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An Interdisciplinary Approach to Understanding Predator-Prey Relationships in a Changing Ocean: From System Design to Education

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by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
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DEDICATION

Le dedico esta disertación a mi madre, Ileana Ortiz Alicea, por exponerme al mundo de la ciencia y el descubrimiento desde temprana edad. He logrado llegar hasta este punto en mi educación gracias a tus esfuerzos, sacrificios, y apoyo incondicional. Recuerdo con mucho orgullo tu dedicación por completar tu grado ya siendo madre con trabajo a tiempo completo. Tu perseverancia y empeño me han enseñado mucho acerca de la vida y la educación. Gracias mami, te amo.

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ABSTRACT

Climate change is ecologically and socially complex, deemed the most important issue of our generation. Through this dissertation I have approached climate change research through an interdisciplinary perspective, investigating how this phenomenon will affect marine ecological systems, how we can better develop experimental systems to answer ecological questions, and how we can effectively educate about this issue.

In Chapter 2, I provided accessible alternatives for researching the effects of climate change (elevated temperatures and pCO_2) on marine ecosystems. I designed, built, and troubleshooted two accurate and inexpensive climate-controlled experimental systems capable of maintaining target conditions: a temperature-controlled system and an ocean acidification system. The temperature-controlled system was designed to manipulate experimental tank temperatures indirectly by controlling the temperature in a surrounding water bath, which buffered fluctuations and resulted in a high level of control. The ocean acidification experimental system was designed to elevate normally fluctuating pCO_2 levels by a constant factor, which allowed pCO_2 to fluctuate as expected in natural environments and made it more ecologically relevant than active pCO_2-controlled systems.

In Chapter 3, I experimentally tested the morphological responses of southern ribbed mussels *Geukensia granosissima* to two simultaneous stressors (elevated temperatures and the presence of water-borne predation cues from blue crab *Callinectes sapidus*) and if any effects of

these treatments led to differences in handling times by predatory crabs. Bivalves may become more susceptible to predation as increased temperatures decrease the protection afforded by their shells, but few studies have tested the effects of elevated temperatures on inducible defenses in bivalves. Results showed that chronic heat stress can have detrimental morphological effects on intertidal mussels. Mussels reared in elevated temperatures manifested elongated shell shapes, exhibited a disruption of the predator effect on inducible defenses, and experienced decreased predator handling times. The observed responses to elevated temperatures could make southern ribbed mussels more vulnerable to predation.

In Chapter 4, I experimentally tested the morphological responses of southern ribbed mussels to elevated pCO_2 levels and the presence of water-borne predation cues from blue crabs, and if these effects led to differences in handling times by predatory crabs. Elevated pCO_2 can have negative effects on bivalves' morphology and physiology, but the consequences of these effects on predator-prey interactions are still unclear. I found that adult southern ribbed mussels' inducible defenses were not affected by a medium-term exposure to elevated pCO_2. Mussels grew more in shell length and width as a response to predation cues, independent of pCO_2 conditions. However, and unexpectedly, mussels reared under elevated pCO_2 exhibited greater growth in shell width independent of predator treatment, driving mussels reared in the presence of a predator under elevated pCO_2 conditions to develop rounder shapes. On average, these effects on mussel morphometrics did not affect crab handling times, but mussels reared in the presence of a predator under elevated pCO_2 conditions had highly variable handling times. It is important to consider the complexity of animal physiology, morphology, and interspecies relationships when making deductions on predator-prey relationships in a changing ocean.

In Chapter 5, I analyzed the effectiveness of using an interdisciplinary approach to climate change education. Literature suggests that an interdisciplinary instructional framework in an outdoor setting, using tools from the experiential, active, and inquiry- and place-based learning approaches, as well as the socioscientific issues pedagogical framework, would be an excellent approach for climate change education. I found that students: increased their content knowledge on climate change causes and consequences, exhibited a deeper understanding of climate change through the words they used to describe it, and corrected common climate change misconceptions. This work can serve as an example for the development of effective climate change programs that uses already available instructional materials with intentional interdisciplinary goals.

Our search to understand how marine ecosystems will cope with a changing climate has emphasized emerging issues in the way we gather data, the questions we seek to answer through research, and how we translate science of social importance to the public. Through this dissertation I strove to seek the answers to some of these questions and provide feasible solutions to some of the problems in climate change research and education through an interdisciplinary approach. As science continues to move towards answering questions of concern for both science and society, science research is moving towards more interdisciplinary approaches. This dissertation is an example of how this can be an efficient and comprehensive approach.

CHAPTER 1. INTRODUCTION

"-- there's one issue that will define the contours of this century more dramatically than any other, and that is the urgent threat of a changing climate."

Barack Obama (The White House 2014)

Climate change is an ecologically and socially complex issue deemed the most important issue of our generation. Its effects have consequences for the Earth's physical, chemical, and biological systems (Pachauri et al. 2015) and have the potential to disrupt the social-ecological systems that depend on them (Perry et al. 2011). Such a complex and layered socioscientific issue should, therefore, be studied through an approach that mirrors its complexity and allows for the exploration of different aspects of the issue: interdisciplinarity (Bhaskar et al. 2010). Through this dissertation I have approached climate change research through an interdisciplinary perspective, investigating how this phenomenon will affect marine ecological systems, how we can better develop experimental systems to answer scientific questions, and how we can effectively educate about this issue.

The main goals of this dissertation were to (1) develop standardized designs for climate change experimental systems that are accurate and ecologically-relevant, (2) test the effects of climate change on predator-prey relationships between coastal marine organisms through controlled laboratory experiments, and (3) determine the efficacy of an interdisciplinary climate change education program. This work was divided into four chapters: an engineering chapter, two data chapters, and an education chapter.

In Chapter 2, *Designing and troubleshooting climate-controlled experimental systems*, I tackled the issue of accessibility of experimental systems. Climate change has garnered increasing interest by biologists and ecologists, which has resulted in the development of elaborate experimental systems that manipulate different parameters to investigate their effects (Wahl et al. 2015), but these system designs are often financially inaccessible to graduate students and small laboratories. To tackle this issue I designed, built, and troubleshooted a set of accurate and inexpensive climate-controlled experimental systems. The goal of this chapter was to provide accessible alternatives for researching the effects of climate change on marine ecosystems.

In Chapter 3*, Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel*, I experimentally tested the morphological responses of southern ribbed mussels *Geukensia granosissima* to two simultaneous stressors: elevated temperatures and the presence of water-borne predation cues from blue crab *Callinectes sapidus*. Bivalves may become more susceptible to predation as increased temperatures decrease the protection afforded by their shells (Fitzgerald-Dehoog et al. 2012), but few studies have tested the effects of elevated temperatures on inducible defenses in bivalves and how these in turn affect predator-prey interactions. To understand how these stressors may affect predator-prey interactions, I tested whether mussel growth and morphology was affected by elevated temperatures and the presence of water-borne predator cues, and if any effects of these treatments on growth and mussel morphology led to differences in how long it took for predatory crabs to consume them (*i.e.*, predator handling times).

Following the work of Chapter 3, in Chapter 4*, Inducible defenses of intertidal mussel not affected by pCO_2-induced seawater acidification*, I experimentally tested the morphological responses of southern ribbed mussels to elevated *p*CO_2 and the presence of water-borne predation cues from blue crabs. Elevated *p*CO_2 can have negative effects on bivalves' morphology and physiology (Berge et al. 2006, Talmage and Gobler 2011). However, the consequences of these effects on predator-prey interactions are still unclear, with limited information providing contradictory findings (Gazeau et al. 2013, Kroeker et al. 2014). To understand how these stressors might affect predator-prey interactions, I used a similar approach as in Chapter 3 to test whether mussel growth and morphology was affected by elevated *p*CO_2 conditions and the presence of water-borne predation cues, and if these effects led to differences in handling times by predatory crabs. The goals of Chapters 3 and 4 were to provide data that could aid in understanding how predator-prey interactions could transform in a changing climate due to elevated temperatures and *p*CO_2.

In Chapter 5, *Idaho students gain deeper understanding of climate change and show correction of misconceptions after interdisciplinary climate change outdoor education program*, I analyzed the effectiveness of using an interdisciplinary approach to climate change education. Most of the programs that have reported successfully using interdisciplinary instructional approaches have taken place in the classroom, and very few have taken place in informal settings (Monroe et al. 2017). Outdoor education, specifically, does not seem to be well represented in the climate change education literature, although it is inherently place-based and experiential (Woodhouse and Knapp 2000). The literature suggests that the combination of an interdisciplinary instructional framework in an outdoor setting would be an excellent approach for climate change education. Therefore, in this chapter I aimed to (1) determine the efficacy of the program on students' content knowledge about the causes and consequences of climate change to natural and human communities, (2) analyze students' depth of understanding of these concepts before and after the program, and (3) understand how students make meaning of climate change within their greater social context, including actions and behavioral changes they could implement.

Our search to understand how marine ecosystems will cope with a changing climate has emphasized emerging issues in the way we gather data, the questions we seek to answer through research, and how we translate science of social importance to the public. Through this dissertation I strove to seek the answers to some of these questions and provide feasible solutions to some of the problems in climate change research and education.

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CHAPTER 2. DESIGNING AND TROUBLESHOOTING CLIMATE-CONTROLLED EXPERIMENTAL SYSTEMS

2.1. Introduction

The consequences of climate change are many and include further warming, long-lasting changes in all components of the climate system, and amplify existing risks for natural and human systems (Pachauri et al. 2014). Models predict extreme changes to environmental conditions in all natural environments (Pachauri et al. 2014), and ecologists and natural resource managers have taken on the task of modeling the consequences of these effects for marine systems and the economy. They report considerable threats to fisheries and aquaculture (Cochrane et al. 2009, Mohanty et al. 2010, Hollowed et al. 2013, Weatherdon et al. 2016) and ecosystem services (Cooley et al. 2009). These models depend on data from experimental manipulations of species under controlled environmental conditions.

Studies investigating how increased temperatures and ocean acidification affect marine organisms have used a variety of observational field approaches and controlled laboratory experiments (Kroeker et al. 2013, Kroeker et al. 2014, Browman 2016). However, the broad spectrum of methodologies used for determining the effects of climate change and ocean acidification on species makes comparisons across studies difficult and sometimes misleading. This problem has been partially addressed through publications that aim to standardize methodologies, such as the “Guide to best practices for ocean acidification research and data reporting" (Riebesell et al. 2010). Although documents like these delineate guidelines for climate change research, the accuracy and stability required of laboratory experimental systems remain unclear. Simulating future water chemistry is complex and several methodological issues have emerged with the increasing interest in climate change and ocean acidification research (Cornwall and Hurd 2015, Browman 2016). Teams of scientists and engineers have developed elaborate experimental systems that allow for accurate manipulation of different chemical and physical parameters (Wahl et al. 2015), but these system designs are often financially inaccessible solutions for graduate students and small laboratories.

As a potential solution for this problem, I have designed and built a set of inexpensive climate-controlled systems capable of accurately reaching and maintaining target experimental conditions. Two separate experimental laboratory systems were built, designed to address two of the main variables of interest for climate change studies focused on marine organisms: (1) a temperature-controlled system (Section 2.2), and (2) an ocean acidification system (Section 2.3). Below I describe the system designs, provide information on troubleshooting, and report on the systems' accuracy and stability.

2.2. Temperature-controlled experimental system

The temperature-controlled experimental system was built in the Aquarium Laboratory at the College of Marine Science during the summer and fall of 2014. Since its creation, the system has been used to gather data for three separate studies, including Chapter 2 of this dissertation, and has been capable of sustaining target temperatures (up to 34°C) for 10+ weeks. The design consisted of a flow-through glass aquaria system within a mesocosm (Figure

2.1). Water originated from a temperature-controlled sump (Figure 2.1 a), flowed through a primary tank (Figure 2.1 b), and gravity fed to a secondary tank (Figure 2.1 c). This design allowed for movement of water-borne cues (*e.g.,* from predators) from the primary tanks to the secondary tanks, while preventing direct interactions between organisms. Water from all secondary tanks overflowed into a temperature-controlled water bath (Figure 2.1 d) to maintain constant and homogeneous temperatures across all experimental tanks.

Water was pumped from the sump through a main water line and circulated back to the sump. Water flow to each tank was controlled using miniature gate valves attached to the main water line. This circulation homogenized water pressure across gate valves and, therefore, experimental tanks. All experimental tanks were aerated by ambient air supplied by an air compressor. The system was equipped with timed fluorescent lamps, exposing all experimental tanks to a controlled, and easy to manipulate, photoperiod. The full system included three independently manipulated mesocosms.

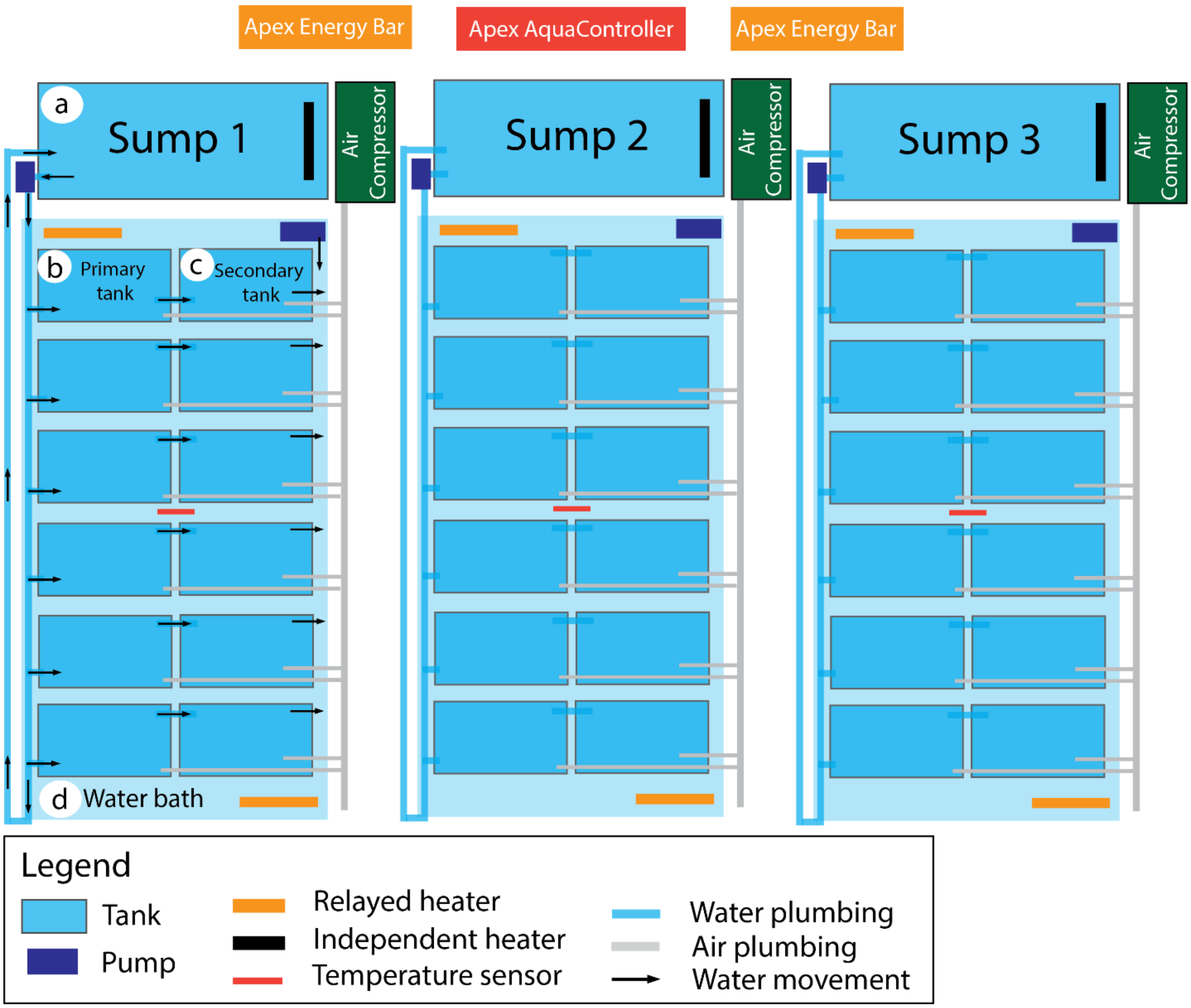

Figure 2.1 Detailed schematic of the temperature-controlled experimental system. Letters represent the flow-through trajectory of water from the sump (a) to the water bath (d)

I achieved accurate temperature control by using an Apex AquaController system (Neptune Systems©) to monitor and change water bath temperatures as needed. The AquaController system used the information from the Apex temperature sensor in the water bath to turn on or off two relayed titanium heaters connected to the Apex Energy Bars. The system continuously calculated the difference between the measured temperature and the desired set point and then used this difference to adjust the power supplied to the heaters, in this case turning the relayed receptacle on or off. I added a submersible pump to ensure homogeneity of the water bath temperature, which stimulated water circulation and continuously moved water over the titanium heaters.

Experimental tank temperatures in this system were manipulated indirectly by controlling the temperature in the surrounding water bath. Using the water bath as an indirect temperature controlling mechanism buffered high temperature fluctuations in the experimental tanks and resulted in a high level of temperature control across experimental tanks (Figure 2.2). The minimum accuracy measured across the three mesocosm systems was ± 0.6°C (Table 2.1). This high accuracy allowed for setting temperatures as close as 1.2°C apart, without overlapping temperature fluctuations (Figure 2.3). To achieve this accuracy, the full system was covered with a thick plastic film on the top and all four sides. This protective film prevented heat loss to the air, which proved critical to maintaining constant temperatures within the system (Figure 2.4).

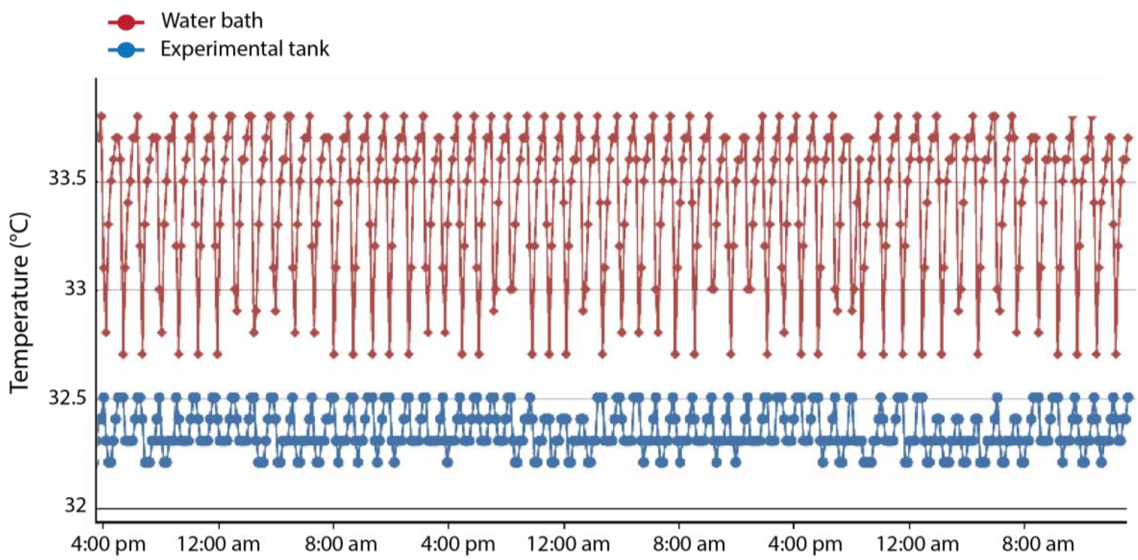

Figure 2.2 Time series of temperature fluctuations in the system water bath (red) compared to an experimental tank (blue)

Table 2.1 Mean (± 1SD) temperature values in experimental tanks during a 4-week period

Temperature treatment	Target temperature (°C)	Observed temperature (°C) ± 1SD
Low	30	29.7 ± 0.2
Mid	32	32.1 ± 0.2
High	34	33.9 ± 0.6

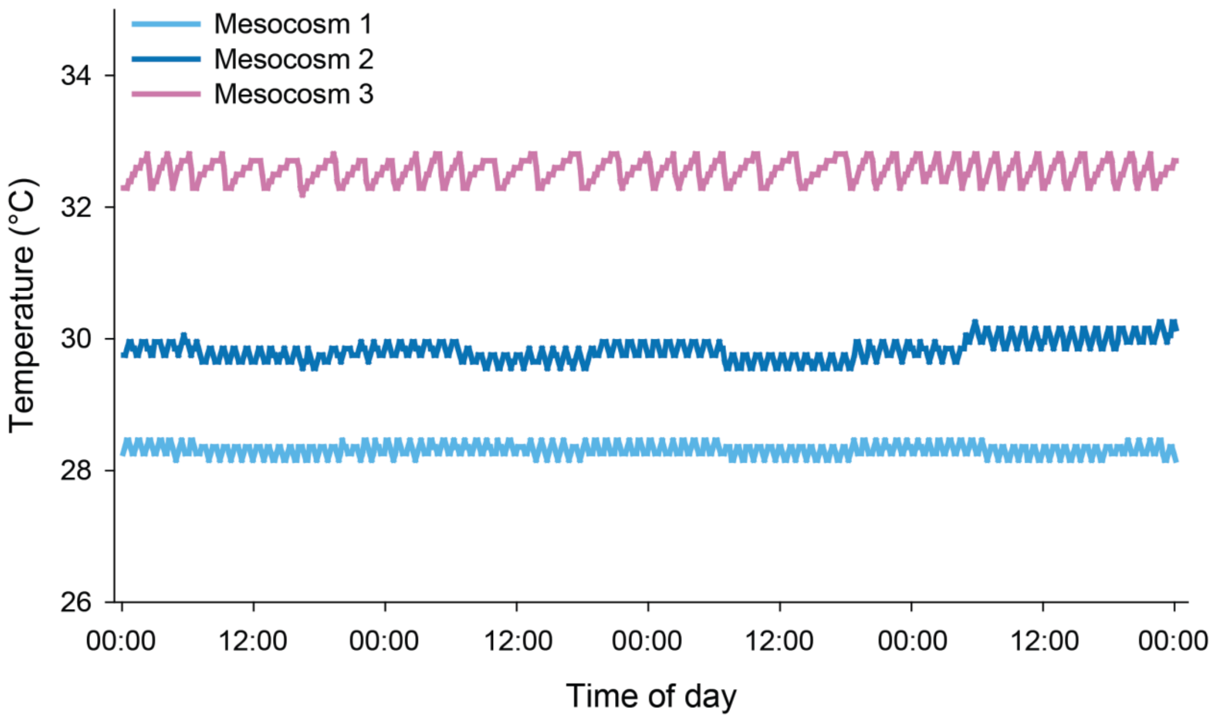

Figure 2.3 Time series depicting temperatures in an experimental tank at each of the mesocosm systems showing precise temperature control throughout four days. Target temperatures were 28°C (mesocosm 1), 30°C (mesocosm 2), and 32°C (mesocosm 3)

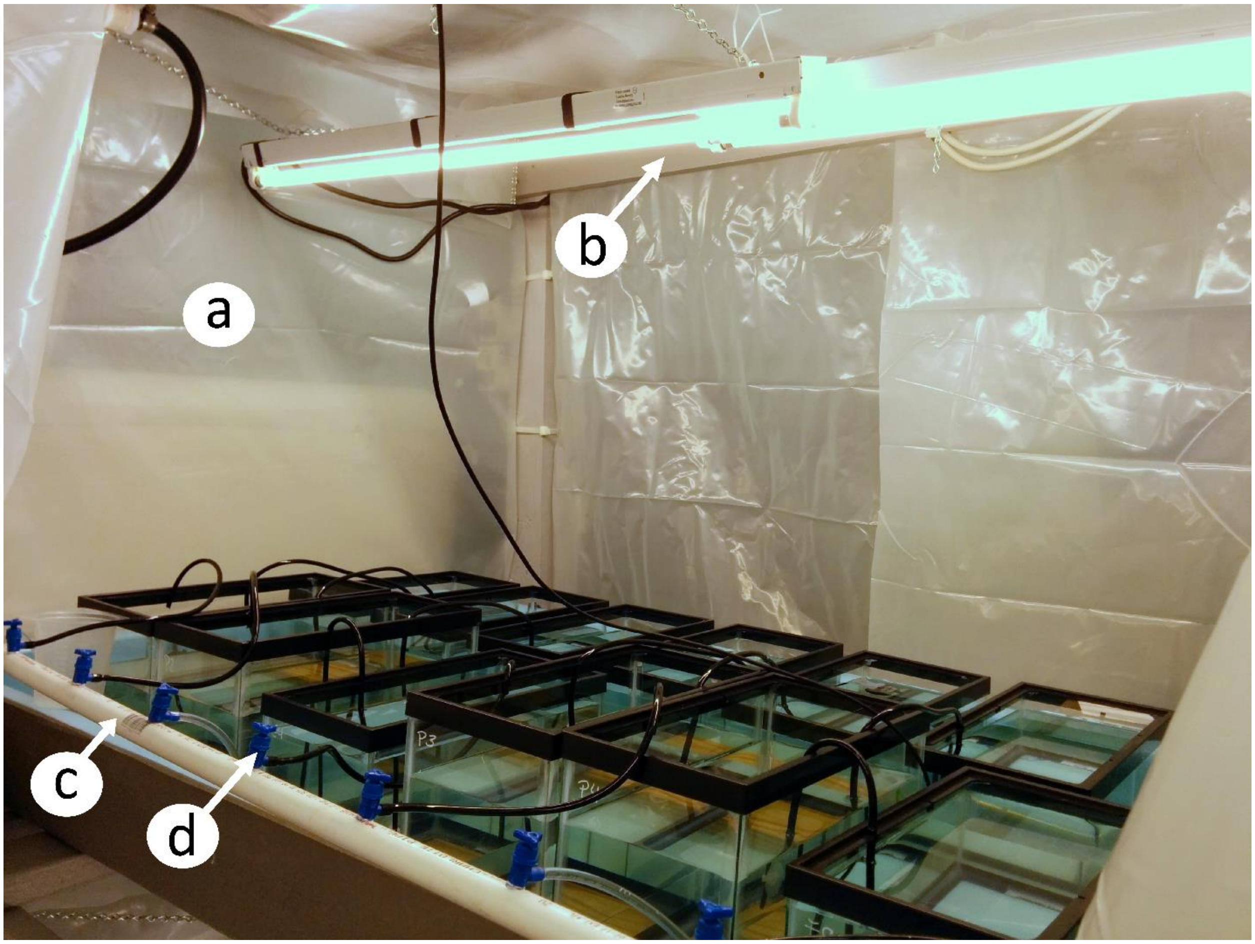

Figure 2.4 Photograph of one mesocosm of the temperature-controlled experimental system. Several aspects of the system are visible: plastic film cover (a), lighting (b), main water supply line (c), and gate valve water supply control (d)

2.3. Ocean acidification experimental system

The ocean acidification experimental system was built in the Climate Change Laboratory at the University of Miami (UM-RSMAS) in Florida, USA, during the spring and summer of 2015. Since its creation, the system has been used to gather data for Chapter 3 of this dissertation and has been capable of sustaining target pCO_2 levels (up to 1,000 ppm) for a period of 8 weeks. The design consisted of a flow-through glass aquaria system within a mesocosm, similar to that of the temperature-controlled system (Figure 2.5). From the sump (Figure 2.5 a), water was pumped to the primary tanks (Figure 2.5 b) and gravity fed to the secondary tanks in the system (Figure 2.5 c). From the secondary tanks, water overflowed into a water bath (Figure 2.5 d) that buffered temperature fluctuations and maintained temperatures constant across tanks in a single mesocosm.

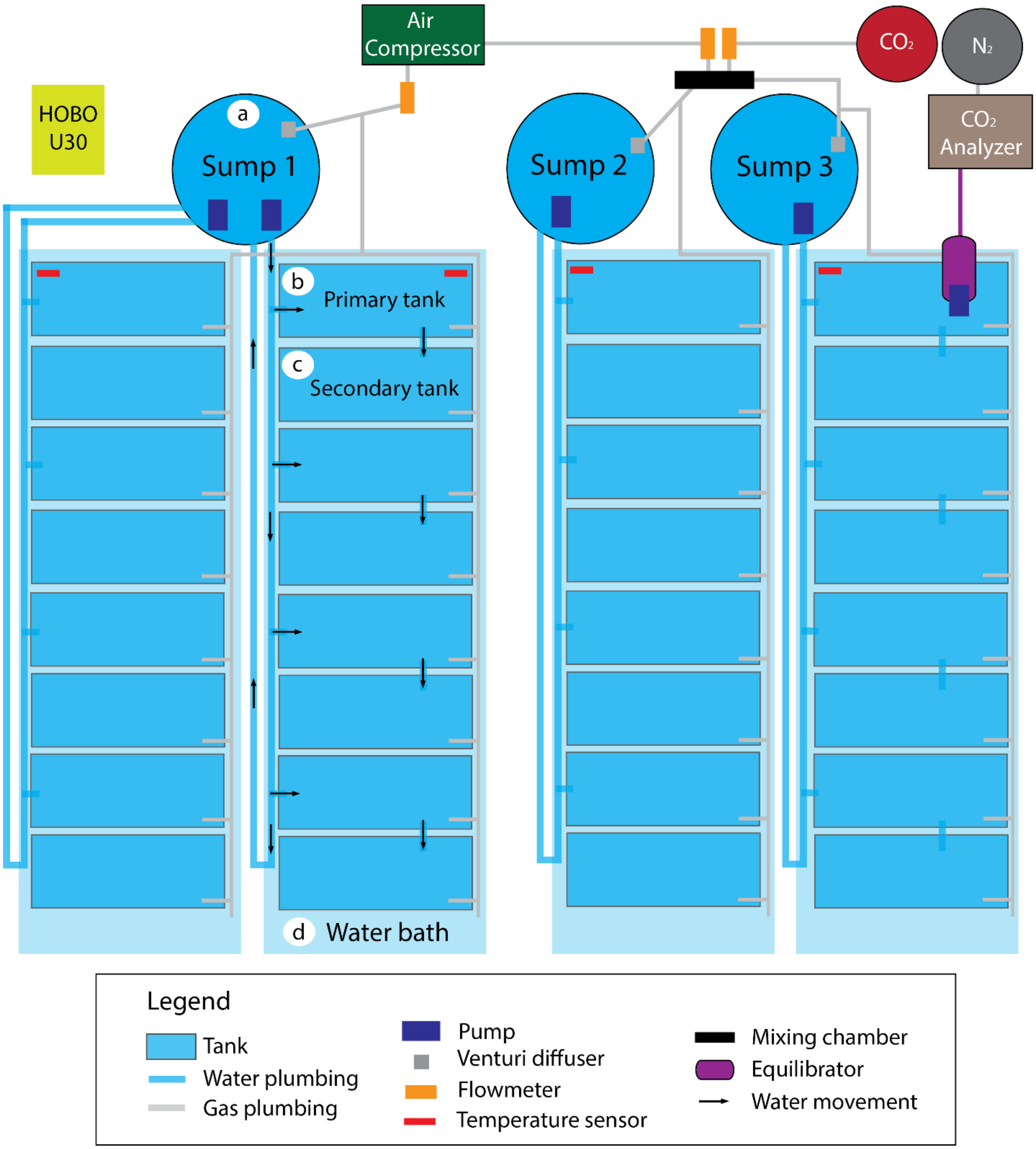

Figure 2.5 Detailed schematic of ocean acidification experimental system. Letters represent the flow-through trajectory of water from the sump (a) to the water bath (d)

Sumps were bubbled with a gas mixture relative to the target pCO_2 level to alter the chemical parameters in the experimental tanks. Control tanks were bubbled with ambient air directly from an oil-free air compressor. Sumps in the high pCO_2 treatments (sumps 2 and 3 in Figure 2.5) were bubbled with a mixture of ambient air from the compressor and pure CO_2 gas. The concentration of CO_2 in the mixed gas was regulated by the amount of ambient air and pure CO_2 flowing into a PVC mixing chamber, which I modified by adjusting flow controllers (Sierra Instruments 810C) attached to each gas source. The gas flow necessary to reach the desired pCO_2 levels was determined iteratively by independently adjusting the flow of ambient air and pure CO_2 gas until reaching target levels in the experimental tanks.

After mixing in the PVC chamber, the target pCO_2 gas mixture flowed into the sumps through Venturi diffusers. The small bubbles of gas released by the diffusers facilitated the absorption of CO_2 into the surrounding water, allowing the water to equilibrate to the pCO_2 of the gas. In an attempt to reach equilibrium with the surrounding air, CO_2 gas in the water in the primary and secondary experimental tanks diffused into the air, causing the pCO_2 of the water in the experimental tanks to decrease slightly. To address this issue and maintain the targeted pCO_2 levels, experimental tanks were also aerated with the same gas mixture being diffused into the sumps.

We monitored CO_2 concentrations in the experimental tanks by using a shower-head equilibrator/Licor (LI-820) CO_2 analyzer system. Water was pumped from an experimental tank to the equilibrator (Figure 2.6), where water sprayed evenly into a closed air chamber by a spiral spray nozzle. The closed air chamber allowed CO_2 gas in the sampled water to equilibrate with the air in the chamber, which was then pumped out of the equilibrator into a LiCor® CO_2

gas analyzer (LI-820) and circulated back into the equilibrator. The partial pressure of CO_2 in the equilibrator was logged every five minutes by a HOBO U30 data acquisition system. This method allowed for continuous real-time monitoring of pCO_2 in the experimental tanks.

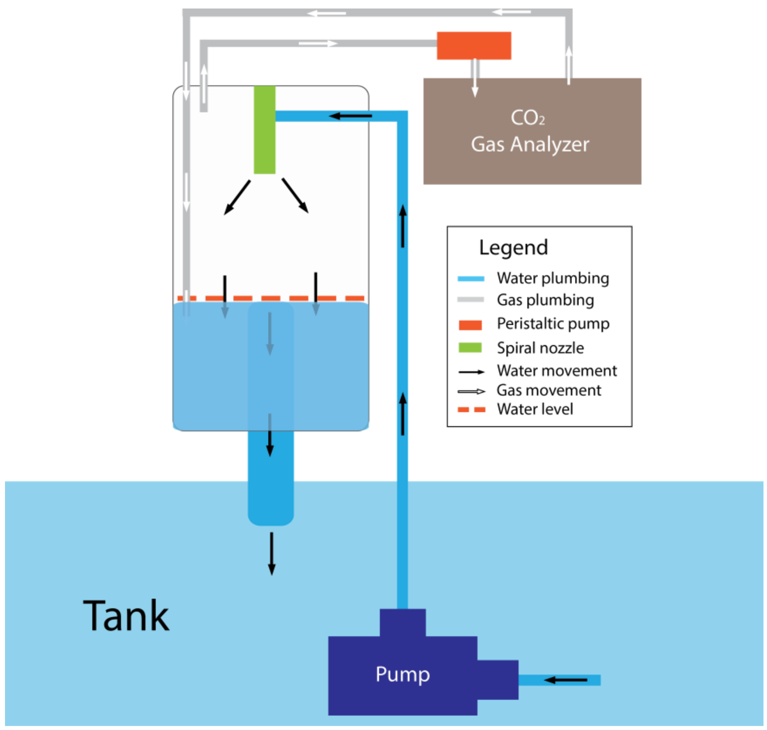

Figure 2.6 Detailed schematic showing equilibrator and communication with the LiCor® CO_2 gas analyzer

Natural seawater for the experimental system was supplied from intakes near Bear Cut, Key Biscayne, Florida, USA. Experimental tanks were exposed to natural light conditions, attenuated by a neutral density shade cloth, and water flow was maintained at a constant rate of 0.3 L/minute, resulting in complete water turnover in experimental tanks approximately every 30 minutes. Temperature in the experimental tanks was measured and logged every five minutes by the HOBO system. An image of the system with its components is included in Figure 2.7.

