Supplement 1

Methods 1. Determination of lux to PAR conversion factors

The following procedures were applied to calculate numerical factors for conversion of illuminance values (in lx) of artificial actinic light and sunlight measured in the lab and field, to irradiance (PAR) values (in µmol photons m^{-2} s^{-1}).

1.1 Artificial actinic light

Illuminance and irradiance at the bottom of one mesocosm were recorded simultaneously for 15 min for each of two actinic fluorescent tubes at each of the three experimental irradiances (low, intermediate, and high). Tubes were chosen randomly from the pool of tubes used in the laboratory experiment. The two trials were performed in the dark to measure the sole contribution of each tube to light environment. Illuminance was recorded once every second with the same model of temperature and light logger (HOBO Pendant; Onset Computer Corporation) used in the mesocsom experiment. Irradiance was recorded 240 times min^{-1} with a quantum sensor (LI-192; LI-COR). One conversion factor was calculated for each tube and irradiance treatment. This was done by averaging illuminance and irradiance data for each of the 15 min that each trial lasted, and then by dividing each mean illuminance by corresponding mean irradiance. Means of the resulting 15 conversion factors (one per minute for each combination of irradiance and tube) were similar for both tubes within a same irradiance treatment, and hence averaged, yielding one overall conversion factor per irradiance treatment (Table S1).

lxµmol photons m−2s−1) for each of the two actinic fluorescent tubes chosen randomly among the five tubes used in the laboratory experiment, at each of the three experimental irradiances (n=15 for each combination of tube and irradiance and 30 for each of the three overall factors pooled across tubes).

	Irradiance		
Actinic tube	**Low**	**Intermediate**	**High**
1	13.9 (0.9)	18.4 (0.9)	21.6 (0.7)
2	15.5 (0.9)	17.8 (0.5)	22.6 (0.6)
Tubes pooled	14.7 (1.2)*	18.1 (0.8)*	22.1 (0.8)*

*Overall factors used to convert individual actinic illuminance values to PAR values in the low, intermediate, and high irradiance treatments of the laboratory mesocosm experiment.

1.2 Sunlight

Illuminance and irradiance above the rhodolith bed were recorded simultaneously for 15 min at each of the three experimental depths (8, 15, and 25 m), on a partly cloudy day with low winds in both April and August, when phytoplankton abundance was respectively high (during spring bloom) and low (after spring bloom) (Parrish et al. 2005). Illuminance was recorded once every second with the same model of temperature and light logger (HOBO Pendant; Onset Computer Corporation) used in the laboratory mesocosm experiment. Irradiance was recorded 240 times min^{-1} with a quantum sensor (LI-192; LI-COR). Both instruments were attached next to one another on a metal frame deposited on the surface of the rhodolith bed and pointed towards the sea surface. One conversion factor was calculated for each depth on each sampling day. This was done by averaging illuminance and irradiance data for each of the 15 min that each trial lasted, and then by dividing each mean illuminance by corresponding mean irradiance. Means of the resulting 15 conversion factors (one per minute for each combination of depth and day) were similar among the six combinations of depth and day, and hence averaged, yielding one overall conversion factor applicable to all depths (Table S2).

Table S2. Mean (±SD) illuminance to PAR conversion factors (in lx / µmol photons m^{-2} s^{-1}) for each of the three depths of the field experiment, based on measurement of illuminance and irradiance above the rhodolith bed on a partly cloudy day with low winds in both April and August, when phytoplankton abundance was respectively high and low (n=15 for each conversion factor per depth and day, 30 for each factor per depth pooled across days, 45 for each factor per day pooled across depths, and 90 for the overall factor pooled across depths and days).

	Depth (m)			
Sampling day	**8**	**15**	**25**	**Depths pooled**
1 (April)	21.3 (1.0)	25.0 (0.1)	25.9 (0.2)	24.1 (2.0)
2 (August)	24.0 (1.6)	21.9 (0.5)	22.1 (1.0)	22.7 (1.5)
Days pooled	22.7 (1.9)	23.5 (1.6)	24.0 (2.1)	23.4 (1.9)*

*Overall factor used to convert sunlight illuminance values to PAR values in the laboratory and field experiments.

