SUPPLEMENTARY METHODS

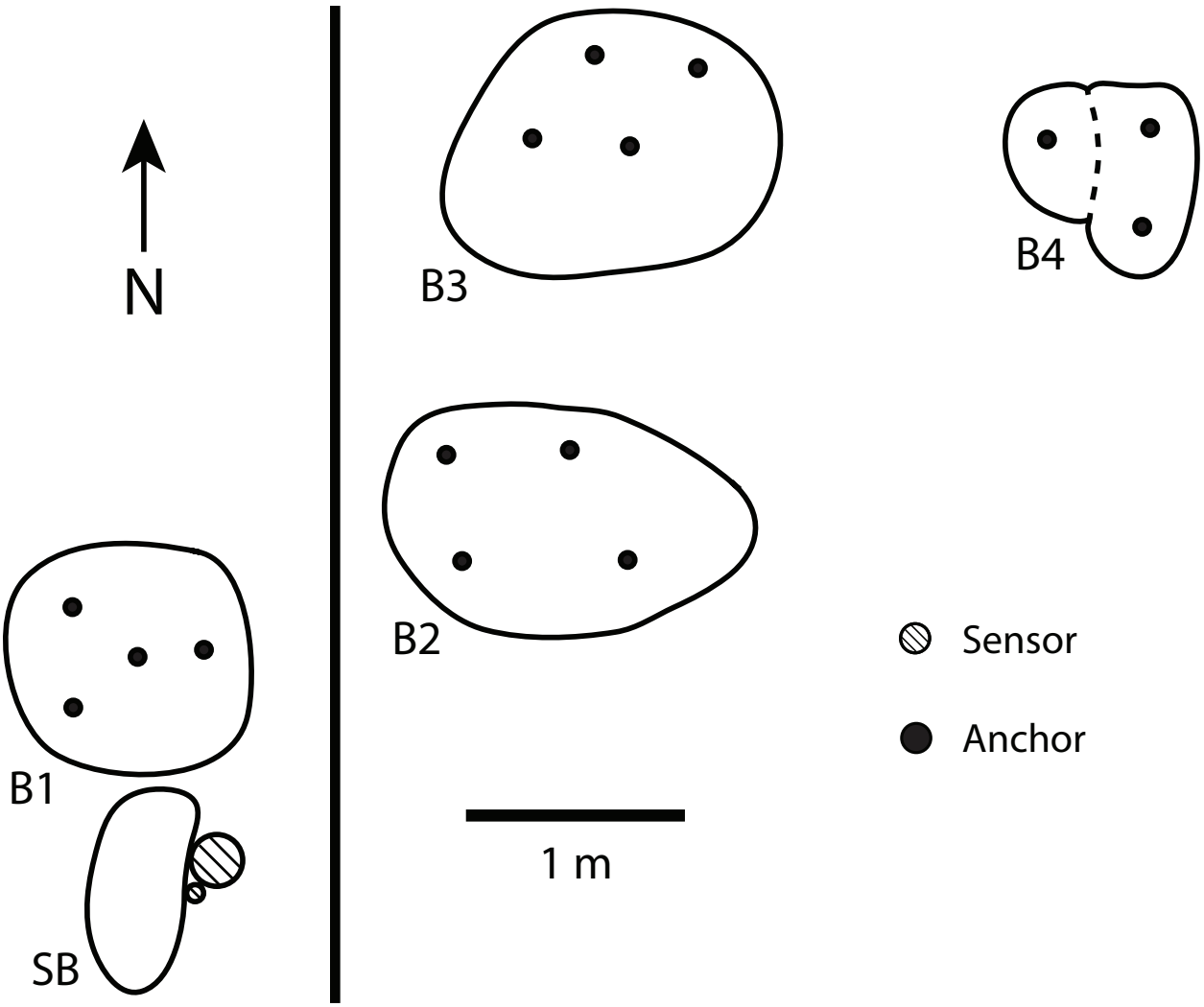

Figure S1. Schematic of field site (top-down view) including experiment boulders (B1 – B4) with their anchors and the sensor boulder (SB) with a dissolved oxygen/temperature sensor (smaller) and a pH sensor (larger). Dotted line indicates crevice running through Boulder 4. Black line represents approximate location of permanent cable line running through the kelp forest next to the Hopkins Marine Station (Pacific Grove, CA, USA).