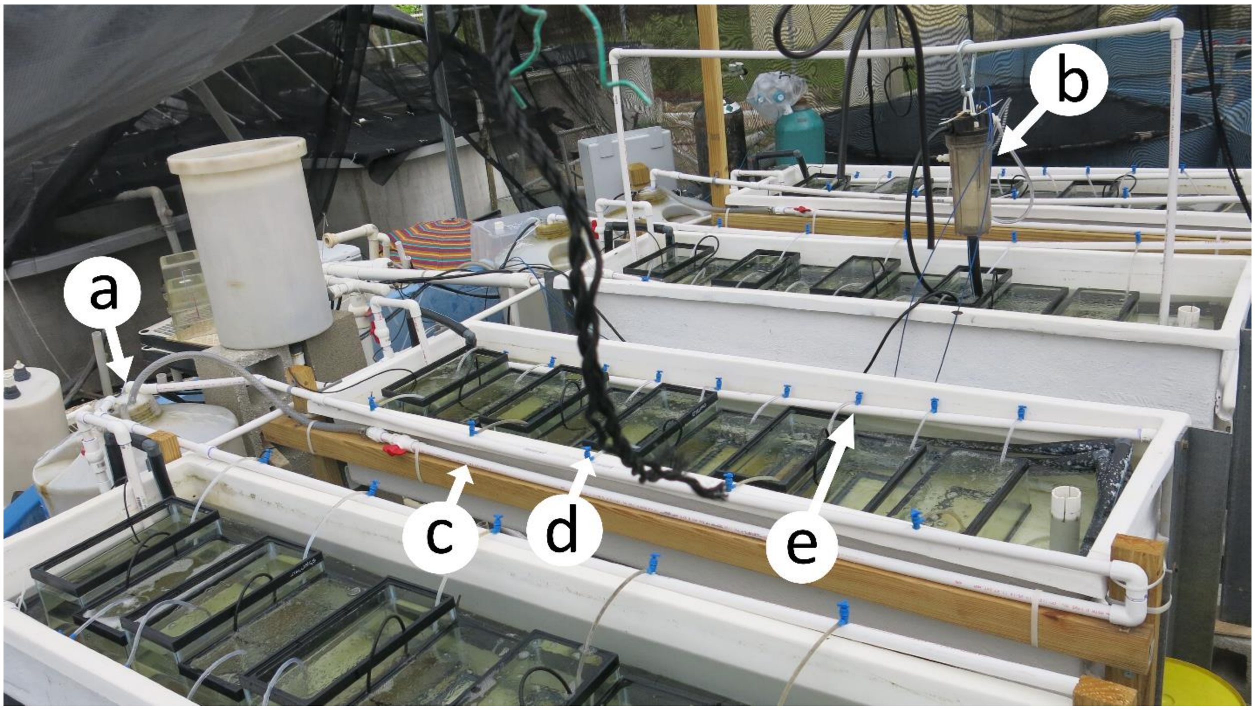

Figure 2.7 Photograph of the ocean acidification experimental system. Several aspects of the system are visible: sump (a), equilibrator (b), main water supply line (c), gate valve water supply control (d), and aeration gas supply line (e)

It is important to note that this experimental system did not actively control pCO_2 like other systems. Systems designed to actively control pCO_2 require the use of a proportional-integral-derivative (PID) loop relay and a sensor (pH or CO_2), which can be prone to calibration issues. Unlike a PID controller, this system elevated normally fluctuating pCO_2 levels due to diel cycles by a constant factor, allowing the system's pCO_2 to fluctuate as expected in natural environments in the coming century. Monitored pCO_2 data from this system showed similar daily fluctuations in the elevated pCO_2 than in the ambient experimental tanks (see Figure 4.4

in Chapter 4). Therefore, this design not only made it more ecologically relevant than active $p$$CO_2$-controlled systems, but also offered an alternative to systems sensitive to equipment malfunctions.

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CHAPTER 3. ELEVATED TEMPERATURES SUPPRESS INDUCIBLE DEFENSES AND ALTER SHELL SHAPE OF INTERTIDAL MUSSEL

Note to reader

This chapter was published in the peer-reviewed journal Marine Biology and is included in Appendix A. Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel. The full citation is: Freytes-Ortiz, I.M., Stallings, C.D. (2018) Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel. Marine Biology **165**(7): 113. DOI: 10.1007/s00227-018-3371-6. Authorization for inclusion in this dissertation can be found in Appendix H. Author contributions and permissions for reprinting previously-published work.

CHAPTER 4. INDUCIBLE DEFENSES OF INTERTIDAL MUSSEL NOT AFFECTED BY *P*CO_2-INDUCED SEAWATER ACIDIFICATION

4.1. Introduction

Predator-prey interactions are complex and can be affected both by biotic (*e.g.*, an organism's ability to develop inducible defenses) and abiotic conditions (*e.g.*, their surrounding physical environment) (Connell 1961, Hughes and Seed 1981, Blundon and Kennedy 1982, Kishida et al. 2010, Gestoso et al. 2015). Morphological plasticity as a response to the threat of predation is a type of inducible defense important to understanding species interactions (Kishida et al. 2010). For example, bivalves can develop larger and thicker shells as a response to water-borne predation cues to better protect themselves against shell-crushing predators (Harper and Skelton 1993, Caro and Castilla 2004, Freeman 2007). However, abiotic stressors in the physical environment, such as elevated partial pressure of carbon dioxide (pCO_2), can have negative effects on the morphological attributes bivalves usually develop as inducible defenses.

Evidence of the effects of increasing pCO_2 on bivalves include reductions in shell growth (Berge et al. 2006), thickness (Berge et al. 2006, Melzner et al. 2011, Zhao et al. 2017), and calcification rates (Gazeau et al. 2007). Elevated pCO_2 levels can also affect other physiological processes in bivalves, such as respiration (Wang et al. 2015), food clearance rates (Navarro et al. 2012), and oxygen uptake (Navarro et al. 2012). These morphological and physiological effects could ultimately affect an organism's ability to allocate energetic resources to developing inducible defenses (Trussell and Nicklin 2002, Kroeker et al. 2014), thus making them more susceptible to predation by reducing the amount of energy and time needed for their predators to consume them (*i.e.*, handling times) (Amaral et al. 2012). The consequences, however, of the effects of elevated pCO_2 on predator-prey interactions are still unclear due to their complexity, with limited and equivocal research, and predictions for interspecies relations remain mostly theoretical (Gazeau et al. 2013, Kroeker et al. 2014).

Estuarine organisms commonly exist at the edges of their abiotic tolerance thresholds and thus can be sensitive to extreme changes (Connell 1972, Somero 2002, Davenport and Davenport 2005). Living in environments with fluctuating pCO_2 conditions is more energetically expensive than living in static conditions (Mangan et al. 2017); therefore, some estuarine organisms are already living near or at their physiological tolerance limits (Somero 2010). This potential sensitivity of esturaine organisms to extreme environmental conditions presents a challenge as ocean chemistry undergoes significant changes due to increasing pCO_2, otherwise known as ocean acidification (Meehl et al. 2007). This effect is especially pronounced for sessile organisms, such as bivalves, due to their inability to move from unfavorable conditions (Nicholson 2002).

Estuarine and intertidal bivalves (*e.g.*, mussels, oysters) provide valuable ecosystem services, such as filtering suspended particles from the water column and promoting seagrass growth (Newell 2004), preventing erosion by providing structure (Bertness 1984), increasing the concentration of nutrients in sediments (Bertness 1984), serving as key foundation species (Suchanek 1992, Beck et al. 2011), and contributing to food security and the economy (Khoshnevis Yazdi and Shakouri 2010). On the Gulf of Mexico coast of Florida, USA, the southern ribbed mussel *Geukensia granosissima* is a prevalent bivalve commonly associated with oyster-reef intertidal and estuarine habitats. Ribbed mussels in these habitats serve as a food source for many predators including the blue crab *Callinectes sapidus* (Peterson et al. 2003), a key predator for intertidal mussels (Sherwood and Petraitis 1998, Macreadie et al. 2011). To protect themselves from these crab predators, mussels develop larger and thicker shells as an inducible defense (Caro and Castilla 2004, Freeman 2007). The predator-prey relationship between crabs and intertidal mussels is especially important, as these biotic interactions play a crucial role for controlling the distribution and vertical zonation of intertidal species (Connell 1972). The ecological importance of this intertidal predator-prey interspecies relationship, together with mussels' ability to develop morphological inducible defenses, make this a model predator-prey system to study the interactive effects of elevated pCO_2 and water-borne predation cues on mussel defenses, and how these might in turn affect their susceptibility to predation.

There has been a call in recent literature to build upon existing research on the effects of pCO_2-induced seawater acidification and characterize how multiple stressors might affect organisms' ability to survive in these environmental conditions, shedding light on what those effects might mean for species interactions (Landes and Zimmer 2012, Shaw et al. 2013, Kroeker et al. 2017). This study was, therefore, designed to investigate the morphological responses of southern ribbed mussels to two simultaneous stressors: elevated pCO_2 and the presence of water-borne predation cues from blue crabs. Based on results from previous research (Bibby et al. 2007, Kroeker et al. 2014), we hypothesized that southern ribbed mussels would develop inducible defenses in the form of shell growth in the presence of predation cues, but that this effect would be disrupted in elevated pCO_2 conditions. Specifically, we tested whether (1) mussel growth and morphology was affected by elevated pCO_2 conditions and the presence of water-borne predation cues, and if (2) any effects of elevated pCO_2 and water-borne predation cues on growth and mussel morphology led to differences in handling times by predatory crabs.

4.2. Methods

4.2.1. Laboratory setup

Southern ribbed mussels were maintained in one of four pCO_2*predator treatments: 400ppm and 1000ppm (present day [pCO_2] and that expected for the year 2100, respectively (Meehl et al. 2007, Sokolov et al. 2009)), and the presence (P^+) or absence (P^-) of water-borne chemical cues from a predatory blue crab for a 4-week period. This medium-term exposure period has been considered an appropriate time frame to observe the effects of ocean acidification (*i.e.*, pCO_2-induced seawater acidification) and water-borne predation cues on mussel morphology (Berge et al. 2006, Kroeker et al. 2014, Gestoso et al. 2016), with some studies observing effects in as little as 20 days (Duarte et al. 2015). The ambient, or present-day, pCO_2 target level of 400ppm was comparable to average pCO_2 levels observed in Tampa Bay, Florida, USA, where mussels for this study were collected (Yates et al. 2007). Mussels were housed in an outdoor experimental pCO_2 system at the Climate Change Laboratory, University of Miami in Florida, USA. The design of the system consisted of a one-way flow-through glass aquaria system within a mesocosm (Figure 4.1). From the sump (Figure 4.1 a), water was pumped to the primary tanks (Figure 4.1 b) and gravity fed to the secondary tanks in the system (Figure 4.1 c). From the secondary tanks, water overflowed into a water bath (Figure 4.1 d) that buffered temperature fluctuations. The resulting system contained a total of four primary and four secondary tank replicates per treatment. Mussels reared for the growth experiment were frozen directly after we took the last live growth measurements and subsequently oven-dried to determine soft tissue and shell weight growth; therefore, these mussels could not be used for the handling time experiments. Thus, we had two groups of mussels used for the growth and handling time experiments. Each experimental tank housed a total of 24 mussels, 10 of which were monitored for the growth experiment, and 14 were included in the handling time experiment.

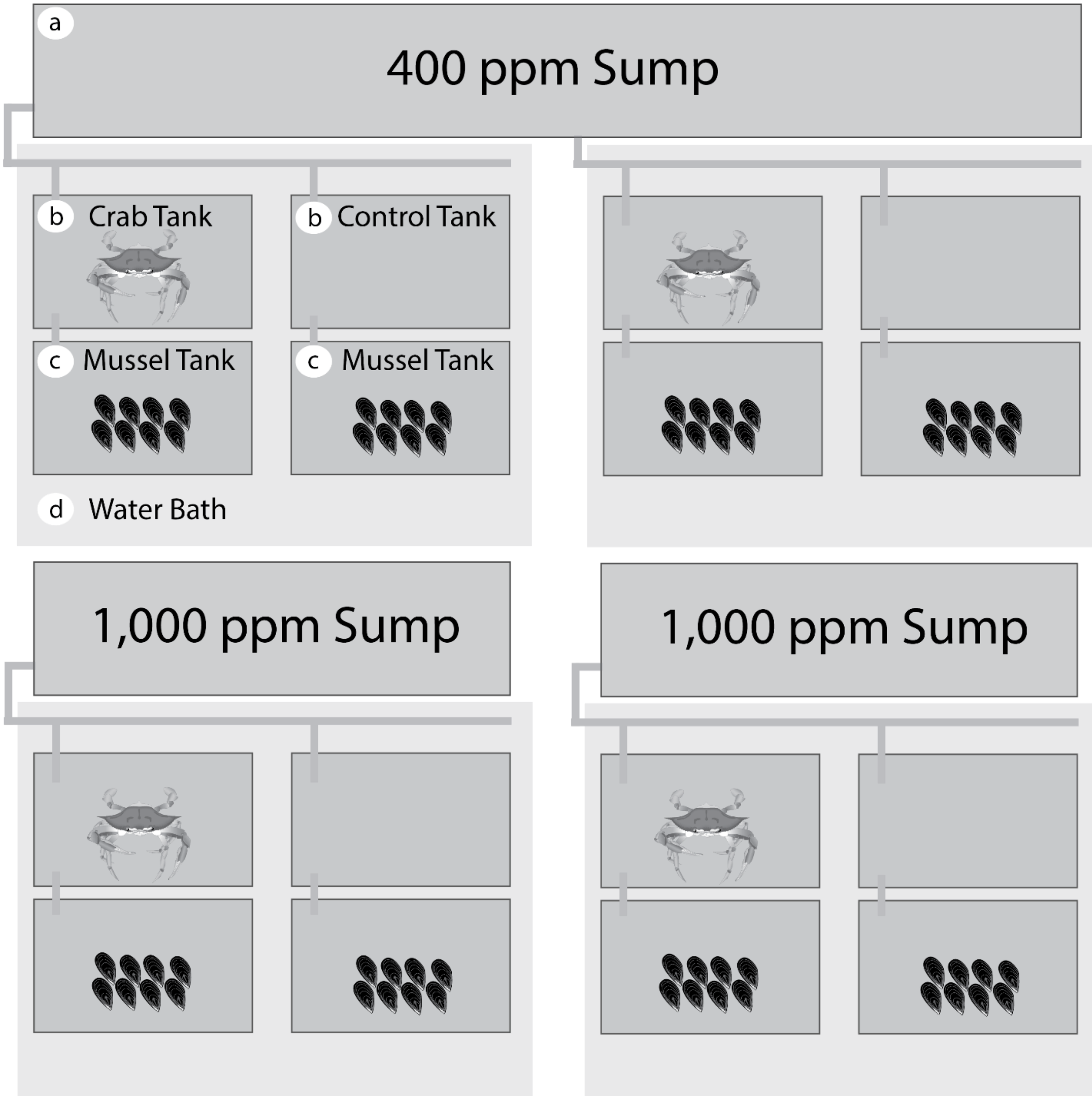

Figure 4.1 Schematic of the ocean acidification experimental system. Letters represent the sequence of water flow from the sump (a) to the water bath (d)

Natural seawater for the experimental system was supplied from intakes near Bear Cut, Key Biscayne, Florida, USA. Seawater passed through a series of biological filters down to ten microns before reaching the experimental tanks. Blue crabs have been observed occasionally near the water intake pipe, so it is possible some predator cues from the environment were taken into the system. However, the presence of these cues would not have been constant and their concentration would have been extremely low. Due to the flow rate of the system, we did not anticipate the occasional presence of diluted cues to influence our results.

Control tanks were bubbled with ambient air directly from an oil-free air compressor. Sumps in the high pCO_2 treatments were bubbled with a mixture of ambient air and pure CO_2 gas, regulated by adjusting mass flow controllers (Sierra Instruments 810C) and bubbled through venturi diffusers. The experimental tanks were open to exchange gas with the atmosphere; therefore, experimental tanks were also aerated with the appropriate gas mixture to maintain the targeted pCO_2 levels. We monitored CO_2 concentrations in the experimental tanks in real time using a shower-head equilibrator/Licor (LI-820) CO_2 analyzer system, calibrated against a zero and a 700-ppm span gas at the beginning of the experimental period. The partial pressure of CO_2 in the equilibrator was logged every five minutes by a HOBO U30 data acquisition system. Experimental tanks were exposed to natural light conditions, attenuated by a neutral density shade cloth, and water flow was maintained at a constant rate of 0.3 L/minute, resulting in complete water replacement in experimental tanks approximately every 30 minutes.

4.2.2. Chemical and physical parameter measurements

Temperatures in the experimental tanks were measured and logged every five minutes by the HOBO system. We recorded salinity weekly using a YSI Model 30 Temperature/Salinity meter that was calibrated prior to each use against a 50.0 mSiemen standard solution. We monitored water chemistry by collecting weekly water samples (150 mL) from experimental tanks at 10 am (time of day when the CO_2 level in the tanks crossed the midpoint between the early morning maximum and the late afternoon minimum), fixing them with 60 µL of saturated $HgCl_2$, and measuring their total alkalinity (TA) and dissolved inorganic carbon (DIC). TA was measured on an automated open-cell Gran titrator (precision 0.2%). The HCl titrant was standardized against certified reference material (Andrew Dickson Lab, Scripps Institute of Oceanography). DIC was measured using a DIC analyzer (Apollo SciTech Inc.) and standardized to the same certified reference seawater. The carbonate system parameters pCO_2 and aragonite saturation state (Ω_{Ar}) were computed from the measured temperature, salinity, DIC, and TA using the CO2Sys Macros Excel sheet (Version 2.1, 18 September 2012).

4.2.3. Specimen collection and response parameters

Southern ribbed mussels (mean $\pm$ SD shell length = 17.38 ± 1.46 mm, n = 140), were collected from intertidal habitats in Tampa Bay, Florida, USA (27.84°N, 82.61°W) in May 2015. Mussels acclimated at ambient pCO_2 for two days, after which pCO_2 was increased by 150ppm every 24 hours from ambient until reaching target pCO_2 levels. Live blue crabs (n = 8) were obtained from local fishermen in Biscayne Bay, Florida, USA and were transported to the lab less than 24 hours after capture.

Southern ribbed mussels were fed 2.1x10^4 cells/day/mussel of refrigerated phytoplankton (Shellfish Diet 1800) to standardize food availability across treatments and through time, per convention in existing literature (Kroeker et al. 2014). Mussels did not receive significant nutrition from plankton introduced to their tanks by the seawater supply due to intake water filtration (Towle et al. 2015). Homogenate conspecific signals have been shown to induce anti-predator traits in prey (Yamada et al. 1998, Robson et al. 2010); therefore, crabs were fed southern ribbed mussel conspecifics once a day to mimic natural conditions and increase the probability of eliciting induced defenses on mussel morphology.

Southern ribbed mussel growth rates were calculated from morphometric traits (*i.e.*, shell length, shell width, and mussel wet weight in air and in water) measured weekly during the 4-week experimental period. Mussels were removed from their holding tanks to determine mussel weight in water (buoyant weight) to the nearest 0.001 g. They were then blot dried and measured for shell morphometrics to the nearest 0.01 mm and measured wet weight to the nearest 0.001 g. Mortality was low (percent mortality per treatment: elevated pCO_2*P^- = 2.5%, elevated pCO_2*P^+ = 2.5%, ambient pCO_2*P^- = 7.5%, and ambient pCO_2*P^+ = 5%); therefore, mussels that did not survive the 4-week period were not included in the analysis. We considered a mussel dead when it did not close its valves after being mechanically stimulated.

Mussel shell and soft tissue weight growth rates were calculated from changes in their buoyant and wet weights, respectively, verified with dry weight measurements of the shells after the end of the experiment (Palmer 1982). At the end of the growth experiment mussels were frozen in -80°C and transported to the College of Marine Science, University of South Florida, St. Petersburg, Florida, USA for further analysis. Mussels were dried at 60°C for 48 hours, weighed, and dried again in a muffle furnace at 500°C for 6 hours. The regression model used for calculating shell and soft tissue weight growth rates was developed using a separate subset of mussels not used for the growth experiment, which varied in shell length between 11.34 mm and 33.33 mm (mean $\pm$ SD shell length = 16.31 ± 3.87 mm, n = 30). Regressions for dry weight vs wet weight were extremely precise (shell weight linear regression, r^2 = 0.999, soft tissue weight linear regression, $r^2 = 0.857$). Calculated values for soft tissue and shell weight were used for all further analyses, since calculated values were significantly and strongly correlated to post-experiment measured values (soft tissue weight linear regression, $r^2 = 0.493$, $F_{2,136} = 134.2$, $P = 0.001$; shell weight linear regression, $r^2 = 0.999$, $F_{2,131} = 17{,}358$, $P = 0.001$).

4.2.4. Handling time experiment

We followed the 4-week growth experiment with a predation experiment to determine how any effects of increased pCO_2 and predation cues on southern ribbed mussel morphology affected predation susceptibility. Specifically, we measured handling times of mussels by predatory crabs across experimental treatments. Blue crabs (mean ± SD carapace width = 133 ± 8 mm, $n = 24$) were acclimated to target pCO_2 levels for a period of four days prior to the feeding experiment. Crabs were fed southern ribbed mussel conspecifics *ad libitum* for three days and starved for one day prior to the feeding trial to normalize hunger among test crabs. Each crab was placed in a test tank and allowed to feed uninterrupted for 1 hour on mussels reared in the experimental treatments. Trials were videotaped and handling times were measured via video analysis to prevent altered feeding behaviors due to human presence. We measured handling time from the crab's first crushing behavior to when it abandoned the empty shell.

4.2.5. Statistical analyses

Parametric statistical analyses were performed using the R statistical software (version 3.4.4) (R Core Team 2018). Outliers at two standard deviations were excluded from the analyses. Growth rates for shell length and width were correlated to the initial shell length and width measurements; therefore, we analyzed morphometric growth data using two-way Analyses of Covariance (ANCOVA). Data were square root transformed prior to ANCOVA to meet the normality assumptions of the analysis.

For those data that did not meet the assumption of normality, we used non-parametric (np) permutation-based tests, using the Fathom Toolbox for Matlab (Jones 2014). All permutation-based tests were performed using 5,000 permutations of the data and a significance level of $\alpha = 0.05$. We used three-way non-parametric Analyses of Variance (npANOVA) to test whether individuals in different tanks exhibited different responses independently of the pCO_2 and predator treatments in which they were reared. Since there was no significant effect of rearing tank on growth of any morphometric, nor synergistic effect of tank with any other variable, (all p-values > 0.05), individuals within a tank were considered replicates for all further analyses. The effects of elevated pCO_2 and presence of water-borne predator cues on crab handling times were tested using one- and two-way npANOVAs.

4.3. Results

4.3.1. Experimental system

The experimental system maintained target pCO_2 levels throughout the experimental period (Table 4.1), with no significant differences across the control and predator present treatments (Table 4.2). As expected, TA did not differ across treatments (Figure 4.2) while DIC was significantly higher in the elevated pCO_2 than the ambient treatment (Figure 4.3). The fact that we observed no difference in TA across treatments provides evidence that, as expected of effective experimental pCO_2 systems, observed differences in pCO_2 and Ω_{Ar} were driven by differences in DIC. Rather than static conditions, this experimental system was designed to expose mussels to more ecologically-relevant variable pCO_2 conditions. The system was successful in meeting this goal, as pCO_2 in experimental tanks fluctuated throughout the day both in the ambient and elevated pCO_2 treatments (Figure 4.4). Further information about carbonate system parameters can be found in the supplementary data Appendix B. Supplementary data for Chapter 3. Inducible defenses of intertidal mussel not affected by pCO_2-induced seawater acidification (Table B.1).

Table 4.1 Carbonate system parameters for the experimental pCO_2 system. DIC and TA were measured in situ, and both pCO_2 and Ω_{Ar} were calculated using the CO2Sys Macros Excel sheet (Version 2.1, 18 September 2012). Data are average of samples taken weekly from each experimental tank. P^- and P^+ symbolize predator absent (control), and predator present treatments, respectively. Reported here are mean values ± 1 SD

Treatment	Salinity	Temperature (°C)	DIC	TA	pCO_2	Ω_{Ar}
Ambient pCO_2 P^-	37.5 ± 0.8	29.9 ± 1.8	1972.6 ± 60.9	2301.4 ± 66.7	466.8 ± 95.9	3.62 ± 0.54
Ambient pCO_2 P^+	37.6 ± 0.7	29.6 ± 1.0	1955.3 ± 49.6	2303.5 ± 67.8	423.9 ± 65.8	3.82 ± 0.41
Elevated pCO_2 P^-	37.6 ± 0.7	29.8 ± 1.1	2146.8 ± 44.4	2306.7 ± 65.6	1114.2 ± 196.4	2.02 ± 0.30
Elevated pCO_2 P^+	37.5 ± 0.7	30.0 ± 1.1	2128.3 ± 69.1	2306.6 ± 72.6	1027.0 ± 260.1	2.20 ± 0.45

Table 4.2 Two-way npANOVA results for the effects of pCO_2 and predator treatments on the measured carbonate system parameters DIC and TA (n = 80); bold depicts significance at the α = 0.05 level

System Parameter	Treatment	df	F	p-value
DIC	pCO_2	1	138.8	**< 0.001**
	Predator	1	1.949	0.153
	pCO_2*Predator	1	0.002	0.965
TA	pCO_2	1	0.074	0.780
	Predator	1	0.004	0.946
	pCO_2*Predator	1	0.005	0.947

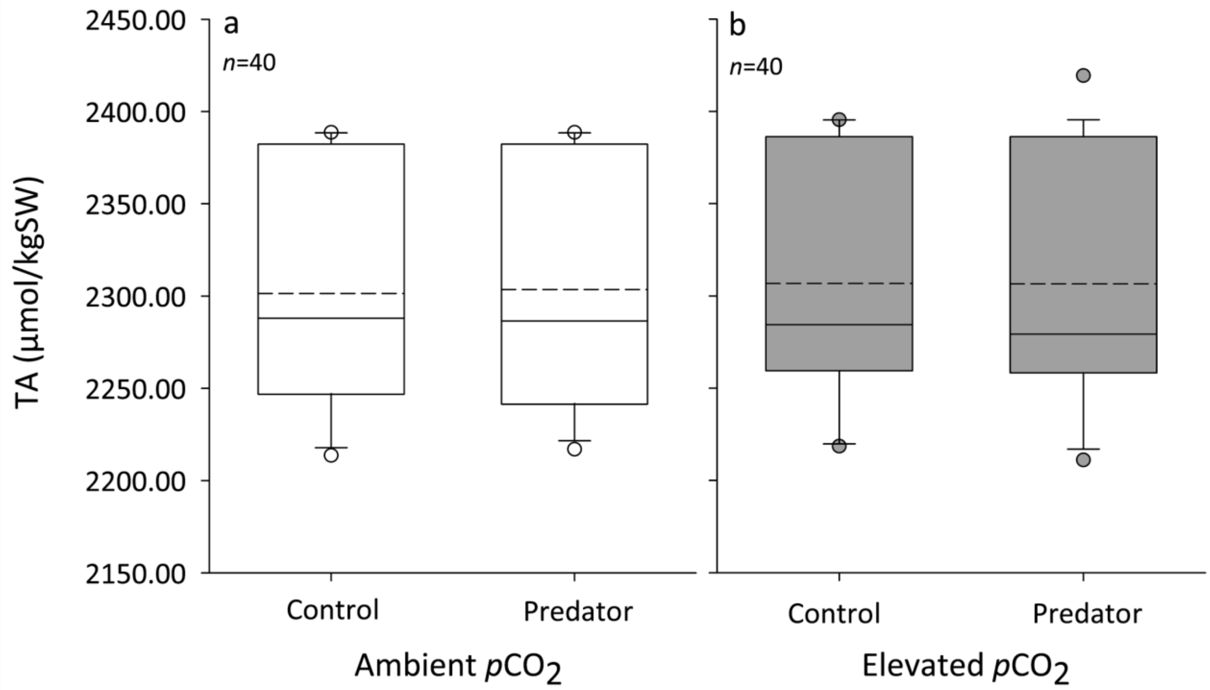

Figure 4.2 Boxplots a and b show comparisons of TA between predator absent (P^-) and predator present (P^+) treatments at ambient and elevated pCO_2 treatment levels, respectively. Dashed lines represent the mean, solid lines represent the median, and dots represent outliers at the 95th percentile. Shading represents pCO_2 level: white (ambient) and grey (elevated)

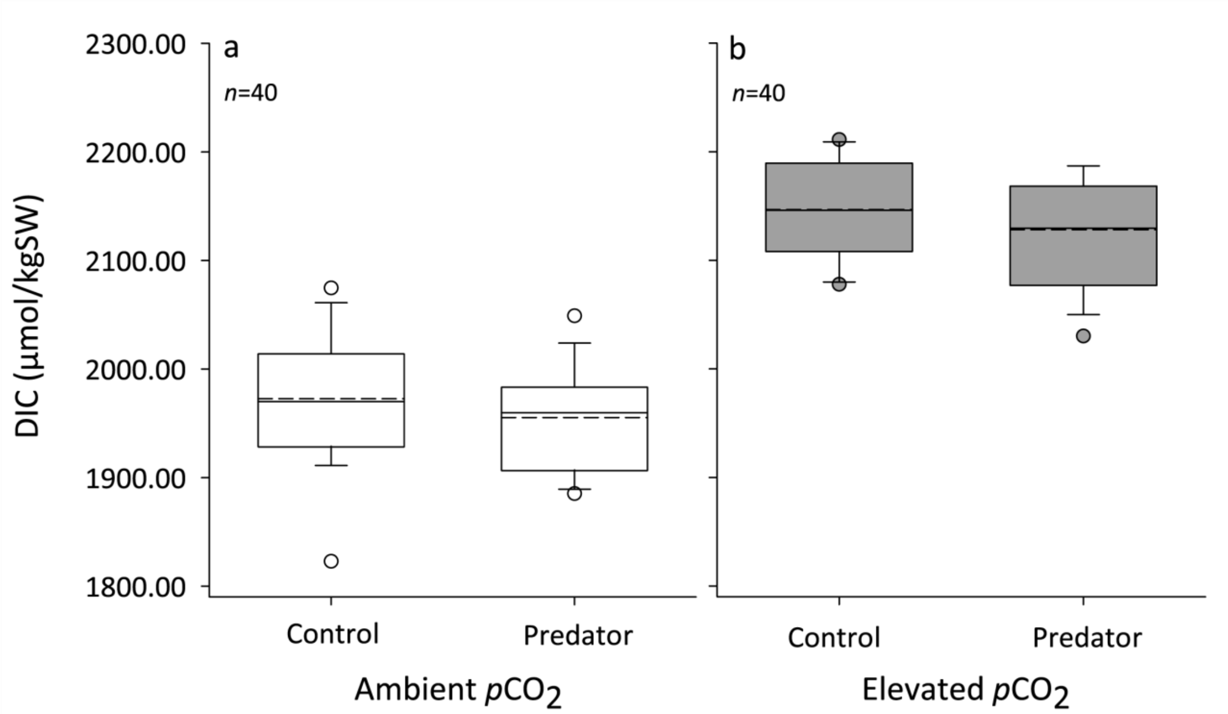

Figure 4.3 Boxplots a and b show comparisons of DIC between predator absent (P^-) and predator present (P^+) treatments at ambient and elevated pCO_2 treatment levels, respectively. Dashed lines represent the mean, solid lines represent the median, and dots represent outliers at the 95th percentile. Where dashed line is not visible the mean and median overlap. Shading represents pCO_2 level: white (ambient) and grey (elevated)

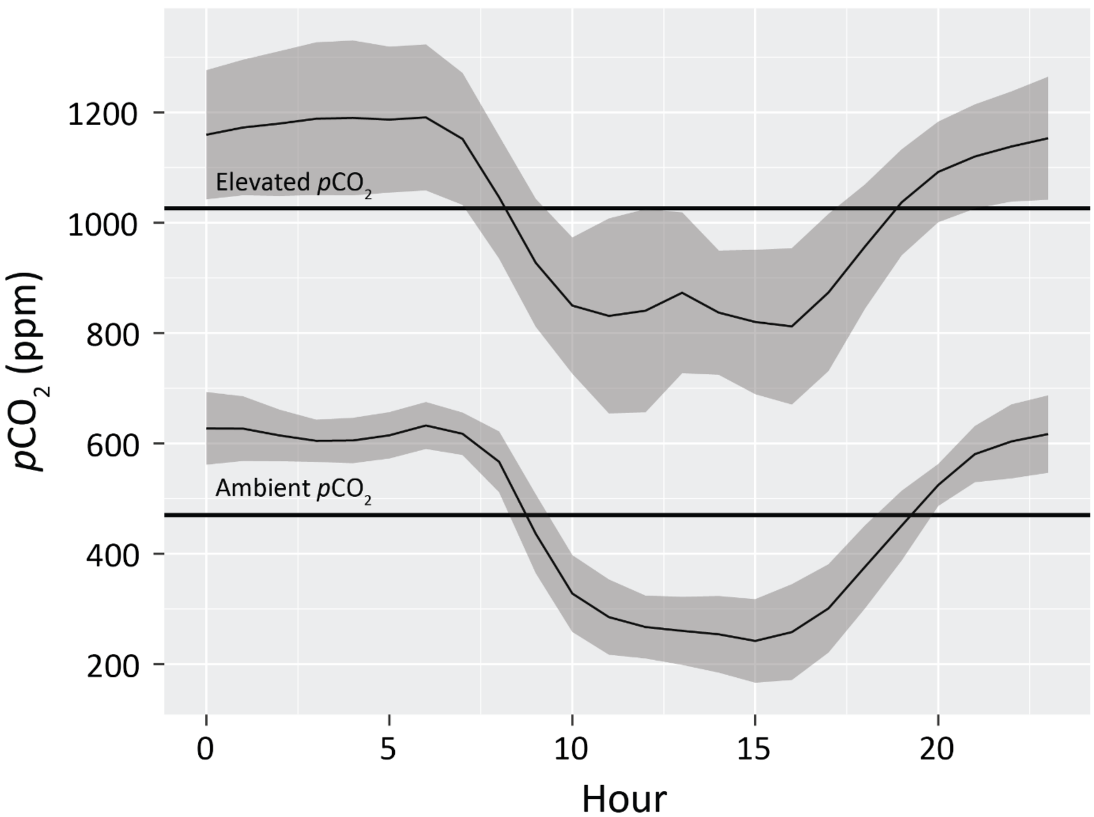

Figure 4.4 Composite plot of *p*CO_2 fluctuations throughout a 24-hour period. Data were aggregated into hourly bins and then averaged. Black lines represent average at that hour, gray bands depict ± 1 SD, and thick black lines represent average *p*CO_2 for that experimental treatment

4.3.2. Mussel growth response

Southern ribbed mussels reared in the presence of a predator exhibited significantly higher growth rates in shell length and shell width than those in the control treatment, independent of the *p*CO_2 treatment (Table 4.3). Mussels showed increased shell depth in elevated *p*CO_2 conditions compared to ambient *p*CO_2 conditions (Table 4.3). However, mussel shell weight and soft tissue weight growth did not differ across *p*CO_2 or predator presence treatments (Table 4.3).