LITERATURE CITED

Parrish C, Thompson R, Deibel D (2005) Lipid classes and fatty acids in plankton and settling matter during the spring bloom in a cold ocean coastal environment. Mar Ecol Prog Ser 286:57-68 https://doi.org/10.3354/meps286057

Supplement 2

Implementation of data dependency structures

2.1. Mixed-effect models

Failure of a statistical analysis (model) to properly incorporate the true structure of randomness present in the data (often termed "pseudoreplication") is an issue that contemporary statistical approaches can effectively address (Millar & Anderson 2004). This phenomenon can arise when two or more test subjects exposed to a given experimental treatment in a same monitoring unit are treated as independent. In the present study, rhodoliths (our test subjects) within each experimental mesocosm (laboratory experiment) or cage (field experiment) cannot be considered fully independent because they share the same space and conditions and can potentially influence each other's response to the treatment applied. If no random or nested factors are included in the structure of the statistical models, and if all the fixed factors are tested against the models' overall error (i.e. the "residuals"), then the power of the analysis can inflate unduly and yield artificially small and potentially significant *p*-values (Hurlbert 1984, Freeberg & Lucas 2009).

Mixed-effects models that include random effects and nested designs have become the norm to best deal with non-independent observations like in the present study (Millar & Anderson 2004, Chaves 2010, Crawley 2013, Davies & Gray 2015). A critical component of mixed-effects models is the proper incorporation of the true structure of randomness present in the data. This is essentially done by calculating, for each model's term of interest, the right F-ratio based on correct allocation of the expected mean squares (EMS) that form the F-ratio denominator (Quinn & Keough 2012). Below we explain how we implemented mixed-effects models for our laboratory and field experiments.

2.2. Split-plot ANCOVA - Laboratory mesocosm experiment

Quinn & Keough (2012) thoroughly explain split-plot analysis of covariance (ANCOVA) models and their implementation. These models typically include a within plot fixed factor A, a random factor B nested within A [B(A)], a between plot fixed factor C, and a covariate X (see section "12.7.4 Partly nested models with one covariate" in Quinn & Keough 2012). They recommend fitting a model that includes all fixed factors by covariate interactions and to test the homogeneity of the slopes for A, C, and A x C based on the significance of the following F-ratios: A x X against B(A), C x X and A x C x X against B(A) x X (Quinn & Keough 2012).

In our laboratory experiment, Temperature (T) corresponds to the fixed factor A, Mesocosm (M) corresponds to the random factor B nested within T [M(T)], Irradiance (I) corresponds to the between-plot fixed factor C, and Time [t] corresponds to the covariate X. Table S3 shows that 1) none of the F-ratios for the terms of interest are based on the model's residuals; and 2) we tested the homogeneity of the slopes (rhodolith growth as a function of time) across Temperature (T x t), Irradiance (I x t), and Temperature and Irradiance combined (T x I x t), as per the procedures outlined above and further detailed in Quinn & Keough (2012).

Table S3. F-ratio test and degrees of freedom of the F-ratio numerator and F-ratio denominator for each term of the split-plot ANCOVA model used to analyze rhodolith growth response in the laboratory experiment. MS = Mean squares, numDF = degrees of freedom of the F-ratio numerator, denDF = degrees of freedom of the F-ratio denominator, asterisks (*) indicate the terms of interest.

