Received: 14 December 2020 | Accepted: 10 May 2021

DOI: 10.1111/2041-210X.13662

PRACTICAL TOOLS

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

Adapting a propane turkey fryer to manipulate temperature in aquatic environments

Cassandra A. Konecny[1] | Graham R. P. Brownlee[1] | Christopher D. G. Harley[1,2]

[1]Department of Zoology, University of British Columbia, Vancouver, BC, Canada

[2]Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada

Correspondence
Graham R. P. Brownlee
Email: brownlee@zoology.ubc.ca

Funding information
Natural Sciences and Engineering Research Council of Canada

Handling Editor: D.J. (Johan) Kotze

Abstract

1. There is a growing need to better understand the potential impacts of altered thermal regimes on biodiversity and ecosystem function as mean temperatures, and the likelihood of extreme temperatures, continue to increase.
2. One valuable approach to identify mechanisms and pathways of thermally driven change at the community level is through the manipulation of temperature in the field. However, where methods exist, they are often costly or unable to produce ecologically relevant changes in temperature.
3. Here, we present a low-cost, easily assembled and readily customizable thermal manipulation system for tide pools or other small bodies of water—the Seaside Array for Understanding Thermal Effects (SAUTE)—and demonstrate its ability to effectively alter the temperature in tide pools.
4. During our 3-hr heating manipulation, heated pools reached temperatures 4°C warmer than unmanipulated pools. During the cooling manipulation, cooled pools remained on average 1.8°C cooler than control pools.
5. The novel SAUTE system can be used to alter the temperature of tide pools in situ. Furthermore, it could be modified to heat other environments such as freshwater vernal pools and settlement tiles in a realistic and meaningful manner, serving as a useful tool to test questions surrounding the relationship between climate warming, thermal variability and ecological processes in natural aquatic communities.

KEYWORDS

aquatic environments, climate change, field manipulation, heat exchanger, temperature, tide pools, warming experiment

1 | INTRODUCTION

Currently, predicting ecological responses to warming and changes in thermal variation is challenging—particularly in marine systems—due to a paucity of data collected at appropriate scales of biological organization and with appropriate controls. While many studies have documented the impacts of gradual warming and extreme temperature events on species and ecosystems (e.g. Thomsen et al., 2019; Thomson et al., 2015; Wernberg et al., 2013), few have conducted in-situ temperature manipulations to understand the mechanisms behind these changes (but see Gedan & Bertness, 2010; Gehman & Harley, 2019; Kordas et al., 2015; Smale et al., 2011; Sorte & Bracken, 2015).

Although rarely undertaken due to logistical challenges, field-based warming experiments have distinct advantages in incorporating indirect ecological interactions that often dictate community- and ecosystem-level responses to environmental change, and are more controlled than natural experiments (e.g. El Niño events or stochastic

Cassandra A. Konecny and Graham R. P. Brownlee contributed equally to this work.

heatwaves) which are difficult to replicate and may be accompanied by confounding factors. Here, we present a thermal manipulation system that can be configured to heat a variety of aquatic habitats (e.g. tide pools, vernal pools, plots within mudflats, settlement plates, etc.). This improves on a prior method used to heat intertidal pools during low tide via rechargeable hand warmers, which raised tide pool temperatures under certain conditions by <0.5°C (Sorte & Bracken, 2015). We tested our method by manipulating tide pools on rocky intertidal shores at low tide. Tide pools can host complex food webs (Metaxas & Scheibling, 1996), serving as microcosms to understand the impacts of climate change in marine ecosystems. Furthermore, due to their isolated nature during low tide, it is easy to maintain treatment and control pools on the same shoreline. Our goals were to develop a method of thermal manipulation that would (a) allow for active manipulation of temperatures in the field with the option to create multiple temperature treatments (warmer or cooler than unmanipulated controls), (b) allow for deployment in a variety of configurations and settings and (c) provide an inexpensive option for field manipulations of temperature. We developed a low-cost, customizable and effective recirculating heat exchanger for in-situ manipulation of temperature in a variety of settings.

