocerata* eat juvenile salmon (Fig. 27; Roth et al.  
605 (2008); Thayer et al. (2008)) . In 2005 and 2006, chicks of these species in the  
606 Gulf of the Farallones, the initial ocean locale of juvenile Chinook from the Central  
607 Valley, had juvenile salmon in their diet at 1-4% for rhinoceros auklets and 7-10%  
608 for murre. This represented a smaller than typical contribution to stomach contents  
609 for auklets, and a larger than typical proportion for murre during the 1972-2007  
610 time period (calculated from data in Fig. 27; Bill Sydeman, Farallon Institute for  
611 Advanced Ecosystem Research, Petaluma, California, unpublished data).

612 The rhinoceros auklet population in the Gulf of the Farallones has remained  
613 stable at about 1,500 birds for the past 20 years, but murre numbers have doubled  
614 between the 1990s and 2006 to about 220,000 adults (Bill Sydeman, Farallon Insti-  
615 tute for Advanced Ecosystem Research, Petaluma, California, personal communi-  
616 cation). A study in 2004 found that murre in the Gulf of the Farallones consumed  
617 about four metric tons of juvenile salmon (Roth et al., 2008). This represents the



**Figure 24:** Time series of catches from pelagic trawl surveys along the central California coast from 1983 to 2005 for (a) the dominant nekton species and (b) juvenile rockfishes. From Brodeur et al. 2006.



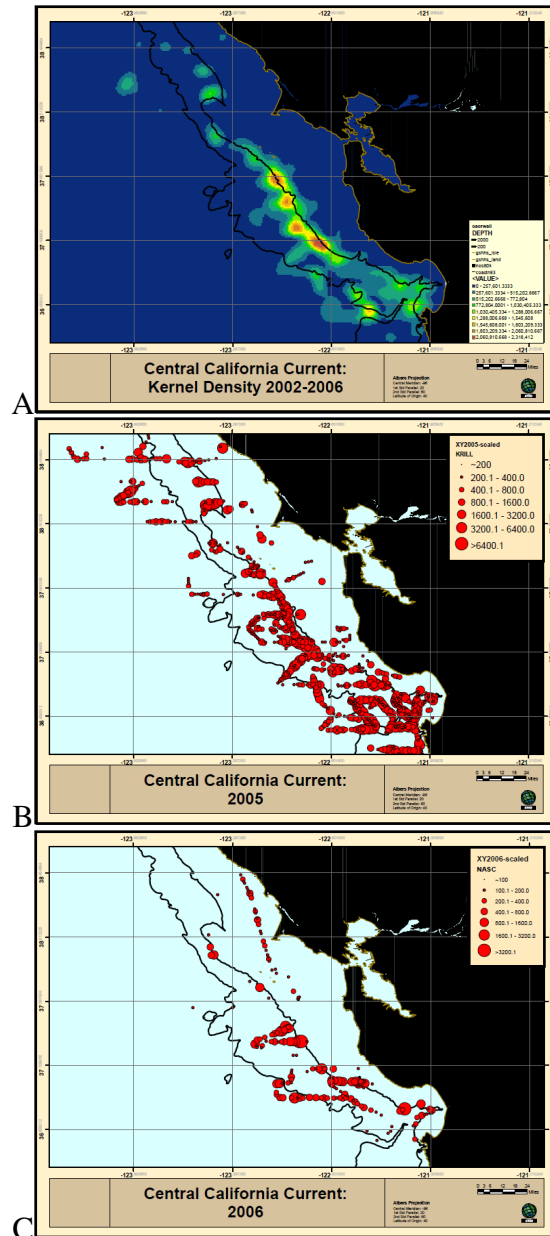
**Figure 25:** Standardized abundances (bars) of four Chinook salmon prey items (the ten most frequently encountered rockfish of the NOAA trawl survey, market squid, sardines and anchovies) estimated from the mid-water trawl survey conducted by NOAA Fisheries, Santa Cruz. Lines indicate the frequency of occurrences of sardines and northern anchovy in the trawls.

618 equivalent of about 20,000 to 40,000 juvenile Chinook salmon (100-200 g each).  
 619 Although a greater proportion of murre stomach contents were salmon in 2005 and  
 620 2006 than in 2004, considering that >30 million juvenile salmon entered the ocean  
 621 each year, this increase could not account for the poor survival of the 2004 and 2005  
 622 broods.

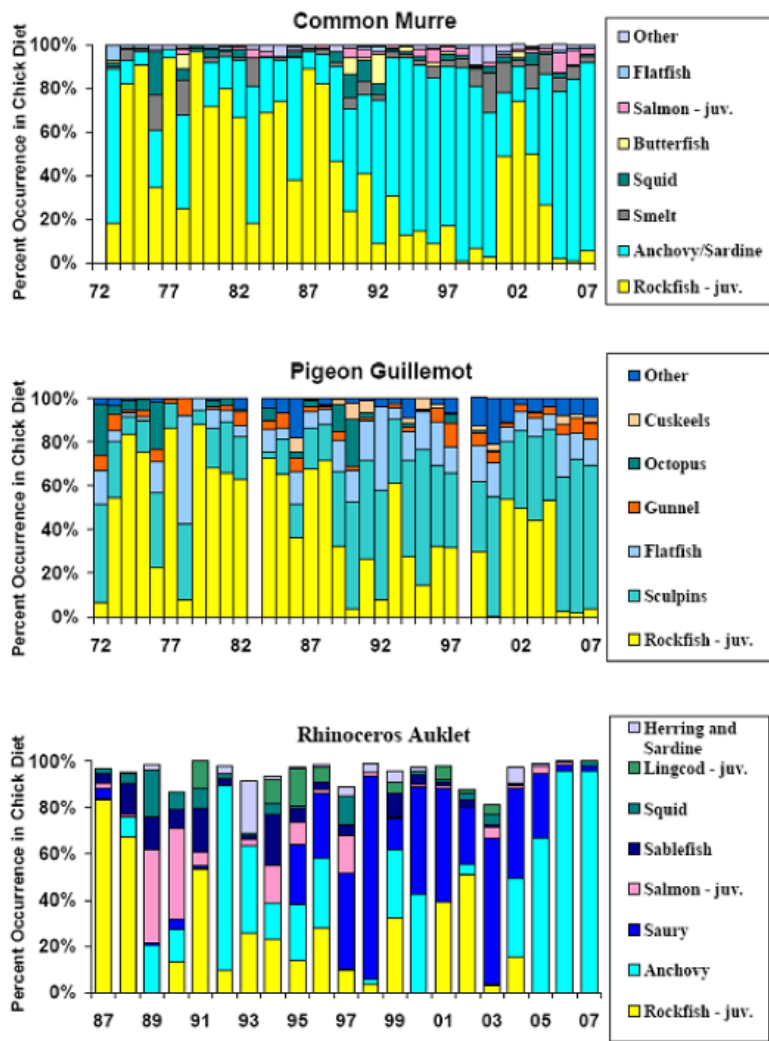
### 623 7.3 Was there an increase of marine mammal predation on these broods?