Source	**F-ratio test**	**numDF**	**denDF**
Between plots			
T*	$MS_T / MS_{M(T)}$	3	4
t	$MS_t / MS_{Residuals}$	1	144
M(T)	$MS_{M(T)} / MS_{Residuals}$	4	144
T x t*	$MS_{T \times t} / MS_{M(T)}$	3	4
Within plots			
I*	$MS_I / MS_{M(T) \times I}$	2	8
T x I*	$MS_{T \times I} / MS_{M(T) \times I}$	6	8
I x t*	$MS_{I \times t} / MS_{M(T) \times I}$	2	8
M(T) x I	$MS_{M(T) \times I} / MS_{Residuals}$	8	144
T x I x t*	$MS_{T \times I \times t} / MS_{M(T) \times I}$	6	8

2.3. Nested ANCOVA (one covariate) – Field experiment (3 depths, first 2 rhodolith collections)

Nested ANCOVA models typically include a fixed factor A, a random factor B nested within A [B(A)], and a covariate X (see section "12.7.3 Nested design with one covariate" in Quinn & Keough 2012). The recommendation for these models is to test the homogeneity of the slopes among levels of A based on the significance of the following F-ratio: A x X against B(A) x X.

In our field experiment, Depth (D) corresponds to the fixed factor A, Cage (C) corresponds to the random factor B nested within D [C(D)], and Time [t] corresponds to the covariate X. Table S4 shows that 1) none of the F-ratios for the terms of interest are based on the model's residuals, and 2) we tested the homogeneity of the slopes (rhodolith growth as a function of time) across depth (D x t), as per the procedures outlined above and further detailed in Quinn & Keough (2012).

Table S4. F-ratio test and degrees of freedom of the F-ratio numerator and F-ratio denominator for each term of the nested ANCOVA model used to analyze rhodolith growth response during the first part of the field experiment (first 2 rhodolith collections). MS = Mean squares, numDF = degrees of freedom of the F-ratio numerator, denDF = degrees of freedom of the F-ratio denominator, asterisks (*) indicate the terms of interest.

Source	**F-ratio test**	**numDF**	**denDF**
D*	$MS_{D} / MS_{C(D)}$	2	6
T	$MS_{t} / MS_{Residuals}$	1	22
C(D)	$MS_{C(D)} / MS_{Residuals}$	6	22
D x t*	$MS_{D \text{ x } t} / MS_{C(D) \text{ x } t}$	1	6
C(D) x t	$MS_{C(D) \text{ x } t} / MS_{Residuals}$	3	22

2.4. Two-way nested ANOVA – Field experiment (2 depths, 8 rhodolith collections)

Two-way nested analysis of variance (ANOVA) models typically include two crossed, fixed factors A and C, as well as a random factor B nested within C [B(C)] (see section 9.1 "Nested (hierarchical) designs" in Quinn & Keough 2012). In these models, the terms of interest are the two fixed factors and their interaction. In our field experiment, Collection (Co), and Depth (D) correspond to the fixed factors A and C, respectively, and Cage (C) corresponds to the random factor B nested within C [C(D)]. Table S5 shows that none of the F-ratios for the terms of interest are based on the model's residuals.

Table S5. F-ratio test and degrees of freedom of the F-ratio numerator and F-ratio denominator for each term of the nested ANOVA model used to analyze rhodolith growth response throughout the field experiment (8 rhodolith collections). MS = Mean squares, numDF = degrees of freedom of the F-ratio numerator, denDF = degrees of freedom of the F-ratio denominator, asterisks (*) indicate the terms of interest.

Source	**F-ratio test**	**numDF**	**denDF**
Co*	$MS_{Co} / MS_{Co \text{ x } C(D)}$	7	28
D*	$MS_{D} / MS_{C(D)}$	1	4
C(D)	$MS_{C(D)} / MS_{Residuals}$	4	48
Co x D*	$MS_{Co \text{ x } D} / MS_{Co \text{ x } C(D)}$	7	28
Co x C(D)	$MS_{Co \text{ x } C(D)} / MS_{Residuals}$	28	48

