Appendix AB-J, Winter and Spring Pulses and Delta Outflow

Attachment J.6 Bay-Delta Species Abundance-Delta Outflow Relationships

J.6.1 Model Overview

This analysis assesses potential effects of the proposed project and alternatives on four Bay-Delta aquatic species with known relationships from Kimmerer et al. (2009) between indices of annual abundance and Delta outflow: striped bass, American Shad, starry flounder, and California bay shrimp. The analysis relies on historical Delta outflow values and species abundance indices from regional monitoring programs. Modeled Delta outflow values from CalSim 3 are then used as input to these relationships to compare scenarios for each species.

J.6.2 Model Development

J.6.2.1 Methods

Several linear regressions between abundance indices[1] of various Bay-Delta species and Delta outflow were used to compare the modeled scenarios. The approach was similar to that employed by Kimmerer et al. (2009) but focused on historical data from 2003 to the most recently available year (2022 for most species) to represent the most recent ecological regime following the Pelagic Organism Decline (POD) and considered Delta outflow as opposed to X2. The statistically significant ($P<0.05$) resulting regressions (see below) were applied to CalSim 3-modeled Delta outflow outputs for the modeled scenarios. The regression for California bay shrimp was not statistically significant and so comparison of scenarios was not undertaken for this species. The analyses were conducted with R statistical software (R Core Team 2023).

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[1] Abundance indices for striped bass, and American shad were from https://apps.wildlife.ca.gov/FMWT, accessed 28 June, 2023. Abundance indices for age 1+ starry flounder were provided by J. Burns (pers. comm.). California bay shrimp (*Crangon franciscorum*) abundance indices were developed from data downloaded from https://filelib.wildlife.ca.gov/Public/BayStudy/, accessed 30 August, 2023. Historical Delta outflow data were from Dayflow.

- Striped bass (2003–2022): $\log_e$(Fall midwater trawl index) = -1.272 + 0.610*$\log_e$(April–June Delta outflow, cfs), $r^2 = 0.54$, P = 0.0002
- American shad (2003–2022): $\log_e$(Fall midwater trawl index) = -1.260 + 0.794*$\log_e$(February–June Delta outflow, cfs), $r^2 = 0.43$, P = 0.0017
- Starry flounder (2003–2022): $\log_e$(Age 1+ bay otter trawl abundance index) = -5.883 + 1.050*$\log_e$(prior year March–June Delta outflow, cfs), $r^2 = 0.26$, P = 0.0356
- California bay shrimp (2003–2016): $\log_e$(Bay otter trawl catch per 1,000 m^2 in May–November) = 2.408 + 0.306*$\log_e$(March–May Delta outflow, cfs), $r^2 = 0.09$, P = 0.3012

J.6.2.2 Assumptions / Uncertainty

A primary assumption of the model is that the relationship between Delta outflow and each species' abundance is causal such that Delta outflow drives the abundance of each species. Although the assumption of causality is reasonable, a manipulative experiment to demonstrate causality has not been conducted, nor is it practical to conduct such an experiment.

J.6.2.3 Code and Data Repository

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

J.6.3 Results

The overall average abundance indices and average abundance indices by water year type are presented for the three taxa with statistically significant regressions in Table J.6-1 to Table J.6-3 and Figure J.6-1 to Figure J.6-5 for all alternatives considered. Alternatives are abbreviated as follow: No Action Alternative (NAA), Alternative 1 (A1), Alternative 2 with TUCP without VA (Alt2wTUCPwoVA), Alternative 2 without TUCP without VA (Alt2woTUCPwoVA), Alternative 2 without TUCP Delta VA (Alt2woTUCPDeltaVA), Alternative 2 without TUCP Systemwide VA (Alt2woTUCPAllVA), Alternative 3 (A3), Alternative 4 (A4).

Table J.6-1. Mean Striped Bass Abundance Fall Midwater Trawl Abundance Index (Percent Difference from NAA) Based on April-June Delta Outflow.