624 Among marine mammals, killer whales (*Orcinus orca*), California sea lions (*Za-*  
 625 *lophus californianus*), and harbor seals (*Phoca vitulina*) are potential predators on  
 626 salmon (Parsons et al., 2005; Weise and Harvey, 2005; Ford and Ellis, 2006; Za-  
 627 mon et al., 2007). A coast-wide marine mammal survey off Washington, Oregon,  
 628 and California conducted in 2005 to 550 km offshore reported cetacean abundances  
 629 similar to those found in the 2001 survey (K. Forney, NMFS, unpublished data).  
 630 In coastal waters of California during July 2005 the population estimate for killer  
 631 whales was 203, lower than abundance estimates from surveys in 1993, 1996, and  
 632 2001 (Barlow and Forney, 2007) (Fig. 28).

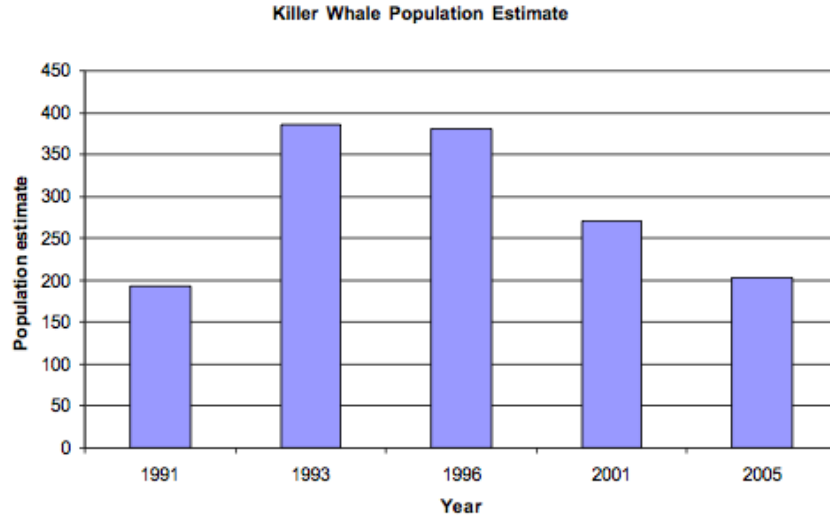
633 Of five recognized killer whale stocks within the Pacific U.S. Exclusive Eco-  
 634 nomic Zone, the Eastern North Pacific Southern Resident stock has been most im-  
 635 plicated in preying on salmon. This stock resides primarily in inland waters of  
 636 Washington state and southern British Columbia, but has been observed as far south



**Figure 26:** Abundance of krill measured by echosounder during May-June survey cruises off central California in 2004-2006. A) Average abundance of krill over the survey period. B) Abundance of krill in 2005 and C) 2006. Unpublished data of J. Santora.



**Figure 27:** Diet of three species of seabirds in the Gulf of the Farallones between 1972 and 2007. (Source: Bill Sydeman, Farallon Institute for Advanced Ecosystem Research)



**Figure 28:** Population estimates of killer whales (*Orcinus orca*) off the California coast (to 300 nautical miles). Source: Barlow and Forney (2007).

637 as Monterey Bay. This population increased in abundance between 1984 and 1996,  
 638 then experienced a decline to 2001. Since 2001, the numbers have increased but  
 639 not to levels seen in the mid-1990s (Carretta et al., 2007). Considering population  
 640 trends and absolute abundance estimates, this stock does not appear to be significant  
 641 cause of the poor survival of the 2004 and 2005 broods.

