SUPPLEMENTARY INFORMATION

Supplement 1. Field Collections of Delta Smelt and Methods Across Surveys

Text S1. Archived Delta Smelt specimens were provided by several surveys conducted by the California Department of Fish and Wildlife (CDFW) and the U.S. Fish and Wildlife Service (USFWS). Surveys were conducted across a variety of spatial and temporal scales (Tables S1, S2) using several gear types. Surveys were designed with different purposes, but due to the conservation status of Delta Smelt, Delta Smelt were often preserved and archived for future analyses.

San Francisco Bay Study (SFBS)

The San Francisco Bay Study is conducted by the CDFW and surveys once a month throughout the year. The survey samples 52 sites from the southeastern bay up through the Delta. Each survey takes 7 days to complete. The survey uses a midwater trawl and bottom otter trawl. The midwater trawl has a 3.7 m^2 mouth and mesh size decreases from 20.3 cm at the mouth to 1.3 cm at the code end. The SFBS also uses a four-seam otter trawl with a 4.9-m headrope, a 2.5-cm stretch mesh body and a 13-mm stretch mesh cod end. Tows are conducted for 12 minutes (midwater trawl) and 5 minutes (otter trawl) (Honey et al. 2004).

Fall midwater trawl (FMWT)

The Fall Midwater Trawl survey is conducted by the CDFW during the months of September through December, once monthly. Each survey takes 8 days to complete. They sample 116 sites from San Pablo Bay up through the Lower Sacramento River and the Lower San Joaquin River. It uses the same midwater trawl net and trawling method as in the SFBS (Honey et al. 2004).

Summer Townet Survey (TNS):

The Summer Townet survey is conducted by the CDFW and samples every other week from June through August. The survey takes 5 days to complete and samples 32 locations from San Pablo Bay through the Lower Sacramento River and Lower San Joaquin River. The survey uses a 4.3m long net attached to a skid mounted frame with a 1.5m^2 mouth. Mesh size is20mm woven mesh for the 2.1 meters of the body of the net and 4mm for the 2.1m cod end. At each location, three 10-minute oblique tows are conducted, unless no fish are caught, in which case only two tows are completed (Honey et al. 2004).

Enhanced Delta Smelt Monitoring (EDSM)

The Enhanced Delta Smelt Survey is conducted by the USFWS between the months of July and November using a Kodiak Trawl towed for up to 10 minutes between 2 boats. EDSM surveys sample 24-37 random sites per week using a GRTS spatial sampling procedure (Stevens and Olsen 2004), with at least 2 tows conducted in each stratum. The Kodiak net has a 1.83m x 7.62m mouth Mesh ranges from 5.1cm at mouth to 0.3cm at cod end, which consists of a live box with baffles and flow holes to reduce mortality. Up to three crews sample concurrently at 2 or more sites per day with 2-8 tows per site (10 minutes max tow length). Towing ceases if at least 1 DS is caught in the first 2 tows.

Gear Evaluation Survey (GES)

The gear evaluation survey used a variety of nets and protocols of several other surveys in 2012-2013 to assess relative capture efficiencies for conversion of abundance estimates among gear types including the TNS, FMWT, SFBS, and EDSM Kodiak gears described above.

Covered Cod End survey (CCE)

Samples were conducted at two FMWT sites in the Sacramento Delta. They used the FMWT net and methodology with an additional fine mesh cover over the cod end to capture smaller fish. Surveys were conducted with paired surface tows and oblique tows with the goal of calculating the FMWT contact selectivity curves (Mitchell et al. 2017).

Fork Length Measurements

Of the 459 fish included in this study, 93% could be linked with fork lengths measured in the field. For those missing field measurements, lengths were measured post-preservation and converted into field lengths using standard conversion equations. For the 21 ethanol-preserved fish, field fork lengths were calculated as $FL_{Field} = 1.0225 * FL_{EtOH} + 0.3368$ (N = 175, R^2 = 0.994), based on shrinkage observed for a similar species (Longfin Smelt). The 13 fish preserved in liquid nitrogen were converted to field fork lengths using a previously published conversion for Delta Smelt: $FL_{Field} = 0.972 * FL_{LN} + 2.558$ (Teh et al. 2016).