2.5. Nested ANCOVA (one or two covariates) – Field experiment (thermal and irradiance indices)

The first two models presented in Table S6 are analogous to the model described in section 2.3 above. Here, Depth (D) corresponds to the fixed factor A, Cage (C) corresponds to the random factor B nested within D [C(D)], and Degree-day (DD), or PAR-day (PD) correspond to the covariate X. The third and fourth models in Table S6 only differ from the first two models in that they include individual (DD + PD) or interactive (DD x PD) effects of both covariates, respectively. F-ratios are for each models' terms of interest and are formed after the principles detailed in section 2.3; 1) none of the F-ratios for the terms of interest are based on the model's residuals, and 2) we tested the homogeneity of the slopes (rhodolith growth as a function of DD, PD, or DD x PD) across depth (D x DD, D x PD, or D x DD x PD), as per the procedures outlined above and detailed in Quinn & Keough (2012).

Table S6. F-ratio test and degrees of freedom of the F-ratio numerator and F-ratio denominator for each term of the nested ANCOVA models used to analyze rhodolith growth response as it relates to thermal [Degree-day, DD] and irradiance [PAR-day, PD] indices throughout the field experiment (8 rhodolith collections). MS = Mean squares, numDF = degrees of freedom of the F-ratio numerator, denDF = degrees of freedom of the F-ratio denominator, asterisks (*) indicate the terms of interest.

Model	Source	F-ratio test	numDF	denDF
DD	D*	$MS_{D} / MS_{C(D)}$	1	4
	DD	$MS_{DD} / MS_{Residuals}$	1	84
	C(D)	$MS_{C(D)} / MS_{Residuals}$	4	84
	D x DD*	$MS_{D \times DD} / MS_{C(D) \times DD}$	1	4
	C(D) x DD	$MS_{C(D) \times DD} / MS_{Residuals}$	4	84
PD	D*	$MS_{D} / MS_{C(D)}$	1	4
	PD	$MS_{PD} / MS_{Residuals}$	1	84
	C(D)	$MS_{C(D)} / MS_{Residuals}$	4	84
	D x PD*	$MS_{D \times PD} / MS_{C(D) \times PD}$	1	4
	C(D) x PD	$MS_{C(D) \times PD} / MS_{Residuals)}$	4	88
DD + PD	D*	$MS_{D} / MS_{C(D)}$	1	4
	DD	$MS_{DD} / MS_{Residuals}$	1	78
	PD	$MS_{PD} / MS_{Residuals}$	1	78
	C(D)	$MS_{C(D)} / MS_{Residuals}$	4	78
	D x DD*	$MS_{D \times DD} / MS_{C(D) \times DD}$	1	4

Model	Source	F-ratio test	numDF	denDF
	D x PD*	$MS_{D \times PD}/ MS_{C(D) \times PD}$	1	4
	C(D) x DD	$MS_{C(D) \times DD} / MS_{Residuals}$	4	4
	C(D) x PD	$MS_{C(D) \times PD}/ MS_{Residuals}$	4	4
DD x PD	D*	$MS_{D} / MS_{C(D)}$	1	4
	DD	$MS_{DD} / MS_{Residuals}$	1	72
	PD	$MS_{PD} / MS_{Residuals}$	1	72
	C(D)	$MS_{C(D)} / MS_{Residuals}$	4	72
	D x DD*	$MS_{D \times DD} / MS_{C(D) \times DD}$	1	4
	D x PD*	$MS_{D \times PD} / MS_{C(D) \times PD}$	1	4
	DD x PD	$MS_{DD \times PD} / MS_{Residuals}$	1	72
	C(D) x DD	$MS_{DD \times C(D)} / MS_{Residuals}$	4	72
	C(D) x PD	$MS_{PD \times C(D)} / MS_{Residuals}$	4	72
	D x DD x PD*	$MS_{D \times DD \times PD} / MS_{C(D) \times DD \times PD}$	1	4
	C(D) x DD x PD	$MS_{C(D) \times DD \times PD)} / MS_{Residuals}$	4	72

LITERATURE CITED

Davies GM, Gray A (2015) Don't let spurious accusations of pseudoreplication limit our ability to learn from natural experiments (and other messy kinds of ecological monitoring). Ecol Evol 5:5295-5304 https://doi.org/10.1002/ece3.1782

Chaves LF (2010) An entomologist guide to demystify pseudoreplication: data analysis of field studies with design constraints. J Med Entomol 47:291-298 https://doi.org/10.1093/jmedent/47.1.291

Crawley MJ (2013) The R book 2nd ed. John Wiley & Sons Inc. 1051 p.

