Appendix J, Winter and Spring Pulses and Delta Outflow

Attachment J.2 Sturgeon Year Class Index and Delta Outflow

J.2.1 Model Overview

This analysis assesses potential effects of the proposed project and alternatives on white or green sturgeon year-class strength (YCI) using a correlative relationship between Delta outflow and white sturgeon YCI based on Fish (2010). The analysis uses historical Delta outflow and white sturgeon YCI data to establish the relationships. Modeled Delta outflow values from Calsim 3 are then used as input to these relationships to estimate white sturgeon YCI. White sturgeon YCI is used as a surrogate to estimate green sturgeon YCI because a quantitative model for green sturgeon abundance does not yet exist and a similar positive correlation between annual outflow and green sturgeon larval and juvenile abundance has been observed (Heublein et al 2017a, Beccio pers comm. On August 12, 2021).

J.2.2 Model Development

J.2.2.1 Methods

This analysis was originally used by ICF International (2016:5-197–5-205) to assess potential effects of the California WaterFix project on white and green sturgeon. The analysis was updated for the current document to include new white sturgeon YCI and Delta outflow data through 2020 (Table J.2-1). Annual white sturgeon YCI data obtained from the California Department of Fish and Wildlife (CDFW) San Francisco Bay Study (CDFW unpubl. data) and historical daily Delta outflow data were extracted from the California Department of Water Resources Dayflow data (https://data.cnra.ca.gov/dataset/dayflow). Daily outflow data were averaged for each year for either March–July or April–May. White sturgeon YCI data were regressed against CalSim3 modeled mean Delta outflow data for March–July and April–May (Figure J.2-1) to establish the relationships between YCI and Delta outflow. The updated relationships used are:

$$Log_{10}(YCI+1) = [0.0000227 * \text{Delta Outflow (Apr–May)}] + 0.246,\ r^2 = 0.56,\ P<0.0001$$

$$Log_{10}(YCI+1) = [0.0000275 * \text{Delta Outflow (Mar–Jul)}] + 0.169,\ r^2 = 0.59,\ P<0.0001$$

Table J.2-1. Historical Data Used to Develop Regressions of White Sturgeon Year-Class Strength versus Mean Delta Outflow Data (cfs) for March–July and April–May.

Year	Year-Class Index	March-July Delta Outflow (cfs)	April-May Delta Outflow (cfs)
1980	11.1	35,060	24,652
1981	21.8	11,478	10,375
1983	599.6	119,942	108,220
1984	40.7	15,798	12,836
1985	44.0	6,911	7,072
1986	23.5	49,947	30,923
1987	8.5	8,261	5,517
1988	0	5,451	7,983
1989	0	14,130	9,497
1990	0	5,248	6,826
1991	0	7,946	3,783
1992	0	5,854	4,732
1993	72.5	33,974	34,585
1994	0	7,006	8,044
1995	348.6	92,926	94,501
1996	161.0	40,478	44,059
1997	46.7	15,662	13,266
1998	327.7	72,580	77,724
1999	18.2	30,309	28,753
2000	0	31,258	24,678
2001	0	11,539	10,942
2002	0	11,153	12,762
2003	0	20,299	32,159
2004	19.1	20,857	17,137
2005	0	31,406	40,624
2006	234.6	84,048	129,578
2007	30.2	9,580	10,327
2008	0	8,193	8,867
2009	0	12,255	13,994
2010	0	17,082	22,611
2011	48.8	59,129	65,740

Year	Year-Class Index	March-July Delta Outflow (cfs)	April-May Delta Outflow (cfs)
2012	11.1	15,209	20,012
2013	0	9,165	11,444
2014	0	6,863	6,013
2015	No index	N/A	N/A
2016	No index	N/A	N/A
2017	284.0	66,842	85,730
2018	0	19,282	27,057
2019	66.0	59,427	67,608
2020	0	8,470	10,200

Notes: cfs = cubic feet per second.

Modeled monthly Delta outflow from CalSim 3 for the full simulation period (1922-2021) are used as inputs to the analysis. Since the model is used to predict new values of YCI, not just assess the goodness of fit to the historical data, cross-validation to assess its predictive ability was completed to estimate the predictive error using a repeated k-fold approach (5-fold, repeated 4 times). For the March-July outflow relationship the Root Mean Square Error (RMSE) value was 0.66, multiple R^2 value was 0.63, and Mean Absolute Error value was 0.57. This translated into an average prediction error of 3 to 4 YCI for a historical average of 80+/-165 (standard deviation). For the April-May outflow relationship, RMSE was 0.67, Multiple R^2 was 0.6 and MAE was 0.6. Outputs from the analysis are white sturgeon YCI for each modeled scenario. The regression operates at an annual time step. The analysis was conducted using R statistical software (R Core Team 2023).

J.2.2.2 Assumptions / Uncertainty

A primary assumption of this analysis is that the correlation between white sturgeon YCI and Delta outflow is causal such that Delta outflow drives white sturgeon YCI. Although this assumption of causality is reasonable, there is little evidence that Delta outflow itself drives the YCI. The two variables, Delta outflow and white sturgeon YCI, may both vary in response to another variable. Interpreting the results of this analysis should consider this.

Another assumption of this analysis is that, because no green sturgeon YCI has been developed, white sturgeon is an appropriate surrogate species for green sturgeon. Although the two sturgeon species share several life history traits, the spatial and temporal use of upstream and Delta habitat, as well as their movement within their ranges, differ between the species. Therefore, the results of the analysis for green sturgeon YCI have higher uncertainty than those for white sturgeon YCI.

J.2.2.3 Code and Data Repository

Code, input, and output files for this analysis are available upon request.

J.2.3 Results

These results describe potential effects to white sturgeon, although they are applied similarly to green sturgeon.

J.2.3.1 BA:

Table J.2-2. Year-Class Strength of Green Sturgeon Based on April–May Regression with Delta Outflow.

