The future of a vulnerable fishery: Can red urchins adapt to marine heatwaves?

Statement of Improvements in the Full Proposal:

Comments from reviewers noted areas of improvement in the preliminary proposal, and aspects of the study that could be further clarified. In the full proposal, I have attempted to respond to and address all the reviewers' suggestions as follows for each objective:

<u>Objective 1:</u>

- Suggestions were made to specify which lipid metrics would be measured and how the proposed lipid biochemistry is relevant to answering my research questions. Here, I specify that three specific aspects of lipid biochemistry will be measured and calculated for eggs: total lipid content, lipid density (ng/nL), and energy content of lipids (mJ). These metrics are important because differences in maternal provisioning of lipids to eggs can impact performance, growth, and cellular morphology during embryonic and larval development. I will measure these metrics to determine if there is an effect of marine heatwave (MHW) conditions on maternal provisioning of lipids.
- I have clarified the experimental design to reflect that the control for this experiment will be urchins held in flow-through tanks with filtered seawater (FSW) at ambient temperature. This experiment will be replicated twice, once in Year 1 and once in Year 2 (see Table 1).
- Reviewers suggested conducting the experiment with variable elevated temperatures to mirror the actual conditions of a three-month MHW. To conduct the experiment with a variable elevated temperature to mirror in-situ conditions, I have designed, created, and tested a marine heatwave simulator (see Preliminary data in support of the project).
- To address whether we have the equipment and facility to conduct this project, I am confirming that the equipment and experimental facility for conducting the laboratory exposures and physiological analyses already exists in the Hofmann Lab in the Marine Science Institute at UC Santa Barbara (UCSB).

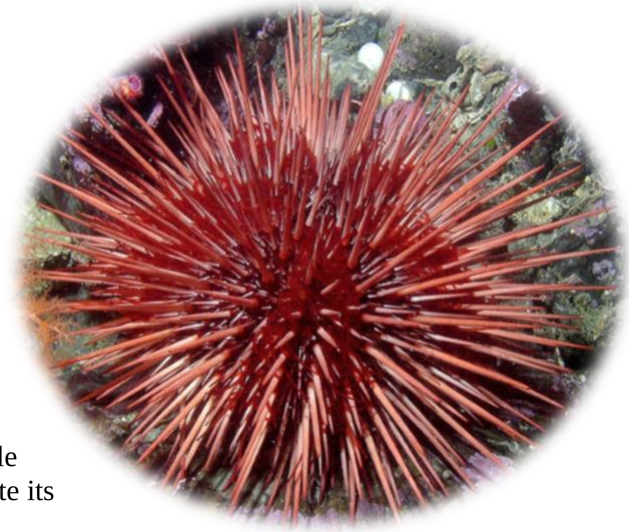
<u>Objective 2:</u>

- Suggestions were made to clarify the goals of the feeding trials, and to describe the approach in more detail. This has been done, and briefly, I plan for 6 urchins being fed a pre-weighed amount of ~40g of *Sargassum horneri* or *Macrocystis pyrifera* once a week for four weeks during the period of gametogenesis.
- Reviewers asked if the data to address Objective 1 could be derived from one of the parental feeding treatments. Briefly, this is not possible because the feeding treatments are terminal for the adults. Additionally, gonads cannot be assessed for quality after spawning is induced.

<u>Objective 3:</u>

- Reviewers commented that Objective 3 seems less connected than the first two objectives, but the project team feels that it plays an important role in the broader goals of the proposed project. Specifically, objective 3 is included to meet a priority management need explicitly described by the California Department of Fish and Wildlife (CDFW) in the Red Sea Urchin Enhanced Status Report.[4] Overall, because my lab has ready access to long-term data, I would like to add this analysis effort to the project in order to support the management goals set forth by CDFW.
- Reviewers asked what type of analysis will be used for objective 3. I propose to use a linear mixed effects model. I will also be taking Statistics & Data Analysis for Environmental Science & Management in the Fall of 2021 to prepare for the data analysis component of my project.

Introduction and Background



The study organism:

Distributed from Baja California to Alaska[6] (shown at right), *Mesocentrotus franciscanus* is both ecologically and commercially important. As ecosystem engineers, red urchins control algal abundances in kelp forest ecosystems. They are also the primary urchin species harvested for gonads or "uni" in California[22]. Recently, *M. franciscanus* abundance has declined dramatically due to overfishing in the last few decades; in addition, warmer water temperatures are thought to have increased disease and mass mortalities events[7]. Additionally, *M. franciscanus* competes with the purple urchin, *Stronglyocentrotus purpuratus* for food. Despite its importance and vulnerability, little is known about *M. franciscanus*' ability to respond to prolonged temperature stress.

