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

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1 Purpose of the appendix

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

2 Freshwater Biological Focus

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

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

2.2 Was the level of parent spawners too high, for natural or hatchery populations?

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

2.3 Was there a disease event in the hatchery or natural spawning areas? Was there a disease event in the egg incubation, fry emergence, rearing, or downstream migration phases? Was there any disease event during the return phase of the 2 year old jacks?

There were no known disease events affecting naturally-produced brood-year 2004 and 2005 fall-run Chinook in the Sacramento River or tributaries, although there is no routine fish health sampling program for naturally produced fish the Sacramento River system. In the Feather River Hatchery, brood-year 2004 and 2005 Chinook were treated an average of five to six times a year, primarily for bacterial infection. The typical treatment was copper sulfate flushes. This incidence of disease was not unusually high compared to other recent years. In the Mokelumne River Hatchery, brood-year 2004 and 2005 Chinook experienced minimal losses from coagulated yolks. At the Nimbus Hatchery, there were no significant disease events affecting brood-year 2004 Chinook. Brood-year 2005 fall-run Chinook experienced an outbreak of infectious hematopoietic necrosis (IHN). Losses began to spike in mid-April and continued through May before declining. Losses incurred represented 44% of the fish on hand at the time of the outbreak. However, the hatchery planted 3,002,600 brood-year 2005 fish, approximately 75% of the mitigation goal of 4 million fish. There were no significant disease outbreaks at the Coleman National Fish hatchery for the 2004 and 2005 broods. We therefore conclude that disease events during the freshwater lifestages are an unlikely explanation for the poor performance of the 2004 and 2005 broods.

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

No unusual mortality events were noted for these broods.

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

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

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

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

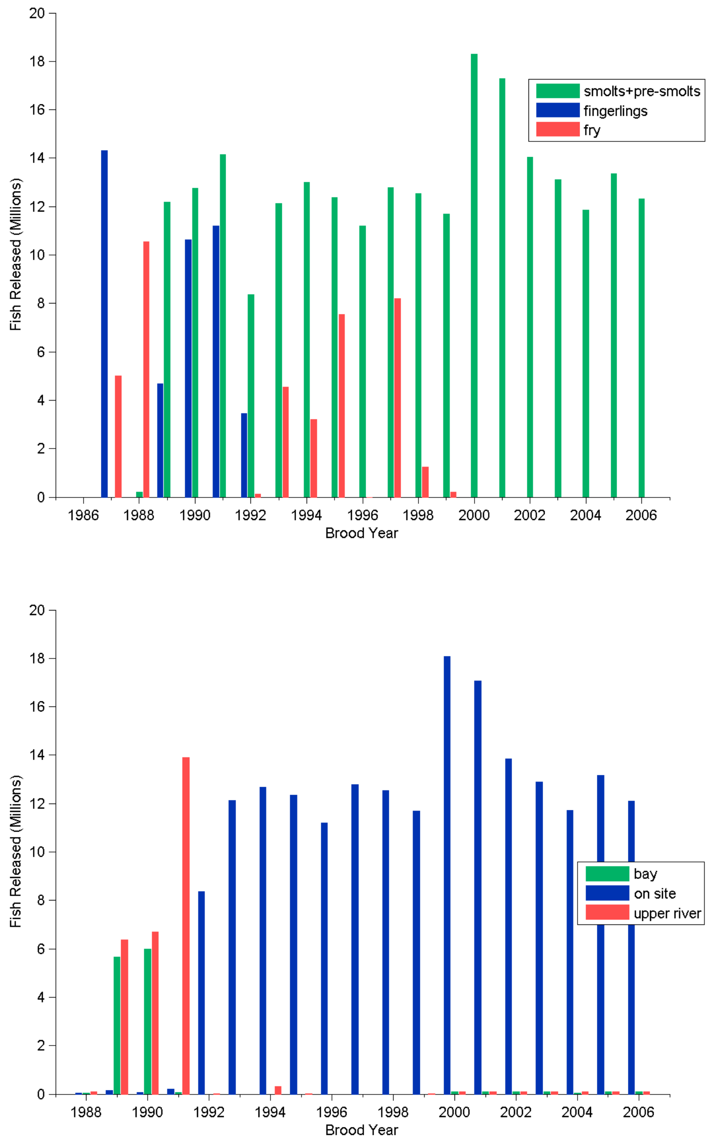


Figure 1: Top: Releases of fall-run Chinook from Coleman National Fish Hatchery. Bottom: number of smolts and pre-smolts released to the bay, upper river and on site (Battle Creek).

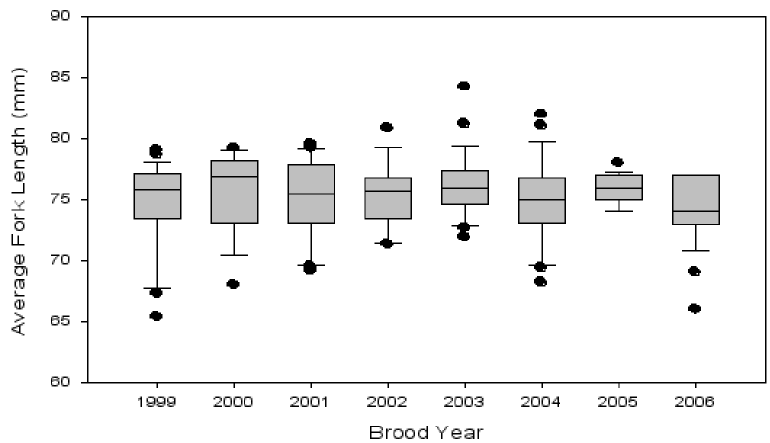


Figure 2: Size of fall Chinook released from Coleman National Fish Hatchery. Horizontal lines indicate mean size, boxes delineate the inner-quartile range, and whiskers delineate the 95% central interval.

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

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

Table1 shows the release locations of fall-run Chinook from each of the Sacramento River Basin state hatchery facilities, 1990 to 2006. Instream releases include releases into the stream of origin, the mainstem Sacramento River, or within the Delta. Bay releases include fish transported for release in the San Pablo Bay/Carquinez Straits/San Francisco Bay area or to ocean net pens.

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

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

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

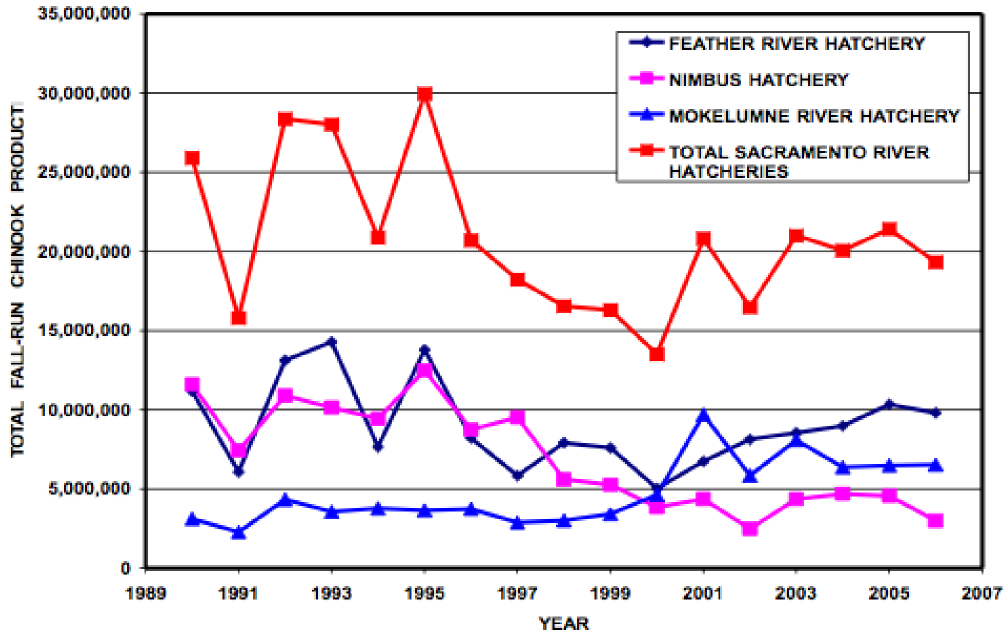


Figure 3: Releases of fall-run Chinook from state hatcheries.

Table 1: Releases of Chinook from state hatcheries.

		Feather River		Nimbus		Mokelumne	
Release Year	Brood Year	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

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

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

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

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

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

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

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

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

All chemical treatments at the state hatcheries were used under the guidelines set by the CDFG Fish Health Lab. There were no significant changes in chemical use or feeds over the 1990-2007 period. Some Bio-Oregon/Skretting salmon feeds 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

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

3 Freshwater Habitat Areas Focus

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

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

3.2 Was there any pollution event where juveniles were present?

The possibility has been raised that exposure of outmigrating juvenile salmon to 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.

