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Acidification, warming, and nutrient management are projected to cause reductions in shell and tissue weights of oysters in a coastal plain estuary

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SUPPLEMENTARY MATERIALS

Introduction

These supplementary materials include five tables and four figures. Tables S1-S4 include the *EcoOyster* model equations. Table S5 includes bottom environmental variables averaged across all model grid cells for each model simulation (analogous to Table 3, which includes the same variables averaged over only grid cells that support oyster growth). Figure S1 demonstrates the *EcoOyster* assimilation and respiration functions in relation to temperature and other environmental limitations. Figure S2 illustrates the model grid cells that support oyster growth in the reference run. Figure S3 shows a comparison of the *Reference* and *Combined Future* runs for bottom temperature, salinity, dissolved oxygen, and total suspended solids, averaged annually across the entire model domain. Figure S4 represents the same variables as in Figure S3 but compares the *AtmCO*$_2$, *Temp*, and *TMDL* runs.

Table S1: Growth functions in *EcoOyster*; weight (w) is in grams dry weight and time (t) in days; sub-equations are provided in Table S2.

Equation	
1 Total weight	$w^{total} = w^{tissue} + w^{gonad}$
2 Gonadal weight	$\frac{d}{dt} w^{gonad}(t) = reprod(t) - resorb(t) - spawn(t)$
3 Tissue weight	$\frac{d}{dt} w^{tissue}(t) = A(t) - R(t) - reprod(t) + resorb(t)$
4 Shell weight	$\frac{d}{dt} w^{shell}(t) = net\_calcification(t)\, w^{total}$

Table S2: Supporting equations for growth functions; temperature (T) is in °C, particulate organic carbon (POC) has units of g C m^{-3}.

Equation #	
5 Gonadal tissue growth	$reprod(t) = \max[0, A(t) - R(t)]\, rep_{eff}(t)$
6 Reproduction efficiency	$rep_{eff}(t) = \begin{cases} \min[\max(0, 0.054T(t) - 0.729), 1] & \text{for January to June,} \\ \min[\max(0, 0.047T(t) - 0.809), 1] & \text{for July to December} \end{cases}$
7 Resorption of gonadal tissue	$resorb(t) = \max[0, -(A(t) - R(t))] \dfrac{w^{gonad}}{w^{gonad} + 0.01}$
8 Spawning	$spawn(t) = \max\left[0, \dfrac{w^{gonad}(t)}{w^{gonad}} - 0.2\right] w^{gonad}$
9 Assimilation	$A(t) = \frac{F(t)POC(t)}{C{:}dw} AE$ *C:dw = 0.45. AE = 0.75*
10 Respiration	$R(t) = 0.0095\,(w^{total}(t))^{3/4} \exp[0.069(T(t) - 20)] + A(t)RF$ *RF = 0.1*
11* Filtration	$F(t) = F^{max}(t)\, f_T(t)\, f_S(t)\, f_{tss}(t)\, f_{O2}(t)\, f_{chla}(t)p$ *p = 0.15*
12 Maximum filtration	$F^{max}(t) = 0.17\,(w^{total}(t))^{3/4}$
13 Net calcification	$net\_calcification(t) = a \dfrac{1 - \exp(-b(\Omega_{ca}(t) - c))}{1000} \exp[0.0271(T(t) - 25)],$ $a = 158.2$, $b = 1.052$, $c = 0.9323$

*Environmental limitation functions for Equation 11 are provided in Table S3.

Table S3: Dimensionless environmental limitation functions for filtration (Eq. 11, Table S2); units are: T (°C), O_2 (mg L^{-1}), chla (mg m^{-3}), TSS (mg L^{-1}). Salinity has no units.

Equation #	
14 Temperature limitation	$f_T(t) = \exp\left[-0.006(T(t) - 27)^2\right]$
15 Salinity limitation	$f_S(t) = \begin{cases} 0 & if\ S \leq 5, \\ 0.0926\, S(t) - 0.139 & if\ 5 < S < 12, \\ 1 & if\ S \geq 12 \end{cases}$
16 TSS limitation	$f_{tss}(t) = \begin{cases} 1 & if\ TSS < 25, \\ 10.364\, (\ln TSS(t))^{-2.04777} & if\ TSS \geq 25 \end{cases}$
17 Dissolved oxygen limitation	$f_{O2}(t) = \left[1 + \exp\left(1.1 \frac{1.75 - O2(t)}{1.75 - 1.5}\right)\right]^{-1}$
18 Chlorophyll limitation	$f_{chla}(t) = \max\left[0, 1 - \exp\left(-0.26(chla(t) - 2.2)\right)\right]$

Table S4: Allometric equations for shell height (mm) and shell dry weight (g) as a function of tissue dry weight.

