

PRACTICE BRIDGE

Empowering hope-based climate change communication techniques for the Gulf of Maine

Aimee Bonanno¹, Megan Ennes^{1,2}, Jennifer A. Hoey^{1,3}, Emily Moberg^{1,*}, Sarah-Mae Nelson^{1,4}, Nette Pletcher^{1,5}, and Richelle L. Tanner^{1,6}

The Gulf of Maine is one of the fastest warming marine areas on the planet: The industries and creatures that call it home face an unprecedented shift in their interactions and existence. Scientists, policy makers, and practitioners often want to communicate to the public about the seriousness of the situation to encourage mitigation and adaptation. Many standard communication strategies that rely on fear and scientific authority alone—rather than comprehensive explanations that include solutions—can leave audiences feeling overwhelmed and disengaged, instead of hopeful and motivated to act. In this practice bridge, we showcase a social science research-based climate change communication “tool-kit” for the Gulf of Maine, using one example for each climate driver addressed at the Gulf of Maine 2050 Symposium (temperature and circulation: lobster fisheries; coastal and ocean acidification: seagrass restoration; sea-level rise: coastal development). Communication models that involve the head (understanding of climate change), heart (hope through agency and efficacy), and hands (intentions to participate in community action) further engagement in climate change conversations. We explain the research behind our communication framework, enabling practitioners to extend this case study to their own work.

Keywords: Climate change, Communication, Framing

Background

From 1982 to 2013, the Gulf of Maine’s sea surface temperature increased at a rate of 0.03°C/year, greater than the mean global rate of 0.01°C/year (Belkin, 2009; Taboada and Anadón, 2012; Pershing et al., 2015). From 2004 to 2013, the rate of increase accelerated to 0.23°C/year, meaning that the Gulf of Maine warmed faster than 99.9% of the global ocean (Pershing et al., 2015). This rapid warming prompted the Gulf of Maine 2050 Symposium in November 2019. The Symposium asked participants to envision the future of the Gulf of Maine as it responds to three drivers of climate change: temperature and circulation, coastal and ocean acidification, and sea-level rise (Brickman et al., 2021; Chisholm et al., 2021;

Siedlecki et al., 2021). For each of these drivers, current understanding of these drivers and how conditions are likely to change over the next 30 years were synthesized. This article fills a critical gap of how to best convey these climate impacts to broad audiences.

To protect the people, industries, and organisms that rely on the Gulf of Maine, scientists, policy makers, and educators must communicate the gravity of the situation while sustaining a sense of agency and efficacy among the public (Geiger et al., 2017). Framing climate change using a values-centric, research-based approach has been highlighted over the last decade as an effective method for increasing advocacy in the public domain (Gifford and Comeau, 2011; McEvoy et al., 2013; Wolsko et al., 2016; Nabi et al., 2018).

In addition to strengthening advocacy, science communication is often used to increase an audience’s awareness, enjoyment, interest, opinions, or understanding of scientific topics (Burns et al., 2003). Audiences may include scientists, science communicators (including educators), decision makers, the general public, the attentive public (already engaged), or the interested public (interested but unformed; Burns et al., 2003). For the general public, research examining the impacts of science communication has found that increased knowledge of an issue does not necessarily translate into pro-environmental behavior (Carmi et al., 2015). Several theoretical frameworks have evolved to examine the factors that influence

¹National Network for Ocean and Climate Change Interpretation, Boston, MA, USA

²Department of Natural History, University of Florida, Gainesville, FL, USA

³Ecology and Evolutionary Biology Department, University of California Santa Cruz, Santa Cruz, CA, USA

⁴UC California Naturalist Program, University of California Agriculture and Natural Resources, Davis, CA, USA

⁵Beez Kneez Creative, San Diego, CA, USA

⁶Department of Animal Science, University of California at Davis, Davis, CA, USA

* Corresponding author:
Email: emily.a.moberg@gmail.com

pro-environmental behavior such as the theory of planned behavior, models of responsible human behavior, and value-belief-norm theory (Li et al., 2019). A recent study found that an individual's subjective knowledge, what they believe they understand about a topic, has a stronger influence than their objective knowledge on whether they choose to engage in pro-environmental behavior and that both of these are mediated by their environmental emotions (Carmi et al., 2015). To address these various factors, we have been conducting research to establish best practices for effective climate change communication for over a decade (e.g., Bales et al., 2015).

Best-practice communication techniques for climate communication have been developed and are continually refined over time. Communication cannot simply be the dissemination of scientific facts but is rather the negotiation of meaning between the speaker and listener; therefore, science must be communicated in a method that addresses the values, interests, and worldviews of the audience (Nisbet, 2009). An approach widely used in communication about partisan sociopolitical topics is called framing (Borah, 2011). Framing allows diverse peoples to converge on a shared understanding of an issue or topic through the activation of cultural values and literal “frames of mind” (Price et al., 1997; Miller, 2000). Framing allows us to reach across aisles or further solidify boundaries, depending on its targeted use. Studies have shown that if communicators can activate the appropriate positive frame, our audiences are more likely to connect with and be open to the implications of the information we are sharing (Morton et al., 2011; Bilandzic et al., 2017). The suite of framing communication tools presented here have been designed and developed by the FrameWorks Institute and tested for their efficacy in informal educational settings across the United States.

In order to be effective, communication strategies must vary based on the intended audience (Burns et al., 2003). The intended audience for this work were educators in informal science settings (zoos, aquariums, science centers) engaged in climate change communication with the general public. The specific outcomes of the framing tools were as follows: building public understanding of climate science, inspiring action to mitigate emissions and adapt to changing conditions, and promoting public discourse (Swim et al., 2014; Geiger et al., 2017; Swim and Geiger, 2017). These communication tools together comprise *Strategic Framing* (Manuel and Davey, 2009). Strategic framing is a set of research-based strategies for organizing a topic in such a way that it helps audiences understand the mechanisms of climate change, shows the public how they can be “heroes” of the climate change story, and leaves the audience and the communicator with a sense of hope. We do not exhaustively cover all elements of strategic framing or climate-science communication, but rather focus on a key suite of tools and their usage: a reasonable tone, values (“why should I care”), explanatory metaphors (making abstract ideas concrete and sticky), explanatory chains (connecting the dots from topic of interest to issue to audience), and solutions. These tools are summarized in reports prepared by the FrameWorks Institute (Volmert et

al., 2013; Simon et al., 2014; Bales et al., 2015; see **Table 1**) and are well-aligned with other, extensive work on best practices in science communication.

Common communication strategies

Often, climate communication employs “crisis messaging”—using shock and fear in an effort to galvanize a sense of responsibility to act to avert disaster (Shome et al., 2009). Another frequently employed strategy uses scientific authority as the sole explanation for why action should be taken (e.g., citing scientific consensus *sensu* Oreskes, 2004). Yet, research has shown that fear and scientific authority alone can leave audiences feeling overwhelmed and disengaged, instead of hopeful and action-oriented (O'Neill and Nicholson-Cole, 2009; Swim et al., 2014; Geiger et al., 2017). Operating on an information deficit model, or the idea that a lack of information is responsible for inaction among the audience, is a common practice that directly contradicts our findings on using scientific authority to communicate about climate (for other criticisms of the information deficit model, see Owens and Driffill, 2008; Suldovsky, 2017). Additional work shows that references to scientific authority do not motivate people to engage the way values such as *Protection* and *Responsible Management* do (Maddux and Rogers, 1983; Weber and Stern, 2011; Leombruni, 2015; Ranney and Clark, 2016; Geiger et al., 2017).