Text S1.1 Kelp culturing

Juvenile giant kelp (1–2 mm in size) were grown in the lab at the Hopkins Marine Station in Pacific Grove, CA, USA. We collected sporophylls by hand on SCUBA from the kelp forest near the marine station (8–10 m depth) and kept them in flowing seawater up to three hours before the spore release process. To prepare the sporophylls, we wiped them to remove any epibionts and rinsed them with a 10% iodine solution followed by filtered seawater from the Monterey Bay Aquarium, which is next to the marine station (post sand-filtered, nominal 20 μm). They were layered with wet paper towels, left to desiccate for 30 minutes in 10–12 °C, and then transferred to a dish of filtered seawater to induce spore release.

Spores were settled at a concentration of 5 spores/mm^2 in plastic tubs (50.3 cm x 34.3 cm) and trays (38.1 cm x 15.2 cm). The tubs were lined with fifteen beige travertine tiles (10.16 x 10.16 cm) (Jeffrey Court) with holes drilled in the center, and the trays were lined with 3 tiles. The tubs were placed in a shallow trough-shaped aquarium with flowing seawater in a semi-enclosed outdoor facility and kept at 10–12 °C with a 14:10 light:dark cycle for approximately six weeks. The trays were placed in incubators at the same temperature and light cycle. Water was replaced every week for tubs and trays with new growth media (Provosoli's enriched seawater) (Andersen 2005) until the sporophytes were 1–2 mm in length. The use of both an outdoor facility and laboratory incubators was to ensure enough tiles were successfully cultured for each experiment throughout the entire upwelling season. Due to consistent lighting, temperature, and nutrients between the two culturing systems, kelp quality was assumed to be the same among all tiles. The average percent cover (±SE) across tiles was 14.2% ± 0.6%.

Text S1.2 Cage deployment

The cages were made from plastic Snapware containers consisting of a lid lined with rubber and four locking tabs, which lock into the bottom portion of the container. For the cage treatment, windows were cut out of all sides and lids of the containers and replaced with clear nylon mesh (1 mm openings) to allow for water flow and light penetration but still blocked out smaller grazers, such as amphipods (exclusion of grazers was confirmed in pilot studies, C. Ng, unpubl. data). A small slit was made in the mesh on the container lids. To secure the tiles to the boulders, the stainless steel screws in the anchors were placed through the tile and the slit in the lid mesh of the container and screwed back into the anchor. The bottom portion of the container was then placed over the tile and clipped into place. For the cage control treatment, the containers only had mesh on two sides, allowing grazers to access the tiles from two sides and the top. This accounted for any effects of the cage on kelp survival. The exposed treatment consisted of the kelp tile and lid of the container only. We rotated the treatments among the anchors for each experiment.

Text S1.3 Estimates of grazing impact using ImageJ

Prior to and after each caging experiment, tiles were photographed using a digital camera (Canon Powershot G9 X) and analyzed for kelp cover with the program ImageJ. This was done by calculating the area of the tile and measuring the kelp cover using color thresholding for the before and after photos. The hue, saturation, and brightness levels were adjusted to capture as much of the kelp on the tiles as possible. To account for small variations in the percent cover

depending on the levels, we took three measurements and averaged them (though percent cover only varied about 5% between the measurements). To calculate and compare grazing rates, we divided the percent of kelp removed by the kelp cover before the experiment for every tile to get a proportion removed over the 24-hour experimental period.