Equation #	
19 Shell height	$h^{shell\ allo} = 73.85(w^{total})^{0.2680}$
20 Shell weight	$w^{shell\ allo} = 58.05(w^{total})^{0.8681}$

Table S5. Bottom environmental variables for each model simulation (annual mean ± standard deviation) for all model grid cells.

Model Simulation	Temperature (°C)	Salinity	POC (g C m^{-3})	Ω_{Ca}	Dissolved Oxygen (mg O_2 L^{-1})	TSS (mg L^{-1})
Reference	16.9 ± 1.0	15.7 ± 5.8	0.81 ± 0.3	2.2 ± 0.75	8.6 ± 0.9	15.9 ± 18
Combined Future	18.4 ± 1.1	16.0 ± 5.8	0.74 ± 0.3	1.4 ± 0.53	8.3 ± 0.8	15.7 ± 18
AtmCO$_2$	16.9 ± 1.0	15.7 ± 5.8	0.81 ± 0.3	1.4 ± 0.52	8.6 ± 0.9	15.9 ± 18
Temp	18.4 ± 1.1	16.0 ± 5.8	0.76 ± 0.3	2.2 ± 0.75	8.3 ± 0.9	15.7 ± 18
TMDL	16.9 ± 1.0	15.7 ± 5.8	0.78 ± 0.3	2.1 ± 0.76	8.6 ± 0.9	15.8 ± 18
Temp + CO$_2$	18.4 ± 1.1	16.0 ± 5.8	0.76 ± 0.3	1.5 ± 0.52	8.3 ± 0.9	15.7 ± 18