2 | METHODS AND MATERIALS

2.1 | System assembly

The SAUTE (Seaside Array for Understanding Thermal Effects) is a thermal manipulation system designed to actively alter the temperature of tide pools and other habitats in-situ (Figure 1). The heating source is a propane-powered turkey fryer with a 35-L pot (Master Chef Aluminum Turkey Fryer, Canadian Tire) of water (Figure 2). Vinyl irrigation tubing (¼″ ID) is run from the pot of water to coils made to fit individual tide pools. Coils are made from the same vinyl tubing—copper was considered due to its thermal properties but was rejected due to its toxic effects—and secured with cable ties. The coils are connected to irrigation lines on both ends using clear vinyl tubing (⅜″ OD, ¼″ ID) secured with cable ties. The downstream pieces of irrigation line are connected to a manifold, which is constructed from a piece of PVC pipe (12″ L × 1″ OD) with nylon hose barbed fittings (¼″) installed along one side of the pipe, with a PVC cap (1″) closing off one end and a reducer glued onto the other. Each irrigation line is connected to a barbed fitting at the manifold. Vinyl tubing is used to connect the reducer on the manifold to the inflow (⅝″ OD, ½″ ID) on the submersible pump (Aquarium Systems Maxi-Jet 900 Pro 3-in-1 Powerhead; 230/1000 GPH, Marineland) and outflow (½″ OD, ⅜″ ID vinyl tubing) back to the pot of hot water. Vinyl tubing is secured to the manifold and pump using hose clamps (½–1¼″, Waterline). The pump is placed in a container of water to ensure no air is pumped in and is powered by a portable power bank (Moto Master Eliminator PowerBox 600, Canadian Tire). The 35-L pot can be filled with seawater or any other convenient source of water (since the water is recirculating). The vinyl lines can then be primed by siphoning the system downstream of the manifold. Once water is flowing, the manifold can be connected back to the submersible pump and the pump can be turned on. Finally, the propane can be turned on, the turkey fryer lit and gas flow adjusted on the fryer base to manipulate heating intensity. Once materials were sourced for the SAUTE, it took 10 person-hours to assemble and test the system.

In addition to the heating system, we created a cooling variant of our SAUTE design by replacing the fryer with a cooler filled with blocks of ice and water to create a cold-water bath. The ice can be replenished as needed throughout the period of manipulation (low

FIGURE 1 The SAUTE system setup in the intertidal on Quadra Island, BC. Heated water flows from the propane turkey fryer pot (upper right), through the black irrigation lining to the heat-exchanging coils (bottom right tide pool), to the manifold, the portable battery pack (middle left) powered submersible pump (placed in a white tub of water, middle left) and back to the pot of heated water. Inset image shows a heating coil close-up during thermal manipulation

