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Appendix A. Detailed description of cost or benefit model structure and two tables of model equations and parameters.

A.1 Model Description

To simulate interaction outcomes under a variety of biotic and abiotic contexts, benefit and cost functions include effects of symbiont density (z; A.1), symbiont type (clade C or D), ambient temperature (15-32°C), and irradiance (1-30 mol quanta m^{-2} d^{-1}; these ranges were used to standardize values between 0 and 1). Effects of symbiont type were implemented by assigning clade-specific values for cell size (v; A.2 (Cunning & Baker 2013)), optimum temperature (t_{opt}; A.3), and optimum irradiance (i_{opt}; A.4), with clade D assumed to be more tolerant of high irradiance (van Oppen *et al.* 2009). Clade D was also assumed to provide lower carbon translocation (Cantin *et al.* 2009) but greater environmental tolerance (of heat (Rowan 2004), cold (LaJeunesse et al. 2010), and high irradiance (Ragni et al. 2010)), a tradeoff implemented by the variable f (A.5).

Interaction outcomes are also affected by deviations of ambient temperature and irradiance from optima. These deviations are squared to represent increasing impact with further deviation, and separated piecewise to isolate the effects of low temperature (T_{sub}; A.6), high temperature (T_{super}; A.7), low irradiance (I_{sub}; A.8), and high irradiance (I_{super}; A.9). Each of these biotic and abiotic influences are subsequently incorporated into benefit and cost functions below.

Gross benefits as a function of symbiont density ($B_{gross}(z)$; A.10) were modeled using a Ricker curve to represent an initial increase in benefit as symbionts are added (proportional to their productivity (P)), and subsequent decrease due to density-dependent light limitation (D). Symbiont productivity (P; A.11) is determined by relative carbon translocation (f) and abiotic productivity limitation (L; A.12). Productivity was assumed to be limited by heat (T_{super}), cold (T_{sub}), and excess light (I_{super}), with f included to represent greater sensitivity of clade C. The density above which benefits of photosynthesis decrease due to self-shading (D; A.13), is affected by low irradiance (I_{sub}) and symbiont size (v), with larger symbionts and lower irradiance resulting in self-shading occurring at lower densities.

The gross costs of interaction ($C_{gross}(z)$; A.14) were calculated as the sum of symbiont maintenance costs and oxidative stress costs. Symbiont maintenance costs ($C_{maint}(z)$; A.15), which include basic metabolic and respiratory costs such as symbiosome maintenance, CO2 concentration (Weis *et al.* 1989), and scavenging of symbiont waste, were modeled as a linear function of symbiont density, with costs increasing at higher temperatures (due to higher metabolic rates), and for more productive (i.e., clade C) symbionts (which are assumed to have higher metabolic rates).

The oxidative stress costs ($C_{stress}(z)$; A.16) associated with detoxifying reactive oxygen species (ROS) produced by symbionts and repairing oxidative damage, are a product of f (representing higher ROS production in clade C than clade D (McGinty *et al.* 2012)) and S (ROS production due to environmental stress; A.17). S increases exponentially with heat, cold, and light stress, and is greater for clade C than clade D (McGinty *et al.* 2012). In addition, $C_{stress}(z)$ includes an exponential component, representing exacerbation of oxidative stress by density-dependent feedback (Weis 2008), which occurs at lower densities (due to S in the denominator) as abiotic stress becomes more severe.

The net interaction benefit to the host as a function of symbiont density ($B_{net}(z)$; A.18) is calculated as the difference between gross benefits and gross costs. The maximum net benefit (b_{max}; A.19) is the peak of this curve, and the optimal density (z_{opt}; A.20) is the density at which maximum net benefit occurs.