Marine heatwaves & red urchins:

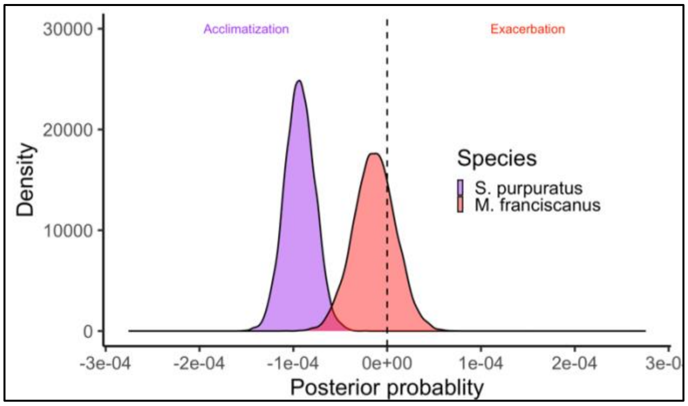


Fig. 1. *S. purpuratus* and *M. franciscanus* recruitment at high sea surface temperature over time. Data were collected from 2004 to 2016 at Arroyo Quemado, an SBC LTER site. *Figure courtesy of Sam Bogan, a UCSB Graduate student.*

MHWs are predicted to increase drastically in frequency, duration, range, and intensity due to anthropogenic climate change[12]. Studies have shown that the biological consequences of MHWs include impacts on species abundances, biogeographic range shifts, physiology, and reducing fisheries landings[15,8,9]. Some species may fare better in MHW conditions than others. Recent data have demonstrated that *S. purpuratus* has a competitive advantage over *M. franciscanus* in recruitment at high sea surface temperatures (Fig. 1). With forecasted increases in MHWs and red urchin populations already on the decline, it is important to determine if future generations of red urchins can rapidly adjust their phenotypes for survival in future MHWs on the California coast.

The question then arises: what is the impact of future MHWs on red urchins, and further can they be resilient to future heat stress events? One mechanism to explore is the role of parental effects; here, how the experiences of the adults influence the quality and tolerances of their progeny. Within larval ecology of marine invertebrates, transgenerational plasticity (TGP) – a phenomenon in which parental environment alters offspring phenotype – is a potential way for organisms to rapidly cope with environmental changes on ecological timescales[5]. Here, parental history, for example the temperature at which adults perform gametogenesis, may change progeny phenotypes through non-genetic mechanisms, potentially resulting in increased resistance to environmental stressors such as high temperature. The over-arching goal of my project is to assess whether the thermal history of adult red urchins could alter the thermal tolerance of their progeny. Specifically, do adults that make their gametes under MHW conditions produce progeny that are more tolerant of heat stress as they develop in situ?

The red urchin fishery in California is currently experiencing its lowest landings in history. The "warm water Blob" in 2014, a strong El Niño event in 2015, disease, and a purple urchin population boom all contributed to the fishery's drastic decline[4]. In 2018, landings plummeted to only 3.1 million pounds, the lowest recorded in the history of the fishery[1]. Furthermore, fierce competition for food between red urchins and the overly abundant purple sea urchin has led to less marketable red sea urchins with poor gonad quality. The red urchin fishery is already vulnerable and is bound to suffer further in the future with forecasted increases in marine heatwaves. During spawning season in a MHW year, early development occurs at unusually high temperatures (Fig 2). Santa Barbara sea urchin populations spawn in December to March; and Santa Barbara Coastal Long Term Ecological Research (SBC LTER) data indicate that these early events may occur at temperatures as 3-4 °C above a non-MHW year average of 14 °C (Fig. 2). These early events include fertilization *in situ*, hatching of blastulae, and gastrulation. Two key takeaways from these data are (1) anomalously high temperatures can, and do, occur during significant windows in the life history *M. franciscanus*, and (2) significant losses of progeny will impact the future population of adults.

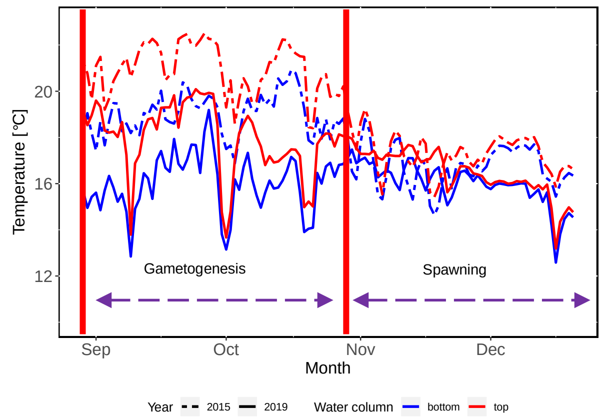


Fig. 2. Daily temperature at Arroyo Quemado study site for 2015 and 2019. Temperature from the surface and benthic location are shown for 2015, a MHW year), and for 2019, a cooler year. Data were collected using Onset Tidbits loggers deployed at the benthos and on SBC LTER moorings.

<u>*Preliminary data in support of the project*</u>:

To demonstrate how this process might operate, I conducted a pilot experiment on purple urchins. In this pilot experiment, *S. purpuratus* embryos hatched blastulae (HB) and late gastrulae (GS) were exposed to temperatures ranging from 15 to 32 °C (Fig. 3.). These data highlight that early-stage embryos are sensitive to MHW temperatures observed in the Santa Barbara Channel. In addition, other work on purple urchins shows that the thermal history of the parents, especially when they are performing gametogenesis, can affect the thermal tolerance of their progeny[23].