	Month					
Water Year	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

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

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

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

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

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

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

3.5 Was there anything unusual about the water withdrawals in the rivers or estuary areas when this brood was present?

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

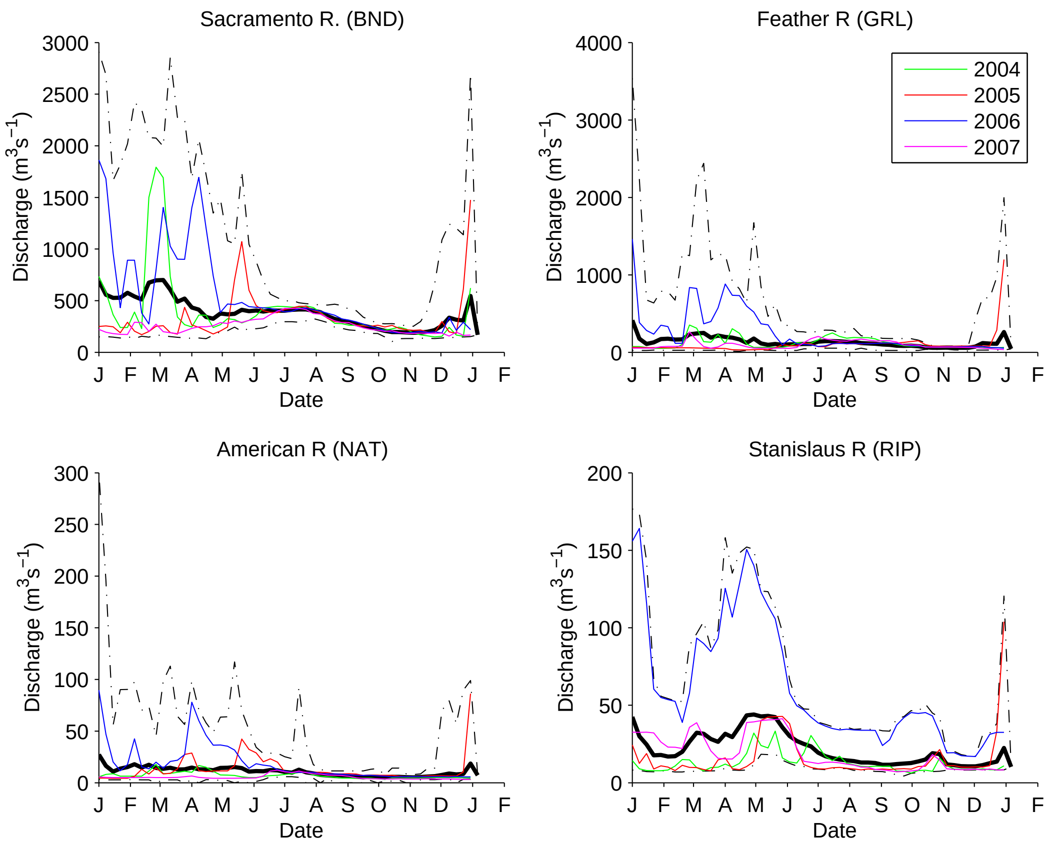


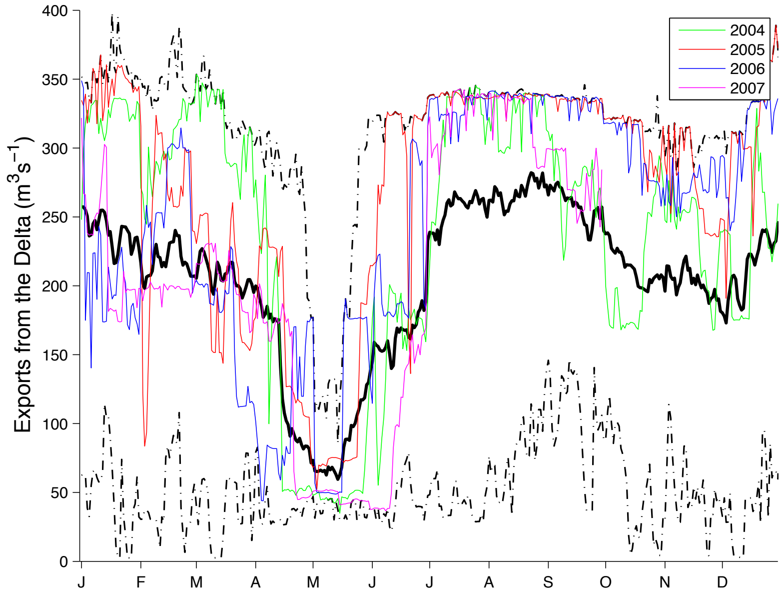
Figure 4: Weekly mean discharge at selected stations on the Sacramento, Feather, American and Stanislaus rivers. Heavy black line is the weekly mean flow over the period of record at each station (BND=1993-2007; GRL=1993-2007, NAT=1990-2007, RIP=1999-2007); dashed black lines are the maximum and minimum 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

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

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



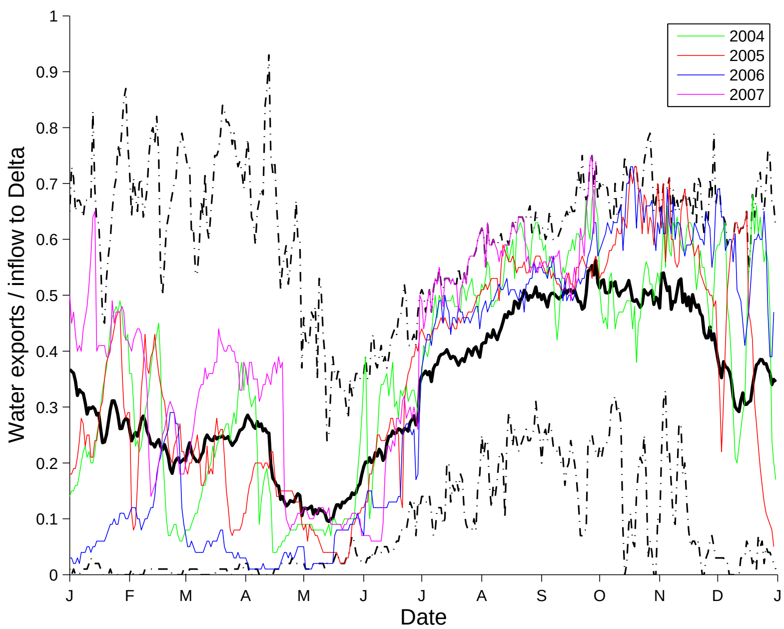


Figure 5: Daily export of freshwater from the delta (upper panel) and the ratio of exports to inflows (bottom panel). Heavy black line is the daily average discharge over the 1955-2007 period; dashed black lines indicate daily maximum and minimum discharges. Flow estimates from the DAYFLOW model (`http://www.iep.ca.gov/dayflow/`).

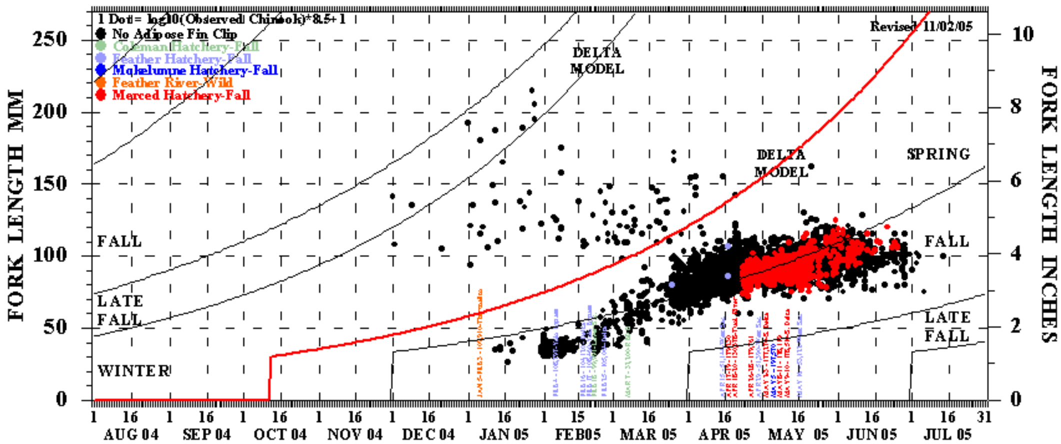


Figure 6: Observed Chinook salvage at the State Water Project and Central Valley Project pumping facilities in the Delta, Aug 2007 through July 2005. Classification of run is based on growth models (represented by curved lines). Note that almost no Chinook are salvaged at the facilities after July 1. Unpublished data of California Department of Water Resources.

3.6 Was there an oil spill in the estuary when the 2005 brood was present, as juveniles or jacks?

The cargo ship *Cosco Busan* spilled 58,000 gallons of bunker fuel into San Francisco Bay on 7 November 2007, when the bulk of 3-year-olds from the 2004 brood and 2-year-olds from the 2005 brood would have been upstream of the Bay by November, so it is unlikely that this spill had much effect on these broods. No other spills were noted.

3.7 Were there any unusual temperature or other limnological conditions when this brood was in freshwater or estuarine areas?

Upper river– Water temperatures were fairly normal at Red Bluff Diversion Dam for 2005 and 2006 (Fig. 7). Temperatures were slightly warmer than normal in the early part of 2005, and slightly colder than normal in the early part of 2006. In the early part of both years, and especially in 2005, turbidity at Red Bluff Diversion Dam was quite low for extended periods between turbidity pulses.

Estuary and Bay– An analysis of water quality and quantity data found no indications that aquatic conditions contributed to the decline of the 2004 or 2005 brood year fall-run Chinook. Mean water temperature between January and June, which spans the time of juveniles emigrating through the estuary, was 14.4°C and 12.5°C for 2005 and 2006, respectively, when the juveniles of the 2004 and 2005 broods outmigrated. These temperatures are well within the preferred range of juvenile Chinook, and within the range of annual means between 1990 and 2008 (19-year mean: 13.8±1.0°C (SE).) (Figure 8a).

Mean salinity in the estuary between January and June was 11.9 and 8.7 for 2005 and 2006, respectively. These are typical values for San Francisco Estuary and reflect relative differences in freshwater outflow and/or measurements at different

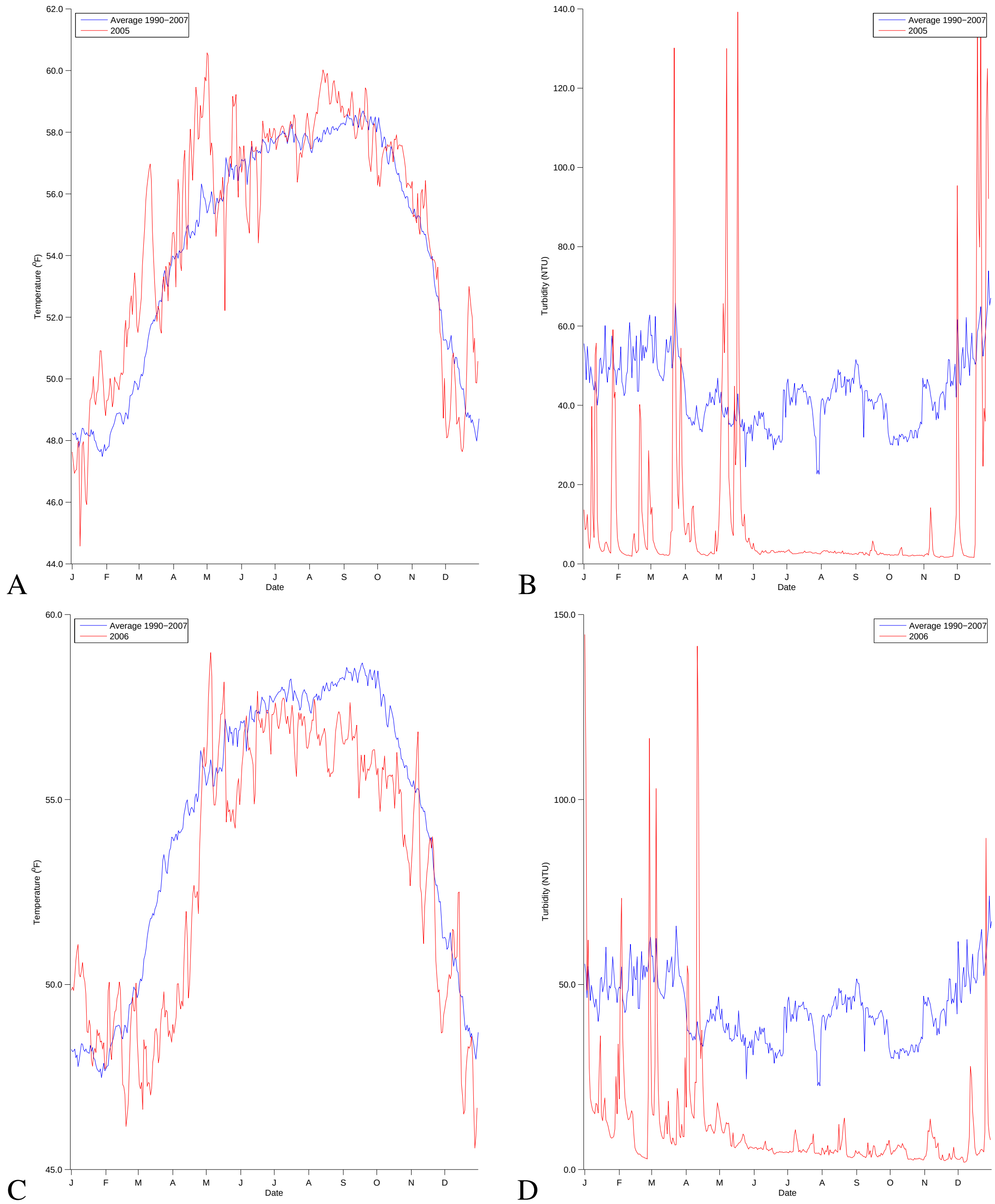


Figure 7: Temperature (A and C) and turbidity (B and D) in 2005 and 2006 at Red Bluff.