WYT	EXP 1	EXP 3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
W	139.1	58.2	30.3	29.0	29.0	29.5	29.7
AN	16.9	8.5	5.8	5.1	5.2	5.4	6.0
BN	8.8	4.7	3.5	3.2	3.3	3.4	3.8
D	3.4	2.3	2.2	2.2	2.2	2.2	2.4
C	1.7	1.6	1.4	1.6	1.5	1.6	1.7
All	46.6	20.2	11.2	10.7	10.7	10.9	11.2

Note: Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the April-May regression with Delta-Outflow are presented in Table J.2-2, Figure J.2-1, and Figure J.2-2. Excluding EXP 1 and EXP 3, the average overall YCI values would generally be similar across all alternatives, with the highest average values under the NAA and Alt 2 Without TUCP Systemwide VA at 11.2 and the lowest average values under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA at 10.7. This pattern would hold true across water year types with ranges (min-max) of average YCI going from 0.3 in Critically Dry years to 1.3 in Wet years. In Critically Dry years, the lowest average YCI would be under the NAA (1.4) and the highest under Alt 2 Without TUCP Systemwide VA (1.7). In Dry years, the average YCI would be consistent across alternatives with Alt 2 Without TUCP Systemwide VA at 2.4 and all others (excluding EXP 1 and EXP 3) at 2.2. In Below Normal years, the lowest average YCI would be under Alt 2 With TUCP Without VA (3.2) and the highest under Alt 2 Without TUCP Systemwide VA (3.8). In Above Normal years, the lowest average YCI would be under Alt 2 With TUCP Without VA (5.1) and the highest under Alt 2 Without TUCP Systemwide VA (6). In Wet years, the lowest average YCI would be under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA (29) and the highest under the NAA (30.3). EXP 1 and EXP 3 unsurprisingly would follow the same patterns of increasing average YCI from Critically Dry years to Wet years, with values ranging from 1.7 to 139.1 and 1.6 to 58.2, respectively.

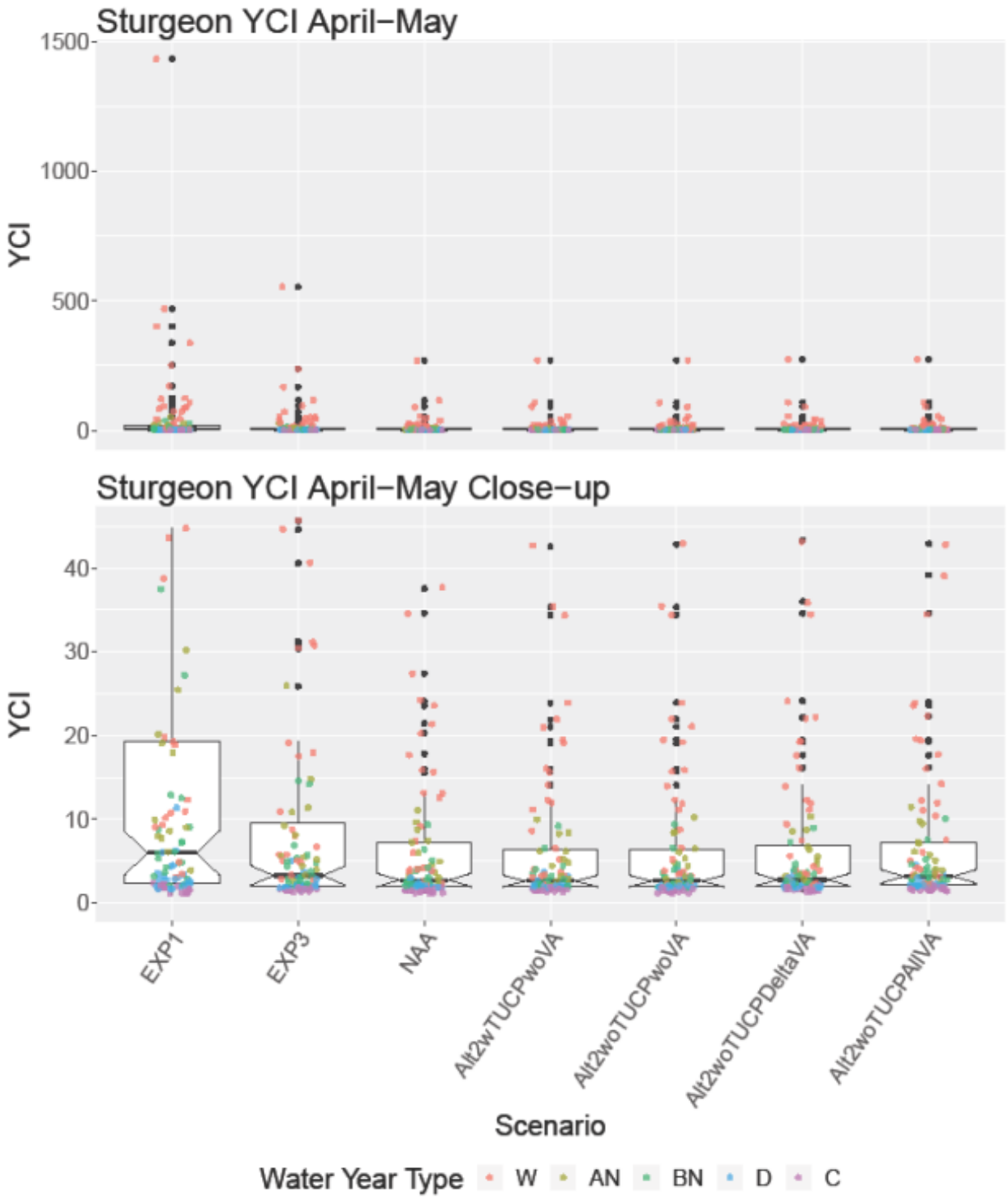


Figure J.2-1. Green sturgeon Year-Class Strength (YCI) based on the April-May regression with Delta Outflow for all considered alternatives. Overlaid color dots represent individual data points by Water Year Type (WYT). Upper panel: full range of data. Lower panel: close-up view excluding most extreme outliers.