Text S1.4 SeaFET pH sensor calibration

We collected 13 discrete water samples during every experiment using standard operating protocols (Dickson et al. 2007). We measured salinity of the water samples using a YSI 3200 Conductivity Instrument. Total alkalinity was measured using titration with an SI Analytics TitroLine 6000 and was standardized using certified reference materials (Andrew Dickson, Scripps Institute of Oceanography). Spectrophotometric determination of pH was obtained using a Shimadzu UV-1800. We used these values and calculated pH_T in the water samples using the program CO2SYS (https://www.nodc.noaa.gov/ocads/oceans/CO2SYS/co2rprt.html) with K1 and K2 constants from Mehrbach et al. (1973) refit by Dickson & Millero (1987) and $KHSO_4$ from Dickson 1990. We then used the calculated pH values to calibrate the sensor readings (Martz et al. 2010, Bresnahan et al., 2014), and used the calibrated data for analyses.

Supplementary Methods: Literature Cited

Andersen RA (2005) Algal Culturing Techniques. Elsevier, Burlington, MA

Bresnahan PJ, Martz TR, Takeshita Y, Johnson KS and LaShomb M (2014) Best practices for autonomous measurement of seawater pH with the Honeywell Durafet. Methods in Oceanography 9:44-60 https://doi.org/10.1016/j.mio.2014.08.003

Dickson AG (1990) Standard potential of the reaction: AgCl (s)+ 12H2 (g)= Ag (s)+ HCl (aq), and the standard acidity constant of the ion HSO_4 in synthetic sea water from 273.15 to 318.15 K. J. Chem. Thermodyn. 22:113-127

Dickson AG and Millero FJ (1987) A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. Deep Sea Research Part A. Oceanographic Research Papers 34:1733-1743 https://doi.org/10.1016/0198-0149(87)90021-5

Dickson AG, Sabine CL and Christian JR (2007). Guide to best practices for ocean CO2 measurements. North Pacific Marine Science Organization

Martz TR, Connery JG and Johnson KS (2010) Testing the Honeywell Durafet® for seawater pH applications. Limnol. Oceanogr. Methods 8:172-184

Mehrbach C, Culberson CH, Hawley JE and Pytkowicx RM (1973) Measurement of the apparent dissociation constants of carbonic acid in seawater at atmospheric pressure. Limnol. Oceanogr. 18:897-907

SUPPLEMENTARY RESULTS: FIGURES AND TABLES

Table S1. Species composition and abundance of invertebrate grazers across boulders on three survey dates. Surveys were performed immediately after pulling the caging experiment on that date, and all herbivorous and omnivorous grazers (>1 cm) within a 50 cm radius of all cage anchors were counted.

Species	Date	Boulder 1	Boulder 2	Boulder 3	Boulder 4	Total
T. brunnea	July 11	1	0	2	0	3
	August 30	0	0	0	1	1
	October 18	0	1	0	0	1
C. ligatum	July 11	3	1	16	10	30
	August 30	15	11	25	15	66
	October 18	38	17	49	25	129
S. purpuratus	July 11	0	7	8	13	28
	August 30	4	6	4	25	39
	October 18	1	4	4	31	40
M. franciscanus	July 11	0	0	0	0	0
	August 30	0	0	0	2	2
	October 18	0	0	0	0	0
P. hemphilli	July 11	1	0	0	0	1
	August 30	1	0	0	0	1
	October 18	0	0	1	1	2