Table S1. Sample size of Delta Smelt included in this study by year and capture survey

Survey	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
CCE	0	0	0	83	0	0	0	0	0	83
EDSM	0	0	0	0	0	0	60	82	8	150
FMWT	29	14	0	3	4	3	0	0	0	53
GES	0	46	42	0	0	0	0	0	0	88
SFBS	2	0	0	0	19	0	0	0	0	21
TNS	28	12	4	7	1	0	12	0	0	64
Total	59	72	46	93	24	3	72	82	8	459

Table S2. Sample size of Delta Smelt included in this study by subregion (EDSM 2017 Strata) and survey.

EDSM Stratum	CCE	EDSM	FMWT	GES	SFBS	TNS	Total
Carquinez Straight and San Pablo Bay	0	0	3	0	0	2	5
Suisun Bay/Marsh	0	31	14	0	2	34	81
Lower San Joaquin	0	1	0	0	0	2	3
Lower Sacramento	63	55	26	88	19	11	262
Cache Slough/Liberty Island	20	33	10	0	0	15	78
Sac Deep Water Shipping Channel	0	30	0	0	0	0	30
Total	83	150	53	88	21	64	459

Table S3. Sample size of Delta Smelt included in this study by year and month

Year	Aug	Sep	Oct	Nov	Total
2011	30	12	7	10	59
2012	12	28	28	4	72
2013	4	33	0	9	46
2014	55	34	4	0	93
2015	10	13	1	0	24
2016	0	0	0	3	3
2017	31	17	21	3	72
2018	21	40	14	7	82
2019	3	2	3	0	8
Total	166	179	78	36	459

References

Honey, K., Baxter, R., Hymanson, Z., Sommer, T., Gingras, M. and Cadrett, P., 2004. IEP long-term fish monitoring program element review. Interagency Ecological Program

Mitchell, L., Newman, K. and Baxter, R., 2017. A Covered Cod-End and Tow-Path Evaluation of Midwater Trawl Gear Efficiency for Catching Delta Smelt (Hypomesus transpacificus). San Francisco Estuary and Watershed Science, 15(4)

Teh SJ, Baxa DV, Hammock BG, Gandhi SA, Kurobe T (2016) A novel and versatile flash-freezing approach for evaluating the health of Delta Smelt. Aquatic Toxicology 170:152–161