Table 4.3 Two-way ANCOVA results for the effects of pCO_2 and predator treatments on the measured mussel morphometrics, with initial morphometric measurement as a covariate. Bold depicts significance at the $\alpha = 0.05$ level

Morphometric	Treatment	df	F	p-value
Shell length	Correlation with initial	1	6.14	**0.015**
	pCO_2	1	0.82	0.366
	Predator	1	4.66	**0.033**
	pCO_2*Predator	1	0.08	0.776
Shell width	Correlation with initial	1	6.41	**0.013**
	pCO_2	1	0.71	0.402
	Predator	1	6.91	**0.009**
	pCO_2*Predator	1	1.48	0.226
Shell depth	Correlation with initial	1	1.74	0.189
	pCO_2	1	3.94	**0.049**
	Predator	1	0.56	0.454
	pCO_2*Predator	1	0.28	0.598
Soft tissue weight	Correlation with initial	1	1.439	0.232
	pCO_2	1	0.006	0.936
	Predator	1	1.917	0.169
	pCO_2*Predator	1	1.551	0.215
Shell weight	Correlation with initial	1	0.920	0.339
	pCO_2	1	2.198	0.141
	Predator	1	2.893	0.091
	pCO_2*Predator	1	0.003	0.955

4.3.3. Handling time experiment

Average handling times for crabs on mussels reared in the presence of predator cues did not differ from those reared in control conditions, for either ambient or elevated pCO_2 treatments (Figure 4.5). However, in elevated pCO_2 conditions handling times were significantly more variable for mussels reared in the presence of a predator than those in the control group (Figure 4.5, dispersion $F_{1,66} = 4.24$, dispersion p-value = 0.042, $n = 67$). Under elevated pCO_2 conditions, handling times for mussels from the control treatment ranged from 38 to 213 seconds, while they varied from 32 to 334 seconds in the predator present treatment (Figure 4.5).

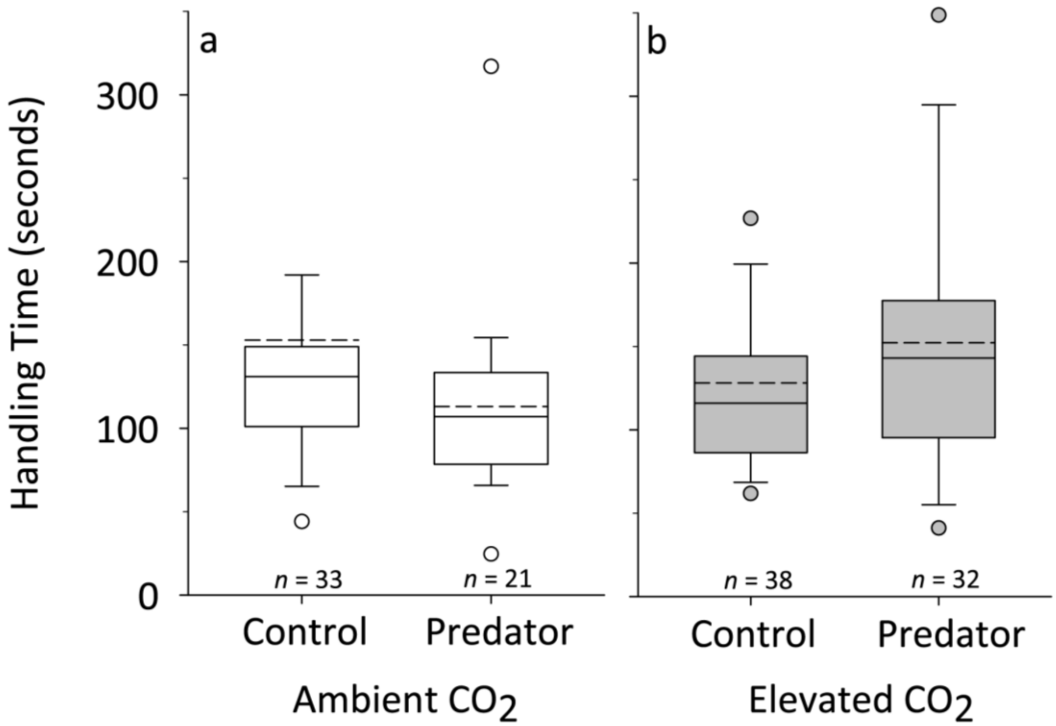

Figure 4.5 Boxplots a and b show comparisons of handling times between predator absent (P^-) and predator present (P^+) treatments at ambient and elevated $p\mathrm{CO_2}$ treatment levels, respectively. Dashed lines represent the mean, solid lines represent the median, and dots represent outliers at the 95th percentile. Where dashed line is not visible the mean and median overlap. Shading represents $p\mathrm{CO_2}$ level: white (ambient) and grey (elevated)

4.4. Discussion

Our results indicate that inducible defenses of adult southern ribbed mussels (*G. granosissima*) were not affected by mid-term exposure to elevated pCO_2. However, and counterintuitively, growth in shell depth was higher for mussels reared in elevated pCO_2 conditions. On average, these effects on mussel morphometrics did not affect crab handling times, but mussels reared in the presence of a predator under elevated pCO_2 conditions had highly variable handling times.

Southern ribbed mussels exhibited greater shell length and width growth rates in the presence of predation cues than in the control, independent of pCO_2 treatment. This response was expected, as mussels grow their shells as an inducible defense against the threat of predation (Leonard et al. 1999, Smith and Jennings 2000, Caro and Castilla 2004, Freeman 2007). In their studies, Freeman (2007) and Smith and Jennings (2000) reported that mussels thickened their shells in response to cues from crab predators, but had to limit linear shell growth (*i.e.*, shell length and width) to focus their available energy towards increasing shell thickness. In our study, however, we observed the opposite effect; the observed increases in shell length and width were not accompanied by increased shell weight, meaning that mussels increased linear shell growth (*i.e.*, shell length and width) at the expense of shell weight. Although we did not measure shell thickness or shell crushing force in this study, growth in shell weight is positively related to shell thickness (Reimer and Tedengren 1996, Frandsen and Dolmer 2002) and shell thickness is positively correlated to a mussel's ability to withstand crushing force (Leonard et al. 1999). Consequently, prey with thicker shells are less likely to be consumed by predatory crabs (Palmer 1985). We can assume, then, that when mussels in our study did not increase shell weight in response to the presence of predation cues, they also did not increase shell thickness or strength. Therefore, these mussels would have been just as vulnerable to predation as those reared in control conditions. This was evidenced by our results for the handling time experiments, which showed no difference in average handling times for mussels reared in the presence of a predator when compared to those reared in control conditions.

The question remains, however, of why mussels would grow in shell length and width instead of shell weight, since this is the trait to offer the most effective protection against predation. Adult blue crabs prefer feeding on ribbed mussels with shells shorter than 25 mm to maximize energy ingestion while minimizing energy expenditure and handling time (Elner and Hughes 1978, Hughes and Seed 1981). It is possible that mussels in our study expended energy in growth in shell length and width, instead of shell weight, to move out of their predators' preferred feeding size range. However, mussels from the predator-present treatment in our study, under both ambient and elevated pCO_2 conditions, were consumed in a similar timeframe as mussels reared in the absence of a predator. Therefore, the growth in shell length and width that mussels developed as a response to predation cues was unable to provide protection from predation.

The available literature on the effects of elevated pCO_2 on mussels to date is equivocal. Some studies have found elevated pCO_2 decreased linear shell growth (Michaelidis et al. 1999, Berge et al. 2006, Thomsen and Melzner 2010, Melzner et al. 2011, Range et al. 2012), decreased calcification (Gazeau et al. 2007, Zhao et al. 2017), and increased shell dissolution (Melzner et al. 2011), while others have provided evidence for no effect of elevated pCO_2 on shell growth (Thomsen et al. 2010, Hiebenthal et al. 2013), shell breaking force (Hiebenthal et al. 2013), calcification (Ries et al. 2009), or somatic and tissue growth (Beesley et al. 2008, Thomsen et al. 2010, Thomsen and Melzner 2010, Melzner et al. 2011, Range et al. 2012). It is important to note, however, that most studies reported shell growth solely in terms of linear length, which has been deemed a poor indicator of pCO_2 effects on mussel growth and morphology (Gazeau et al. 2013). In our case, and contrary to our expectations, results indicated that mussel growth rates in shell depth increased under elevated pCO_2 conditions when compared to those reared in ambient conditions, independent of predator treatment. Mussels reared in the presence of a predator under elevated pCO_2 conditions were, therefore, the only group that had increased growth in all three morphometrics (shell length, width, and depth) compared to all other treatments. These mussels developed rounder, more globular shapes, and were the only group to experience significantly more variable handling times than any other group. Rounder, thicker shells have been shown to improve survival from shell-crushing predators, such as crabs (Bronmark et al. 2011). Therefore, the observed change in shell shape could have been a form of inducible defense to improve protection, even when mussels were not able to develop thicker shells (Fitzer et al. 2015).

Changes in both shape and structural integrity of bivalve shells can be affected by elevated pCO_2 levels, and, therefore, alter their ability to protect themselves against predation (Amaral et al. 2012). Although continuous deposition of calcium carbonate structures is not affected by elevated pCO_2 (Findlay et al. 2011, Fitzer et al. 2014), some studies have found that the composition and structure of those calcium carbonate layers is compromised under elevated pCO_2 in the form of compensated protein metabolism, increased calcite growth, structural disorientation of calcite crystals, stiffer and harder calcite shells, and reduced aragonite shell layer (Fitzer et al. 2014, Fitzer et al. 2015). Together, these effects resulted in shells with brittle calcite outer layers and less stiff inner aragonite layers with a decreased ability to flex before failing, and therefore, a higher vulnerability to fractures, like those that might occur during a predator attack (Mackenzie et al. 2014, Fitzer et al. 2015, Fitzer et al. 2015).

The effects of elevated pCO_2 on mussel shell structures indicate that, although mussels in our study grew in shell depth and developed more globular shapes in the presence of predation cues under elevated pCO_2 conditions, these changes might not have been enough to protect them against the threat of predation. Our data partially support this notion; we did not observe differences in average handling times across predator and pCO_2 treatments. We did, however, observe significantly more variable handling times for mussels reared in the presence of predation cues under elevated pCO_2. More specifically, these differences were driven by greater variability at the higher end of handling times. This means, then, that some mussels reared in the presence of predation cues under elevated pCO_2 conditions experienced longer handling times than mussels reared in control conditions under elevated pCO_2. It is possible that the changes in shell shape shown by mussels reared in the presence of predation cues under elevated pCO_2 conditions provided some protection against predation, but not enough to elicit differences in average handling times when compared to mussels reared in control conditions.

This study allowed us to observe a possible relationship between predation cues, elevated pCO_2, and changing shell shape. More research is needed to elucidate how these changes in mussel morphology could affect crab predator handling times under CO_2-induced seawater acidification, perhaps through a longer mussel rearing period, using a greater sampling size, or taking into account cross-generational effects through a multi-generational study. Offspring of bivalves exposed to elevated pCO_2 have shown to be more resilient to this environmental stressor (Parker et al. 2012), and species with greater phenotypic variation have more options under natural selection (Sunday et al. 2011). These traits could affect how mussels respond to CO_2-induced seawater acidification and predation cues under stressful environmental conditions. Another possible future area of research would be to focus on predators in predator-prey interactions. Under elevated pCO_2 conditions, crustaceans have been observed to express altered behavior to chemical cues from food odor (de la Haye et al. 2012), and crabs have reduced prey consumption (Dodd et al. 2015) and claw strength (Landes and Zimmer 2012). These effects of elevated pCO_2 on crab predators' morphology and behavior related to predation could have further consequences for their interactions with mussel prey.

As intertidal estuarine organisms, southern ribbed mussels are usually exposed to variable environmental conditions and have developed adaptations for these habitats (Lent 1969). Although some intertidal organisms can be especially vulnerable to extreme environmental changes (Somero 2010), others have shown greater resilience when exposed to stressful physical conditions. For example, Leung *et al.* (2017) found that intertidal gastropods were more resilient to shell dissolution by elevated pCO_2 than their subtidal counterparts. Southern ribbed mussels are not only intertidal organisms, but they are also prevalent in estuarine environments. Many estuarine organisms are already living at their physiological tolerance limits (Connell 1972, Somero 2002, Davenport and Davenport 2005), but sensitivity to these extreme environmental conditions is species-specific and research is only now determining how these sensitivities relate to the effects of pCO$_2$-induced seawater acidification on bivalve morphology (Gazeau et al. 2013, Shaw et al. 2013, Guo et al. 2015). It is possible that southern ribbed mussels in our study may be tolerant of elevated pCO$_2$ levels due to their adaptation to these highly variable environments. Guo *et al.* (2015) expressed a similar idea, hypothesizing that the tolerance of oysters to elevated pCO$_2$ levels might be due to their adaptability to estuarine habitats with fluctuating environmental parameters.

Most of the work researching the effects of pCO$_2$-induced seawater acidification on bivalves so far has focused on measuring morphological effects under static conditions, but pCO$_2$ is a highly variable environmental parameter with significant diel cycles (Shaw et al. 2013). Moreover, the effects of these changes to mussel morphology on predator-prey interactions remain primarily theoretical, as very few studies have tested how the development of inducible defenses might be affected by pCO$_2$-induced seawater acidification (Kroeker et al. 2014). Through this study we aimed to investigate how predator-prey interactions might be affected by pCO$_2$-induced seawater acidification by including these considerations, using an experimental system that allowed for the inclusion of diurnal pCO$_2$ variability and including exposure to predation cues as a simultaneous stressor. We found that under these conditions, pCO$_2$-induced seawater acidification did not affect the development of inducible defenses, and therefore average handling times by crab predators, in adult southern ribbed mussels. Most studies evaluating pCO$_2$-induced seawater acidification on mussel morphology tend to extrapolate on how their results, often obtained under static conditions without the presence of predation cues, could affect predator-prey interactions, but these data are not enough to deduce future effects on species interactions (Landes and Zimmer 2012). Even when prey morphology is affected by treatment conditions, it does not necessarily mean this effect will translate across trophic levels. It is important to consider the complexity of animal physiology, morphology, and interspecies relationships when making deductions on predator-prey relationships in a changing ocean.

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CHAPTER 5. IDAHO STUDENTS GAIN DEEPER UNDERSTANDING OF CLIMATE CHANGE AND SHOW CORRECTION OF MISCONCEPTIONS AFTER INTERDISCIPLINARY CLIMATE CHANGE OUTDOOR EDUCATION PROGRAM

5.1. Introduction

The vulnerability of human communities to climate change depends on location, reliance on predictable weather patterns (*e.g.*, agricultural communities), exposure to extreme weather events (*e.g.*, heat waves), and economic dependency on natural ecosystems (*e.g.*, fisheries), among others (Pachauri et al. 2014). The public's perception to climate change, however, can be heavily influenced by the framing of the message (Gifford and Comeau 2011) and often depends on the perceived level of risk it presents to the individuals in question (Brody et al. 2008). It is argued, then, that to increase the public's concern and willingness to act to ameliorate the effects of climate change, we, as science educators and communicators, must present it as a current phenomenon with tangible consequences for human communities (Busch 2016).

The North American Association for Environmental Education (2004) states that effective environmental education is learner-centered, engaging, active, "hands-on, minds-on", provides real-word context, and views the environment within the context of human influences, among other factors. Based on these guidelines, effective climate change education could be attained by using a variety of instructional approaches, including experiential (Kolb and Kolb 2009), active, and inquiry- and place-based learning (Theobald 2006, Monroe et al. 2017), and the socioscientific issues teaching and learning model (Burek and Zeidler 2015). Each of these educational approaches has specific benefits for the learner. Experiential learning draws on learners' natural curiosity to lead the learning process through first-hand experience (Kolb 1984), which makes it a natural and seamless approach to learning. Place-based educational approaches aim to bridge the social and environmental aspect of science education by drawing upon the environmental, cultural, economic, and political facets of environmental issues (Smith 2007). It has many benefits, including increasing the likelihood that students will work on projects that are of real value to their communities, increasing collaboration, enhancing students' attitudes toward their schoolwork and communities, affecting students' motivation for and engagement in learning, and better retaining content knowledge (Powers 2004). The socioscientific issues pedagogical framework introduces science as an important part of society, rather than it being separate, adding an element of real-world application of science to the larger social structure (Dolan et al. 2009, Zeidler et al. 2009). This pedagogical framework puts emphasis on evidence-based reasoning, ethical and controversial issues, character formation, and scientific inquiry (Zeidler 2014). The benefits from using the socioscientific instructional framework include increasing science content knowledge, enhancing science literacy, developing critical thinking skills, and improving reasoning and argumentation skills (Dolan et al. 2009, Burek and Zeidler 2015). Used together, these frameworks can create a learner-centered instructional approach that includes student engagement through hands-on activities, first-hand experience with the scientific method and the inquiry process, placement of science in a social context, and discussions of how human communities might be affected by these scientific concepts and what actions we can take to counteract those effects.

Climate change education has made use of some of these frameworks in unison and has provided evidence of the efficacy of their approaches (Monroe et al. 2017). However, most of the programs that have reported successfully using interdisciplinary instructional approaches have taken place in the classroom, and very few have taken place in informal settings (Monroe et al. 2017). Outdoor education, a type of informal education, is not well represented in the climate change education literature. Outdoor environmental education is inherently place-based and experiential, as it emerges from the particular geographic, ecological, social, and political dynamics of that place (Woodhouse and Knapp 2000). Therefore, it is a fitting setting for an interdisciplinary climate change educational approach, especially in Idaho, USA, where natural resources and outdoor recreation contribute significantly to the economy (Southwick et al. 2009). However, a careful review of the literature (Monroe et al. 2017) revealed no studies assessing the efficacy of climate change informal programs, such as in an outdoor education setting, for middle school students (grades 6-8) through empirical data analysis.

The literature suggests that the combination of an interdisciplinary instructional framework in an outdoor setting would be an excellent approach for climate change education. Therefore, this study was designed to investigate how middle-school students in Idaho make meaning about climate change after experiencing an interdisciplinary instructional program taking place at an outdoor school. We aimed to (1) determine the efficacy of the program on students' content knowledge about the causes and consequences of climate change to natural and human communities, (2) analyze students' depth of understanding of these concepts before and after the program, and (3) understand how students make meaning of climate change within their greater social context, including actions and behavioral changes they could implement.

5.2. Methods

5.2.1. Study location and audience

The effects of climate change are global and include further warming and long-lasting changes in all components of the climate system (Pachauri et al. 2014). Climate change is, therefore, expected to have adverse social consequences and amplify existing risks for natural and human systems (Khoshnevis Yazdi and Shakouri 2010, Perry et al. 2011, Hollowed et al. 2013, Pachauri et al. 2014, Weatherdon et al. 2016). In Idaho, the expected effects of climate change include increased number of days of high fire danger (Brown et al. 2004), expansion of desert areas (US Environmental Protection Agency 2016), and decreased snowpack and earlier springtime melts (Stewart et al. 2004). Decreased snowpack is expected to reduce streamflows and detrimentally affect salmon, steelhead, trout, and other cold-water fish (Agency 2016), which could have further socioeconomic repercussions, as many human communities economically depend on these fisheries (Firth and Fisher 2012). Furthermore, effects on snowpack and streamflow could in turn reduce crop yields (Isik and Devadoss 2006) and livestock production (US Environmental Protection Agency 2016). These predictions provide evidence that Idaho is particularly vulnerable to the consequences of climate change. However, only 65% of Idaho residents believe global warming is happening and, although 52% of Idaho residents agree that global warming will harm people in the US, only 35% think global warming will harm them personally (Howe et al. 2015). Climate change education in Idaho is, therefore, extremely important, making it a model location to evaluate the efficacy of an interdisciplinary educational program.

The McCall Outdoor Science School (MOSS) is an outdoor, residential K-12 school specialized in STEM (Science Technology Engineering and Math) education, administered by the University of Idaho and located in Ponderosa State Park, McCall, Idaho, USA. Students in Idaho travel to MOSS for weeklong immersive STEM programs. MOSS' mission is to facilitate place-based, collaborative science inquiry within the context of Idaho's land, water, and human communities. The program's focus on science education through place-based approaches made this an ideal setting for the implementation and assessment of our interdisciplinary climate change program. A total of 22 middle school age students (6^{th} to 8^{th} grade) from Idaho, USA, attended the weeklong (Monday through Friday) climate change program at MOSS during the summer of 2017.

5.2.2. Program curriculum and assessment

We developed the program curriculum using tools from the experiential, active, and inquiry- and place-based learning approaches, as well as the socioscientific issues pedagogical framework. This interdisciplinary approach focused on using local natural and social examples that were personally relevant to the students to address the science and issues of climate change. The program curriculum focused on student-centered practices where instructors took a facilitator role providing structure and context, and relied heavily on the scientific inquiry process. It also addressed Disciplinary Core Ideas from the Next Generation Science Standards (States 2013), as well as essential principles from the science and climate literacy standards (US

Global Change Research Program 2009) (see Appendix D. The natural and human dimensions of climate change in Idaho). This program also aimed to develop social literacy skills in students by allowing them to engage in the processes of inquiry, exploration, and decision-making (Arthur et al. 2014). With so many tried and tested instructional resources available, our goal was to compile already developed climate change activities and organize them in a way that they built upon each other to reach the main goals of the program. An activity guide with step-by-step instructions for instructors, and background information was also developed and provided to the instructors (see Appendix E. Climate change curriculum activity guide).

The program curriculum consisted of four content time blocks and two evening programs with specific goals. The curriculum content was organized in time blocks to allow for flexible and versatile programming that field instructors could manipulate to work within the limitations of the field conditions. A full visualization of the program schedule is included in Table 5.1. Students arrived midday Monday and departed midday Friday. The content blocks and evening programs took place during two field days and two evening program time slots on Tuesday and Wednesday. Students also spent approximately 15 minutes in the mornings and afternoons with the program leader to introduce the day's topics and to discuss their findings, respectively. On Thursday, students developed either an inquiry project or engineering challenge to further investigate the causes or consequences of anthropogenic climate change. The results of these student-led projects were presented on Friday to an audience of fellow students, MOSS staff, and students' family members.

During the weeklong climate change program, the program leader divided the group of 22 students into three field groups of 7-8 students, each led by a field instructor. Field instructors had been trained in student-centered instructional practices and inquiry-based learning in an outdoor setting during the previous academic year (2016-2017). Instructors received a one-day training in the climate change program activities prior to the program week and participated in the development of field materials. Groups were with their field instructors Tuesday, Wednesday, and Thursday during the morning and afternoon time blocks (Table 5.1). All students were together for the evening programs, pre- and post-assessments, and project presentations (Table 5.1).

Table 5.1 At-a-glance schedule of the climate change program. Times were approximate and depended on field conditions. Dark grey boxes depict times before arrival and after departure of students. Colors represent which instructors the students were with during that period: blue (program leader), green (field instructors), yellow (program leader + field instructors)

Time	Monday (Arrival Day)	Tuesday (Field Day)	Wednesday (Field Day)	Thursday (Project Day)	Friday (Departure Day)
Morning (9-9:15am)		Morning Meeting	Morning Meeting	Morning Meeting	Project Presentations
Morning Block (9am-12pm)		Content Block 1	Content Block 3	Inquiry Project	
Afternoon Block (1pm-4pm)	Arrival & Setting of Expectations	Content Block 2	Content Block 4		
Afternoon (4-4:15pm)		Afternoon Meeting	Afternoon Meeting	Afternoon Meeting	
Evening (6pm-8pm)	Pre-Assessment	Evening Program	Evening Program	Post-Assessment	

This study was developed as an instructional intervention with pre/post assessment, approved by the University of South Florida Internal Review Board (see Appendix G. Institutional Review Board (IRB) determination letter and Appendix C. Supplementary data for Chapter 5. Idaho students gain deeper understanding of climate change and show correction of misconceptions after interdisciplinary climate change outdoor education program 1. Considerations for research with human subject). Climate scientists and environmental educators, following the goals of the program, developed the pre/post assessment instruments. Two instruments were used: a concept map prompt and a short open-ended questionnaire (available in Appendix F. The natural and human dimensions of climate change in Idaho: Assessment tools). Concept maps have served as an assessment tool to determine learning and conceptual change (Rebich and Gautier 2005) and questionnaires are common instructional assessment tools in climate change educational research (Anderson 2012). The two assessment instruments were analyzed through a mixed-methods approach including both quantitative and qualitative data analysis (Ponce and Pagán-Maldonado 2015). For the concept maps, we compared the list of concepts used by students pre- and post-program. Answers to the open-ended questionnaire were scored (from 0 to 4) using a taxonomic scoring rubric (see Appendix F. The natural and human dimensions of climate change in Idaho: Assessment tools) to determine depth of content understanding and compare pre- and post-program answers. The scoring rubric was developed by a climate change scientist and incorporated whether students used concepts from a master concepts list. The master list was created by using students' answers to the concept maps. Thus, the analysis of the two assessment tools built upon each other. Questionnaire answers were also analyzed qualitatively to determine overarching themes, identify misconceptions, and investigate shifts in perspectives and how students make meaning about climate change.

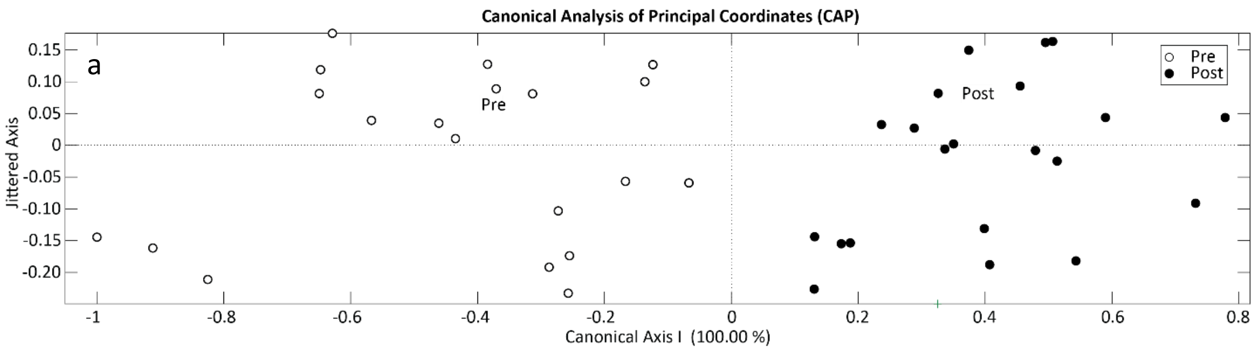
5.2.3. Statistical data analysis

All statistical analyses were performed using the Fathom Toolbox for Matlab (Jones 2014). Non-parametric permutation-based tests were used for all statistical analyses using 5,000 permutations of the data and a significance level of $\alpha = 0.05$. Questionnaire scores were compared pre- and post-program through a non-parametric permutation-based Analysis of Variance (npANOVA). We used a Canonical Analysis of Principal Coordinates (CAP) (Anderson and Willis 2003) to test differences in the list of concepts used during the pre- and post-program concept maps. We used a Jaccard distance matrix, an appropriate approach to presence-absence data (Hubalek 1982), as an input for the CAP analysis. The CAP analysis also used the Leave-One-Out (LOO) method to determine significant differences between words and language used in pre- and post-program concept maps. Using the CAP method allowed us to not only determine significance of differences pre- and post-program, but also determine which concepts contributed most to the distribution of data. A proportional chance criterion test was then used to determine if the classification success rate of the CAP was significantly better than a null model that assigns group membership via random allocation. The p-value in this test represented the probability that the observed classification success rate was no better than that expected by chance.

5.3. Results

5.3.1. Concept maps

The words used by students in the concept maps were statistically different pre- and post-program (Figure 5.1, % variance explained by model = 69.91%, LOO success rate = 80.95%, p-value < 0.001). There was a clear division in the data, suggesting a considerable shift in students' choice of language to describe climate change before and after the program (Figure 5.1 a). The concepts used pre-program focused on the effects of climate change on the Earth's physical system (*e.g.*, temperature, warmth) while post-program concepts used spanned a greater conceptual range, including both causes (*e.g.*, fossil fuels) and consequences (*e.g.*, fire) of anthropogenic climate change (Figure 5.1 b). Post-program concept maps also included the term 'blanket', an analogy used during the climate change program in reference to the Earth's greenhouse effect. Further information can be found in the supplementary data in Appendix C. Supplementary data for Chapter 5. Idaho students gain deeper understanding of climate change and show correction of misconceptions after interdisciplinary climate change outdoor education program, Table C.2.



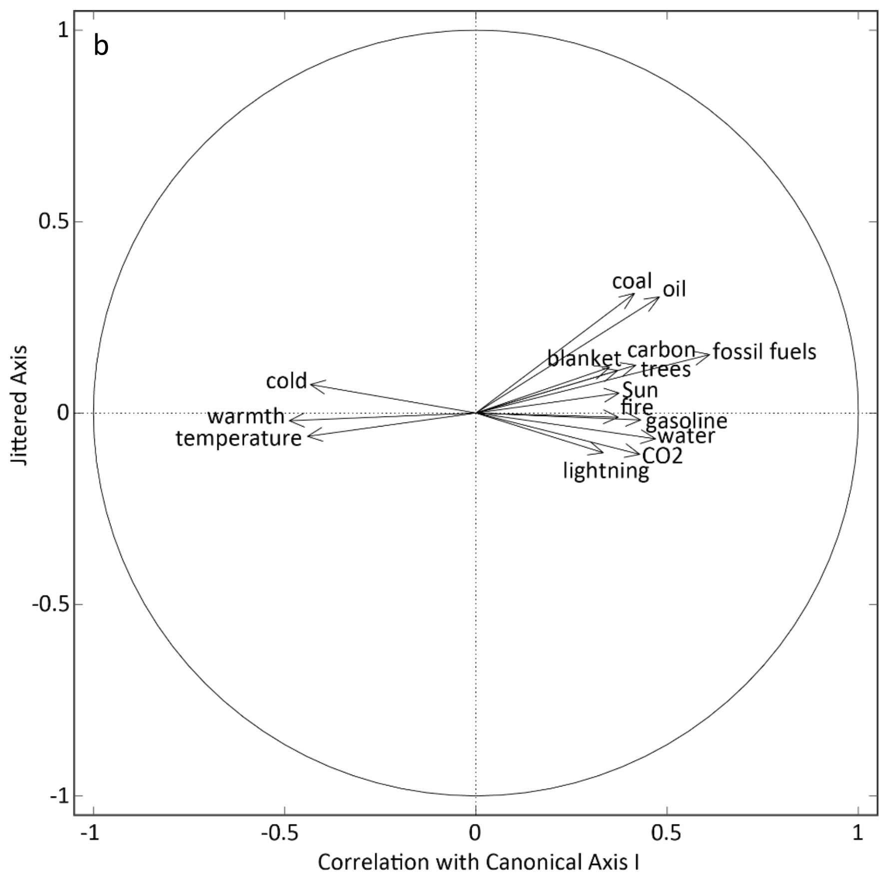


Figure 5.1 (a) Canonical Analysis of Principal Coordinates (CAP) plot for concept map data. Each dot represents a student and shading represents timing, prior to (white) and after (black) students completed the climate change week curriculum. The “Pre” and “Post” labels represent

the central tendency of the data at that time frame. (b) Correlation vector plot corresponding to CAP plot. Direction and length of the arrows represent direction and magnitude, respectively, of the influence of this concept on the spread of the data on plot (a). The jittered axis on the y-axis of both graphs is only for visualization purposes; the spread of the data along this axis was not considered in the analysis

5.3.2. Questionnaires

Student scores significantly increased post-program for all four of the open-ended questions included in the questionnaire (Figure 5.2 a-d). In pre-program answers, students provided distant examples of the effects of climate change on animals and people, but provided more local examples during the post-program assessment (Table 5.2). Although some students scored similarly pre- and post-program, they showed improved understanding of how climate change might affect their *local* communities and ecosystems in their post-program answers. Answers to the questionnaire also showed correction of some common misconceptions related to climate change (Table 5.3). Further information can be found in the supplementary data in Appendix C. Supplementary data for Chapter 5. Idaho students gain deeper understanding of climate change and show correction of misconceptions after interdisciplinary climate change outdoor education program.

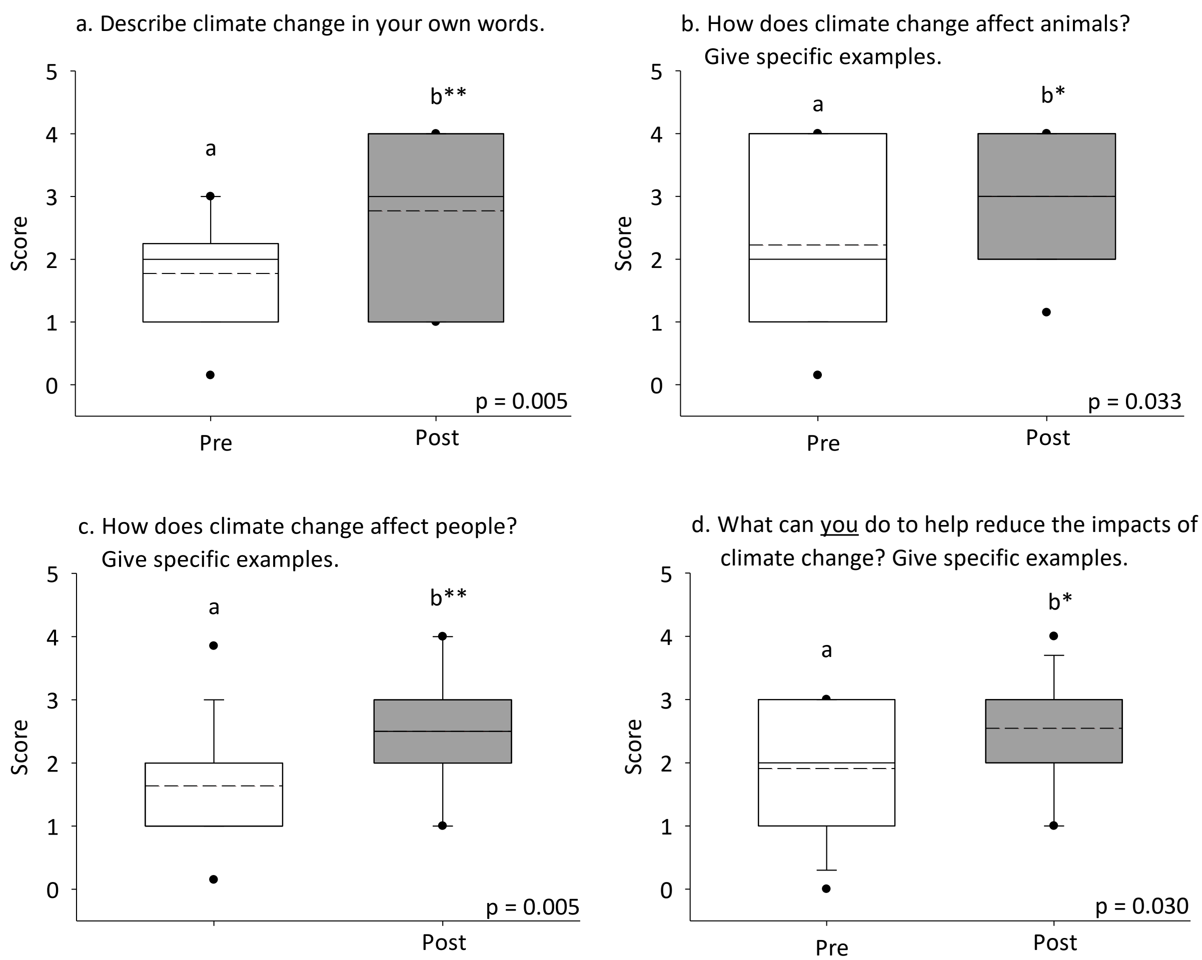


Figure 5.2 Boxplots of scores to questionnaire questions 1-4 (a-d, respectively) before (white) and after (grey) students completed the climate change week curriculum. Dashed lines represent the mean, solid lines represent the median, and dots represent outliers at the 95th percentile. Where dashed line is not visible the mean and median overlap. Lower case letters represent pairs with significant differences in mean scores and asterisks depict level of significance (*< 0.05, **<0.01); n=22 for all questions

Table 5.2 Sample questionnaire answers that showed a shift from using distant examples of climate change effects on animals and people to more local examples. Each row includes answers for pre- and post-program questionnaire answers by the same student

Pre-program answer	Post-program answer
"Climate change affects animals because of the certain adaptations an animal has for living in that specific environment. For example, if the arctic is getting warmer, the amount of fur on a polar bear might cause it to overheat, and eventually die off. Along with their environment melting."	"Climate change affects animals by forcing out of their habitat or forcing them to adapt. For example, picas might not have a place to go if squirrels and porcupines keep moving into its habitat in search of a cooler climate."
"[Climate change] could melt the cold climate they live in. The melting of ice could cause penguins to lose their homes. Glaciers melting could affect wildlife."	"[Climate change] can destroy their habitat, like for salmon water is getting warmer so they can't migrate. It could cause overcrowding of one habitat due to animals having to move."
"Climate change affects people because it can give situations that they have never had to be prepared for, like tsunamis, hurricanes, extensive rain and snow, heat stroke, among other things."	"Climate change affects others because when animals (like fish) die, it cuts off resources/food, like the Nez Perce tribe."