Many communications may also cue up unproductive models of thinking. Everyday people use mental models as shortcuts interpreting the world around them (Denzau and North, 1994). People living near one another who share common cultural backgrounds tend to have very similar mental models that social scientists often refer to as cultural models (Kronenfeld, 2018). Cuing certain cultural models can be more productive than others in motivating individuals to change their behavior. A few key cultural models to consider when communicating about climate change and the ocean are shared in **Table 2**. One unproductive model of thinking common to climate communication is the use of economic motivation for both individual and collective actions (e.g., overfishing, drought-induced agricultural losses, tax benefits for solar panels). In these scenarios, linking economics and climate action serves to promote individualism and greed, instead of the intrinsic value of protecting our human and ecological communities (Volmert et al., 2013; Simon et al., 2014; Bales et al., 2015).

Finally, communications often only focus on the impact part of the story; they neglect the initial cause, leave gaps that result in confusion, and end before solutions are presented. Many Americans do not understand the mechanism of climate change or what actions influence it (Ballew et al., 2019). When the explanation they receive contains gaps in understanding, the cognitive holes can be filled with inaccuracies that lead to false conclusions.

An effective communication strategy

We focus here on strategic framing, an approach that draws from framing theory built across disciplines

Table 1. Frame elements of the climate change story. DOI: <https://doi.org/10.1525/elementa.2020.00051.t1>**Why does this matter to society?**

Values	The story you're telling:
Protection	We need to protect the people and the places that we care about from being harmed by issues facing our environment.
Responsible management	We need to take practical, common sense steps today to address problems facing our environment. Being responsible with our environment is in the best interest of future generations.

How does it work?

Explanatory metaphors	Explains:	The story you're telling:
Heat-trapping blanket	The basic mechanism of climate change	When we burn fossil fuels like coal, oil, and natural gas for energy and transport, we add carbon dioxide into the atmosphere. Carbon dioxide acts like a heat-trapping blanket that traps heat that would normally be reemitted back to space. This excess heat warms the earth.
Regular and rampant CO ₂	Anthropogenic carbon dioxide	"Regular" carbon dioxide levels are cycled by living organisms like plants and animals, but "Rampant" carbon dioxide levels come from burning fossil fuels for energy. We need to reduce rampant CO ₂ . It's getting out of control.
Climate's heart	The role of the ocean in the climate system	A heart is critical for circulating blood and regulating the body's temperature. In the same way, the ocean acts as the "climate's heart," controlling the circulation of heat and moisture throughout the climate system.
Osteoporosis of the sea	Some of the effects of ocean acidification	Ocean acidification changes ocean chemistry, causing "osteoporosis of the sea." These changes in ocean chemistry make it harder for shell-building organisms to make and maintain their shells.

How do we improve the situation?

Community-based solutions	The story you're telling:
A specific example that focuses on moving away from fossil fuels toward renewable energy, reducing our demand for and use of fossil fuels, or empowering others to raise the topic of climate change in more settings.	Concern for our climate is normal, and actions to combat climate change are happening all around us. We need to work together to address climate change by promoting collective solutions and modifying the decision-making context, so that the sustainable choice is the easy choice.

Frame elements used to tell the core story of climate and ocean change. Modified from Volmert et al. (2013).

including linguistics, sociology, and psychology (Lakoff, 2006, 2014; Lakoff and Johnson, 2008). Framing in the social sciences is a conceptual collection of the perspectives that govern the way individuals, groups, and societies experience reality (Chong and Druckman, 2007; Borah, 2011). Many framing strategies, including the one we employ here with strategic framing, start with a commonly held value, use metaphors and clear explanations to link the problem to the topic of interest, and end with a solution or call to action. When incorporating these key elements, mental models that are counterproductive to the desired framing (i.e., positive) of the problem should be avoided. We illustrate the conceptual arc of this communication strategy in **Figure 1**.

Instead of invoking fear or relying on scientific authority, the use of shared cultural values serves to disarm defensive responses from most individuals (Maddux and Rogers, 1983; Weber and Stern, 2011; Leombruni, 2015; Ranney and Clark, 2016; Geiger et al., 2017). These shared values are widely held beliefs among the population of

interest. For the U.S. public, the values of protection and responsible management (see **Table 1** for more information on these values) resonate broadly across demographics (Maddux and Rogers, 1983; Geiger et al., 2017). Beginning communications with these commonly held values serves to build a connection between the speaker and the audience, creating a willingness to listen to further information. A value embedded into an opening remark can be as simple as, "Resilient communities work together to protect the people and places that matter to them." After establishing a commonly held value, we must clearly link human actions with climate change and its impacts. Explicitly defining climate change as human-induced helps audiences understand the urgency of the issue and the responsibility they carry. This can be achieved using metaphors (see Kuhn, 1979; Raad, 1989; Gentner and Jeziorski, 1993; Simon et al., 2014; Giles, 2017; Taylor and Dewsbury, 2018) and clear, sequentially linked explanations of intervening processes. Incorporating metaphors and clear explanations avoids the use of

Table 2. Productive and unproductive examples of cultural models. DOI: <https://doi.org/10.1525/elementa.2020.00051.t2>

Cultural Models by Topic	Explanation
Climate change	
Something needs to be done (+)	This model takes advantage of a shared belief that problems that receive a lot of public attention deserve to be addressed. Most Americans believe that climate change is real, is happening now, and is caused by human activity. People are concerned about its impacts, and because of the shared belief that acknowledged problems need solutions, they feel a sense of urgency about addressing the issue.
Oceans	
Oceans support humans (+)	People innately understand that the ocean supports human life through food, transportation, and work. In addition, this model includes the idea that the ocean is a unique and valuable natural resource. This line of thinking helps people to understand that the ocean is intricately connected to human life, and people can easily understand why the ocean needs to be protected.
Nature	
<i>Nature works in cycles (-)</i>	This model portrays nature as a set of dependable cycles. If the cycles are disrupted, nature will reestablish the cycles on its own. Because the cycles are viewed as outside human control, this cultural model redirects attention away from more productive ideas that climate change is caused by humans, earth systems cannot continue to absorb the effects of human activities, and that people and nature are highly interconnected.
Consumerism	
<i>Eat it while you can! (-)</i>	This model instigates the line of thinking that “supplies are limited.” The logical response to scarcity is to consume more quickly and to accept the inevitability of species loss and the occasional unavailability of certain products.
Ecosystems are valuable resources (+)	This model recognizes the practical and economic utility of ecosystems. When applied to ocean systems, this line of thinking recognizes that seafood is a major source of protein for people around the world and that the oceans are critical for moving resources around the planet. Using this model, people realize that a functioning and healthy ocean ecosystem is key for maintaining access to important resources. This type of thinking results in agreement that important ecosystems need to be protected and conserved.
Pollution	
<i>Ocean problems = material pollution (-)</i>	This mode of thinking results in the false conclusion that material pollution, like plastic bags or runoff from dirty industrial practices, is the cause of all the ocean’s problems. Once this line of thinking is initiated, it is difficult to communicate about the ways in which “invisible” heat-trapping gases are affecting ocean temperature or how chemical processes are leading to ocean acidification.
Public affairs	
<i>Individualism (-)</i>	Individualism is a pervasive cultural model in America. This model highlights the individual as the agent of change and leads to individual-level solutions, making it a major obstacle to communicating about solutions that need to match the scale of ocean and climate change. With this model, people are skeptical of how public policies can lead to effective solutions. People also assume that any government action would limit individual actions and freedoms.
Civic responsibility (+)	This model taps into the idea that every community member has a duty to contribute to their community and to engage in social action. For Americans, communication is a key component of civic responsibility. People recognize that they are responsible for “being informed” and for sharing their perspectives with their communities and their public representatives. This model encourages the idea that responsible community members need to think about the public interest, taking measures to align civic institutions with their values.
Americans are problem solvers (+)	This model involves the idea that Americans can tackle and overcome any challenges that arise through determination, courage, intelligence, practicality, cooperative spirit, and inventiveness. When thinking through this model, people can easily imagine that big problems are solved by working together and that American ingenuity and technology will result in a solution. This model offers highly productive entry points for considering ways to address environmental challenges.