Supplement 2. Variation in growth and water quality among years and regions

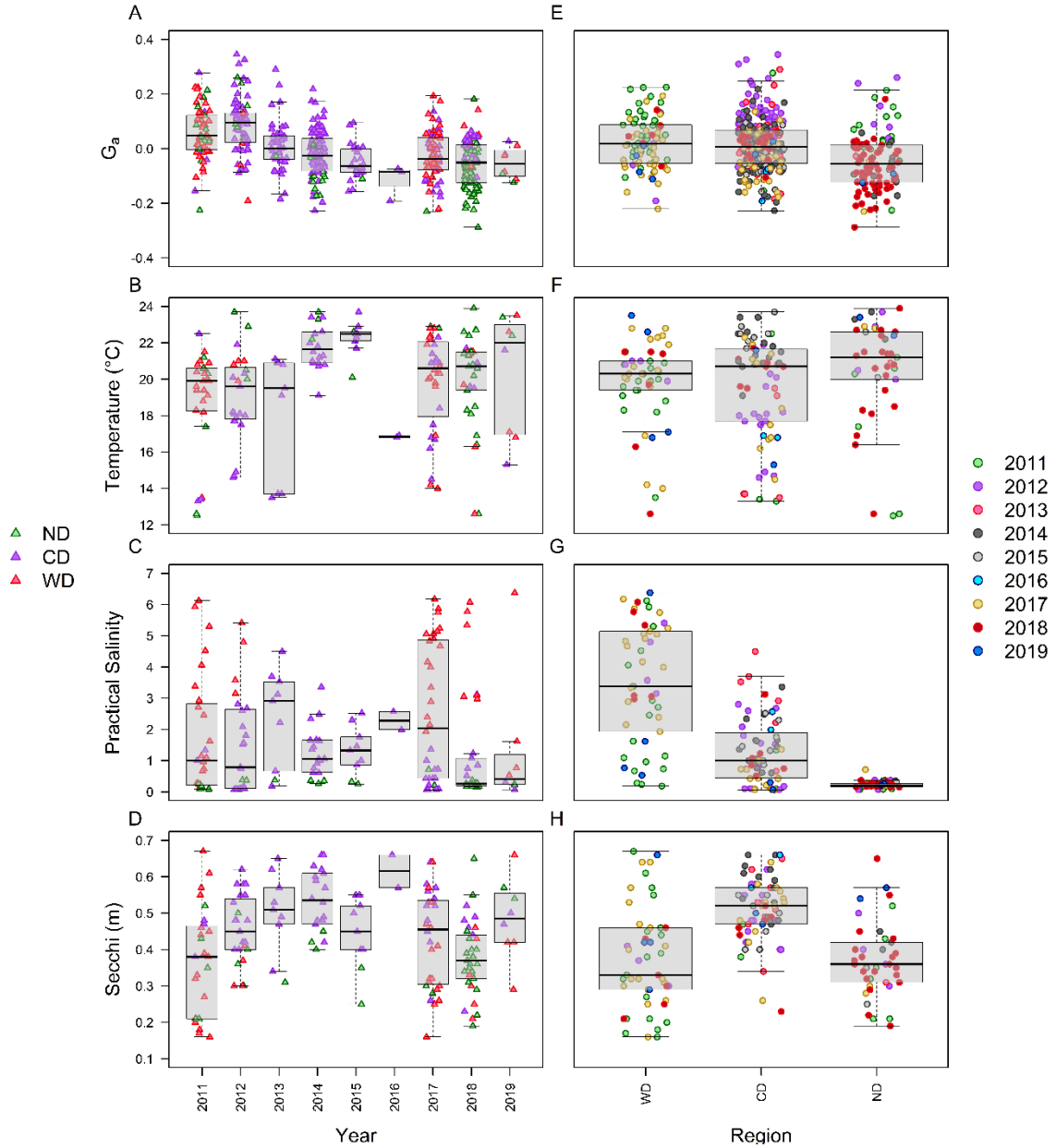

Figure S1. Temporal (A-D) and spatial (E-H) variation in age-adjusted growth rates (G_a, in log(mm/d)) of subadult Delta Smelt, along with variation in water quality including temperature, salinity, and Secchi depth (top-bottom, respectively) at capture. Colors indicate region (left legend, A-D) for temporal plots or year (right legend, E-H) or regional plots. Age-adjusted growth rates (G_a) are the residuals of the intrinsic model for Delta Smelt captured in August-November. Strata are as in Table 1 and Fig. 1.

Supplement 3. Environment-only Model Comparisons

Text S2. We used generalized additive models (GAMs) to examine G_a as smooth functions of three physical water quality metrics: temperature (t) in ºC, practical salinity (s), and clarity (c) in m Secchi Depth (Table S4). Model structures were specified using the gam() function of the mgcv package in R, and the dredge function of the MuMIn package was used to conduct model comparisons and selection. Dredge evaluates the fully interactive model and then contrasts results among all simpler nested model structures, providing the coefficient of determination (R^2), estimated degrees of freedom (EDF), and corrected Akaike information criterion (AIC_c), which are commonly used to inform model selection (Fig. S2). The fully interactive model included a total of 7 terms including three main effects, the three 2-way tensor product smooths, and one 3-way tensor product smooth; however, all models including a 3-way interaction exhibited high concurvity (> 0.9) for many terms, and were thus excluded from further consideration. As is common, several models appeared similarly valid for describing the effects of abiotic environmental attributes on G_a. Here, Model 18 (tsc*), including each main effect and the three two-way interactions, was selected as the preferred model as it exhibited the lowest AIC_c, highest R^2, and allowed for visualization and comparison of each of the 2-way interaction surfaces.