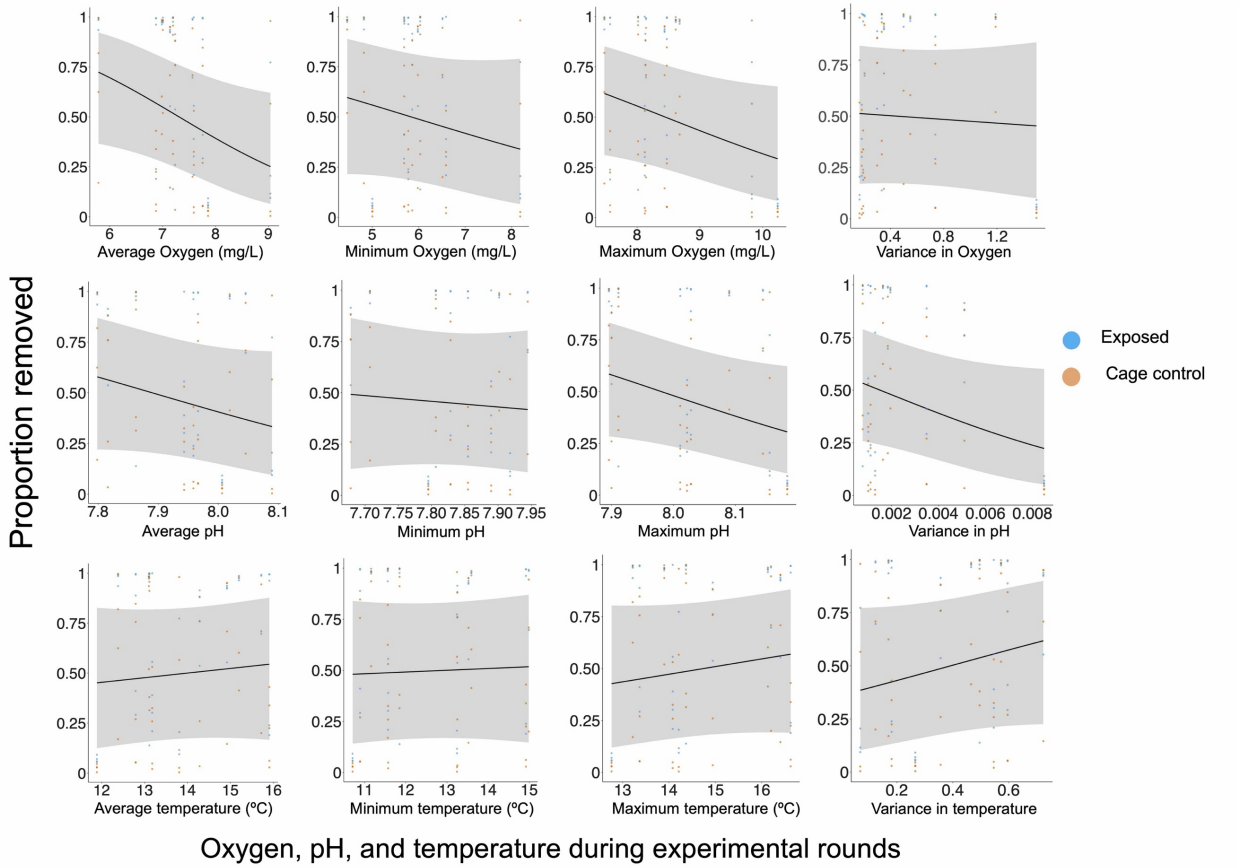

Figure S2. Beta regression models (mean ± 95% confidence intervals) showing proportion of juvenile kelp (1–2 mm) removed in exposed and cage control treatments correlated with average, minimum, maximum, and variance in dissolved oxygen, pH, and temperature during experiments. Because sensors were deployed for 12 of the 13 experiments, data are shown for Experiment #2–#13 (May 1–October 18). Since pH readings from the SeaFET were unstable August 23–October 4, data from Experiments #10 (August 29) and #11 (September 19) were excluded in the pH analyses and are not included in the pH panels. None of the models showed a significant difference in proportion of kelp removed depending on oxygen, pH, or temperature (critical $p < 0.004$).