WYT	NAA	A1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	A3	A4
W	148	145 (-2%)	145 (-2%)	145 (-2%)	146 (-1%)	147 (-1%)	162 (9%)	145 (-2%)
AN	110	107 (-3%)	106 (-4%)	106 (-4%)	109 (-1%)	112 (2%)	124 (13%)	106 (-4%)
BN	89	87 (-2%)	87 (-2%)	87 (-2%)	88 (-1%)	93 (4%)	99 (11%)	86 (-3%)
D	75	74 (-1%)	74 (-1%)	74 (-1%)	74 (-1%)	78 (4%)	82 (9%)	74 (-1%)
C	52	58 (12%)	59 (13%)	53 (2%)	58 (12%)	60 (15%)	62 (19%)	53 (2%)
All	100	100 (0%)	99 (-1%)	98 (-2%)	100 (0%)	103 (3%)	111 (11%)	98 (-2%)

Note: Table only includes annual mean responses and does not consider model uncertainty.

Because the yearly striped bass abundance index is based on a linear regression indicating a positive relationship with spring (April-June) Delta Outflow, the projected average abundance index increases about 2.5 to 2.8-fold from Critical years to Wet years for all alternatives and the NAA (Table J.6-1). The overall average abundance index was highest for Alternative 3 at 111 (11% higher than the NAA), and lowest for Alternative 2 without TUCP without VA and for Alternative 4, both at 98 (-2% compared to the NAA). Overall, as evidenced by the substantial overlap in "notches" between the boxplots of most alternatives and those for the NAA (Figure J.6-1 top panel, Figure J.6-3, notches represent 95% confidence intervals around the median), only Alternative 3 would likely lead to higher median striped bass abundance compared to the NAA. This pattern holds true for all water years except in Critically Dry years and some Dry years. Most alternatives would yield striped bass abundances similar to what would be observed under the NAA: from slightly higher in Below Normal years and Dry years for Alternative 2 without TUCP Systemwide VA (93 *vs* 89 and 78 *vs* 75 for the NAA. respectively, +4%), to slightly lower in Above Normal years (106, -4%) for Alternative 2 with TUCP without VA, Alternative 2 without TUCP without VA, and Alternative 4. Only Alternative 3 would potentially lead to higher abundances of striped bass compared to the NAA: 162 *vs* 148 in Wet years (+9%), 124 *vs* 110 in Above Normal years (+13%), 99 *vs* 89 in Below Normal years (+11%) and 82 *vs* 75 (+9%) in Dry years. In Critically Dry years, the projected performance measure would be much more contrasted among alternatives. While the mean abundance index for striped bass under Alternative 3 would still be highest at 62 (+19% compared to the NAA), there would be substantial year to year variability (Figure J.6-3) and median projected abundances for Alternative 3 would likely not be different from Alternatives 1, Alternative 2 with TUCP without VA, Alternative 2 without TUCP Delta VA, and Alternative 2 without TUCP Systemwide VA, which would all yield higher striped bass abundances than the NAA (58 to 60 *vs* 52, +12 to +15%). Alternative 2 without TUCP without VA and Alternative 4 however show considerably more variability with some years yielding potentially higher striped bass abundances than under the NAA and some potentially yielding substantially lower abundances than under the NAA (mean of 53 vs 52 for the NAA, +2%).

Table J.6-2. Mean American Shad Fall Midwater Trawl Abundance Index (Percent Difference from NAA) Based on February-June Delta Outflow.

WYT	NAA	A1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	A3	A4
W	1980	1938 (-2%)	1959 (-1%)	1960 (-1%)	1968 (-1%)	1971 (0%)	2132 (8%)	1956 (-1%)
AN	1331	1262 (-5%)	1300 (-2%)	1307 (-2%)	1324 (-1%)	1347 (1%)	1472 (11%)	1303 (-2%)
BN	862	814 (-6%)	852 (-1%)	853 (-1%)	871 (1%)	900 (4%)	968 (12%)	846 (-2%)
D	606	571 (-6%)	607 (0%)	606 (0%)	620 (2%)	640 (6%)	683 (13%)	600 (-1%)
C	404	410 (1%)	437 (8%)	404 (0%)	436 (8%)	446 (10%)	458 (13%)	399 (-1%)
All	1129	1091 (-3%)	1122 (-1%)	1118 (-1%)	1134 (0%)	1150 (2%)	1239 (10%)	1113 (-1%)

Note: Table only includes annual mean responses and does not consider model uncertainty.