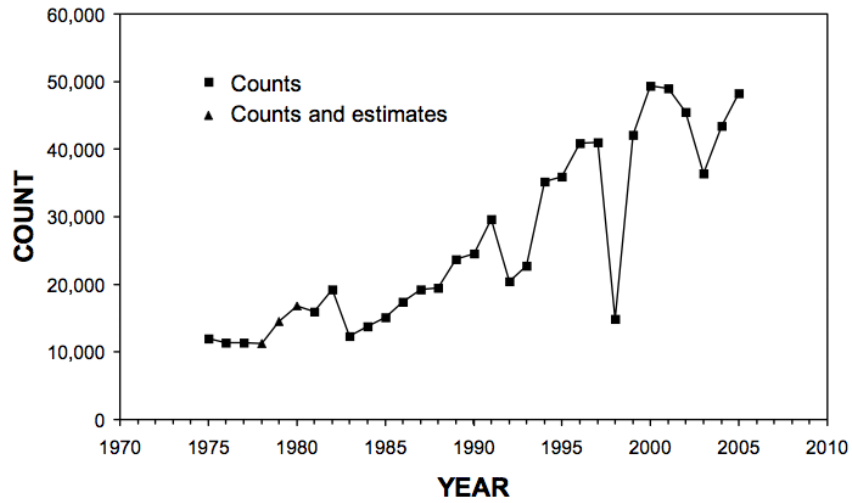
642 Sea lion population trends reveal a steady increase in numbers on the California  
 643 coast between 1975 and 2005 (Fig. 29) (Carretta et al., 2007). Over this period,  
 644 sea lions have taken an increasing percentage of Chinook hooked in commercial  
 645 and recreational fisheries (Weise and Harvey, 2005). The results of data analysis  
 646 following the 2005 survey determined that the population had reached carrying ca-  
 647 pacity in 1997; thus, no significant increase in sea lion numbers in 2005 occurred.  
 648 Weise et al. (2006) observed that sea lions were foraging much farther from shore  
 649 in 2005, which suggests that they had a lower than usual impact on salmon in that  
 650 year.

651 As with sea lions, harbor seal abundance appears to have reached carrying ca-  
 652 pacity on the West Coast (Fig. 30) (Carretta et al., 2007). Seal populations expe-  
 653 rienced a rapid increase between 1972 and 1990. Since 1990, the population has  
 654 remained stable through the last census in 2004. Because SRFC achieved record  
 655 levels of abundance during the recent period of high harbor seal abundance, it is  
 656 unlikely that harbor seals caused the poor survival of the 2004 and 2005 broods.

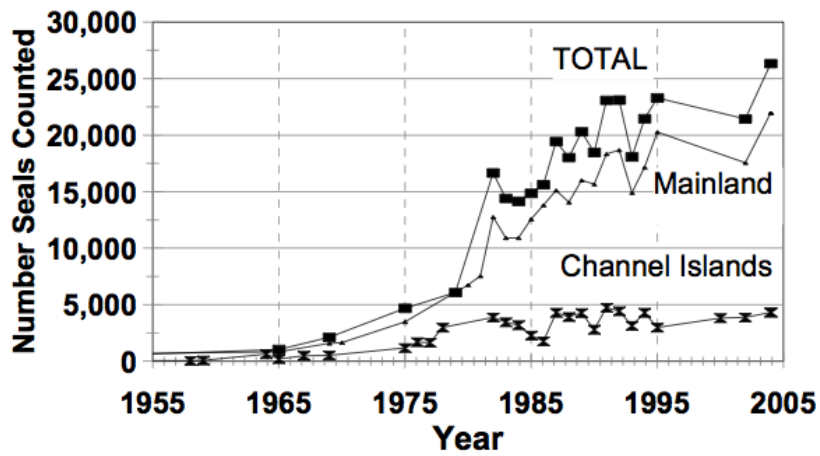
#### 657 7.4 Was there predation on salmonids by Humboldt squid?

658 Jumbo squid (*Dosidicus gigas*) are an important component of tropical and sub-  
 659 tropical marine ecosystems along the Eastern Pacific rim, and in recent years have  
 660 expanded their range significantly poleward in both hemispheres. In the California  
 661 Current, these animals were observed in fairly large numbers during the 1997-1998





**Figure 29:** Count of California sea lion pups (1975-2005). Source: Carretta et al. (2007)



**Figure 30:** Harbor seal haulout counts in California during May and June (Source: Carretta et al. 2007)

662 El Niño, and since 2003 they have been regularly encountered by fishermen and  
663 researchers throughout the West Coast of North America as far north as South-  
664 east Alaska. While the primary drivers of these range expansions remain uncertain,  
665 climate-related mechanisms are generally considered the most likely, and some evi-  
666 dence suggests that that an ongoing expansion of the oxygen minimum zone (OMZ)  
667 in the California Current could be a contributing factor (Bograd et al., 2008). Al-  
668 though accounts of squid off of Southeast Alaska consuming salmon have been  
669 reported, ongoing monitoring of food habits from squid collected off of California  
670 (with limited sampling in Oregon) since 2005 have failed to document any predation  
671 on salmonids. While salmon smolts are clearly within the size range of common  
672 squid prey, their distribution (generally inshore of the continental shelf break) likely  
673 overlaps very little with the distribution of squid (generally offshore of the conti-  
674 nental shelf break), and predation on older salmon is probably unlikely given their  
675 swimming capabilities relative to other prey.

676 In a sample of 700 jumbo squid stomachs collected in California waters, the  
677 most frequent prey items have been assorted mesopelagic fishes, Pacific hake, north-  
678 ern anchovy, euphausiids, Pacific sardine, several species of semi-pelagic rockfish  
679 (including shortbelly, chilipepper, widow and splitnose rockfish) and other squids  
680 (Field et al., 2007). The size of prey items ranges from krill to fishes of sizes up to  
681 45 centimeters, however most of the larger fishes (and squids) consumed by squid  
682 can probably be considered relatively weak swimmers (Pacific hake, rockfish, Pa-  
683 cific ratfish). Although squid have also been reported to strike larger salmon, rock-  
684 fish, sablefish and other species that have been hooked on fishing lines, predation  
685 on larger prey items that may be swimming freely seems unlikely. Similarly, squid  
686 caught in purse seines in the Eastern Tropical Pacific will often attack skipjack  
687 and yellowfin tuna schools, while predation by free-swimming squids appears to  
688 be limited almost exclusively to mesopelagic fishes and invertebrates (Olson et al.,  
689 2006). However, the impacts of jumbo squid on fisheries could possibly be more  
690 subtle than direct predation alone, as recent research conducted during hydroacous-  
691 tic surveys of Pacific hake in the California Current has suggested that the presence  
692 of squid may lead to major changes in hake schooling behavior, confounding the  
693 ability to monitor, assess, and possibly manage this important commercial resource  
694 (Holmes et al., 2008). Although unlikely, it is plausible that the presence of squid  
695 could result in changes in the behavior of other organisms (such as salmon or their  
696 prey or other predators) as well, even in the absence of intense predation.

