■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

VOLUME 26, NUMBER 4, 2013

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Further Investigations into San Francisco Estuary White Sturgeon (*Acipenser transmontanus*) Year-Class Strength

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Introduction

Successful management of White Sturgeon, its fishery, and its habitat requires a time series of year-class strength indices. Indices of White Sturgeon year-class strength from observations of very young fish avoid most of the inaccuracies and expenses associated with assignment of ages to older fish through examination of hard parts and provide upwards of 10 years advance notice of recruitment to the fishery. Fish (2010) reported the relation between Sacramento-San Joaquin Delta (Delta) outflow and a year-class index (YCI_{BS}) from catch-per-unit-effort (CPUE) of age-0 and age-1 White Sturgeon collected systematically by the San Francisco Bay Study's otter trawl from throughout much of the area young White Sturgeon occur, and suggested that the metric was of more utility than preceding indices and certain categories of alternative indices. Here we describe a brief investigation intended to help understand YCI_{BS} and some other potential White Sturgeon year-class strength indices.

Methods

We contrasted YCI_{BS} with a possible index (YCI_{Ep}; as in Counihan et al. 1999) from collection of White Sturgeon by Bay Study otter trawl and with a possible index (WST_{SAL}) derived from the estimated salvage of White Sturgeon entrained at the State Water Project (SWP) Skinner Fish Protective Facility in the South Delta. The contrasts we describe are from comparing plots of WST_{SAL}, YCI_{BS}, and YCI_{Ep} as time series and from the linear regression statistics (R statistical software Version 2.15.2, 2012) coefficient of determination (as R^2) and p-value. We also investigated possible indices from catch of White Sturgeon reported by the recreational anglers who sub-mitted Sturgeon Fishing Report Cards and catch by the Department using experimental setlines (DuBois et al. 2010), but — largely because those time series are so brief — we found them to be of little use and they will not be described here.

E_P is the annual percentage of Bay Study otter trawls in which age-0 or age-1 White Sturgeon were collected. YCI_{Ep} is an annual metric based on E_P, is calculated using only the original 35 Bay Study stations, and is the sum of the percentage of total otter trawl tows which contained at least one age-0 White Sturgeon (April-October) and the percentage of total otter trawl tows which contained at least one age-1 White Sturgeon (February-October) lagged by one year:

$$YCI_{EP_t} = [E_p(\text{Apr-Oct})]_t + [E_p(\text{Feb-Oct})]_{t+1}$$

We investigated the use of estimated salvage to index White Sturgeon year-class strength because the estimates vary substantially year to year and it seems that more young White Sturgeon are salvaged than are documented anywhere else in the system. Estimated salvage at the SWP is an extrapolation from the number of fish collected at the Skinner Fish Facility during exports and — due in large part to variations in sampling effort, sampling efficiency, and water operations (e.g., exports and operation of the Delta Cross Channel) — is not itself a plausible index of White Sturgeon year-class strength. WST_{SAL} is White Sturgeon density at the SWP from estimated salvage relative to the volume of water exported, and is more likely to vary in proportion to White Sturgeon year-class strength than estimated salvage. WST_{SAL} is calculated using the following formula:

$$WST_{SAL} = \sum_{May-December} \left(\left[\frac{\frac{\sum Salvage}{m}}{(\sum Acre\ Feet) \times 1233.48} \right] \times 10,000 \right)$$

where:

Salvage = expanded salvage of White Sturgeon
Acre Feet = volume of water pumped
m = individual month (May through December only)
1233.48 = factor to convert acre feet to cubic meters
10,000 = factor to convert density to per 10,000 cm

Although White Sturgeon larvae and juveniles are salvaged at the SWP, estimates of White Sturgeon salvage, and thus salvage density, are not stratified by fish length or age. In an effort to assure that WST_{SAL} represents White Sturgeon production each year rather than production over the course of more than one year, annual WST_{SAL} values only include densities for the May-December period when age-0 White Sturgeon were likely the dominant age-class salvaged.

Results

Trends in YCI_{BS} and YCI_{Ep} were nearly identical (Figure 1, Table 1). The relationship between the two metrics was strongly linear (Test for zero slope: F = 419.2; DF = 1.30; p < 0.001; R^2 = 0.933). With few exceptions, juvenile White Sturgeon were relatively abundant only in years classified as wet.
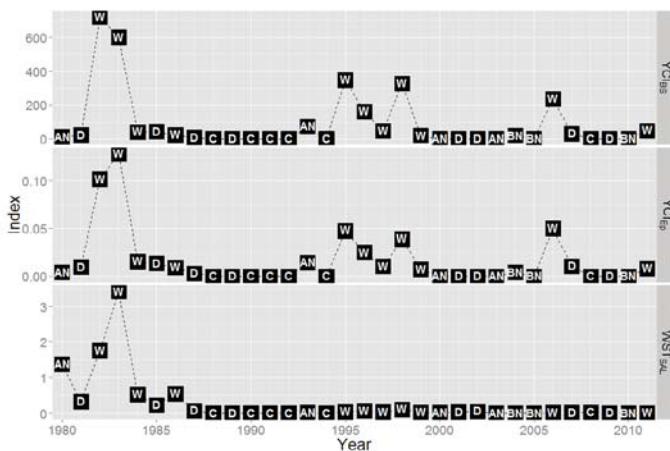

Figure 1 Time series from 1980 to 2011 of year-class strength indices for White Sturgeon from Bay Study (YCI_{BS} and YCI_{Ep}) and White Sturgeon density at the SWP (WST_{SAL}). Data points labeled with water-year type, see Table 1 for water-year type descriptions.