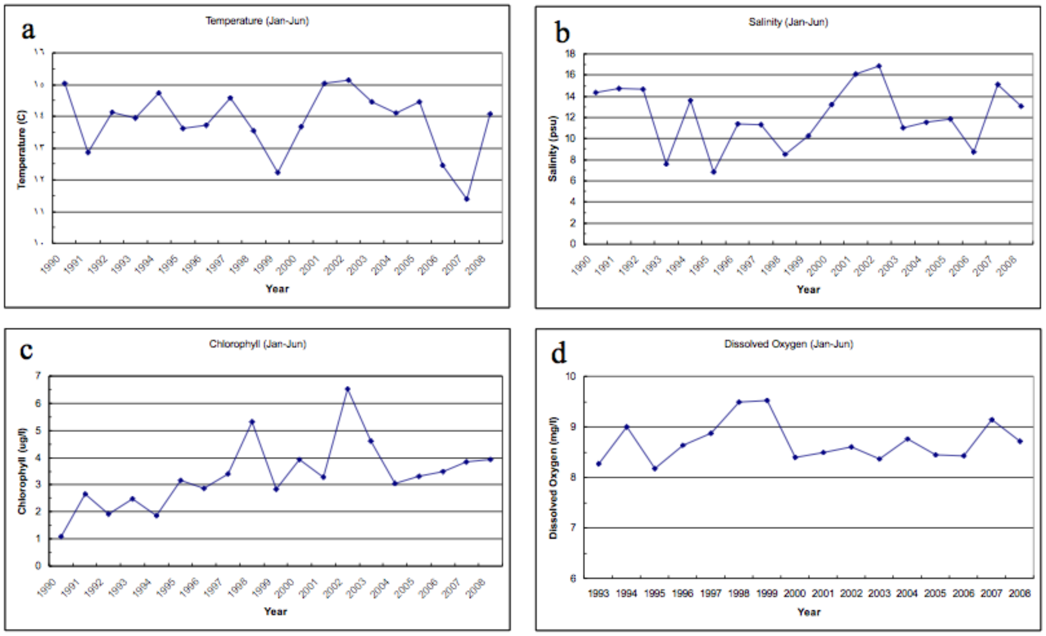


Figure 8: Mean annual values near the surface between January and June for a) water temperature, b) salinity, c) chlorophyll, and d) dissolved oxygen for San Francisco Estuary between Chipps Island and the Golden Gate. (Source: USGS Water Quality of San Francisco Bay: `http://sfbay.wr.usgs.gov/water`.)

times on the tidal cycle. Mean salinity for the 19 years was 12.1±2.9 (Fig. 8b).

Mean chlorophyll concentrations, an indicator of primary productivity, were similar to the long-term mean of 3.3±1.2 mg/l (Fig. 8c). The mean chlorophyll concentrations for 2005 and 2006 were 3.3 and 3.5 Î$\frac{1}{4}$g/l, respectively, indicating neither an oligotrophic or eutrophic system. The long-term trend, however, does suggest an increasing amount of phytoplankton in the estuary.

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

Freshwater outflow has been highly variable in the period 1990 to 2007 (Figure 9). During the outmigrating season, mean flows were 963 and 3,033 m3s-1 for 2005 and 2006, respectively. The long-term mean for January to June is 1,190±978 m^3s^{-1}, thus 2005 was a relatively dry year and 2006 a relatively wet year. In fact, 2006 had the greatest mean outflow of any year in the past 18. High flows through the estuary are considered beneficial for juvenile salmonids, thus 2006 was favorable. Although 2005 had lower flows, it was situated in the middle of the range: nine years had lower flows, eight had higher. Since 2001 and 2005 had similar values, and since fall Chinook returns were high and low respectively in those years, it would seem that flow does not appear to be a factor contributing to the poor survival of the 2004 and 2005 broods.

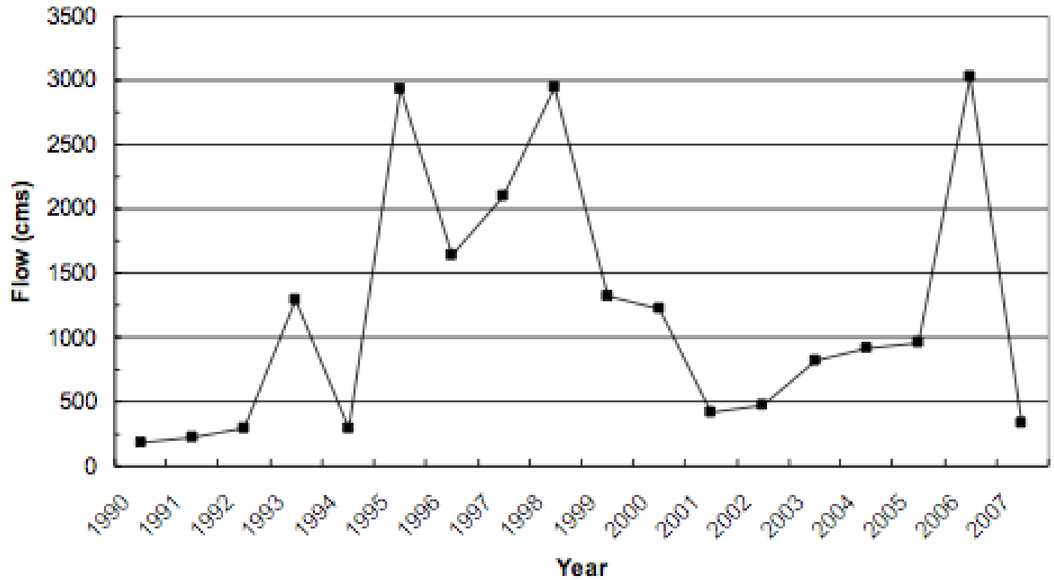


Figure 9: Mean annual freshwater outflow through San Francisco Estuary between January and June. (Source: `http://iep.water.ca.gov/dayflow/`).

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

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.

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

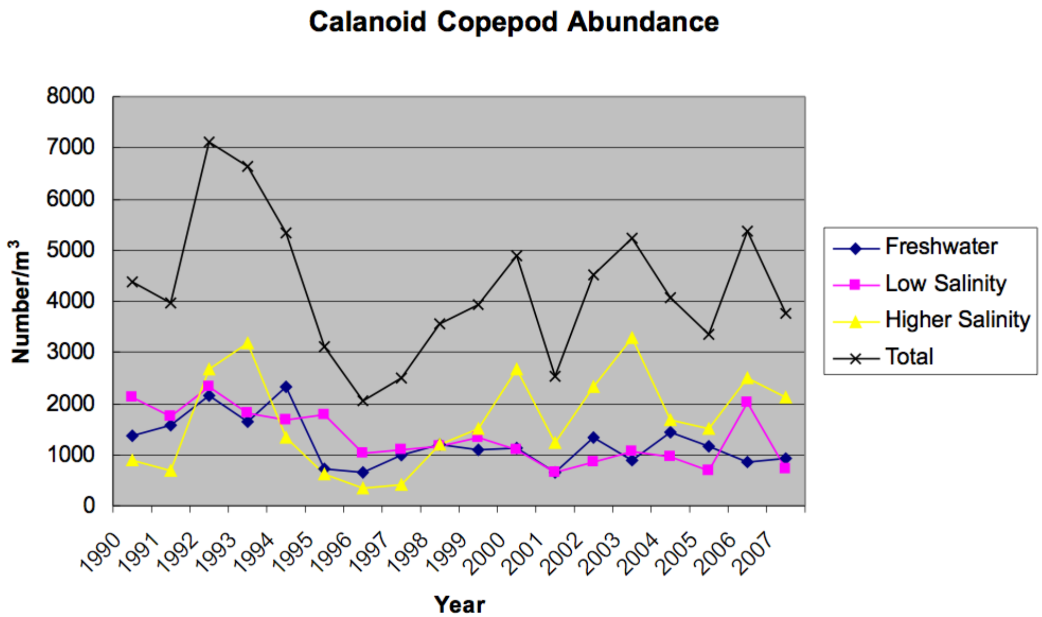


Figure 10: Mean annual abundance of calanoid copepods in the Delta, Suisun Bay and San Pablo Bay from 1990 and 2007 (Sources: Wim Kimmerer, Romberg Tiburon Center for Environmental Studies, San Francisco State University, Tiburon, California; `http://www.delta.dfg.ca.gov/baydelta/monitoring/`). Freshwater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

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

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

No unusual habitat conditions were noted.

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

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

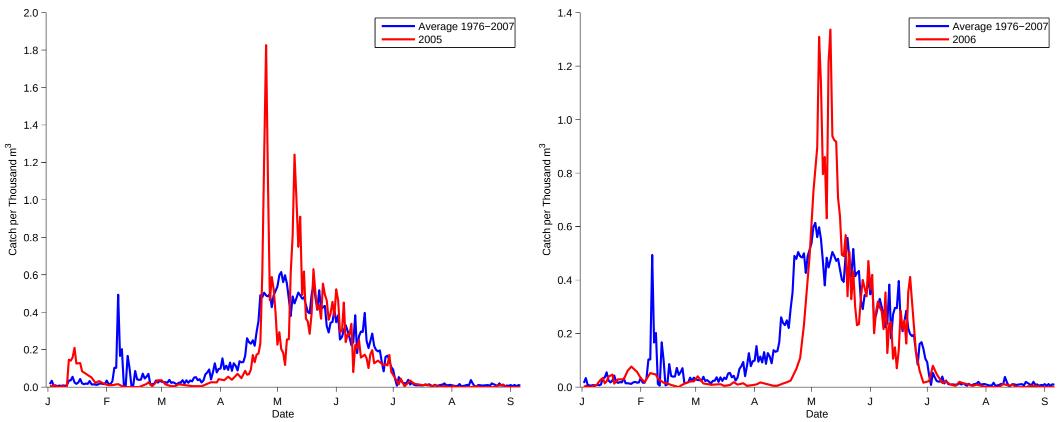


Figure 11: Daily catches of juvenile fall-run Chinook at Chipps Island in 2005 (left) and 2006 (right), in red, compared to average daily catches (in blue) for 1976-2007.

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

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

4 Freshwater Species Interactions Focus

4.1 Was there any unusual predation by bird species when this brood was in freshwater or estuarine areas?

None was noted.

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

None was noted.