Table 5.3 Sample questionnaire answers that showed correction of common climate change misconceptions. Each row includes answers for pre- and post-program questionnaire answers by the same student

Misconception	Pre-program answer	Post-program answer
Climate = weather/seasons	"Climate change affects people by giving them seasons. We always have to dress appropriately. Also, some climates are getting warmer with global warming."	"Climate change affects people a lot. People continue to add more and more CO_2 to the atmosphere, which makes it hotter. This could mean acidic water. Hotter temperatures, and maybe less crops or food from animals."
Relationship to ozone depletion	"Climate change is the difference in temperature/weather in certain areas. It can make some places warmer, as well as other places cooler. It happens because of depletion of the ozone layer, caused by pollution."	"Climate change is the heating of the planet caused by extra carbon in the atmosphere."
Relationship to Earth axis	"Climate change is caused because the Earth is on an axis and causes only some parts of the world heat up quicker than other parts."	"Climate change is how carbon gets released into the atmosphere and traps heat in so it can't get out of the atmosphere as well as it could before."

When discussing how they could help reduce the effects of climate change (question 4 of the questionnaire), students' pre-program answers were broad and seemingly unfocused. Some students included measures that, although environmentally conscious, would not directly help mitigate climate change. Post-program, however, student answers spanned from reducing fossil fuel emissions, to engineering solutions for adaptation, to more age-appropriate and accessible actions like engaging their communities through communicating about and raising awareness of the issue (Table 5.4).

Table 5.4 Sample questionnaire answers to "What can you do help reduce the impacts of climate change? Give specific examples." Each row includes answers for pre- and post-program questionnaire answers by the same student

Pre-program answer	Post-program answer
*	"I can help reduce impacts of climate change by spreading the word about it."
"Recycle, replant, precycle, etc."	"I can use less energy, buy electric-powered cars. Start a change in my community for less fuel emissions, etc."
"I can check the weather and make sure people are aware of temperature and climate."	"I can conduct experiment and test thing [*sic*] that could help like finding ways to put fires out faster, and stronger structures that floods or earthquakes can't harm."
"Not pollute a lot of bad things into the environment. And promptly dispose of dangerous waste."	"Don't use as much fossil fuel related things. When people mine gas, oil, etc. It releases CO_2 into the air which is one [of] the leading factors in climate change."

*Left question blank

5.4. Discussion

The results of this study show the efficacy of an interdisciplinary climate change educational program using tools from the experiential, active, and inquiry- and place-based learning approaches, as well as the socioscientific issues pedagogical framework. Data showed that students: (1) increased their content knowledge on climate change causes and consequences, (2) exhibited a deeper understanding of climate change through the words they used to describe it, and (3) corrected common climate change misconceptions.

Questionnaire scores for all four questions showed evidence for learning about climate change, its effects on animals and humans, and what actions students could take to address the problem. It was not surprising to see increased post-program scores, since the program's main goal was to increase content knowledge in these areas. What was surprising, however, was the change we observed in how students expressed themselves regarding climate change. The pre- and post-concept maps provided evidence of a significant change in the concepts and language students used to describe climate change and its consequences. Students shifted from using concepts that mainly focused on the consequences of climate change on the Earth's physical system (*i.e.*, temperature changes) to including concepts that more closely described the causes of anthropogenic climate change (*i.e.*, fossil fuels, greenhouse gases). This is an especially important result, since there have been observations of middle-school students lacking rich conceptualizations of climate change, especially as it related to the greenhouse effect and the emission of fossil fuels (Shepardson et al. 2009).

Answers to the questionnaire open-ended questions allowed us to observe other trends not visible in the concept map and questionnaire score analyses. We observed how students shifted from thinking about climate change as a distant phenomenon in pre-program answers, to seeing it as a problem that could affect their local natural environments and human communities. For example, several students mentioned salmon as an example of an organism that would be affected by climate change, which has economic and cultural importance in Idaho (National Research Council 1996). Similarly, some students also mentioned how the Nez

Perce people would be affected by these changes, since they are dependent upon salmon for their livelihood (Colombi 2012). Several students also mentioned how farmers would be affected by climate change in their post-program questionnaire answers. The effects of climate change of agricultural crop yields are an important issue in the USA (Isik and Devadoss 2006), especially for Idaho, a state whose economy depends strongly on agriculture (Watson 2016). The fact that students chose to use the local examples discussed throughout the curriculum rather than default to the more distant examples they had used in the pre-program assessment points toward an internalization of the problem of climate change and what that means for their local communities.

Students appeared to have remediated some common climate change misconceptions, based on the questionnaire answers. Three common climate change misconceptions stood out in the analysis of the pre- vs. post-program answers: the difference between climate and weather, anthropogenic climate change due to the hole in the ozone layer, and climate change due to the tilt in the Earth's axis. Although correcting these misconceptions was not a primary goal of the program, our inquiry-based learning approach allowed students to work through these ideas and ultimately gain a better understanding of the processes that contribute to anthropogenic climate change. These results support previous findings that active, student-centered activities are more effective at remediating climate change misconceptions than teacher-centered learning (Karpudewan et al. 2015).

Through the climate change program, we presented the phenomenon as a socioscientific issue, addressing the social aspect of climate change through discussing its consequences on local communities. The climate change educational program used here was student-centered and focused on local examples of the effects of climate change, the complexities of these effects for local communities, and the environmental social justice repercussions of this controversial issue through evidence-based reasoning. These traits effectively placed this climate change program within the socioscientific issues pedagogical framework (Zeidler 2014). Students, therefore, benefitted from the outcomes of this pedagogical framework on content learning and increased concern for this social justice issue (Dolan et al. 2009), as evidenced by results from both the concept maps and questionnaires.

Wibeck (2014) warns against using “doomsday messages” to frame climate change education and communication, as they can lead to feelings of hopelessness and apathy; therefore, we also included in the program experiential activities to discuss possible actions to address the issue. Busch (2014) suggested a similar approach, including the social dimension and making it personally relevant to students. Answers to the questionnaire provided an insight into how these activities affected students’ willingness to act to limit the effects of climate change. Before completing the program, students’ answers spanned from expressing apathy to engaging in environmentally friendly practices that were not directly related to climate change mitigation. Students’ pre-program answers were in line with actions the public erroneously assume help mitigate the effects of climate change (Whitmarsh 2009). After the program, students identified actions and behaviors that were more focused and attainable, such as communicating the problem with others and leading a community effort. This result, allowing students to make a connection between their actions and global climate change, was deemed a sign of effective climate change communication by Cordero *et al.* (2008). These results show that by exposing students to different options for actions that are age-appropriate and attainable, they shifted their attitudes about their role in responding to climate change and provided a more hopeful and positive outlook. This type of student engagement with climate change might inspire action in conservation (Burek and Zeidler 2015, Busch 2016).

Socioscientific approaches to climate change education have been effective, with students developing a more accurate, detailed, and sophisticated understanding of climate change (Klosterman and Sadler 2010), and place-based and experiential learning approaches have been commonly used and effective for science and climate change education (Theobald 2006, Kolb and Kolb 2009, Hallar et al. 2011). The results of this study provided evidence of the efficacy of an interdisciplinary instructional approach that borrows from these different educational frameworks on increasing content knowledge and understanding of climate change science and its consequences for natural and human systems. What made this program so effective was not necessarily the content, but the student-centered instructional approach applied, supporting previous research on the efficacy of active, student-centered activities for student learning (Karpudewan et al. 2015).

This study is part of a limited amount of research that has assessed an educational intervention taking place at an outdoor school through empirically tested results (Monroe et al. 2017). The climate change program assessed in this study directly addressed four of the six strategies for effective climate change education identified by Monroe *et al.* (2017): (1) provide information that is personally relevant and meaningful to students, (2) engage learners through active practices, (3) use deliberate discussions, and (4) experience the scientific process personally. The program also indirectly addressed the remaining two strategies: (5) address misconceptions through discussions, and (6) designing and implementing school or community projects by asking what students can do to help mitigate the effects of climate change in the post-questionnaire and having students engage in an end-of-program project.

As we face the consequences of climate change, it is imperative to educate the public about the issue in ways that are relevant and engaging to our audiences (Wibeck 2014, Monroe et al. 2017), while also inspiring behavioral change to mitigate or adapt to these environmental changes (Lester et al. 2006). The discourse around climate change education and communication has too long been focused on climate change being a science problem; there is a need to transition our message to the fact that climate change is also a social problem, as it will inevitably have impacts on human communities (Busch 2016). Therefore, there is a call for our goals as climate change educators to go beyond merely understanding the science and move our efforts to engage the public to be a part of the scientific process (Wibeck 2014). The program assessed here takes such an approach, presenting climate change as a socioscientific issue and addressing its causes and consequences, for both natural systems and human communities. This interdisciplinary instructional approach can serve as an example for the development of effective climate change programs that uses already available instructional materials with intentional interdisciplinary goals.

5.5. Literature cited

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CHAPTER 6. CONCLUSIONS

The goal of this dissertation was to take an interdisciplinary approach to explore the issue of climate change for both coastal ecosystems and human communities through research that encompassed the systems engineering, marine ecology, and science education fields. Through this work I: (1) developed designs for climate change experimental systems that are accurate and ecologically-relevant, (2) presented evidence for the effects of climate change (elevated temperatures and pCO_2) on predator-prey relationships between coastal marine organisms through laboratory experiments, and (3) developed and assessed an interdisciplinary climate change curriculum for middle school students.

In Chapter 2, I presented designs for inexpensive climate-controlled systems capable of accurately reaching and maintaining target experimental conditions. Two separate experimental laboratory systems were built: a temperature-controlled system and an ocean acidification system. Experimental tank temperatures in the temperature-controlled system were manipulated indirectly by controlling the temperature in the surrounding water bath. This approach buffered fluctuations and resulted in a high level of control, allowing for setting temperatures as close as 1.2°C apart. The ocean acidification experimental system was designed to elevate normally fluctuating pCO_2 levels by a constant factor. This allowed the system's pCO_2 to fluctuate as expected in natural environments in the coming century, making it more ecologically relevant than active pCO_2-controlled systems.

In Chapter 3, I demonstrated that chronic heat stress can have detrimental morphological effects on intertidal mussels. I documented the ability of southern ribbed mussels (*Geukensia granosissima*) to survive chronic thermal stress, although with significant changes in shell morphometrics compared to lower temperatures. Mussels reared in elevated temperatures manifested more elongated shell shapes, which could affect their ability to protect themselves against predation. I provided evidence for the disruption of the predator effect on inducible defenses by thermal stress in temperatures over 30°C for southern ribbed mussels, followed by decreases in predator handling times. The observed shell elongation and lack of anti-predatory responses in elevated temperatures could make southern ribbed mussels more vulnerable to predation by blue crabs and other predators. Therefore, the presence of predator cues in natural environments should be considered when addressing the effects of elevated temperatures on marine organisms and when making inferences on the effects of climate change on coastal ecosystems.

In Chapter 4, I found that adult southern ribbed mussels' inducible defenses were not affected by a medium-term exposure to elevated pCO_2. Mussels grew more in shell length and width as a response to predation cues, independent of pCO_2 conditions. However, and unexpectedly, mussels reared under elevated pCO_2 exhibited greater growth in shell width independent of predator treatment, driving mussels reared in the presence of a predator under elevated pCO_2 conditions to develop rounder shapes. On average, these effects on mussel morphometrics did not affect crab handling times, but mussels reared in the presence of a predator under elevated pCO_2 conditions had highly variable handling times. It is possible that southern ribbed mussels in our study may be tolerant of elevated pCO_2 levels due to their adaptation to the variable conditions of their natural intertidal and estuarine environments. It is important to consider the complexity of animal physiology, morphology, and interspecies relationships when making deductions on predator-prey relationships in a changing ocean.

In Chapter 5, I demonstrated the efficacy of an interdisciplinary climate change educational program using tools from the experiential, active, and inquiry- and place-based learning approaches, as well as the socioscientific issues pedagogical framework. I found that students: increased their content knowledge on climate change causes and consequences, exhibited a deeper understanding of climate change through the words they used to describe it, and corrected common climate change misconceptions. The results of this study provided evidence of the efficacy of an interdisciplinary instructional approach that borrows from different educational frameworks on increasing content knowledge and understanding of climate change science and its consequences for natural and human systems. This work can serve as an example for the development of effective climate change programs that uses already available instructional materials with intentional interdisciplinary goals.

Climate change is a complex socio-scientific issue with layers embedded in the engineering, natural sciences, and educational fields, among others. My approach to such a complex issue was interdisciplinary in nature and involved working in collaboration with faculty and professionals in different fields. As science continues to move towards answering questions of concern for both science and society, research in STEM fields is moving towards more interdisciplinary approaches. This dissertation is an example of how this can be an efficient and comprehensive approach.

APPENDIX A. ELEVATED TEMPERATURES SUPPRESS INDUCIBLE DEFENSES AND ALTER SHELL SHAPE OF INTERTIDAL MUSSEL

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ORIGINAL PAPER

Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel

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Abstract
As ocean temperatures continue to rise due to climate change, many questions remain on how coastal species will cope with a changing environment. The effects of increased temperatures on bivalves has been well examined through single-species studies, showing reductions in tissue mass, shell growth, oxygen uptake, feeding rates, and survival. However, the consequences of these effects on predator–prey interactions remain poorly understood. We examined how increased temperatures (30, 32, 34 °C) and the presence of water-borne predation cues from blue crabs (*Callinectes sapidus*) affected the morphology and growth rate of southern ribbed mussels (*Geukensia granosissima*), as well as their handling times when attacked by predatory crabs. Although southern ribbed mussels were able to survive under chronic heat stress, exposure to higher temperatures resulted in more elongated shell shapes. Growth rates in mussel wet weight were higher for mussels reared in the presence of a predator than in the predator-free control, but only in the low-temperature treatment. Likewise, handling times were greater for crabs eating mussels grown in the presence of a predator, but the effect was lost at the mid- and high-temperature treatments. These findings suggest that predation-induced defenses were suppressed when prey were under chronic thermal stress, which could make mussels more vulnerable to predation. The presence of predation cues in natural environments should be taken in consideration when estimating or predicting the effects of climate change on organisms.

Introduction

Increases in ocean temperatures as a consequence of climate change (Meehl et al. 2007) raise questions on how coastal species will cope with a changing environment. Estuarine and coastal marine environments can have highly variable ambient conditions, such as temperature and salinity. Because organisms living in these habitats have a wide tolerance to ambient abiotic conditions, many are already living at the edges of their environmental thresholds and can be sensitive to extreme changes (Connell 1972; Davenport and Davenport 2005; Somero 2002). Some intertidal organisms are already living near or at their physiological tolerance limit (Somero 2010). Sessile organisms, such as bivalves, are especially vulnerable to extreme environmental changes (Nicholson 2002), due to their inability to move from unfavorable conditions.

Coastal bivalves play important ecological roles, as they prevent erosion by providing structure and can increase concentration of nutrients in sediments (Bertness 1984). The southern ribbed mussel *Geukensia granosissima* is common in intertidal habitats across Florida, USA and is often associated with oyster-reef intertidal habitats. Ribbed mussels have a wide thermal tolerance and can occupy tropical intertidal habitats where both acute and chronic average temperatures can exceed 30 °C (Jost and Helmuth 2007; Read and Cumming 1967). Exposure to these and higher levels of chronic heat stress, however, can have detrimental effects. The effects of climate change on single species of coastal bivalves has been an area of special interest in recent years, with evidence that increased temperatures can drive reductions in shell growth and size-specific tissue mass (Fitzgerald-Dehoog et al. 2012; Miller et al. 2014; Zhao et al. 2017), reduced oxygen consumption (Ganser et al. 2015), metabolic energy deficiency (Tateda et al. 2015), increased cellular protein denaturation (Buckley et al. 2001), and decreased survival (Pincebourde et al. 2008; White et al.

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2015). However, the consequences of these single-species effects on predator–prey interactions remain poorly understood and predictions regarding how predator–prey species interactions will be affected by climate change are primarily theoretical (Kordas et al. 2011).

Ribbed mussels in oyster-reef intertidal habitats serve as a food source for many predators including the blue crab *Callinectes sapidus*, common in oyster-reef habitats (Peterson et al. 2003) and an important predator on intertidal mussels (Macreadie et al. 2011; Sherwood and Petraitis 1998). Crab predators can also induce anti-predator defenses on bivalves through water-borne chemical cues (Caro and Castilla 2004; Freeman 2007), making this a model predator–prey system to study the interactive effects of increased temperature and predator presence on mussel defenses and their consequences for predation susceptibility.

Predator–prey relationships are complex and can be affected by biological and physical processes (Blundon and Kennedy 1982; Connell 1961; Gestoso et al. 2015; Hughes and Seed 1981). Biological processes, such as inducible defenses in the form of increased shell size and thickness in bivalves, can be especially important for protection against predators (Caro and Castilla 2004; Freeman 2007; Harper and Skelton 1993). Abiotic stressors, such as increased temperatures, can negatively affect growth and alter the morphology of bivalves (Fitzgerald-Dehoog et al. 2012; Rodland et al. 2009; Talmage and Gobler 2011; Tateda et al. 2015). Thus, bivalves may become more susceptible to predation as increased temperatures decrease the protection afforded by their shells. However, few studies have tested the effects of elevated temperatures on inducible defenses in bivalves and how these in turn affect predator–prey interactions. There is, therefore, a need to examine how bivalve prey respond to elevated temperatures while in the presence of predation cues to better understand the effects of these environmental changes through a broader ecological perspective.

This study was designed to investigate the morphological responses of southern ribbed mussels to two simultaneous stressors: elevated temperatures and the presence of water-borne predation cues from blue crabs. More specifically, we tested whether (1) mussel growth and morphology were affected by elevated temperatures and the presence of water-borne predation cues, and if (2) any effects of these treatments on growth and mussel morphology led to differences in handling times by predatory crabs.

Materials and methods

Laboratory setup

Southern ribbed mussels were held in one of six cross-factored temperature × predator treatments: 30, 32, or 34 °C [seawater temperatures of present day and those expected for the years 2050 and 2100, respectively (Meehl et al. 2007; Sokolov et al. 2009)], and the presence (P^+) or absence (P^-) of water-borne chemical cues from a predatory blue crab for a 4-week period. This medium-term exposure period has been an appropriate time frame to observe the effects of temperature on mussel morphology (Gestoso et al. 2016; Kroeker et al. 2014), with some studies observing effects in as little as 2 weeks (Keppel et al. 2015). Temperature levels were maintained using an Apex AquaController system (Neptune Systems), equipped with 300-W Finnex titanium heaters. The experimental system was exceptionally efficient, maintaining tank temperatures within 0.2–0.6 °C of target temperatures (Table 1).

The experimental setup consisted of a flow-through, two-tank glass aquaria system (Fig. 1). Water originated from a temperature-controlled sump, flowed through a primary (predator) tank, and gravity fed to a secondary (mussel) tank. Water from all secondary (mussel) tanks overflowed into a temperature-controlled water bath to maintain constant and homogeneous temperatures across all tanks. Each primary (predator) tank held a single blue crab, and each secondary (mussel) tank held fifteen southern ribbed mussels. Predator-free control groups were held in the same two-tank experimental setup, but without a predator. The design of the experimental system allowed for movement of water-borne cues from the predators to the mussels, while preventing direct interactions. Each of the six temperature × predator presence treatments had 3 tank replicates, for a total of 18 experimental tanks. Each experimental tank held fifteen mussels, of which eight were monitored for shell growth (total mussels: 18 experimental tanks × 15 mussels per tank = 270 mussels; mussels monitored for growth: 18 experimental tanks × 8 mussels per tank = 144 mussels).

Flow was maintained at a constant rate of 3.28 mL/min, resulting in complete water turnover every 48 h. To avoid external chemical cues, artificial sea water (mix of DI water and Instant Ocean sea salt) was used, mixed to a target salinity of 32 ppt. Experimental tanks were exposed to a controlled 12:12 photoperiod and aerated with ambient air. Southern ribbed mussels were fed 5.7×10^7 cells/day per mussel (163 mg of organic matter per day per mussel) of refrigerated phytoplankton (Shellfish Diet 1800),

Table 1 Mean (± 1 SD) temperature values for each treatment during the 4-week laboratory experimental period

Temperature treatment	Number of observations (n)	Target temperature (°C)	Observed temperature (°C) ± 1 SD
Low	3702	30	29.7 ± 0.2
Mid	3556	32	32.1 ± 0.2
High	3403	34	33.9 ± 0.6

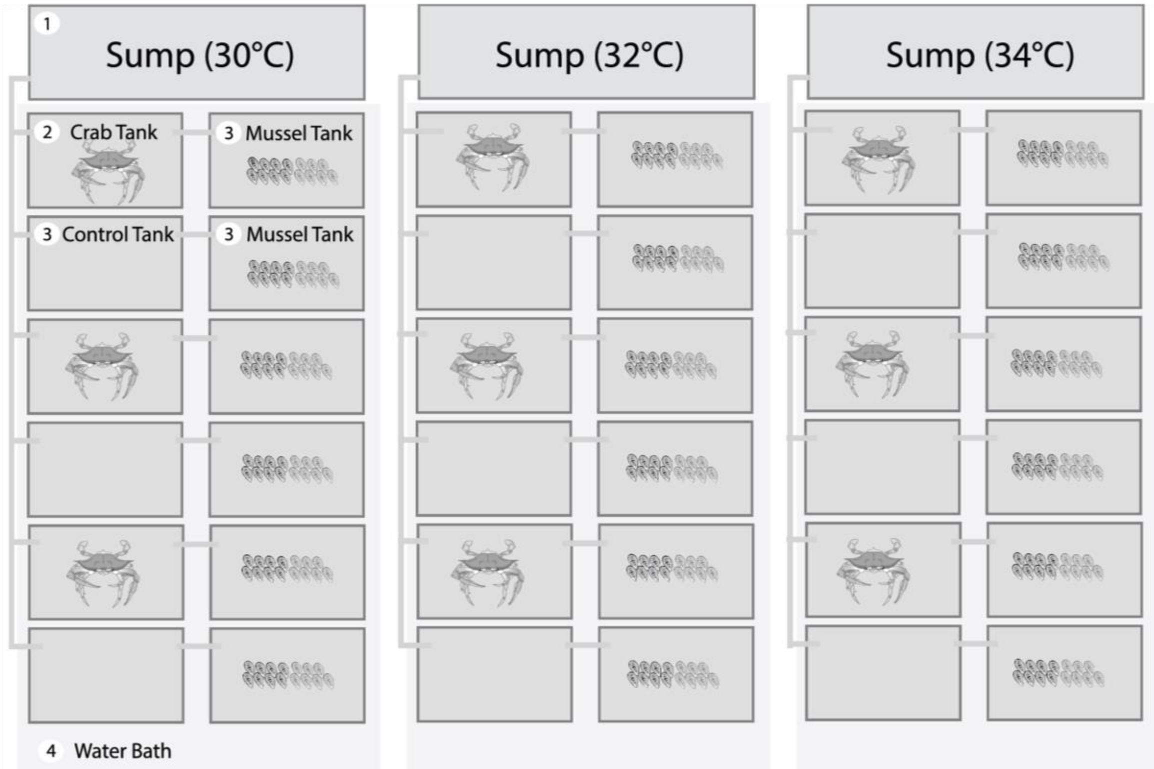

Fig. 1 Schematic of experimental temperature-controlled system. Water was pumped from (1) a temperature-controlled 190 L sump to (2) the 9.5 L crab/control tanks. Water then gravity fed to (3) the 9.5 L mussel tanks and overflowed onto (4) a temperature-controlled water bath that maintained temperatures constant and homogeneous across all experimental tanks. There were a total of 15 mussels per experimental tank, of which 8 (shaded dark) were monitored for shell growth

representing a minimum of 14% of the tissue dry weight of the mussels in the study. This amount of organic matter was greater than the recommended 3% by the food manufacturer (Reed Mariculture Inc. 2015; Helm et al. 2004), the amount of organic matter available in the mussels' natural environment (Environmental Protection Commission of Hillsborough County 2018), and food concentrations used in similar studies (Kroeker et al. 2014). Homogenate conspecific signals have been shown to induce anti-predator traits in prey sometimes even more than the presence of a predator itself (Robson et al. 2010; Yamada et al. 1998); therefore, crabs were fed southern ribbed mussel conspecifics once a day to mimic natural conditions and increase the probability of eliciting induced defenses on mussel morphology. By feeding crabs with mussel conspecifics we aimed to mimic natural environmental conditions where crabs commonly consume mussels in the immediate proximity of other mussels. Using this experimental design, we compared growth in mussels exposed to a combination of crab and mussel conspecific water-borne cues vs. growth in mussels exposed to neither.

Specimen collection and response parameters

Southern ribbed mussels (mean ± SD shell length = 19.47 ± 5.75 mm, $n = 270$), were collected from intertidal habitats in Tampa Bay, Florida, USA (27.84°N, 82.61°W) in October 2014. Mussels were transported in aerated containers to the laboratory and allowed to acclimate at a baseline temperature of mean ± SD = 25.25 ± 0.03 °C for 10 days. After the acclimation period, temperatures were increased by 1 °C every 12 h from the baseline temperature until target temperatures were reached. Live blue crabs (mean ± SD carapace width = 150 ± 11 mm, $n = 9$) were obtained from local fishermen in Tampa Bay and were transported to the lab less than 24 h after capture.

Morphometric traits of the southern ribbed mussels (i.e., shell length, shell width, and wet weight) were measured at the beginning and end of the 4-week experimental period. Mussels were removed from their holding tanks, blot dried, and measured for shell length and shell width using digital calipers to the nearest 0.01 mm. Mussels were then immediately placed on a digital scale to measure wet weight to the nearest 0.001 g. Mortality was low, with a total of 4 mussels that died from different experimental treatments during the experimental period (overall survival = 98.5%). Mussels that did not survive the 4-week period were not included in the analysis. We considered a mussel dead when it did not close its valves after being mechanically stimulated. Growth was represented as the change in shell length, shell width, and wet weight from start to end of the 4-week period, normalized by the initial values and expressed as a percentage.

Handling time experiment

To determine how any effects of increased temperature and predation cues on southern ribbed mussel morphology affected predation susceptibility, we followed the 4-week growth experiment with a predation experiment, measuring handling times of mussels by blue crabs across experimental treatments. Blue crabs (mean ± SD carapace width = 146 ± 16 mm, $n = 33$) were acclimated to target temperatures for a period of 4 days prior to the feeding experiment. Crabs were fed southern ribbed mussel conspecifics ad libitum for 2 days and starved for 1 day prior to the feeding trial to normalize hunger among test crabs. Each crab was placed in a test tank and allowed to feed uninterrupted for 1 h on mussels reared in the experimental treatments. We lost 28 mussels to an escaped predator during the handling time experiments; therefore, a total of 242 mussels were presented to crabs for the handling time experiments (66, 88, and 88 for low-, mid-, and high-temperature treatments, respectively; note that most of the lost mussels were from the low-temperature treatment, hence the difference in sample size). To prevent altered feeding behaviors due to human presence, trials were videotaped, and handling times were measured via video analysis. Handling time was measured from the crab's first crushing behavior to when it abandoned the empty shell. Not all crabs consumed all mussels made available to them during the handling time experiments; therefore, only handling times for mussels that were consumed were included in the analysis.

Statistical analyses

All statistical analyses were performed using the Fathom Toolbox for Matlab (Jones 2014). Data did not meet the assumption of normality; therefore, non-parametric permutation-based tests were used for all statistical analyses. All permutation-based tests were performed using 5000 permutations of the data and a significance level of $\alpha = 0.05$. Outliers at two standard deviations were excluded from the analyses. Initially, 144 mussels were monitored for morphometric growth. After accounting for the 4 mussel deaths and one outlier removed, a total sample size of 139 mussels remained for all growth data analyses. We used three-way analyses of variance (npANOVA) with tank as a nested factor to test whether individuals in different tanks exhibited different responses independently of the temperature and predator treatments in which they were reared. Since there was no significant effect of rearing tank on growth of any morphometric, nor interactive effects of tank with either temperature or predator presence (all P values > 0.25), individuals within a tank were considered replicates for all further analyses.

The effects of temperature and presence of water-borne predation cues on percent growth were tested using two-way npANOVAs followed by pair-wise tests. The effects of temperature and presence of predation cues on crab handling times were tested through analyses of covariance (npANCOVAs) using crab size as a covariate, since handling times were dependent on crab size [$r^2 = 0.035$, F (2,202) = 7.241, $P = 0.006$].

Results

Growth in shell length of southern ribbed mussels did not differ across temperature treatments (Table 2a, Fig. 2a). Percent growth in shell width varied across temperatures (Table 2a), with no differences between the low- and mid-temperature treatments, but significantly lower growth at the high-temperature treatment (Table 2b, Fig. 2b). These differences were largely driven by differences in the dispersion of the data [dispersion across temperature treatments npANOVA F (2,136) = 19.225, $P < 0.001$; low × high dispersion pair-wise test $t90 = 5.244$, $P < 0.001$; mid × high dispersion pair-wise test $t89 = 5.987$, $P < 0.001$]. The significant differences in data dispersion reflected the variability in the morphological response to temperature stress, with decreased magnitude and variance of percent growth in shell width as temperature increased (Fig. 2b). Percent growth in mussel wet weight was higher in the low-temperature treatment compared to the mid- and high-temperature treatments (Table 2a, b, Fig. 2c). Dispersions for percent growth in mussel wet weight were homogeneous across temperature treatments (all npANOVA P values > 0.05).

Water-borne predation cues did not affect percent growth in shell length or shell width, and had a marginally nonsignificant effect on mussel wet weight (Table 2a). Pair-wise comparisons revealed that at the low-temperature treatment, mussel wet weight was significantly higher in the presence than in the absence of predation cues (Fig. 3a) (pair-wise test $t45 = 2.465$, $P = 0.017$). This effect was not observed at the mid- (Fig. 3b) and high-temperature treatments (Fig. 3c) (pair-wise test P values > 0.05).

Table 2 (a) Non-parametric two-way ANOVA results for the effects of temperature and predator treatments on southern ribbed mussel percent growth in shell length, shell width and mussel wet weight ($n = 139$); (b) non-parametric pair-wise test results for the effects of temperature treatment on southern ribbed mussel percent growth in shell width and mussel wet weight; bold depicts significance at the $\alpha = 0.05$ level

(a) Morphometric	Parameter	*df*	*F*	*P* value
Length	Temperature	2	1.141	0.331
	Predator	1	0.0004	0.983
	Temperature × predator	2	0.487	0.625
Width	Temperature	2	**11.82**	**< 0.001**
	Predator	1	0.005	0.948
	Temperature × predator	2	0.533	0.581
Wet weight	Temperature	2	**13.48**	**< 0.001**
	Predator	1	3.442	0.066
	Temperature × predator	2	1.444	0.244
(b) Morphometric	Temperature level	*N*	*T* statistic	*P* value
Width	Low × mid	93	1.595	0.111
	Low × high	93	**3.629**	**< 0.001**
	Mid × high	92	**4.990**	**< 0.001**
Wet weight	Low × mid	93	**3.874**	**< 0.001**
	Low × high	93	**4.936**	**< 0.001**
	Mid × high	92	0.601	0.555

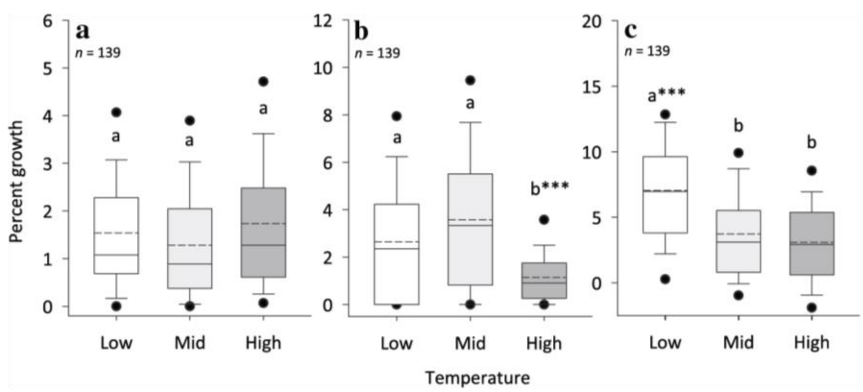

Fig. 2 Boxplots of percent growth in **a** shell length, **b** shell width, and **c** mussel wet weight by temperature treatment. Dashed lines represent the mean and dots represent outliers at the 95th percentile. Lower case letters represent pairs with significant differences in mean percent growth and asterisks depict level of significance (***< 0.001)

Temperature did not influence mussel handling times by crab predators [npANCOVA F (1,202) = 1.096, $P = 0.363$]. However, after removing the effect of crab size, residuals for mussel handling time in the low temperature treatment reflected the pattern observed in mussel wet weight growth (Fig. 4a). Crabs spent more time handling and consuming mussels reared in the presence of predation cues than those in the predator-free control group [npANCOVA F (1,57) = 4.108, $P = 0.048$], but only at the low-temperature treatment. This effect was not observed between predator treatments at the mid- [Fig. 4b, npANCOVA F (1,79) = 0.170, $P = 0.675$] and high-temperature treatments [Fig. 4c, npANCOVA F (1,62) = 0.589, $P = 0.456$].

Discussion

Responses to climate change across taxa are diverse and vary by species (Kroeker et al. 2013). Through this study we demonstrated how elevated temperatures affected southern ribbed mussel morphology and its capacity to develop inducible defenses in the presence of predation cues. When exposed to increased temperatures, southern ribbed mussels: (1) exhibited altered shell shapes, (2) lacked apparent inducible defenses, and (3) experienced similar handling times by predatory crabs regardless of their predator treatment, demonstrating the consequences of loss of inducible defenses.