697 The absolute abundance of squid in the California Current in recent years is an  
698 important factor in assessing the potential impacts of predation, yet this is entirely  
699 unknown. However, the total biomass could potentially be quite large based on the  
700 significance of squid in the diets of some predators (such as mako sharks, for which  
701 jumbo squid appear to be the most important prey in recent years), the frequency of  
702 squid encounters and catches during recreational fishing operations and scientific  
703 surveys, and the magnitude of catches in comparable ecosystems. For example, in  
704 recent years jumbo squid landings in similar latitudes in the Southern Hemisphere  
705 have grown from nearly zero to over 200,000 tons per year.

706 Although it is impossible to conclusively rule out squid predation as a primary

707 cause of the poor survival of the 2004 and 2005 broods of SRFC, it is unlikely that  
708 squid predation is a major contributing factor. Instead, the large numbers of jumbo  
709 squid observed since 2003, and particularly during 2005-2006, may have been a  
710 reflection of the same unusual ocean conditions (poor upwelling, heavy stratifica-  
711 tion, warm offshore water, poor juvenile rockfish and seabird productivity, etc) that  
712 contributed to the poor feeding conditions for salmon during those years.

713 7.5 *Was there increased predation on salmonids by other finfish species (e.g., ling-*  
714 *cod)?*

715 Predation is typically considered to be a major source of salmon mortality, particu-  
716 larly during ocean entry (Pearcy, 1992). Seabirds and marine mammals (addressed  
717 in section 7.3) are often considered the greatest sources of salmon smolt and adult  
718 predation mortality, respectively. In general, available food habits data do not in-  
719 dicate that groundfish or other fishes are substantial predators of either juvenile or  
720 adult salmon, although as Emmett and Krutzikowsky (2008) suggest, this could be  
721 in part due to biases in sampling methodologies. As very little data are available for  
722 piscivorous predators in the Central California region, we summarize examples of  
723 those species of groundfish that could potentially have an impact on Pacific salmon  
724 based on existing food habits data, much of which was collected off of the Pa-  
725 cific Northwest, and briefly discuss relevant population trends for key groundfish  
726 species. However, it is unlikely that any are at sufficiently high population levels,  
727 or exhibit sufficiently high predation rates, to have contributed to the magnitude of  
728 the 2008 salmon declines.

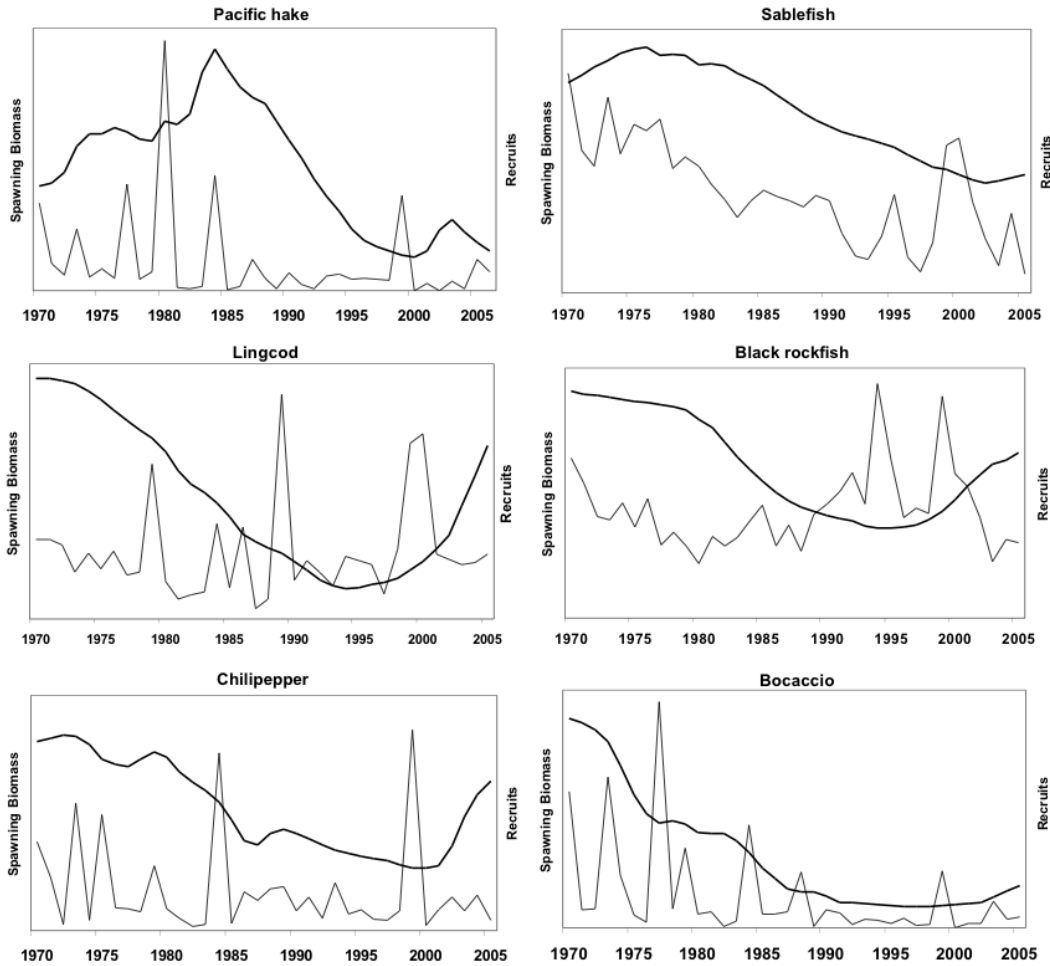
729 Pacific hake (*Merluccius productus*) are by far the most abundant groundfish  
730 in the California Current, and are widely considered to have the potential to drive  
731 either direct or indirect food web interactions. However, despite numerous food  
732 habits studies of Pacific hake dating back to the 1960s, evidence of predation on  
733 salmon smolts is very limited, despite strong predation pressure on comparably  
734 sized forage fishes such as Pacific sardines, northern anchovies and Pacific herring.  
735 Emmet and Krutzikowsky (2008) found a total of five Chinook (four of which were  
736 ocean entry year fish, one of which was age one) in six years of monitoring predator  
737 abundance and food habits near the mouth of the Columbia river. As the population  
738 of Pacific hake is substantial, their extrapolation of the potential impact to salmon  
739 populations suggested consumption of potentially millions of smolts during years  
740 of high hake abundance, although the relative impact to the total number of smolts  
741 in the region (on the order of 100 million per year) was likely to be modest (al-  
742 beit uncertain). Jack mackerel (*Trachurus symmetricus*) were another relative abun-  
743 dant predator with limited predation on salmon in their study, and Pacific mackerel  
744 (*Scomber japonicus*) have also been implicated with inflicting significant predation  
745 mortality on outmigrating salmon smolts at some times and places (Ashton et al.,  
746 1985).