Freeberg TM, Lucas J (2009) Pseudoreplication is still a problem. J Comp Psychol 123:450-451 https://doi.org/10.1037/a0017031

Hurlbert SH (1984) Pseudoreplication and the design of ecological field experiments. Ecol Monogr 54:187-211 https://doi.org/10.2307/1942661

Millar RB, Anderson MJ (2004) Remedies for pseudoreplication. Fish Res 70:397-407 https://doi.org/10.1016/j.fishres.2004.08.016

Quinn GP, Keough MJ (2012) Experimental design and data analysis for biologists. Cambridge University Press, New York, NY

Supplement 3

Methods 2. Comparison of water temperatures between the first and second runs of the laboratory mesocosm experiment

Daily mean water temperature (DMWT) in the controlled temperature mesocoms (2, 4, 7, and 10°C) was generally similar between the first and second experimental runs (Fig. S1). The accidental reduction of seawater delivery to mesocosms at 2 and 4°C during the acclimation period of the second run increased temperature by ~4.5°C above that of the first experimental run over approximately three days. Such a small and brief difference was deemed inconsequential to rhodolith growth.

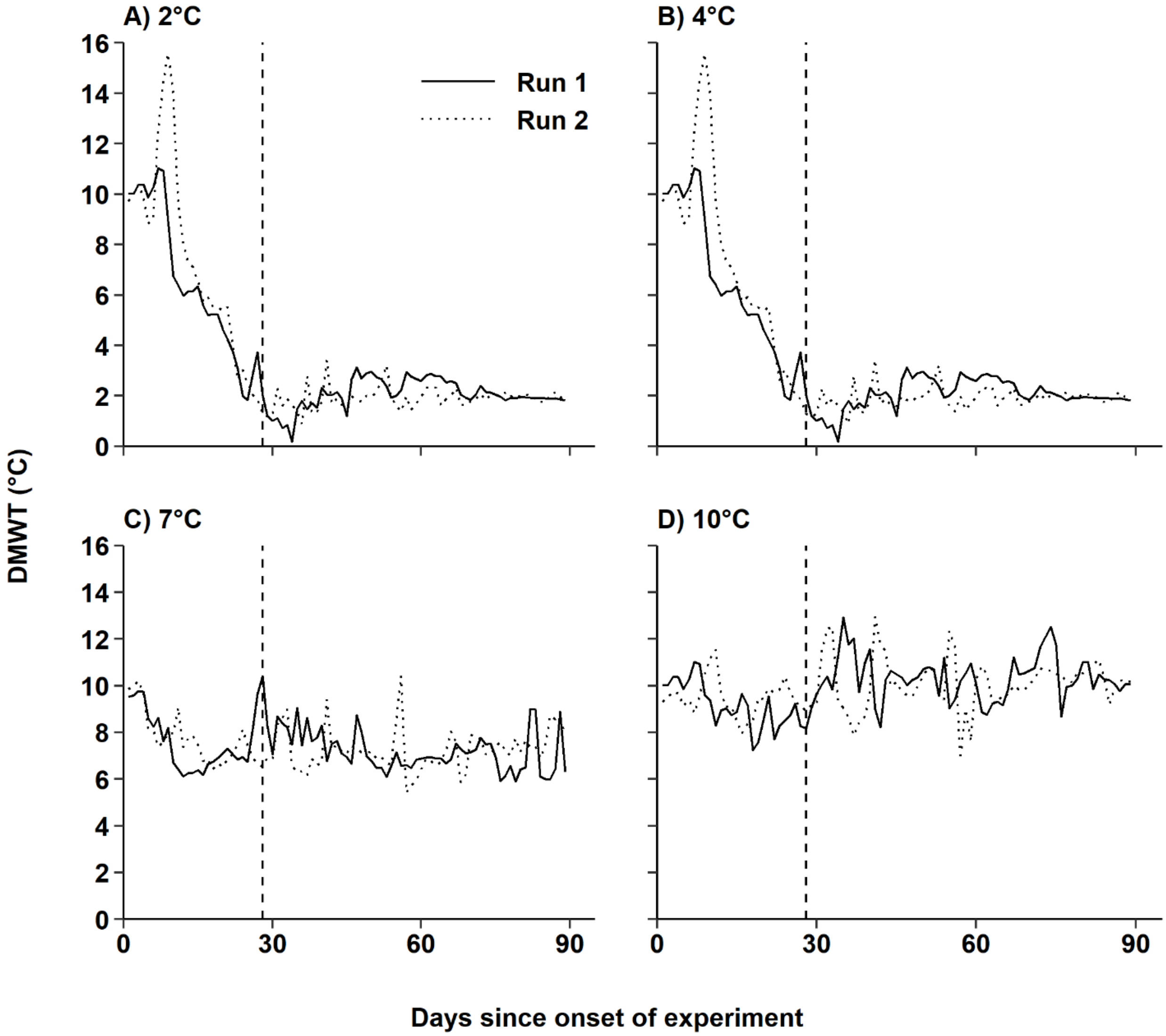

Fig. S1. Daily mean water temperature (DMWT) in each of the four mesocosms with controlled temperature [2, 4, 7, and 10°C] during the first 89 d of the first experimental run and 89 d that the second experimental run lasted. Vertical dashed lines mark the end of acclimation during which rhodoliths in mesocosms at 2, 4, and 7°C were exposed to decreasing temperatures from an initial temperature of 10°C.

Supplement 4