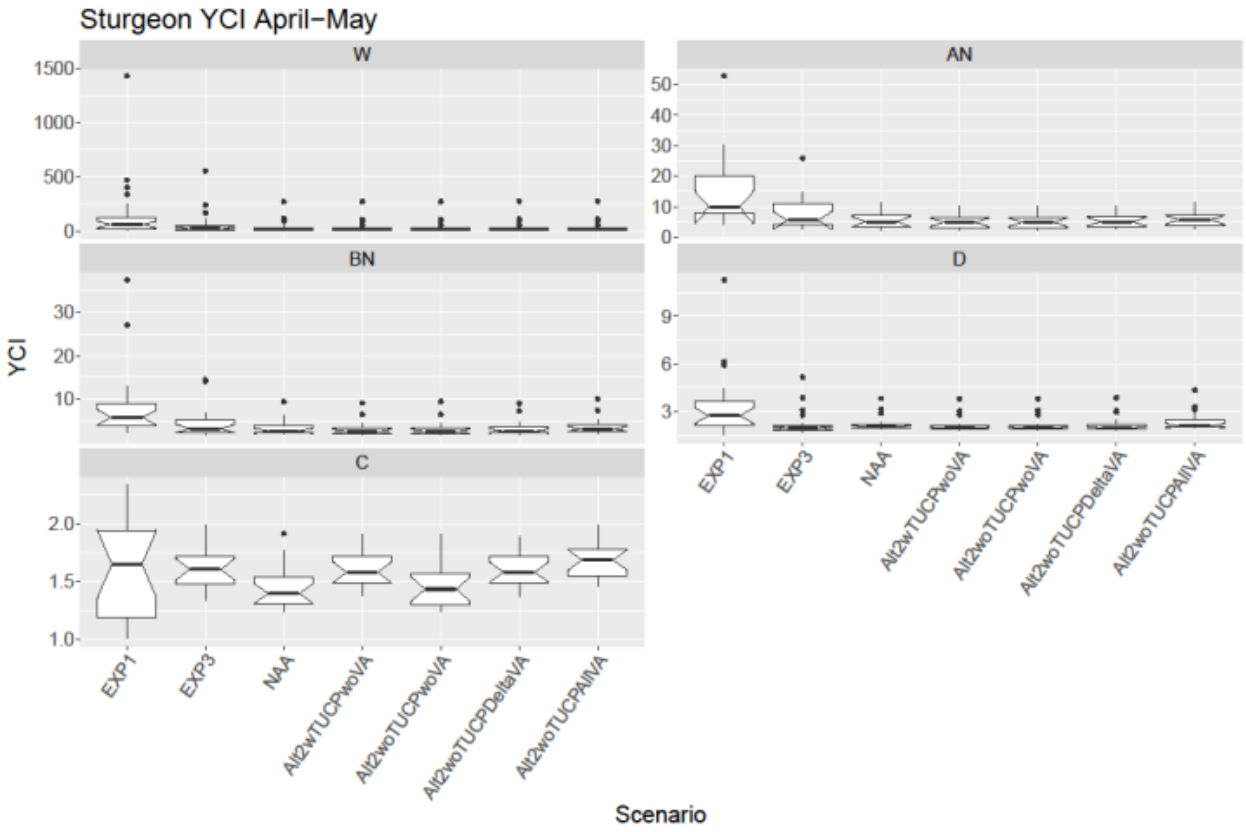


Figure J.2-2. Green sturgeon Year-Class Strength (YCI) based on the April-May regression with Delta Outflow for all considered alternatives and Water Year Type (WYT).

Table J.2-3. Year-Class Strength of Green Sturgeon Based on March–July Regression with Delta Outflow.

WYT	EXP 1	EXP 3	NAA	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
W	159.6	90.0	48.9	47.9	47.9	48.3	48.3
AN	14.5	9.9	6.7	6.2	6.3	6.5	6.9
BN	5.5	3.8	2.9	2.8	2.8	2.9	3.1
D	2.8	2.3	2.0	1.9	1.9	2.0	2.1
C	1.4	1.4	1.2	1.3	1.2	1.3	1.4
All	51.7	29.7	16.7	16.3	16.3	16.6	16.7

Note: Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the March-July regression with Delta-Outflow are presented in Table J.2-3, Figure J.2-3, and Figure J.2-4. Excluding EXP 1 and EXP 3, the average overall YCI values would generally be similar across all alternatives, with the highest average values under the NAA and Alt 2 Without TUCP Systemwide VA at 16.7 and the lowest average values under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA at 16.3. This pattern would hold true across water year types with ranges (min-max) of average YCI going from 0.2 in Critically Dry years to 1 in Wet years. In Critically Dry years, the lowest average YCI would be under the NAA and Alt 2 Without TUCP Without VA (1.2) and the highest under Alt 2 Without TUCP Systemwide VA (1.4). In Dry years, the lowest average YCI would be under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA (1.9) and the highest under Alt 2 Without TUCP Systemwide VA (2.1). In Below Normal years, the lowest average YCI would be under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA (2.8) and the highest under Alt 2 Without TUCP Systemwide VA (3.1). In Above Normal years, the lowest average YCI would be under Alt 2 With TUCP Without VA (6.2) and the highest under Alt 2 Without TUCP Systemwide VA (6.9). In Wet years, the lowest average YCI would be under Alt 2 With TUCP Without VA and Alt 2 Without TUCP Without VA (47.9) and the highest under the NAA (48.9). EXP 1 and EXP 3 would follow the same patterns of increasing average YCI from Critically Dry years to Wet years, with values ranging from 1.4 to 159.6 and 1.4 to 90, respectively.