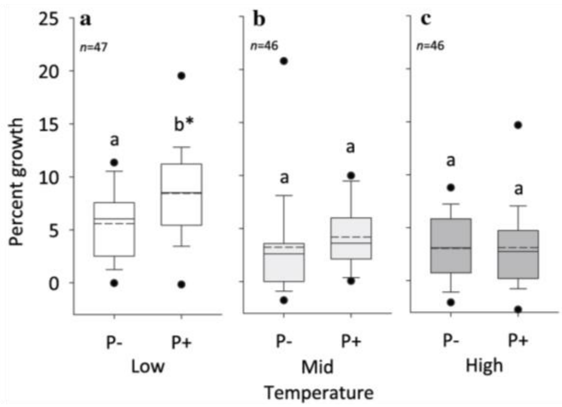

Fig. 3 Boxplots **a–c** show comparisons of percent mussel wet weight growth between predator absent (P^-) and predator present (P^+) treatments at low-, mid- and high-temperature treatment levels, respectively. Dashed lines represent the mean and dots represent outliers at the 95th percentile. Lower case letters represent pairs with significant differences in mean percent growth and asterisks depict level of significance (*< 0.05). Shading represents temperature treatment level: white (low), light grey (mid), and dark grey (high)

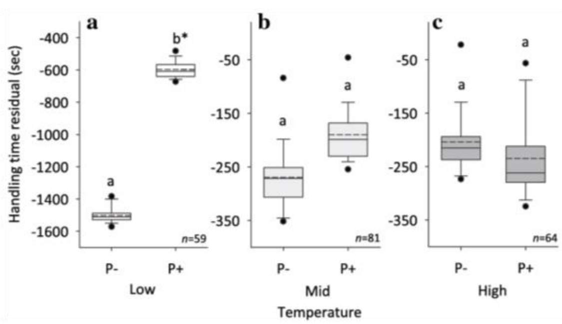

Fig. 4 Boxplots **a–c** show comparisons of npANCOVA residuals for handling time (after correcting for the effect of crab size) between predator absent (P^-) and predator present (P^+) treatments at low-, mid- and high-temperature treatment levels, respectively. Dashed lines represent the mean and dots represent outliers at the 95th percentile. Lower case letters represent pairs with significant differences in mean handling time and asterisks depict level of significance (*< 0.05). Shading represents temperature treatment level: white (low), light grey (mid), and dark grey (high)

Reductions in mussel growth

Growth in shell width and mussel wet weight decreased as temperature increased. Differences in dispersion of growth data suggested heterogeneity among individual mussels in their response to stressors. Southern ribbed mussels survived at temperatures above 30 °C, but with significant reductions in growth, supporting recent findings (Fitzgerald-Dehoog et al. 2012; Miller et al. 2014; Zhao et al. 2017). This effect could be due to physiological limitations. Many marine species have limited growth rates above 31 °C (Goodwin et al. 2001; Schöne and Giere 2005; Schöne et al. 2002) due to limitations in oxygen uptake and metabolic activity (Rodland et al. 2009; Schöne and Giere 2005). Moreover, many bivalves, including ribbed mussels, respire more as temperature increases (Noisette et al. 2015; Wilbur and Hilbish 1989). Thus, the negative effects of increased temperature on mussel growth observed in this study may be due to physiological energy demands.

Heat stress can increase the energy demands on the production of proteins that prevent and repair heat-induced cellular damage. In intertidal mussels, thermal stress is linked to denaturation and structural damage of proteins, evidenced by the up-regulation of oxidative-stress (Fields et al. 2012), cytoskeletal (Fields et al. 2012; Tomanek and Zuzow 2010), and heat-shock chaperone proteins (Fields et al. 2012; Hofmann and Somero 1995; Roberts et al. 1997; Tomanek and Zuzow 2010). The energy costs associated with producing and maintaining the activities of these proteins likely reduces the energy available for biological demands, such as reproduction and growth (Han et al. 2013; Hofmann and Somero 1995). The demands on energy allocation due to thermal stress may cause diversion of energy to growth in specific morphological traits that may be especially beneficial to the organism's survival. We hypothesize, then, that these energetic physiological demands due to thermal stress affected mussels' abilities to respond to water-borne predation cues.

Alterations in shell shape

Southern ribbed mussels grew in length, but had limited growth in width, with increasing temperatures, creating a more elongated shell shape. Blue crabs exhibit preference for ribbed mussel with shells shorter than 25 mm to maximize energy ingestion while minimizing energy expenditure and handling time (Elner and Hughes 1978; Hughes and Seed 1981). Therefore, it is possible that mussels in our study expended energy in growth in shell length rather than shell width to move out of their predators' preferred feeding size range. However, mollusks have been observed to adopt rounder, flatter shells, the opposite of the alterations in shell shape due to increased temperatures observed in this study, to better protect themselves from shell-crushing predators (Bronmark et al. 2011). These differences in shell morphology can alter predation rates and feeding preference by predators, affecting predator–prey interactions and resulting in diet shifts (Lopez et al. 2010). Therefore, the observed elongation of shell shapes could be detrimental for mussel survival and could have further consequences for intertidal predator–prey relationships.

Suppression of inducible defenses

Southern ribbed mussels reared in the presence of predation cues grew significantly more in terms of wet weight than those reared in the absence of predation cues, but only in the low-temperature treatment. Loss of this predator effect at the experimental mid- and high-temperature treatments demonstrated the capacity of increased temperatures to affect the production of inducible defenses in mussels. This effect was further evidenced by the differences in predator handling times only observed at the low-temperature treatment.

The significant increase in wet weight observed did not match increases in shell length or shell width, and therefore, must be due to growth in a different morphometric. We were unable to calculate shell thickness with the available data; however, a probable explanation for increased mussel wet weight is an increase in shell thickness, a common inducible anti-predatory response used by mollusks for defense against predation, often at the expense of growth in shell length and width (Caro and Castilla 2004; Freeman 2007; Freeman and Byers 2006; Smith and Jennings 2000). Predator-induced shell thickening is essential for southern ribbed mussels, as it defends against crab predation by increasing handling times (Freeman 2007) and makes them less energetically feasible prey. In laboratory studies, blue crabs have been observed to abandon mussel prey with high handling times to minimize energy usage (Hughes and Seed 1995), and exhibit preference for feeding on thin-shelled mussels (Caro and Castilla 2004). Southern ribbed mussels in our study may have adopted this shell thickening approach to respond to the presence of predation cues at the low-temperature treatment. At elevated temperatures, however, the demands on energy allocation (Ganser et al. 2015; Hofmann and Somero 1995) may have attributed to the apparent disruption of the predator effect.

The effects of temperature on behavioral inducible defenses have been recorded for scallops in the form of altered escape performance (Schalkhausser et al. 2014) and snails as alterations in righting behavior (Schram et al. 2014). However, to our knowledge, this is the first documentation of increased temperatures interfering with morphological inducible defenses, and thus predator handling times, in southern ribbed mussels.

Study limitations

The results of this study provide evidence on the effects of increased temperatures and predation cues on southern ribbed mussel growth. However, it is possible that the length of the experiment was insufficient to reflect the full scope of the synergistic effects of elevated temperatures and predation cues. 4 weeks may have been insufficient for mussels to grow out of blue crabs' preferred prey size (< 25 mm) (Hughes and Seed 1981). Although a longer experimental period may have been beneficial, it is interesting that we were able to observe differences in shell shape and disruption of inducible defenses so clearly, which attests to the strength of the temperature effect on southern ribbed mussel morphology. Our efforts are a step forward from classic studies that have examined the effects of increased temperatures on single species, by including and measuring the effect of another crucial stressor in natural systems: the presence of predation cues.

Conclusions

We have demonstrated that chronic heat stress can have detrimental morphological effects on intertidal mussels. We documented the ability of southern ribbed mussels to survive chronic thermal stress up to 34 °C, although with significant reductions of both growth in shell width and wet weight compared to lower temperatures. Mussels reared in elevated temperatures also manifested more elongated shell shapes, which could affect their ability to protect themselves against predation. Mussels under constant heat stress may be energetically limited by cellular-repairing processes (Fields et al. 2012; Hofmann and Somero 1995; Roberts et al. 1997; Tomanek and Zuzow 2010), leading to limitations in growth and the loss of predator-induced defenses. Here we provided evidence for the disruption of the predator effect on inducible defenses by thermal stress in temperatures over 30 °C for southern ribbed mussels, followed by decreases in predator handling times. The observed shell elongation and lack of anti-predatory responses in elevated temperatures could make southern ribbed mussels more vulnerable to predation by blue crabs and other predators. The effects of temperature alone on single species can induce shifts in species abundances, distributions, and interspecies interactions, leading to important consequences for coastal ecosystem dynamics (Miller et al. 2014; Schiel et al. 2004). Therefore, the presence of predation cues in natural environments should be considered when addressing the effects of elevated temperatures on marine organisms and when making inferences on the effects of climate change on coastal ecosystems.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Statement of welfare of animals All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

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APPENDIX B. SUPPLEMENTARY DATA FOR CHAPTER 3. INDUCIBLE DEFENSES OF INTERTIDAL MUSSEL NOT AFFECTED BY *P*CO_2-INDUCED SEAWATER ACIDIFICATION

Table B.1 Weekly measurements of carbonate system parameters for the experimental pCO_2 system. Temperature, salinity, DIC and TA were measured in situ, and both pCO_2 and aragonite saturation state (Ω_{Ar}) were calculated using the CO2Sys Macros Excel sheet (Version 2.1, 18 September 2012). P^- and P^+ symbolize predator absent (control), and predator present treatments, respectively.

pCO_2 treatment	Predator treatment	Tank #	Initial (Week 0)						Week 1					
			Salinity	Temperature	DIC	TA	pCO_2	Ω_{Ar}	Salinity	Temperature	DIC	TA	pCO_2	Ω_{Ar}
Elevated pCO_2	P+	12	36.7	29.8	2171.7	2395.5	799.7	2.68	36.9	27.7	2149.5	2368.2	746.5	2.57
Elevated pCO_2	P+	16	36.5	29.7	2188.6	2395.5	866.1	2.31	36.2	27.4	2346.3	2420.6	1780.3	2.36
Elevated pCO_2	P+	22	36.5	30.1	2172.8	2386.2	843.7	2.52	37.1	28.0	2170.2	2366.3	855.0	1.34
Elevated pCO_2	P+	26	36.4	30.0	2162.6	2386.2	795.1	2.31	37.0	29.2	2098.0	2390.6	559.8	2.51
Elevated pCO_2	P-	14	36.5	29.7	2211.1	2395.5	978.4	2.59	37.1	27.7	2191.6	2387.3	860.4	2.35
Elevated pCO_2	P-	18	36.5	29.8	2210.8	2395.5	980.4	2.50	37.1	27.5	2182.9	2394.5	788.3	2.10
Elevated pCO_2	P-	24	36.5	30.1	2181.8	2386.2	884.8	2.69	36.7	27.9	2186.5	2355.1	976.8	3.34
Elevated pCO_2	P-	28	36.6	30.2	2190.5	2386.2	932.9	2.42	36.4	27.7	2113.6	2306.7	808.6	2.31
Ambient pCO_2	P+	32	36.7	29.6	2022.3	2388.7	405.0	4.11	37.0	28.2	1964.0	2364.4	326.8	4.38
Ambient pCO_2	P+	36	36.6	29.5	2018.4	2388.7	395.7	3.73	37.0	28.1	1969.3	2386.1	310.4	3.93
Ambient pCO_2	P+	42	37.0	28.9	2050.4	2382.5	459.2	4.15	37.1	28.1	1971.6	2365.6	335.8	4.56
Ambient pCO_2	P+	46	36.9	28.8	2024.1	2382.5	406.3	3.89	37.0	28.0	1955.6	2382.5	295.5	4.40
Ambient pCO_2	P-	34	36.6	29.5	2059.5	2388.7	473.7	3.72	36.9	27.6	2017.7	2373.6	388.7	4.31
Ambient pCO_2	P-	38	36.7	29.4	2043.2	2388.7	440.1	3.61	37.0	28.2	1981.4	2382.6	331.4	5.03
Ambient pCO_2	P-	44	37.0	28.9	2061.2	2382.5	482.0	3.99	35.9	37.6	1818.3	2284.1	217.1	4.66
Ambient pCO_2	P-	48	36.9	29.1	2075.3	2382.5	516.7	3.48	37.1	27.9	1958.7	2386.0	295.8	4.66

			Week 2						Week 3					
pCO_2 treatment	Predator treatment	Tank #	Salinity	Temperature	DIC	TA	pCO_2	Ω_{Ar}	Salinity	Temperature	DIC	TA	pCO_2	Ω_{Ar}
Elevated pCO_2	P+	12	38.2	30.4	2049.1	2216.8	1008.4	2.03	37.5	30.9	2091.3	2259.0	1042.3	2.08
Elevated pCO_2	P+	16	38.2	30.3	2072.2	2218.0	1146.8	1.73	38.0	30.9	2109.8	2262.3	1156.3	1.78
Elevated pCO_2	P+	22	38.2	30.5	2064.7	2221.7	1082.3	1.84	38.1	31.0	2093.5	2260.0	1069.1	1.93
Elevated pCO_2	P+	26	38.1	31.5	2029.3	2210.8	962.3	1.79	38.0	31.7	2058.3	2258.1	905.5	1.94
Elevated pCO_2	P-	14	38.2	30.3	2085.6	2219.4	1236.9	1.94	37.9	30.8	2126.1	2261.4	1275.1	2.05
Elevated pCO_2	P-	18	38.2	30.3	2077.7	2218.5	1183.3	1.82	38.1	30.8	2105.2	2259.4	1140.3	1.73
Elevated pCO_2	P-	24	38.2	30.5	2079.4	2223.0	1175.5	2.17	38.1	31.0	2129.6	2259.5	1332.3	2.37
Elevated pCO_2	P-	28	38.2	30.4	2121.1	2242.2	1365.9	1.64	38.0	31.0	2106.5	2267.1	1109.5	2.01
Ambient pCO_2	P+	32	38.3	29.8	1902.3	2226.6	442.5	3.50	38.2	30.3	1929.9	2259.1	453.5	3.58
Ambient pCO_2	P+	36	38.2	30.2	1894.7	2216.7	448.9	3.12	38.2	30.8	1918.9	2240.3	471.0	3.39
Ambient pCO_2	P+	42	38.2	30.1	1885.0	2221.6	420.0	3.48	38.2	30.6	1911.4	2253.8	429.9	3.50
Ambient pCO_2	P+	46	38.2	30.1	1888.7	2221.7	427.0	3.27	38.2	30.6	1905.8	2246.5	430.3	3.45
Ambient pCO_2	P-	34	38.2	29.9	1945.0	2229.1	537.6	3.62	38.2	30.5	1941.6	2251.1	497.0	3.71
Ambient pCO_2	P-	38	38.2	30.2	1915.9	2216.6	496.3	3.30	38.3	30.9	1925.0	2241.2	485.9	3.20
Ambient pCO_2	P-	44	38.3	29.9	1944.2	2246.7	501.3	3.59	38.2	30.6	1958.6	2249.0	545.0	3.69
Ambient pCO_2	P-	48	38.2	30.0	1919.7	2213.5	507.8	3.20	38.2	30.5	1910.7	2251.2	430.8	3.69

pCO_2 treatment	Predator treatment	Tank #	Week 4 Salinity	Temperature	DIC	TA	*p*CO_2	Ω_{Ar}
Elevated pCO_2	P+	12	38.3	30.7	2128.3	2277.2	1192.8	1.90
Elevated pCO_2	P+	16	38.3	30.6	2143.3	2279.2	1282.7	1.79
Elevated pCO_2	P+	22	38.2	30.8	2131.0	2279.4	1287.6	1.78
Elevated pCO_2	P+	26	38.2	30.9	2136.0	2279.4	1263.5	1.82
Elevated pCO_2	P-	14	38.2	30.6	2144.9	2281.3	1199.8	1.90
Elevated pCO_2	P-	18	38.2	30.6	2147.5	2287.0	1343.9	1.78
Elevated pCO_2	P-	24	38.1	31.4	2148.5	2281.7	1240.8	1.86
Elevated pCO_2	P-	28	38.2	30.7	2194.5	2326.2	1365.7	1.77
Ambient pCO_2	P+	32	38.0	30.6	1985.4	2286.9	531.9	3.35
Ambient pCO_2	P+	36	37.9	30.7	1979.7	2286.2	587.1	3.13
Ambient pCO_2	P+	42	38.0	30.5	1973.3	2286.8	520.0	3.40
Ambient pCO_2	P+	46	38.2	30.4	1955.6	2283.4	468.3	3.38
Ambient pCO_2	P-	34	38.2	30.5	2005.1	2286.0	525.6	3.46
Ambient pCO_2	P-	38	38.0	30.6	1985.2	2289.8	565.9	3.23
Ambient pCO_2	P-	44	37.9	30.6	2002.2	2290.8	501.1	3.59
Ambient pCO_2	P-	48	38.0	30.5	1983.6	2295.2	509.2	3.45

APPENDIX C. SUPPLEMENTARY DATA FOR CHAPTER 5. IDAHO STUDENTS GAIN DEEPER UNDERSTANDING OF CLIMATE CHANGE AND SHOW CORRECTION OF MISCONCEPTIONS AFTER INTERDISCIPLINARY CLIMATE CHANGE OUTDOOR EDUCATION PROGRAM

1. Considerations for research with human subjects

1.1. Participant recruitment and costs

Participation in the program was voluntary and there were no costs required to take part in the research This was a convenient sample of elementary school students (6th to 8th grade) from a local school that were participating in a residential program at the McCall Outdoor Science School (MOSS).

1.2. Risks and benefits

There were no known risks to those who took part in this study. The potential benefits of this research to the children involved included: learning about climate change and how this environmental issue is expected to affect their environment, and practicing science, math and writing skills necessary for the Idaho Standards Achievement Test.

1.3. Consent process

Parental consent forms, modeled after the template provided by the University of South Florida's Internal Review Board (USF IRB), were sent home with students so that the parent or legal guardian had time to read and understand it. Completed and signed forms were required prior to start of the program in order for a child to be included in the research. Child assent forms, modeled after the template provided by USF IRB, were printed and provided to students prior to the research. Students were asked to read and sign the form if they were willing to take part in the research.

1.4. Safeguards for research with children

Research took place in a classroom setting at the MOSS and the research methods used did not differ greatly from normal educational practices.

1.5. Privacy and confidentiality

Students were assigned a number that they used as the personal identifier for the concept maps and questionnaires to be able to make comparisons pre- and post-program, while protecting students' identifiable information.

2. Supplementary data tables

Table C.1 Supplementary data for gender of students that participated in the study. Of the 22 total participant students, 10 (45%) were female (F) and 12 (55%) were male (M)

Student	Gender	Student	Gender
1	M	12	F
2	M	13	F
3	M	14	F
4	M	15	M
5	F	16	M
6	F	17	M
7	F	18	M
8	F	19	M
9	F	20	M
10	F	21	M
11	F	22	M

Table C.2 Supplementary data for concept map responses of students to the prompt "climate change". Concepts are in alphabetical order; a total of 220 distinct concepts were used by students. A "0" denotes that concept was not present in the concept map of that student at that time (pre- or post-completion of the program), while a "1" denotes the presence of that concept

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A/C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
acidified water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
acidity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
activists	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
adaptation	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Africa	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
aging	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
air	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Americas	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Animalia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
animals	1	0	0	1	1	1	1	0	0	1	1	0	1	0	0	1	0	1	1	0	1	1	1	1	1	0	0	0	1	0	0	1	1	0	1	1	1	0	1	1	1	1	1	1
Antartica	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
aspen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
atmosphere	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0
atoms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
axis tilt	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
bacteria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
beaches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
behavior	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
benefit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0
birds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
blanket	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
burning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
burps	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
campfires	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
carbon	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0
carbon sinks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cars	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0
causes	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CFCs	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
change in climate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
change in fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
chemicals	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
civilization	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
clouds	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	0	1	1	1	0	0	0	1	0	1	1	1
coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1
cold	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
cold front	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Concept	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
concepts	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
continents	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
convection currents	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cooling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
core cooling	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
crops	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
damage	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dams	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
death	0	0	0	1	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
decaying plants	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
decrease	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
deforestation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
deserts	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
drastic	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
drought	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
dry season	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Earth	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Earth rotation	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ecosystems	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
effects	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
electricity	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0
energy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
enhance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
environment	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Europe	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
excessive sunlight	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
exhaust	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
expansion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
extinction	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
extreme weather	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
factories	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
farming	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
farts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
feels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fire	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	1
fire pits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0
fish death	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
floods	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
food	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
food chain	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	0	0	0	1	0	1	0	0	1	1	1
frequency	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
frosts	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fungi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1
gasoline	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0
GHG	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
glaciers	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
global warming	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
government	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
grass circles	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
growth	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
habitat	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
habitat loss	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hail	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
heat	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
heat radiation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
heat waves	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
heaters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
herders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
homes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
humans	0	0	0	1	0	0	1	0	0	1	1	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	0	0	1	0	0	0	0	1	0	1	1	0	1	0	1	0	1	1
hurricanes	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hydroelectric	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
humidity	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hyperthermia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hypothermia	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
illness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
increase	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
industries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
landfills	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
landscape	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lasting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
less cool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
less good	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
less growth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
life	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
light	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lightning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0
limited water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
longer summer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
looks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
magma	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
melting	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
methane	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
migration	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
mining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
money	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
moon	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
mountains	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
natural	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
natural disasters	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
negative	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
nitrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
North America	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ocean	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0
oil	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	1	0	1
oil rigs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
overcrowding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
oxygen	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1
ozone	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
penguins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
plants	0	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	1	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1
plate tectonics	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
polar bears	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
poles	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
politics	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pollution	0	0	0	1	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0
positive feedback	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
precipitation	1	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
precipitation change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pressure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
production	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
rain	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
recycling	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
reefs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
refinery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
reproductive cycles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
resources	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																						Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
respiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
rising temperatures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
rivers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Sahara	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
salmon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
science	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
season	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
severe	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sheep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
shelter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
short winters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
shrinkage	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sleet	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
smoke	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
snow	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
social	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
source	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
spawning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
starvation	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
steam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
storms	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Sun	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
surrounding	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
survival	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
temperature	0	0	0	1	0	1	1	1	1	0	0	0	1	0	1	1	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0
temperature change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
terrain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
thrive	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
tilt on axis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tornadoes	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
trapped heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
treaty	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
trees	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0
tsunamis	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Concept	Pre Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
underdeveloped countries	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
unhealthy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
victims	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
videos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
warm winters	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
warmer water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
warming	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
warmth	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	1
waste	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
water	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
water use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
waves	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
weather	1	0	1	1	0	1	1	0	0	0	1	0	0	1	1	0	0	0	1	0	0	1
wet season	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wildfires	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wildlife	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wind	1	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1

Concept	Post Student #																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
underdeveloped countries	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
unhealthy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
victims	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
videos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
warm winters	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
warmer water	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
warming	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
warmth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
waste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
water	0	1	1	1	0	1	0	0	1	0	0	1	1	0	0	1	0	0	1	0	1	1
water use	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
waves	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
weather	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1
wet season	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wildfires	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
wildlife	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wind	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Table C.3 Student answers for question 1 in the questionnaire “Describe climate change in your own words.” pre- and post-completion of the program. These are direct transcriptions of student answers (originally on paper). Asterisk (*) denotes blank answer

Student	Pre	Post
1	The change from one climate to another, gradual or fast, because of factors affecting weather, rainfall, wind, storms, and clouds.	The difference between 30 years or greater periods of weather.
2	*	Climate change is the heating of the Earth by the Sun and CO2.
3	Climate change is the slow warming of the Earth in relation to the weather year round.	Climate change is the warming of the Earth due to CO2 build up in the atmosphere.
4	The climate changes because of a bigger problem.	The climate changing from its normal state.
5	Climate change is the effect of pollution and deforestation on an environment. Climate change is essentially the usual climate of an area changing.	Climate change is the effect of CO2 getting trapped in the atmosphere creating a blanket that doesn’t let the Sun’s energy escape. In doing so, the overall climate is warmer.
6	The warming of the Earth causing a change in weather.	It’s the buildup of pollution that has been stuck in the atmosphere causing global warming. CO2 gets trapped in the atmosphere.
7	Climate change is the difference in temperature/weather in certain areas. It can make some places warmer, as well as other places cooler. It happens because of depletion of the ozone layer, caused by pollution.	Climate change is the heating of the planet caused by extra carbon in the atmosphere.
8	Climate change is when the temperature drops or rises.	Climate change is when the climate changes.
9	When temperatures drop and rise and wind blows and precipitation.	Climate change is when natural things can change to affect human, animal, and plant life.

10	Climate change is when weather or outside forces alter the surrounding climate, or (humans/animals) surrounding area.	Climate change is the change in climate or weather that usually damages the area around it, but can have benefits too. Climate change now is the rising of temperature.
11	Climate change is when the weather over a period of time shifts dramatically caused by pollution.	An excess of CO_2 put into the air by human action that causes high temperatures and drought.
12	Climate change is the Earth's heating and cooling.	CO_2 causes sun rays to get trapped and create heat.
13	Climate change is when the climate changes drastically.	Heating of the Earth because of CO_2.
14	Climate change is caused because the Earth is on an axis and causes only some parts of the world heat up quicker than other parts.	Climate change is how carbon gets released into the atmosphere and traps heat in so it can't get out of the atmosphere as well as it could before.
15	Climate change is the change of climate in an area.	Climate change is the climate change all over the world.
16	The climate change is making the Earth hotter.	Climate change is like the Sun into clouds.
17	When either the Earth warms up or when it cools down, at a quick rate.	Either the Earth will warm up or cool down which could cause many different situations.
18	When the temperature changes a lot. When it goes from Winter to Summer and Summer to Winter.	When CO_2 gets into the air and starts to warm the Earth.
19	I don't know.	It is when climate increases in temperature.
20	Something that is affecting animals as well as people.	The change of climate over the entire world.
21	Climate change is when the climate of the Earth is warming up.	Climate change is when the Earth slowly warms up and affects habitats and animals.
22	When pressure moves and drifts through the world holding weather.	Where the weather changes due to causes that affect life.

Table C.4 Student answers for question 2 in the questionnaire "How does climate change affect animals? Give specific examples." pre- and post-completion of the program. These are direct transcriptions of student answers (originally on paper). Asterisk (*) denotes blank answer

Student	Pre	Post
1	Climate change makes animals migrate.	Salmon die from too hot temperatures.
2	*	The climate change affects animals by destroying their habitats.
3	Climate change might dry up their water or give them too much water that it drowns them.	Climate change affects animals by causing them to move to cooler areas and thereby killing all animals eventually in the cooler areas.
4	If it decreases the carrying capacity, there could be population fluctuations and the possible elimination of a keystone species (really bad). One example would be the Great Barrier Reef. When the water warms up, it becomes uninhabitable for certain species.	Some animals used cold climates and will not survive if it gets warmer, such as salmon.
5	Climate change affects animals because of the certain adaptations an animal has for living in that specific environment. For example, if the arctic is getting warmer, the amount of fur on a polar bear might cause it to overheat, and eventually die off. Along with their environment melting.	Climate change affects animals by forcing out of their habitat or forcing them to adapt. For example, picas might not have a place to go if squirrels and porcupines keep moving into its habitat in search of a cooler climate.
6	It could melt the cold climate they live in. The melting of ice could cause penguins to lose their homes. Glaciers melting could affect wildlife.	It can destroy their habitat, like for salmon water is getting warmer so they can't migrate. It could cause overcrowding of one habitat due to animals having to move.
7	Climate change affects animals by giving them temperatures that their habitat/bodies are not adapted for. For instance, polar bears are getting warmer, as well as the icy climate they live in. It makes food shortage supply shortage as well.	Climate change causes animals to have to group habitat, like polar bears.

8	When they hibernate, find water and food.	Climate change affects the animals by changing the climate. For example, when animals can only survive in cold weather and when it turns warm the animals die.
9	Tells them when to hibernate like a bear when it's cold.	It could kill them or they can suffer losing a home from a forest fire or flooding.
10	1. Animals might not adjust well. 2. Animals may die off. 3. Animals may have to move.	1. Animals will have no food. 2. Animals will have no place to live. 3. Animals will slowly die out. 4. Fish will not be able to spawn.
11	Climate change affects animals because it changes their habitat. Some specific examples include monkeys, penguins, and birds. Monkeys are when trees die, penguins are when glaciers melt, and birds are also when trees die.	Climate change affects animals positively and negatively. Negative includes fish because of drought, and animals who like the cold like polar bears. Positive includes bark beetles and bacteria.
12	Climate change could affect certain animals by having them migrate because of certain temperature changes.	Climate change can cause animals to overcrowd an area, such as a mountain.
13	Specific animals have adapted to the environment and climate which means they will have to adapt once more. If the climate changes in the rainforest and it becomes very cold then the fur of some animals would have to adapt.	The place animals could get crowded. If they live higher up in the mountain then it will get crowded because the bottom of the mountain got hotter at the bottom.
14	Climate change affects animals by global warming. For example, ice melts quicker in the warming atmosphere. Certain animals live in those warming areas and the ice that they live on is decreasing. Also, animals get climate like seasons as well.	Climate change affects animals in many ways. Climate change could affect the ecosystem by making salmons' water worse or causing them to change their migration routes. This could collapse the entire ecosystem. Also, global warming forces animals to migrate out of their habitats.
15	Climate change doesn't affect animals. Animals still live where they used to. I saw a deer in my yard once, that was cool.	It kills them. A mountain squirrel might die because of the heat cheat grass would migrate.
16	The climate affects animals because the move to find colder places.	Climate change affects animals because animals live in hot places.
17	Some of the habitats get destroyed or they have to find another place to live.	When either it warms up or cools down animals have to find different places to

		live or they can't move back to the headquarters.
18	It makes them change what they do every day, like a bear getting fatter to get ready for winter.	It makes it so they can't go to certain places and not do as many things they could have done. When salmon can't go into warmer water and don't go to the same place for the giving birth part.
19	I don't know.	It affects animals by killing salmon and steelhead.
20	It is causing them to lose their habitat.	It hurts animals because it is too hot for them. It hurts animals by destroying their shell.
21	Climate change affects animal by warming up areas animals live in like sharks and fish. Fish also have to move out of their reefs because the reefs are getting bleached by climate change.	Climate change affects animals by making habitats warmer so animals either have to move to a colder climate or die off. Salmon are dying because rivers are getting warmer and birds have to change migration patterns.
22	Climate changes the habitat for animals. If too much wind tree will fall destroying bird nests. Too much rain causes floods.	It can get too warm, too much CO2 and unhealthy water to the acidity.

Table C.5 Student answers for question 3 in the questionnaire “How does climate change affect people? Give specific examples.” pre- and post-completion of the program. These are direct transcriptions of student answers (originally on paper). Asterisk (*) denotes blank answer

Student	Pre	Post
1	People, a lot. The Sahara used to be a people-filled jungle with rivers. The Earth tilts, and, desert.	Firefighters can be paid more, but fishers and farmers can have their product die.
2	Climate change affects people by making them hot or cold.	Climate change affects us by acidifying water and destroying the ozone layer.
3	It might affect us by us not having enough water to grow food or to work with, or so much water that it floods where we live.	Climate change affects people by forcing us to use more heating and A/C units because of the warmer summer and cooler winters.
4	It can lead to more frequent and severe storms and natural disasters.	There will be more severe weather patterns and natural disasters along with a greater frequency of them.
5	*	Climate change affects people because it limits our natural resources and causes extreme weather. For example, extreme heat lightning and flooding may occur if climate change keeps happening.
6	The climate change could cause natural disasters which could people to losing their homes and safety. Poor places might not ever recover.	It could get rid of their food source and melt snow around them, for farmers it could affect these crops.
7	Climate change affects people because it can give situations that they have never had to be prepared for, like tsunamis, hurricanes, extensive rain and snow, heat stroke, among other things.	Climate change affects others because when animals (like fish) die, it cuts off resources/food, like the Nez Perce tribe.

8	What they wear or act like.	People get affected by climate change by how they dress and they don't like it and try to pass the law.
9	Makes people cold and hot like in summer most don't wear long sleeves and pants.	It could leave people homeless or dead, in floods or fires.
10	1. The area may not suitable to live in. 2. Humans may die. 3. Those not suited well to sudden changes of weather may not make it.	1. Our world is dying. 2. CO2 is harmful to us. 3. We will have no food. 4. Forest fires are more frequent.
11	Climate change affects people because they cause it and can die from things like hypo/hyperthermia.	1. They cause it. 2. They suffer from it.
12	Climate change affects people by causing them to develop asthma or some other illness.	Climate change could cause fires, burning down houses, or giving sheep grazing area.
13	People often buy clothes that are needed for the temperature. Money could be lost and gained in some situations.	People are affected because major weather could occur or change.
14	Climate change affects people by giving them seasons. We always have to dress appropriately. Also, some climates are getting warmer with global warming.	Climate change affects people a lot. People continue to add more and more CO2 to the atmosphere which makes it hotter. This could mean acidic water. Hotter temperatures, and maybe less crops or food from animals.
15	Climate change affects people by making them be worried and have arguments about whether it is real or not. My mom and dad talked about people talking about climate change and how worried people are.	Climate change affects people by making them put their whole life into trying to get people to stop doing it even though they aren't doing anything. I'm not good at giving examples.
16	People move because water rises.	Climate change affects people because people in the shade.
17	I have no clue, but maybe give them a hard time breathing or even living in some areas.	People 100 years from now won't be able to see polar bears in their natural habitat.
18	It makes them change what they wear every day. Like when its winter people dress warmly. When its summer people dress lightly.	It makes It so that certain things won't happen and affects the way people do stuff. When salmon don't go up the same route.
19	I don't know.	It affects people by starting more forest fires.

20	People are losing homes to rising water and some are living in poor conditions.	The Nez Perce tribe depend on the salmon.
21	Climate change affects people by making the temperature of the Earth.	Climate change affects people by reducing population of fish that are eaten and the air being more poisonous and dangerous.
22	It can affect the pressure and can harm the food we eat due to the climate change.	It can get through foods and water causing to get sick and get too warm. Also, can increase in CO_2.

Table C.6 Student answers for question 4 in the questionnaire "What can you do to help reduce the impacts of climate change? Give specific examples." pre- and post-completion of the program. These are direct transcriptions of student answers (originally on paper). Asterisk (*) denotes blank answer

Student	Pre	Post
1	Me, nothing.	I can put sheep in the foothills and make a lawsuit.
2	*	I can help reduce impacts of climate change by spreading the word about it.
3	Use less power in our homes, try to use less water.	We can use less A/C and warming units, use less fires, drive our cars less, and most of all think about our climate is changing all the time!
4	Recycle, replant, precycle, etc.	I can use less energy, buy electric-powered cars. Start a change in my community for less fuel emissions, etc.
5	*	I can choose not to drive a gasoline car, not littering, and letting others know about what I've learned here.
6	Carpool with friends, don't pollute the air. Acknowledge climate change.	Try your best to not pollute and use more electricity than necessary. You could carpool with friends, walk, etc.
7	Something I could do to help reduce the impacts of climate change would be to help stop littering, raise awareness for animals, and donate supplies and money for causes that help victims of climate change.	I can stop breathing (jk but really we breathe too much (overpopulation)), drive an electric car, and help to try and prevent fracking, oil spills, gas spills, among other things.
8	Check and make sure you have enough supplies to last through tough times and when the weather changes.	I can help by taking good care of my community so climate change doesn't happen.
9	I can check the weather and make sure people are aware of temperature and climate.	I can conduct experiment and test thing that could help like finding ways to put fires out faster, and stronger structures that floods or earthquakes can't harm.
10	I can try not to use things that damage the environment.	1.Don't be stupid with pyrotechnics. 2. Don't rely on household appliances. 3.