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

Annual abundance estimates for adult striped bass in the Sacramento-San Joaquin Estuary from 1990 through 2005 are shown in Table 5. Estimates represent the number of adult fish in the estuary in the spring of the reporting year. The estimate for 2005 is preliminary and subject to change based on additional data. There is no 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

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

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

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

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

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

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

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

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

5 Marine Biological Focus

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

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

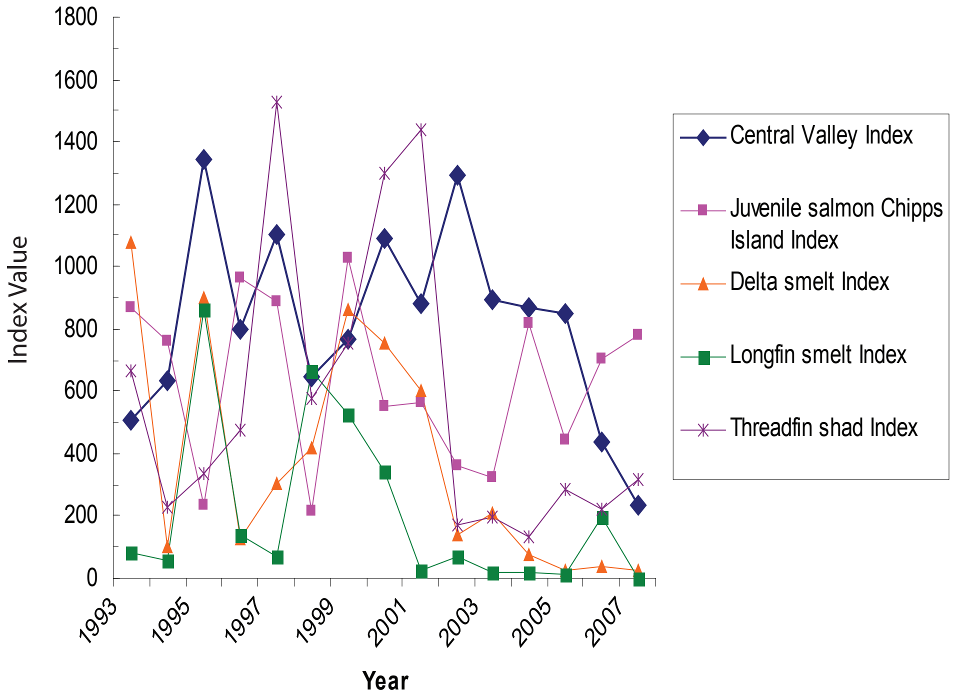


Figure 12: Abundance indices for Delta smelt, longfin smelt, and threadfin shad from California Department of Fish and Game Mid-water Trawl Surveys between 1993 and 2007 in the Delta, Suisun Bay, and San Pablo Bay (Source: `http://www.delta.dfg.ca.gov`)

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

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

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

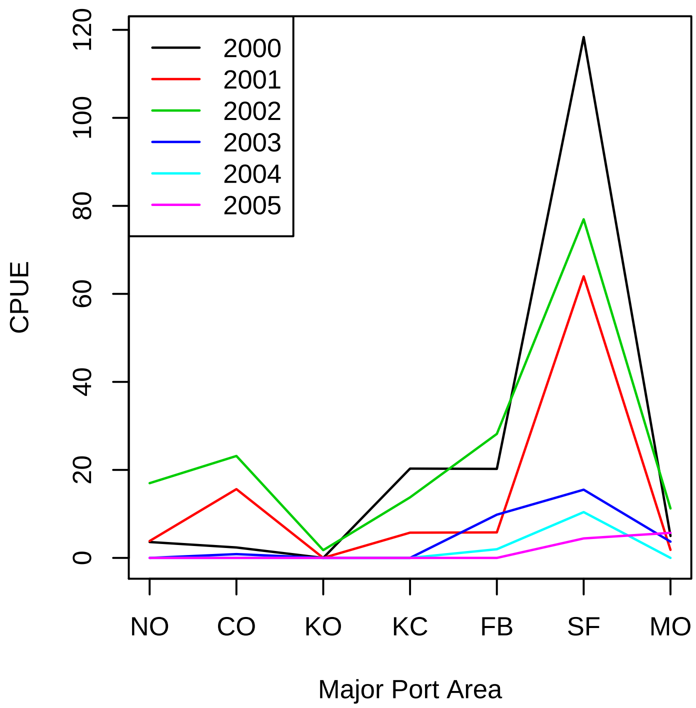


Figure 13: Recreational fishery CPUE of age-2 FRH fall Chinook by major port area; brood-years 2000-2005. CPUE was calculated as Recoveries / Effort, where "Recoveries" is coded-wire tag recoveries expanded for sampling; "Effort" is fishing angler days $\times 10-^{4}$. Major port areas shown from north 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.

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

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

6 Marine Habitat Areas Focus

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

Conditions in the coastal ocean in the spring of 2005 were unusual. Most notably, the onset of upwelling was delayed significantly compared to the climatological 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

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

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

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

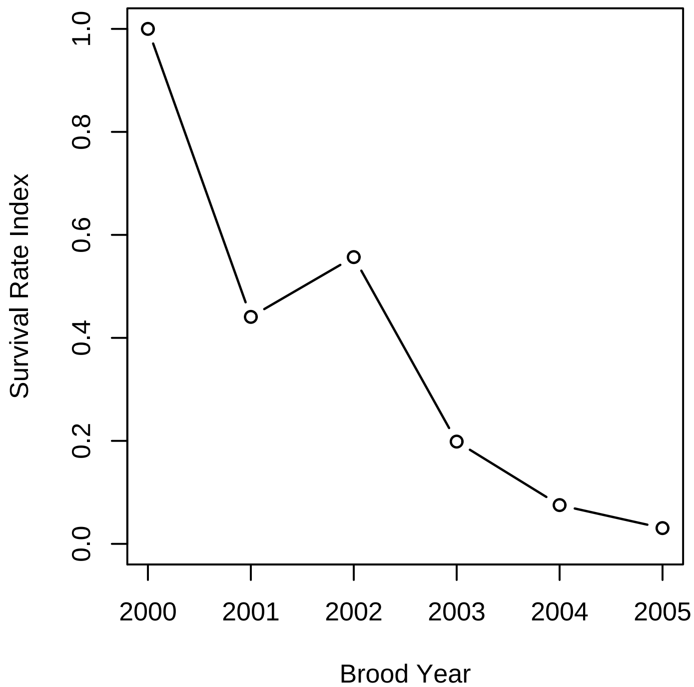


Figure 14: Index of FRH fall Chinook survival rate between release in San Francisco Bay and ocean age-2 based on coded-wire tag recoveries in the San Francisco major port area recreational fishery; brood-years 2000-2005. Survival rate index was derived as described in Table 6.

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

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

In the Gulf of the Farallones region, northwest winds were stronger offhsore

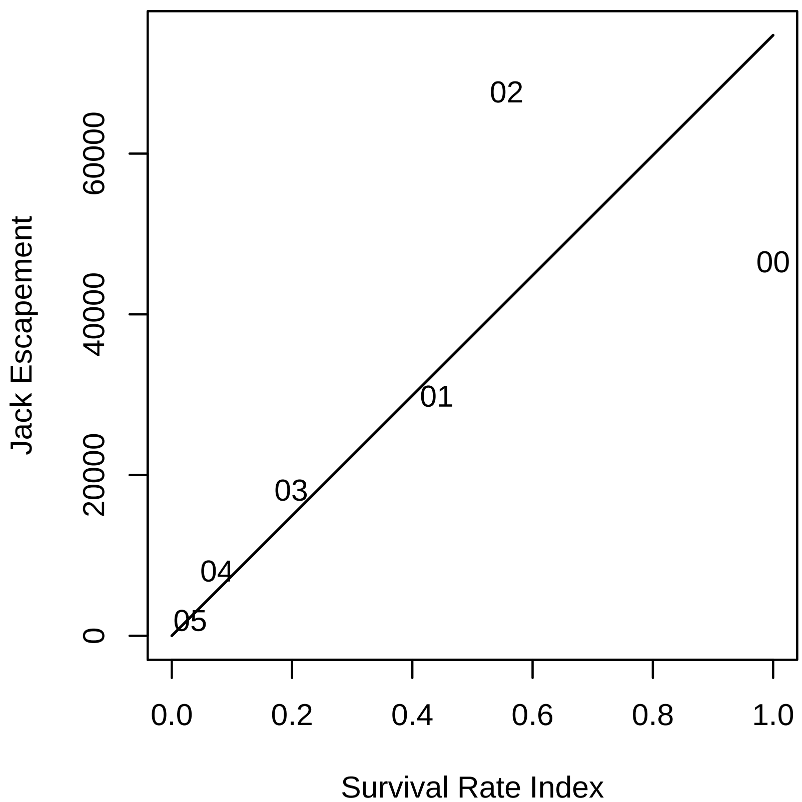
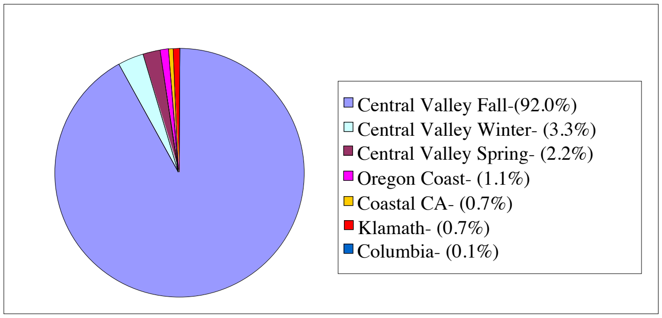


Figure 15: SRFC jack spawning escapement versus FRH fall Chinook survival rate index. Line is ratio estimate. Numbers in plot are last two digits of brood year; e.g., "05" denotes brood-year 2005 (jack return-year 2007). Line denotes ratio estimator fit to the data (through the origin with slope equal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

a)



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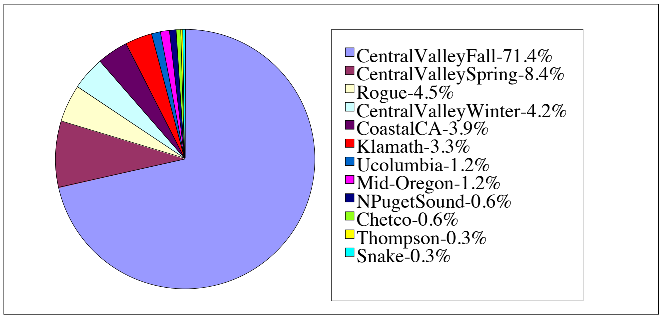

Figure 16: Composition of the Monterey Bay sport fishery landings as determined by genetic stock identification. Based on samples of 735 fish in 2006 and 340 fish in 2007. NMFS unpublished data.

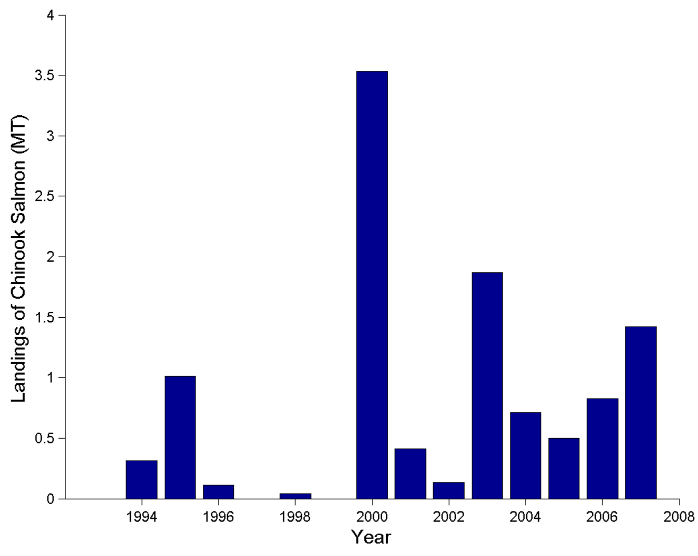

Figure 17: Landings of Chinook taken in trawl fisheries and landed at California ports. Data from the CALCOM database (D. Pearson, SWFSC, pers. comm.).