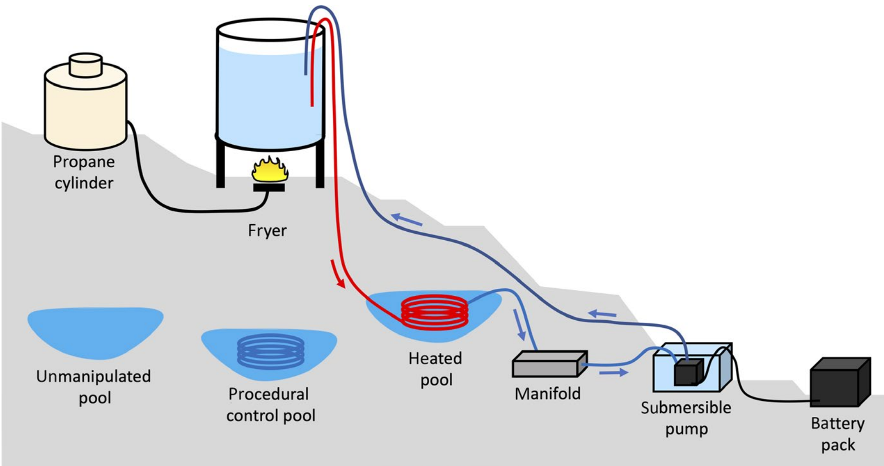
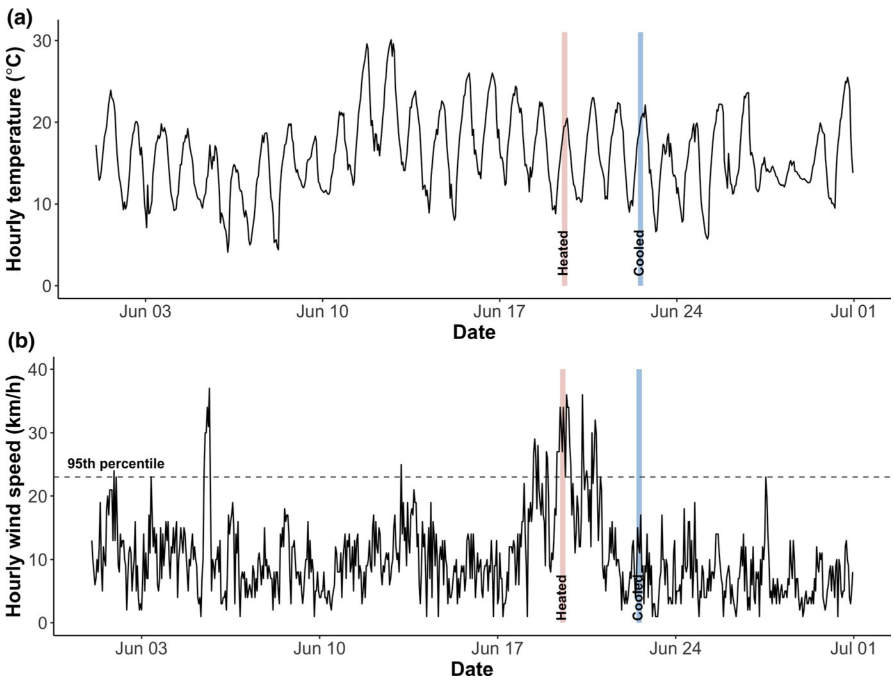


FIGURE 2 A Diagram of the SAUTE system showing the arrangement of the components: a propane powered turkey fryer (or, for cooling, a cooler filled with ice and water); heating coils and procedural control coils; vinyl tubing for connecting the elements of the closed-loop system; a manifold for lines exiting tide pools; a submersible pump for driving water back to the heater and a portable power bank for the pump. Arrows indicate direction of flow for hot (red) and cool (blue) water. Only one heated pool is shown for simplicity, but many can be heated simultaneously with multiple water lines connecting at the manifold

FIGURE 3 Mean hourly air temperature (a) and wind speed (b) for the month of June 2019 in Campbell River, BC. Days of heating (June 19) and cooling (June 22) are highlighted in each panel, and the 95th percentile of June wind speeds is shown with a dashed line in panel b



tide, in our case). This method is preferable to dumping ice directly into pools as it avoids introducing fresh water (via melt) or shading and allows for easier control from a single cooling source.

2.2 | Field testing

Natural tide pools were heated 19 June 2019 at April Point (50.064067°, −125.236816°, tidal range ≈ 4.5 m) on Quadra Island, BC. Tide pools ranged in elevation on the shore from approximately 2.0–3.5 m above Canadian Chart Datum and were spread over ~10 m of shoreline. Pools were divided into three size classes (small, $n = 6$; medium, $n = 6$; large, $n = 3$) and randomly assigned to treatments (unmanipulated, procedural control, heated; $n = 5$) within each size class. Tide pools ranged in surface area from 0.026 to 0.164 m^2, 0.119–1.26 m^2, 0.742–0.910 m^2 and in volume from 0.2 to 1.2 L, 1.4 to 5.2 L and 11.0 to 20.0 L, by small, medium and large size classes, respectively, and the diameter of the heating coils scaled with size class. Plumbed coils were placed in heated pools and coils (disconnected from the system) were placed in pools as a procedural control. Our field trial required approximately four person-hours of set up (select tide pools and cut and plumb irrigation lining). Temperature was measured with a handheld meter (Pro 30, Professional Series, YSI) just prior to the initiation of the thermal manipulation and every

30 min thereafter over the course of the 3-hr experiment. Salinity, pH and dissolved oxygen were also monitored (Figure S1).