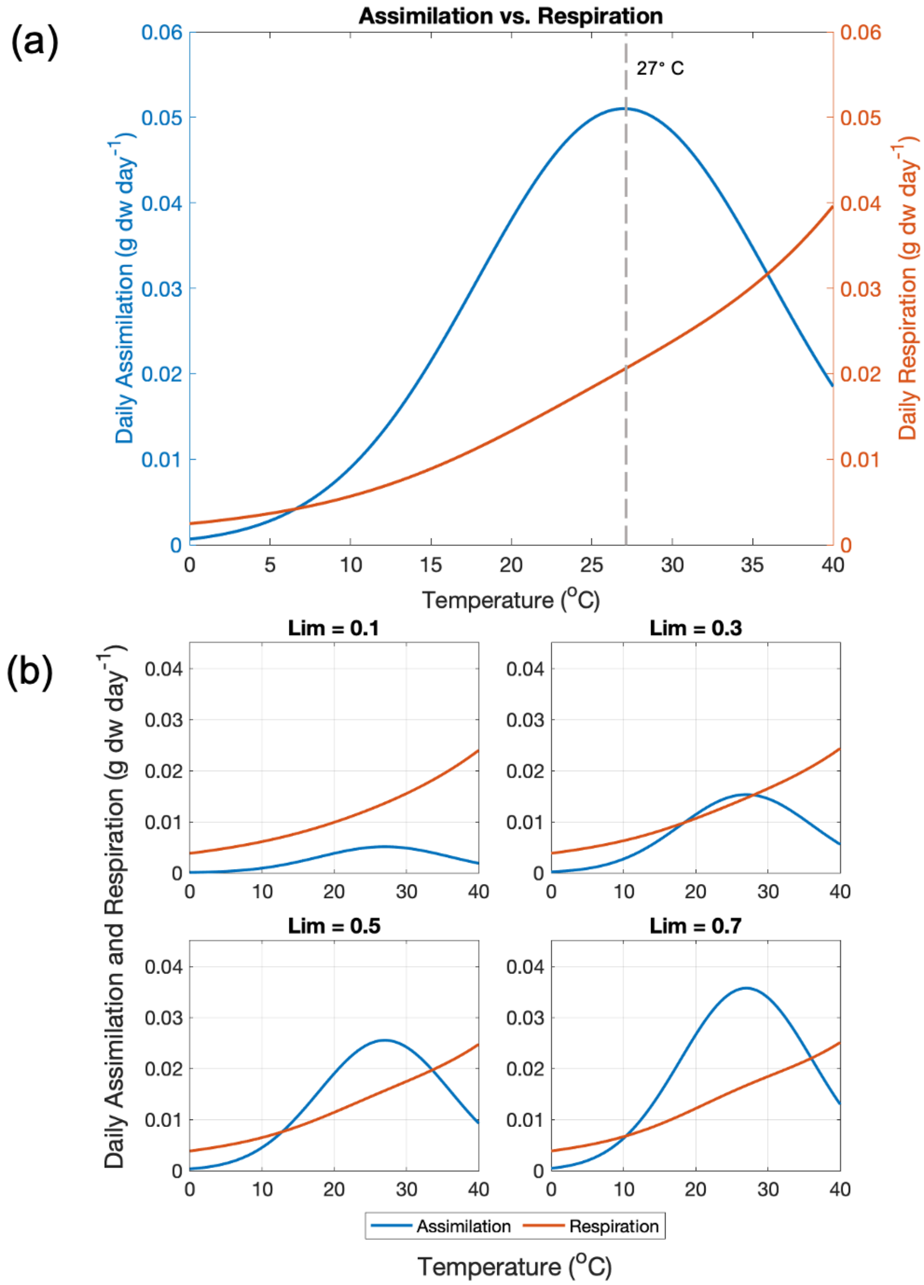

Figure S1. Daily assimilation and respiration rates of Eastern oysters as a function of temperature as simulated by the *EcoOyster* model. Rates are shown (a) assuming no limitation on filtration (Lim = 1) and (b) when filtration is limited by other environmental conditions. (Lim = a dimensionless product of limiting functions of salinity, TSS, dissolved oxygen, and chl*a*).

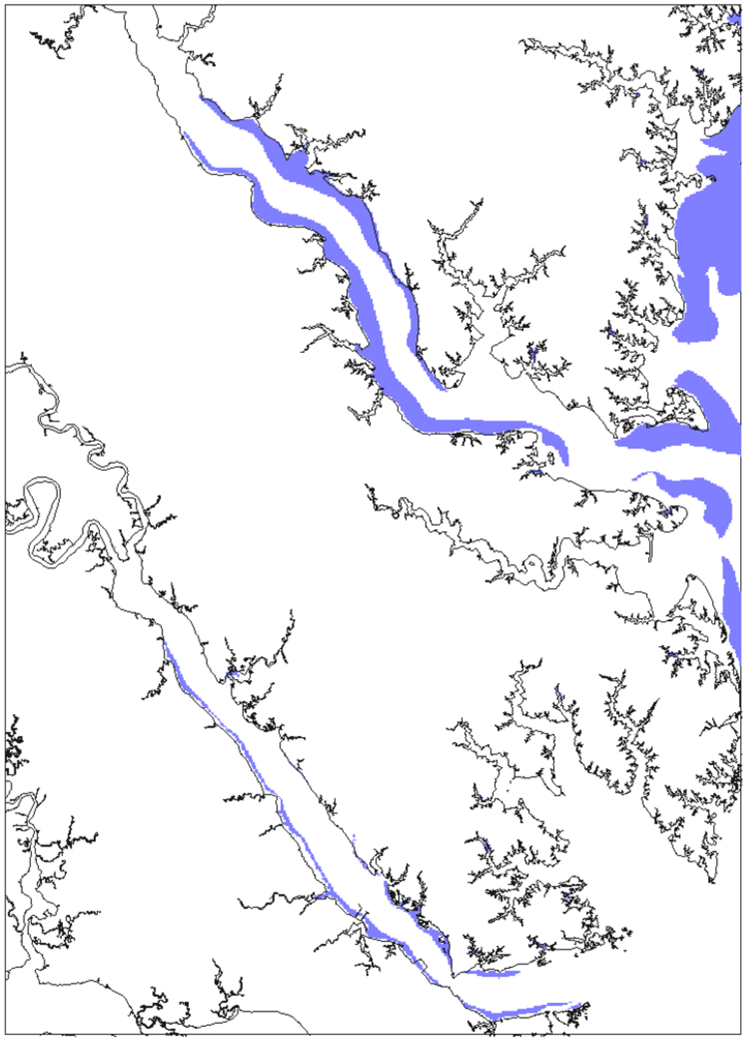

Figure S2. ROMS-ECBO model grid cells that support oyster growth (purple), defined as all grid cells where tissue weight in the reference run exceeds 1 g dry weight at the end of one year of growth.