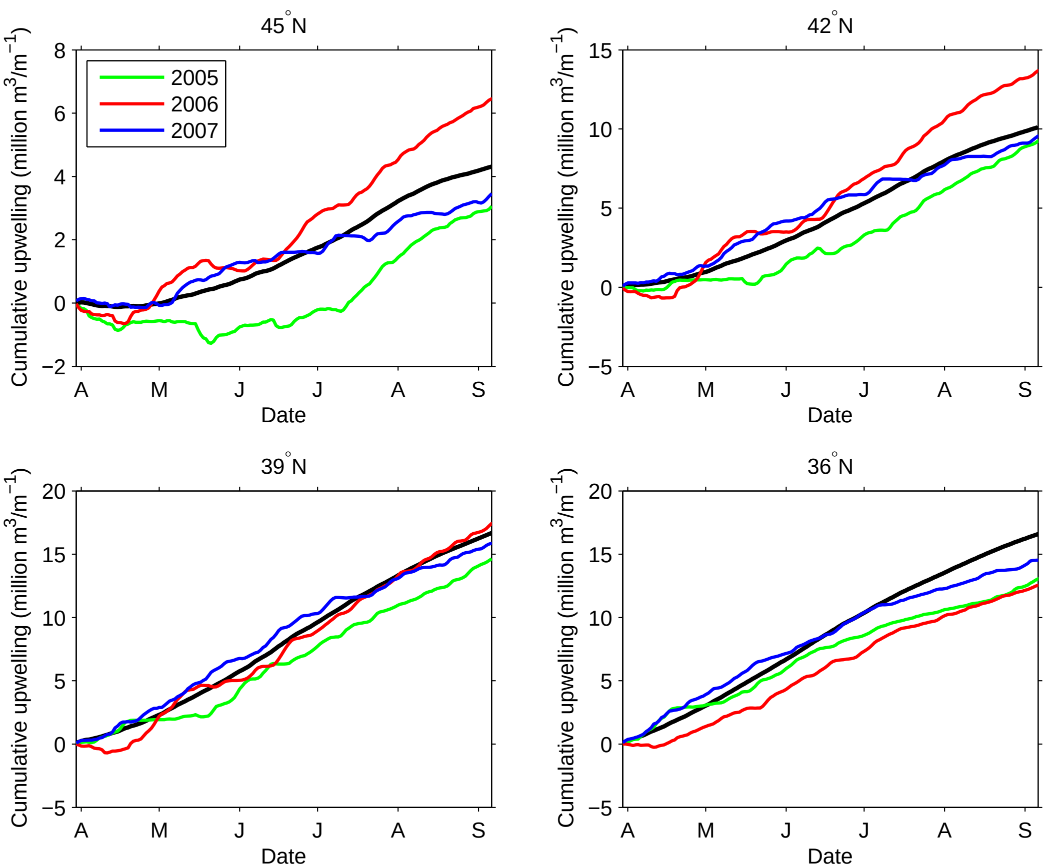

Figure 18: Cumulative upwelling at four locations along the California and Oregon coast; 45°N is near Lincoln City, Oregon; 42°N is near Brooking, Oregon, 39°N is near Pt. Arena, and 36°N is near Santa Cruz, California. Units are in millions of cubic meters per meter of shoreline. The black line represents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

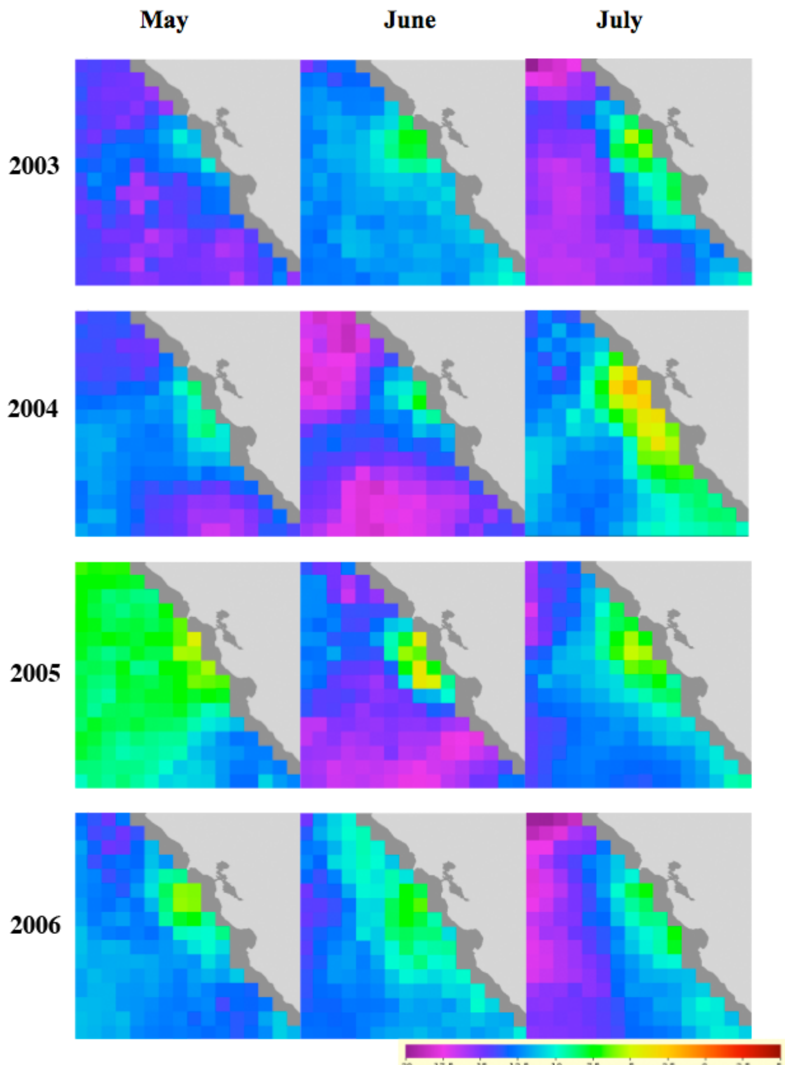

Figure 19: Strength of meridional winds (negative from the north) along the central California coast in 2003-2006. Note weak winds near the coast and in the Gulf of the Farallones in 2005 and 2006.

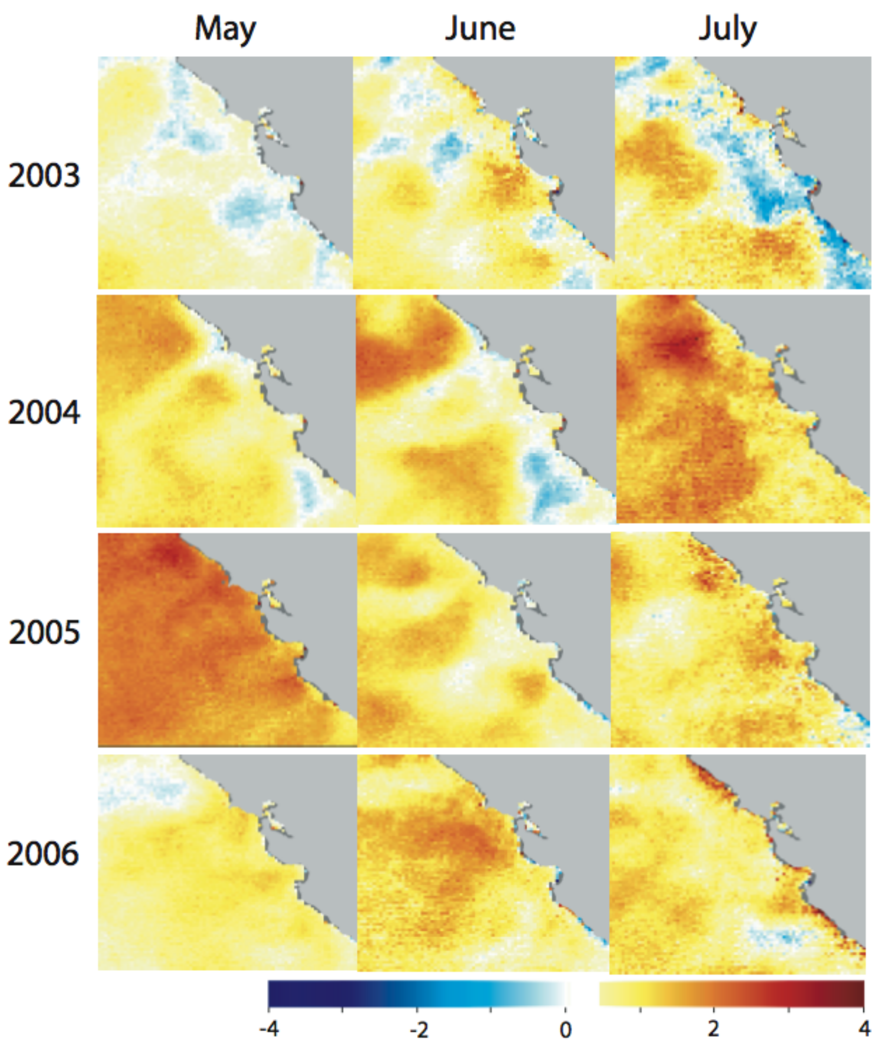

Figure 20: Sea surface temperature anomalies off central California in May (left), June (center) and July (right). Note especially warm temperatures in the Gulf of Farallones in May 2005 and June 2006, and warm temperatures along the coast in 2006. Data obtained from CoastWatch (`http://coastwatch.noaa.gov/`).

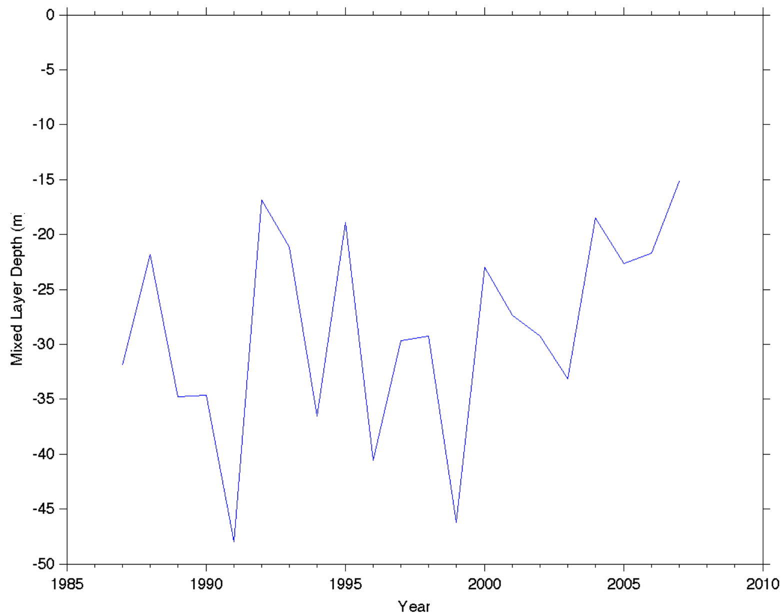

Figure 21: Average depth of the thermocline during May and June in the Gulf of the Farallones. NMFS unpublished data.

