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Improved Methods for Indexing San Francisco Estuary Sturgeon Recruitment with Long-Term Survey Data

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Introduction

The San Francisco Estuary (SFE) watershed is the southern extent of spawning habitat for both White Sturgeon (*Acipenser transmontanus*) and Green Sturgeon (*A. medirostris*). Green Sturgeon were listed as threatened in 2006 under the Federal Endangered Species Act (NMFS 2006). White Sturgeon were included as a "California Fish Species of Special Concern" (Moyle et al. 2015) but remain the target of a significant sport fishery. Fishery managers require quantitative indicators of annual production, or year-class indices (YCI), to evaluate habitat conditions during spawning and early rearing, and to indirectly estimate the harvestable or reproductive stock (Quist 2007). Thus, YCI are fundamental metrics for tracking recovery of Green Sturgeon and sustainability of the White Sturgeon fishery.

Long-term monitoring of age-0 and age-1 sturgeon in the SFE watershed is limited to three surveys: 1) the San Francisco Bay Study trawl survey (Bay Study); 2) fish entrainment sampling (known as 'salvage') at the State Water Project Skinner Fish Protective Facility (SWP), and 3) salvage sampling at the Central Valley Project Tracy Fish Collection Facility (CVP). The Bay Study occurs in the SFE and is operated by the California Department of Fish and Wildlife (CDFW). Salvage sampling occurs at state and federal water diversion facilities in the South Delta, where the California Department of Water Resources (CDWR) operates the SWP the US Bureau of Reclamation (USBR) operates the CVP.

A putative White Sturgeon YCI is calculated with catch of age-0 and age-1 White Sturgeon in the Bay Study otter trawl (Fish 2010). This YCI is used to forecast trends in the population (and sport fishery) and to relate recruitment to river conditions (Fish 2010). Trends in White Sturgeon and Green Sturgeon recruitment have been investigated with estimated salvage number at the SWP and CVP, which requires extrapolation (known as 'expansion') from fish identified during entrainment sampling (CDFG 1992; NMFS 2006). Recent evaluations of recruitment, however, have found that estimated salvage of juvenile White Sturgeon at the SWP is not a plausible YCI (Gingras et al. 2013).

There has been no formal evaluation of long-term juvenile Green Sturgeon catch records in development of YCIs. A YCI using catch of juvenile White Sturgeon at the CVP also remains untested. Accordingly, this article provides methodology for calculating possible Green Sturgeon and White Sturgeon YCIs from available long-term datasets (SWP, CVP, and Bay Study). We also include a simple statistical comparison of index method results by species and discuss future opportunities for YCI validation and synthesis.

Investigation

Data

We used datasets from the CDFW, CDWR, and the USBR:

- San Francisco Bay Study (https://www.wildlife.ca.gov/Conservation/Delta/Bay-Study)
- SWP and CVP Fish Salvage Monitoring (https://www.wildlife. ca.gov/Conservation/Delta/Salvage-Monitoring)
- Sacramento Valley Water Index (http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

data files: Bay Study

We obtained Bay Study data from Microsoft® Access database <Fish CPUE and Index calc_Jan2018.mdb>, copy provided by Bay Study personnel. Data includes sampling from 1980-2017.

data files: Salvage

We obtained these data from the Salvage ftp site (ftp://ftp.dfg.ca.gov/salvage/). Salvage data are bifurcated (i.e., beginning-1992 and 1993-present), and not all data used herein were available via database or spreadsheet format. Some operations (e.g., acre-feet; minutes pumping) and count data — particularly from 1980 — were curated by J. Morinaka (CDFW, retired) from raw datasheets.

Sturgeon length data prior to 1993 were from file <LGTS7992.DBF>, and data 1993-present were from Microsoft® Access database <Salvage_data_FTP.mdb> (both available on the Salvage ftp site listed above).

data files: Sacramento Valley Water Year Hydrologic Classification

We used these data to associate the following water year-types to our annual indices: W (wet year); AN (above normal); BN (below normal); D (dry); and C (critical). Prior investigations indicated positive correlation between White Sturgeon recruitment and wet years (Kohlhorst 1980; Shirley 1987; Kohlhorst et al. 1991; CDFG 1992; Fish 2010; Gingras et al. 2013). Water year is defined as 1-Oct to 30-Sep.