747 In nearshore waters, examples of piscivores preying upon salmonids are rel-  
748 atively rare. Brodeur et al. (1987) found infrequent but fairly high predation on  
749 salmon smolts (both Chinook and coho) from black rockfish (*Sebastes melanops*)

750 collected from purse-seine studies off of the Oregon coast in the early 1980s, but  
751 no other rockfish species have been documented to prey on salmonids. Cass et al.  
752 (1990) included salmon in a long list of lingcod prey items in Canadian waters,  
753 but studies in California have not encountered salmon in lingcod diets and there  
754 is no evidence that lingcod are a significant salmon predator. In offshore waters,  
755 sablefish (*Anoplopoma fimbria*) are one of the most abundant higher trophic level  
756 groundfish species, however with the exception of trace amounts of *Oncorhynchus*  
757 sp. reported by Buckley et al. (1999), several other sablefish food habits studies in  
758 the California Current have not reported predation on salmonids. Salmon have also  
759 been noted as important prey of soupfin sharks (*Galeorhinus galeus*) in historical  
760 studies off of Washington and California. Larger salmon have also been noted in the  
761 diets of sleeper sharks, and presumably salmon sharks (*Lamna ditropis*) are likely  
762 salmon predators when they occur in the California Current. However, none of  
763 these species are likely to be sufficiently abundant, nor were reported to be present  
764 in unusual numbers, throughout the 2005-2006 period.

765 Population turnover rates for most groundfish species are typically relatively  
766 low, and consequently it is unlikely that short term fluctuations in the relative  
767 abundance of predatory groundfish could make a substantive short-term impact on  
768 salmon productivity. However, many groundfish population in the California Cur-  
769 rent have experienced significant to dramatic changes in abundance over the past  
770 decade, a consequence of both reduced harvest rates and dramatically successful  
771 recruitment observed immediately following the 1997-98 El Niño. Specifically, for  
772 most stocks in which recruitment events are reasonably well specified, the 1999  
773 year class was estimated to be as great or greater than any recruitment over the  
774 preceding 15 to 20 years (Fig. 31). For example, the 1999 bocaccio (*Sebastes pau-*  
775 *cispinis*) year class was the largest since 1989, resulting in a near doubling of stock  
776 spawning biomass between 1999 and 2005 (MacCall, 2006). Similarly, the 1999  
777 Pacific hake year class was the largest since 1984, which effectively doubled the  
778 stock biomass between 2000 and 2004 (Helser et al., 2008). Lingcod, cabezon,  
779 sablefish, most rockfish and many flatfish also experienced strong year classes, re-  
780 sulting in a doubling or even tripling in total biomass between 1999 and 2005 for  
781 many species. There is growing evidence that many of these species also experi-  
782 enced a strong 2003 year class, although the relative strength may not have been  
783 as great as the 1999 event. Biomass trends for jack mackerel are unknown but  
784 there is no evidence of recent, dramatic increases; the Pacific mackerel biomass has  
785 been increasing modestly in recent years based on the latest assessment, but is still  
786 estimated to be far below historical highs.

787 These population trends could potentially have increased the abundance, and  
788 therefore predation rates, on salmon by some of these species. However, all of  
789 these species are considered to still be at levels far below their historical (unfished)  
790 abundance levels, and many have again shown signs of population decline (Pacific  
791 hake and sablefish) heading into the 2005-2006 period. For Pacific hake, the dis-  
792 tributional overlap of larger hake with salmon smolts is likely to be much less than  
793 that off of the Columbia River, particularly in warm years when adult hake tend to  
794 be distributed further north. In the absence of any evidence for unusual distribution



**Figure 31:** Spawning biomass (black line) and recruitment (light gray line) of selected groundfish species off of central California.

795 or behavior of these stocks, it is difficult to envision a mechanism by which these  
 796 species could have inflicted any more than modest changes in predation mortality  
 797 rates for Pacific salmon in recent years.

## 798 **8 Cumulative Ecosystem Effects Focus**

799 *8.1 Were there other ecosystem effects? Were there synergistic effects of signifi-*  
 800 *cant factors?*

801 These questions are addressed in the main text.

## 802 9 Salmon Fisheries Focus

### 803 9.1 To what extent did fisheries management contribute to the unusually low SRFC 804 spawning escapements in 2007 and 2008?