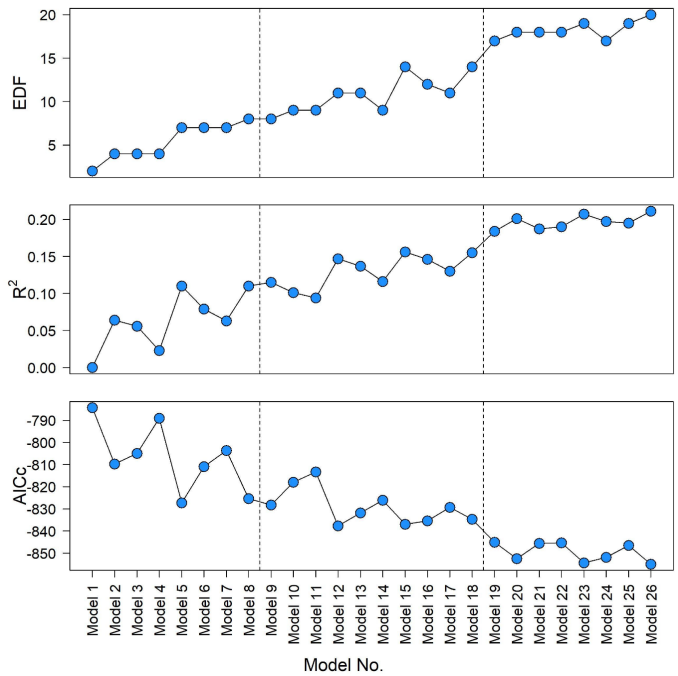

Figure S2. Estimated degrees of freedom (A), coefficient of determination (B), and corrected Akaike information criterion (C) for generalized additive models examining adjusted growth rates as additive and interactive effects of environmental conditions (temperature, salinity, and clarity) (Fig. Table S4). Models are ordered by the number of terms, generally increasing complexity from left to right. Vertical dashed lines delineate models including main effects only (left), two-way interactions (middle), and 3-way interactions (right).

Table S4. Generalized additive environment-only models constructed using the dredge function in the MuMIn R package. Factors include temperature (t), salinity (s), and clarity (c). Main and interactive effects were fit using ti() in the mgcv gam() package. The preferred model (Model 18) is identified with an asterisk (*).

Model Name	Model Structure
Model 1	$G_a \sim 1$
Model 2	$G_a \sim$ ti(t)
Model 3	$G_a \sim$ ti(s)
Model 4	$G_a \sim$ ti(c)
Model 5	$G_a \sim$ ti(t) + ti(s)
Model 6	$G_a \sim$ ti(t) + ti(c)
Model 7	$G_a \sim$ ti(s) + ti(c)
Model 8	$G_a \sim$ ti(t) + ti(s) + ti(c)
Model 9	$G_a \sim$ ti(t) + ti(c) + ti(t,c)
Model 10	$G_a \sim$ ti(t) + ti(s) + ti(s,c)
Model 11	$G_a \sim$ ti(s) + ti(c) + ti(t,s)
Model 12	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,c)
Model 13	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(s,c)
Model 14	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s)
Model 15	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,c) + ti(s,c)
Model 16	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(s,c)
Model 17	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(t,c)
Model 18*	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(t,c) + ti(s,c)
Model 19	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s,c)
Model 20	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(t,s,c)
Model 21	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,c) + ti(t,s,c)
Model 22	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(s,c) + ti(t,s,c)
Model 23	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(t,c) + ti(t,s,c)
Model 24	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(s,c) + ti(t,s,c)
Model 25	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,c) + ti(s,c) + ti(t,s,c)
Model 26	$G_a \sim$ ti(t) + ti(s) + ti(c) + ti(t,s) + ti(t,c) + ti(s,c) + ti(t,s,c)

Supplement 4. Model Evaluation

Text S3. The assumptions of each model were evaluated using by examining normal Q-Q plots of residuals, plots of residuals versus estimated values, and histograms of the residuals for each model (left to right, respectively). (A) Models included the interactive tsc* (Model 18) environmental model (A), the model including additive effects of environment, region, and year (random) (B) and the three separate models examining responses to environmental conditions and year (random) for the North Delta, Central Delta, and West Delta (C-D, respectively). All models appeared to satisfy the assumptions of the approach.