A reduced design was used to assess experimental cooling at the same site on 22 June 2019. Pools were divided into relative size classes (small, $n = 4$; medium, $n = 2$; large, $n = 2$) and pools were randomly assigned to two treatment conditions (procedural control, cooled; $n = 4$) within each size class. Temperature data were collected as described above; salinity was also monitored during this experiment (Figure S2) but pH and DO were not. For testing of maximum heating rates conducted with higher-resolution temperature monitoring (30 s sampling interval) in ~17 L pools of different shapes and in a larger (~100 L) pool, see 'additional testing' in Supporting Information.

To provide additional environmental context for our thermal manipulations, air temperature and windspeed data from the Campbell River Airport weather station (Environment & Climate Change Canada, 2019), approximately 13 km south of April Point, are provided. Graphics were made using ggplot2 (v.3.3.2; Wickham, 2016), ANOVAs with car (v.3.0.9; Fox & Weisberg, 2019) and post-hoc tests with emmeans (v.1.5.0; Lenth, 2016) using R statistical software v3.6.1 (R Core Team, 2019).

3 | ASSESSMENT

The average air temperature on the day of the heating manipulation (19 June 2019) was 14.6°C and reached temperatures as high as 20.5°C, which is representative for this site in the month of June (Figure 3a). There were, however, stronger than average winds during the manipulation with a maximum speed of 34 km/hr (Figure 3b). Prior to heating, there were no differences between tide pool temperatures across treatments. During the manipulation, there was a significant effect of time on tide pool temperature, as tide pools warmed through the afternoon, and a significant interaction between time and temperature treatment, as treatments diverged through time (Figure 4a; Table 1A). There was also a significant main effect of temperature treatment, with significantly higher temperatures in heated tide pools (mean ± *SE*; 28.36 ± 0.60°C) than in procedural control (23.58 ± 0.44°C) and unmanipulated pools (24.07 ± 0.35°C; Table S2). There were no significant differences between procedural control and unmanipulated pools over the course

TABLE 1 ANOVA summary statistics on linear mixed-effect models exploring the effects of temperature treatment and sampling point (time) on abiotic parameters during warming (A) and cooling (B) manipulations with significant differences ($p < 0.05$) in bold

Source	Num *df*	Den *df*	*F*	*p*-value
(A) Linear mixed-effect model: Experimental warming				
Thermal treatment	2	12	7.04	**0.0095**
Time	6	72	43.33	**<0.001**
Treatment × Time	12	72	4.08	**<0.001**
(B) Linear mixed-effect model: Experimental cooling				
Thermal treatment	1	6	3.18	0.1248
Time	7	42	48.20	**<0.001**
Treatment × Time	7	42	3.49	**0.0049**