The model was fit to the data by including scaling multipliers, which were optimized by a gradient-based search algorithm that consecutively adjusted each of the ten scaling parameters from manually-selected starting values in a direction that increased the overall model fit. 1000 iterations of this algorithm resulted in stabilization of scaling parameter values that maximized the model fit. Parameter b_3 (which scales the effect of high temperature) was not well constrained by the data due to a lack of data from warm temperatures (>~28.5°C), and was therefore manually constrained to a value of 10 which produced ecologically realistic results. (Higher values of this parameter resulted in destabilization of symbiosis due to oxidative stress at unrealistically low temperatures). The initial and final values of scaling parameters are presented in Table A2. The full R code implementing the model and fitting algorithm are included as supplementary files.

TABLE A1. Equations used to model interaction cost-benefit outcomes.

Biotic factors			
	Symbiont density	z	A.1
	Relative cell volume	$v = \begin{cases} 1 & \text{, clade C} \\ 0.478 & \text{, clade D} \end{cases}$	A.2
	Temperature optimum	$t_{opt} = 28$	A.3
	Irradiance optimum	$i_{opt} = \begin{cases} 10 & \text{, clade C} \\ 16 & \text{, clade D} \end{cases}$	A.4
	Carbon translocation / environmental sensitivity	$f = \begin{cases} 1 & \text{, clade C} \\ 0.5 & \text{, clade D} \end{cases}$	A.5
Abiotic factors			
	Low temperature	$T_{sub} = \begin{cases} (t_{amb} - t_{opt})^2 & , t_{amb} < t_{opt} \\ 0 & , t_{amb} > t_{opt} \end{cases}$	A.6

High temperature

$$T_{super} = \begin{cases} 0 & , t_{amb} < t_{opt} \\ \left(t_{amb} - t_{opt}\right)^2 & , t_{amb} > t_{opt} \end{cases} \tag{A.7}$$

Low irradiance

$$I_{sub} = \begin{cases} \left(i_{amb} - i_{opt}\right)^2 & , i_{amb} < i_{opt} \\ 0 & , i_{amb} > i_{opt} \end{cases} \tag{A.8}$$

High irradiance

$$I_{super} = \begin{cases} 0 & , i_{amb} < i_{opt} \\ \left(i_{amb} - i_{opt}\right)^2 & , i_{amb} > i_{opt} \end{cases} \tag{A.9}$$

Gross benefit

$$B_{gross}(z) = Pze^{-Dz} \tag{A.10}$$

Symbiont productivity

$$P = \frac{b_1 f}{L} \tag{A.11}$$

Productivity limitation

$$L = 1 + \left(f\left(b_2 T_{sub} + b_3 T_{super}\right) + I_{super}\right) \tag{A.12}$$

Light-limiting density

$$D = b_4 v\left(1 + b_5 I_{sub}\right) \tag{A.13}$$

Gross cost

$$C_{gross}(z) = C_{maint}(z) + C_{stress}(z) \tag{A.14}$$

Maintenance cost

$$C_{maint}(z) = b_6 f t_{amb} z \tag{A.15}$$

Oxidative stress cost

$$C_{stress}(z) = fSze^{b_9\left(z - \frac{b_{10}}{S}\right)} \tag{A.16}$$

ROS production

$$S = e^{b_7\left(f\left(b_2 T_{sub} + b_3 T_{super}\right) + b_8\left(\frac{i_{amb}}{i_{opt}}\right)^2\right)} \tag{A.17}$$

Net benefit

$$B_{net}(z) = B_{gross}(z) - C_{gross}(z) \tag{A.18}$$

Maximum benefit

$$b_{max} = \max B_{net}(z) \tag{A.19}$$

Optimal density

$$z_{opt} = \underset{z}{\arg\max}\, B_{net}(z) \tag{A.20}$$

TABLE A2. Scaling parameter values. For each scaling parameter, given are the initial values and the final values after 1000 iterations of a gradient search fitting algorithm.

Scaling parameter	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
Initial value	50	1.8	10	6	55	7	10	0.08	20	0.32
Final value	39.29	0.58	10	4.67	46.66	16.13	24.91	0.02	28.38	0.28

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