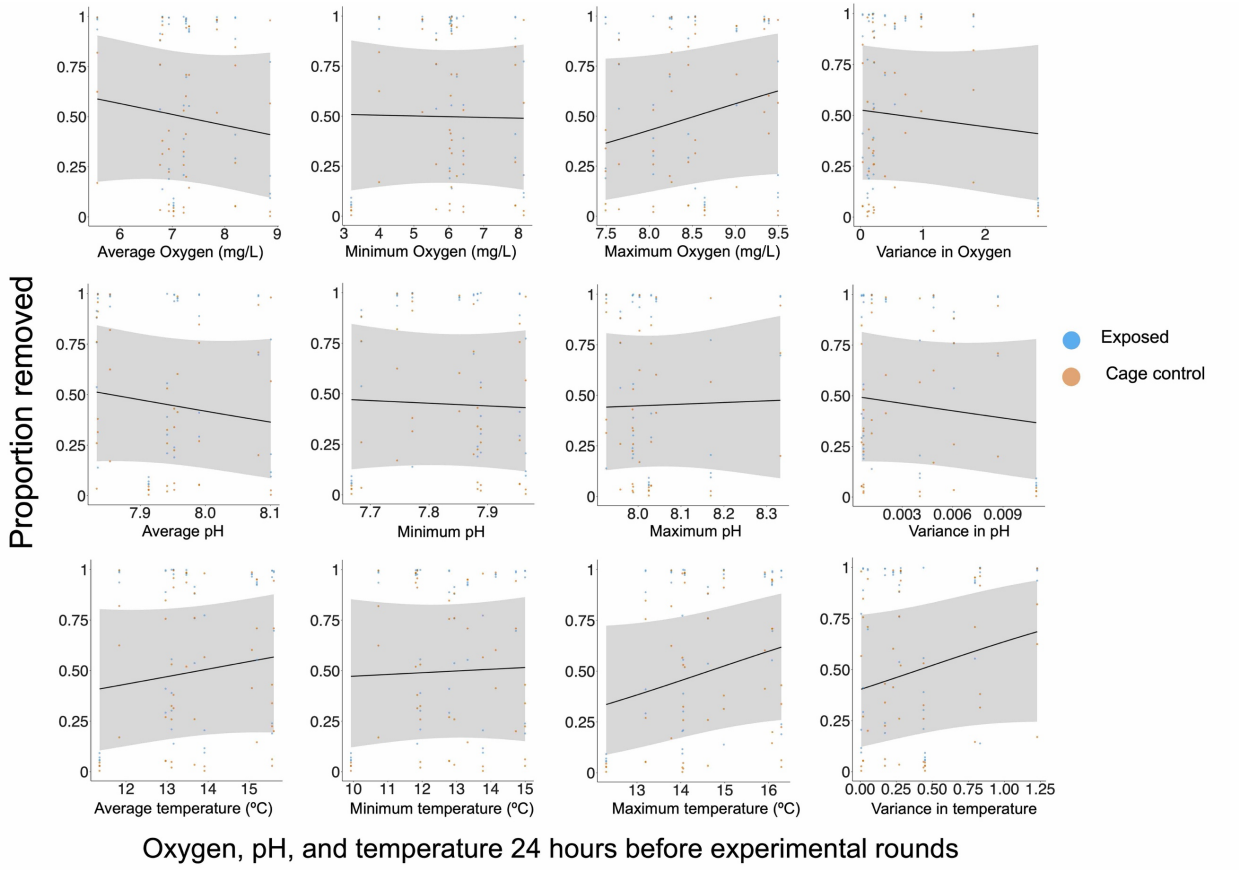

Figure S3. Beta regression models (mean ± 95% confidence intervals) showing proportion of juvenile kelp (1–2 mm) removed in exposed and cage control treatments correlated with average, minimum, maximum, and variance in dissolved oxygen, pH, and temperature 24 hours before experiments. Because sensors were deployed for 12 of the 13 experiments, data are shown for Experiment #2–#13 (May 1–October 18). Since pH readings from the SeaFET were unstable August 23–October 4, data from Experiments #10 (August 29) and #11 (September 19) were excluded in the pH analyses and are not included in the pH panels. None of the models showed a significant difference in proportion of kelp removed depending on oxygen, pH, or temperature (critical $p < 0.004$).

