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A White Sturgeon Year-Class Index for the San Francisco Estuary and Its Relation to Delta Outflow

Maxfield A. Fish (CDFG), mfish@dfg.ca.gov

Introduction

Little is known regarding recent trends in white sturgeon (*Acipenser transmontanus*) recruitment in the San Francisco Estuary. Tremendous variations in white sturgeon year-class strength and long periods between strong recruitment events have been obvious in the age distribution data since the 1930s (Pycha 1956, Shirley 1987). High Delta outflow during spring has long been associated with strong year classes (Kohlhorst 1980, Shirley 1987, Kohlhorst et al. 1991). Management actions to address the sporadic and infrequent recruitment have been limited to increasingly restrictive regulations on the sturgeon sport fishery, plans to improve passage of migrating adults past impediments, research, monitoring, and outreach. To aid the development and application of management options, I describe a 28-year time series of year-class strength (as in Kohlhorst et al. 1991) and its relationship to aspects of Delta outflow (as in CDFG 1992). The objective of this analysis was to: 1) Develop a year-class index (YCI) and 2) Determine the response of the index to various outflow periods and magnitudes from 1980-2007.

Methods

White sturgeon catch data was provided by the California Department of Fish and Game's (CDFG) San Francisco Bay Study (Bay Study). The 1980-2007 YCIs were calculated from 163 age-0 fish and 164 age-1 fish collected from 1980 through 2008 at the original 35 Bay Study stations by otter trawl sampling. Collected white sturgeon were designated age-0, age-1, or age-2+ based on total length (TL, mm) using criteria developed from historic monthly length-frequency distributions (Table 1). Additional information about Bay Study sampling methods can be found in IEP Technical Report 63 (Baxter et al. 1999).

Table 1 Monthly age-class cutoff lengths for San Francisco Bay Study otter trawl catch of white sturgeon.

Month	Minimum (mm)	Age-0 (mm)	Age-1 (mm)
January	20	80	380
February	20	80	390
March	20	80	400
April	20	80	410
May	20	160	420
June	20	200	440
July	20	240	460
August	20	280	480
September	20	320	500
October	20	340	510
November	20	360	520
December	20	380	530

Once catch by age was determined, monthly abundance indices were calculated for age-0 and age-1 fish independently. Indices for each age class were determined by first calculating catch-per-unit-effort (CPUE) at each station as:

CPUE= (# caught / tow area)*10,000

Next, the mean monthly CPUE for all stations in a region was multiplied by a regional weighting factor to account for the size of each embayment and all 5 regional indices were summed. Once monthly indices were calculated, annual indices were determined by averaging the monthly indices for when fish of each age group were most effectively captured. April to October was used for the age-0 indices and February to October was used for the age-1 indices. To develop the YCI, the age-0 index from the year in question was added to the age-1 index from the following year:

$$YCI_{(t)} = (\text{age-0 index})_{(t)} + (\text{age-1 index})_{(t+1)}$$

Where t=year

Associations between the YCI and Delta outflow were explored with correlation analysis using least squares linear regression in Microsoft® Excel. To determine the correlation coefficient (r) between white sturgeon recruitment and several measures of freshwater outflow, Dayflow (available at www.iep.ca.gov/dayflow/index.html) was used to calculate average monthly outflow at Chipps Island. For the purposes of presentation, the YCI was plotted against the mean monthly Delta outflow for two periods: 1) November to February, which represented the winter period of spawning migration and 2) March to July, which represented spring conditions experienced by eggs, larvae, and small juvenile fish. Outflow values and YCI values were both $\log_{10}$ transformed for use in correlation analyses and plots.

Results

Year-class strength varied greatly, from several very high indices to 2 long periods of zero or near-zero indices (Figure 1, Table 2).

Positive correlations existed between the YCI and all monthly and seasonal outflow periods (Table 3). The strong relationship between winter outflow and YCI (Figure 2, r = 0.74) was likely due to attraction flows. Spring outflow also showed a strong correlation with the YCI (Figure 3, r = 0.71), which likely indicates a positive relationship between outflow and successful spawning, hatching, rearing, and increased downstream transport of small juveniles to the estuary.