Cultural models (i.e., patterns of thinking) that lead to unproductive (italic text, -) climate and ocean change outcomes and some existing productive cultural models (bold text, +; Volmert et al., 2013; Simon et al., 2014; Bales et al., 2015).

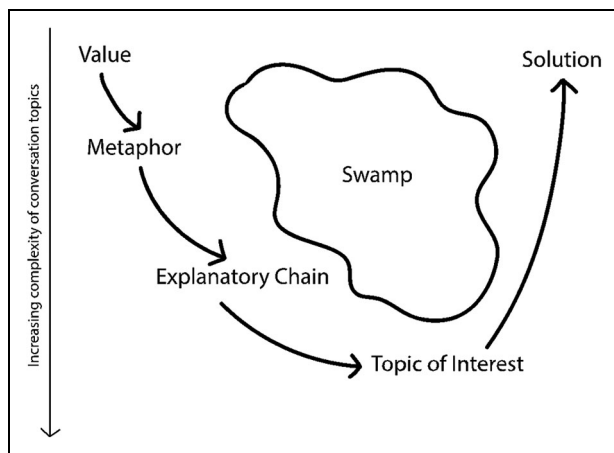


Figure 1. A climate communication strategy. Using framing elements (see **Table 1**) to navigate a positive climate communication around a swamp of unproductive cultural models. DOI: <https://doi.org/10.1525/elementa.2020.00051.f1>

jargon, which even when explained decreases interest and engagement in science and scientific topics (Maddux and Rogers, 1983; Bullock et al., 2019).

Four metaphors, developed by FrameWorks, were included as part of the National Network of Ocean and Climate Change Interpretation's national training and implementation (**Figure 1**, **Table 1**). These metaphors have been tested for efficacy among the U.S. population (Simon et al., 2014; Bales et al., 2015; Geiger et al., 2017; Swim et al., 2017). Metaphors can be used in concert with clear explanations of processes, also called “explanatory chains” (*sensu* Geiger et al., 2017). Explanatory chains help improve the listener's subjective knowledge about climate change (Carmi et al., 2015) by “describing the causal connections between the source of our changing climate and the effects of that phenomenon” (Geiger et al., 2017). They eliminate any guess work on the part of the audience as they process sequential consequences. This guess work may lead to audiences substituting inaccurate assumptions that materially alter their understanding of the problem and solutions. Statements like “rising temperatures negatively affect turtle populations” can be improved with an explanatory chain; for example, “Turtles' sex is determined by the temperature, so rising temperatures cause imbalances between the sexes. This imbalance leads to lower mating success, which in turn reduces their population.” The steps between the cause and effect are now clearly spelled out. Explanatory chains may be long, as they sequentially link multiple concepts.

Finally, once carbon dioxide has been clearly established as the problem, communicators must provide solution pathways that invite the audience to engage in community-level solutions—actions that engage communities and present solutions at the scale of the problem (Geiger et al., 2017). It is important, however, to acknowledge the spectrum that exists for both climate and other environmental action behaviors (Lubell, 2002). That is, people do not generally start out taking large-scale,

collective, community-level behaviors; instead, they will take smaller, individual actions that seem achievable (Shaw et al., 2019). Because hope is a particularly critical emotion for advocacy behavior as a communication outcome (Nabi et al., 2018), ending with attainable solutions is crucial. Using goal-setting theory, Manning et al. (2009) demonstrated that audiences feel they can see themselves as part of a climate change solution when it is communicated as a specific, somewhat challenging, but realistically attainable goal (Swim et al., 2018).

We acknowledge that communicating climate solutions appropriate to the audience and at the appropriate scale of the issue can be complex. Throughout this practice bridge, we use broad solution examples because they are most relevant to the targeted audiences' sphere of influence. For example:

Communities working toward climate resilience are exploring community energy storage—large battery systems that allow them to store energy to be used in times of need. Solar energy can be generated during the day and stored for use at night and renewable energy can be stored long-term for use during emergencies.

Additionally, it is important during the entire framing to avoid language that cues up unproductive mental models. An unproductive mental model is one that typically leads listeners to thoughts like “my actions don't matter,” “this seems suspect,” or confusion. In contrast, productive mental models are those that have been shown to consistently leave listeners understanding the gravity of the situation and feeling empowered to change it (see Sterman, 2008; Eakin et al., 2019, for examples). Here, we refer to unproductive mental models as a “swamp”—a place where ways of thinking can sink experts' and advocates' messages. Climate change communicators will be better able to navigate through this swamp if they understand what's in it. A selection of cultural models, or mental models for the American public, is described in **Table 2** (modified from Volmert et al., 2013).

Beginning conversations with values, using explanatory metaphors to make the science accessible, connecting the dots with explanatory chains, and showing how acting in community allows people to be the “heroes” of the climate story are the steps of framing climate change effectively (**Table 1**).

Communicating about changes in the Gulf of Maine with strategic framing

Here, we provide evidence-based suggestions for scientists, policy makers, and stakeholders when communicating about changes that the Gulf of Maine faces related to warming ocean temperatures, ocean acidification, and sea-level rise. For each driver of change, we describe what is known about its impact in the Gulf of Maine, apply the communication strategies and tools we previously discussed to the topic at hand and then provide a well-framed example of what communication practitioners might say when engaging with the public. Each example

uses tested values, metaphors, explanatory chains, and hopeful solutions while avoiding unproductive cultural models that lead to less agency and action on climate change. These examples were collaboratively written by trained experts in strategic framing and use the above-detailed peer-reviewed framework recommended by the National Network for Ocean and Climate Change Interpretation (Swim et al., 2014; Geiger et al., 2017; Swim and Geiger, 2017). While this framework was tested for adult visitor audiences at informal education centers, ongoing studies suggest they have similar efficacy for other public audience demographics in North America (Bunten and Arvizu, 2013). Currently, these examples are used by zoo, aquarium, and park interpreters in live settings and in exhibit design. They have also been incorporated into public presentations by NNOCCI-trained academic and agency scientists.

Creating framed messages with positive, action-oriented language requires an understanding of communications science and demographic-specific risk perception in addition to a basic understanding of the underlying scientific topic. We provide a peer-reviewed framework that addresses these underlying multidisciplinary needs, so that a broad audience of scientists, policy makers, and stakeholders can incorporate communication tools into their own specialized work. Orienting live presentations, written reports, and press releases within this communication framework will unify the user's messaging around the theme of values-based action on climate change.

Climate challenge 1: Temperature and circulation **Scientific background for this example**

American lobster (*Homarus americanus*) is an iconic and economically important species to the people living on the Gulf of Maine. Between 2015 and 2018, 29% of the fish catch in the states bordering the Gulf were lobster (by weight), and they represented 48% of the value (NOAA Fisheries Office of Science and Technology, 2020). The health of this fishery is subject to intense scientific, political, and local interest and often debate. With increasing carbon emissions, this region is projected to warm 2–3 times faster than the average global ocean due to shifts in climatic and oceanographic patterns, particularly a northerly shift of the warm Gulf Stream and a weakening of the cool Labrador Current (Saba et al., 2016; Brickman et al., 2021).

Fish and marine invertebrates, as ectotherms or “cold-blooded” animals, are dependent on favorable water temperatures to regulate their metabolism, reproductive health, and ability to fight disease (Gillooly et al., 2002). In lobsters, warmer temperatures are expected to accelerate growth and maturation and reduce fecundity of small females (Koopman et al., 2015); the settlement behavior of larvae is also temperature dependent, with recent warming in the Gulf potentially increasing settling habitat (Goode et al., 2019). Modeling work suggests lobsters in the Gulf of Maine are highly affected by temperature and salinity (McLeese, 1956; Chang et al., 2010), and evidence suggests rising water temperatures may contribute to epizootic shell disease (Glenn and Pugh, 2006). As a result of these changing conditions and fishing pressure, the abundance and distribution of lobsters have dramatically

changed over the last 50 years. In particular, the Gulf of Maine population has increased, likely as a result of conservation actions by fishermen preserving the largest females and bottom water temperatures that are warmer—but not too warm—for the species, while the lobsters to the south have dramatically declined (Le Bris et al., 2018). This recent boom of lobster population may not last in the face of continued warming; however, Le Bris et al. suggest that by 2050, under the warmest, business-as-usual scenario they investigated, lobster could decline by over 60%, while the coolest scenario resulted in a 40% decline (relative to 2014).