Because the yearly American shad abundance index is based on a linear regression indicating a positive relationship with late winter-spring Delta Outflow (February-June), the projected average abundance index increases about 4.5 to 5-fold from Critical years (399 to 458 depending on the alternative) to Wet years (1938 to 2132) for all alternatives and the NAA. The overall average abundance index would be highest for Alternative 3 at 1239 (10% higher than the NAA), and lowest for Alternative 1 at 1091 (-3% compared to the NAA). Alternative 3 would lead to higher mean American shad abundance compared to the NAA in all water year types (from +8% in Wet years to +13% in Dry and Critically Dry years), with Alternative 2 without TUCP Systemwide VA also potentially leading to slightly higher American shad abundances than the NAA in the driest years (+4% in Below Normal years, +6 % in Dry years, +10% in Critically Dry years). Alternative 2 with TUCP without VA and Alternative 2 without TUCP Delta VA might also yield higher American shad abundances than the NAA, but only in Critically Dry years (+8%). In all other cases, across all water years, American shad abundances would essentially be similar to the NAA under most of the alternative considered. Alternative 1 might even yield lower American shad abundances than the NAA in most years except the wettest or driest (-5% in Above Normal years, -6 % in Below Normal and Dry years). However, note that for all water year types, there is substantial overlap in "notches" between the boxplots of all alternatives and those for the NAA (Figure J.6-1 mid panel, Figure J.6-4), indicating high inter-annual variability.

Table J.6-3. Mean Starry Flounder Age 1+ Bay Otter Trawl Abundance Index Under Each Alternative (Percent Difference from NAA) Based on Prior Year March-June Delta Outflow.

WYT	NAA	A1	Alt2 wTUCP woVA	Alt2 woTUCP woVA	Alt2 woTUCP DeltaVA	Alt2 woTUCP AllVA	A3	A4
W	221	216 (-2%)	217 (-2%)	217 (-2%)	219 (-1%)	220 (0%)	247 (12%)	217 (-2%)
AN	134	125 (-7%)	128 (-4%)	130 (-3%)	133 (-1%)	136 (1%)	154 (15%)	129 (-4%)
BN	75	70 (-7%)	73 (-3%)	73 (-3%)	77 (3%)	81 (8%)	89 (19%)	73 (-3%)
D	53	51 (-4%)	53 (0%)	53 (0%)	55 (4%)	58 (9%)	63 (19%)	52 (-2%)
C	29	33 (14%)	34 (17%)	30 (3%)	34 (17%)	36 (24%)	37 (28%)	30 (3%)
All	114	111 (-3%)	113 (-1%)	112 (-2%)	115 (1%)	117 (3%)	131 (15%)	112 (-2%)

Note: Table only includes annual mean responses and does not consider model uncertainty.

Because the yearly starry flounder abundance index (Age 1+) is based on a linear regression indicating a positive relationship with the prior spring Delta Outflow (March-June), the projected average abundance index increases about 6 to 7-fold from Critical years (29 to 37 depending on the alternative) to Wet years (216 to 247) for all alternatives and the NAA. The overall average abundance index would be highest for Alternative 3 at 131 (15% higher than the NAA), and lowest for Alternative 1 at 111 (-3% compared to the NAA). Alternative 3 would lead to higher mean starry flounder abundances compared to the NAA in all water year types (from +12% in Wet years to +28% in Critically Dry years), with Alternative 2 without TUCP Systemwide VA also potentially leading to slightly higher starry flounder abundances than the NAA in the driest years (+8% in Below Normal years, +9 % in Dry years, +24% in Critically Dry years). Alternative 1, Alternative 2 with TUCP without VA, and Alternative 2 without TUCP Delta VA might also yield higher starry flounder abundances than the NAA, but only in Critically Dry years (+14% to +17%). In all other cases, across all water years, starry flounder abundances would essentially be similar to the NAA under most of the alternative considered (-4% to +4% in mean abundances, with considerable overlap in confidence intervals around median values indicating substantial variability between years, Figure J.6-2 and Figure J.6-5). Alternative 1 might even yield lower starry flounder abundances than the NAA in most years except the driest (up to -7 % in Above Normal and Below Normal years).