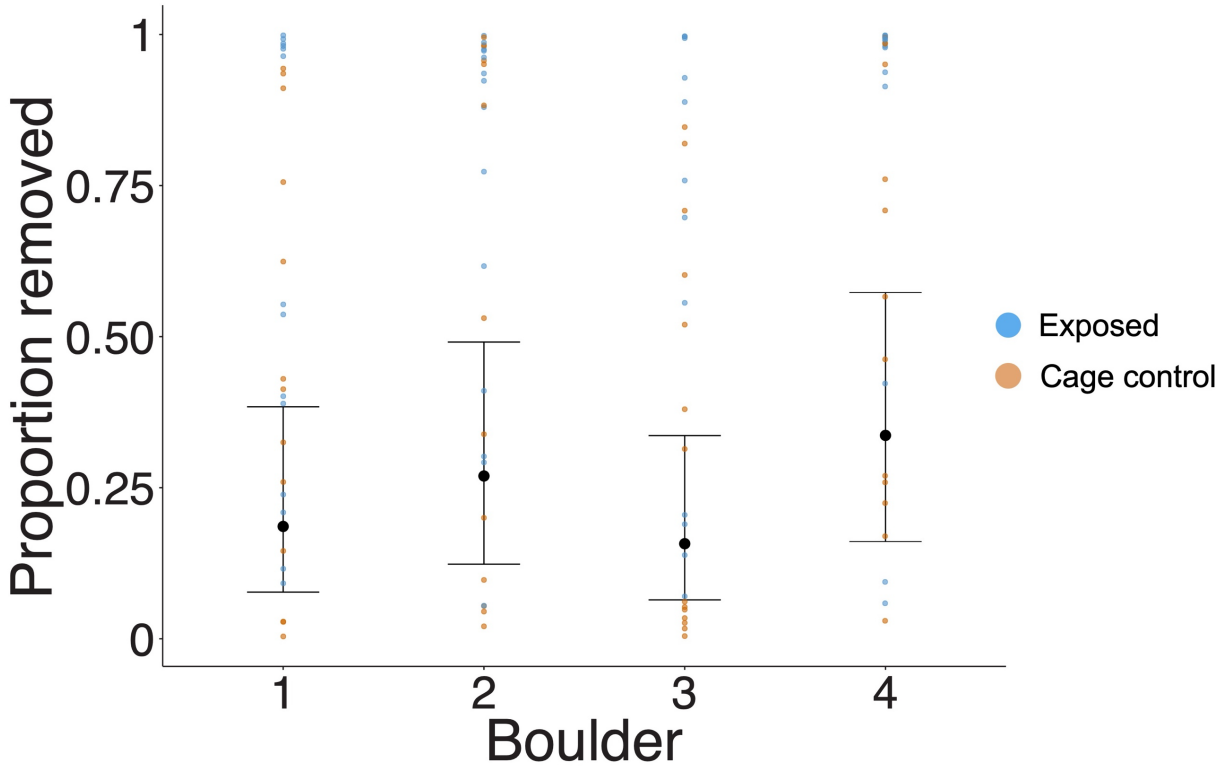

Figure S4. Beta regression model (mean ± 95% confidence intervals) showing proportion of juvenile kelp (1–2 mm) removed across the four experiment boulders in exposed and cage control treatments. Thirteen 24-hour experiments were conducted from April 18–October 18, 2018. There was no significant difference in proportion of kelp removed across boulders.