Specific communication tools used in example framed communication

In framing climate impacts for lobster, we will want to focus on linking human actions to the warming conditions that cause lobster population declines. The *Heat-Trapping Blanket* metaphor (**Table 1**) is a useful tool for this. We can then use explanatory chains to clearly link how these warmer temperatures affect the physiology and populations in the Gulf.

There are several elements of the framing swamp we will need to avoid. Consumerism/“eat it while you can”: cueing up information about a species' future disappearance in the context of its use as food can breed a sense of fatalism and desire to take advantage of a resource before it disappears. Instead, we want audiences to focus on solutions and actions they can take to ameliorate the situation. Nature works in cycles: Because the lobster population is currently thriving in the Gulf of Maine, communicating that future increases in temperature will cause harm may cause audiences to think that this is a cyclic pattern rather than human-induced change. Focusing on the mechanisms for how temperature affects lobster—both positively and negatively—will help avoid this. Ocean problems are material pollution: Fishers in this area do see climate change as a threat but rate it below other pollution (McClenachan et al., 2020); this is a common belief. It is important to avoid steering listeners toward thinking about material pollution as the cause of ocean problems.

Because we are talking about an animal, we also want to avoid falling into the “cute critter trap,” in which we focus on the creature's charm. While this can endear the listener temporarily, this communication technique tends to focus on the animal's value for our entertainment, rather than how climate change will impact their physiology and instincts, and ultimately their persistence as an ecosystem player. Finally, we will want to focus on solutions. Current modeling work suggests that good fisheries management can build climate resilience (Le Bris et al., 2018, for lobster; Gaines et al., 2018), and communicating this fits well with the values of Responsible Management and Protection.

Framed communication example

Start with a tested value: We rely on ocean creatures like lobsters for food and for tourism. At the same time, these creatures rely on

us for a livable ocean habitat. We can protect these creatures and their habitats.

Use a tested metaphor: When we burn fossil fuels like coal, oil, and natural gas for electricity and transport, we release carbon dioxide into the atmosphere. This carbon dioxide acts like a heat-trapping blanket, keeping heat close to the Earth that would normally be emitted into space. The more carbon dioxide we emit, the thicker the blanket gets and the warmer our atmosphere becomes.

Provide explanatory chains: Much of this extra heat in the atmosphere also ends up in the ocean, slowly raising its temperature. For many ocean creatures, such as lobsters, metabolic rates, oxygen levels, and disease resistance are influenced by water temperature. Temperatures that are too cold can cause problems by slowing down their metabolism, but temperatures that are too hot are particularly dangerous because warmer water tends to hold less oxygen, and that warmth also causes their growth and metabolism to speed up. For the moment, in the Gulf of Maine, the warming temperatures are beneficial for lobsters, providing lots of suitable habitat for young to settle and allowing them to grow quickly. However, as temperatures continue to increase, the waters will become too warm for lobsters, and populations are likely to decline as higher rates of disease and early death set in. We can already see this pattern occurring in more southern populations of lobster where the temperatures right now are warmer.

End with a solution: Together, we can take steps to help species like lobster. Americans are innovative, and fishermen in Maine have already been testing effective ways to protect the lobster populations by protecting the large females that produce the most offspring. By continuing to take steps to keep the population healthy, the community helps support resilience against other stressors like climate. At the same time, we need to address the root of the problem—carbon dioxide emissions. We can take actions like pushing community leaders and industries to use wind and solar power for energy, so we emit less heat-trapping gases—like carbon dioxide—when we use energy for electricity and transportation.

Climate challenge 2: Coastal and ocean acidification

Scientific background for this example

Ocean acidification, while often addressed as “the other CO₂ problem,” is an important abiotic stressor globally. In the Gulf of Maine, coastal waters are highly variable in carbonate chemistry on multiple timescales due to strong benthic-pelagic coupling (Waldbusser and Salisbury, 2014; Colarusso et al., 2016). While they are some of our most vulnerable habitats, nearshore ecosystems also have great potential to mitigate the effects of climate change (Hendriks et al., 2014; Siedlecki et al., 2021). One such habitat is seagrasses, which are important for carbon sequestration and local pH buffering (Roman et al., 2000). For Maine communities, this is a particularly pressing issue, as nearly 25,000 ha of seagrasses reside in coastal areas, and they have faced significant decline since European settlement (on average 20% decline, locally varying). Because seagrasses produce oxygen by photosynthesis, they modulate local pH for residing fishes and invertebrates on a daily basis by up to 1 unit of pH. Under conditions of ocean acidification, many consider this “buffering” effect to be producing local nearshore refugia from declining pH conditions for vulnerable populations and life stages of invertebrates and fishes (Saderne et al., 2015). Seagrasses not only host great biodiversity but also provide significant ecosystem services to nearshore human communities through erosion control and wave attenuation (Burkholder et al., 2007; Heck et al., 2008; Shelton et al., 2017). Communication about pH within seagrass beds is particularly nuanced, as pH fluctuates heavily on a daily basis outside of the effects of climate change (Pacella et al., 2018).

Specific communication tools used in example framed communication

As in the previous example, we use a value: Seagrasses are important ecosystems that humans and other species rely upon, and this is a critical connection. Next, it is also important to acknowledge the many facets of how ocean acidification impacts biological processes and doing so in a nuanced way for seagrasses in the Gulf of Maine requires strategy. Here, we recommend using a two-pronged approach to address each impact separately (see **Table 1**). First, describe the chemical consequences of decreased pH on physical shell formation and then discuss the biochemical impacts of decreased pH on physiological processes (e.g., growth, reproduction, species interactions). Since there are predictable fluctuations in abiotic conditions regularly within the habitat, it is also important to redirect away from the unproductive mental model that nature works in cycles.

The “osteoporosis of the sea” metaphor is useful when describing how larvae with shells are unable to mature properly, which addresses declining fishery species like oysters, clams, and mussels. However, there are physiological (of the body) impacts of ocean acidification as well. The “regular and rampant CO₂” metaphor uses alliteration to make the concept *sticky* and allows us to distinguish between background and human-induced levels of CO₂. Although seagrass beds have fluctuations in pH regularly, residing organisms are not

acclimatized to pH caused by “rampant” CO₂ outside of the “regular” range of pH. This means that biochemical reactions that rely on pH (i.e., olfactory senses, cell kinetics, and neural firing) are experiencing new conditions under human-induced climate change.

Framed communication example

Start with a tested value: Seagrasses play an important role in keeping ecosystems healthy by providing habitat for the organisms that live within seagrass beds. In turn, this helps to maintain productive fish populations that human communities rely on for food and livelihoods. As a result, managing seagrasses in the Gulf of Maine is the responsible choice to ensure our health and the health of our environment.

Use a tested metaphor: While regular levels of carbon dioxide are used and created by normal life processes like photosynthesis and respiration, rampant levels of carbon dioxide come from burning fossil fuels for energy. Rampant carbon dioxide levels lead to warmer waters and changing ocean chemistry. One type of ocean chemistry change is ocean acidification, or “osteoporosis of the sea.”