Index Criteria

We calculated the Bay Study year-class index according to Fish (2010) and created novel indices from salvage data using an alternative algorithm. This approach followed a more conventional CPUE method dividing catch by some effort (or volume in this case). Criteria for both calculations are summarized below.

Bay Study

- 35 original sampling stations
- otter trawl collections only
- limited to age-0 fish & age-1 fish
  - age-0: Apr-Oct only in year t
  - age-1: Feb-Oct only in year t+1
- use of length-cutoff table to age fish

Salvage

- use of length-cutoff table (Bay Study) to estimate predominant age-class in given month
- non-calendar year summary
  - SWP 1-Aug –> 31-Jul
  - CVP 1-Jun –> 31-May
- using count data rather than expanded salvage

Equations

Herein we provide algorithms for the various indices.

Bay Study

We first calculated CPUE by age group (0, 1, 2+) for each sampling station (age-class based on Table 1).

Next, we averaged CPUE by month (survey), bay, net, series, and age group. We then multiplied average CPUE by a weighting factor according to bay number (Table 2). Finally, we added the sum of age-0 indices and the sum of age-1 indices to produce YCI_t.

$$CPUE = \frac{\sum C}{A_t} \times 10^4 \qquad (1)$$

- $\sum C$ = total sturgeon caught
- A_t = tow area by station (or tow); distance towed in meters * 3.42 meters (otter door spread)
- 10^4 = converts density to per 10,000 m^2

$$Index_{age} = \overline{X}_{age} \times \beta \qquad (2)$$

- $\overline{X}_{age}$ = average CPUE by age group
- β = bay weighting factor

$$YCI_t = \sum_{m_t} Age0 + \sum_{m_{t+1}} Age1 \qquad (3)$$

- t = year
- m = appropriate months given age (see *Index Criteria*)

Salvage

Daily operational data at the SWP and CVP is reported in exported water volume (acre-feet — AF) and pumping time. Fish species are enumerated in short blocks of time during pumping (referred to as a 'species count'); the duration of a species count is reported in minutes. We calculated the daily proportion of volume pumped during species counts using equation 4. We use AF_p as "effort" in our index calculation (eqn 5).

$$AF_p = \frac{\sum_{hs} \text{minutes of count}}{\sum_{ha} \text{minutes pumping}} \times AF_d \qquad (4)$$

- AF_d = daily acre-feet
- hs = hourly values on species counts only
- ha = all hourly values (see caveats below)

caveats

- does not include (daily or hourly) records denoted as special study (StudyCode = ‘8888’) or as predator removal (StudyCode = ‘9999’)
- does not include total fish count UNLESS count is 0 or NA

We calculated per facility a species-specific annual index (If; eqn 5). In this context, “annual” applied differently between facilities (i.e., non-calendar year, see Salvage under Index Criteria).

$$I_f = \sum_{Iy}[\frac{\sum_m C}{\sum_m AF_p \times 1233.48} \times 10^8] \qquad (5)$$

- f = facility (SWP or CVP)
- I_y = index year
- C = sturgeon identified in fish counts
- m = month
- 1233.48 = converts acre-feet to cubic meters
- 10^8 = converts density to per 100 million cubic meters

Table 1. Monthly total length age-class limits in millimeters for Bay Study otter trawl catch of white sturgeon from Fish (2010).

Month	*Minimum*	*Age-0 Maximum*	*Age-1 Maximum*
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

Table 2. Bay weighting factors for Bay Study otter trawl.