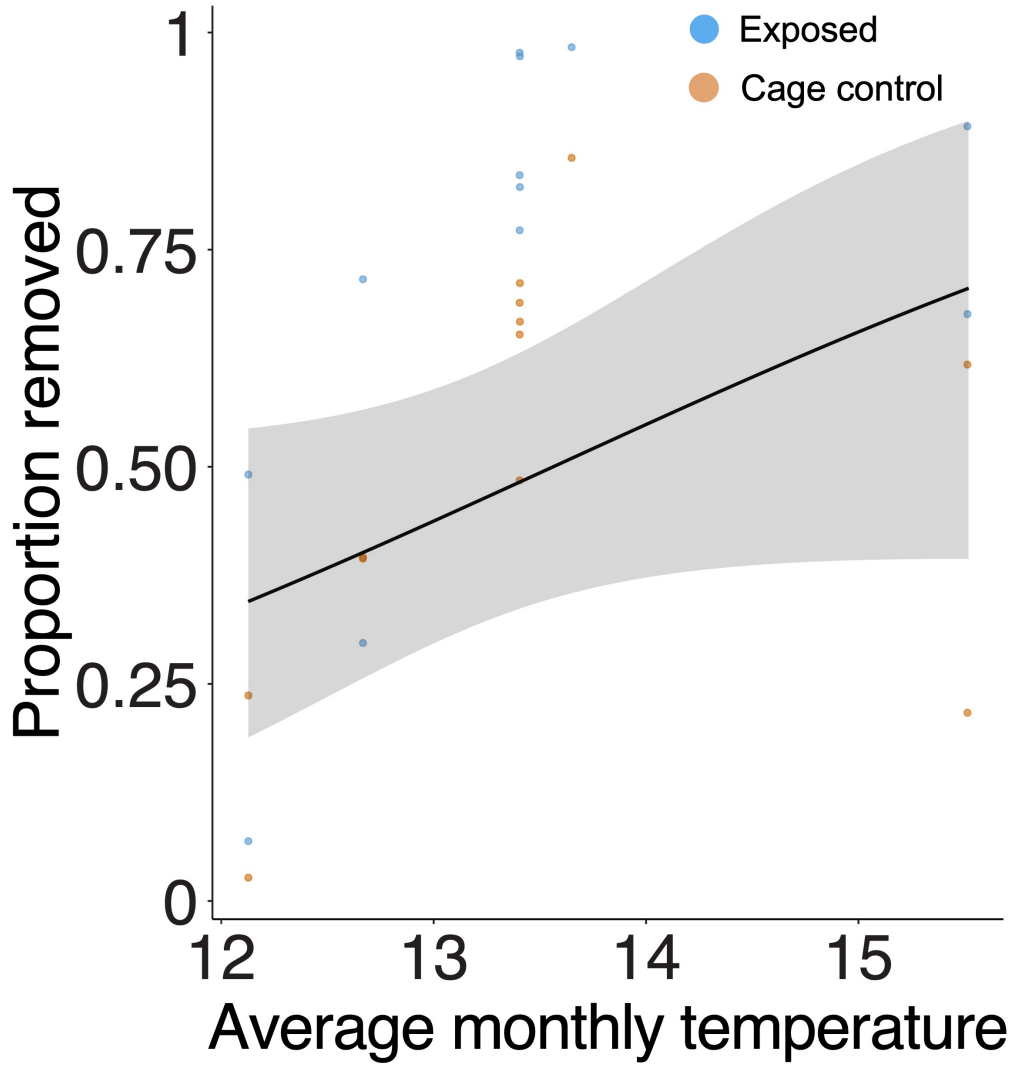

Figure S5. Beta regression model (mean ± 95% confidence intervals) showing average proportion of juvenile kelp (1–2 mm) removed on outplanted tiles in exposed and cage control treatments correlated with average monthly temperature. Data are average proportions removed in each experiment in each treatment plotted against the monthly average temperature from May 1 to October 18, 2018. There was no significant difference in proportion of kelp removed depending on temperature (critical $p < 0.017$).