Provide explanatory chains: When carbon dioxide enters the ocean, it changes the chemical makeup of the water so that the pH—a measure of how acidic or basic it is—is lowered, pushing it toward the more acidic end of the pH scale. Organisms that live in the water can also influence the pH of their surroundings through their normal life processes such as photosynthesis. When plants like seagrasses take up CO₂ by photosynthesis during the day, they temporarily reduce the acidity of the water (i.e., increase the pH). At night, when seagrasses stop taking up CO₂ and instead take up oxygen to break down their food (i.e., respiration), the acidity of the water goes up again (i.e., pH decreases). This results in daily changes in pH levels, creating a pH range that is normally experienced in the seagrass bed. With the addition of rampant levels of carbon dioxide, these normal life processes can actually decrease pH below the regular daily range experienced in these ecosystems. Lower-than-normal pH conditions in seagrass beds make it hard for other organisms to maintain their normal life processes, and they

may no longer be able to interact with other species or their environment in the same way. For example, some fishes have reduced sensory capabilities (i.e., smell) under elevated CO₂ conditions, which limits their ability to evade predators and find food (Cripps et al., 2011; Kroeker et al., 2014).

End with a solution: While seagrass ecosystems are susceptible to climate change and ocean chemistry change, they also provide an opportunity for our community to buffer the effects of ocean acidification for important fishery species and other organisms that can use seagrass beds as a refuge during the day, when seagrass beds are less acidic than other surrounding ocean areas. By protecting seagrasses from ship damage and dredging on our local coastlines, we can make sure these buffer zones remain for animals to escape the impacts of ocean acidification.

Coastal challenge 3: Sea-level rise

Scientific background for this example

Maine boasts almost 3,500 miles of coastline, putting the state at the receiving end of immediate sea-level rise impacts (Gehrels et al., 2002; Chisholm et al., 2021). Rising sea levels are primarily due to a combination of melting glaciers and thermal expansion of the ocean (Wigley and Raper, 1987). Currently, the world is experiencing an increase of about $\frac{1}{8}$ inch per year in sea levels (Strauss et al., 2012). Sea-level rise is a global issue, but its effects vary regionally with differences in wind, ocean currents, and topographic features (Engelhart et al., 2009). Low-lying towns along Maine's coastline are at risk to lose millions of dollars in property, infrastructure, highways, and 20%–30% of their land area (Gehrels et al., 2002).

Increasing sea-level rise brings a host of issues, including nuisance flooding, coastal erosion, saltwater intrusion, and increased storm damage (Moftakhari et al., 2015). Nuisance flooding, also called high tide flooding, leads to road closures, flooded storm drains, and overwhelmed infrastructure (Moftakhari et al., 2018). The United States has experienced a 50% increase of nuisance flooding on average in the last 20 years and a 100% increase in the last 30 years (Moftakhari et al., 2015). Increasing sea levels also lead to an average increase in coastal erosion of 150 times that of the rise in sea level (Leatherman et al., 2000). In Maine, where almost half of the coast is made up of soft bluffs, 40% of the coast is at risk of increased erosion (Gehrels et al., 2002). In addition to loss of shoreline, rising sea levels can flood farmland, inundating them with salt. About 9% of the coastal United States is at risk of increased saltwater intrusion (Sawyer et al., 2016). These issues are further exacerbated by the loss of coastal habitats such as wetlands, seagrass beds, and oyster reefs that serve as buffers for storm surge.

Specific communication tools used in example-framed communication

When discussing issues such as sea-level rise, it is important to focus on values and collective solutions. It is too easy to slide into discussions about individuals or personal property rights when discussing the impacts of sea-level rise. Rather, the conversations should focus on civic responsibility and draw on the public's view of Americans as problem solvers. Using the value *Responsible Management* for coastal areas, we can discuss our ability to work together to manage coastal resources before the problems get worse. Additionally, the value of *Protection* may be used here (see **Table 1**); we must protect and preserve the habitats and ecosystems we depend on to protect us from storm surge and saltwater intrusion. Protection also increases a sense of agency for the listener as protection means actively reducing or eliminating risks.

As sea-level rise is influenced by both melting land-ice and thermal expansion of the water, the *Heat-Trapping Blanket* and *Climate's Heart* metaphors are useful tools. As discussed above, these metaphors help your audience understand the mechanisms that drive sea-level rise. As the climate's heart, the ocean regulates the earth's climate by moving heat and moisture and stabilizes the earth's temperature by absorbing heat from the sun and transferring it to different parts of the climate system. This means the ocean absorbs much of the heat itself, which leads to thermal expansion of the water and sea-level rise, as well as increased extreme weather events and storm surge.

Finally, employing cultural models of our community members as problem solvers who can work together to protect one another through responsible management of our resources leads audiences toward productive, community solutions thinking. These solutions could include innovative changes to real-estate development and rezoning of high-risk areas, or the development of marine protected areas and increasing state or national park protections as buffer zones that can help offset the impacts of sea-level rise and help protect the people who live in coastal areas.

Framed communication example

Start with a tested value: By responsibly managing our coastal areas, we minimize the impacts of the climate changes we are experiencing today and will continue to experience in the future.

Use a tested metaphor: Carbon dioxide emissions from the burning of fossil fuels (i.e., coal, oil, and natural gas) for energy and transportation are adding to the heat-trapping blanket effect of the atmosphere.

Provide explanatory chains: As more heat is trapped by the atmosphere, some of that heat is absorbed by the ocean. When water warms, it expands, which increases the space that

ocean water takes up. At the same time, warmer air temperatures melt ice on land; this meltwater then flows into the ocean, increasing the overall volume and thus the sea level. The ocean acts like the heart of the climate system, moving heat around the globe through currents. Because weather events like storms and hurricanes are influenced by the temperature of the ocean, as well as air and wind currents, changes to the ocean—climate's heart—affect the size and strength of these extreme events. Large storm surges on top of rising sea-level increase the risk of coastal flooding.

End with a solution: Maine has already demonstrated the capacity to minimize impacts of climate change by adopting policies to responsibly manage shared resources. One example is the Natural Resources Protection Act's Sand Dune Rules and shoreland zoning program. This program offers communities tools to identify areas vulnerable to sea-level rise and helps in decision making to protect their community from future harm. By planning for future sea-level rise, these communities are responsibly managing their resources and protecting future generations, roads, and other infrastructure along the coast of Maine.

Conclusion

The purpose of the Gulf of Maine 2050 Symposium was to build a vibrant, productive, and resilient community by clearly identifying what we know about three drivers of environmental change. The translation of critical, public-facing environmental issues like these climate change drivers can be improved by using framing techniques. Here, we provide an alternative method to the information deficit model of communicating about divisive sociopolitical topics. The framing techniques demonstrated here have been shown to increase understanding of the mechanisms of climate change—which is critical for connecting appropriate solutions and increasing a sense of hope and motivation to act (Swim and Fraser, 2013). These methods are flexible; the order of framing elements and which ones are used can be altered to suit a particular topic or format. These are a set of tools, not a prescriptive formula, and mastery of effective climate communication strategies does require practice. Discussions with colleagues help to increase hope and confidence in communicators, which, in turn, leads to more discussions about climate change (Swim and Fraser, 2013). As a result, we recommend practicing framing elements with trusted family, friends, and peers and seeking iterative feedback from

listeners when working to develop effective and hopeful communication pieces about climate change.

In this piece, we focused on the transformative effect of climate communication on the listener. It is also critical to note that climate communicators and scientists can also experience severe stress from this emotionally draining, potentially hopeless feeling work (Fraser et al., 2013). Messaging with hope has been a critical component in the motivation of a network of informal science educators and scientists who routinely use these tools in their work. Finally, these tools scratch the surface of rich field of science communication and teaching (e.g., Morgan et al., 2002; Schunk, 2012; Fiske and Dupree, 2014), climate communication (e.g., Moser, 2016; Levine and Kline, 2017; Van der Linden et al., 2017), and framing practice (e.g., Kahneman and Tversky, 2013; Nabi et al., 2018). Additional resources on the set of tools described here and an online community of practice, where practitioners can ask and answer questions about these framing techniques, can be found at www.nnocci.org.

Data accessibility statement

No data were collected as part of this paper.