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

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

Hypoxia in inner-shelf waters can extend from the bottom to within 12 m of the surface at certain times and places (Chan et al., 2008), but juvenile salmon are usually found in the upper 10 m of the water column and are capable of rapid movement, so are not expected to be directly impacted by hypoxic events. Furthermore, hypoxia has not been observed on the inner shelf in California waters, where juvenile Chinook from the Central Valley are thought to rear. It is conceivable that outbreaks of hypoxia alter the distribution of Chinook, their prey, and their predators, but this seems an unlikely explanation for the poor performance of brood-year 2004 and 2005 Sacramento River fall-run Chinook.

6.3 Were plankton levels depressed off California, especially during the smolt entry periods?

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

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

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

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

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

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

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

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

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

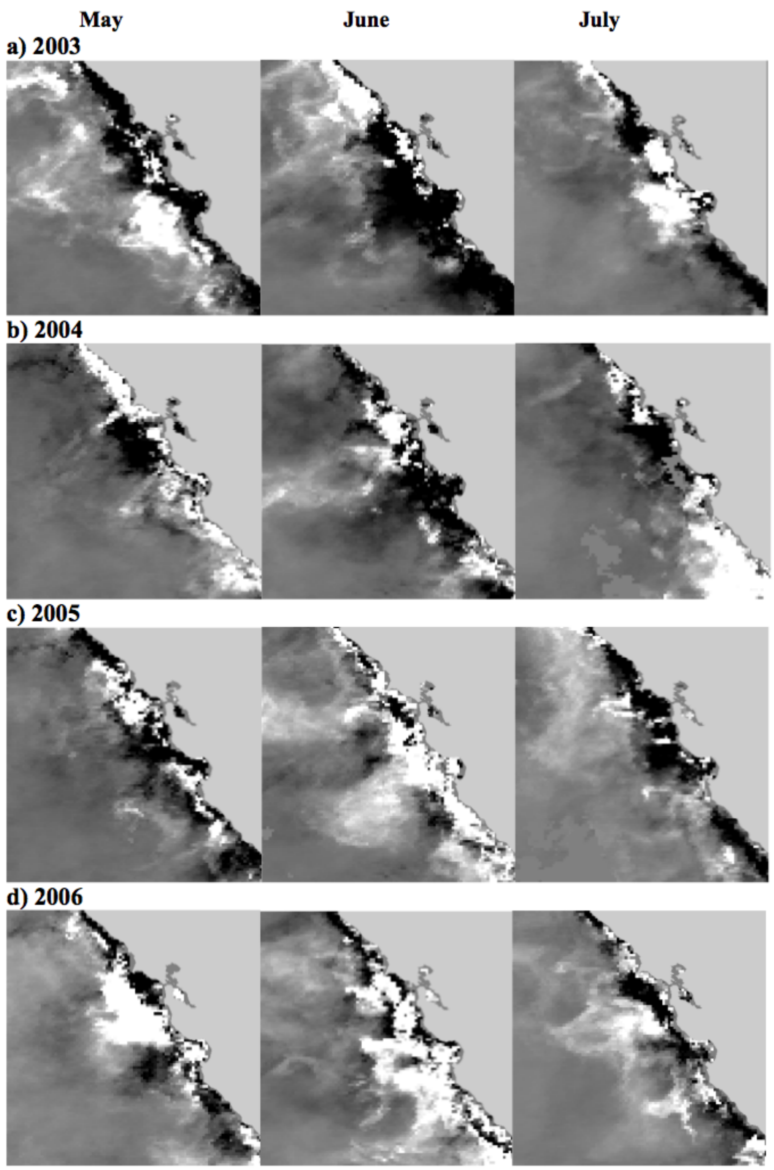

Figure 22: Chlorophyll-a (Chl-a) anomalies obtained from MODIS (CoastWatch) during May, June, and July. Black indicates low values and white high values. Anomalies represent monthly Chl-a concentrations minus mean Chl-a concentration values at the pixel resolution for the 1998-2007 period. From Wells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

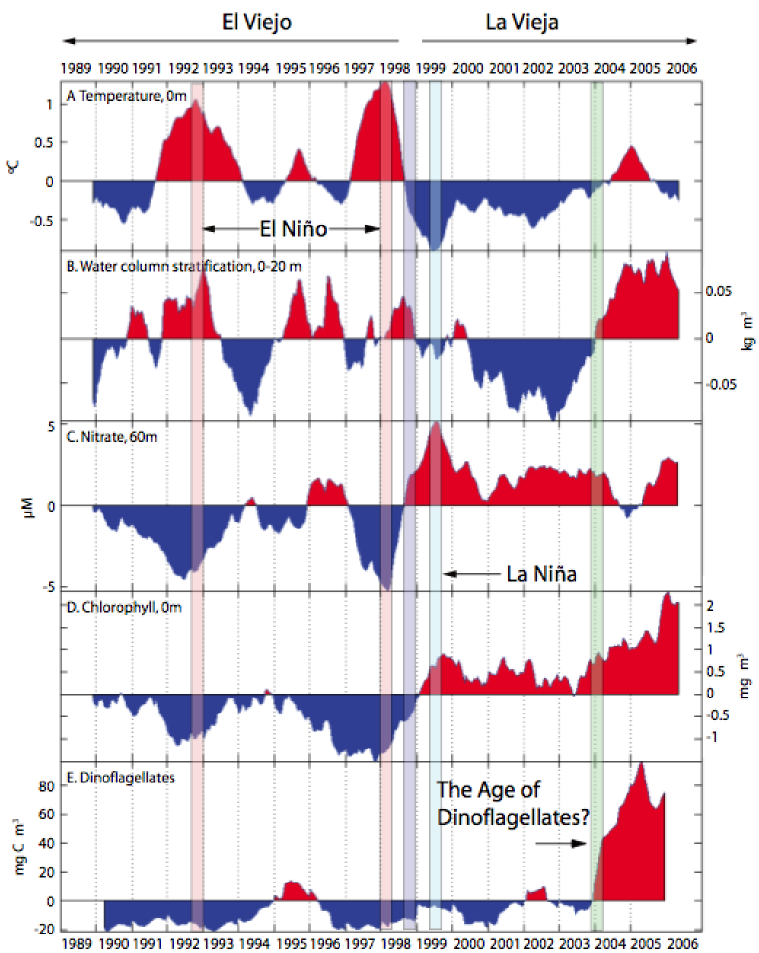

Figure 23: Time series of temperature, water column stratification, nitrate, chlorophyll and and dinoflagellates observed in Monterey Bay. “El Viejo” refers to the warm-water regime lasting from 1976-1998, and “La Veija” refers to the present regime. El Niño and La Niña events are indicated by the colored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

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

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

7 Marine Species Interactions Focus

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

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

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

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

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

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

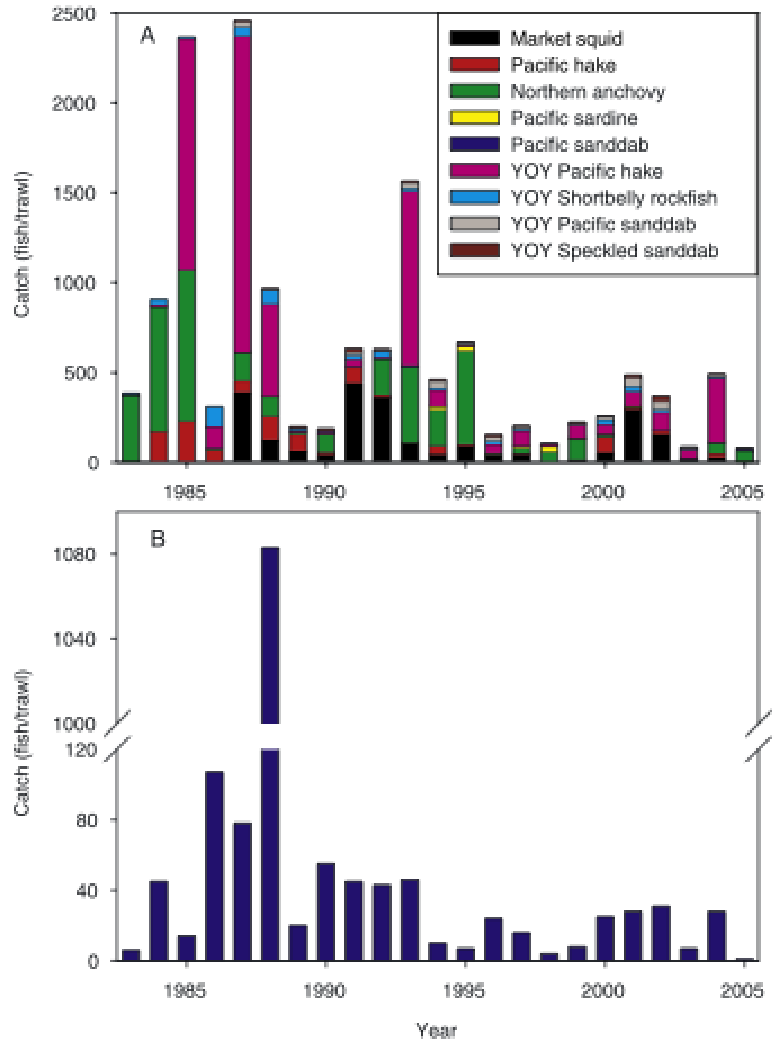

Figure 24: Time series of catches from pelagic trawl surveys along the central California coast from 1983 to 2005 for (a) the dominant nekton species and (b) juvenile rockfishes. From Brodeur et al. 2006.

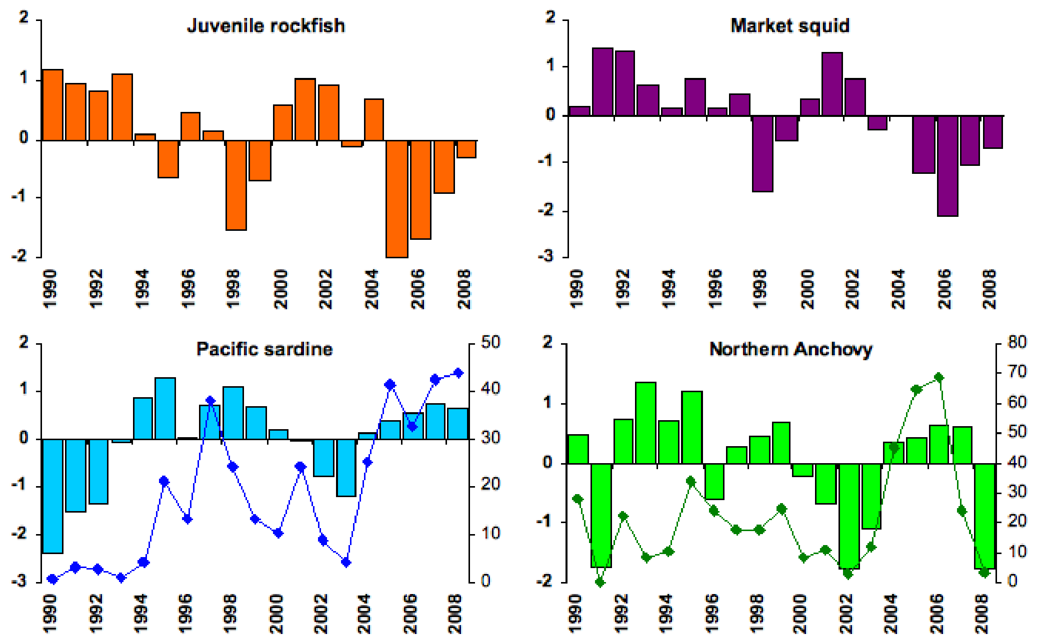

Figure 25: Standardized abundances (bars) of four Chinook salmon prey items (the ten most frequently encountered rockfish of the NOAA trawl survey, market squid, sardines and anchovies) estimated from the mid-water trawl survey conducted by NOAA Fisheries, Santa Cruz. Lines indicate the frequency of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