J.6.3.1 Figures

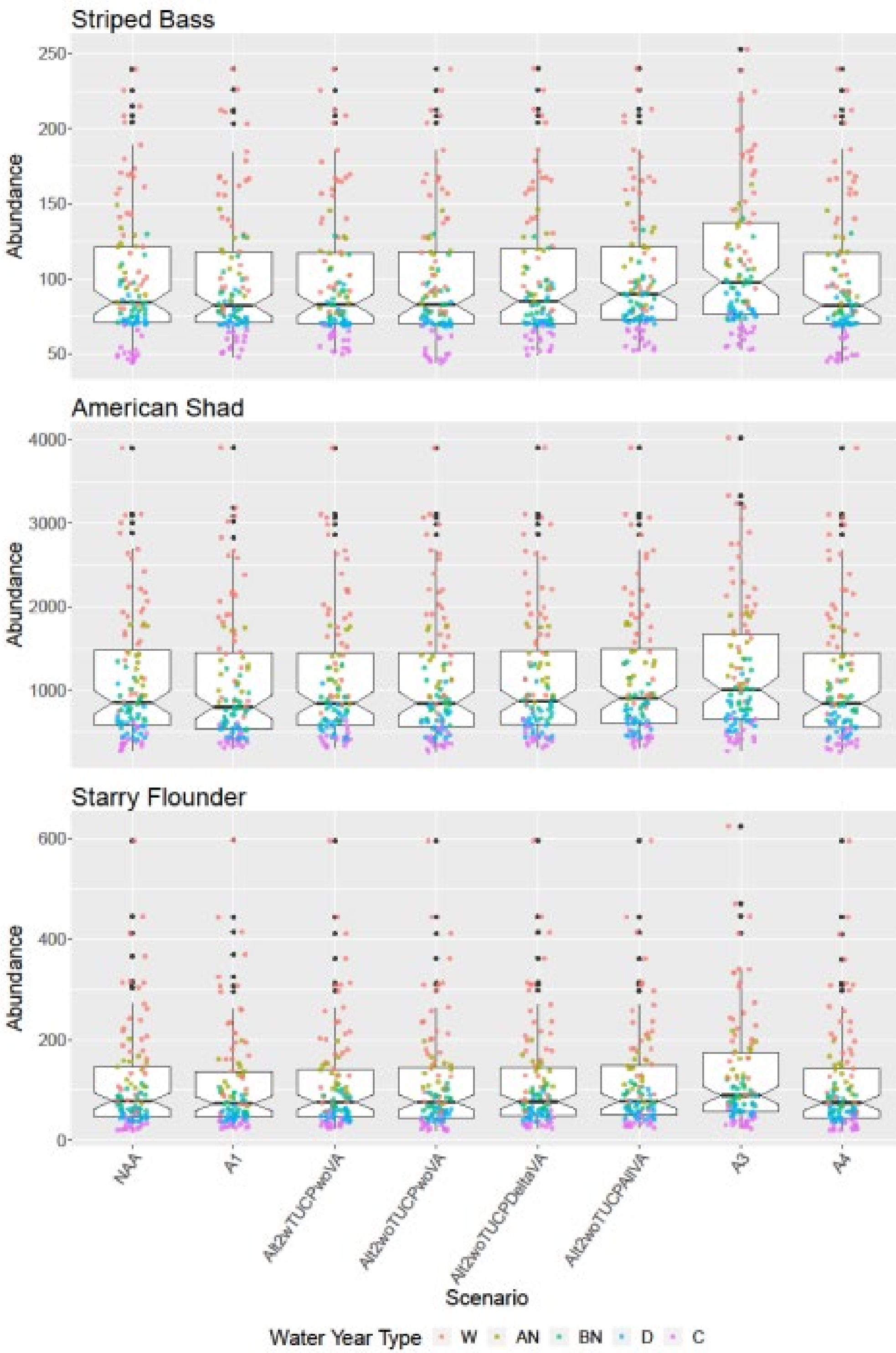

Figure J.6-1. Boxplots of projected striped bass, American shad, and starry flounder abundance indices for all considered alternatives. Overlaid color dots represent individual data points by water year type (individual years from 1922 to 2021).