Acknowledgments

This article was contributed by a collective of scientists and educators from the National Network for Ocean and Climate Change Interpretation (NNOCCI). NNOCCI is a national network of informal science educators and climate scientists who work to change the national conversation on climate change to be more hopeful, civic-minded, and solutions-focused. NNOCCI uses research-based, tested communication techniques to clearly teach climate science, impacts, and solutions. We thank the members of the National Network for Ocean and Climate Change Interpretation for their support and in the practice of these principles. FrameWorks and Knology have been critical partners in developing and assessing the effects of these training programs.

Funding

The New England Aquarium and the Monterey Bay Aquarium supported this work through the administration of NNOCCI and NNOCCI's online platform, Climate Interpreter, respectively.

Competing interests

The authors have declared that no competing interests exist.

Author contributions

Contributed to conception and design: AB, ME, JAH, EM, SMN, NP, RLT.

Contributed to acquisition of data: N/A.

Contributed to analysis and interpretation of data: N/A.

Drafted and/or revised the article: ME, JAH, EM, SMN, NP, RLT.

Approved the submitted version for publication: AB, ME, JAH, EM, SMN, NP, RLT.

References

- Bales, S, Sweetland, J, Volmert, A.** 2015. *How to talk about oceans and climate change*. Washington, DC: Frameworks Institute.
- Ballew, MT, Leiserowitz, A, Roser-Renouf, C, Rosenthal, SA, Kotcher, JE, Marlon, JR, Lyon, E, Goldberg, MH., Maibach, EW.** 2019. Climate change in the American mind: Data, tools, and trends. *Environment Science and Policy for Sustainable Development* **61**: 4–18. DOI: <http://dx.doi.org/10.1080/00139157.2019.1589300>.
- Belkin, I.** 2009. Rapid warming of large marine ecosystems. *Progress in Oceanography* **81**: 207–213. DOI: <http://dx.doi.org/10.1016/j.pocean.2009.04.011>.
- Bilandzic, H, Kalch, A, Soentgen, J.** 2017. Effects of goal framing and emotions on perceived threat and willingness to sacrifice for climate change. *Science Communication* **39**: 466–491.
- Borah, P.** 2011. Conceptual issues in framing theory: A systematic examination of a decade's literature. *Journal of Communication* **61**: 246–263.
- Brickman, D, Alexander, MA, Pershing, A, Scott, JD, Wang, Z.** 2021. Projections of physical conditions in the Gulf of Maine in 2050. *Elementa: Science of the Anthropocene* **9**. DOI: <http://dx.doi.org/10.1525/elementa.2020.20.00055>
- Bullock, OM, Colón Amill, D, Shulman, HC, Dixon, GN.** 2019. Jargon as a barrier to effective science communication: Evidence from metacognition. *Public Understanding of Science* **28**: 845–853.
- Bunten, A, Arvizu, S.** 2013. Turning visitors into citizens: Using social science for civic engagement in informal science education centers. *Journal of Medical Education* **38**: 260–272.
- Burkholder, J, Tomasko, D, Touchette, B.** 2007. Seagrasses and eutrophication. *Journal of Experimental Marine Biology and Ecology* **350**: 46–72. DOI: <http://dx.doi.org/10.1016/j.jembe.2007.06.024>.
- Burns, TW, O'Connor, DJ, Stockmayer, SM.** 2003. Science communication: A contemporary definition. *Public Understanding of Science* **12**: 183–202.
- Carmi, N, Arnon, S, Orion, N.** 2015. Transforming environmental knowledge into behavior: The mediating role of environmental emotions. *The Journal of Environmental Education* **46**: 183–201.
- Chang, JH, Chen, Y, Holland, D, Grabowski, J.** 2010. Estimating spatial distribution of American lobster *Homarus americanus* using habitat variables. *Marine Ecology Progress Series* **420**: 145–156. DOI: <http://dx.doi.org/10.3354/meps08849>.
- Chisholm, L, Talbot, T, Appleby, W, Tam, B, Rong, R.** 2021. Projected changes to air temperature, sea-level rise, and storms for the Gulf of Maine region in 2050. *Elementa: Science of the Anthropocene* **9**. DOI: <http://dx.doi.org/10.1525/elementa.2021.00059>.
- Chong, D, Druckman, JN.** 2007. Framing theory. *Annual Review of Political Science* **10**: 103–126.
- Colarusso, P, Simpson, J, Novak, A, Ford, K, DiBona, P, Vella, P, Deane, J, Stanley, S.** 2016. Blue carbon,

- green eelgrass: Estimating carbon storage in eelgrass in the Gulf of Maine. U.S. EPA Climate Ready Estuaries Program Technical Report. Available at <https://www.mass.gov/files/documents/2016/12/vb/blue-carbon-greeneelgrass-2015-final.pdf>.
- Cripps, IL, Munday, PL, McCormick, MI.** 2011. Ocean acidification affects prey detection by a predatory reef fish. *PLoS One* **6**. DOI: <http://dx.doi.org/10.1371/journal.pone.0022736>.
- Denzau, AT, North, DC.** 1994. Shared mental models: Ideologies and institutions. *Kyklos* **47**: 3–31. DOI: <http://dx.doi.org/10.1111/j.1467-6435.1994.tb02246.x>.
- Eakin, H, Siqueiros-García, JM, Hernández-Aguilar, B, Shelton, R, Bojórquez-Tapia, LA.** 2019. Mental models, meta-narratives, and solution pathways associated with socio-hydrological risk and response in Mexico City. *Frontiers in Sustainable Cities* **1**: 4.
- Engelhart, SE, Horton, BP, Douglas, B.C, Peltier, WR, Tömqvist, TE.** 2009. Spatial variability of late Holocene and 20th century sea-level rise along the Atlantic coast of the United States. *Geology* **37**: 1115–1118.
- Fiske, ST, Dupree, C.** 2014. Gaining trust as well as respect in communicating to motivated audiences about science topics. *Proceedings of the National Academy of Sciences of the United States of America* **111**: 13593–13597. DOI: <http://dx.doi.org/10.1073/pnas.1317505111>.
- Fraser, J, Pantesco, V, Plemons, K, Gupta, R, Rank, SJ.** 2013. Sustaining the conservationist. *Ecopsychology* **5**: 70–79. DOI: <http://dx.doi.org/10.1089/eco.2012.0076>.
- Gaines, SD, Costello, C, Owashi, B, Mangin, T, Bone, J, Molinos, JG., Burden, M, Dennis, H, Halpern, B, Kappel, CV.** 2018. Improved fisheries management could offset many negative effects of climate change. *Science Advances* **4**: eaao1378. DOI: <http://dx.doi.org/10.1126/sciadv.aao1378>.
- Gehrels, WR, Belknap, DF, Black, S, Newnham, RM.** 2002. Rapid sea-level rise in the Gulf of Maine, USA, since AD 1800. *The Holocene* **12**: 383–389. DOI: <http://dx.doi.org/10.1191/0959683602hl555ft>.
- Geiger, N, Swim, JK, Fraser, J.** 2017. Creating a climate for change: Interventions, efficacy and public discussion about climate change. *Journal of Environmental Psychology* **51**: 104–116. DOI: <http://dx.doi.org/10.1016/j.jenvp.2017.03.010>.
- Gentner, D, Jeziorski, M.** 1993. **The shift from metaphor to analogy in Western science.** 447–480. DOI: <http://dx.doi.org/10.1017/CBO9781139173865.0221>
- Gifford, R, Comeau, LA.** 2011. Message framing influences perceived climate change competence, engagement, and behavioral intentions. *Global Environmental Change* **21**: 1301–1307. DOI: <http://dx.doi.org/10.1016/j.gloenvcha.2011.06.004>.
- Giles, TD.** 2017. *Motives for metaphor in scientific and technical communication.* Routledge.
- Gillooly, J, Charnov, E, West, G, Savage, V, Brown, J.** 2002. Effects of size and temperature on developmental time. *Nature* **417**: 70–73. DOI: <http://dx.doi.org/10.1038/417070a>.
- Glenn, RP, Pugh, TL.** 2006. Epizootic shell disease in American lobster (*Homarus americanus*) in Massachusetts coastal waters: Interactions of temperature, maturity, and intermolt duration. *Journal of Crustacean Biology* **26**: 639–645. DOI: <http://dx.doi.org/10.1651/S-2754.1>.
- Goode, AG, Brady, DC, Steneck, RS, Wahle, RA.** 2019. The brighter side of climate change: How local oceanography amplified a lobster boom in the Gulf of Maine. *Global Change Biology* **25**: 3906–3917. DOI: <http://dx.doi.org/10.1111/gcb.14778>.
- Heck, K, Carmthers, T, Duarte, C, Hughes, AR, Kendrick, G, Orth, R, Williams, S.** 2008. Trophic transfers from seagrass meadows subsidize diverse marine and terrestrial consumers. *Ecosystems* **11**: 1198–1210. DOI: <http://dx.doi.org/10.1007/s10021-008-915>.
- Hendriks, IE, Olsen, YS, Ramajo, L, Basso, L, Moore, T, Howard, J, Duarte, C.** 2014. Photosynthetic activity buffers ocean acidification in seagrass meadows. *Biogeosciences* **11**: 333–346. DOI: <http://dx.doi.org/10.5194/bg-11-333-2014>.
- Kahneman, D, Tversky, A.** 2013. Choices, values, and frames, in MacLean, LC ed., *Handbook of the fundamentals of financial decision making: Part I.* Hackensack, NJ: World Scientific Publishing Co.: 269–278.
- Koopman, HN, Westgate, AJ, Siders, ZA.** 2015. Declining fecundity and factors affecting embryo quality in the American lobster (*Homarus americanus*) from the Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences* **72**: 352–363. DOI: <http://dx.doi.org/10.1139/cjfas-2014-0277>.
- Kroeker, KJ, Sanford, E, Jellison, BM, Gaylord, B.** 2014. Predicting the effects of ocean acidification on predator-prey interactions: A conceptual framework based on coastal molluscs. *The Biological Bulletin* **226**: 211–222. DOI: <http://dx.doi.org/10.1086/BBLv226n3p211>.
- Kronenfeld, DB.** 2018. Cultural models. *The International Encyclopedia of Anthropology* 1–8. DOI: <http://dx.doi.org/10.1002/9781118924396.wbiea1567>.
- Kuhn, TS.** 1979. Metaphor in science. *Metaphor Thought* **2**: 533–542.
- Lakoff, G.** 2006. *Thinking points: Communicating our American values and vision.* New York, NY: Macmillan.
- Lakoff, G.** 2014. *The all new don't think of an elephant! Know your values and frame the debate.* White River Junction, VT: Chelsea Green Publishing.
- Lakoff, G, Johnson, M.** 2008. *Metaphors we live by.* Chicago, IL: University of Chicago Press.
- Leatherman, SP, Zhang, K, Douglas, BC.** 2000. Sea level rise shown to drive coastal erosion. *Transactions of the American Geophysical Union* **81**: 55–57.
- Le Bris, A, Mills, KE, Wahle, RA, Chen, Y, Alexander, MA, Allyn, AJ, Pershing, J.** 2018. Climate vulnerability and resilience in the most valuable North American fishery. *Proceedings of the National*