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

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

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

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

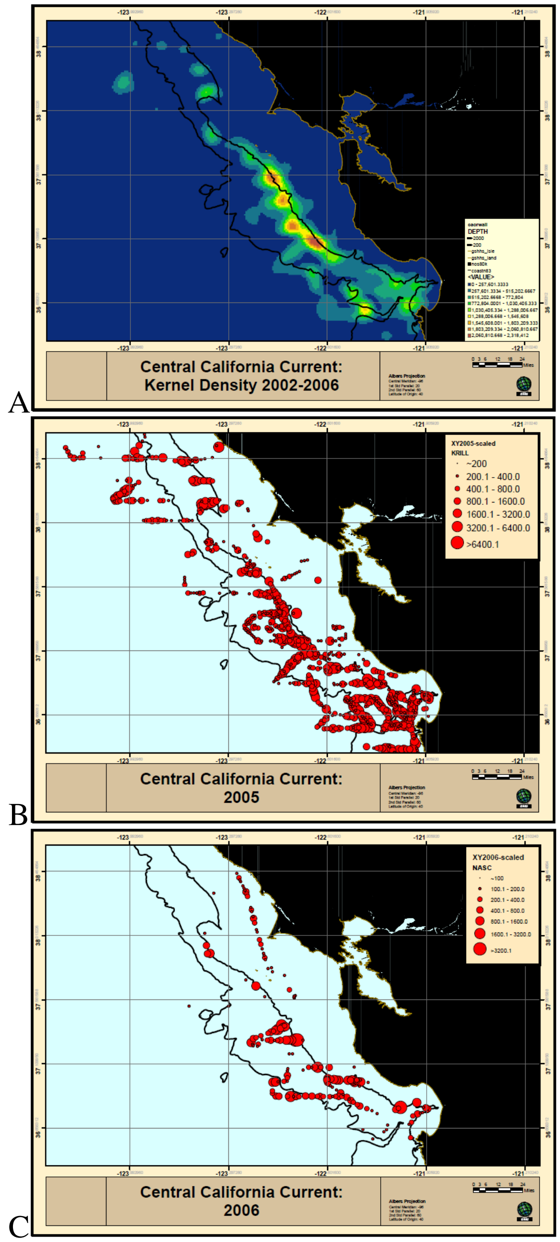

Figure 26: Abundance of krill measured by echosounder during May-June survey cruises off central California in 2004-2006. A) Average abundance of krill over the survey period. B) Abundance of krill in 2005 and C) 2006. Unpublished data of J. Santora.

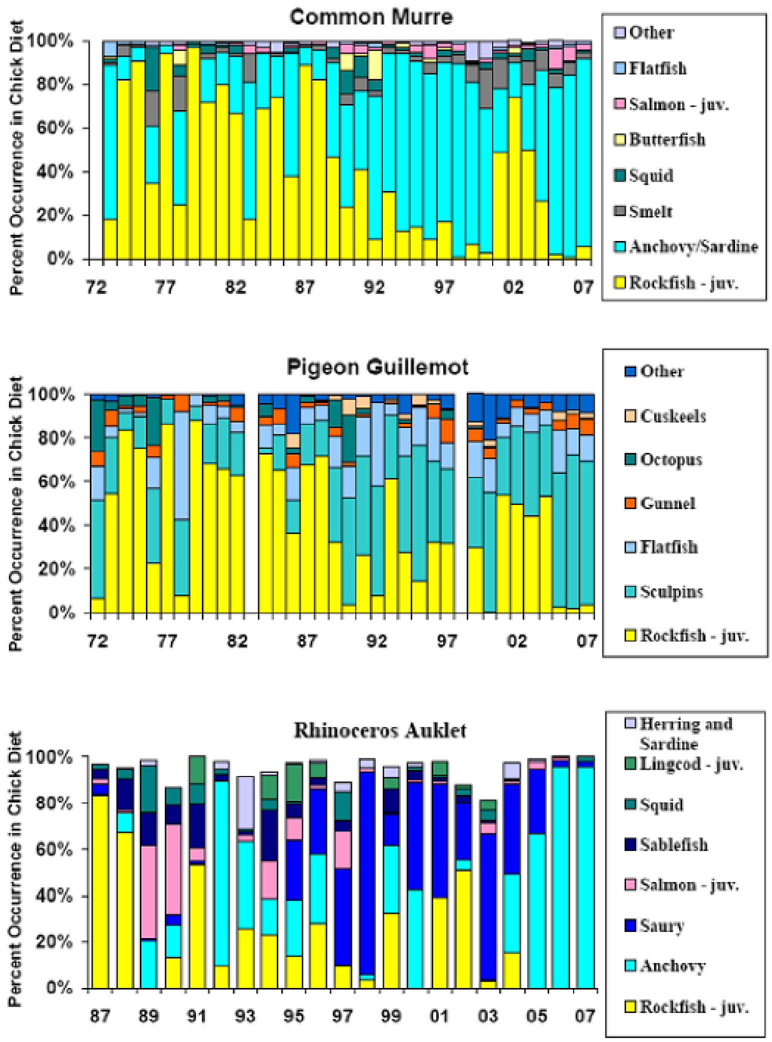

Figure 27: Diet of three species of seabirds in the Gulf of the Farallones between 1972 and 2007. (Source: Bill Sydeman, Farallon Institute for Advanced Ecosystem Research)

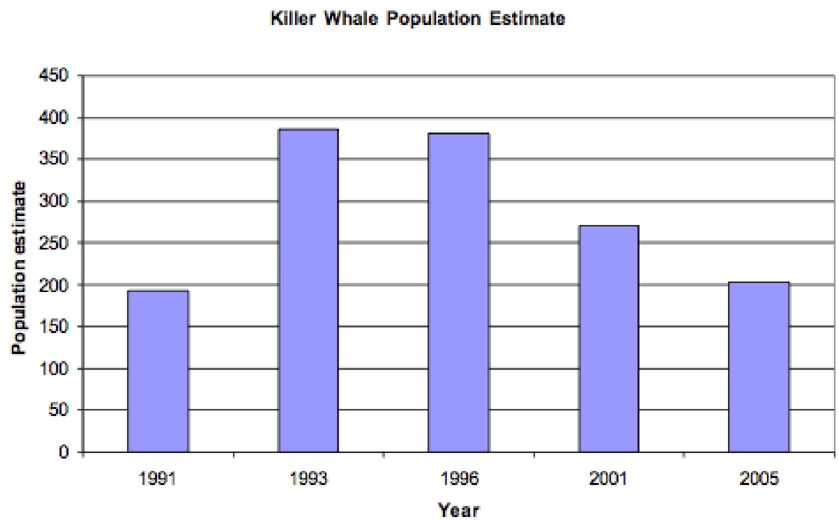

Figure 28: Population estimates of killer whales (*Orcinus orca*) off the California coast (to 300 nautical miles). Source: Barlow and Forney (2007).

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

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

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

7.4 Was there predation on salmonids by Humboldt squid?

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

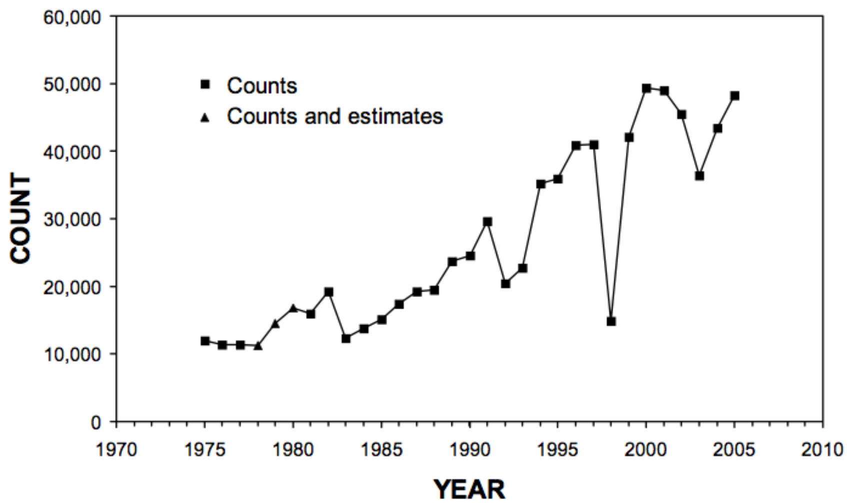

Figure 29: Count of California sea lion pups (1975-2005). Source: Carretta et al. (2007)

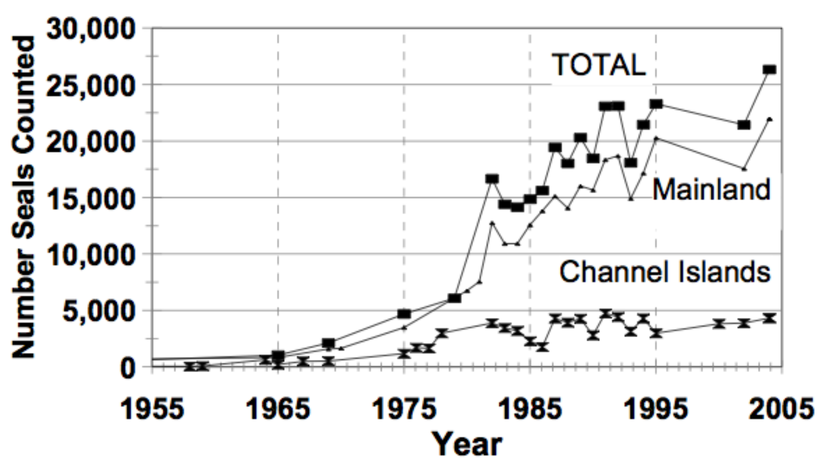

Figure 30: Harbor seal haulout counts in California during May and June (Source: Carretta et al. 2007)

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

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

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

Although it is impossible to conclusively rule out squid predation as a primary cause of the poor survival of the 2004 and 2005 broods of SRFC, it is unlikely that squid predation is a major contributing factor. Instead, the large numbers of jumbo squid observed since 2003, and particularly during 2005-2006, may have been a reflection of the same unusual ocean conditions (poor upwelling, heavy stratification, warm offshore water, poor juvenile rockfish and seabird productivity, etc) that contributed to the poor feeding conditions for salmon during those years.