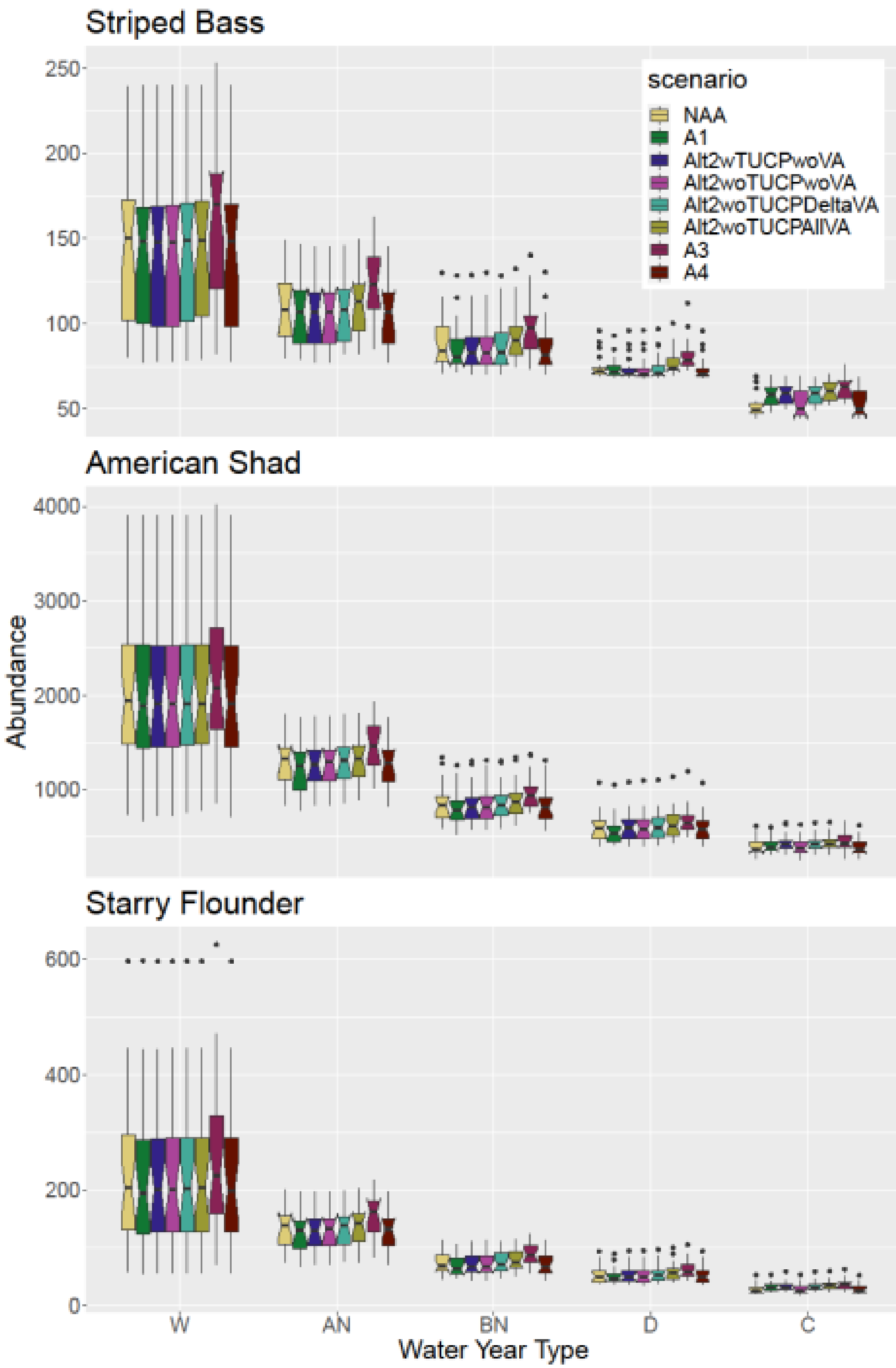

Figure J.6-2. Boxplots of projected striped bass, American shad, and starry flounder abundance indices based for all considered alternatives by water year types.