Bay	*Bay Weight*
1	250.15
2	216.34
3	153.54
4	55.29
5	28.01

Salvage Index Year

Length is not recorded in all sturgeon observed in SWP and CVP monitoring (Table 3). Calculation of indices using only sturgeon records with lengths would involve a substantially reduced sample size and potentially biased by inconsistent data collection protocols (e.g., increased percentage of length measurement). Thus, we established the ‘Salvage Index Year’ (i.e., non-calendar year) using Table 1 and available length data. We set the beginning of the 12-month Salvage Index Year as the first month in which age-0 sturgeon comprised an equal or greater proportion of the measured catch. Based on Table 1, age-0 was the predominant age-class of both White Sturgeon and Green Sturgeon at SWP in August, while age-0 were in equal or greater proportions of measured sturgeon catch at CVP in June. Green Sturgeon and White Sturgeon cohorts also remained the dominant age-class for our established 12-month Salvage Index Year at the SWP and CVP (i.e., SWP: 1-Aug –> 31-Jul; CVP: 1-Jun –> 31-May).

Table 3. Summary of identified sturgeon (n), length measurement, and total length mean and range in millimeters from SWP and CVP entrainment monitoring, 1980-2016 (index year).

Species & Facility	*Date Range*	*n*	*Number of Sturgeon Measured (% n)*	*Mean Length (SE)*	*Length Range*
White Sturgeon SWP	Aug 1, 1980- July 31, 2017	382	217 (57%)	333 (6)	69-622
White Sturgeon CVP	June 1, 1980-May 31, 2017	210	129 (61%)	276 (9)	50-676
Green Sturgeon SWP	Aug 1, 1980-July 31, 2017	92	42 (46%)	368 (16)	206-596
Green Sturgeon CVP	June 1,1980-May 31, 2017	88	70 (80%)	295 (13)	125-774

Green Sturgeon Age-class

An age-length key is not available to evaluate the aforementioned Green Sturgeon metrics or to track recruitment patterns with existing survey data. As a workaround, we assessed the merits of using Table 1, which was developed for calculating SFE White Sturgeon YCI. Using published and unpublished sources, we compiled young Green Sturgeon age data where age was estimated through pectoral fin ray analysis or — for some age-0 — using a conceptual growth curve based on hatch date range (Table 4). We compared estimated ages with assigned ages, where the assignments were based in part on capture data (month and length; assigned per Table 1). Based on these limited data (Table 4), we concluded Table 1 could be reasonably applied to Green Sturgeon for Bay Study index calculations and for establishment of Salvage Index Year.

Data and Statistical Analysis

Annual White Sturgeon Bay Study indices (WST BS) were calculated using the methods described above and catch of 143 age-0 and 140 age-1 White Sturgeon during otter trawl sampling at the original 35 Bay Study stations from 1980-2017 (monthly mean length and sample size provided in Figure 1). A Green Sturgeon YCI based on Bay Study catch data (GST BS) was generated using the same calculation and Table 1 from Fish (2010). Annual GST BS indices were calculated from catch of 6 age-0 and 10 age-1 Green Sturgeon during otter trawl sampling at the original 35 Bay Study stations from 1980-2017 (Figure 1).

Annual White Sturgeon indices from salvage data (WST SWP and WST CVP) were calculated using the methods described above from 382 White Sturgeon identified at the SWP and 210 identified at the CVP from 1980-2017 (monthly mean length and sample size provided in Figure 2). Using the same methods, we calculated annual GST SWP and GST CVP indices from 92 Green Sturgeon identified at the SWP and 88 Green Sturgeon identified at the CVP from 1980-2017 (Figure 2). We contrasted the six metrics (WST BS, WST SWP, WST CVP, GST BS, GST SWP, and GST CVP) by comparing time series plots and p-values from correlations (R statistical software Version 3.4.0).

Table 4. Collection summary for estimated age-0, age-1, and age-2 Green Sturgeon with corresponding total length mean, range, and age-class limit by sample month in millimeters.

Estimated Age	*Sample Location[1]*	*Sample Date*	*n*	*Mean Length*	*Length Range*	*Age-class Maximum[2]*	*Assigned Age[3]*
Age-0[4]	Sacramento River RKM 391	October 27, 1991	4	240.5	211-273	20-340	Age-0
Age-0[5,6]	Sacramento River RKM 352-400	August 7, 2015	2	159	109-209	20-280	Age-0
Age-0[6]	Sacramento River RKM 352-400	July 23- October 30, 2015	35	231	73-344	20-320	Age-0
Age-1[7]	Klamath River Estuary	July 23- October 2, 1990	1	420	120	280-480	Age-1
Age-2[7]	Klamath River Estuary	July 23- October 2, 1990	10	500	330-610	280-480 (age-1 max)	>Age-1