- Academy of Sciences of the United States of America* **115**: 1831–1836. DOI: <http://dx.doi.org/10.1073/pnas.1711122115>.
- Leombruni, LV**. 2015. How you talk about climate change matters: A communication network perspective on epistemic skepticism and belief strength. *Global Environmental Change* **35**: 148–161. DOI: <http://dx.doi.org/10.1016/j.gloenvcha.2015.08.006>.
- Levine, AS, Kline, R**. 2017. A new approach for evaluating climate change communication. *Climatic Change* **142**: 301–309. DOI: <http://dx.doi.org/10.1007/s10584-017-1952-x>.
- Li, D, Zhao, L, Ma, S, Shao, S, Zhang, L**. 2019. What influences an individual's pro-environmental behavior? A literature review. *Resources, Conservation & Recycling* **146**: 28–34.
- Lubell, M**. 2002. Environmental activism as collective action. *Environment and Behavior* **34**: 431–454.
- Maddux, JE, Rogers, RW**. 1983. Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change. *Journal of Experimental Social Psychology* **19**: 469–479. DOI: [http://dx.doi.org/10.1016/0022-1031\(83\)90023-9](http://dx.doi.org/10.1016/0022-1031(83)90023-9).
- Manning, C.M, Amel, EL, Scott, BA, Forsman, J**. 2009. Framing climate change solutions: Get the numbers right. *International Journal of Climate Change Strategies and Management* **1**: 326–339.
- Manuel, T, Davey, L**. 2009. Strategic Frame Analysis: Providing the “evidence” for evidence-based communications. *New Directions for Youth Development* **2009**: 29–38. DOI: <http://dx.doi.org/10.1002/yd.322>.
- McClenachan, L, Scyphers, S, Grabowski, JH**. 2020. Views from the dock: Warming waters, adaptation, and the future of Maine's lobster fishery. *Ambio* **49**: 144–155. DOI: <http://dx.doi.org/10.1007/s13280-019-01156-3>.
- McEvoy, D, Fünfgeld, H, Bosomworth, K**. 2013. Resilience and climate change adaptation: The importance of framing. *Planning Practice and Research* **28**: 280–293. DOI: <http://dx.doi.org/10.1080/02697459.2013.787710>.
- McLeese, DW**. 1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. *Journal of the Fisheries Research Board of Canada* **13**: 247–272. DOI: <http://dx.doi.org/10.1139/f56-016>.
- Miller, CA**. 2000. The dynamics of framing environmental values and policy: Four models of societal processes. *Environmental Values* **9**: 211–233.
- Moftakhari, HR, AghaKouchak, A, Sanders, BF, Al-laire, M, Matthew, RA**. 2018. What is nuisance flooding? Defining and monitoring an emerging challenge. *Water Resources Research* **54**: 4218–4227. DOI: <http://dx.doi.org/10.1029/2018WR022828>.
- Moftakhari, HR, AghaKouchak, A, Sanders, BF, Feldman, DL, Sweet, W, Matthew, RA, Luke, A**. 2015. Increased nuisance flooding along the coasts of the United States due to sea level rise: Past and future. *Geophysical Research Letters* **42**: 9846–9852. DOI: <http://dx.doi.org/10.1002/2015GL066072>.
- Morgan, MG, Fischhoff, B, Bostrom, A, Atman, CJ**. 2002. *Risk communication: A mental models approach*. Cambridge, UK: Cambridge University Press.
- Morton, TA, Rabinovich, A, Marshall, D, Bretschneider, P**. 2011. The future that may (or may not) come: How framing changes responses to uncertainty in climate change communications. *Global Environmental Change* **21**: 103–109.
- Moser, SC**. 2016. Reflections on climate change communication research and practice in the second decade of the 21st century: What more is there to say? *Wiley Interdisciplinary Reviews: Climate Change* **7**: 345–369. DOI: <http://dx.doi.org/10.1002/wcc.403>.
- Nabi, RL., Gustafson, A, Jensen, R**. 2018. Framing climate change: Exploring the role of emotion in generating advocacy behavior. *Science Communication* **40**: 442–468. DOI: <http://dx.doi.org/10.1177/1075547018776019>.
- Nisbet, MC**. 2009. Framing science: A new paradigm in public engagement. *Understanding Science: New Agendas in Science Communication* **40**: 67.
- NOAA Fisheries Office of Science and Technology**. 2020. Commercial Landings Query. Available at <https://www.fisheries.noaa.gov/foss>.
- O'Neill, S, Nicholson-Cole, S**. 2009. “Fear won't do it” promoting positive engagement with climate change through visual and iconic representations. *Science Communication* **30**: 355–379. DOI: <http://dx.doi.org/10.1177/1075547008329201>.
- Oreskes, N**. 2004. The scientific consensus on climate change. *Science* **306**: 1686–1686. DOI: <http://dx.doi.org/10.1126/science.1103618>.
- Owens, S, Driffill, L**. 2008. How to change attitudes and behaviours in the context of energy. *Energy Policy* **36**: 4412–4418.
- Pacella, SR, Brown, CA, Waldbusser, GG, Labiosa, RG, Hales, B**. 2018. Seagrass habitat metabolism increases short-term extremes and long-term offset of CO₂ under future ocean acidification. *Proceedings of the National Academy of Sciences of the United States of America* **115**: 3870–3875. DOI: <http://dx.doi.org/10.1073/pnas.1703445115>.
- Pershing, AJ, Alexander, MA, Hernandez, CM, Kerr, LA, Le Bris, A, Mills, KE, Nye, JA, Record, NR, Scannell, HA, Scott, JD**. 2015. Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science* **350**: 809–812. DOI: <http://dx.doi.org/10.1126/science.aac9819>.
- Price, V, Tewksbury, D, Powers, E**. 1997. Switching trains of thought: The impact of news frames on readers' cognitive responses. *Communication Research* **24**: 481–506.
- Raad, B**. 1989. Modern trends in scientific terminology: Morphology and metaphor. *American Speech* **64**: 128–136. DOI: <http://dx.doi.org/10.2307/455039>.
- Ranney, MA., Clark, D**. 2016. Climate change conceptual change: Scientific information can transform