Table S7. Summary of split-plot ANCOVA (applied to raw data) examining the effect of between-plot factor water Temperature (T; four levels: 2, 4, 7 and 10°C), within-plot factor Irradiance (I; three levels: low, intermediate, and high), and covariate Time (t; number of days elapsed since the onset of the experiment on each rhodolith sampling event in the first [89, 179, 272 and 361 d] and second [89 d] experimental runs), while correcting for the random factor Mesocosm (each of the 8 experimental mesocosms [4 mesocosms in each of the first and second experimental runs]) nested within Temperature (two mesocosms per controlled temperature [2, 4, 7, and 10°C]) on rhodolith (*Lithothamnion glaciale*) growth in the laboratory mesocosm experiment (see section 2.2 for a description of the experiment). Random-factor effects are not relevant to the present study, and hence not shown for simplicity. numDF = degrees of freedom of the F-ratio numerator; denDF = degrees of freedom of the F-ratio denominator.

Source of variation	**numDF**	**denDF**	**F-ratio**	**p-value**
T	3	4	10.922	0.021
I	2	8	16.396	0.002
t	1	144	268.558	<0.001
T x I	6	8	0.943	0.515
T x t	3	4	0.914	0.449
I x t	2	8	15.531	<0.001
T x I x t	6	8	0.784	0.591

Table S8. T-test comparisons of growth rates of rhodoliths (*Lithothamnion glaciale*) exposed to ambient (naturally fluctuating) seawater temperature and each of the four controlled seawater temperatures (2, 4, 7, and 10°C) for the three irradiance treatments in the laboratory mesocosm experiment (see section 2.2 for a description of the experiment). *Adjusted p-value based on Tukey method for multiple tests.