		Use gas-powered things less. 4. Plant more trees.
11	Riding bicycles more than cars, pick up trash, and walking.	1.Don't be stupid with pyrotechnics. 2. Avoid depending on household appliances.
12	I could, instead of taking a car to places a short distance away, ride my bike to the places close to me.	I can spread the word of climate change and try to use less energy/fuel.
13	You could help plant trees and not pollute. Pick up your trash.	We could preserve energy and try to work with it.
14	Some things people could do to make a better atmosphere is to litter less, recycle, and start using things like solar power on something other than gas and steam.	We could reuse energy and conserve it. Also, we need to stop putting as much oil, gas, and steam into the air.
15	Nothing. I can do what I normally do and watch people who care do something about it or people be worried about it.	Nothing. I can sit and think about it but nobody ever listens to me and my parents won't let me do anything because they hate me.
16	Drive less cars because it changes when you walk.	That climate change affects people and animals so that is why animals live in the light and people live in the shade.
17	Drive smart cars, less fuel, less oil, maybe cleaner fuel.	Drive smart cars, don't use as much fuel, start a movement to help reduce the impacts of climate change.
18	Not pollute a lot of bad things into the environment. And promptly dispose of dangerous waste.	Don't use as much fossil fuel related thigs. When people mine gas, oil, and etc. it releases CO_2 into the air which is one the leading factors in climate change.
19	I don't know.	I can find more efficient travel methods.
20	Try to recycle more and bike to places	By using less energy and getting an electric car.
21	To help reduce the impacts of climate change by not burning lots of gas in cars and factories.	I can reduce impacts of climate change by telling people to become more aware of climate change and to reduce the use of fossil fuels.
22	Don't create pressure from major cities. Don't affect the atmosphere. Don't use poisons like fuel, gas, or harm trees.	Quit using fossil fuel that warm up Earth. Quit killing or eliminating keystone life (causing unbalance in the world).

APPENDIX D. THE NATURAL AND HUMAN DIMENSIONS OF CLIMATE CHANGE IN IDAHO

1. Program overview

1.1. Need for program

Local examples are crucial for students to understand global phenomena that is often abstract or distant, but they aren't a regularly used teaching tool in the classroom. With this program, I aimed to identify local examples of climate change for students to learn about this phenomenon through the lens of their local environment and communities. As part of the deliverables of the curriculum, students completed a project to investigate the effects of these changes on organisms they had become familiarized with. The experience of this project allowed students to understand the concepts of climate change through first-hand exposure and understand in-depth the science of this issue. This program not only filled a need in content learning, but also helped students become proficient in the scientific process. Science, climate, and social literacy principles were addressed through this curriculum.

1.2. Identify audience

The McCall Outdoor Science School's (MOSS) mission is to facilitate place-based, collaborative science inquiry within the context of Idaho's land, water and communities. Residential programs at MOSS welcome students from schools all over the state of Idaho. MOSS has been working on creating curricula focused on climate change and its effects on local environments and communities. Their approach to science education coupled with their interest in this subject made MOSS an ideal setting for this curriculum. Through MOSS' residential programs students develop connections and a sense of place within their environment at Ponderosa State Park. The climate change program's goal was to use these connections to encourage students to gain an in-depth understanding of a global phenomenon that affects their local environments and communities.

2. Philosophy of education

I believe that schools should be laboratories for the real world helping students develop the skills necessary to become successful members of society. Because of this, I consider skills that promote critical thinking and community living as the most important in a school setting. Although content knowledge is important, being scientifically and socially literate goes further than content, and curricula should reflect that. Scientific and social skills that can be applied to different situations are the key to successful members of society. Developing science (AAAS, 1993) and social literacy skills (Arthur *et al*., 2014) are, therefore, the main goals of this curriculum.

I aim for students to develop scientific and social literacy through the use of student-centered practices in which they construct their own meanings. I believe that student-led teaching methods, especially those centered on local examples, allow students to develop a sense of ownership over their own learning and promote deeper understandings and emotional connections. It is thus important for the teacher to take on more of a "facilitator" role, in which

I provide structure and context, but allow students to take charge of their learning. Through these methods, my curriculum not only tackles the science issues at hand, in this case climate change, but also what social processes are involved in the development of solutions to these issues and how these issues might affect different communities.

3. Themes, essential questions and driving concepts

3.1. Goals

- Develop science literacy skills
- Develop social literacy skills
- Obtain content knowledge on climate change
- Obtain content knowledge on water acidification

3.2. Overarching themes

- Climate Change
- Water Acidification
- Anthropogenic Impacts
- Socio-Scientific Issues

3.3. Essential questions

- What is "normal" for temperature and pH fluctuations?
- What makes temperature and pH levels be "out of the norm"?
- Who decides what is "normal" for temperature?
- Are the current changes in temperature part of natural fluctuations? How do we know?

- Are all communities affected by climate change in the same way? Are some communities more vulnerable than others?
- What can we do to increase the resilience of systems affected by climate change?
- Can we serve as agents of local change?

3.3.1. Sub-questions:

  - What is climate change?
  - What is water acidification?
  - Does climate change affect animals?
  - Does climate change affect humans?
  - Can organisms adapt to climate change?
  - What is the importance of rate of change?

3.4. Driving concepts

- Greenhouse gases are gases in the atmosphere that trap solar radiation from exiting Earth.
- Current climate change refers to changes in climate due to increased carbon dioxide in the atmosphere, which acts as a greenhouse gas.
- Increases in greenhouse gases increase temperature on Earth.
- Human activities affect the climate of the Earth through the release of greenhouse gases.
- Both the concentrations of carbon dioxide in the atmosphere and global temperatures have fluctuated in the past, but current changes are happening at a much faster rate than deemed "normal".

- What is “normal” for temperature fluctuations is determined by past data, when numbers are outside of the range of past data, then it is deemed “out of the norm”.
- Changes in temperature can affect organisms.
- Changes in water pH can affect the organisms that live in it.
- Some organisms are more vulnerable to the effects of climate change than others.
- Climate change affects human communities.
- Some human populations are more vulnerable to the effects of climate change than others.

3.5. Acceptable evidence

Students could choose one of two options for their end-pf-program project. This exercise was meant to foster collaborative work ethic and discussion and communication of ideas. This assessment not only served to evaluate students’ understanding of content, but also their use of science and social literacy skills necessary for collaborative work.

3.5.1. Choice A: Inquiry project

At the end of the program, students designed an experiment to test the effects of climate change on organisms present in Ponderosa State Park or at their local school environment. Students used the resources in the classroom, as well as external resources, to design an experiment that helped them understand the effects of climate change on organisms.

3.5.2. Choice B: Social action plan

At the end of the program students created an action plan to address the threat of climate change to their local environment. Possible action items could range from making a change that improves energy-efficiency at their school, to communicating the results of their experiment to a broader audience.

4. Standards and essential principles

4.1. Science literacy essential principles

4.2. Climate literacy essential principles (US Global Climate Research Program 2009)

1. The Sun is the primary source of energy for Earth's climate system.
2. Climate is regulated by complex interactions among components of the Earth system.
3. Life on Earth depends on, is shaped by, and affects climate.
4. Climate varies over space and time through both natural and man-made processes.
5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.
6. Human activities are impacting the climate system.
7. Climate change will have consequences for the Earth system and human lives.

4.3. Next generation science standards disciplinary core ideas (NGSS Lead States 2013)

4.3.1. ESS2.A: Earth's Materials and Systems

- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future.

4.3.2. ESS2.D: Weather and Climate

- Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns. (MS-ESS2-6)
- Because these patterns are so complex, weather can only be predicted probabilistically. (MS-ESS2-5)
- The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents. (MS-ESS2-6)

4.3.3. ESS3.A: Natural Resources

- Humans depend on Earth's land, ocean, atmosphere, and biosphere for many different resources. Minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. These resources are distributed unevenly around the planet as a result of past geologic processes. (MS-ESS3-1)

4.3.4. ESS3.C: Human Impacts on Earth Systems

- Human activities in agriculture, industry, and everyday life have had major effects on the land, vegetation, streams, ocean, air, and even outer space. But individuals and communities are doing things to help protect Earth's resources and environments.

4.3.5. ESS3.D: Global Climate Change

- Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities. (MS-ESS3-5)

4.3.6. LS2.A: Interdependent Relationships in Ecosystems

- Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1)
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1)

- Growth of organisms and population increases are limited by access to resources. (MS-LS2-1)
- Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2)

4.3.7. LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4)
- Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health. (MS-LS2-5)

4.3.8. LS4.D: Biodiversity and Humans

- Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling. (secondary to MS-LS2-5)

4.3.9. LS4.C: Adaptation

- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. (MS-LS4-6).

Note: Standards from "Next Generation Science Standards," by NGSS Lead States, 2013, Washington, DC: The National Academies Press. Used with Permission (Appendix H. Author contributions and permissions for reprinting previously-published work 2.2 NGSS Lead States, 2013, Washington, DC: The National Academies Press).

5. Learning activities

5.1. Overarching lesson plan

Lessons were provided over the course of two field days (9am-4pm) and two evening time blocks (6pm-7:30pm). The lessons were divided into a total of 9 activities throughout the span of the two field days and two evening programs. The first and last meeting days (Monday evening and Friday morning) were reserved for curriculum assessment. The lessons were presented as a series of activities to the field instructors, which were then integrated into daily lesson plans. Activity descriptions were included in the "Climate Change Activity Guide" document.

5.1.1. **Module 1:** What is climate change?

Guiding Questions:

1. What are greenhouse gases and the greenhouse effect?
2. How do greenhouse gases become a problem?
3. What does science say about the current increases in temperature?
4. How does the warming we're experiencing now compare to the Earth's normal warming rhythms?
5. What is climate change?

5.1.2. **Module 2:** Water acidification

Guiding Questions:

1. How do greenhouse gases, like CO_2, become a problem in water?
2. What does science say about the current increases in water pH?
3. How does the water acidification we're experiencing now compare to the Earth's normal rhythms?
4. What is water acidification?

5.1.3. **Module 3:** Effects of climate change & water acidification on organisms

Guiding Questions:

1. How do climate change and water acidification affect organisms?
2. How does climate change and water acidification affect ecologically and economically important species?

5.1.4. **Module 4:** Effects of climate change on humans

Guiding questions:

1. How does climate change affect fisheries?
2. How does climate change affect agriculture?
3. Is everyone affected by these issues equally?

5.1.5. **Group project choice A:** Inquiry project: experimental design

Guiding questions:

1. Can we use the resources we have to investigate the effects of climate change?
2. What question do we need to answer? What resources do we need to answer that question?
3. How can we use the results from this experiment to inform the public on the effects of climate change?

5.1.6. **Group project choice B:** Social action plan

Guiding questions:

1. Is there anything we can do to help with this issue?
2. Can students be agents of change in their communities?
3. Could we put together an action plan? Maybe include ways to make the school more energy-efficient or ways to communicate our findings and what we've learned?

5.2. Lesson / Activity Plan

Field Day 1 Instructor: Program Lead Field Instructor

Activity (Activity #)	Time Block	Driving Concept	Guiding Questions
Greenhouse gas video	Morning Meeting	DC1 | DC2 DC3 | DC4	What are greenhouse gases? How do greenhouse gases affect the Earth's climate? How do humans affect greenhouse gases?
Temperature anomaly visualization	Morning Meeting	DC4	How do greenhouse gases affect the Earth's climate? How do humans affect greenhouse gases?
Carbon Cycle Activity (A1)	Block 1	DC4 | DC5 DC6	How do humans affect greenhouse gases? How have CO_2 concentrations and temperature fluctuated in the past?
Feeling the Heat Activity (A2)	Block 1	DC4	How do human activities affect climate? How do human activities end up affecting human communities?
Climate Change Winners and Losers (A3)	Block 1	DC7 | DC9	How does climate change affect organisms? Are all organisms affected the same?
Document-Based Inquiry (A4)	Block 2	DC7 | DC9	How does climate change affect organisms? How does climate change affect ecologically and economically important species? How does climate change affect human communities?
Water Quality (A5)	Block 2	DC7 | DC8	How does an environment affect the organisms that live in it?
Ocean Acidification Video	Evening Program	DC8	What is water acidification? How does water acidification affect organisms?
CO_2 Acidic Solution Activity (A6)	Evening Program	DC8	How does CO_2 decrease water pH?
Ocean Acidification & Shells Activity (A7)	Evening Program	DC8	How does water acidification affect organisms?
Marine Osteoporosis Activity (A8)	Evening Program	DC8	How does water acidification affect organisms?

Field Day 2

Activity (Activity #)	Time Block	Driving Concept	Guiding Questions
Dendroclimatology video	Morning Meeting	DC5 | DC6	How has climate changed in recent history? How can we use tree rings to get data on climate change?
Tree Rings Lesson (A9)	Block 3	DC5 | DC6 DC7	How has climate changed in recent history? How can we use tree rings to get data on climate change?
Pine Beetles Lesson (A10)	Block 3	DC7 | DC9	How does climate change affect organisms? Are all organisms affected the same way? How will climate change affect local environments?
Fire Lesson (A11)	Block 4	DC6 | DC9 DC10	How will climate change affect local environments? How will climate change affect local human communities?
Faces of Climate Change Activity (A12)	Block 4	DC10 | DC11	How will climate change affect local human communities? Are all human communities affected the same way?
Social Action Video	Evening Program	DC10	Is there anything we can do to help with this issue? Can students be agents of change in their communities?
Nature Art Activity (A13)	Evening Program	DC10	How can art be used for social action in response to climate change?

Field Day 3 (Inquiry Day)

Activity (Activity #)	Time Block	Driving Concept	Guiding Questions
Social Action video	Morning Meeting	DC10	Is there anything we can do to help with this issue? Can students be agents of change in their communities?
Inquiry Project	Inquiry Day	Assessment	Can we use the resources we have to investigate the effects of climate changes? What question do we need to answer? What resources do we need to answer that question? How can we use the results from this experiment to inform the public on the effects of climate change?
Social Action Project	Inquiry Day	Assessment	Is there anything we can do to help with this issue? Can students be agents of change in their communities? Could we put together an action plan? Maybe include ways to make the school more energy-efficient or ways to communicate our findings and what we've learned?
Concept Map & Questionnaire	Evening Program	Assessment	

6. Literature Cited

US Global Change Research Program (2009) Climate literacy: The essential principles of climate science.

NGSS Lead States (2013) Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

APPENDIX E. CLIMATE CHANGE CURRICULUM ACTIVITY GUIDE

Ileana M. Freytes-Ortiz

Selected Videos for Curriculum

- Greenhouse Gases: Climate Change, Lines of Evidence: Chapter 3

  Accessed on 5/31/2017: https://www.youtube.com/watch?v=3JX-ioSmNW8&list=UUliT4Dc2JUMM6QVhMo0ENrQ&index=98

- Greenhouse Effect Video – Scott Denning

  Accessed on 5/31/2017: https://scied.ucar.edu/greenhouse-effect-video-scott-denning

- Four Degree Interactive Map

  Accessed on 5/31/2017: http://www.metoffice.gov.uk/climate-guide/climate-change/impacts/four-degree-rise/map

- Ocean Acidification Video – Video from Science Communication class

- How Tree Rings Tell About Climate

  Accessed on 5/31/2017: https://www.youtube.com/watch?v=T391URPJVT0

- Tree Rings: Counting the Years of Global Warming

  Accessed on 5/31/2017: https://www.youtube.com/watch?v=vqicp4PvHrY

- TRUST: The Climate Kids

  Accessed on 5/31/2017: https://www.ourchildrenstrust.org/short-films/

- Weather Channel – Xiuhtezcatl segment

  Accessed on 6/8/2017:

  https://www.youtube.com/watch?v=1Up3yJRqydI&index=3&list=PLVbQKnMSQUosnpjjO8oUfctcGcr12SX6W

A1: The Carbon Cycle and its Role in Climate Change

Summary: Students have heard about climate change, but most do not yet have the chemical background to understand what is happening. This activity is designed to give students a basic chemical understanding of the carbon cycle and thereby giving them an understanding of how human activity contributes to climate change.

Key Concepts:

- Burning fossil fuels releases CO_2 into the atmosphere.
- CO_2 is a greenhouse gas.
- Humans affect natural processes by releasing excess greenhouse gases into the atmosphere.
- CO_2 concentrations and temperatures have fluctuated in the past, but at a slower rate than the last 200 years.

Time block: ~20 minutes

Materials:

- Natural objects to create a miniature city
- Signs (carbon, oil, coal, gas, miner, power plant operator, car driver, homeowner, oil refinery worker, gas refinery worker)
- String
- Soil or sand
- Tarp
- Graphs: CO_2 concentrations, temperature

- Science journals
- White board & dry erase markers

Activity:

1. Prep: Dig tarp under the sand/soil.
2. Review the respiration process (sugar + O_2 = energy + water + CO_2).
3. Create a circle that represents an old forest that is now a mine.
   - Explain to the students that a long time ago some forests and swamps died and were buried in the earth by geologic forces. Put some soil or sand over the carbon signs.
4. Explain that after a long time, and a lot of pressure from the soil and rocks above and heat from the earth below, the forests turned into fossil fuels such as gas, oil, and coal.
   - Pull out a black "carbon" sign and show the oil, coal, or gas labels.
   - Put the "mine" sign on the site that was once a tree and is now a mine.
5. Assign roles to the students as miners, power plant operators, oil refinery workers, gas refinery workers, car drivers, or home owners. Using natural objects have them set up a little city near the mine.
6. Have some students acting as miners take the oil, coal, or gas out of the ground. They should take the oil signs to a refinery, the coal signs to a power plant, and the gas signs to a gas company.
   - Now the students working for each of the companies delivers the sign to the appropriate next place, such as a gas station or gas tanks at the homes.
   - The order for each resource is as follows:

- Oil → Oil Refinery → Car driver
- Gas → Gas Refinery → Homeowner
- Coal → Power Plant → Homeowner

7. Stop the students and explain that up to this point, the carbon has stayed locked (sequestered) in the fuel. Remind the students about the respiration equation. Explain that burning is the same as respiration, breaking the carbon compounds, and reassembling the CO_2.
8. Next have the students act as people in the city burning the fuel. Every time someone uses energy (drives a car, makes toast, watches a movie, heats their house), the CO_2 tarp gets pulled farther out of the mine (the "miner" students can do this) and the Earth gets warmer.
   - As the tarp is pulled out of the mine, begin to explain how this increases the warmth of the Earth.
   - Mention the term greenhouse gas and how it affects the Earth's temperature.
9. Using a dry erase board or their individual field journals, have the students create a model that illustrates the path of the carbon from dead forest, to fossil fuel, to mine, to power plants, to homes and cars, and finally to the air.
10. Present the students with a graph of CO_2 concentrations in the atmosphere and temperature fluctuations over the last 400K years. Discuss how the burning of fossil fuels from human activity has contributed to the patterns on the graph.

11. As part of the discussion, have students explain one action they can take to lower their carbon footprint. Have them use chemistry to explain why their action would use less carbon and why their action would reduce global warming.

Guiding Questions:

- What are the human influences on the carbon cycle?
- How does burning fossil fuels affect the Earth's atmosphere?
- How does excess CO_2, a greenhouse gas, affect the Earth's climate?

Background Information:

"All living things are made of carbon. Carbon is also a part of the ocean, air, and even rocks. Because the Earth is a dynamic place, carbon does not stay still. In the atmosphere, carbon is attached to some oxygen in a gas called carbon dioxide (CO_2). Plants use CO_2 and sunlight to make their own food and grow. The carbon becomes part of the plant. Plants that die and are buried may turn into fossil fuels made of carbon like coal and oil over millions of years. When humans burn fossil fuels, most of the carbon quickly enters the atmosphere as CO_2. CO_2 is a greenhouse gas and traps heat in the atmosphere. Without it and other greenhouse gases, Earth would be a frozen world. But humans have burned so much fuel that there is about 30% more CO_2 in the air today than there was about 150 years ago, and Earth is becoming a warmer place."

Kid's Crossing, n.d.

Carbon exists in various forms in the atmosphere. Carbon dioxide (CO_2) and methane (CH_4) are partly responsible for the greenhouse effect and among the most important human-contributed greenhouse gases. The largest human impact on the carbon cycle is through direct emissions from burning fossil fuels, which transfers carbon from the geosphere into the atmosphere. The rest of this increase is caused mostly by changes in land-use, particularly deforestation. In the past two centuries, human activities have altered the global carbon cycle, most significantly in the atmosphere. "Since the industrial revolution, human activity has modified the carbon cycle by changing its components' functions and directly adding carbon to the atmosphere" (Wikipedia, n.d.). Although CO_2 levels have changed naturally over the past several thousand years, human emissions of CO_2 into the atmosphere have created unnatural fluctuations. Changes in the amount of atmospheric CO_2 are considerably altering weather patterns and indirectly influencing oceanic chemistry.

> "On November 2015, NASA scientists reported that human-made CO_2 continues to increase above levels not seen in hundreds of thousands of years: currently, about half of the carbon dioxide released from the burning of fossil fuels remains in the atmosphere and is not absorbed by vegetation and the oceans."
>
> Wikipedia, n.d.

Activity Adapted from:

The Carbon Cycle and its Role in Climate Change: Activity 3. *Climate Change, Wildlife and Wildlands: A Toolkit for Formal and Informal Educators.* June 2009. Accessed on 5/31/2017: www.globalchange.gov/climate-toolkit

Background Information from:

Carbon Cycle. *Wikipedia.* CC-BY-SA by Wikipedia. Used with Permission (See Appendix H.2.4). Accessed on 6/7/2017 https://en.wikipedia.org/wiki/Carbon_cycle

The Carbon Cycle. Living in the Greenhouse. *Kid's Crossing.* Used with Permission (See Appendix H.2.3) Accessed on 6/7/2017: https://eo.ucar.edu/kids/green/cycles6.htm

A2: Feeling the Heat Activity

Summary: Students learn about the urban heat island effect by investigating which areas of their environment have higher temperatures. Through this activity students make connections about how human activity can change local climates.

Key Concepts:

- Humans affect both local and global climates.
- The effects of human activity on our environments ultimately affect human communities.
- The urban heat island effect: concentrations of surfaces that absorb heat affect the temperature in cities.

Time block: ~45 minutes

Materials:

- IR Thermometers (1 for each group of ~3 students)
- String
- Science journals
- White board & dry erase markers

Activity:

1. This activity would be most productive in an area that has both man-made and natural surfaces.

2. Ask students to look around and make predictions about which areas are the warmest and which are the coolest.
3. Choose 6-8 areas that students have identified. Students will collect temperature data in these areas. Make sure that there is a mix of sunny and shaded areas as well as a mix of paved and grass/natural areas.
4. Provide each student group with a journal and an IR thermometer and a piece of string. Instruct students on how to use the thermometers.
    a. If using IR thermometers, remind students to point the thermometer directly at the ground surface they wish to measure (*i.e.*, concrete, asphalt, grass, dirt, etc.) See the Background Section (below) for more information about IR thermometers.
    b. Remind students to keep it in place for at least two minutes and to shade the thermometer from direct sunlight while taking a measurement. To ensure each measurement is taken the same distance from the ground students should measure from the ground to the top of the string and then make their measurement there. It's important that all groups collect data from the same height above the ground so that data can be compared.
5. Have student groups head to their locations, take 5 temperature measurements, and record descriptive information about their location in their journal. Students should then calculate the average of the temperature measurements.
6. Create a chart of the locations on a white board. Have student groups fill in the data about their location including average temperature, sun/shade, and ground cover.

7. Discuss the results. Are the results what students predicted? Introduce the concept of microclimates (see Background Section below). Microclimates allow different locations to have different temperatures. Ask students what aspects of the environment affect temperature in these areas. (The most likely result is that areas in the sunshine were warmer than those in the shade, and areas that had a paved surface were warmer than grass or natural areas.)
8. Ask students, based on these results, which they think would be warmer: urban areas or rural areas. (In urban areas where surfaces like asphalt and concrete are abundant, temperature will be higher.) Introduce the concept of urban heat islands (see Background Section below).

Guiding Questions:

- How do man-made structures affect temperature?
- How do humans influence microclimates?
- How does the human effect on microclimates affect the global climate?

Background information:

"The Urban Heat Island Effect: The air in urban areas can be 2 - 5°C (3.6 - 9°F) warmer than nearby rural areas. This is known as the heat island effect. It's most noticeable when there is little wind. An urban heat island can increase the magnitude and duration of a heat wave. It can also influence the weather, changing wind patterns, clouds, and precipitation. What makes cities warmer? There are many factors that can influence the urban heat island effect. The modifications to the land surface that are made in urban areas have a large impact on whether a heat island forms. For example, many cities have fewer trees than surrounding rural areas. Trees shade the ground, preventing radiation from the Sun from being absorbed. Without them, the ground surface heats up. Dark rooftops and dark pavement absorb more radiation too. Tall buildings reflect and absorb sunlight. Automobiles, which make heat from their engines and exhaust, also contribute to the heat island effect. Fewer plants in urban settings mean that less evapotranspiration occurs, a process that cools the air. Today, many cities are making an effort to combat the heat island effect. White or reflective materials are being used for roofing and roads. Trees are being planted along city streets. And, in many areas, green roofs - living plants on rooftops - are being installed.

<u>Microclimates:</u> The term microclimate can be used to describe differences in small areas of just a few square meters or much larger areas a few kilometers apart. Factors that contribute to microclimates in a small area include the presence or absence of shade (from trees, buildings) and the type of material at the ground surface (dirt, grass, asphalt, concrete). Shaded areas are generally cooler since much solar radiation is unable to be absorbed by the Earth surface. Ground materials like asphalt and concrete absorb solar energy readily and dark paving will typically be warmer than light color paving because dark colors absorb more heat.

IR Thermometers: Infrared thermometers (IR thermometers) are recommended for this activity. IR thermometers measure temperature by assessing the amount of energy emitted from an object. When sunlight hits the Earth surface, some of that energy is absorbed and some is reflected. The energy that is absorbed heats and is radiated from the surface."

Windows to the Universe, 2009

Activity Adapted from:

Feeling The Heat. Windows to the Universe. *National Earth Science Teachers Association (NESTA).* Last modified April 207, 2009 by Lisa Gardiner. CC BY-NC-SA 3.0 Used with Permission (See Appendix H.2.5). Accessed on 5/31/2017: https://www.windows2universe.org/?page=/teacher_resources/teach_heat.html

Background Information from:

Feeling The Heat. Windows to the Universe. *National Earth Science Teachers Association (NESTA).* Last modified April 207, 2009 by Lisa Gardiner. CC BY-NC-SA 3.0 Used with Permission (See Appendix H.2.5). Accessed on 5/31/2017: https://www.windows2universe.org/?page=/teacher_resources/teach_heat.html

A3: Climate Change Winners and Losers

Summary: Students will discuss how climate change affects organisms. They will experience how climate change forces mountain life zones to gradually shift up slope, with some habitats and species ultimately being displaced.

Key Concepts:

- Climate change affects organisms.
- Some organisms are more vulnerable to the effects of climate change than others.
- Climate change forces life zones to move up in elevation.

Time Block: ~45 minutes

Materials:

- Stick or object to draw on the ground
- Top of the Mountain animal cards
- Winners and Losers cards

Activity:

Part 1: Top of the Mountain activity

1. Explain the concept of life zones, and how each plant and animal community thrives at an elevation that provides the appropriate mix of temperature and moisture conditions for it.
2. Using a stick, draw a long, wide triangle in the dirt, about 10 feet high. This is your mountain (you can give it a name, if you like).

3. Select about ~4 “volunteers” to represent a species that lives in the hot, dry conditions at the bottom of the mountain (White-tailed antelope squirrel) and place them in a line parallel to the base of the triangle. Ask this group to hold up the picture of their species.
4. Select another ~3 “volunteers” and ask them to represent an animal of low elevation forests (Idaho ground squirrel). Ask this group to hold up the picture of their species. Arrange them parallel to the White-tailed antelope squirrel, but “higher up” the mountain.
5. ~2 more “volunteers” can become an animal of high elevation forests (Porcupine). Ask this group to hold up the picture of their species. Arrange them parallel to the Idaho ground squirrel, but “higher up” the mountain.
6. Finally, at the summit, choose ~1 “volunteer” to be Pikas, which live in rock slides and meadows above timberline.
7. Once everyone is located on the mountain, suggest that climate change makes the lower elevations hotter and drier. The Idaho ground squirrel layer can’t survive where it is, so it moves “upward,” displacing the Porcupines. “But that’s OK, because the White-tailed antelope squirrel can move into the Idaho ground squirrel’ former territory. And hey, the Porcupines can move up the mountain to higher elevations.” But it will become clear that to do so, they have to push the Pikas farther up . . . and they have nowhere to go. They get pushed off the mountain and have no home, ultimately dying.
8. If you want to avoid the depressing end of the Pikas, you can suggest that they may continue to survive in reduced numbers in reduced habitats on the very tallest mountains; and some day in the distant future when the climate changes again, they will be able to

move downwards to occupy their former habitats as conditions become cooler and moister.

Part 2: Winners and Losers discussion

1. Give out the Winners and Losers cards, one to each student.
2. Ask students to read their cards and share with the rest of the group.
3. Discuss how different species are affected by climate change. You can also reference what they learned during the Top of the Mountain activity.

Guiding Questions:

- How does climate change affect organisms?
- Are all organisms affected in the same way?
- How will climate change affect habitats in Idaho?

Background Information:

"Climate change affects high latitudes and high altitudes most severely. As the climate at lower elevations warms and dries, species may be forced to move their range up slope to stay in the "sweet spot" of conditions that they prefer. For example, as the climate warms, low elevation ponderosa pines may find it too hot to survive in the foothills, and gradually shift their range upslope as temperature and moisture gradients change. Other plants, such as sagebrush, may favor the new conditions in the foothills and move in to take over the area formerly occupied by the pines. As life zones gradually shift upwards, the tundra habitat at the top of the peaks has nowhere to go to escape the changing conditions, and may gradually vanish as it is replaced by plants and animals moving up from below. If tundra becomes increasingly scarce, its plants and animals will vanish from all but the very tallest peaks."

Sutherland, n.d.

"Change can be good for some – a longer spring with more food, a comfortable niche to call home and a stressful migration avoided. However, as warming continues, winners may hit new limits and lose their edge. Which species adapt well to rapid change? Generalists that tolerate a range of climates, those with diverse genes and speedy reproduction (which lets helpful traits enter the gene pool fast), those that can travel to a suitable new habitat – and that have somewhere to go, and competitive, often invasive species. Which do poorly? Specialists with narrow climate needs, those already battling for survival, small and fragmented populations, or those hemmed in by unsupportive landscapes, animals competing with humans, groups lacking genetic diversity, high-elevation species, island dwellers, many coral-dependent animals and those needing ice to survive."

Sim, 2015

Activity Adapted from:

Sutherland, D. Teaching Games: How Climate Change Affects Species. *City of Boulder Open Space & Mountain Parks.* Used with Permission (See Appendix H.2.6). Accessed on 5/31/2017: https://scied.ucar.edu/sites/default/files/images/event/0000036365-How%20Climate%20Change%20affects%20Species.pdf

Background Information from:

Sutherland, D. Teaching Games: How Climate Change Affects Species. *City of Boulder Open Space & Mountain Parks.* Used with Permission (See Appendix H.2.6). Accessed on 5/31/2017: https://scied.ucar.edu/sites/default/files/images/event/0000036365-How%20Climate%20Change%20affects%20Species.pdf

Sim, D. 2015. Climate Change winners and losers: Which animal species will thrive? *International Business Times.* Used with Permission (See Appendix H.2.7). Accessed on 6/8/2017 http://www.ibtimes.co.uk/climate-change-winners-losers-which-animal-species-will-thrive-photos-1524912

A4: Document-Based Inquiry

Summary: Students will use the Document-Based Inquiry method to investigate the effects of climate change on an economically and culturally important Idaho species: salmon. Students will develop science literacy skills as well as observational and argumentation skills through this activity.

Key Concepts:

- Changes in temperature can affect organisms.
- Some organisms are more vulnerable to the effects of climate change than others.
- Climate change affects species that are ecologically, economically, and culturally important.
- Climate change affects human communities by affecting the resources those communities need.

Time Block: ~45 minutes

Materials:

- DBI document packets
- Science journals

Activity:

1. Divide students into groups of 3-5 students.
2. Instruct the students that they will be investigating a mystery based on some clues you will provide them. Introduce them to the worksheet in their science journals.
3. Provide DBI packet #1, allow students to work through the clues. Students should write their observations of the resources provided. What do they wonder about these resources?
4. Repeat step 2 with DBI packet #2. Guide students in discovering how this new information answers some of the questions they posed while making observations about DBI packet #1.
5. Repeat step 2 with DBI packet #3. Guide students in discovering how this new information answers some of the questions they posed while making observations about DBI packet #1 & DBI packet #2.
6. Guide students in filling out the synthesis portion of their worksheet:
   - What did you discover? Share your final thoughts on this case.
   - Why should people care about water temperatures in aquatic environments?
   - What might be some solutions to a water temperature problem in an aquatic environment?
   - How can you relate these concepts to your local area in Eagle, Idaho?
7. Ask students to share the conclusion of their investigation with the larger group.

Guiding Questions:

- How does climate change affect organisms?
- How does climate change affect ecologically and economically important species?
- How does climate change affect human communities?

Background Information:

Impacts of climate change on salmon:

"Warmer Water: Optimum water temperature range for most salmonids is 55°-64°F (12.8°-17.8°C). Warmer summers are also raising stream temperatures, making salmon more susceptible to predators, parasites and disease. Massive fish kills have occurred at or above 71.6°F (22°C). Unprecedented high temperatures in early summer 2015 hit the lower mainstem Columbia River and tributaries. Of all Redfish Lake sockeye salmon detected passing Bonneville Dam, only 4% survived to Lower Granite Dam, and none survived after temperatures exceeded 20°C at Bonneville. Warmer ocean waters and shifting currents are also prompting a northward shift in the range of some salmon and other fish populations, such as barracuda and Pacific cod.

Loss of food source: CO_2 is making the oceans more acidic, dissolving the shells of pteropods (tiny mollusks), an important food source for juvenile North Pacific salmon. Evidence continues to show declines of pteropods in the southern California Current System due to ocean acidification.

Loss of Snowpack: Loss of snowpack and shrinking glaciers mean reduced stream flows in summer and fall. Not only would it would be difficult for returning salmon to reach spawning grounds and for juvenile fish to reach the ocean, lower stream volumes also mean warmer water.

Forest Fires: Warmer, dryer conditions have resulted in a 400% increase in the number of major fires and 600% increase in the average area burned since the 1980s. Intense forest fires can completely burn out root systems, contributing to erosion and siltation of nearby rivers.

More Severe Storms and Floods: Increasingly heavy winter floods wash away salmon eggs, even scouring away the gravel spawning beds. Severe floods can wash toxic materials into rivers.

Sea Level Rise: Sea level rise may inundate low-lying estuaries, a critical habitat for salmonids as they make their transition between river and ocean life stages."

National Wildlife Federation, n.d.

Salmon are important for Idaho:

"Salmon runs function as enormous pumps that push vast amounts of marine nutrients from the ocean to the headwaters of otherwise low productivity rivers. For example, sockeye salmon runs in southwest Alaska contribute up to 170 tons of phosphorous per year to Lake Illiamna. These nutrients are incorporated into food webs in rivers and surrounding landscapes by a host of over 50 species of mammals, birds, and fish that forage on salmon eggs, juveniles, and adults in freshwater. Predators, such as brown bears, disperse these marine nutrients into surrounding forests, enhancing the growth of stream-side trees that shade and protect stream banks from excessive erosion. In southeastern Alaska, spawning salmon contribute up to 25% of the nitrogen in the foliage of trees, resulting in tree growth rates nearly three-times higher than in areas without salmon spawning. Pacific salmon fuel a $3 billion industry, supporting tens of thousands of jobs and local economies and communities around the Pacific Rim. Millions of people around the Pacific rely on salmon as a healthy and reliable source of protein. Native people have always seen the salmon as the life-sustaining centerpiece of their culture, dating back millennia. The importance of salmon extends beyond food value. Around the Pacific Rim, salmon have figured centrally in the worldview and daily life of indigenous people."