7.5 *Was there increased predation on salmonids by other finfish species (e.g., lingcod)?*

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

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

In nearshore waters, examples of piscivores preying upon salmonids are relatively rare. Brodeur et al. (1987) found infrequent but fairly high predation on salmon smolts (both Chinook and coho) from black rockfish (*Sebastes melanops*) collected from purse-seine studies off of the Oregon coast in the early 1980s, but no other rockfish species have been documented to prey on salmonids. Cass et al. (1990) included salmon in a long list of lingcod prey items in Canadian waters, but studies in California have not encountered salmon in lingcod diets and there is no evidence that lingcod are a significant salmon predator. In offshore waters, sablefish (*Anoplopoma fimbria*) are one of the most abundant higher trophic level groundfish species, however with the exception of trace amounts of Oncorhynchus sp. reported by Buckley et al. (1999), several other sablefish food habits studies in the California Current have not reported predation on salmonids. Salmon have also been noted as important prey of soupfin sharks (*Galeorhinus galeus*) in historical studies off of Washington and California. Larger salmon have also been noted in the diets of sleeper sharks, and presumably salmon sharks (*Lamna ditropis*) are likely salmon predators when they occur in the California Current. However, none of these species are likely to be sufficiently abundant, nor were reported to be present in unusual numbers, throughout the 2005-2006 period.

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

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

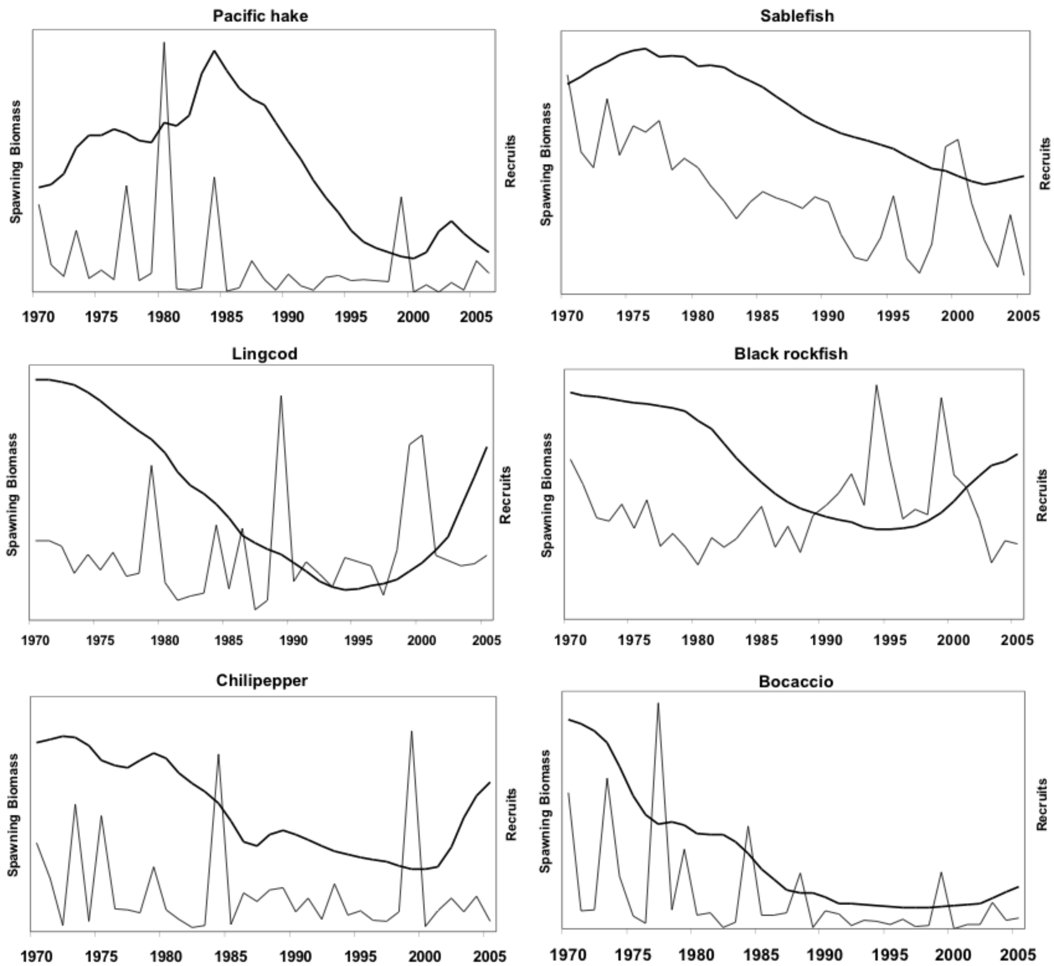

Figure 31: Spawning biomass (black line) and recruitment (light gray line) of selected groundfish species off of central California.

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

8 Cumulative Ecosystem Effects Focus

8.1 Were there other ecosystem effects? Were there synergistic effects of significant factors?

These questions are addressed in the main text.

9 Salmon Fisheries Focus

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

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

Ocean fishery management regulations are developed anew each year by the PFMC with the aim of meeting, in expectation, the annual conservation objectives for all stocks under management. For SRFC, the annual conservation objective is a spawning escapement of 122,000–180,000 adults (hatchery plus natural area spawners). The PFMC uses mathematical models to forecast SRFC expected spawning escapement as a function of the stock's current ocean abundance and a proposed set of fishery management regulations.

For 2007, the PFMC forecast SRFC expected spawning escapement as

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

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

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

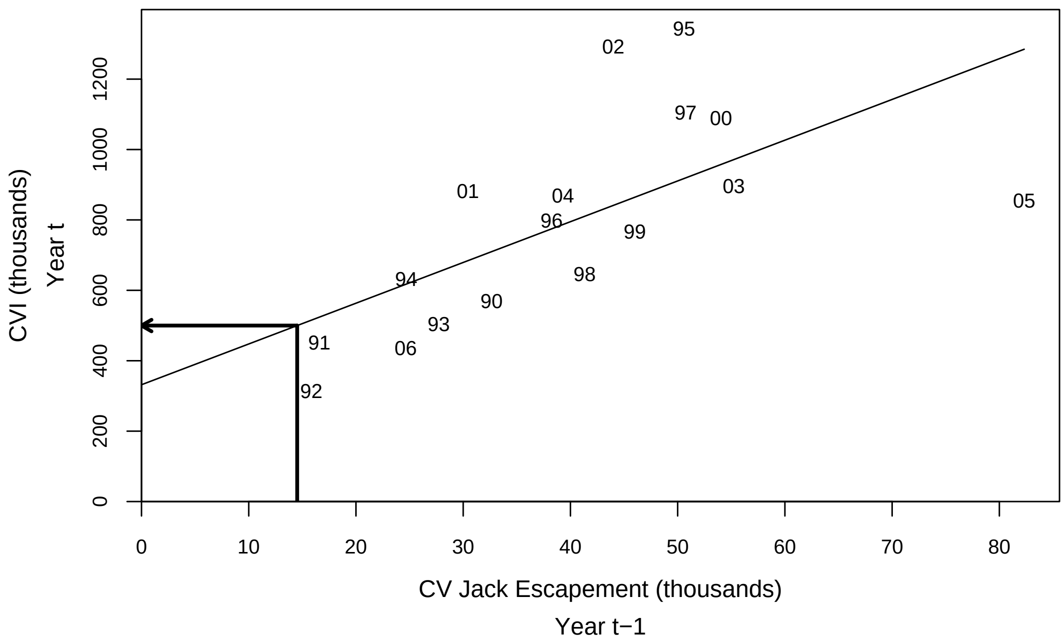

Figure 32: PFMC 2007 CVI forecast regression model. Numbers in plot are last two digits of CVI year; e.g., "92" denotes CVI year 1992. Arrow depicts CVI prediction of 499,900 based on the 2006 Central Valley Chinook spawning escapement of 14,500 jacks.

forecast to be (PFMC, 2007b)

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

exceeding the upper end of the escapement goal range.

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

optimistic forecast of the strength of the 2004 brood.

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

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

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

[1] the SI has since been modified to include SRFC adult river harvest as well for assessments beginning in 2009 (O'Farrell et al., 2009).

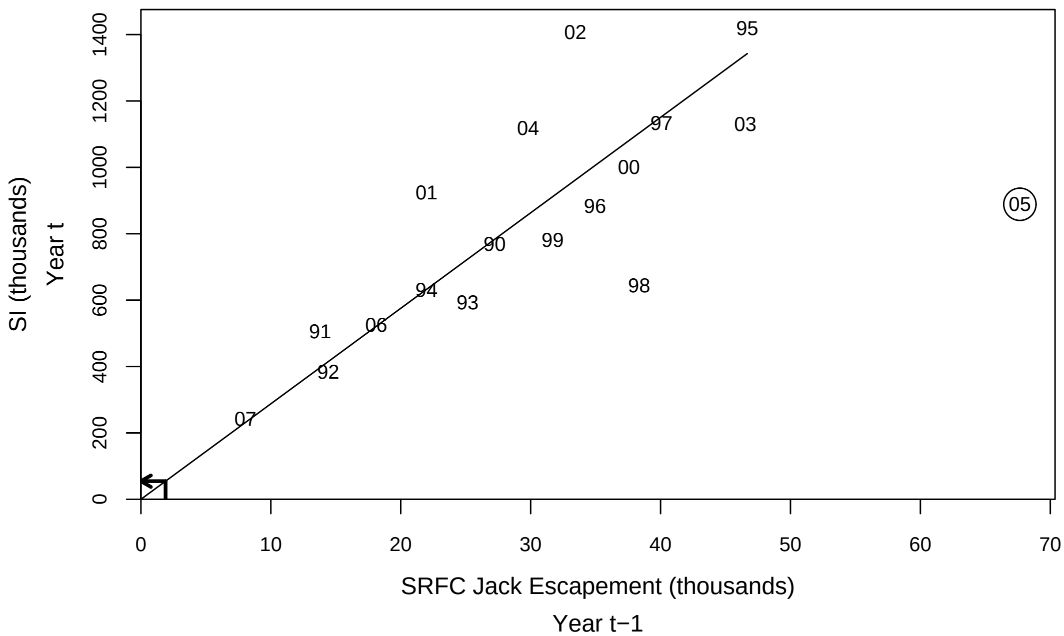

Figure 33: PFMC 2008 SI forecast regression model. Numbers in plot are last two digits of SI year; e.g., "07" denotes SI year 2007. Circled data point (SI year 2005) omitted from model. Arrow depicts SI prediction of 54,600 based on the 2007 SRFC spawning escapement of 1,900 jacks.

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

The 2008 SI forecast model is displayed in Figure 33. The 2004 record high jack escapement data point (SI year 2005) was omitted from the model, and the relationship was fitted through the origin. From the 2007 SRFC spawning escapement of 1,900 jacks, the 2008 SI was forecast to be 54,600 (PFMC, 2008b). For $h_{SRFC,o}$, a forecast model was developed by relating the SRFC month-area-fishery-specific historical harvest rate indices to the observed fishing effort and, subsequently, fishing effort to operative management measures. The previous year September 1 through December 31 SRFC harvest was estimated directly using observed coded-wire tag recoveries, divided by the forecast SI, and incorporated in the $h_{SRFC,o}$ forecast. Methods were also developed to include in $h_{SRFC,o}$ non-landed fishing mortality in the case of non-retention fisheries. With the PFMC adopted fishery closures in 2008, the forecast $h_{SRFC,o}$ was 0.08. The non-zero forecast was primarily due to SRFC ocean harvest the previous fall (2007), with a minor harvest impact ($<$ 100 fish) expected from the 2008 mark-selective coho recreational fishery conducted off Oregon. For the river fishery, the average harvest rate under normal management regulations was estimated to be 0.14 based on the historical angler survey data (O'Farrell et al., 2009). With the California Fish and Game Commission (CFGC) closure of the 2008 SRFC river fishery, $h_{SRFC,r}$ was forecast to be 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 ÷ 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

2008c)

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

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

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

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