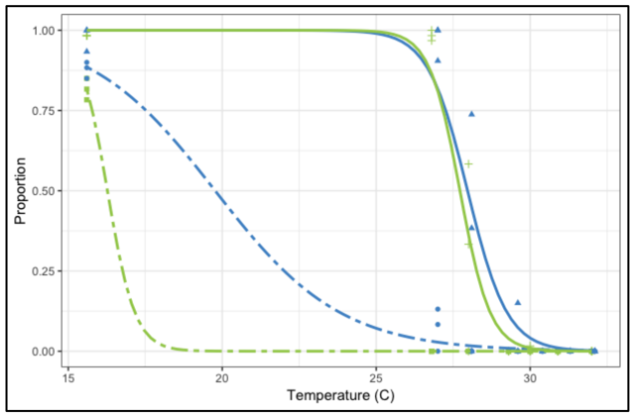
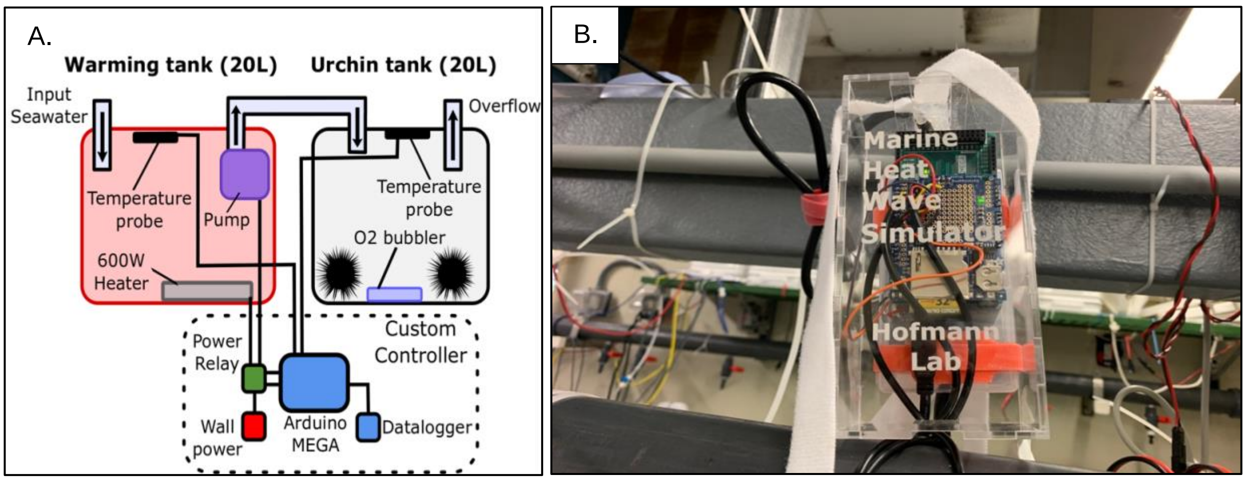


Fig. 3. Effect of temperature on survival and developmental progression in purple sea urchin embryos. Proportion of embryo *survival* and *developmental success* are shown for two stages: hatched blastulae (Green) and late gastrulae (Blue). Triplicate vials of embryos containing 100 embryos each were exposed for 1h, and 60 embryos per vial were scored. Survival (solid line) and progression to the next developmental stage (dashed line) were scored 19 h and 36 h after the thermal trial for hatched blastulae and gastrulae, respectively. Data courtesy of Jannine Chamorro & Adriane McDonald, UCSB Graduate students.

Furthermore, from a TGP perspective, gametogenesis in adult sea urchins occurs from August – December, a period when temperatures can reach 23°C in MHW years (Fig. 2). Teck et al. (2018) found that average gonadosomatic indexes of red urchins, harvested from the Channel Islands, increased dramatically from June to October, peaking in November and beginning to decrease in December (See Fig. 2 in Teck et al.).[22] During this period, sea urchin gonads grow and will only be marketable if they are developed and of good quality. Local urchin divers from the California Sea Urchin Commission (CSUC) noted that one of the greatest limiting factors of the fishery is the lack of kelp during warming events, which ultimately leads to starved urchins that are not marketable. Recent studies have also shown that the extreme temperatures experienced during MHWs can cause widespread mortality and deforestation of kelp forests.[18] With predicted increases in MHWs, we must also consider how both MHWs and food availability impact adult urchins and their gonadal quality.

In support of this project, I designed a MHW simulator (MHWSim) system. Instead of using traditional static temperature controllers, I replaced the controller with an Arduino Mega, an inexpensive and commercially available microcontroller board, to have programmable and dynamic control over the temperature of the tanks in the proposed MHW experiments (Fig. 4). The Arduino Mega microcontroller is connected to D218B20 temperature probes and a 600W titanium heater to have closed loop feedback control over any desired temperature. The system logs data onto an SD card, allowing me to view data on a laptop and optimize the programmed thermal profile. It is possible to input existing time series of previous marine heatwave events and directly replicate them using our simulator (Fig. 5). Unlike customized simulators from aquatic design and manufacturing companies, the MHWSim is strikingly affordable at just $1,700 for a full experimental system with six tanks (three warming tanks and three urchin acclimation tanks), creating a more equitable approach for MHW laboratory experiments.