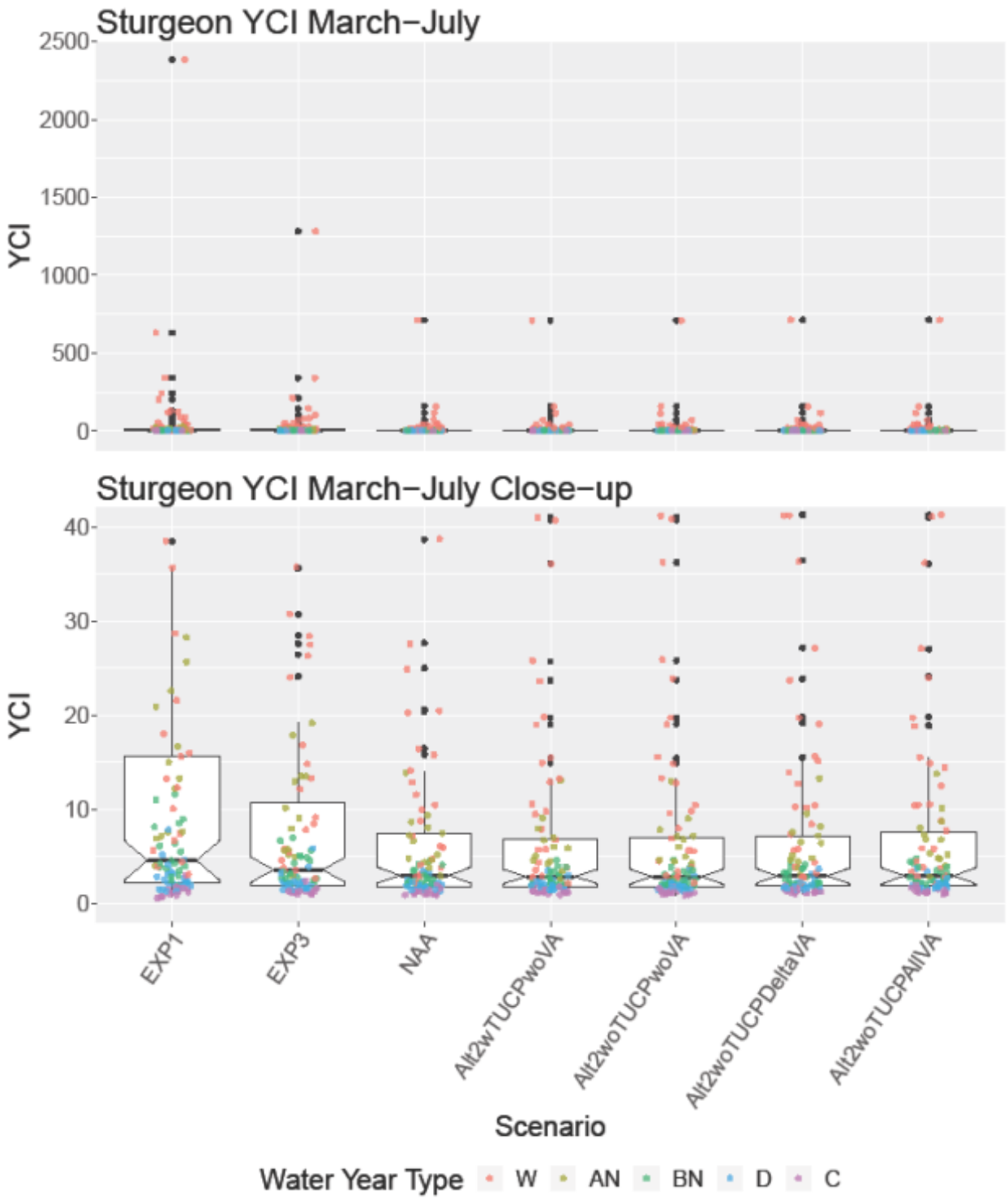


Figure J.2-3. Green sturgeon Year-Class Strength (YCI) based on the March-July regression with Delta Outflow for all considered alternatives. Overlaid color dots represent individual data points by Water Year Type (WYT). Upper panel: full range of data. Lower panel: close-up view excluding most extreme outliers.

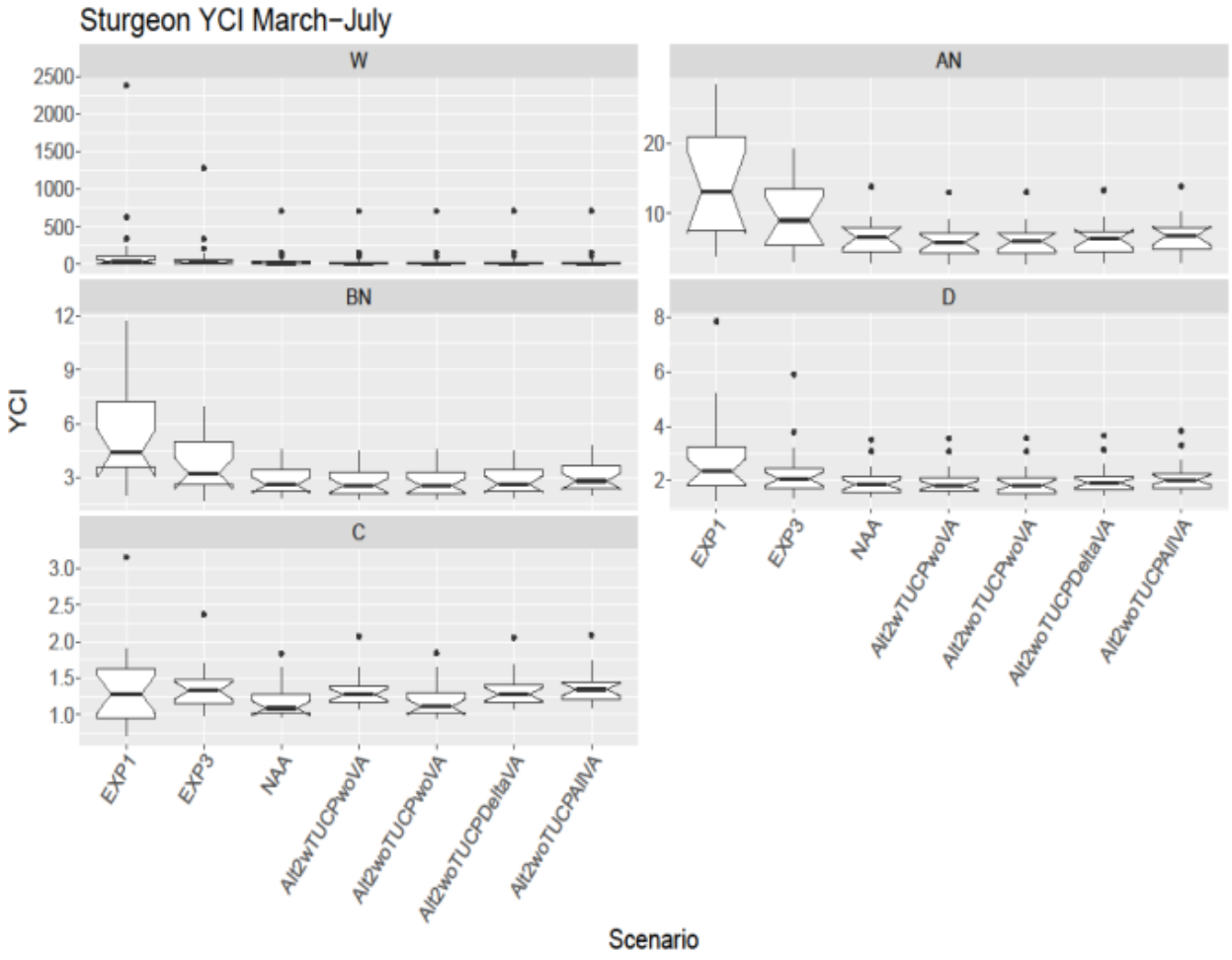


Figure J.2-4. Green sturgeon Year-Class Strength (YCI) based on the March-July regression with Delta Outflow for all considered alternatives and Water Year Type (WYT).

Similar to the additional request in the other Attachment: could you provide 2 more pieces one that relates to the biology and the time-frame of modeling and the other that relates to what the CalSim 3 parameter input is doing which is the sole driver of this model.