Rahr, n.d.

Salmon population decline is due to a variety of factors:

"A combination of factors contribute to the continuing decline of salmon. On the west coast, it is widely accepted that the most important factors that affect salmon are the "four Hs"—hydropower, habitat, harvest, and hatcheries. With the presence of dams, salmon are unable to ascend to the spawning grounds of their natal streams, and juveniles are hindered from migrating downstream. Redfish Lake in Idaho's Sawtooth Mountains historically would receive hundreds of thousands of bright red adult Sockeye salmon returning to spawn via the Columbia River system. Now only one or two fish may be observed reaching their annual destination.

Habitat loss to urban growth and degraded watersheds from generations of farming and logging has left spawning grounds choked with pollutants and silt. Fishing activities (harvest) are putting further strains on salmon stocks. Hatchery fish sometimes are interbreeding with native species, modifying the population's genetic characteristics.

To help reduce mortality of juvenile salmon as they encounter dams and hydroelectric turbines on their downstream migration, fisheries managers and biologists transport critical populations in barges and trucks. Juvenile fish transportation programs represent only a small component of the larger strategy to assist the recovery of salmon populations.

On a global scale, the effect of changing ocean temperatures is speculated to have a connection to the number of salmon returning to spawn. Scientists believe the continued decline in native Atlantic salmon numbers appears to be caused by increased mortality in the ocean. Possible explanations are the depletion of the salmon's normal food source by commercial fisheries."

Crouse, n.d.

Activity Adapted from:

Document-Based Inquiry Lesson: John Day River Fishkill. Deirdre Abrams. Personal communication. Used with Permission (See 2.8). 5/22/2017

Background Information from:

National Wildlife Federation. Salmon and Global Warming. Used with Permission (See Appendix H.2.9). Accessed on 6/7/2017 http://www.nwf.org/Wildlife/Threats-to-Wildlife/Global-Warming/Effects-on-Wildlife-and-Habitat/Salmon.aspx

Rahr, G. Why Protect Salmon. *Wild Salmon Center.* Used with Permission (See Appendix H.2.10). Accessed on 6/8/2017 https://www.wildsalmoncenter.org/work/why-protect-salmon/

Crouse, R. Salmon Decline and Recovery. Used with Fair-use Considerations (See Appendix H.2.11). *Water Encyclopedia: Science and Issues.* Accessed on 6/8/2017 http://www.waterencyclopedia.com/Re-St/Salmon-Decline-and-Recovery.html

A5: Water Quality

Summary: Students will learn about water quality and water chemistry through investigating habitat suitability for salmonids. They will be introduced to the concept of water acidification and how current climate change is contributing to the increase of water pH.

Key Concepts:

- Water quality refers to the chemical, physical, biological, and radiological characteristics of a body of water. It provides information as to how suitable a body of water is for animal use and human consumption.
- Salmonids need a habitat with water quality parameters that fall within a specific range. Anything above or below these ranges is unsuitable for salmonids.
- Water acidity is a parameter of water quality. pH refers to the amount of hydrogen atoms in the water, which affects its acidity.
- Bodies of water like lakes and oceans have pH, or acidity, gradients that depend on depth. Animals can move to the surface or depths of the water to get away from areas that may unsuitable for them.
- CO_2 in the atmosphere is absorbed by bodies of water, where it reacts with water and turns the water acidic.
- As water turns acidic it makes it a difficult environment for animals.

Time Block: ~1 hour

Materials:

- Vernier LabQest2 (1 per 3-4 students)
- Probes: Temperature, pH, DO, conductivity
- Water quality parameter cards
- Turbidity tube
- Macros supplies
- Water sampler
- Water bottles/containers
- Map: Acid-sensitive areas
- Science journals

Activity:

Part 1: Water Quality Activity

1. Introduce the concept of trout fishing and how different water quality parameters affects where these fish live. Introduce and define the concept of habitat.
2. Have students open their field notebooks to the water quality table and identify the water quality parameters.
3. Divide students into 5 groups/pairs and provide each group/pair with a water quality parameter card and the accompanying measuring device. Give each group/pair a few minutes to read over their water quality parameter card and discuss. Have each

group/pair share what they learned about their water quality parameter with the rest of the group.

4. Allow each group to take the water quality measurement they learned about with the appropriate measuring device.
5. Give students a few minutes to share their data with other groups/pairs until all students have filled in the entire table.
6. Organize the group into a discussion circle. As a group, use the last column of the table to determine if the measured water quality parameters meet the requirements of a healthy habitat for trout.
7. As a group, make a final conclusion on whether this is good trout habitat based on the water quality parameters measured.

Part 2: Depth Profiles

1. Introduce the concept of depth profiles. Ask students what type of information a depth profile might be able to provide that we cannot get with only one surface data point.
2. While in the canoe, use the sampler to obtain a water sample at 20m (or as deep as the lake is at that point). Take water quality data from the water sample.
3. Repeat step #2 every 5m or less.
4. Ask the students to create graphs of the depth profile data they collected. Discuss patterns that arise.
    - Do water quality parameters stay the same throughout the water column?
    - How could this be a good thing or a bad thing for the organisms that live in the water?

5. Discuss how climate change could change these depth profiles.
   - How will temperature change?
   - How will pH change?
   - What could these changes mean for the organisms that live in the water?

Guiding Questions:

- What is water quality?
- What type of information can water quality parameters provide as to the suitability of this habitat for organisms?
- What is pH?
- What are depth profiles and what are they used for?
- How does climate change affect water quality parameters?
- How does climate change affect aquatic habitats?

Background Information:

"Climate change is already beginning to affect plants and animals that live in freshwater lakes and rivers, altering their habitat and bringing life-threatening stress and disease.

<u>Displacement of cold-water species:</u> As air temperatures rise, water temperatures do also—particularly in shallow stretches of rivers and surface waters of lakes. Streams and lakes may become unsuitable for cold-water fish but support species that thrive in warmer waters. Some warm-water species are already moving to waters at higher latitudes and altitudes.

<u>Dead zones:</u> In a warming climate, a warmer upper layer in deep lakes slows down air exchange—a process that normally adds oxygen to the water. This, in turn, often creates large "dead zones"—areas depleted of oxygen and unable to support life. Persistent dead zones can produce toxic algal blooms, foul-smelling drinking water, and massive fish kills.

<u>Effects on reproduction</u>: Earlier snowmelt, rising amounts of precipitation that falls as rain rather than snow, and more severe and frequent flooding—all linked to global warming—may affect the reproduction of aquatic species. Some salmon populations have declined, for example, as more intense spring floods have washed away salmon eggs laid in stream beds.

<u>Stress</u>: When stream flow peaks earlier in the spring owing to warmer temperatures, low stream flow begins earlier in the summer and lasts longer in the fall. These changes stress aquatic plants and animals that have adapted to specific low-flow conditions. The survival rates of fish such as salmon and trout are known to diminish when water levels in rivers and streams are dangerously low, for example. That's partly because bears can snag spawning salmon more easily in very shallow water, as the salmon struggle upstream.

<u>Disease:</u> The more intense precipitation that accompanies a warming world makes river flooding more likely. This flooding—combined with sewer system overflows and other problems stemming from inadequate sanitation infrastructure—can lead to disease outbreaks from water-borne bacteria."

Union of Concerned Scientists, 2011

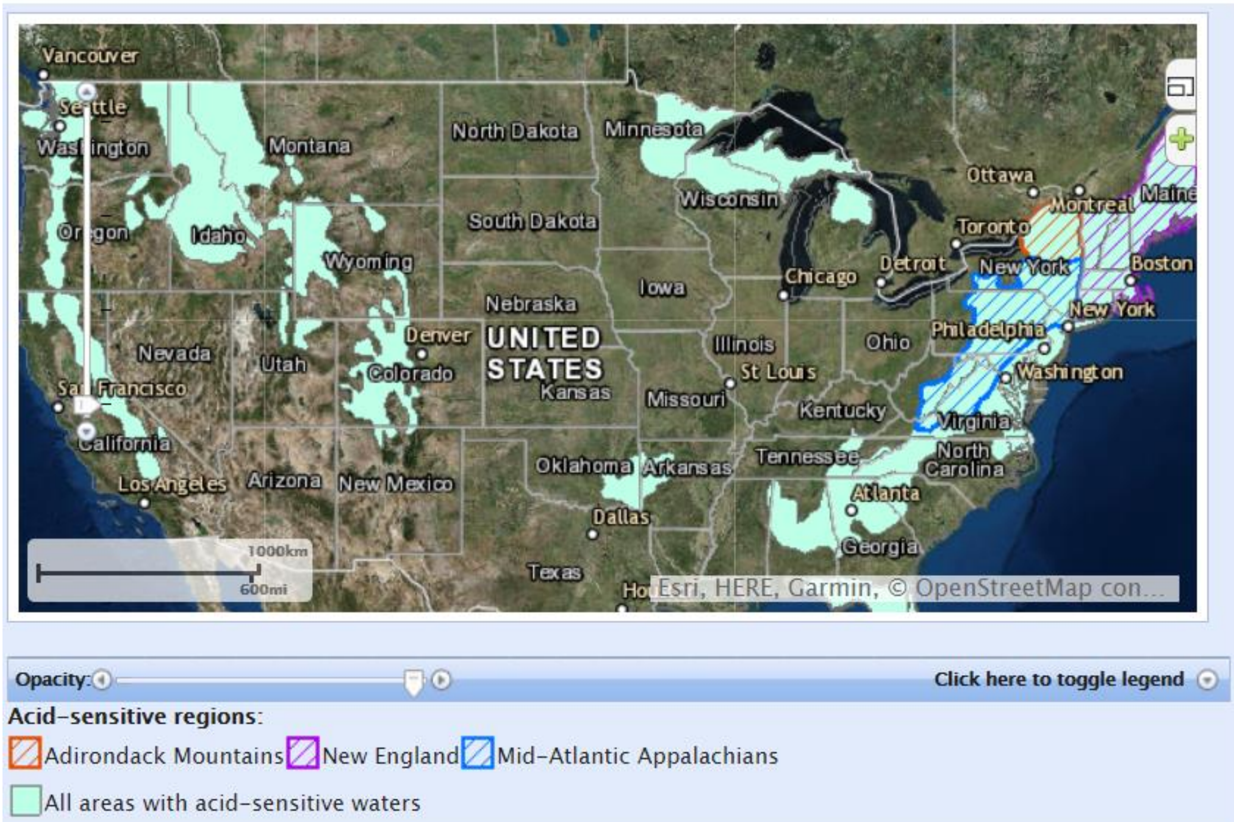
“As in the oceans, carbon dioxide (CO_2) from the atmosphere could throw off water chemistry in large freshwater bodies like the Great Lakes, putting the food web at risk. While most research CO_2 absorption from the atmosphere has focused on oceans and the resulting acidification, it is widely believed that CO_2 levels also will rise in large freshwater lakes. Assuming CO_2 emissions remain at the current rate, they estimated that pH in the Great Lakes would decline about .29-.49 units over the next century—roughly the same rate as ocean acidification projections. Phytoplankton, microscopic plants that live near the surface of water, seem to have reduced nutritional quality when more CO_2 is introduced, according to Canadian researchers. This, in turn, could reduce the growth of the next level of the food chain, called zooplankton, which are tiny aquatic creatures, including things like small crustaceans and fish larvae. Both types of plankton are the basis for healthy communities of fish and other species higher up on the food chain. Scientists this year reported that a predator fish up the food chain—pink salmon—had stunted growth when exposed to elevated levels of CO_2.”

Bienkowski, 2015

“Acid deposition can have serious effects on aquatic ecosystems. For example, aquatic organisms in acidified waters can develop calcium deficiencies that weaken bones and exoskeletons and cause eggs to be weak or brittle. Acidified waters can impair the ability of fish gills to extract oxygen from water and change the mobility of certain trace metals (*e.g.*, aluminum, cadmium, manganese, iron, arsenic, mercury), which in turn can place fish and other species sensitive to these metals at risk.”

Environmental Protection Agency, n.d.

Exhibit 2. Areas with acid-sensitive waters in the contiguous U.S.



Trend analysis has not been conducted because these data represent a single snapshot in time. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: NAPAP, 1991

Figure E.1 Reprinted from "Acidity in Lakes and Streams" by the Environmental Protection Agency, 2017, Report on the Environment. Reprinted with Permission. Accessed on 6/8/2017: https://cfpub.epa.gov/roe/indicator.cfm?i=12#2

Background Information from:

Union of Concerned Scientists. 2011. Lakes and Rivers. *Climate Hot Map: Global warming effects around the world.* Used with Fair-use Considerations (See Appendix H.2.12). Accessed on 6/8/2017: http://www.climatehotmap.org/global-warming-effects/lakes-and-rivers.html

Bienkowski, B. 2016. Acid Trip: Great Lakes could face similar acidification risk as the seas. *Great Lakes Echo.* CC BY-NC-SA 3.0 Used with Permission (See Appendix H.2.13). Accessed on 6/8/2017: http://greatlakesecho.org/2016/01/07/acid-trip-great-lakes-could-face-similar-acidification-risk-as-the-seas/

Environmental Protection Agency. Acidity in Lakes and Streams. Report on the Environment. Accessed on 6/8/2017: file:///C:/Users/ilean/Downloads/lake-stream-acidity.pdf

A6: CO_2 Makes Solutions Acidic

Summary: Water acidification is an abstract concept that is usually difficult to picture. Through this activity students learn about acidity and experiment with sources of CO_2 and their potential to acidify water.

Key Concepts:

- pH is a measure of the acidity of a substance. As the number lowers, the acidity increases.
- Carbon dioxide (CO_2) gas dissolved in water can cause water to become acidic.

Time Block: ~45 minutes

Materials:

- Vernier LabQest2 (1 per 3-4 students)
- pH probe
- Water
- Carbonated water (club soda or seltzer water) in a wide clear plastic cup
- 1 plastic cup per group
- 2 tall clear plastic cups per group
- Graduated cylinder
- Paper straw
- Activity sheet

Activity:

Part 1: Respired CO_2 changes the acidity of water

1. Show students both samples of water. Use a pH strip in each solution to test the acidity of the water.
2. Have students place a straw in one of the samples so that the straw goes all the way to the bottom of the cup.
3. Ask students to blow into the straw for 5 seconds and check its acidity with a pH strip.
4. Does blowing into the indicator solution change its pH?
   - Yes, the color changes, so there must be a change in pH, too.
5. Does the solution become a little more acidic or a little more basic?
   - The color change shows that the solution is a little more acidic.
6. Tell students that a chemical reaction occurs between the molecules of CO_2 and the molecules of H_2O to create a very small amount of an acid called carbonic acid (H_2CO_3).

Part 2: CO_2 from carbonated drink changes the acidity of water

1. Pour 25 mL of carbonated water into a wide, clear, plastic cup for each group.
2. Measure 30 mL of tap water and divide it evenly into two small, clear, plastic cups.
3. Add 25 mL of water to a wide plastic cup and 25 mL of carbonated water to another wide cup.
4. Stand the small cups with indicator solution in the liquid in the wider cups.
5. Turn the two tall cups upside down and place them over the two wider cups.

6. While holding the top and bottom cups to keep them together, gently swirl both sets of cups. Use pH strips to check the acidity in both cups and see if there is any change.
7. Compare the color of the pH strip to the pH Color Chart to find out whether the solution is acidic, neutral, or basic.
8. The carbonated water should not have splashed into the indicator. Why did the indicator solution change color in one set of cups?
    - The carbon dioxide from the carbonated water dissolved in the indicator solution. The molecules of CO_2 reacted with the water, forming carbonic acid, and changed the color of the indicator.
9. Tell students that they have seen CO_2 gas from your breath and CO_2 gas from carbonated water turn an indicator solution acidic.

Guiding Questions:

- How does CO_2 decrease water pH?
- Can a gas in the atmosphere affect the chemistry of lakes and oceans?
- What does this have to do with climate change?

Background Information:

Carbon dioxide reacts with water to produce carbonic acid. The chemical equation is:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

"Too much CO_2 in the atmosphere causes Earth and its atmosphere to become warmer. But excess CO_2 can do something else. CO_2 can make water more acidic which is causing a big problem in the oceans and is expected to also affect lakes. The excess acid in ocean water, called ocean acidification, makes it difficult for some organisms to form shells and is especially damaging to coral."

American Chemistry Society, 2016

Activity Adapted from:

American Chemistry Society. 2016. Lesson 6.10 Carbon dioxide can make a solution acidic. *Middle School Chemistry.* Used with Permission (See Appendix H.2.14). Accessed on 5/31/2017: http://www.middleschoolchemistry.com/lessonplans/chapter6/lesson10

Background Information from:

American Chemistry Society. 2016. Lesson 6.10 Carbon dioxide can make a solution acidic. *Middle School Chemistry.* Used with Permission (See Appendix H.2.14). Accessed on 5/31/2017: http://www.middleschoolchemistry.com/lessonplans/chapter6/lesson10

A7: Ocean Acidification & Shells

Summary: This activity allows students to see firsthand the effects water acidification can have on calcifying organisms. When exposed to vinegar, which is an acid, the calcified eggshell produces CO2 bubbles as it dissolves. The shells and skeletons of live calcifying organisms can be similarly affected as the ocean acidifies. If shell-building organisms are affected then all of the organisms that depend on them will also be impacted.

Key Concepts:

- Different solutions affect shells based on their pH. Basic and neutral solutions won't harm the shells, but acidic solutions will slowly dissolve them.
- The effect of pH on shells extends to shelled organisms that live in water.
- Organisms with shells and exoskeletons are especially vulnerable to the effects of water acidification.
- Water acidification and climate change are a consequence of the same issue: too much CO_2 in the atmosphere.

Time Block: ~45 minutes

Materials:

- pieces of empty clean chicken eggshell (these are abundant, calcified shells and serve as a proxy for marine shells)
- lemon juice, vinegar, cola, water, soap and other household solutions
- Vernier LabQest2 (1 per 3-4 students) and pH probe

- Dixie cups
- Medicine dropper or plastic pipette
- Scale
- Hand lens
- Plastic tweezers
- Activity sheet

Activity:

1. Provide students will different solutions: lemon juice, vinegar, cola, water, soap.
2. Ask students to test the pH, or acidity, of each solution.
3. Have students predict the effect of the solutions on the pieces of egg shell.
    - What will happen if I put a piece of egg shell in cola, water, soap, etc? Which solution will have the greatest effect on the shell?
4. Ask students to weigh their pieces of egg shell and write down their data on their worksheet. Place a separate piece of shell into each small dish. Keep one piece in a dish on its own as a control.
5. Use the dropper to place a few drops of selected liquid on the shell piece. Use a different piece of shell for each liquid. Label the dish with the type of liquid you used.
6. Ask students to make observations about what happens.
    - What do you observe? Which liquids react with the shell first?

7. Ask students about what this means for animals with shells that live in water as the climate changes?
    - From your observation on the eggshell, what might be some consequences of ocean acidification for animals with shells? How might you test this hypothesis?

Guiding Questions:

- How do different solutions affect shells?
- How does water acidification affect organisms?
- What does this issue have to do with climate change?

Background Information:

"Shells serve as a protective structure for both marine and terrestrial organisms. Marine ecosystems that depend upon calcium-carbonate to make shells, such as coral reefs or oyster beds, can be impacted by changes in ocean pH due to increased carbon dioxide. In experimental conditions under very high levels of CO_2, shells of clams, oysters, corals, snails and urchin shells dissolve. If these organisms are unable to build or repair shells, due to increased acidification caused by industrial emissions, deforestation and other human activities, they will likely cease to exist in these environments. These results do not occur for all organisms. In experimental conditions, extreme increases in CO_2 result in crabs, lobsters, temperate sea urchins, limpets, and calcifying algae all building thicker shells with the more acidic conditions. Some organisms are able to adapt more rapidly than others, some will leave an environment if they cannot adapt and others may cease to exist in that environment. Nutrient levels, water temperature, food availability and habitat changes also can have an impact. Efforts to reduce that impact have the greatest chance of preserving some of these habitats."

COSSE West, n.d.

Activity Adapted from:

COSEE West. "Shells and the Impacts of Ocean Acidification". Accessed on 11/28/2016: http://www.cisanctuary.org/ocean-acidification/PDFs-WorkshopPage/Hands_on_acivities/OA_Shells.pdf

Background Information from:

COSEE West. "Shells and the Impacts of Ocean Acidification". Accessed on 11/28/2016: http://www.cisanctuary.org/ocean-acidification/PDFs-WorkshopPage/Hands_on_acivities/OA_Shells.pdf

A8: Marine Osteoporosis

Summary: In this lesson students will explore the effects of acidic oceans on certain marine organisms, in the ocean food web, and to humans. Students will conduct a science experiment using the scientific method to see the effects of increased acidity on certain species. They will also investigate the causes for increased ocean acidity and discuss ways to minimize the impact as an individual and as a society.

Key Concepts:

- Water acidification affects organisms that have shells and exoskeletons by dissolving their calcium carbonate structures.
- Some organisms are more vulnerable to the effects of water acidification than others.
- Water acidification affects ecosystems by changing habitat suitability and disrupting ecological balances.
- Water acidification and climate change are a consequence of the same issue: too much CO_2 in the atmosphere.

Time Block: ~45 minutes in intervals

Materials:

- Small dishes (petri dishes, Tupperware dishes)
- Tap water
- Vinegar
- Vernier LabQest2 (1 per 3-4 students) pH probe

- Shells, piece of dead coral, urchin test (skeleton), chicken bones
- Activity sheet

Activity:

1. Have students fill one dish with tap water and the other dish with vinegar.
2. Ask students to hypothesize what the pH of each substance will be and justify your answer
3. Have students measure and record the pH of both substances.
4. Ask students to hypothesize what will happen when the item is immersed in each liquid. Have them justify their answer.
5. Have students record initial observation of the item(s) to be immersed in the fluids.
6. Record observations at 30 minute intervals.
7. Ask students to draw conclusions from their observations.
8. Ask students to create a graphic representation of their results to present to the class.

Guiding Questions:

- How does water acidification affect organisms?
- What are the consequences of water acidification for ecosystems?
- What does water acidification have to do with climate change?

Background Information:

"The process of ocean acidification (the decreasing pH of the ocean water) affects the organisms living within those waters. Many organisms use various forms of calcium carbonate to form their shells and skeleton. The increasing acidity of the water affects these organisms. As CO_2 is absorbed into the water the resulting chemical process reduces the amount of available carbonate ions used to by organisms to create their shells and skeleton. In addition to reducing the available carbonate ions the decreased pH makes the ocean water more corrosive. Some of the organisms most immediately affected by ocean acidification include: sea urchins, abalone, corals, and some species of plankton (such as pteropods and coccolithophores). If the ocean water continues to grow more acidic these organisms will be unable to form their shells and grow. The loss of these organisms will greatly impact the marine food web. Plankton is at the base of the marine food web. Plankton are organisms that cannot swim against the current. Some plankton are algae and some are animals. Phytoplankton (algae-plankton) include coccolithophores and zooplankton (animal plankton) include pteropods. Planktonic feeders include bivalves (mussels, clams, scallops, and oysters), sand crabs, and anchovies. Baleen whales, such as blue whales, are also planktonic feeders. As the base of the marine food web plankton are incredibly important. If oceans become inhospitable to plankton the removal of that portion of the marine food web could result in disaster to many other marine species. The increasing acidity of the ocean also has an effect on habitat. Coral reefs provide habitat for a large and diverse number of organisms. Many species of fish and invertebrates inhabit coral reef. If the coral can no longer successfully grow at optimum rates they will not be able to maintain the reef. Without the reefs the biodiversity of the ocean will decrease.

Ocean acidification may also affect important fisheries. Sea urchins, crabs, lobsters, and shrimp all use calcium carbonate to create their shells and skeletons. These are very important fisheries worldwide. A loss in species population would not only affect the marine food web, but would also affect the availability of food for humans as well as a means of livelihood for many people worldwide."

National Oceanographic and Atmospheric Administration, n.d.

Activity Adapted from:

National Oceanographic and Atmospheric Administration. "Marine Osteoporosis". *Office of National Marine Sanctuaries.* Accessed on 11/28/2016: http://sanctuaries.noaa.gov/missions/2010aquarius/marineos.pdf

Background Information from:

National Oceanographic and Atmospheric Administration. "Marine Osteoporosis". *Office of National Marine Sanctuaries.* Accessed on 11/28/2016: http://sanctuaries.noaa.gov/missions/2010aquarius/marineos.pdf

A9: Trees: Recorders of Climate Change

Summary: Students are introduced to tree rings by examining a cross section of a tree, or a tree core. They discover how tree age can be determined by studying the rings and how ring thickness can be used to deduce times of optimal growing conditions. Students will use the information from tree cores to make deductions about recent climate, looking at year-to-year variation versus long-term trends.

Key Concepts:

- During each growing season trees produce new wood in a ring on the outside of the tree trunk located just inside the bark.
- A series of concentric rings form during consecutive years of growth.
- A single tree ring is an indicator of growing conditions over a single growing season. A thicker ring may indicate a longer growing season or more water availability depending on the environment and tree species.
- A set of many consecutive tree rings provides information on climate trends during a tree's lifetime.
- A few rings can provide information about year-to-year variability. A series of 30 or more rings can provide information on climate and its trends.
- Air temperature increases due to climate change have changed the length of the growing season, which can be observed by changes in the width of the tree rings.
- Climate change affects plant species as well as animal species.

Time Block: ~45 minutes

Materials:

- Tree corer (or pre-prepared tree cookies)
- Hand lenses
- Metric ruler
- Science journals

Activity:

1. Introduce the tree corer tool. Allow students to take a tree core to study for the rest of the activity (one per student if possible).
2. Familiarize students with their tree core (or cookie) cross-section.
    - Explain that trees produce rings as they grow each spring and summer.
    - Ask students to describe the tree ring colors. Is there a pattern to the light and dark rings?
    - Explain that wood made during the first part of the growing season is light in color and wood made late in the growing season is darker. A light and a dark band together are the growth during one year.
3. Explain to students that the study of the ages of tree rings is called <u>dendrochronology</u> ("dendro" is Latin for tree and chronology is the study of a time sequence).
    - Ask students how old their tree is (or was when it was cut for the cookies).
4. Ask students to count the light/dark couplets of rings to estimate age.
    - Ask students which rings they think are youngest. Which are the oldest? (There may be multiple hypotheses suggested by your students. If so, discuss the likelihood of

each hypothesis, leading students to understand that the outer ring is, in fact, the youngest.)

5. If the time that the tree was cut is known, have students count backwards to find the ring that represents the student's year of birth.
6. Explain to students that past climates can be interpreted based on how the tree rings formed. This is called dendroclimatology.
    - Ask students if all the rings are the same thickness. They will likely notice that some rings are thicker than others. This can be for many reasons, but mainly the variations in ring thickness relate to growing conditions. In high latitude areas, tree growth is limited by the length of the growing season, which is controlled by temperature. In other environments, tree growth is greatly controlled by water availability.
7. Tree ring thickness can vary from year to year. Review with students that thick rings indicate a "good" growing season and narrow rings indicate a shorter or dryer growing season. Ask students to identify which year had the best growing season.
    - Tell students that there are two ways to study tree rings. Scientists can use cross-sections, but this is typically only done if the tree has died, because the process kills the tree. Instead, scientists usually take cores from living trees to study the rings. When a tree is cored, a small cylinder of wood is pulled out, smaller than the diameter of a drinking straw. Coring does not harm the tree. The rings can be studied from the cylindrically-shaped core.

Guiding Questions:

- What time of year do trees grow the most?
- How can we estimate tree age from a cross-section?
- What can a tree cross-section tell us about climate?
- How has climate changed in recent history?
- How can we use tree rings to collect data on climate change?

Background Information:

"Dendrochronology: The study of the growth of tree rings

Dendroclimatology: The study of the relationship between climate and tree growth in an effort to reconstruct past climates.

The growth layers of trees, called rings, preserve an interesting record of environmental conditions over the lifespan of the tree. They record evidence of environmental events such as floods, droughts, insect attacks, forest fires, lightning strikes, and even earthquakes. Many consecutive tree rings also record longer term and more subtle changes in climate over time.

Each year, new wood grows on the outside of the tree trunk, just under the bark. A year's growth is called a tree ring. Each tree ring is made of a band of light colored wood produced early in the growing season (spring and early summer) and a dark colored band produced late in the season (late summer and early fall). Counting the rings of a tree will determine its age. Scientists seldom cut down a tree to analyze its rings. Instead, core samples are extracted using a borer that's screwed into the tree and pulled out, bringing with it a cylinder of wood about 4 millimeters in diameter. The hole in the tree is then sealed to prevent disease.

Tree rings are an example of climate proxy data, providing indirect evidence of past climates. Scientists can use tree-ring patterns to reconstruct regional patterns of climatic change. The amount of tree growth depends upon various local environmental conditions. At high latitudes, the amount of tree growth is mostly controlled by temperature. Trees grow thicker rings when the growing season is longer and narrower rings when the growing season is shorter. The length of the growing season is related to the climate, namely the temperature. If the rings are a consistent thickness throughout the tree, the climate likely did not vary over the lifespan of the tree.

Typically, climatologists require at least 30 years of data to establish understanding of climate. To understand changes in climate requires even more data. Generally, dendroclimatologists use large databases of tree ring data to compare the records of many trees, and interpret when, where, and how quickly climates have changed."

National Center for Atmospheric Research, n.d.

Activity Adapted from:

Trees: Recorders of Climate Change. Climate Discovery Teacher's Guide. *National Center for Atmospheric Research.* Used with Permission (See Appendix H.2.15). Accessed on 5/31/2017: http://eo.ucar.edu/educators/ClimateDiscovery/LIA_lesson5_9.28.05.pdf

Background Information from:

Trees: Recorders of Climate Change. Climate Discovery Teacher's Guide. *National Center for Atmospheric Research.* Used with Permission (See Appendix H.2.15). Accessed on 5/31/2017: http://eo.ucar.edu/educators/ClimateDiscovery/LIA_lesson5_9.28.05.pdf

A10: Pine Beetles and Climate Change

Summary: Through this activity students will pine beetles and the importance of this species to Idaho ecosystems. Students will also learn about the effects of climate change to this species and what it means for the future of natural ecosystems in Idaho.

Key Concepts:

- Pine beetles are native species and a natural part of Idaho's ecosystems.
- Climate change affects organisms.
- Some organisms are more vulnerable to the effects of climate change than others.
- Some species, like pine beetles, benefit from climate change.
- The explosion in pine beetle population growth is in part due to increased temperatures due to climate change.
- Pine beetles and fire have an interconnected relationship.

Time Block: ~45 minutes

Materials:

- Science journals
- Pieces of bark with bark beetle galleries
- Bark beetle gallery pictures

Activity:

Part 1: Pine Beetle Exploration

1. Organize students in a discussion circle and introduce the concept of bark beetle galleries. Show pictures of bark beetle galleries.
2. Give students a few minutes to explore their surroundings and find pieces of bark with bark beetle galleries. Regroup in discussion circle.
3. Have students share what they found and draw their bark beetle gallery in their science journal.
4. Guide students in comparing the bark beetle galleries to the guide and identify which species made the galleries they found.
5. Discuss how bark beetles have become more prevalent with a warming climate and what it means for pine forests.

Guiding Questions:

- Are pine beetles native or non-native?
- Why has there been an explosion in pine beetle populations?
- How do pine beetles kill trees?
- How does climate change affect organisms?
- Are all organisms affected the same way? How could some organisms benefit from climate change?
- How do fires affect pine beetle populations, and vice versa?
- How will climate change affect local environments?

Background Information:

"The mountain pine beetle (*Dendroctonus ponderosae*) is a forest insect found in the southern Rocky Mountains and in area west of the Continental Divide; however, until recently it had not occurred in the northeastern slopes of the Rocky Mountains. Because it is a bark beetle, the majority of its life cycle is spent under the outer bark of mature pine trees. Adult female beetle bore into the inner bark called the phloem. They create j-shapes vertical galleries into which eggs are laid. The eggs mature and develop into larvae. The larvae tunnel away from the egg galleries. Generally, the life cycle of the mountain pine beetle is one year, but can take two years to compete if conditions are not favorable (*e.g.*, rainy summers, cool summers, high altitudes).

Once a female beetle colonizes a new host tree, she releases pheromones that attract other female and male beetles to the tree – meaning a successful mountain pine beetle colonization always involves many more than one beetle. The sharp mouthparts of the adult mountain pine beetle are ideally suited for boring through the bark to make the long, vertical galleries where the eggs are laid. It is also those mouthparts that carry blue stain fungus (their body carries it too). Blue stain fungal spores clog up the tree's water-conducting vessels, or xylem.

In addition, the larvae cause even more direct feeding damage than the adults. They tunnel horizontal galleries around the tree. These galleries girdle the tree and disrupt the phloem layer. The phloem is important because it transports nutrients throughout the tree. By disrupting both the xylem and phloem of pine trees, the mountain pine beetle larvae and their accompanying blue stain fungus make a deadly combination. The girdling of the tree and cutting off nutrient flow in the phloem layer is what causes the tree to die so quickly – within one year of colonization, in most cases.

Normally, mountain pine beetle populations are kept in check by natural factors such as predators, parasites, wet summers, and early, cold winters (-30°C or lower in November) or late, cold springs. However, the general warming climate trend is a contributing factor to the mountain pine beetle's population recent increase. Since the winters are not getting cold enough to kill the beetle, it is able to survive the winter and continue to reproduce. This has also allowed it to expand its range further north and east than its historical distribution.

From a human perspective, there is also a greater reliance than ever before on the forest to meet a variety of economic and social needs. The widespread mountain pine beetle outbreak in British Columbia has had significant economic and social impacts on the forest products industry, communities and tourism. Loss of income, resources and jobs are a result of the growing issue of mountain pine beetle outbreaks."

Cunnian et al., 2006

"Of the two major mountain pine beetle outbreaks that preceded the 1988 fires, the earlier outbreak (1972–75) was significantly correlated with the burn pattern, whereas the more recent one (1980–83) was not. Although regional drought and high winds were responsible for the large scale of this event, the analysis indicates that mountain pine beetle activity in the mid-1970s increased the odds of burning in 1988 by 11% over unaffected areas. Although relatively small in magnitude, this effect, combined with the effects of aspect and spatial variation in drought, had a dramatic impact on the spatial pattern of burned and unburned areas in 1988."

Lynch et al., 2006

Background Information from:

Lynch, H. J., Renkin, R. A., Crabtree. R. L., Moorcroft P. R. 2006. The influence of previous mountain pine beetle (*Dendroctonus ponderosae*) activity on the 1988 Yellowstone fires. *Ecosystems*. **9**:1318-1327 Used with Fair-use Considerations (See Appendix H.2.16).

Cunnian, J., Gluck, E., McIsaac, S. 2006. Mountain Pine Beetle Mania: A Junior High Science Resource. *Inside Education.* Used with Permission (See Appendix H.2.17). Accessed on 6/18/2018: http://learnmoreaboutclimate.colorado.edu/uploads/model-lessons/mountain-pine-beetles/beetle-mania.pdf

A11: Fire: A Burning Issue

Summary: Through this activity students will discover that fire is an integral part of Idaho ecosystems. Students will also learn about the effects of climate change to this important abiotic part of natural ecosystems in Idaho.

Key Concepts:

- Fire is an important part of Idaho ecosystems.
- There are different ways to manage fire: thinning, prescribed burns, and allowing large fires to burn are some examples of fire management.
- Some organisms are more vulnerable to the effects of climate change than others.
- Climate change is expected to increase the amount and intensity of forest fires in Idaho through altered precipitation patterns and increased temperatures.
- Human communities that live close to, or depend on, forest fires will be more vulnerable to the effects of climate change than others.