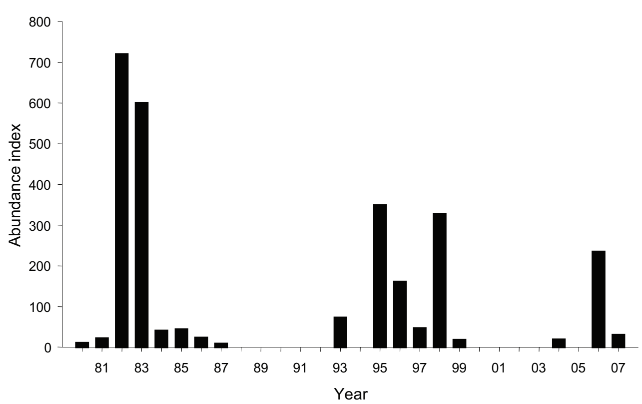

Figure 1 White sturgeon year class indices for the San Francisco Estuary developed from otter trawl catch by the San Francisco Bay Study.

Table 2 1980-2008 age-0 (April-October) and age-1 (February-October) San Francisco Bay Study white sturgeon abundance indices and YCI (combined age-0 and age-1$_{(t+1)}$).

Year	Age-0 Abundance Index April-Oct	Age-1 Abundance Index Feb-Oct	YCI (age-0 & age-1(t+1))
1980	11	6	11
1981	0	0	22
1982	487	22	720
1983	104	233	600
1984	0	496	41
1985	16	41	44
1986	0	28	24
1987	0	24	8
1988	0	8	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	51	0	72
1994	0	21	0
1995	267	0	349
1996	120	81	161
1997	33	41	47
1998	312	14	328
1999	8	16	18
2000	0	10	0
2001	0	0	0
2002	0	0	0
2003	0	0	0
2004	19	0	19
2005	0	0	0
2006	151	0	235
2007	0	84	30
2008	0	30	

Table 3 Correlation coefficients between the 1980-2007 San Francisco Bay Study white sturgeon year-class indices (Log_{10}(YCI+1)) and Delta outflow (Log_{10}). November and December outflow data is from the year prior toindex year.

Outflow Period	Correlation Coefficient
Nov(Y-1)	0.474
Dec(Y-1)	0.577
Jan	0.633
Feb	0.680
Nov-Feb	0.738
March	0.662
April	0.727
May	0.636
June	0.686
July	0.728
Mar-Jul	0.711

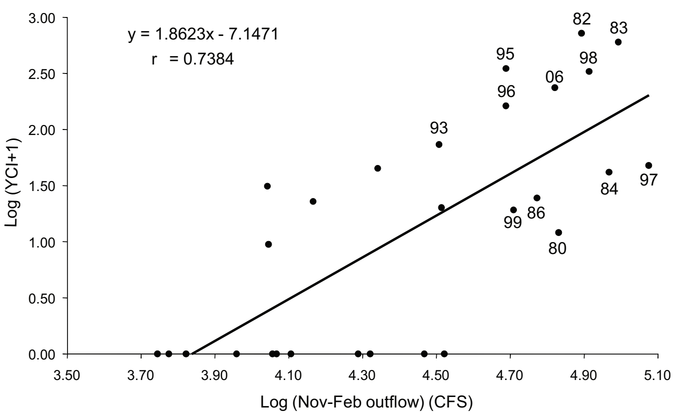

Figure 2 White sturgeon year-class index (YCI) from San Francisco Bay Study otter trawl catch versus mean daily Delta outflow for November through February. Numbers adjacent to points designate select year classes.

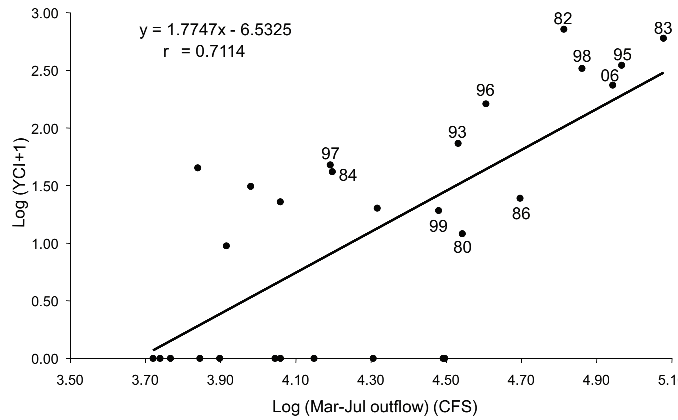

Figure 3 White sturgeon year-class index (YCI) from San Francisco Bay Study otter trawl catches versus mean daily Delta outflow for March through July. Numbers adjacent to points designate select year classes.