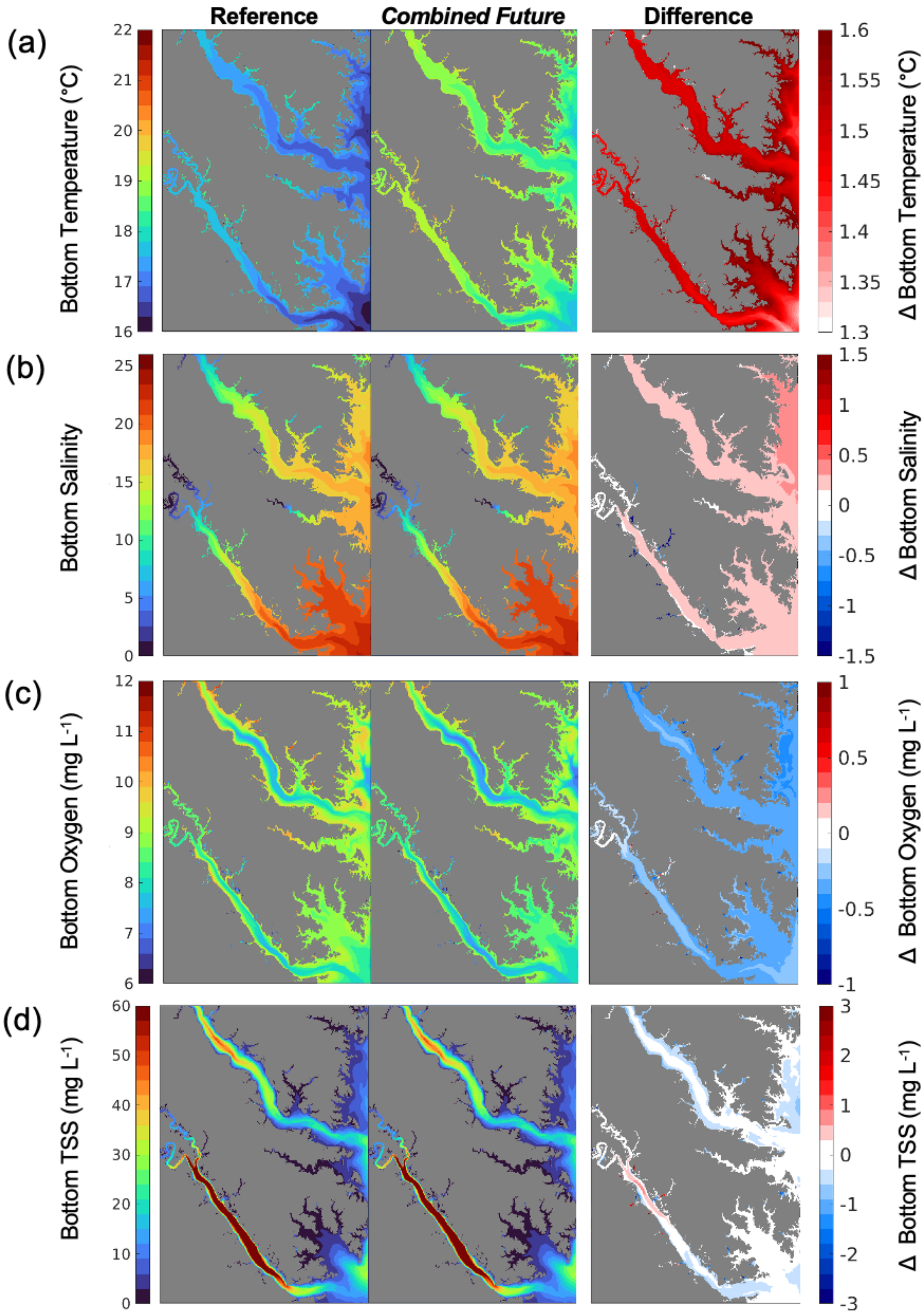

Figure S3. Annual mean ROMS-ECBO bottom (a) temperature, (b) salinity, (c) O_2, and (d) TSS from the reference run, the *Combined Future* simulation, and *Combined Future* minus reference.