805 While the evidence clearly indicates that the weak year-class strength of the 2004  
806 and 2005 broods was well established by ocean age-2, prior to fishery recruitment,  
807 the question nevertheless arises, to what extent did ocean and river fisheries con-  
808 tribute to the unusually low SRFC spawning escapements in 2007 and 2008? SRFC  
809 contribute to fishery harvest and spawning escapement primarily as age-3 fish, and  
810 thus the 2004 and 2005 broods primarily contributed to the 2007 and 2008 escape-  
811 ments, respectively, which in turn were primarily impacted by the 2007 and 2008  
812 fisheries, respectively.

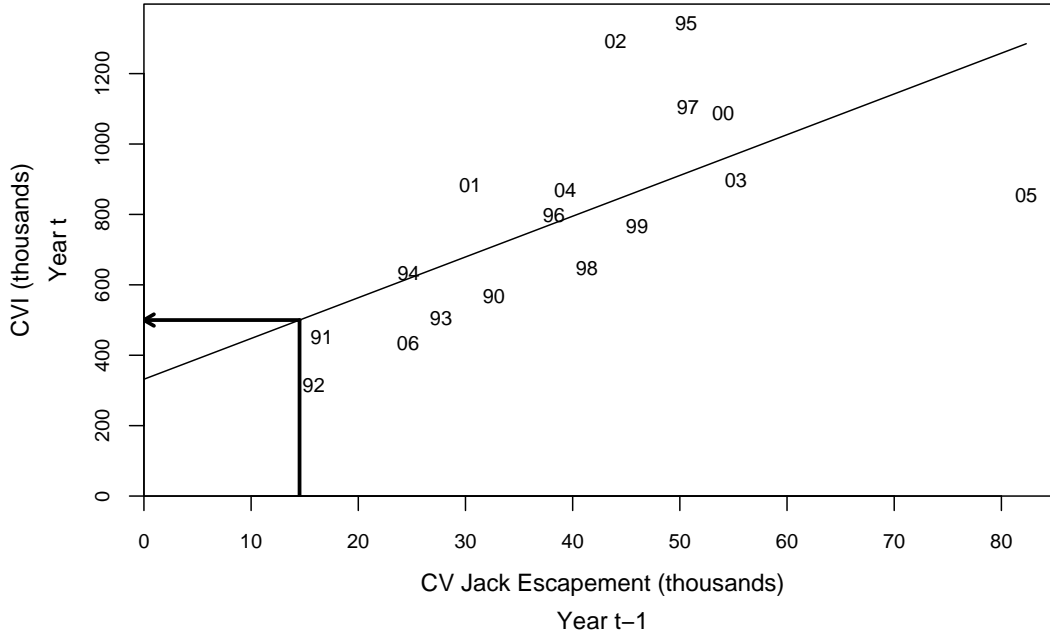
813 Ocean fishery management regulations are developed anew each year by the  
814 PFMC with the aim of meeting, in expectation, the annual conservation objec-  
815 tives for all stocks under management. For SRFC, the annual conservation ob-  
816 jective is a spawning escapement of 122,000–180,000 adults (hatchery plus natural  
817 area spawners). The PFMC uses mathematical models to forecast SRFC expected  
818 spawning escapement as a function of the stock’s current ocean abundance and a  
819 proposed set of fishery management regulations.

820 For 2007, the PFMC forecast SRFC expected spawning escapement as

$$E_{SRFC} = CVI \times (1 - h_{CV}) \times p_{SRFC} \quad (1)$$

821 based on forecasts of the three right-hand side quantities. The Central Valley In-  
822 dex ( $CVI$ ) is an annual index of ocean abundance of all Central Valley Chinook  
823 stocks combined, and is defined as the calendar year sum of ocean fishery Chinook  
824 harvests in the area south of Point Arena, California, plus the Central Valley adult  
825 Chinook spawning escapement. The  $CV$  harvest rate index ( $h_{CV}$ ) is an annual in-  
826 dex of the ocean harvest rate on all Central Valley Chinook stocks combined, and  
827 is defined as the ocean harvest landed south of Point Arena, California, divided  
828 by the  $CVI$ . Finally,  $p_{SRFC}$  is the annual proportion of the Central Valley adult  
829 Chinook combined spawning escapement that are Sacramento River fall Chinook.  
830 The model above implicitly assumed an average SRFC river fishery harvest rate for  
831 2007, which was appropriate given that the fishery was managed under the normal  
832 set of regulations.

833 The model used to forecast the 2007  $CVI$  is displayed in Figure 32. Based on  
834 the previous year’s Central Valley Chinook spawning escapement of 14,500 jacks,  
835 the 2007  $CVI$  was forecast to be 499,900 (PFMC, 2007a). The harvest rate index,  
836  $h_{CV}$ , was forecast as the sum of the fishery-area-specific average harvest rate in-  
837 dices observed over the previous five years, each scaled by the respective number  
838 of days of fishing opportunity in 2007 relative to the average opportunity over the  
839 previous five years. The 2007  $h_{CV}$  was forecast to be 0.39. The 2007 SRFC spawn-  
840 ing proportion,  $p_{SRFC}$ , was forecast to be 0.87; the average proportion observed  
841 over the previous five years. Thus, the 2007 SRFC adult spawning escapement was



**Figure 32:** PFMC 2007 *CVI* forecast regression model. Numbers in plot are last two digits of *CVI* year; e.g., “92” denotes *CVI* year 1992. Arrow depicts *CVI* prediction of 499,900 based on the 2006 Central Valley Chinook spawning escapement of 14,500 jacks.

842 forecast to be (PFMC, 2007b)

$$E_{SRFC} = 499,900 \times (1 - 0.39) \times 0.87 = 265,500; \quad (2)$$

843 exceeding the upper end of the escapement goal range.