Studies have shown positive relationships between white sturgeon YCI, a surrogate for green sturgeon YCI, and Delta outflow, though the mechanism behind the importance of higher Delta outflow for white sturgeon is unknown and may involve factors that are located either upstream of or in the Delta or both. Hypotheses for the mechanism underlying flow effects include higher flows facilitating young white sturgeon dispersal downstream, providing increased freshwater rearing habitat, increasing spawning activity cued by higher upstream flows, increasing nutrient loading into nursery areas, or increasing downstream migration rate and survival through reduced exposure time to predators (U.S. Fish and Wildlife Service 1995:2-VII-39; Israel pers. comm. Feb. 20, 2012). Upstream of the Delta, higher spring flows may also benefit incubating eggs (Heublein et al. 2017b:17).

Because (white or green) sturgeon YCI is directly proportional to Delta outflow during the months evaluated (April-May and March-July) in the models used to conduct this analysis, increases in simulated Delta outflow from CalSim 3 cause increases in YCI. For example, higher Delta outflow under EXP 1 relative to the other alternatives during March-July resulted in an increase in (white or green) sturgeon YCI (Table J.23, Figure J.23, Figure J.24)..

J.2.3.2 EIS:

Table J.2-4. Year-Class Strength of White Sturgeon (Percent Difference from NAA) Based on April–May Regression with Delta Outflow.

WYT	NAA	Alt 1	Alt2wTUCPwoVA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA	Alt 3	Alt 4
W	30.3	29.1 (-4%)	29 (-4.3%)	29 (-4.3%)	29.5 (-2.6%)	29.7 (-2%)	50.2 (65.5%)	29.1 (-4%)
AN	5.8	5.1 (-12.1%)	5.2 (-10.3%)	5.1 (-12.1%)	5.4 (-6.9%)	6 (3.4%)	9.2 (58.6%)	5.2 (-10.3%)
BN	3.5	3.2 (-8.6%)	3.2 (-8.6%)	3.2 (-8.6%)	3.4 (-2.9%)	3.8 (8.6%)	4.6 (30.9%)	3.2 (-8.6%)
D	2.2	2.2 (0%)	2.2 (0%)	2.2 (0%)	2.2 (0%)	2.4 (9.1%)	2.6 (17.3%)	2.2 (0%)
C	1.4	1.6 (14.3%)	1.5 (7.1%)	1.6 (14.3%)	1.6 (14.3%)	1.7 (21.4%)	1.7 (21.4%)	1.5 (7.1%)
All	11.2	10.7 (-4.5%)	10.7 (-4.5%)	10.7 (-4.5%)	10.9 (-2.7%)	11.2 (0%)	18 (59.9%)	10.7 (-4.5%)

Note: Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the April-May regression with Delta-Outflow are presented in Table J.2-4, Figure J.2-5, and Figure J.2-6. The average overall YCI values would be generally similar across all alternatives except Alt 3, which would be substantially higher at 18 (+59.9% compared to the NAA). Except for Alt 3, values would range from 10.7 for Alt 1, Alt 2 With TUCP Without VA, Alt 2 Without TUCP Without VA and Alt 4 (-4.5% difference with the NAA) to 11.2 for Alt 2 Without TUCP Systemwide VA, which is a similar value to the NAA. This general pattern would be most pronounced for Wet and Above Normal years with Alt 3 yielding the highest average YCI across all alternatives at 50.2 and 9.2, respectively, far exceeding the average YCI of 30.3 and 5.8 under the NAA (a difference of +65.5% and 58.6%, respectively). In those wetter years, the average absolute YCI values for all other alternatives considered would be mostly similar or slightly lower compared to the NAA. In Wet years, they would range from 29 for Alt 2 With TUCP Without VA, Alt 2 Without TUCP Without VA to 29.7 for Alt 2 Without TUCP Systemwide VA (differences of -4.3% to -2% compared to the NAA). The average YCI would vary a bit more during Above Normal water year types for those other alternatives, ranging from 5.1 for Alt 1 and Alt 2 Without TUCP Without VA to 6 for Alt 2 Without TUCP Systemwide VA (differences of -12.2% to + 3.4% compared to the NAA), although these relative differences would still be well within the variation observed among individual Above Normal years for any given alternative besides Alt 3. While less pronounced, these differences between alternatives would still be detected for Below Normal years, ranging from slightly lower than the NAA for Alt 1 at 3.2 (-8.6%) to slightly higher than the NAA for Alt 2 Without TUCP Systemwide VA at 3.8 (+9.1%), or substantially higher than the NAA for Alt 3 at 4.6 (+30.9%). In Dry water year types, Alt 2 Without TUCP Systemwide VA and Alt 3 may yield small positive relative differences compared to the NAA (+9.1 and +17.3%, respectively), while the YCI for all other alternatives would be virtually indistinguishable from those under the NAA. In Critically Dry water year types, all alternatives would lead to small positive differences (from +7.1% for Alt 2 with TUCP without VA and Alternative 4, to +21.4% for Alt 2 Without TUCP Systemwide VA and Alternative 3).

However, it is important to keep in mind that in dryer years (Dry and Critically Dry water year types that historical (observed) yearly YCI were most often at zero or relatively low (and then almost exclusively when immediately following wetter years), with few sturgeons detected in the monitoring programs, leading to low average predicted YCI and low absolute differences between alternatives and the NAA compared to the variation between individual years for a given alternative and water year type. and 2) the linear model predictive performance is expectedly low for low Delta outflow values, with considerable uncertainty in the predicted YCI. For April-May Delta outflow values of less than 25,000 cfs, there are likely strong limitations to the ability of the monitoring programs to reliably detect and estimate abundances of sturgeons, and/or additional mechanisms controlling sturgeons' recruitment/YCI that are not directly linked to Delta outflow.