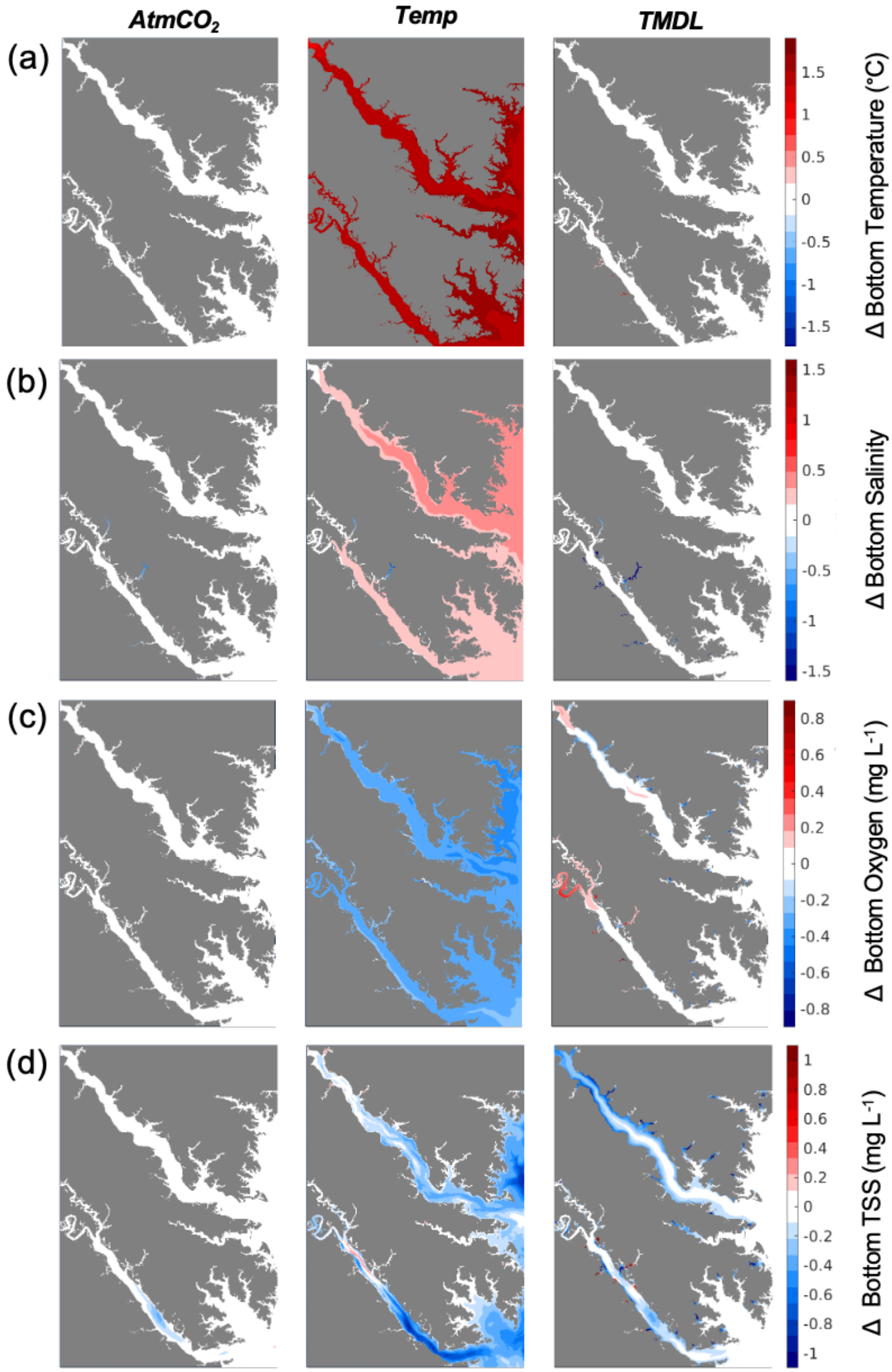

Figure S4. Annual mean ROMS-ECBO bottom (a) temperature, (b) salinity, (c) O_2, and (d) TSS from three sensitivity simulations: *AtmCO₂, Temp,* and *TMDL.* Differences represent future results minus those from the present-day reference run.