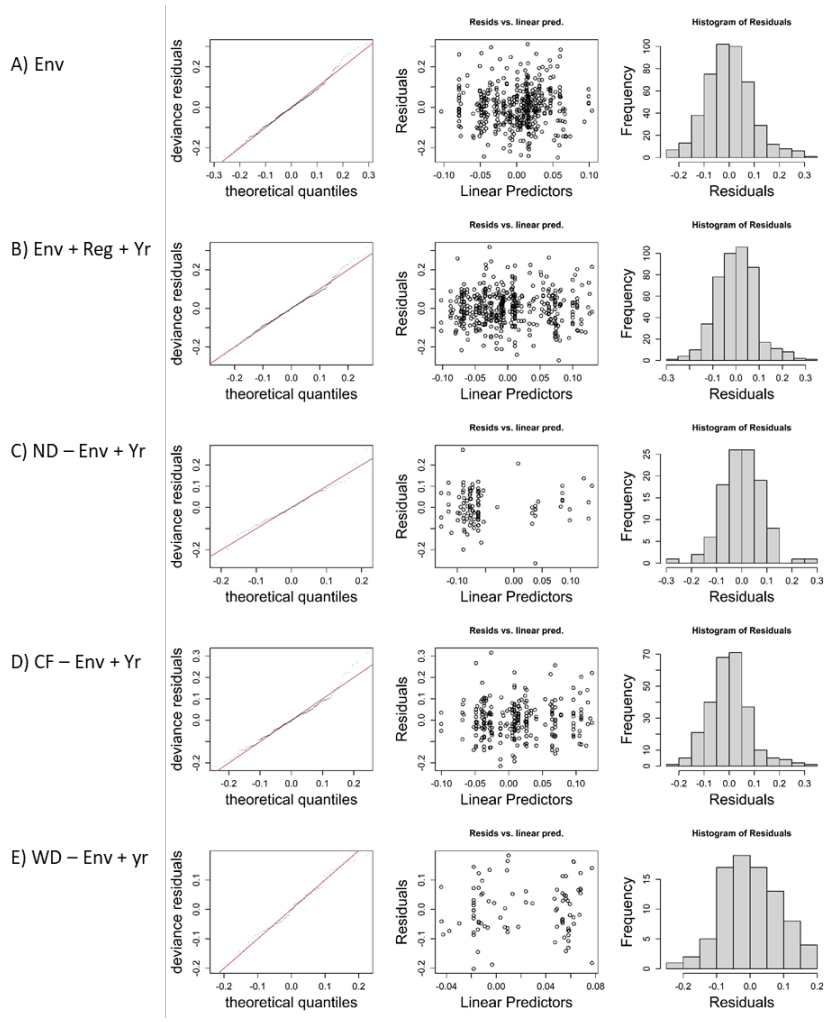

Figure S3. Evaluation of the assumptions associated with each generalized additive model: (A) the selected "environment-only" model with all main effects and two-way interactions (Model 18, tsc*), (B) the "global-regional" model with fixed parametric effects of region, the fixed smooths of temperature, salinity, and clarity, and the random effect of year, (C-E) the three "region-specific" models examining the fixed smooth effects of temperature, salinity, and clarity, and the random effect of year, for each region of the upper SFE, separately (ND, CF, and WD, respectively).