Trends in YCI_{BS} and WST_{SAL} share some attributes — e.g., record-high numbers of White Sturgeon in the same years; long periods when few if any young White Sturgeon were observed (Figure 1, Table 1) — but the relationship cannot be reasonably described by a simple model. A linear fit resulted only because both variables were exceptionally high in 1982 and 1983 (Test for zero slope: F = 30.12; DF = 1.30; p < 0.001; R^2 = 0.501), and

in absence of values from 1982 and 1983 there are hints of a weak inverse relationship. As with YCI_{BS} and YCI_{Ep}, with few exceptions juvenile White Sturgeon appeared relatively abundant only in years classified as wet.

Table 1 Annual White Sturgeon year-class strength indices from Bay Study (YCI_{BS} and YCI_{Ep}) and estimated salvage density (WST_{SAL}). Water-year type included for reader's reference, for further details refer to Fish (2010).

Year	Water Year[a]	YCI_{BS}	YCI_{EP}	WST_{SAL}
1980	AN	11.076	0.004	1.373
1981	D	21.848	0.010	0.330
1982	W	719.697	0.102	1.760
1983	W	599.637	0.128	3.425
1984	W	40.657	0.016	0.526
1985	D	44.039	0.014	0.225
1986	W	23.503	0.010	0.548
1987	D	8.466	0.003	0.075
1988	C	0	0	0
1989	D	0	0	0
1990	C	0	0	0
1991	C	0	0	0
1992	C	0	0	0
1993	AN	72.494	0.015	0.013
1994	C	0	0	0
1995	W	348.611	0.048	0.042
1996	W	160.999	0.025	0.069
1997	W	46.733	0.010	0.034
1998	W	327.740	0.039	0.109
1999	W	18.190	0.007	0.023
2000	AN	0	0	0.011
2001	D	0	0	0.027
2002	D	0	0	0.057
2003	AN	0	0	0
2004	BN	19.131	0.004	0
2005	BN	0	0	0
2006	W	234.599	0.050	0.010
2007	D	30.192	0.011	0.018
2008	C	0	0	0.022
2009	D	0	0	0.005
2010	BN	0	0	0
2011	W	48.806	0.008	0.003

[a] AN = above normal, BN = below normal, C = critical, D = dry, W = wet

Discussion

Although both YCI_{BS} and YCI_{Ep} were calculated using the same Bay Study survey data, their strong correlation was not inevitable and suggests that observed White Sturgeon spatial patchiness did not necessarily affect the accuracy of either. We consider these two measures complementary rather than alternatives, because future White Sturgeon patchiness could affect either or both year-class strength indices.

Use of WST_{SAL} to index White Sturgeon year-class strength would be inherently suspect for the same reasons that salvage is not a plausible index (e.g., variations in sampling effort and water operations) and because most young White Sturgeon — by virtue of the distribution of adults during spawning (see DuBois et al. 2010) and behavior of young White Sturgeon — likely moved along the bottom (Kynard and Parker 2005) down the Sacramento River rather than into the south Delta (as in Stevens and Miller 1970) where they might be salvaged. Thus, given that annual trends in YCI_{BS} (and the closely-related YCI_{Ep}) and WST_{SAL} are only coarsely similar, we do not consider WST_{SAL} an index of White Sturgeon year-class strength but will consider WST_{SAL} when assessing annual White Sturgeon year-class strength.

Having explored potential year-class indices from the pertinent surveys we are aware of, we plan to gain additional insight into YCI_{BS} and YCI_{Ep} — and White Sturgeon year-class strength in general — by mining data that speaks to the phenology of White Sturgeon spawning and age-0 recruitment to the Delta and bays of the San Francisco Estuary. Our hope is that we will reduce uncertainty about White Sturgeon year-class strength and learn more about environmental factors influencing White Sturgeon year-class strength (as in Coutant 2004, Fish 2010, Mayfield and Cech 2004, and McAdam et al. 2005).

Management Note: The University of California at Davis (UCD) and commercial aquaculture facilities produced and released White Sturgeon fry and fingerlings from 1980-1988 as mitigation for collection of broodstock, but survival of the stocked fish was not evaluated. Although we have not yet found detailed records of the dates, locations, sizes, or numbers of released fish, we have recently learned that UCD released roughly 200,000 fingerlings in the spring of 1982 (Monaco 1983) and UCD was reported to have released a total of 500,000 fish by 1986 (Steinhart 1986). We are looking into whether or not it is plausible that record-high 1982 and 1983 White Sturgeon YCI_{BS}, YCI_{Ep}, and WST_{SAL} values were notably affected by stocked fish.

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