[1]Sacramento River Kilometer (RKM) in distance upstream of Chipps Island (RKM 0) listed where applicable. [2]Age class maximum based on Fish 2010 (Table 1) and month of median sample date. [3]Assigned age based on mean length and listed age-class maximum. [4]USFWS unpublished age estimates of Green Sturgeon collected in the Sacramento River at the east diffuser grate of Red Bluff Diversion Dam. [5]USFWS unpublished age estimates of Green Sturgeon collected in the Sacramento River during trawl surveys. [6]Gruber et al. 2017. [7]Nakamoto et al. 1995. Note: some data from this source are approximate.

Figure 1. Sturgeon length data from Bay Study otter trawl catch (1980-2016). Numbers in white at bottom of each bar represent sample size (n).

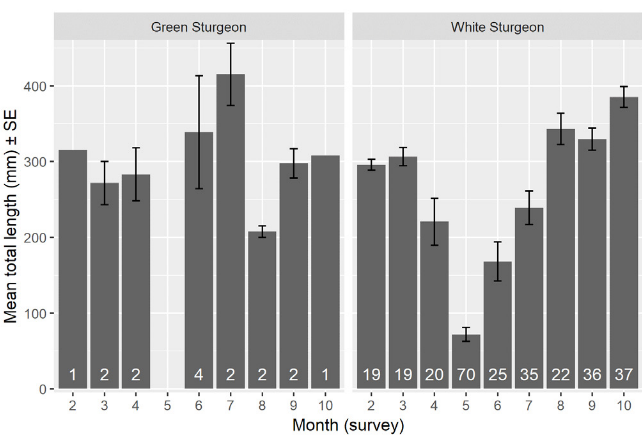
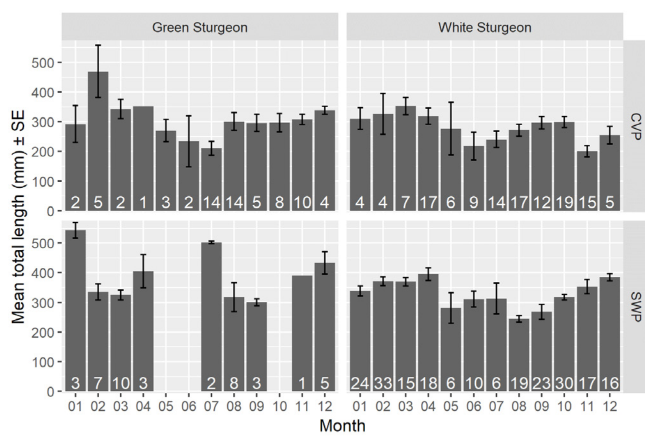


Figure 2. Sturgeon length data from salvage operations (index years 1980-2016). Numbers in white at bottom of each bar represent sample size (n; or number collected & then measured).