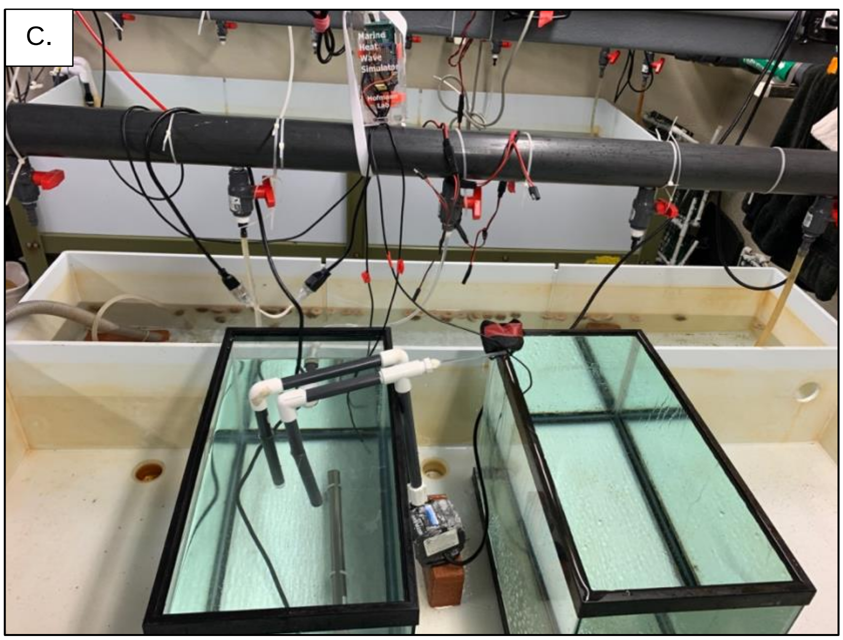


Fig. 4. Marine heatwave simulator schematic. A. Design of the MHWSim system: A continuous flow-through system where ambient water flows into the warming tank at a constant rate. The programmable Arduino MEGA system will heat the warming tank, which flows into the urchin acclimation tank, at a continuous ramp rate until the threshold temperature is reached. The threshold temperature will be held over a specific duration and then ramped down until ambient is reached in the acclimation tank. **B.** Programmable Arduino Mega computer encased in a watertight box. **C.** Preliminary MHWSim system. *Constructed in collaboration with Matthew Devlin, Hawkes Lab - UCSB Mechanical Engineering.*

Preliminary data from the MHWSim illustrates that I can design and control dynamic warming events to mimic the in-situ conditions that have been recorded by the SBC-LTER. In a test of the system, I was able to simulate a one-day extreme "heat spike" warming event, followed by a five-day extreme warming event, by definition, a MHW event (Fig. 5). I programmed the one-day MHW spike event with a ramp-up rate at the fastest rate possible to reach 22°C, followed by an 8 hour hold and ramp-down over 10 hours. The MHWSim then turned off and ambient water flowed through the system for 10 days. For the 5-day MHW, I reprogrammed the system to have a 15-minute sensing interval, which turned the heater on and off. For the real experiment, I will decrease this time step. These data show that I can measure temperature and change the heater status each minute or even several times per minute to better smooth out these data.

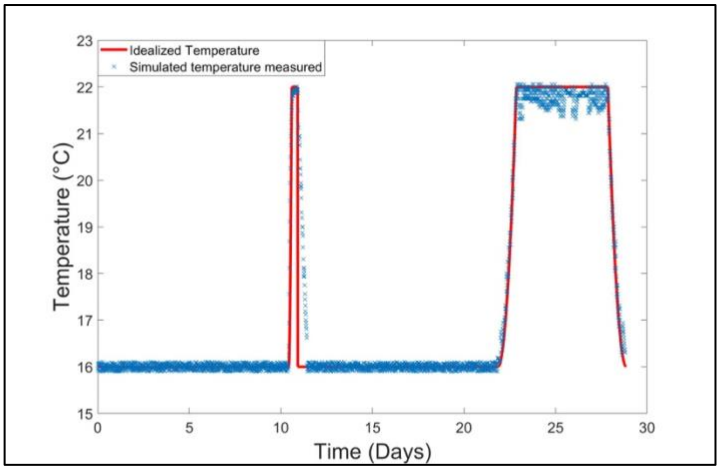


Fig. 5. Data from MHWSim pilot run. Here, I superimposed the measured MHWSim temperature data on top of what an ideal MHW thermal profile would look like.