Supplement 5. Region-specific models

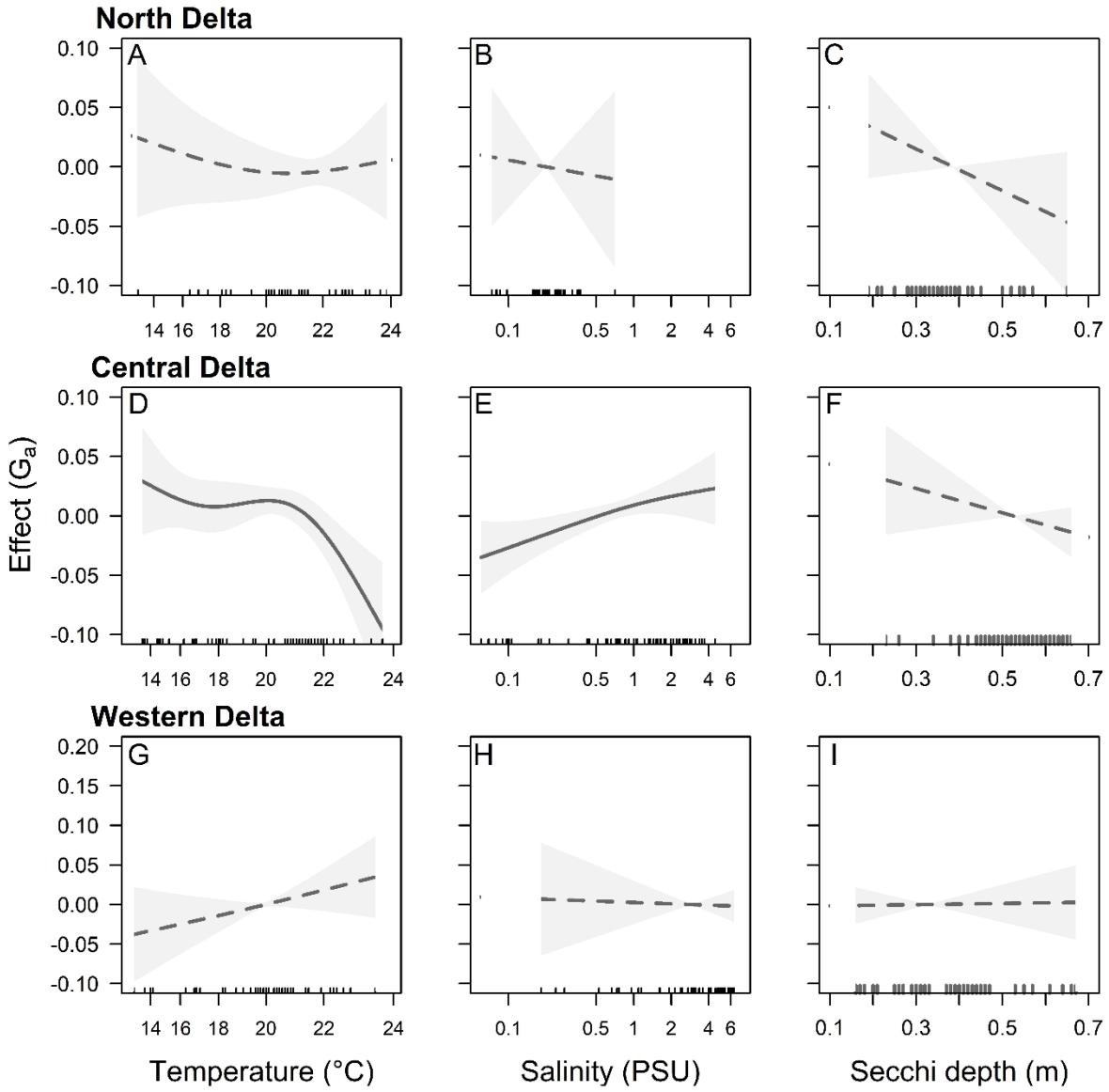

Figure S4. Results of separate "region-specific" GAMs examining variation in growth (Ga) as a function of the additive smooth effects of physical environmental attributes (temperature, salinity, and clarity) and the random year effect. Partial residual smooths demonstrating the effect of each environmental metric on the growth response are shown for the North Delta (A-C), Central Delta (D-F), and West Delta (G-I) regions of the upper SFE. Solid and dashed lines indicate significant and non-significant smooth trends ($\alpha = 0.05$), respectively, and shading reflects the 95% Bayesian credible intervals. Sample sizes are provided in Table 1.

Table S5. Statistical results of separate "region-specific" GAMs examining variation in growth (Ga) as a function of the additive effects of physical environmental attributes (temperature, salinity, and clarity) and the random year effect. Significant p-values ($p < 0.05$) are in bold. are: ND – North Delta, CD – Central Delta, WD – West Delta. The estimated degrees of freedom (EDF), referenced degrees of freedom (RDF), F-ratio (F), and p-values (P1) are provided each term in each region-specific model, as well as the coefficient of determination (R2) and p-value (P2) for the overall model compared to the null model (Ga ~ 1) using a likelihood ratio test. Regions are as in Fig. 1 and Table 1.

Region	Factor	EDF	RDF	F	P_1	R^2	P_2
ND	Temperature	1.465	1.784	0.461	0.644	0.450	**< 0.001**
	Salinity	1.000	1.000	0.081	0.777		
	Secchi	1.000	1.000	2.471	0.119		
	Year	5.376	7.000	6.400	**<0.001**		
CD	Temperature	2.565	2.851	3.880	0.011	0.302	**< 0.001**
	Salinity	1.308	1.527	4.124	0.037		
	Secchi	1.000	1.000	1.747	0.187		
	Year	5.854	8.000	7.343	**<0.001**		
WD	Temperature	1.043	1.082	1.608	0.191	0.197	**< 0.001**
	Salinity	1.000	1.000	0.037	0.848		
	Secchi	1.000	1.000	0.013	0.909		
	Year	2.594	4.000	3.220	**0.002**		