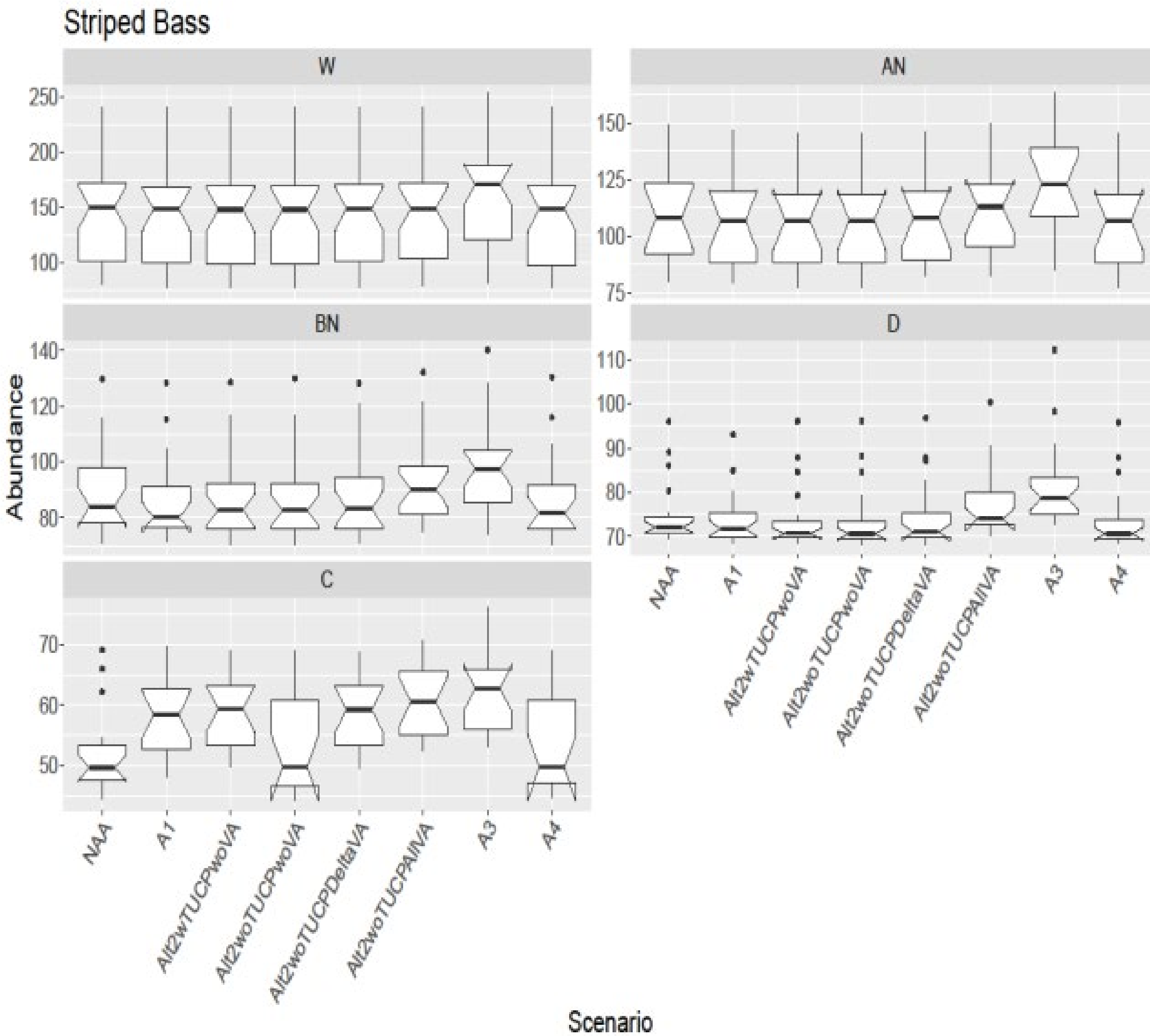

Figure J.6-3. Striped bass boxplots of projected abundance index (Fall Midwater Trawl) based on regression with April-June Delta Outflow, by water year type for all considered alternatives.