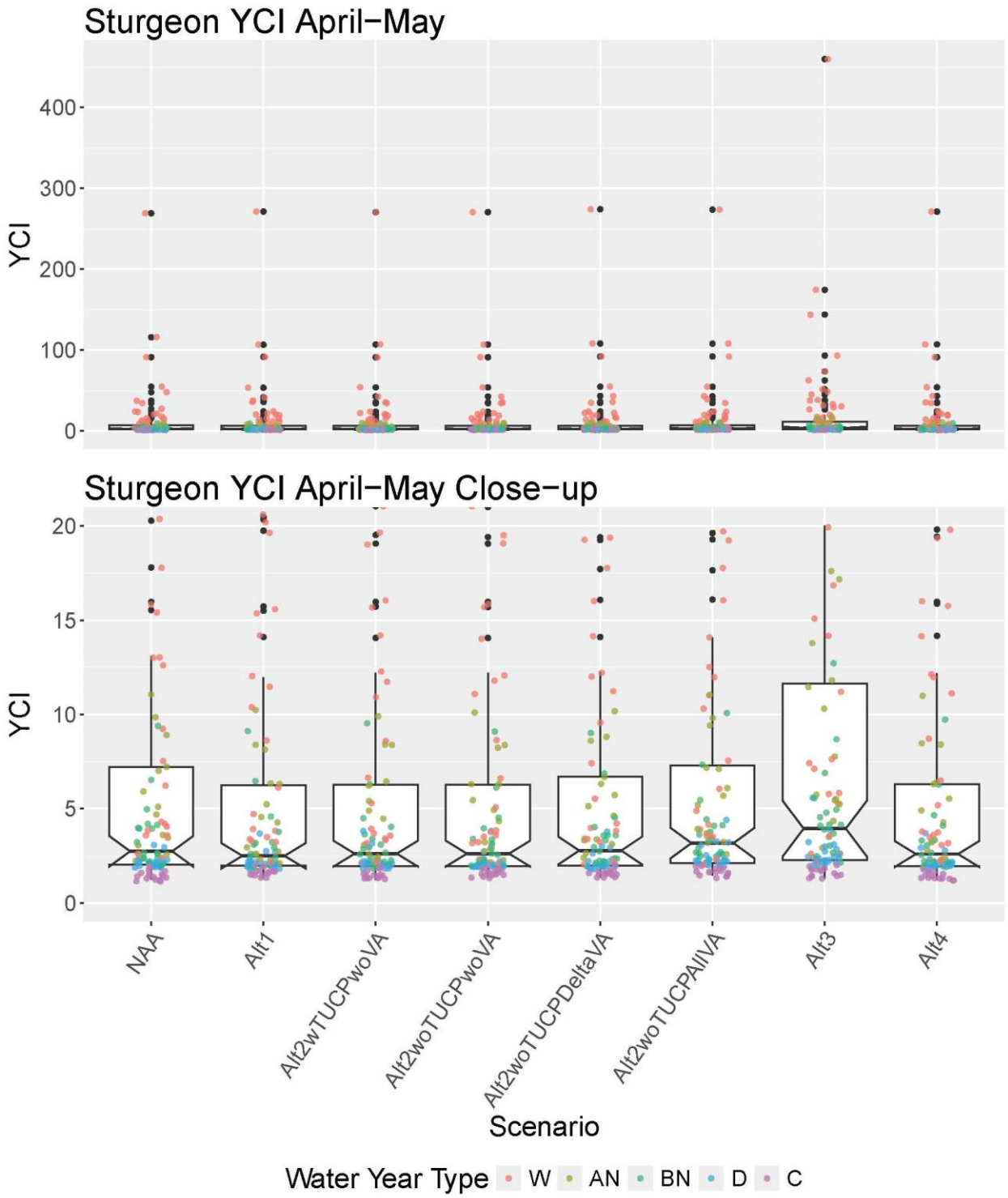


Figure J.2-5. White sturgeon Year-Class Strength (YCI) based on the April-May regression with Delta Outflow for all considered alternatives. Overlaid color dots represent individual data points by Water Year Type (WYT). Upper panel: full range of data. Lower panel: close-up view excluding most extreme outliers.

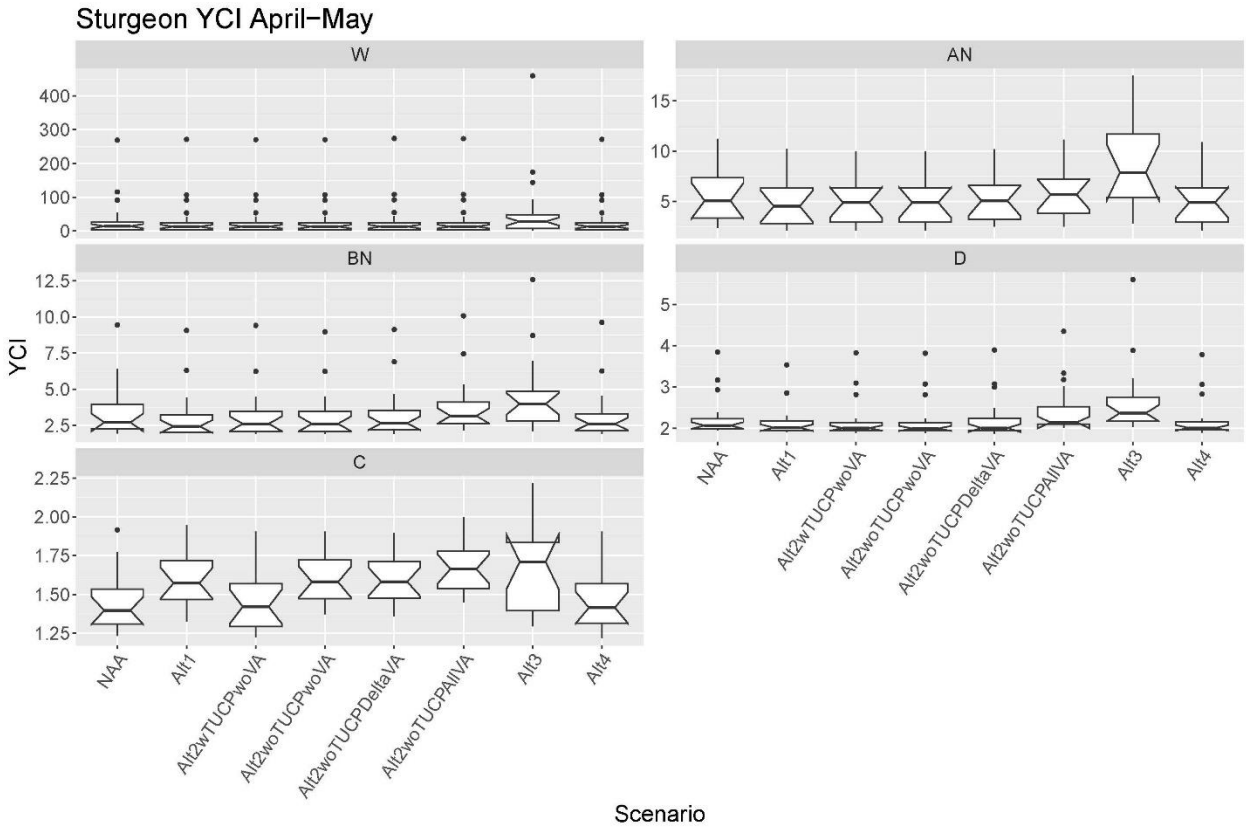


Figure J.2-6. White sturgeon Year-Class Strength (YCI) based on the April-May regression with Delta Outflow for all considered alternatives and Water Year Type (WYT).