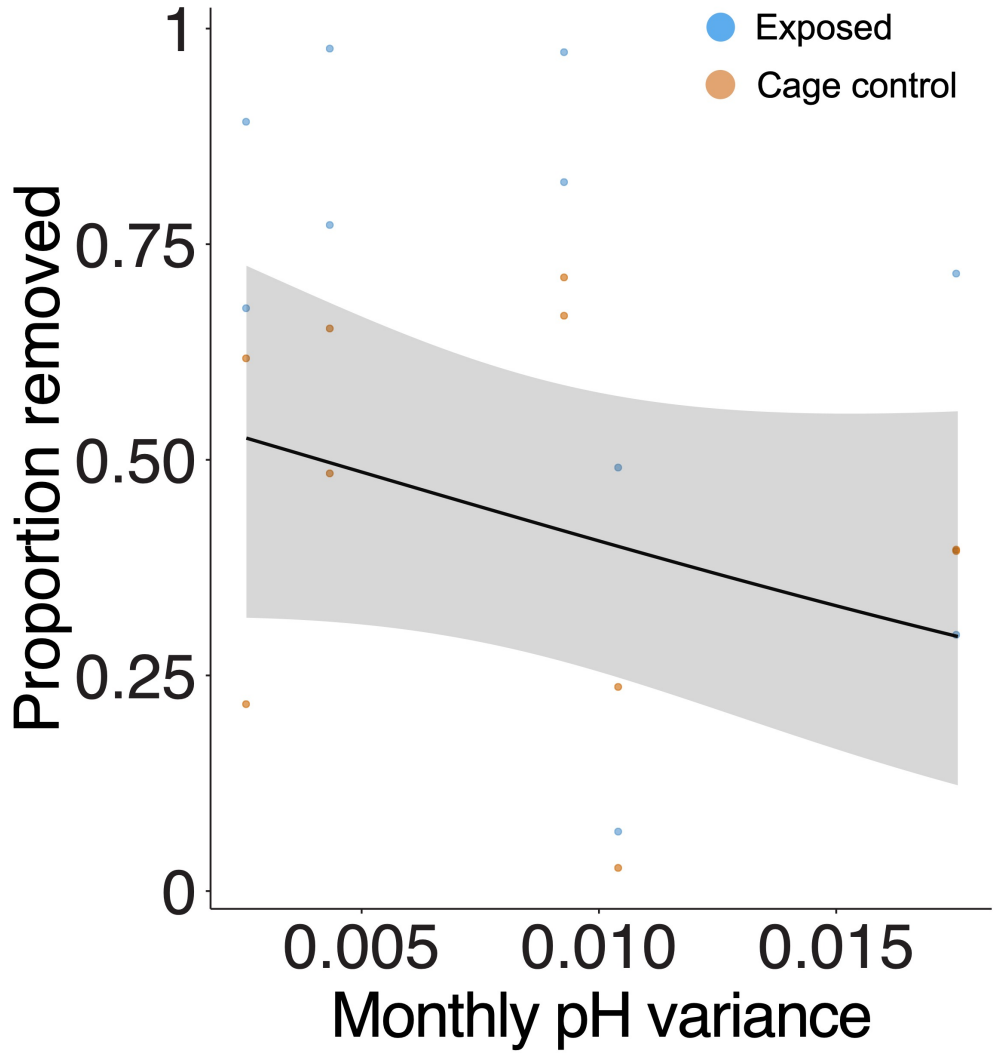

Figure S6. Beta regression model (mean ± 95% confidence intervals) showing average proportion of juvenile kelp (1–2 mm) removed on outplanted tiles in exposed and cage control treatments correlated with monthly pH variance. Data are average proportions removed in each experiment in each treatment plotted against the monthly pH variance from May 1 to October 18, 2018. There was no significant difference in proportion of kelp removed depending on pH variance (critical $p < 0.017$).