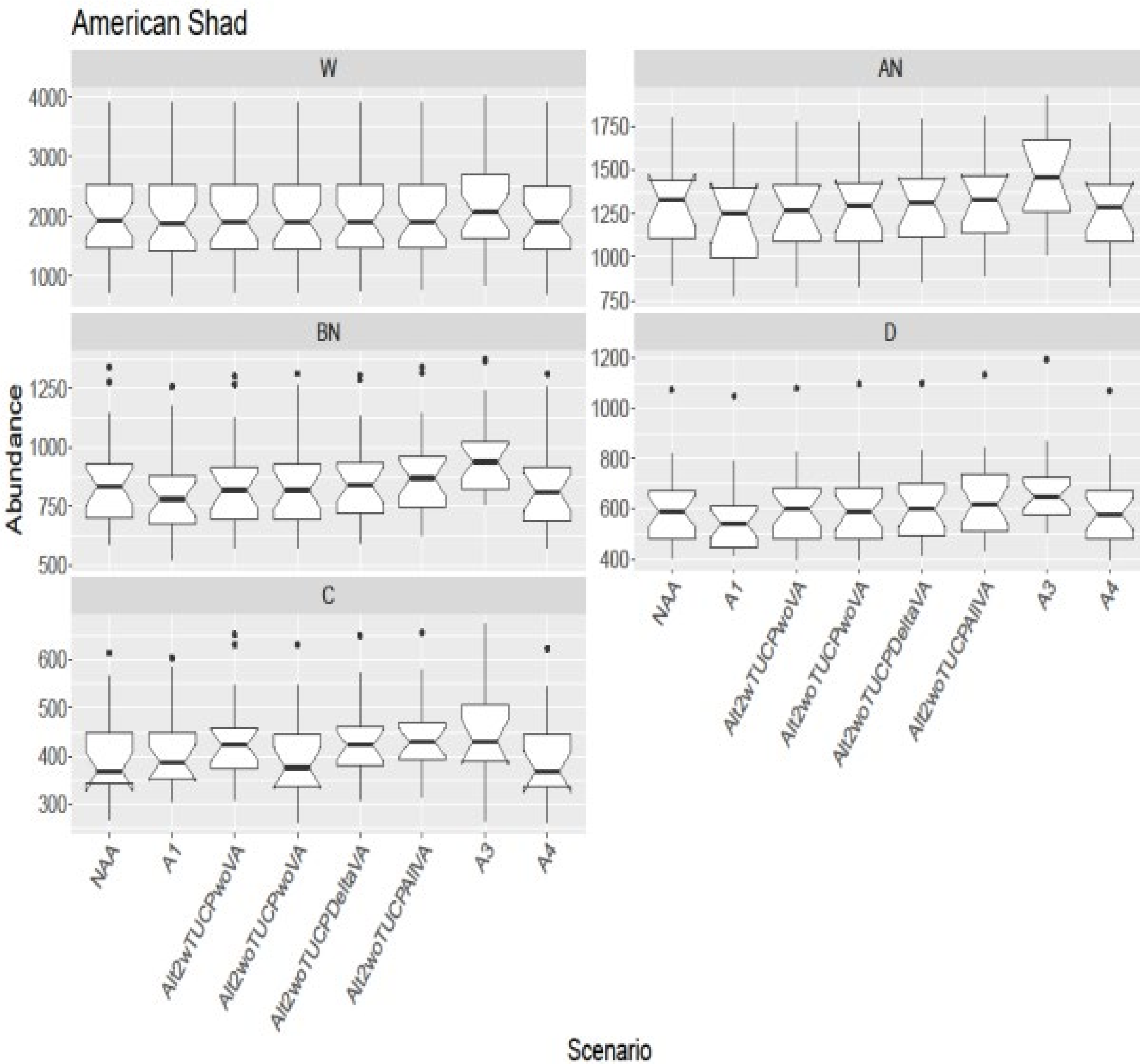

Figure J.6-4. American shad boxplots of projected abundance index (Fall Midwater Trawl) based on regression with February-June Delta Outflow, by water year type for all considered alternatives.