844 The 2007 realized values of the *CVI*,  $h_{CV}$ ,  $p_{SRFC}$ , and  $E_{SRFC}$  are displayed  
 845 alongside their forecast values in Table 7. The errors of all three model compo-  
 846 nent forecasts contributed to the over-optimistic  $E_{SRFC}$  forecast. Ocean harvest of  
 847 Chinook salmon generally off California was about one-third of the previous ten-  
 848 year average in both the commercial and recreational fisheries, and the CPUE in  
 849 the recreational fishery was the lowest observed in the previous 25 years (PFMC,  
 850 2008d). However, the *CVI* was also the lowest on record so that  $h_{CV}$  was higher  
 851 than forecast, although within the range of variation to be expected. The realized  
 852 river fishery harvest rate was 0.14 (O’Farrell et al., 2009), which closely matched  
 853 the average rate implicitly assumed by the  $E_{SRFC}$  forecast model. The realized  
 854  $p_{SRFC}$  was the lowest observed over the previous 20 years, resulting from the low  
 855 escapement of SRFC in 2007 combined with the relatively level escapements of the  
 856 other runs of Central Valley Chinook (late-fall, winter, spring) as discussed earlier  
 857 in this report. The most significant forecast error, however, was of the *CVI* itself.  
 858 Had the *CVI* forecast been accurate and fishing opportunity further constrained  
 859 by management regulation in response, so that the resulting  $h_{CV}$  was reduced by  
 860 half, the SRFC escapement goal would have been met in 2007. Thus, fishery man-  
 861 agement, while not the cause of the weakness of the 2004 brood, contributed to  
 862 the SRFC escapement goal not being achieved in 2007, primarily due to an over-

**Table 7:** PFMC 2007 SRFC spawning escapement prediction model components: forecast and realized values. *Ratio = Realized ÷ Forecast.*

2007	Forecast	Realized	Ratio
<i>CVI</i>	499,900	232,700	0.47
$h_{CV}$	0.39	0.48	1.23
$p_{SRFC}$	0.87	0.73	0.84
$E_{SRFC}$	265,500	87,900	0.33

863 optimistic forecast of the strength of the 2004 brood.

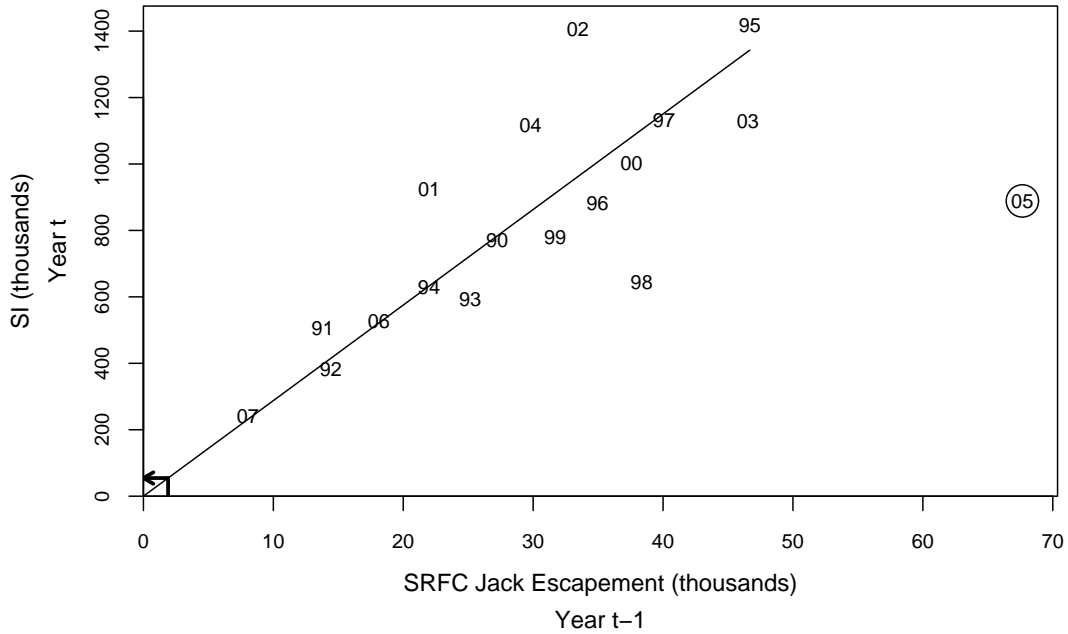
864 The 2007 SRFC escapement of jacks was the lowest on record (1,900 fish),  
 865 significantly lower than the 2006 jack escapement (8,000 fish), which itself was  
 866 the record low at that time. These back-to-back SRFC brood failures and the over-  
 867 optimistic 2007 forecast of  $E_{SRFC}$  prompted a thorough review of the data and  
 868 methods used to forecast  $E_{SRFC}$  prior to the development of fishery management  
 869 regulations for 2008 (PFMC, 2008a,b). The review findings included the following  
 870 recommendations: (1) the  $E_{SRFC}$  model components should all be made SRFC-  
 871 specific, if possible; (2) SRFC ocean harvest north of Point Arena, California, to  
 872 Cape Falcon, Oregon, and SRFC river harvest should be explicitly accounted for in  
 873 the model; and (3) inclusion of the 2004 record high jack escapement data point in  
 874 the ocean abundance forecast model results in overly-optimistic predictions at low  
 875 jack escapement levels; it should be omitted from the model when making forecasts  
 876 at the opposite end of the scale.