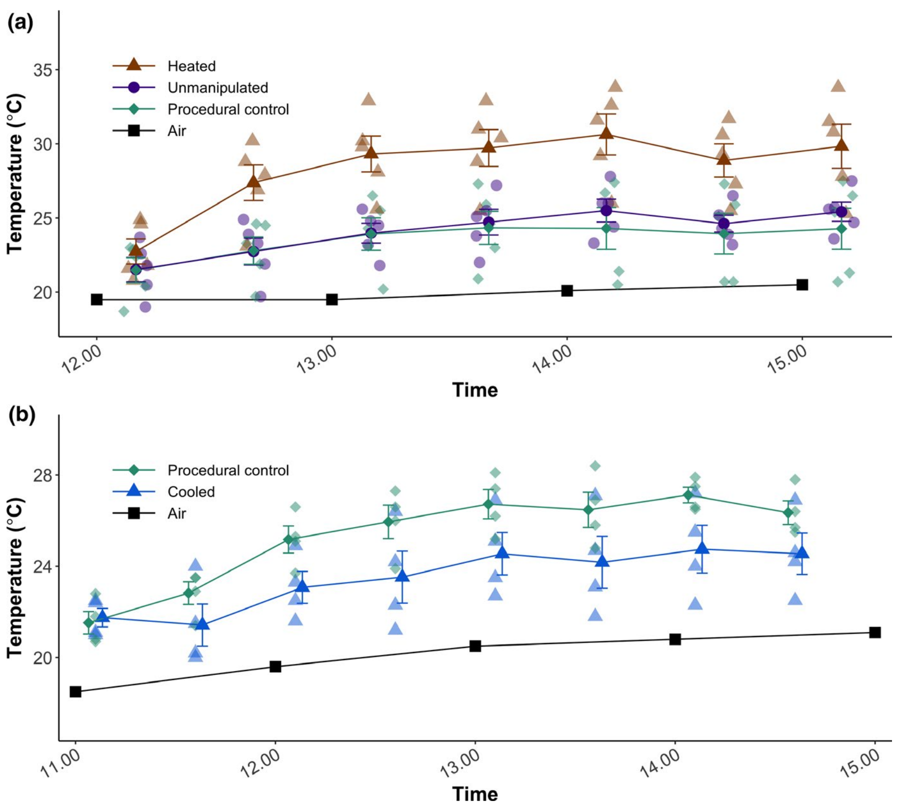


FIGURE 4 Change in tide pool and air temperatures during warming experiment (a) and cooling experiment (b). Faded points show individual observations, darkened points and error bars represent the mean ± *SE* for each treatment

of the manipulation. Salinity increased more rapidly in the experimentally warmed pools as would be expected due to increased evaporation, and there were no treatment-related differences in dissolved oxygen or pH (Table S1).

The average air temperature on the day of the cooling manipulation (22 June 2019) was 17.0°C and the maximum was 22.4°C (Figure 3a). The maximum wind speed was 15 km/hr (Figure 3b). Throughout the manipulation, average temperatures were lower in cooled tide pools (mean ± *SE*; 23.48 ± 0.36°C) compared to the control pools (25.27 ± 0.39°C). Although the main effect of treatment was not significant, the treatment × time interaction indicates the two treatments diverged through time (Figure 4b; Table 1B). The main effect of time was also significant, with temperatures increasing in both treatments throughout the afternoon. Like temperature, salinity increased more slowly in the experimentally cooled pools (Table S3).

4 | COMMENTS AND RECOMMENDATIONS

Our method effectively manipulated tide pool temperatures to achieve thermal differences that simulate anthropogenic warming scenarios or cooler pre-industrial conditions. For additional testing and recommendations for fine-tuning the SAUTE to meet researcher needs, see Supporting Information. For examples of the SAUTE being used for biological experiments, as well as fine-tuned control of multiple warming treatments, see Konecny (2020).

The SAUTE could be modified for a range of habitats and to simulate a range of thermal regimes. In addition to tide pools, SAUTE could be deployed in other habitats such as ponds, vernal pools, soft-sediment habitats (e.g. mudflats) or terrestrial soils. The system could also be used to alter the temperature of settlement plates in aquatic systems by plumbing settlement plates with heat-exchange coils and to create an in situ thermal gradient by setting up a linear counter-current heat exchanger (hot water line with water flowing in one direction, cold-water line with water flowing in the other). For longer-term, low-maintenance intertidal deployments, the system could be altered by substituting the propane heat source for an electric water heater and incorporating a float switch to power the system on and off as the tide falls and rises.

In summary, we have created a low-cost and effective method for manipulating thermal regimes of tide pools and other habitats in the field. By providing a novel method for in situ manipulation of intertidal habitat temperatures, we hope that more ecologically realistic experiments will be conducted in the field to better understand the implications of future warming and heatwaves.

ACKNOWLEDGEMENTS

We gratefully acknowledge that this study was conducted on the traditional territory of the Wei Wai Kai First Nation. Local site access was provided courtesy of the April Point Resort and Spa. Logistical support was generously provided by the Tula Foundation through the Hakai Quadra Island Research Station. We would also like to thank Rob Brownlee for help designing, building and testing our original SAUTE system. This work was supported by a Natural Sciences and Engineering Research Council (NSERC) Canada Graduate Scholarships—Master's to C.A.K., an NSERC Canada Undergraduate Student Research Award to G.R.P.B. and an NSERC Discovery Grant to C.D.G.H.