Discussion

River hydrology has long been known to influence the behavior and recruitment of anadromous fishes in the San Francisco Estuary (Turner and Chadwick 1972, Stevens 1977, Stevens and Miller 1983, Stevens et al. 1985). White sturgeon is known to migrate to spawning areas well before its recognized spawning season (Kohlhorst et al. 1991). In addition, juvenile recruitment appears related to the magnitude of spring flows as found by Stevens and Miller (1970) and this analysis. Based on this information, sturgeon year-class strength is probably a function of fall and winter flows providing stimuli for adult migration and gonadal maturation and spring flows providing stimuli for spawning, increased egg, larval, and early juvenile survival, and transport of juveniles to the estuary.

It appears that recruitment is a function of both spring and winter outflow, but that large year-classes are dependent on high spring outflows in particular. All years with exceptionally high spring outflow on record produce large year-classes regardless of the magnitude of the preceding winter outflow (the record does not include any years with very low winter outflow and very high spring outflow), where as winter outflows of exceptional magnitude only produce large year-classes when followed by wet springs. For example, years with the 5 highest spring outflows produced the 5 highest YCIs on record (1982, 83, 95, 98 and 2006; Figure 3). In contrast, 2 of the 3 highest winter outflows on record (1984 and 97; Figure 2), which were followed by dryer than average springs, produced only the 10th and 8th highest indices respectively. Similar, though less striking patterns can be seen in 1980, 1986, and 1999.

The sporadic and highly variable nature of this YCI was expected based on previously published YCIs (Kohlhorst et al. 1991, CDFG 1992) and length-frequency data from 3 sources: 1) Sturgeon Fishing Report Cards (DuBois et al. 2010), 2) Catch from tagging during the DFG sturgeon population study (Schaffter and Kohlhorst 1999, DuBois and Mayfield 2009), and 3) A pilot effort to determine the relative abundance of juvenile sturgeon using setlines (Schaffter 2000).

Previous San Francisco Estuary white sturgeon year-class indices were developed from age-0 through age-5 fish assigned birth years through the use of a growth equation (Kohlhorst et al. 1991, CDFG 1992) and from length-frequency distributions of subadult and adult fish (Shirley 1987). Because very little recent data exists on growth of white sturgeon in California and length-frequency distributions have been developed using sampling methods likely to be size biased, I think the present YCI is likely more reliable than those developed from historical growth data or length data from relatively old fish. I believe that the year-class index presented here effectively identifies substantial production years. Furthermore, a strong correlation ($r = 0.77$) between the 1986-2002 YCI series and a year-class index of white sturgeon 40-116 cm (16-46”) TL collected by setline (CDFG in prep.) indicates that this YCI can be used to predict recruitment to the sport fishery. Thus, I am confident that the YCI is useful for detecting substantial recruitment events, although it probably does not vary strictly in proportion to the true abundance of age-0 white sturgeon. In addition, YCIs of zero indicate very poor recruitment, but not necessarily a complete lack of recruitment for the estuary.

White sturgeon from the few relatively strong 1990s year classes form the foundation of the current recreational fishery, which allows for the harvest of individuals 46-66” (TL, the slot limit). The relatively strong 2006 year class has recruited to sport fishing gear (DuBois et al. 2010), but will likely have a prolonged recruitment to the slot limit near the middle of the present decade due to variations in growth rate. The periodicity and magnitude of YCIs over the past 20 years suggest a decline in abundance of legal-size fish is likely through the rest of this decade.

It has been suggested that in certain scenarios the proportion of positive tows (Ep) may be more precise than a CPUE based index (Uphoff 1993, Counihan et al. 1999). Because a strong correlation ($r = 0.95$) exists between the YCI and the age-0 Ep, I plan to explore the relative merits of both indices independently in a different analysis.

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