Given the increasing vulnerability of *M. franciscanus* and the fishery, **it is critical to examine the impacts of anthropogenic and climate-related stressors on a key fishery species, *M. franciscanus* (SFA 2-1), and conduct research on *M. franciscanus*' adaptation to changing conditions (SFA 2-2).**

Relationship between the problem statement and the project objectives:

Throughout this fellowship, I will work with my community and research mentors to meet the management needs of stakeholders and determine the future of this vulnerable fishery. My study will establish foundational scientific knowledge that is required for adaptive management strategies and decision-making in future climatic conditions. My proposed work will provide CDFW and CSUC a greater understanding of the climate readiness of the fishery and insight on potential management strategies for augmenting the red urchin fishery while controlling invasive algae populations. With the data generated from my work, stakeholders and decision-makers can create and implement the policies that are necessary to ensure a sustainable red urchin fishery.

Objectives of the proposal - Specific objectives of the proposed project are as follows:

1. To determine if parental thermal history can buffer offspring from temperatures expected in future MHWs.
2. To assess how the interaction of MHWs and food availability impacts adult urchins.
3. Determine if yearly kelp canopy correlates to urchin biomass.

Approach – the text below describes the approach, design and methods used in the 3 objectives of the proposal.

Objective 1: To determine if parental thermal history can buffer offspring from temperatures expected in future MHWs.

I hypothesize that adults conditioned to MHW temperatures will produce more heat tolerant progeny. This objective addresses SFA Strategies 2-1 and 2-2.

Approach: I will hold adult urchins in a dynamic MHW simulator (MHWSim) for three months and then induce spawning. Physiological thermal performance, biochemical, and morphometric analyses will be conducted on the eggs. After fertilization, larvae will be reared in MHW conditions and analyses will be conducted at four different life stages: hatched blastula, gastrula, prism, and echinopluteus.

MHW acclimation:

With data from Arroyo Quemado, a Santa Barbara Coastal Long-Term Ecological Research (SBC-LTER) site, I will create a simulated MHW using temperature data from the 2015 MHWs, anomalous warming events linked with the "Blob"[5]. For the experiment, adult urchins will be collected at sites near Santa Barbara and transported to the Marine Science Institute at the University of California Santa Barbara (UCSB). Prior to spawning, parents will be held in the MHWSim for three months during the period of gametogenesis to determine if the thermal environment of parents influences offspring phenotype and performance. Controls will be held concurrently in tanks with ambient seawater. All urchins will be fed seven blades of *Macrocystis pyrifera* per week.

Collecting in-situ data:

To capture actual temperature conditions at important fishing sites, I will work with CDFW and CSUC to deploy ONSET HOBO TidbiT MX2203 temperature loggers via SCUBA at such sites. Exact locations with geographic coordinates will be identified by local urchin divers in Southern California. These regions will be targeted, as they have been identified by the CSUC: backside northern half of San Clemente Island, backside of Anacapa Island, Yellowbanks at Santa Cruz Island, East Point, Johnson's Lee, Bee Rock, Brockway, and Talcott Shoals at Santa Rosa Island, and Tyler Bight/Crook Point at San Miguel Island (pers. comm. Nathan Rosser, CSUC Board Member, Diver). Data will be collected monthly using the Latitude 7220 Rugged Extreme Tablet.

Spawning and egg assessment

Adults will be spawned via an intracoelomic injection of 0.53 M KCl (Strathmann 1987)[19]. Using methodology developed by my lab,[18] I will conduct protein, lipid, and morphometric analyses on unfertilized eggs using an Iatroscan and ImageJ, respectively, and measure the number of successfully fertilized eggs to evaluate the impact of increased temperatures on maternal provisioning and fertilization success.

Protein quantification

Briefly, protein extraction will follow methods from Byrne et al. (2008)[3] and Prowse et al. (2008)[14] using a homogenization buffer (20 mM Tris-HCl, 130 mM NaCl, 5 mM EDTA containing 1% Triton-X and 1% Protease Inhibitor Cocktail) and a sonic dismembrator. Total soluble protein (ng) will be quantified on a microplate reader using a BCA protein assay kit. Protein density (ng/nl) will be calculated using the average volume of the eggs produced by each adult female urchin. Equivalents of energy content (mJ) and density (mJ/nl) from protein will be estimated using the combustion enthalpy coefficient (24.0 kJ/g protein) from Gnaiger (1983).[7]

Lipid content

Differences in maternal provisioning of lipids to eggs can impact performance, growth, and cellular morphology during embryonic and larval development. To determine if there is an effect of MHW conditions on maternal provisioning of lipids, lipids will be extracted following the method from Sewell (2005)[17] with modifications developed by my research group. Briefly, lipids will be isolated using V-vials, methanol, chloroform, ketone internal standard and centrifugation. Total lipid content will be generated; lipid density (ng/nL) and energy content from lipids (mJ) will be estimated using the combustion enthalpy coefficient (39.5 kJ/g lipid) from Gnaiger (1983).[7]

Morphometric analysis

Eggs will be preserved by adding 4% formalin in 0.01 M phosphate buffered saline (PBS) in a 1:1 volume ratio of seawater with eggs. Eggs will be photographed in my laboratory on a compound microscope (Olympus BX50). Digital images will be calibrated using a stage micrometer for the 20x objective using ImageJ. All images will be analyzed via measurements performed in ImageJ (see Fig. 6).