Irradiance	**Comparison pair**	**t-ratio**	**p-value***
Low	2°C - Ambient	1.452	0.983
	4°C - Ambient	0.409	1.000
	7°C - Ambient	1.216	0.997
	10°C - Ambient	1.306	0.994
Intermediate	2°C - Ambient	0.982	1.000
	4°C - Ambient	1.344	0.992
	7°C - Ambient	0.420	1.000
	10°C - Ambient	2.444	0.482
High	2°C - Ambient	0.474	1.000
	4°C - Ambient	0.061	1.000
	7°C - Ambient	0.346	1.000
	10°C - Ambient	1.314	0.993

Table S9. Summary of (A) nested ANCOVA (applied to raw data) examining the effects of factor Depth (D; three levels: 8, 15 and 25 m) and covariate Time (t; numbers of days elapsed since the onset of the field experiment on each of the first two rhodolith collection events [65 and 103 d]) while correcting for the random factor Cage (each of the nine cages [three cages per depth]) nested within Depth, on rhodolith (*Lithothamnion glaciale*) growth; and (B) two-way ANOVA examining the effects of fixed factors Depth (D; two levels: 15 and 25 m) and Collection (Co; eight levels: each of the eight rhodolith collection events) while correcting for the random factor Cage (each of the six cages [three cages per depth treatment]) nested within Depth, on rhodolith (*L. glaciale*) apical growth (see section 2.3 for a description of the experiment). Random-factor effects are not relevant to the present study, and hence not shown for simplicity. numDF = degrees of freedom of the F-ratio numerator; denDF = degrees of freedom of the F-ratio denominator.

	Source of variation	**numDF**	**denDF**	**F-ratio**	**p-value**
A) First two collections	D	2	6	32.519	0.001
(8, 15, and 25 m depths)	t	1	22	28.654	0.002
	D x t	2	6	1.236	0.355
B) All (eight) collections	Co	7	28	24.826	<0.001
(15 and 25 m depths)	D	1	4	0.110	0.757
	Co x D	7	28	1.513	0.204

Table S10. Summary of nested ANCOVAs (applied to raw data) examining the effects of factor Depth (D; two levels: 15 and 25 m) and covariates Degree-Day (DD: cumulative sea temperature since the onset of the field experiment over the eight rhodolith collection events) and PAR-Day (PD: cumulative daily light integral [DLI] since the onset of the field experiment over the eight rhodolith collection events) while correcting for the random factor Cage (each of the nine cages [three cages per depth]) nested within Depth, on rhodolith (*Lithothamnion glaciale*) growth. Model (A) includes the covariate DD only. Model (B) includes the covariate PD only. Model (C) includes DD and PD without their interaction. Model (D) includes DD and PD and their interaction. Random-factor effects are not relevant to the present study, and hence not shown for simplicity. The Akaike's information criterion (AIC) indicates the strength of each model's fit used in model selection (the lower the AIC, the better the fit of the model). numDF = degrees of freedom of the F-ratio numerator, denDF = degrees of freedom of the F-ratio denominator, AIC = Akaike's information criterion.

Model	**Source**	**numDF**	**denDF**	**F-ratio**	**p-value**	**AIC**
A) DD	DD	1	84	119.18	<0.001	982.12
	D	1	4	6.63	0.062	
	DD x D	1	4	0.22	0.639	
B) PD	PD	1	84	119.31	<0.001	977.15
	D	1	4	21.65	0.010	
	PD x D	1	4	9.53	0.003	
C) DD + PD	DD	1	78	134.81	<0.001	984.70
	PD	1	78	0.09	0.770	
	D	1	4	6.20	0.068	
	DD x D	1	4	1.97	0.164	
	PD x D	1	4	0.03	0.862	
E) DD x PD	DD	1	72	141.78	<0.001	1008.42
	PD	1	72	0.15	0.704	
	D	1	4	6.17	0.068	
	DD x PD	1	72	7.22	0.009	
	DD x D	1	4	4.09	0.046	
	PD x D	1	4	1.06	0.306	
	DD x PD x D	1	4	0.07	0.797	