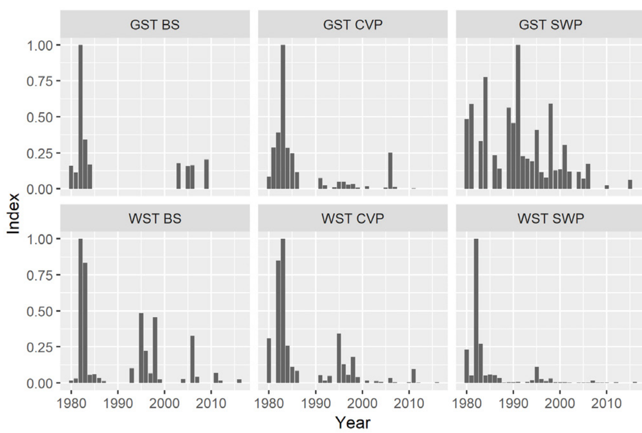
Results

We found a strong linear relationship between all White Sturgeon YCI (WST BS, WST SWP, and WST CVP; Table 5). These YCI shared high values related to water years classified as wet in the Sacramento Valley and included many years with corresponding zero or near-zero values (Figure 3 and Table 6). GST BS and GST CVP showed some plausible patterns in recruitment (i.e., consistent peaks in the early 80s, Figure 3). GST CVP had only a moderately-positive linear relationship to GST BS, most likely due to extremely low sample size in the Bay Study (Tables 5 and 6). GST SWP was unrelated to GST CVP and GST BS (Table 5) and appears to be an unreliable YCI due in-part to the low fraction of Green Sturgeon lengths (Table 3). In the highest GST SWP (1991), length was recorded in only one of eight identified Green Sturgeon (CDFW unpublished data) and the SWP had the lowest fraction of Green Sturgeon lengths of all surveys tested (Table 3). Therefore, we were unable to validate the index year for the GST SWP calculation or confirm the accuracy of high GST SWP values.

Table 5. YCI correlation results. BS= Bay Study, CVP= Central Valley Project, SWP= State Water Project, CL 95% & CU 95% = 95% confidence interval for correlation.

Formula	*Cor*	*CL95*	*CU95*	P_{val}
WSTBS~WSTCVP	0.89618	0.80629	0.94561	6.60E-14
WSTBS~WSTSWP	0.78085	0.61156	0.88177	1.19E-08
WSTCVP~WSTSWP	0.79256	0.63045	0.88843	5.04E-09
GSTBS~GSTCVP	0.56523	0.29529	0.75159	0.0002673
GSTBS~GSTSWP	-0.04992	-0.36799	0.27861	0.7692055
GSTCVP~GSTSWP	0.21713	-0.1149	0.50558	0.196754

Figure 3. Comparison of SFE sturgeon YCI 1980-2016. YCIs were scaled as x / [max(x) – min(x)] for ease of plotting. See Table 6 for actual values.



Discussion

Utility of SFE Sturgeon Recruitment Indices

White Sturgeon salvage indices appear to include sufficient sample sizes to capture year-class strength and population trends. These indices can be independently verified, revised, or updated with publicly-accessible long-term survey data. Consequently, all White Sturgeon indices (WST BS, SWP, and CVP) should be regularly calculated and reported to the public. These indices should also be compared to annual adult sturgeon survey and angler reporting data and evaluated as possible predictors of large juvenile and adult abundance. This may improve White Sturgeon harvest and population forecasting and allow managers to adjust regulations accordingly.

Only historic Green Sturgeon recruitment events may be detectable in long-term surveys. Record-high CVP collection numbers in 2006 were also supported by length and estimated age frequency of larger individuals from other surveys (Table 6; CDFW unpublished data). Thus, it is useful to report both Green Sturgeon and White Sturgeon indices, but likely a major increase in juvenile Green Sturgeon sampling will be necessary to generate a meaningful YCI.

Sources of Error in Salvage Indices

A hypothesis for poor performance of salvage-based sturgeon recruitment indices was historically-inaccurate identification of juvenile sturgeon at SWP and CVP. Sturgeon were not identified to species in the CVP until 1980, and the documented low fraction of length measurements (Table 3) infers some laxity in past sampling protocols. Conversely, species and length were recorded for all sturgeon in Bay Study sampling and we presume species identification was accurate in this survey. Using the Bay Study as a benchmark and considering the strong relationship between all White Sturgeon YCI, we identified no obvious patterns of sturgeon misidentification in SWP and CVP sampling. Similar patterns in seasonal size and abundance of salvaged sturgeon imply that some White Sturgeon could have been historically misidentified as the less abundant Green Sturgeon. However, WST BS and GST BS also show similar patterns despite extremely low sample sizes of Green Sturgeon. Further, the absence of Green Sturgeon larvae — and presence of White Sturgeon larvae — in salvage records supports the notion of accurate sturgeon identification in SWP and CVP sampling. White Sturgeon larvae are routinely collected in SFE larval fish surveys and Green Sturgeon larvae have only been verified in samples from upstream spawning reaches.