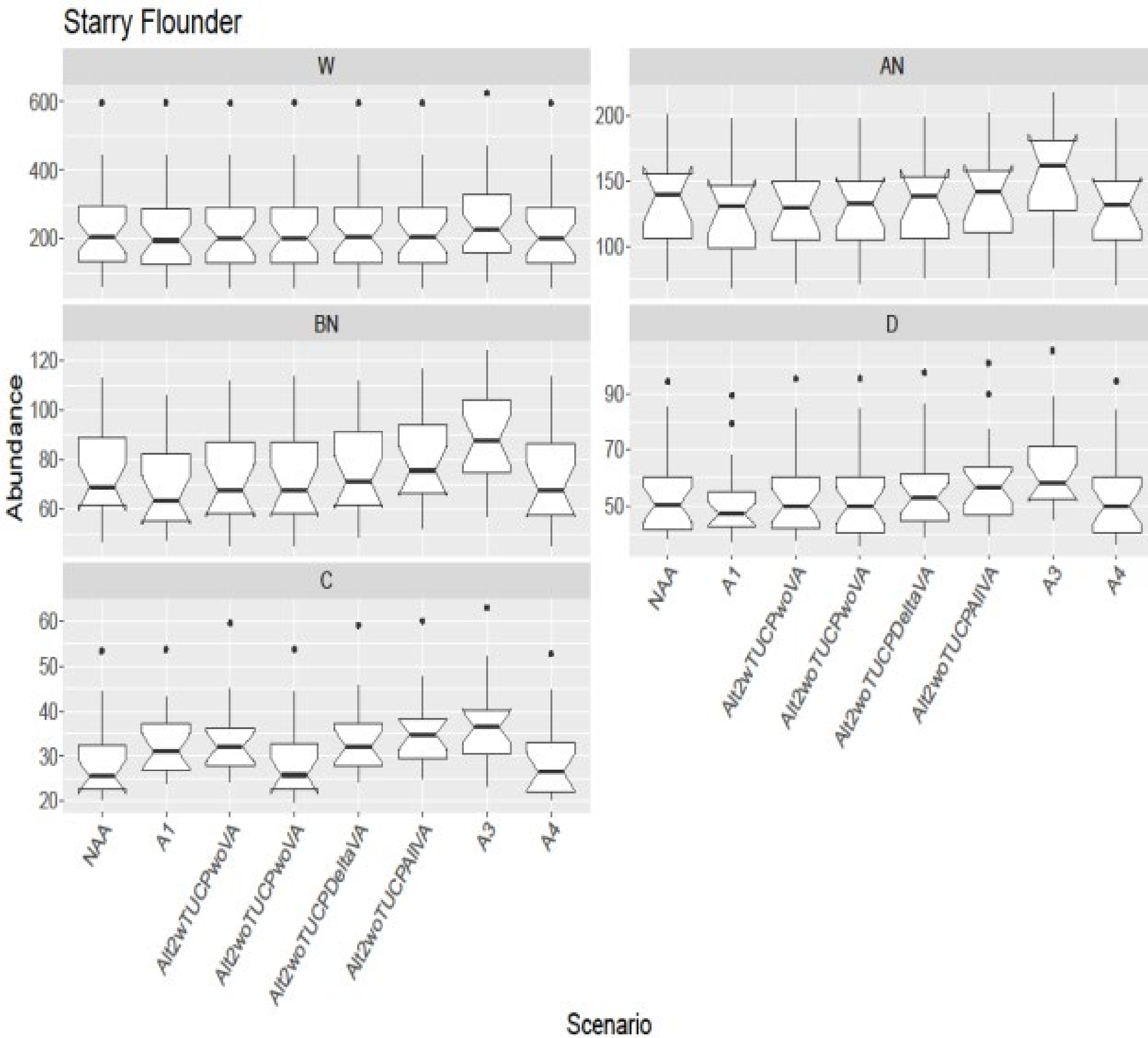

Figure J.6-5. Starry flounder (Age 1+) boxplots of projected abundance index (Bay Otter Trawl) based on regression with prior year March-June Delta Outflow, by water year type for all considered alternatives.

J.6.4 References

Burns, Jillian. Environmental Scientist, Bay-Delta Region, California Department of Fish and Wildlife, Stockton, CA. August 28, 2023—Email containing file: SFBS_STAFLOAnnualIndices_28Aug2023.csv, sent to Marin Greenwood, Aquatic Ecologist, ICF, Sacramento, CA.

Kimmerer, W. J., E. S. Gross, and M. L. MacWilliams. 2009. Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume? *Estuaries and Coasts* 32(2):375–389.

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