Table J.2-5. Year-Class Strength of White Sturgeon (Percent Difference from NAA) Based on March–July Regression with Delta Outflow.

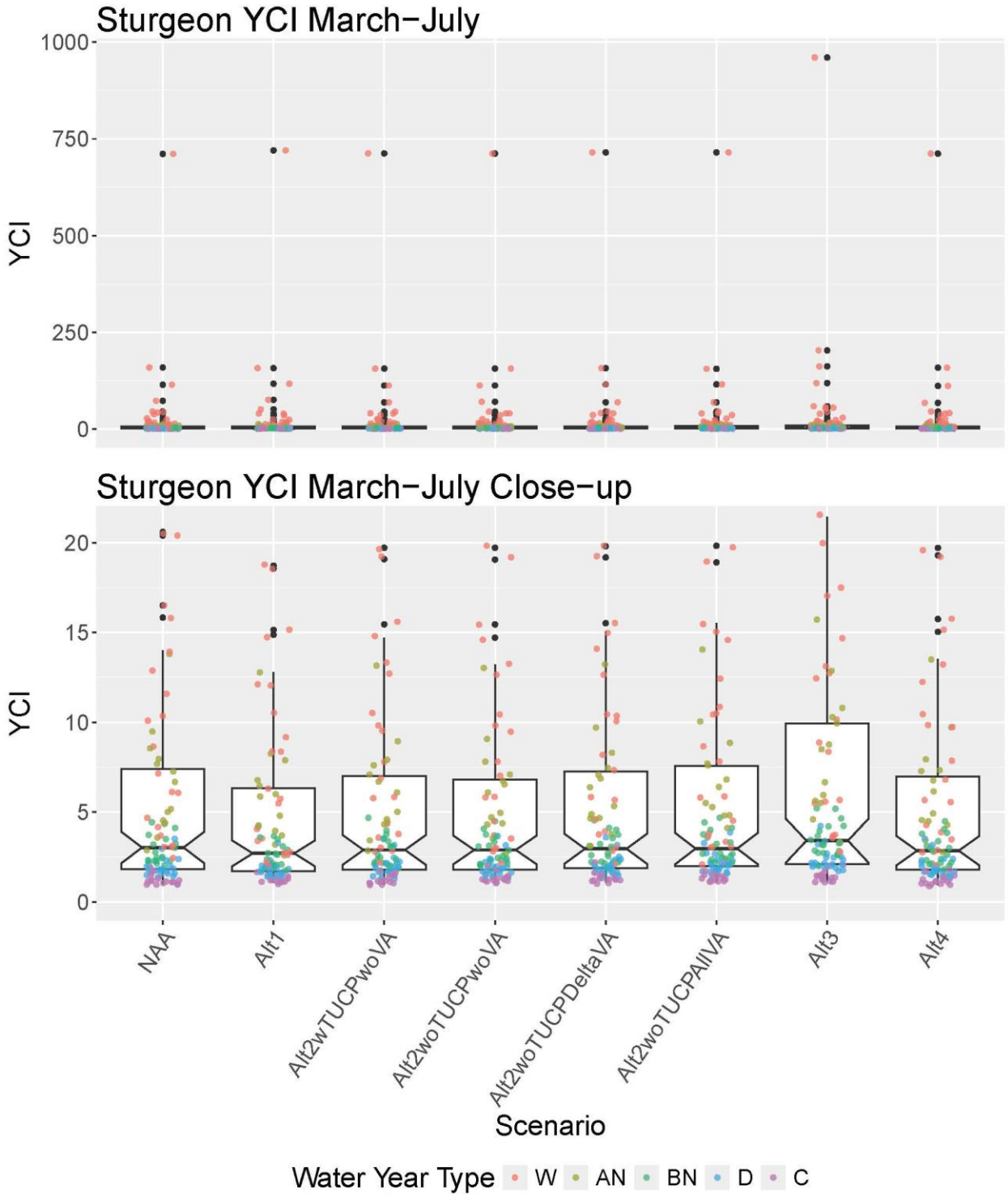
WYT	NAA	Alt 1	Alt2wTUCPwoVA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA	Alt 3	Alt4
W	48.9	48.5 (-0.8%)	47.9 (-2%)	47.9 (-2%)	48.3 (-1.2%)	48.3 (-1.2%)	66.4 (35.9%)	47.9 (-2%)
AN	6.7	5.9 (-11.9%)	6.3 (-6%)	6.2 (-7.5%)	6.6 (-1.5%)	6.8 (1.5%)	8.3 (24.2%)	6.4 (-4.5%)
BN	2.9	2.6 (-10.3%)	2.8 (-3.4%)	2.8 (-3.4%)	2.9 (0%)	3.1 (6.9%)	3.5 (19.7%)	2.8 (-3.4%)
D	2.0	1.9 (-5%)	1.9 (-5%)	1.9 (-5%)	2 (0%)	2.1 (5%)	2.3 (18.7%)	1.9 (-5%)
C	1.2	1.3 (8.3%)	1.2 (0%)	1.3 (8.3%)	1.3 (8.3%)	1.4 (16.7%)	1.4 (20.5%)	1.2 (0%)
All	16.7	16.4 (-1.8%)	16.3 (-2.4%)	16.3 (-2.4%)	16.6 (-0.6%)	16.6 (-0.6%)	22.4 (34.2%)	16.4 (-1.8%)

Note: Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the March-July regression with Delta-Outflow are presented in Table J.2-5, Figure J.2-7, and Figure J.2-8. The