Time Block: ~1 hour

Materials:

- Spray bottle with water

Activity:

Part 1: Circle of Life Activity

1. Every participant chooses to represent an element of a forest ecosystem: favorite plants, animals, air, water, etc. Make sure that fire is part of the group, even if you have to choose it for yourself.
2. Everyone forms a circle by holding hands. Stretch the circle to its very greatest extent.
3. Everyone in the circle then leans back on their heels. They would fall on their butts except for the pull of other members in the circle.
4. Ask participants what would happen if the water is polluted, and can't be in circle anymore. Yank the person representing water out and let the circle collapse.
5. Repeat by focusing on fire as an element of the ecosystem. “What if forest fires are taken from the circle?” By removing the person representing fire, you cause the circle to collapse again.

Part 2: Burn Baby Burn Activity

1. Designate a time keeper and a fire fighter, the rest of the students will be fuel load.
2. Ask your group to imagine that each person represents 10 years of fuel loading.
3. Once a person “catches on fire,” they have 5 seconds to tag another non-burning person, who then catches on fire. Left unchecked, the fire will rapidly spread through the whole group.

4. The fire fighter will have to squirt a burning person three times with your bottle (Spish! Spish! Spish!) to put them out, after which they can no longer tag anyone unless they catch on fire again.
5. A time keeper counts out five second intervals ("One. Two. Three. Four. Five. One. Two. Three. Four. Five.")
6. Start with a small level of fuel loading: one person catches on fire, waving their arms and saying "Crackle! Crackle! Crackle!" You should have no problem spraying them three times before they can tag anyone.
7. Then try again, designating three people to burn (or 30 years of fuel loading). This time the fire will be able to spread much further before you can put it out, and you'll find it a challenge to get everyone.
8. Finally, designate eight people to start burning, representing 80 years of fuel loading. You will be unable to put the fire out in time to prevent its spread.

Guiding Questions:

- What is the importance of fire for ecosystems in Idaho?
- What are the benefits and costs of forest fires?
- What determines whether a forest fire is fought or allowed to burn?
- How are fires expected to change as the climate changes?
- How will climate change affect local environments?
- How will climate change affect local human communities?

Background Information:

“Fire is becoming an ever-increasing risk in Idaho’s mountains, and a topic of great concern for resource managers. Fire can be both friend and foe to people and to the forest. Helping Idaho’s residents better understand the complexities of fire may save lives and property, result in healthier ecosystems and ultimately simplify the work of land managers.

As a friend, fire can:

- Thin the forest, favoring old growth trees
- Remove “duff” from the forest floor or dead material from the prairie, stimulating renewed growth
- Improve wildlife habitat
- Create a “mosaic” of diverse habitat types, favoring increased biodiversity
- (Paradoxically) reduce the risk of future wildfires
- Recycle nutrients and fertilize forest or prairie soils

As a foe, fire can:

- Jeopardize lives and property
- Create soil erosion
- Cost huge amounts of money and resources for fire suppression

Wildfire is a fact of life in Idaho, and has been for thousands of years. Our forests and prairies are adapted to fire and actually require it. Any given patch of dry forest will burn eventually: this is nature's way. Prescribed fires let people control the conditions, timing and magnitude of the inevitable fires. "

Hutchings and Anderson, 2007

"Climate change can increase the frequency and severity of fires that burn forests, grasslands, and desert vegetation. On average, nearly 1 percent of the land in Idaho has burned per year since 1984, making it the most heavily burned state in the nation. Changing the climate is likely to more than double the area in the Northwest burned by forest fires during an average year by the end of the 21st century. Although drier soils alone increase the risk of wildfire, many other factors also contribute.

Higher temperatures and a lack of water can also make trees more susceptible to pests and disease, and trees damaged or killed burn more readily than living trees. Changing the climate is likely to increase the area of pine forests in the Northwest infested with mountain pine beetles over the next few decades. Pine beetles and wildfires are each likely to decrease timber harvests. Increasing wildfires also threaten homes and pollute the air."

Environmental Protection Agency, 2016

Activity Adapted from:

Hutchings, C., Anderson, B. 2007. A Burning Issue. The Learning Network. *The New York Times.* Used with Fair-use Considerations (See Appendix H.2.18). Accessed on 5/31/2017: https://learning.blogs.nytimes.com/2007/06/26/a-burning-issue/?mcubz=0&_r=1

Background Information from:

Hutchings, C., Anderson, B. 2007. A Burning Issue. The Learning Network. *The New York Times.* Used with Fair-use Considerations (See Appendix H.2.18). Accessed on 5/31/2017: https://learning.blogs.nytimes.com/2007/06/26/a-burning-issue/?mcubz=0&_r=1

Environmental Protection Agency. 2016. What Climate Change Means for Idaho. *EPA 430-F-16-014*

A12: Faces of Climate Change

Summary: In this activity, students will learn about the social, political, economic, and human impacts of climate change on individuals and communities in Idaho.

Key Concepts:

- Climate change affects human communities in Idaho.
- Some human communities are more vulnerable than others.

Time Block: ~45 minutes

Materials:

- Character cards
- Science journals

Activity:

1. Begin the activity with a discussion and reflection of students' lives:
    - How do you get to school? How do your parents get to work?
    - What do you do for fun? Do you have a phone? Computer? Ipod?
    - Do you heat your home in the winter? Do you cool your home in the summer? How?
    - Think about other people in Idaho, how would they answer these questions?
    - Do you think there are other people who use fewer resources than you? What might their life be like?
    - Does the climate where you live affect how you live?
2. After this discussion, hand out the "character cards."

3. Have the students read through their card. Ask students to share about their character:
    - What is their name? Where do they live? What do they do for a living?
    - How is their life affected by climate change?
    - How is your character's life different from yours? How are they similar?
4. Pair students with different character cards. Have them work through the following:
    - How is your character's life similar to your partner's life? How are they different?
    - How is your character's view about climate change linked to that of your partner's character?
5. As students "meet" their partners, they will work together to develop solutions for the unique issues that their characters face regarding climate change. One of the partners in each pair of characters has an italicized prompt on the card.
    - Brainstorm solutions to the concerns you both have about climate change. Why did you choose these solutions? Why do you think they will work?
6. Have the students work together, in character, to develop solutions to their characters' concerns regarding climate change. Make sure that the students propose solutions that are relevant to their specific characters needs and lifestyle, rather than generic "tips." For instance, a 50-yearold hunter should not be told to "ride the school bus to save gas."
7. Have each group write their solutions on their journals to present their characters and solutions to the rest of the group.

Guiding Questions:

- How will climate change affect local human communities?
- Are all human communities affected the same way?
- How does your character's life compare to your life?
- How is your character's life affected by climate change?
- How can people from different perspectives agree on solutions to climate change?

Background Information:

Effects of climate change in Idaho:

"Water Resources: Idaho relies primarily on surface, but groundwater is also an important source of supply. Most of Idaho is drained by tributaries to the Columbia River, including the Spokane, Pend Oreille, Kootenai, and Snake rivers. These rivers are regulated by dams and reservoirs to reduce spring flooding and augment summer flows. Runoff in the state is strongly affected by winter snow accumulation and spring snowmelt. A warmer climate could mean less snowfall, more winter rain, and a faster, earlier snowmelt. This could result in lower reservoirs and water supplies in the summer and fall. Additionally, without increases in precipitation, higher summer temperatures and increased evaporation also would contribute to lower streamflows and lake levels in the summer. Drier summer conditions would intensify competition for water among the diverse and growing demands in Idaho.

Agriculture: As climate warms, production patterns could shift northward. Increases in climate variability could make adaptation by farmers more difficult. Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies. In Idaho, production agriculture is a $2.8 billion annual industry, 60% of which comes from crops. Almost 70% of the farmed acres are irrigated. The major crops in the state are wheat, hay, barley, and potatoes. Climate change could increase wheat yields by 9-18%. Barley and hay could increase by 12%, and potato yields could fall by 18% under severe conditions where temperatures rise beyond the tolerance levels of the crop. Farmed acres could rise or fall by 10%, depending on how climate changes.

Forest: Hotter, drier weather could increase the frequency and intensity of wildfires, threatening both property and forests. Drier conditions would reduce the range and health of lodgepole and Douglas-fir forests, and increase their susceptibility to fire.
Grass and rangeland could expand into previously forested areas along the eastern slope of the Rocky Mountains and into some of the western valleys. Changes would significantly affect the character of Idaho forests and the activities that depend on them."

Wikipedia, n.d.

"Climate change invokes images of rising ocean levels and suffering polar bears, but the harm hits much closer to home. The last three years were the hottest in human history, and 16 of the hottest 17 years ever recorded occurred since 2000. Unless we act decisively, Idaho's average temperatures are projected to rise 5-10 degrees over the next century, transforming our state profoundly.
Due to climate change, our fire seasons are now 70 days longer than a few decades ago – dry, fire-prone conditions that once arose in August now start in May. An estimated 16,000

square miles of forest burned in the Northwest since 1984 is attributed to human-caused climate change. These fires are costly and worsen our air quality.

Summer water flows are expected to drop so much that some riverbeds may dry up entirely, devastating affected fish populations. The effects on agriculture and other aspects of Idaho's economy could be severe. One economist projected that costs to Idaho due to climate change could be more than $200 per acre – totaling over $11 billion.

Rapid early snowmelt will lead to soil erosion and flooding, such as the massive flooding just experienced in eastern Idaho in early February (not a typical time for flooding)."

Idaho Rep. Ilana Rubel, 2017

Activity Adapted from:

Activity 4.1: The Faces of Climate change. *Chicago Botanic Garden.* Used with Permission (See Appendix H.2.19). Accessed on 5/31/2017 at: https://www.chicagobotanic.org/downloads/nasa/Unit_4_Grades_7-9_Activity_4-1_FacesOfClimateChange.pdf

Background Information from:

Climate Change in Idaho. *Wikipedia.* CC-BY-SA by Wikipedia. Used with Permission (See Appendix H.2.4) Accessed on 6/7/2017 https://en.wikipedia.org/wiki/Climate_change_in_Idaho#Water_Resources

Idaho Rep. Ilana Rubel. Idaho must address human-caused climate change. *Idaho Press-Tribune.* March 27, 2017. Used with Permission (See Appendix H.2.20). Accessed on 6/7/2017 http://www.idahopress.com/opinion/guest_opinions/idaho-must-address-human-caused-climate-change/article_f1ea7d62-cecf-5ef9-b304-2d7370967616.html

A13: Nature/ Social Justice Art

Summary: Students study Andy Goldsworthy, a British artist who transforms nature into art, photographs it, and lets it return to nature. They then go outside to create art from only nature – no tools allowed. When done, they photograph their work and share with the group about the art they made and the process they used. Students also learn about social action and how art can be used to communicate science.

Key Concepts:

- Nature art can be used to communicate science in a creative way.
- Art can be used for social action in response to climate change in a variety of ways. Communicating the issue is often the first step toward effecting social change.

Time Block: ~1 hour

Materials:

- Social action video
- Nature art presentation
- Camera

Activity:

1. Show students the TRUST Climate Kids social action video (link located in the *Selected Videos* section of this guide).
2. Emphasize how students use art, in their case a mural, to communicate a scientific issue.
3. Show students the nature art presentation about Andy Goldsworthy's art.

4. Ask students, in their field groups, to go outside and create a piece of nature art.
    - First, they will need to find “their place”.
    - Students will have ~30 minutes to complete their work.
5. Guide a gallery walk for groups to present their work.
    - What was their process? What materials did they use? What message are they trying to convey with this art?
    - Take a picture of the group with their art work.
6. Ask students how they would use this tool to communicate what they have learned in class.

Guiding Questions:

- How can nature art be used to communicate science?
- How can art be used for social action in response to climate change?

Background Information:

“Andy Goldsworthy works with nature to make sculptures. He is famous for his unique ideas and fascinating earth-forms. Goldworthy works outside. When Andy goes to create art he explores the area – looking at everything there, playing with the materials finding out how to deal with the weather, and just being curious. Eventually he develops an idea and often experiments with it before making the art. He has many earth-forms that he often repeats in different places and with different materials. He uses materials that he finds in the place he is working, but it isn’t always easy. He has to plan in advance. He may work with branches, leaves, moss, grass, dirt, stones, and even water. He often tries things many times before he has success. He takes no tools with him, but finds his tools in nature. Goldsworthy is a known sculptor and photographer. The pictures he takes capture the art that he makes before the sun, wind, tide or rain destroys them."

Short, n.d.

"Social justice art, and arts for social justice, encompasses a wide range of visual and performing art that aim to raise critical consciousness, build community, and motivate individuals to promote social change. Art has been used as a means to record history, shape culture, cultivate imagination, and harness individual and social transformation. It can not only be a means to generate awareness, but it can also be a catalyst to engage community members to take action around a social issue. Social justice art, consequently allows people to develop agency to interrupt and alter oppressive systemic patterns or individual behaviors. The processes by which people create and engage with art equips them with analytic tools to understand and challenge social injustices through social justice education (teaching for social justice), community building, and social activism/social movements. Examples of visual and performing social justice art includes: drawing, painting, sculpture, murals, graffiti, film, theater, music, dance, spoken word, etc. Art has played a role in social justice education, community building, and social activism/social movements. It provides a universal language that gives voice to individuals and communities and is accessible across social boundaries."

Wikipedia, n.d.

Activity Adapted from:

Short, B. Andy Goldsworthy: Art from the Earth. Project ARTiculate. *Fairbanks North Star Borough School District, Art Center Art Activity Kit.* Used with Fair-use Considerations (See Appendix H.2.21). Accessed on 6/13/2018: https://akartsed.org/wp-content/uploads/2009/11/ARTiculate-ART-Kit-Catalog.pdf

Background Information from:

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Social Justice Art. *Wikipedia.* CC-BY-SA by Wikipedia. Used with Permission (See Appendix H.2.4). Accessed on 6/8/2017: https://en.wikipedia.org/wiki/Social_justice_art

Field Activity Guide

University of Idaho
College of Natural Resources

MOSS

Galileo Field Notebook

Name: ______________________________________

Team Name: ________________________________

1

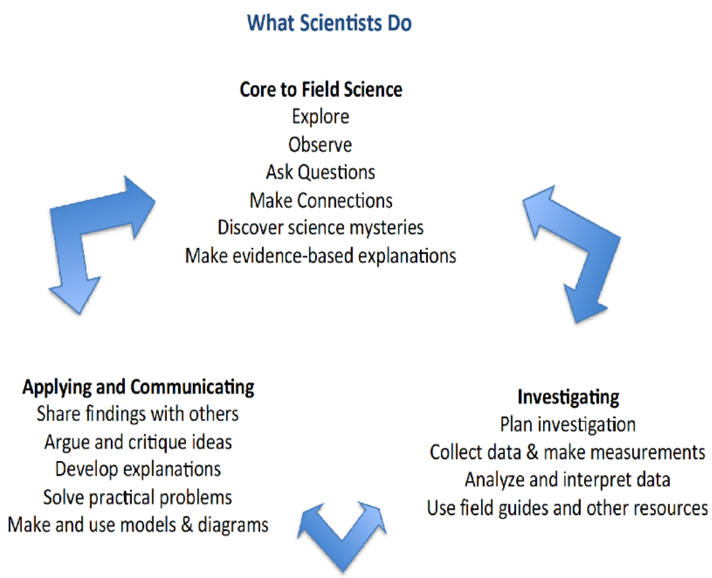
Team contract

The FIVE C's!

Communication **Cooperation**

Collaboration **Caring** **Connections**

What Scientists Do



Leave No Trace

Know Before You Go

Choose the Right Path

Trash Your Trash

Leave What You Find

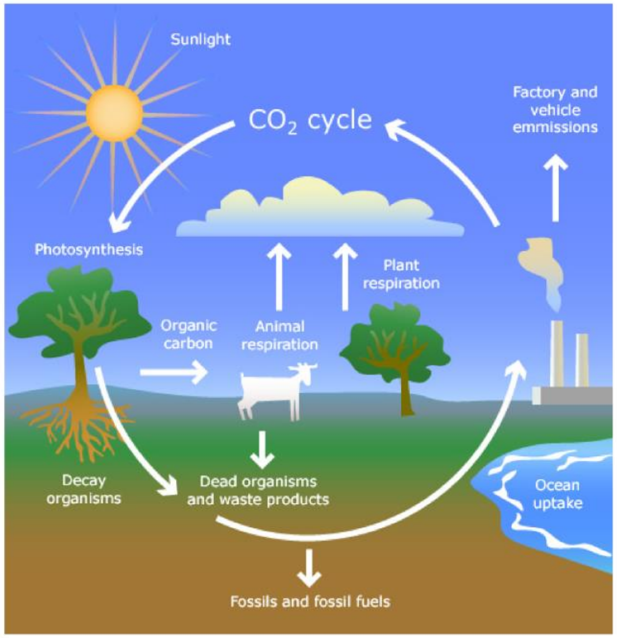
Be Careful With Fire

Respect Wildlife

Be Kind to Other Visitors

Notes

The Carbon Cycle



Source: U.S. EPA, Massachusetts Water Resources Authority

My Carbon Cycle Model

Feeling the Heat

Make a Prediction:
Where in this environment will the temperature be the warmest?

Collect Data:
Your group will work at one of the locations that your class has decided to test. Describe the location and then record the temperature data you collect on the next page.

What's this location like?
(Describe in your own words.)

What's on the ground?
___ Trees
___ A garden
___ Grass
___ Soil
___ Asphalt
___ Concrete

Is there sunshine?
___ Sun
___ Full Shade
___ Part shade

Feeling the Heat

Temperature data

Take temperature readings in degrees Celsius and then record them in the space below. Then take the average of the 5 measurements.)

Measurement #1: ___________°C

Measurement #2: ___________°C

Measurement #3: ___________°C

Measurement #4: ___________°C

Measurement #5: ___________°C

AVERAGE: ___________°C

(Add the five numbers and divide by five to get the average.)

Look at the data collected by all groups.

Where in this environment was the temperature the warmest? Where was it the coolest? Why?

Document-Based Inquiry

Phase I

Notices	Wonders

Document-Based Inquiry

Phase II

Notices	Wonders

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Document-Based Inquiry

Phase III

Notices	Wonders

14

Document-Based Inquiry

Synthesis

- Why should people care about water temperature in aquatic environments?

- What might be some solutions to a water temperature problem in an aquatic environment?

- How can you relate these concepts/solutions to your local area of Eagle?

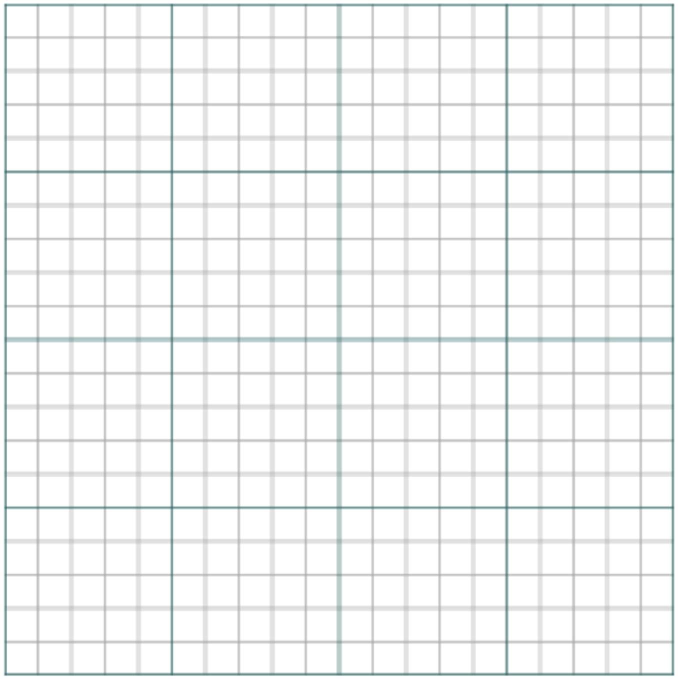
Water Quality

Site: ____

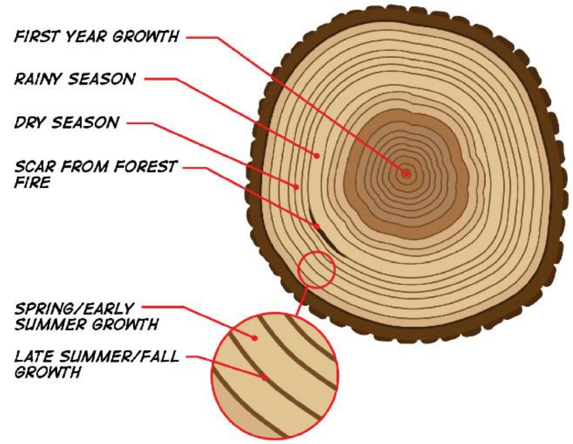
Date: ____

Habitat Component	**"Ideal" Trout Habitat**	**Our Data**	**Is this good trout habitat?**
Temperature (°C)	13°-15.5° (can tolerate 0°-21°)		
Dissolved Oxygen (mg/L)	>7 mg/L		
pH	5.5-7		
Conductivity (µS/cm)	150-500 µS/cm		
Water Clarity	≥ 120cm		
Food	Stoneflies, mayflies, caddisflies, etc.		
Shelter	Snags, rocks, logs, undercut banks, limited erosion		

Depth Profile Graph

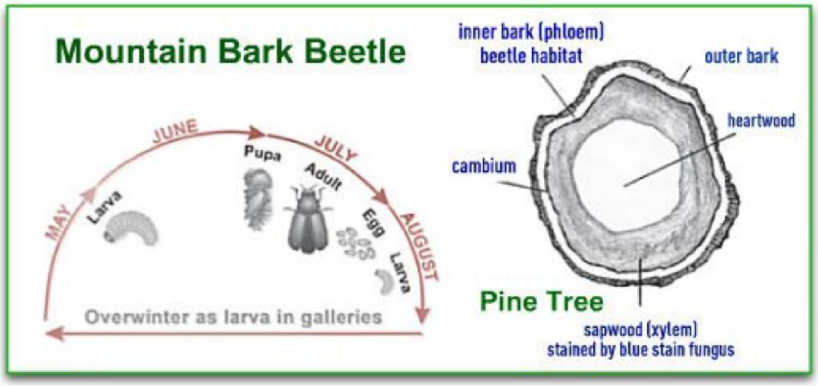


Tree Rings



Source: Climate Kids, NASA

Pine Beetle Life Cycle



Source: Alberta Sustainable Resource Development & Inside Education

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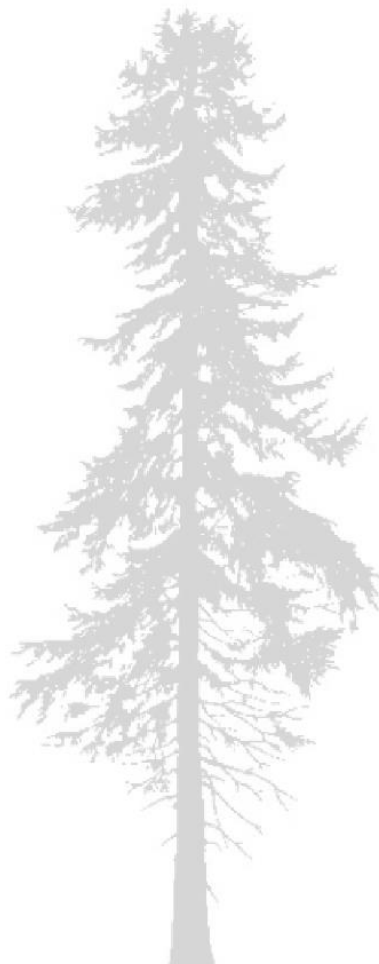
Faces of Climate Change

- How is your character's life similar to your partner's life? How are they different?

- How is your character's view about climate change linked to that of your partner's character?

- Brainstorm solutions to the concerns you both have about climate change. Why did you choose these solutions? Why do you think they will work?

Pondering Page



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APPENDIX F. THE NATURAL AND HUMAN DIMENSIONS OF CLIMATE CHANGE IN IDAHO: ASSESSMENT TOOLS

1. Concept map prompt

Concept Map

Student #______

Create a concept map about climate change.

2. Questionnaire

Climate Change Questionnaire

Student #:_______

Answer each question as best you can. Use complete sentences and related vocabulary words in your answers.

1. Describe climate change in your own words.

2. How does climate change affect animals? Give specific examples.

3. How does climate change affect people? Give specific examples.

4. What can you do to help reduce the impacts of climate change? Give specific examples.

3. Data analysis key for climate change questionnaire

3.1. Rubric matrix

Question	No answer (0)	Insufficient (1)	Fair (2)	Good (3)	Excellent (4)
1. Climate Change	No answer	Insufficient information. May or may not contain acceptable concepts. Does not depict an understanding of the causes (fossil fuels) or effects (temperature changes/ocean acidification) of anthropogenic climate change.	Contains at least 1 concept. Depicts some understanding on the causes (fossil fuels) or effects (temperature changes/ocean acidification) of anthropogenic climate change.	Contains at least 2 concepts. Depicts a good understanding on the causes (fossil fuels) or effects (temperature changes/ocean acidification) of anthropogenic climate change.	Contains at least 3 concepts. Depicts clear understanding on the causes (fossil fuels) AND effects (temperature changes/ocean acidification) of anthropogenic climate change.
2. Animals	No answer	Insufficient information. May or may not contain acceptable concepts. Does not depict an understanding of the effects of climate change on animals. Did not provide an example.	Contains at least 1 concept. Depicts some understanding on the effects of climate change on animals. May or may not have provided an acceptable example.	Contains at least 2 concepts. Depicts a good understanding on the effects climate change on animals. Provided one or more general examples.	Contains at least 3 concepts. Depicts clear understanding on the effects of climate change on animals. Provided at least one specific example describing the mechanism of the climate change effects.
3. Humans	No answer	Insufficient information. May or may not contain acceptable concepts. Does not depict an understanding of the effects of climate change on humans. Did not provide an example.	Contains at least 1 concept. Depicts some understanding of the effects of climate change on humans. May or may not have provided an acceptable example.	Contains at least 2 concepts. Depicts a good understanding of the effects climate change on humans. Provided one or more general examples.	Contains at least 3 concepts. Depicts clear understanding of the effects of climate change on humans. Provided at least one specific example describing the mechanism of the climate change effects.
4. Actions	No answer	Insufficient information. May or may not contain acceptable concepts. Does not depict an understanding of actions that can be taken to limit climate change. Did not provide an example.	Contains at least 1 concept. Depicts some understanding of actions that can be taken to limit climate change. May or may not have provided an acceptable example.	Contains at least 2 concepts. Depicts a good understanding of actions that can be taken to limit climate change. Provided one or more general examples.	Contains at least 3 concepts. Depicts clear understanding of actions that can be taken to limit climate change. Provided at least one specific example describing in detail actions that can be taken.

3.2. Acceptable concepts list

1. Climate Change		2. Animals		3. Humans		4. Actions	
Carbon sinks	Acid	Acid	Acidified Water	Adaptation	Civilization	Acknowledge	Atmosphere
Cold	Acidified Water	CO_2	Adaptation	Animals	CO_2	Activists	CO_2
Exhaust	Air	Cold	Adjust	Bacteria	Cold fronts	Awareness	Educate
Expansion	Atmosphere	Cows	Behavior	Behavior	Damage	Bicycle	Electricity
Food	Benefit	Death	Benefit	Benefit	Drought	Carbon	Energy
Frequency	Blanket	Decay	Bleaching	Burning	Electricity	Carbon footprint	Fuel
Frosts	Carbon	Deforestation	Dams	Cars	Energy	Carpool	Gas
Fuel	Cars	Destroy	Drought	Cold	Environment	Cars	Government
Gasoline	CO_2	Environment	Ecosystem	Communities	Farming	Coal	Mining
Glaciers	Coal	Fish	Extinction	Crops	Fire	Communicate	Politics
Growth	Cooling	Floods	Fire	Destroy	Food	Community	Pollution
Hot	Deforestation	Food	Food Chain/web	Die	Frequent	Damage	Treaty
Humans	Earth	Frosts	Growth	Earth	Harm	Environment	Waste
Melting	Emissions	Glaciers	Heat	Floods	Homes	Factories	
Methane	Energy	Habitat	Home	Frosts	Hydroelectric	Fire	
Nature	Environment	Hot	Illness	Glaciers	Migration	Flood	
Oil	Fire	Humans	Lose	Home/House	Nat. disasters	GHG	
pH	Floods	Hurricanes	Migration	Hot	Overcrowding	Greenhouse	
Pollution	Fossil fuels	Kill	Move	Hurricanes	Population	Movement	
Precipitation	Gas	Melt	Ocean acid.	Illness	Resources	Oil	
Radiation	Greenhouse	Nat. disasters	Overcrowding	Money	Safety	Power	
Rain	GHG	Negative	Overheat	Move	Seasons	Share	
Rate	Heat waves	Ocean	pH	Plants	Severe	Solar	
Refinery	Hurricanes	Plants	Precipitation	Precipitation	Snow	Travel	
Seasons	Ocean	Polar bears	Reefs	Production	Storms	Trees/Plant	
Sun	Ocean	Pollution	Reproduction	Rain	Thrive	Victims	
Temperature	Acidification	Production	Resources	Shelter	Trees	Walk	
Trees	Planet	Rain	Salmon	Smoke	Unhealthy		
Warm	Slow	Rivers	Sheep	Starvation	Water		
Water	Storms	Smoke	Shelter	Survival			
Weather	Time	Spawning	Snow	Temperature			
Wet/Dry Season	Warming	Survival	Starvation	Wet/Dry Season			
	Wildfire	Thrive	Storms	Wildfire			
		Unhealthy	Temperature				
		Warm	Uninhabitable				
		Water	Wet/Dry Season				
		Wildlife	Wildfire				

APPENDIX G. INSTITUTIONAL REVIEW BOARD (IRB) DETERMINATION LETTER

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(813) 974-5638 • FAX (813) 974-7091

5/9/2017

Ileana Freytes-Ortiz
College of Marine Science
140 7th Ave S
St. Petersburg, FL 33701

RE: **Exempt Certification**
IRB#: Pro00029787
Title: Meaning-making about climate change: a place-based education approach

Dear Dr. Freytes-Ortiz:

On 5/8/2017, the Institutional Review Board (IRB) determined that your research meets criteria for exemption from the federal regulations as outlined by 45CFR46.101(b):

(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Research Involving Children as Subjects: 45 CFR §46.404
This research involving children as participants was approved under 45 CFR 46.404: Research not involving greater than minimal risk to children is presented.

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF HRPP policies and procedures.

Please note, as per USF HRPP Policy, once the Exempt determination is made, the application is closed in ARC. Any proposed or anticipated changes to the study design that was previously declared exempt from IRB review must be submitted to the IRB as a new study prior to initiation of the change. However, administrative changes, including changes in research personnel, do not warrant an amendment or new application.

Given the determination of exemption, this application is being closed in ARC. This does not limit your ability to conduct your research project.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John Schinka, Ph.D., Chairperson
USF Institutional Review Board

APPENDIX H. AUTHOR CONTRIBUTIONS AND PERMISSIONS FOR REPRINTING PREVIOUSLY-PUBLISHED WORK

1. Author contributions

Appendix A. Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel.

IM Freytes-Ortiz: provided leadership, collected data, analyzed data, made graphs and figures, and wrote the initial manuscript.

CD Stallings: provided intellectual guidance, edited, and provided extensive written comments on the manuscript.

2. Permissions for reprinting

2.1. Appendix A. Elevated temperatures suppress inducible defenses and alter shell shape of intertidal mussel

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2.6. Sutherland, D. Teaching Games: How Climate Change Affects Species. City of Boulder Open Space & Mountain Parks


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2.7. Sim, D. 2015. Climate Change winners and losers: Which animal species will thrive? International Business Times

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>
> I am writing to request permission to include this activity in my dissertation. Please let me know if you provide permission.
>
> Thank you,
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> PhD Candidate
> College of Marine Science
> University of South Florida
> 140 7th Avenue South
> Saint Petersburg, FL 33701
> email: freytesortiz@mail.usf.edu
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2.9. *National Wildlife Federation. Salmon and Global Warming*

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2.10. Rahr, G. Why Protect Salmon. Wild Salmon Center

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>
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>
> I am happy to provide further information if needed. Please let me know if you provide permission for use of content in this manner.
>
> Thank you for your time.
> Best regards,
> *Ileana M. Freytes-Ortiz*, MSc
> PhD Candidate
> College of Marine Science
> University of South Florida
> 140 7th Avenue South
> Saint Petersburg, FL 33701
> email: freytesortiz@mail.usf.edu
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2.11. Crouse, R. Salmon Decline and Recovery. Water Encyclopedia: Science and Issues

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2.12. Union of Concerned Scientists. 2011. Lakes and Rivers. Climate Hot Map: Global warming effects around the world

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2.13. Bienkowski, B. 2016. Acid Trip: Great Lakes could face similar acidification risk as the seas. Great Lakes Echo. CC BY-NC-SA 3.0

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2.16. Lynch, H. J., Renkin, R. A., Crabtree. R. L., Moorcroft P. R. 2006. The influence of previous mountain pine beetle (Dendroctonus ponderosae) activity on the 1988 Yellowstone fires. Ecosystems. 9:1318-1327

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Smith, Kevin; Macklin, Lisa A.; Gilliland, Anne. A Framework for Analyzing any Copyright Problem. Retrieved from:
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2.17. Cunnian, J., Gluck, E., McIsaac, S. 2006. Mountain Pine Beetle Mania: A Junior High Science Resource. Inside Education

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2.18. Hutchings, C., Anderson, B. 2007. A Burning Issue. The Learning Network. The New York Times

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2.19. Activity 4.1: The Faces of Climate change. Chicago Botanic Garden

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Jennifer Schwarz <jschwarz@chicagobotanic.org> Thu, Jun 14, 2018 at 3:11 PM
To: "freytesortiz@mail.usf.edu" <freytesortiz@mail.usf.edu>

Hello Ileana,

Thank you for getting in touch. We would be happy for you to include the modified activity. We would ask that you credit the Chicago Botanic Garden with the development of the original and provide a link to the original activity on our website.

If you are able to do that, we would be thrilled for you to take and modify. The more we improve and disseminate materials the more collective impact we will have.

Best wishes,

Jennifer

Jennifer Schwarz Ballard, Ph.D.

Vice President, Learning and Engagement

Chicago Botanic Garden

1000 Lake Cook Rd.

Glencoe, IL 60022

jschwarz@chicagobotanic.org

847.835.6832

From: Ileana Freytes Ortiz <freytesortiz@mail.usf.edu>
Sent: Wednesday, June 13, 2018 3:19 PM
To: Gloria Ciaccio
Cc: Julie McCaffrey; Jasmine Leonas
Subject: Permission Request for Use of Educational Materials

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I noticed the activity sheet available at https://www.chicagobotanic.org/downloads/nasa/Unit_4_Grades_7-9_Activity_4-1_FacesOfClimateChange.pdf contains the copyright (C) logo, so I wanted to make sure I had the necessary permissions to include in my dissertation.

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© Chicago Botanic Garden 2 Climate Change" because it attempts to give a personal face to individuals whose lives are affected by climate change.

Please let me know if permission is provided, or if there are any exceptions due to educational use. Thank you for your time.

Best regards,

Ileana M. Freytes-Ortiz, MSc

PhD Candidate

College of Marine Science

University of South Florida

140 7th Avenue South

Saint Petersburg, FL 33701

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2.20. Idaho Rep. Ilana Rubel. Idaho must address human-caused climate change. Idaho Press-Tribune. March 27, 2017

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2.21. Short, B. Andy Goldsworthy: Art from the Earth. Project ARTiculate. Fairbanks North Star Borough School District, Art Center Art Activity Kit

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