877 Following these recommendations, the methods used to forecast  $E_{SRFC}$  in 2008  
 878 were revised as follows (PFMC, 2008b). First, historical SRFC coded-wire tag  
 879 recovery data in ocean salmon fisheries were used to develop estimates of SRFC  
 880 ocean harvest in all month-area-fishery strata south of Cape Falcon, Oregon, for  
 881 years 1983–2007. Second, Sacramento River historical angler survey data was used  
 882 to develop estimates of SRFC river harvest for years in which these surveys were  
 883 conducted (1991–1994, 1998–2000, 2002, 2007). Third, a SRFC-specific annual  
 884 ocean abundance index, the *Sacramento Index (SI)* was derived by summing SRFC  
 885 ocean harvest from September 1, year  $t - 1$  through August 31, year  $t$  and SRFC  
 886 adult spawning escapement, year  $t$ <sup>1</sup>. The fall year  $t - 1$  through summer year  $t$   
 887 accounting of ocean harvest better reflects the period during which ocean fishery  
 888 mortality directly impacts the year  $t$  spawning escapement of SRFC, given the late-  
 889 summer / early-fall run timing of the stock. Fourth, an SRFC-specific ocean harvest  
 890 rate index,  $h_{SRFC,o}$ , was defined as the SRFC harvest divided by the *SI*. Fifth, an  
 891 SRFC-specific river harvest rate,  $h_{SRFC,r}$  was defined as the SRFC river harvest  
 892 divided by the SRFC river run (harvest plus escapement). Sixth, a new  $E_{SRFC}$   
 893 forecast model was constructed based on these quantities as (Mohr and O’Farrell,  
 894 2009)

$$E_{SRFC} = SI \times (1 - h_{SRFC,o}) \times (1 - h_{SRFC,r}) / (1 - h_{SRFC,r}^*), \quad (3)$$

<sup>1</sup>the *SI* has since been modified to include SRFC adult river harvest as well for assessments beginning in 2009 (O’Farrell et al., 2009).





**Figure 33:** PFMC 2008 *SI* forecast regression model. Numbers in plot are last two digits of *SI* year; e.g., “07” denotes *SI* year 2007. Circled data point (*SI* year 2005) omitted from model. Arrow depicts *SI* prediction of 54,600 based on the 2007 SRFC spawning escapement of 1,900 jacks.

895 where  $h_{SRFC,r}^*$  is the SRFC river harvest rate expected under normal management  
 896 regulations. The PFMC used this model in 2008 to predict  $E_{SRFC}$  based on fore-  
 897 casts of the right-hand side quantities.

898 The 2008 *SI* forecast model is displayed in Figure 33. The 2004 record high  
 899 jack escapement data point (*SI* year 2005) was omitted from the model, and the re-  
 900 lationship was fitted through the origin. From the 2007 SRFC spawning escapement  
 901 of 1,900 jacks, the 2008 *SI* was forecast to be 54,600 (PFMC, 2008b). For  $h_{SRFC,o}$ ,  
 902 a forecast model was developed by relating the SRFC month-area-fishery-specific  
 903 historical harvest rate indices to the observed fishing effort and, subsequently, fish-  
 904 ing effort to operative management measures. The previous year September 1  
 905 through December 31 SRFC harvest was estimated directly using observed coded-  
 906 wire tag recoveries, divided by the forecast *SI*, and incorporated in the  $h_{SRFC,o}$   
 907 forecast. Methods were also developed to include in  $h_{SRFC,o}$  non-landed fishing  
 908 mortality in the case of non-retention fisheries. With the PFMC adopted fishery  
 909 closures in 2008, the forecast  $h_{SRFC,o}$  was 0.08. The non-zero forecast was primar-  
 910 ily due to SRFC ocean harvest the previous fall (2007), with a minor harvest impact  
 911 (< 100 fish) expected from the 2008 mark-selective coho recreational fishery con-  
 912 ducted off Oregon. For the river fishery, the average harvest rate under normal  
 913 management regulations was estimated to be 0.14 based on the historical angler  
 914 survey data (O’Farrell et al., 2009). With the California Fish and Game Commis-  
 915 sion (CFGF) closure of the 2008 SRFC river fishery,  $h_{SRFC,r}$  was forecast to be  
 916 zero. Thus, the 2008 SRFC adult spawning escapement was forecast to be (PFMC,

**Table 8:** PFMC 2008 SRFC spawning escapement prediction model components: forecast and realized values.  $Ratio = Realized \div Forecast$ .

2008	Forecast	Realized	Ratio
$SI$	54,600	70,400	1.29
$h_{SRFC,o}$	0.08	0.06	0.75
$h_{SRFC,r}$	0.00	0.01	–
$E_{SRFC}$	59,000	66,300	1.12

917 2008c)

$$E_{SRFC} = 54,600 \times (1 - 0.08) \times (1 - 0.00) / (1 - 0.14) = 59,000; \quad (4)$$

918 less than one-half of the lower end of the escapement goal range.

919 The 2008 realized values of the  $SI$ ,  $h_{SRFC,o}$ ,  $h_{SRFC,r}$ , and  $E_{SRFC}$  are displayed  
 920 alongside their forecast values in Table 8. The  $SI$  and harvest rates were well-  
 921 forecast in April 2008, leading to a forecast of  $E_{SRFC}$  that was very close to the  
 922 realized escapement. Given this forecast, the PFMC and CFGC took immediate  
 923 action to close all Chinook fisheries impacting the stock for the remainder of 2008.  
 924 The one exception to the complete closure was the Sacramento River late-fall run  
 925 target fishery, which was assumed to have a small number of SRFC impacts which  
 926 are reflected in the non-zero realized value of  $h_{SRFC,r}$ . The 2007 ocean fall fisheries  
 927 did contribute to fewer SRFC spawning adults in 2008 than would have otherwise  
 928 been the case, but only minimally so. Clearly, the proximate reason for the record  
 929 low SRFC escapement in 2008 was back-to-back recruitment failures, and this was  
 930 not caused by fisheries management.

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