AUTHORS' CONTRIBUTIONS

G.R.P.B. and C.D.G.H. conceived of the original idea; all authors contributed to the final design; G.R.P.B., C.A.K. and C.D.G.H. collected the data; C.A.K. analysed the data. G.R.P.B. and C.A.K. led the writing of the manuscript. All authors contributed critically to the writing and gave final approval for publication.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/2041-210X.13662.

DATA AVAILABILITY STATEMENT

Abiotic data from thermal manipulations are available on Dryad Digital Repository https://doi.org/10.5061/dryad.ns1rn8pst (Konecny et al., 2021).

ORCID

Cassandra A. Konecny https://orcid.org/0000-0001-7838-0080
Graham R. P. Brownlee https://orcid.org/0000-0002-2670-0406

REFERENCES

Environment and Climate Change Canada. (2019). *Campbell River*. Environment and Climate Change Canada.

Fox, J., & Weisberg, S. (2019). *An R companion to applied regression* (3rd ed.). Sage.

Gedan, K. B., & Bertness, M. D. (2010). How will warming affect the salt marsh foundation species Spartina patens and its ecological role? *Oecologia*, *164*(2), 479–487. https://doi.org/10.1007/s00442-010-1661-x

Gehman, A.-L.-M., & Harley, C. D. G. (2019). Symbiotic endolithic microbes alter host morphology and reduce host vulnerability to high environmental temperatures. *Ecosphere*, https://doi.org/10.1002/ecs2.2683

Konecny, C. A. (2020). *Effects of heatwaves on key ecological processes structuring early successional tidepool communities* (Master's thesis). The University of British Columbia.

Konecny, C. A., Brownlee, G. R. P., & Harley, C. D. G. (2021). Data from: Adapting a propane turkey fryer to manipulate temperature in aquatic environments. *Dryad Digital Repository*, https://doi.org/10.5061/dryad.ns1rn8pst

Kordas, R. L., Dudgeon, S., Storey, S., & Harley, C. D. G. (2015). Intertidal community responses to field-based experimental warming. *Oikos*, *124*(7), 888–898. https://doi.org/10.1111/oik.00806

Lenth, R. V. (2016). Least-squares means: The R package lsmeans. *Journal of Statistical Software*. https://doi.org/10.18637/jss.v069.i01

Metaxas, A., & Scheibling, R. E. (1996). Top-down and bottom-up regulation of phytoplankton assemblages in tide pools. *Marine Ecology Progress Series*, *145*, 161–177. https://doi.org/10.3354/meps145161

R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Smale, D. A., Wernberg, T., Peck, L. S., & Barnes, D. K. A. (2011). Turning on the heat: Ecological response to simulated warming in the sea. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0016050

Sorte, C. J. B., & Bracken, M. E. S. (2015). Warming and elevated CO_2 interact to drive rapid shifts in marine community production. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0145191

Thomsen, M. S., Mondardini, L., Alestra, T., Gerrity, S., Tait, L., South, P. M., Lilley, S. A., & Schiel, D. R. (2019). Local extinction of bull kelp (*Durvillaea* spp.) due to a marine heatwave. *Frontiers in Marine Science*, *6*. https://doi.org/10.3389/fmars.2019.00084

Thomson, J. A., Burkholder, D. A., Heithaus, M. R., Fourqurean, J. W., Fraser, M. W., Statton, J., & Kendrick, G. A. (2015). Extreme temperatures, foundation species, and abrupt ecosystem change: An example from an iconic seagrass ecosystem. *Global Change Biology*, *21*(4), 1463–1474. https://doi.org/10.1111/gcb.12694

Wernberg, T., Smale, D. A., Tuya, F., Thomsen, M. S., Langlois, T. J., De Bettignies, T., Bennett, S., & Rousseaux, C. S. (2013). An extreme climatic event alters marine ecosystem structure in a global biodiversity hotspot. *Nature Climate Change*, *3*(1), 78–82. https://doi.org/10.1038/nclimate1627

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Konecny, C. A., Brownlee, G. R. P., & Harley, C. D. G. (2021). Adapting a propane turkey fryer to manipulate temperature in aquatic environments. *Methods in Ecology and Evolution*, 12, 1835–1840. https://doi.org/10.1111/2041-210X.13662