Changes to Delta water export operations intended to reduce fish entrainment into the Central and South Delta (e.g., winter closure of the Delta Cross Channel) was another hypothesis for low sturgeon salvage densities in recent decades (and associated poor performance of salvage-based indices). However, this phenomenon would presumably involve a divergent pattern between WST BS and salvage indices calculated from data collected in the South Delta. Instead, the consistent trend in WST BS, WST SWP, and WST CVP displays a declining magnitude in White Sturgeon recruitment episodes. This suggests a weakening effect of high flows on recruitment due

Table 6. White and Green Sturgeon total index-year catch (n), index values, and water year classification.

Year	Water Year Type [1]	Bay Study				SWP				CVP			
		White Sturgeon		Green Sturgeon		White Sturgeon		Green Sturgeon		White Sturgeon		Green Sturgeon	
		n	Index	n	Index	n	Index	n	Index	n	Index	n	Index
1980	AN	1	11.1	1	9.1	29	26.2	2	1.8	5	17.3	1	3.5
1981	D	3	21.8	1	6.4	8	5.8	3	2.2	0	0.0	2	11.6
1982	W	78	719.7	6	57.3	93	113.1	0	0.0	12	47.6	4	15.9
1983	W	81	599.6	3	19.7	50	30.7	2	1.2	18	56.1	13	40.5
1984	W	5	40.7	1	9.6	6	5.8	3	2.9	5	14.4	4	11.5
1985	D	4	44.0	0	0.0	6	6.6	0	0.0	5	6.2	8	10.0
1986	W	3	23.5	0	0.0	7	6.1	1	0.9	2	4.6	2	4.6
1987	D	1	8.5	0	0.0	7	3.6	1	0.5	0	0.0	0	0.0
1988	C	0	0.0	0	0.0	1	0.4	0	0.0	0	0.0	0	0.0
1989	D	0	0.0	0	0.0	2	0.7	6	2.1	0	0.0	0	0.0
1990	C	0	0.0	0	0.0	1	0.4	4	1.7	0	0.0	0	0.0
1991	C	0	0.0	0	0.0	2	0.9	8	3.7	1	3.0	1	3.0
1992	C	0	0.0	0	0.0	0	0.0	4	0.8	1	0.9	1	0.9
1993	AN	5	72.5	0	0.0	5	0.8	5	0.8	6	2.7	0	0.0
1994	C	0	0.0	0	0.0	11	2.0	4	0.7	0	0.0	1	0.5
1995	W	22	348.6	0	0.0	67	12.7	8	1.5	49	19.1	5	2.0
1996	W	14	161.0	0	0.0	22	3.1	3	0.4	18	7.2	5	2.0
1997	W	5	46.7	0	0.0	5	1.4	1	0.3	8	3.1	3	1.1
1998	W	28	327.7	0	0.0	14	3.4	9	2.2	23	10.2	3	1.3
1999	W	2	18.2	0	0.0	5	0.6	4	0.5	6	2.3	1	0.4
2000	AN	0	0.0	0	0.0	4	0.7	3	0.5	0	0.0	0	0.0
2001	D	0	0.0	0	0.0	3	0.6	6	1.1	2	0.8	2	0.8
2002	D	0	0.0	0	0.0	1	0.1	3	0.4	0	0.0	0	0.0
2003	AN	0	0.0	1	10.2	0	0.0	0	0.0	2	0.7	0	0.0
2004	BN	2	19.1	0	0.0	1	0.1	3	0.4	1	0.4	0	0.0
2005	BN	0	0.0	1	9.1	2	0.3	2	0.3	0	0.0	1	0.4
2006	W	20	234.6	1	9.4	3	0.4	5	0.6	5	1.8	28	10.2
2007	D	3	30.2	0	0.0	12	1.8	0	0.0	1	0.3	2	0.5
2008	C	0	0.0	0	0.0	1	0.2	0	0.0	0	0.0	0	0.0
2009	D	0	0.0	1	11.7	2	0.3	0	0.0	0	0.0	0	0.0
2010	BN	0	0.0	0	0.0	2	0.2	1	0.1	2	0.3	0	0.0
2011	W	4	48.8	0	0.0	1	0.1	0	0.0	36	5.4	1	0.2
2012	BN	1	11.1	0	0.0	4	0.5	0	0.0	1	0.2	0	0.0
2013	D	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2014	C	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2015	C	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	0	0.0
2016	BN	1	18.4	0	0.0	5	0.9	0	0.0	1	0.3	0	0.0

[1] California Department of Water Resources chronological reconstructed Sacramento Valley Water Year Hydrologic Classification Indices based on measured unimpaired runoff (in million acre-feet). AN = above normal, BN = below normal, C = critical, D = dry, W = wet.

in part to a declining reproductive stock (Figure 3; Kohlhorst et al. 1991).