average overall YCI values would generally be similar across all alternatives except Alt 3, which would be substantially higher at 22.4 (+34.2% compared to the NAA). Except for Alt 3, the other alternatives would range from 16.3 for Alt 2 With TUCP Without VA, Alt 2 Without TUCP Without VA (-2.4% difference with the NAA) to 16.6 for Alt 2 Without TUCP Delta VA and Alt 2 Without TUCP Systemwide VA, which would essentially be similar to the NAA. This general pattern would be slightly more pronounced for Wet and Above Normal years with Alt 3 yielding the highest average YCI across all alternatives at 66.4 and 8.3, respectively, exceeding the average YCI of 48.9 and 6.7 under the NAA (a difference of +35.9% and +24.2%, respectively). In those wetter years, the average absolute YCI values for all other alternatives considered would be mostly similar or slightly lower compared to the NAA. In Wet years, they would range from 47.9 for Alt 2 With TUCP Without VA, Alt 2 Without TUCP Without VA and Alt 4 to 48.5 for Alt 1 (differences of -2 % to -0.8% compared to the NAA). The average YCI would vary a bit more in Above Normal water year types for those other alternatives, ranging from 5.9 for Alt 1 to 6.8 for Alt 2 Without TUCP Systemwide VA (differences of -11.9% to + 1.5% compared to the NAA, although these relative differences would still be well within the variation observed among individual Above Normal water year types for any given alternative besides Alt 3. While less pronounced, these differences between alternatives would still be detected for Below Normal years, ranging from 10.3% lower than the NAA for Alt 1 at 2.6 to 6.9% higher than the NAA for Alt 2 Without TUCP Systemwide VA at 3.1 or 19.7% higher than the NAA for Alt 3 at 3.5. During dry water year types years, Alt 2 Without TUCP Systemwide VA and Alt 3 may yield small positive relative differences compared to the NAA (+5 and +18.7%, respectively), while the YCI for all other alternatives would be similar to the NAA. In Critically Dry Years, all alternatives would lead to either no detectable difference in average YCI with the NAA (Alt 2 With TUCP Without VA and Alt 4) or possibly small positive differences (from +8.3% for Alt 1 to +20.5% for Alt 3).

However, it is important again to keep in mind that in dryer years (D and CD): 1) historical (observed) yearly YCI were most often at zero or relatively low (and then almost exclusively when immediately following wetter years) with no to little sturgeons detected in the monitoring programs, leading to low average modeled YCI and low absolute differences between alternatives and the NAA compared to the variation between individual years for a given alternative and water year type, and 2) the linear model predictive performance is expectedly low for low Delta outflow values, with considerable uncertainty in the predicted YCI. For March-July Delta outflow values of less than 35,000 cfs, there are likely strong limitations to the ability of the monitoring programs to reliably detect and estimate abundances of sturgeons, and/or additional mechanisms controlling sturgeon’s recruitment/YCI that are not directly linked to Delta outflow.


Sturgeon YCI March−July
YCI
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750
500
250
0
Sturgeon YCI March−July Close−up
YCI
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10
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Alt1
Alt2wTUCPwoVA
Alt2woTUCPwoVA
Alt2woTUCPDeltaVA
Alt2woTUCPAllVA
Alt3
Alt4
Scenario
Water Year Type
W
AN
BN
D
C

Figure J.2-7. White sturgeon Year-Class Strength (YCI) based on the March-July regression with Delta Outflow for all considered alternatives. Overlaid color dots represent individual data points by Water Year Type (WYT). Upper panel: full range of data. Lower panel: close-up view excluding most extreme outliers

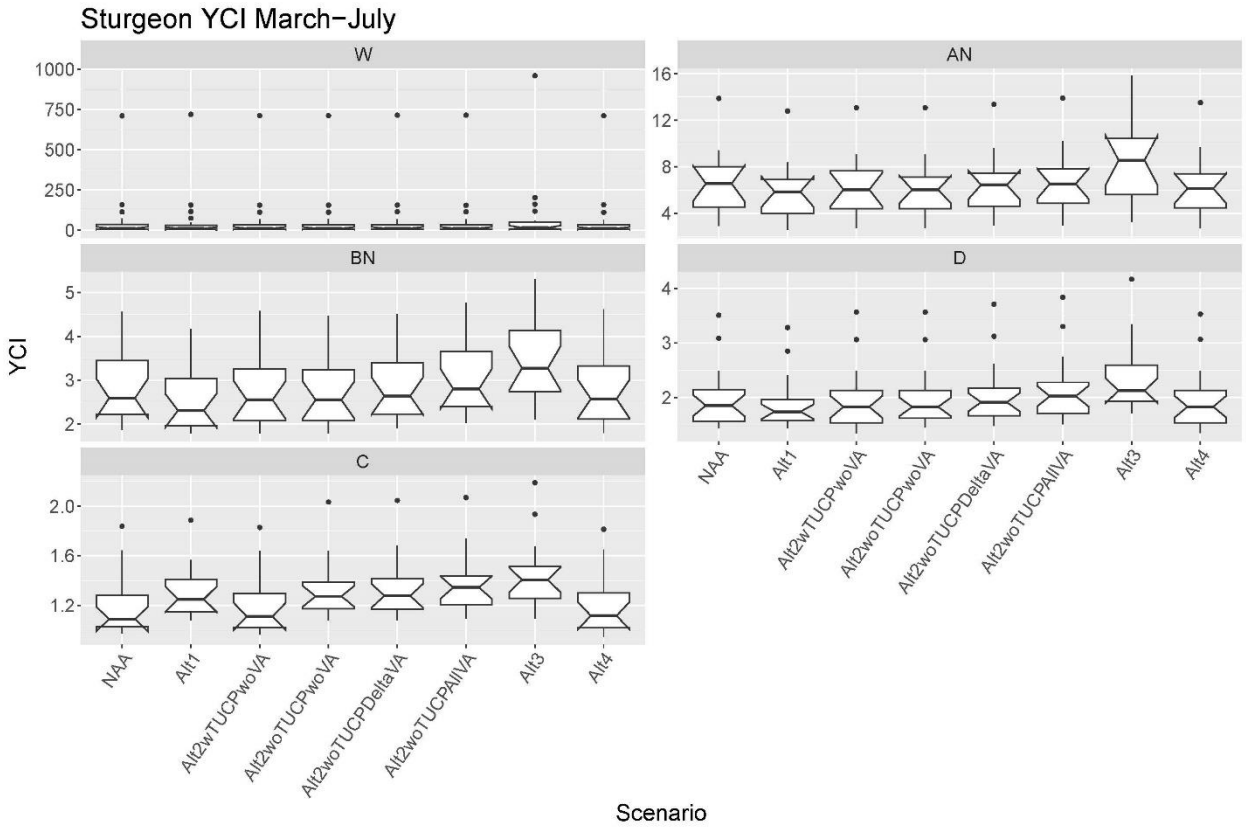

Figure J.2-8. White sturgeon Year-Class Strength (YCI) based on the March-July regression with Delta Outflow for all considered alternatives and Water Year Type (WYT).

J.2.4 References

Beccio, Marc. Environmental Scientist. California Department of Fish and Wildlife, Rancho Cordova, CA. August 12, 2021. Email with unpublished relative abundance of juvenile Green Sturgeon in the San Francisco Bay Delta Estuary, provided to Monique Briard and Sophie Unger, ICF, Sacramento CA.

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