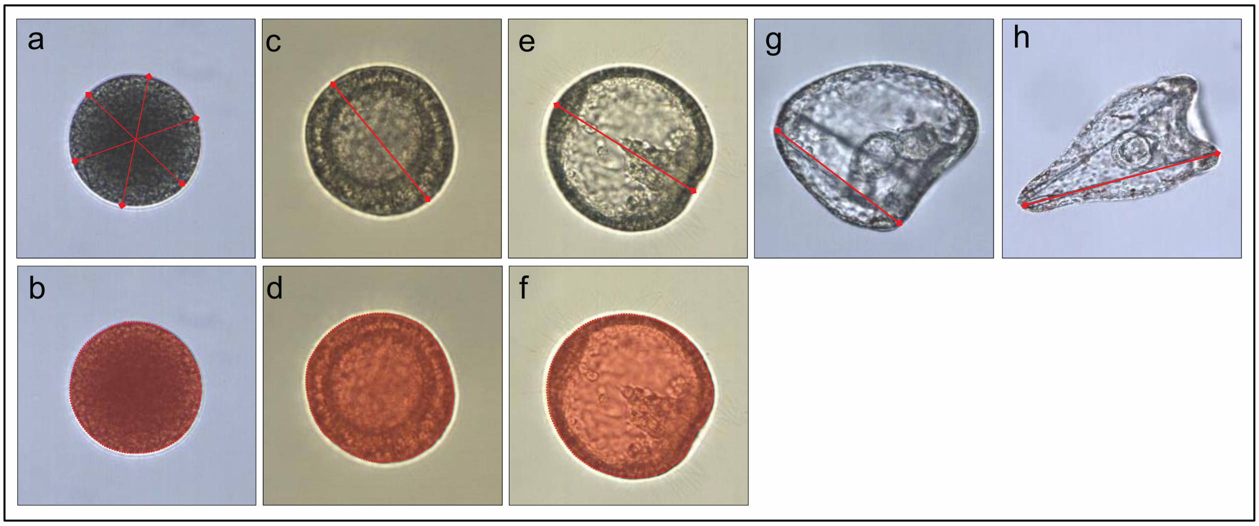


Fig. 6. Morphometric analysis of urchin eggs and embryos. Body size will be measured using ImageJ (National Institutes of Health, USA) following a procedure developed by the Hofmann Lab. Eggs size will be determined by **a.** taking the average of three diameter measurements, and **b.** measuring the 2D area. The average diameter will be used to calculate egg volume by assuming the eggs were spherical in shape. Body size of the hatched blastula stage will be determined by **c.** measuring the maximum length, from the animal to vegetal end, and **d.** measuring the 2D area. Body size of the gastrula stage will be determined by **e.** measuring the maximum length, from the anterior to posterior end, when measured across the center of the archenteron, and **f.** measuring the 2D area. Body size of the prism stage will be determined by **g.** measuring the tip of the body rod to the tip of the postoral rod. Body size of the echinopluteus stage will be determined by **h.** measuring the length of the left postoral arm, from the spicule tip of the postoral arm to the spicule tip of the aboral point.

Embryo and larval culturing

To limit genetic variation and ensure all larvae are genetic full or half-siblings, one male will be crossed with nine females. After fertilization, larvae will be reared in MHW conditions and morphometric and physiological analyses will be conducted at four different life stages: hatched blastula, gastrula, prism, and early echinopluteus larvae to examine potential differences in performance across early development (Fig. 6).

Thermal tolerance trials

Thermal tolerance will be measured using constant, acute temperature exposures. Following the methods developed in Wong & Hofmann (2020)[24], embryos will be divided evenly among seven 20-mL vials. A temperature gradient ranging from ~16°C to ~32°C will be generated using two water baths attached an aluminum heat block. Each of the seven vials will be distributed across the heat block so that the embryos will be exposed along the gradient for a one-hour exposure. After exposure, the vials will be removed and the first 100 embryos from each vial will be scored as alive or dead based on the presence of ciliary locomotion viewed under a light microscope. Lethal temperature (LT) values (LT_{50}, LT_{25}, and LT_{10}) will be calculated using a logistic regression for the control and experimental samples.

All assays will be carried out for the control (non-MHW) samples. This experiment will be repeated once during the fellowship in Year 2 (2023-2024).

<u>Objective 2</u>: To assess how the interaction of MHWs and food availability impacts adult urchin gonad quality.

As mentioned by local urchin divers, low abundance of the native kelp *Macrocystis pyrifera* during extreme warming events is a critical issue preventing the marketability of adult red urchins. However, it has been noted that invasive algae species are often resilient in the face of MHWs (pers. comm. James Ray, CDFW's lead on kelp management, planning, and restoration). Recent studies have shown the pervasiveness of the invasive algae, *Sargassum horneri*, and invasion rates are predicted to increase with climate change.[20] Li et al (1997) has shown the high nutritional quality of *S. horneri*: rich in dietary fiber, laminaran, minerals, vitamins, high unsaturated fatty acids, and essential amino acids.[10] However, because *S. horneri* is in the order Fucales, which is known for having high levels of phenolic compounds that deter grazing, urchins preferentially graze native algae species.[11] Nevertheless, urchins have been shown to graze on non-native algae species only when preferred native kelp is unavailable.[21] Given that native kelp abundance may decrease and invasive algae abundance may decrease with increased ocean warming, I propose laboratory feeding trials using *S. horneri* to determine whether such a diet will yield marketable urchin gonad quality. Results will provide insight on potential management strategies for augmenting the red urchin fishery and controlling invasive algae populations.