Gingras et al. (2013) evaluated a White Sturgeon metric from estimated salvage at SWP ('WSTSAL') through comparison to an established YCI (WST BS — termed 'WSTBS'). WSTSAL was unrelated to WST BS and discounted as a valid YCI (Gingras et al. 2013). The discrepancies between WSTSAL and WST BS were likely due to historically-low sampling effort and associated large expansion factors used in traditional calculations of estimated salvage density. Poor performance of WSTSAL as a YCI could have been influenced by the SWP sampling location to a lesser extent. We found WST CVP more strongly related to WST BS than WST SWP (Table 5). This may be due to the CVP's run-of-the-river diversion point on Old River as opposed to the SWP diversion point inside Clifton Court Forebay. The rapid decline in annual SWP Green Sturgeon salvage numbers and density from the mid-1970s to 2004 reported in Beamesderfer et al. (2007) was also likely an artifact of historically-low sampling effort and large expansion factors. Still, there has been only one Green Sturgeon recorded in SWP entrainment monitoring in over a decade (2007-2018), which is the lowest catch of Green Sturgeon since SWP monitoring began in 1968.

Recommendations

Fish identification sampling at SWP and CVP currently occurs at regular intervals with sample volume tied to export volume. Consequently, sampling effort and precision of indices at SWP and CVP are mostly fixed, aside from refinement of age assignment and analytical techniques. Over time, the fraction of sturgeon length records at the SWP and the CVP has increased, but length of all handled sturgeon should be recorded to refine (or replace) our index-year method with one based on age assignment (via length-at-date). Further, our preliminary salvage index calculations are crude, and a more advanced calculation could address potential sampling error and biases.

Irrespective of length (and age assignment), the Bay Study Survey caught 1,067 White Sturgeon (1980-2016; includes both gear types — midwater and otter trawls — and all sampling stations over all 12 calendar months). Hence, there is an opportunity to substantially increase the sample size of White Sturgeon in Bay Study YCI calculations by including data from all 52 trawl stations, survey months, and trawl types. This more-complete YCI calculation should be explored as an economical improvement to sample-size and precision in trawl-based YCI. Improving Green Sturgeon recruitment estimates and relative cohort strength estimates will not come easily. The total Green Sturgeon catch in the Bay Study Survey was only 82 (1980-2016; includes all trawl types, sampling locations, and calendar months). Preliminary investigation of a YCI using all age-0 and age-1 Green Sturgeon caught in the Bay Study did not appear to show any meaningful differences to the GST BS reported above. Data rather than analytical techniques appear to be the main constraint in monitoring Green Sturgeon recruitment. In turn, a substantial increase in effort in active monitoring like the Bay Study will be necessary to make progress in this area.

The simple goal in management and recovery of SFE sturgeon is to promote population growth. Indicators of age-0 and age-1 juvenile abundance are the most compelling early signals that management actions are effective and that this goal is being met. A heavy emphasis should be placed on monitoring year-class strength and identifying conditions associated with successful reproduction and early life-history success. This should be done concurrently with cohort or brood-year abundance modelling for both sturgeon species using estimated age of larger fish to verify the accuracy of all potential YCIs. All YCIs in this analysis rely on accurate age-length keys for White Sturgeon and Green Sturgeon. Table 1 should be refined regularly as agency data allow. The validity of Table 1 for assigning Green Sturgeon age in YCI calculations is based on a meager amount of data. At minimum, a concerted effort should be made to develop a specific age-length key for Green Sturgeon in the SFE watershed.

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California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

California Department of Fish and Wildlife
U.S. Fish and Wildlife Service
U.S. Geological Survey
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