I hypothesize that adult red urchins will graze on *Sargassum horneri* in MHW conditions, which will result in marketable gonadal quality. This objective addresses SFA Strategies 2-1, 2-2, 2-3, and 3-2.

<u>Approach</u>: Adult urchins will be held in marine heatwave simulator tanks in four-week feeding trials with *Macrocystis pyrifera* or *Sargassum horneri*. Gonad quality and gonadal indexes will be assessed.

<u>Prior to feeding</u>

Adult urchins will be collected at sites near Santa Barbara. Following Foster et al. (2015), to minimize variation in growth potential, consumption potential, and initial gonad weight, urchins will be chosen to be about the same size and presumably age, and collected from urchin barrens where their gonad weight should be low. They will then be acclimated to laboratory conditions for 2 weeks, and then held in the MHW conditions as specified in Objective 1, except they will be held in a large seawater table instead of a tank. These seawater tables are available in the Hofmann Lab in the Marine Science Institute. To standardize their nutritional condition, urchins will be starved for 2 weeks prior to the start of the experiment following Scheibling and Anthony (2001)[16].

<u>Feeding trials</u>

Feeding trials will last four weeks during the period of gametogenesis. There will be six tanks with six urchins per tank: three tanks for the *S. horneri* treatment and three tanks for the *M. pyrifera* treatment. A pre-weighed amount of ~40 grams of *Sargassum horneri* or *Macrocystis pyrifera* per urchin – 240 grams total – will be given to urchins once a week. *M. pyrifera* and *S. horneri* will be blotted dry and weighed prior to being placed in tanks.

<u>Analysis</u>

To measure feeding rates kelp will be removed, dried, and reweighed to determine consumption. To control for kelp and *S. horneri* loss from natural deterioration, kelp and *S. horneri* will be added to individual tanks without urchins. After four weeks, urchins from each treatment will be weighed and dissected in order to examine their gonad tissue. Prior to conducting these analyses, I will be shadowing urchin gonad quality inspection at Catalina Offshore Products with one of my CSUC community mentors David Rudie. Gonadal indexes (GI), the ratio of total gonad tissue wet weight to total body wet weight and expressed as a percentage, will be calculated. Following Pert et al. (2019)[13], gonads will also be photographed to assess their commercial quality based on firmness, color, and texture. I will grade the uni according to CSUC uni grade names and standards and invite local urchin processors to assess gonad quality alongside me.

<u>Objective 3</u>: Determine if yearly kelp canopy correlates to urchin biomass.

Bell et al. (2015) showed that greater sea urchin densities, for both *S. purpuratus* and *M. franciscanus*, were associated with decreases in kelp canopy biomass. Additionally, sea urchin density was the dominant correlate of kelp canopy cover at 25% of their study sites in southern California[1]. More importantly, the CDFW red sea urchin ESR has also identified the need to determine if yearly kelp canopy cover can correlate to urchin biomass as a priority for management.[4]

<u>Approach</u>: I will conduct data analyses on existing SBC-LTER datasets to determine if kelp canopy correlates with urchin biomass.

I will analyze an existing SBC LTER dataset that contains yearly kelp canopy cover, temperature, and urchin abundance. There are 39 annual monitoring plots (40x2 m) distributed across 11 reef sites. In addition, there are five Long Term Experiment (LTE) sites, each with 2 plots the same size, monitored quarterly. Finally, there are 3 monthly net primary productivity (NPP) sites with one plot each (divided into subplots) where urchins and kelp are counted monthly. Methods for measuring kelp cover, temperature, and urchin abundance can be found on the SBC LTER site[2]. These data span the past 19 years for the annual and NPP sites and 7-10 years for the LTE sites. I will use a linear mixed effects model to determine whether there is a relationship between kelp canopy cover and urchin biomass. Urchin biomass will be the response, with kelp canopy cover and year as fixed effects, and plot nested in site as a random effect. I will be taking Statistics & Data Analysis for Environmental Science & Management in the Fall of 2021 to prepare for the data analysis component of my project. I will also work with other researchers in the SBC-LTER to determine the best way to analyze and share these data.

Proposed timeline for the project

The proposed project will be the main focus of my dissertation at UCSB. In terms of start dates, I propose to begin the project in February 2022. Feeding trials described in Objective 2 will begin in February and last one month, as this is when *Sargassum horneri* is most abundant (pers. comm. Christoph Pierre, Director of Marine Operations and Collector). The MHW acclimation described in Objective 1 will begin in September 2022 and last until December 2022. This is ideal timing as the red urchins are performing gametogenesis in situ during this time. Following that, in Year 2, I will follow the same timeline of events as described in Year 1 to ensure I have one replication of each experiment.

<u>Table 1:</u> Time table for the proposed research

	Year 1 (2022-2023)				Year 2 (2023-2024)			
Objective	Feb-Apr	May-Aug	Sept-Oct	Nov-Jan	Feb-Apr	May-Aug	Sept-Oct	Nov-Jan
1			MHW →	→ → Sampling & Analysis →		Repeat MHW experiment		
2	Feeding trial → Analysis				Repeat feeding trial			
3	Data analysis. → → →							

Outcomes and Deliverables

This project will foster collaborations among CDFW, CSUC, SBC-LTER, Erin de Leon Sanchez, and Gretchen Hofmann to prepare the red sea urchin fishery in a rapidly changing climate. I have discussed the possible outcomes and deliverables that will be generated from my research with my community members Derek Stein and Anthony Shiao from CDFW as well as David Goldenberg, Nathan Rosser, and David Rudie from CSUC. We will meet before the work begins to determine a timeline for mentorship activities and deliverable goals. During the project I will meet once a month with my project team. Once results have been generated, I will meet with them more frequently to prepare deliverables and plan for outreach and science communication events. Results will be communicated to stakeholders via reports, presentations, and Shiny apps.

<u>Objective 1:</u>

Outcomes

This experiment will reveal the relationship between environmental change and parental effects as a source of phenotypic plasticity (SFA 2-1 & SFA 2-2). With a focus on early developmental stages, which may be more vulnerable to MHWs, my results will give insight into how other commercially important marine invertebrates with planktonic larvae may fare in future oceans. Furthermore, results from this experiment may be utilized by CDFW to predict the climate readiness of the red urchin fishery (SFA 2-3) and how successful red urchin recruitment events will be in a MHW year. Information from this research will be available to the CA Sea Urchin Commission and local urchin divers to help them adapt and respond to changing environmental conditions.

Deliverables

I will:

- Work with CDFW to create a climate readiness report for the red sea urchin ESR.
- Deploy temperature sensors at five sites relevant to the fishery (in collaboration with CDFW, CSUC, and local urchin divers). With such data, I will create a Shiny app for stakeholders to visualize temperatures at each site.
- Hold a "fleet meeting" with CSUC and local urchin divers to share and discuss my results.
- Generate one publication from this work and present my results at scientific meetings and the Marine Resources Committee of the CA Fish and Game Commission.

<u>Objective 2:</u>

Outcomes:

This experiment will be the first study to examine how MHWs and food availability may interact and affect red urchin gonad quality and marketability. Notably the most intense MHW event occur at times when red urchins would be starting gametogenesis. Because the red urchin fishery's success is heavily dependent on gonad quality, these results will be critical in predicting how red urchin fishery landings may be affected in the event of a MHW. Researchers also may be able to predict how grazing in a MHW year may affect kelp canopy cover and *S. horneri* abundance. Furthermore, if urchins are shown to produce marketable gonads following *S. horneri* feeding trials, CDFW may be able to utilize urchin transplants to reduce invasive algae abundance and augment the red urchin fishery.

Deliverables

I will:

- Generate one publication from this work and present my results at scientific meetings and the Marine Resources Committee of the CA Fish and Game Commission.
- Give presentations at fleet meetings, Santa Barbara and Ventura port meetings, and CSUC board meetings.
- Create a blog post with photos on the CSUC and CDFW website to show gonad quality results from my study to urchin divers and decision-makers in red urchin fishery management and kelp management.

Objective 3:

Outcomes

These results will fill an information need that has been identified as a medium priority for the red sea urchin fishery management[1].

Deliverables

- I will design an interactive Shiny app in R to visualize these data and keep it updated over time for stakeholders to use. App users will also be able to provide feedback in the app for future improvement. A graduate student in the Hofmann Lab has created a similar Shiny app that visualizes benthic survey data collected in kelp forest communities in the Santa Barbara Channel (https://ameliaritger.shinyapps.io/mbon-shiny-app/).

Table 2. Community mentorship and deliverables (see Community Mentor Plan)

Communication	Year 1 (2022-2023)	Year 2 (2023-2024)
Community sessions	- Meet with CDFW and CSUC monthly - Deploy temperature sensors at fishery sites with CDFW - Shadow urchin harvesting and processing at Catalina Offshore Products - Invite CSUC urchin divers and local processors to help with gonad quality assessment	- Meet with CDFW and CSUC monthly - Create climate readiness report with CDFW - Create Shiny apps - Add blog to CSUC and CDFW websites - Fleet meeting with CSUC - Present data to CSUC and Marine Resources Committee of the CA Fish and Game Commission
Publications	none	Manuscript preparation (2 publications)
Scientific Meetings	Western Society of Naturalists	Ocean Sciences Meeting

Permits

My research group at UC Santa Barbara has the permits necessary for urchin and kelp collections (via the Santa Barbara Coastal LTER). In addition, I plan to apply for the California Department of Fish and Wildlife Scientific Collecting Permit (General Use Student) for harvesting the invasive algae *Sargassum horneri*.

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