- attitudes. *Top Cognitive Science Courses* **8**: 49–75. DOI: <http://dx.doi.org/10.1111/tops.12187>.
- Roman, CT, Jaworski, N, Short, FT, Findlay, S, Warren, R, S.** 2000. Estuaries of the northeastern United States: Habitat and land use signatures. *Estuaries* **23**: 743–764. DOI: <http://dx.doi.org/10.2307/1352997>.
- Saba, VS, Griffies, SM, Anderson, WG, Winton, M, Alexander, MA, Delworth, TL, Hare, JA, Harrison, MJ, Rosati, A, Vecchi, GA.** 2016. Enhanced warming of the Northwest Atlantic Ocean under climate change. *Journal of Geophysical Research: Oceans* **121**: 118–132. DOI: <http://dx.doi.org/10.1002/2015JC011346>.
- Saderne, V, Fietzek, P, Aßmann, S, Körtzinger, A, Hiebenthal, C.** 2015. Seagrass beds as ocean acidification refuges for mussels? High resolution measurements of pCO₂ and O₂ in a *Zostera marina* and *Mytilus edulis* mosaic habitat. *Biogeosciences Discuss* **12**: 11423–11461. DOI: <http://dx.doi.org/10.5194/bg-12-11423-2015>.
- Sawyer, AH, David, CH, Famiglietti, JS.** 2016. Continental patterns of submarine groundwater discharge reveal coastal vulnerabilities. *Science* **353**: 705–707. DOI: <http://dx.doi.org/10.1126/science.aag1058>.
- Schunk, DH.** 2012. *Learning theories an educational perspective*. 6th ed. Hoboken, NJ: Pearson.
- Shaw, RM, Howe, J, Beazer, J, Carr, T.** 2019. Ethics and positionality in qualitative research with vulnerable and marginal groups. *Qualitative Research* **20**: 277–293. DOI: <http://dx.doi.org/10.1177/1468794119841839>.
- Shelton, AO, Francis, TB, Feist, BE, Williams, GD, Lindquist, A, Levin, PS.** 2017. Forty years of seagrass population stability and resilience in an urbanizing estuary. *Journal of Ecology* **105**: 458–470. DOI: <http://dx.doi.org/10.1111/1365-2745.12682>.
- Shome, D, Marx, S, Appelt, K, Arora, P, Balstad, R, Broad, K, Freedman, A, Handgraaf, M, Hardisty, D, Krantz, D.** 2009. *The psychology of climate change communication: A guide for scientists, journalists, educators, political aides, and the interested public*. New York, NY: Center for Research on Environmental Decisions.
- Siedlecki, S, Salisbury, J, Gledhill, D, Bastidas, C, Meeseck, S, McGarry, K, Hunt, C, Alexander, M, Lavoie, D, Wang, Z, Scott, J, Brady, D, Mlsna, I, Azetsu-Scott, K, Liberti, C, Melrose, D, White, M, Pershing, A, Vandemark, D, Townsend, D, Chen, C, Mook, W, Morrison, R.** 2021. Projecting ocean acidification impacts for the Gulf of Maine to 2050: New tools and expectations. *Elementa: Science of the Anthropocene* **9**. DOI: <http://dx.doi.org/10.1525/elementa.2020.00062>.
- Simon, A, Volmert, A, Bunten, A, Kendall-Taylor, N.** 2014. *The value of explanation: Using values and causal explanations to reframe climate and ocean change*. Washington, DC: Frameworks Institute.
- Sterman, JD.** 2008. Risk communication on climate: Mental models and mass balance. *Science* **322**: 532–533.
- Strauss, B, Tebaldi, C, Ziemlinski, R.** 2012. *Sea level rise, storms & global warming's threat to the US coast*. Princeton, NJ: Climate Central.
- Suldovsky, B.** 2017. The information deficit model and climate change communication, in *Oxford research encyclopedia of climate science*. Available at <https://oxfordre.com/climatescience/>.
- Swim, JK, Fraser, J.** 2013. Fostering hope in climate change educators. *Journal of Medical Education* **38**: 286–297. DOI: <http://dx.doi.org/10.1080/10598650.2013.11510781>.
- Swim, JK, Fraser, J, Geiger, N.** 2014. Teaching the choir to sing: Use of social science information to promote public discourse on climate change. *Journal of Land Use & Environmental Law* **30**: 91–117.
- Swim, JK, Geiger, N.** 2017. From alarmed to dismissive of climate change: A single item assessment of individual differences in concern and issue involvement. *Environmental Communication* **11**: 568–586. DOI: <http://dx.doi.org/10.1080/17524032.2017.1308409>.
- Swim, JK, Geiger, N, Fraser, J, Pletcher, N.** 2017. Climate change education at nature-based museums. *Curator: The Museum Journal* **60**: 101–119. DOI: <http://dx.doi.org/10.1111/cura.12187>.
- Swim, JK, Geiger, N, Sweetland, J, Fraser, J.** 2018. Social construction of scientifically grounded climate change discussions, in *Psychology and climate change*. Cambridge, MA: Elsevier: 65–93.
- Taboada, F, Anadón, R.** 2012. Patterns of change in sea surface temperature in the North Atlantic during the last three decades: Beyond mean trends. *Climatic Change* **115**: 419–431. DOI: <http://dx.doi.org/10.1007/s10584-012-0485-6>.
- Taylor, C, Dewsbury, BM.** 2018. On the problem and promise of metaphor use in science and science communication. *Journal of Microbiology & Biology Education* **19**. DOI: <http://dx.doi.org/10.1128/jmbe.v19i1.1538>.
- Van der Linden, S, Leiserowitz, A, Rosenthal, S, Maibach, E.** 2017. Inoculating the public against misinformation about climate change. *Global Challenges* **1**. DOI: <http://dx.doi.org/10.1002/gch2.201600008>.
- Volmert, A, Baran, M, Kendall-Taylor, N, Lindland, E, Arvizu, S, Bunten, A.** 2013. *“Just the Earth doing its own thing”: Mapping the gaps between expert and public understandings of oceans and climate change*. Washington, DC: Frameworks Institute.
- Waldbusser, GG, Salisbury, JE.** 2014. Ocean acidification in the coastal zone from an organism’s perspective: Multiple system parameters, frequency domains, and habitats. *Annual Review of Marine Science* **6**: 221–247. DOI: <http://dx.doi.org/annurev-marine-121211-172238>.
- Weber, EU, Stern, PC.** 2011. Public understanding of climate change in the United States. *American*

- Psychologist* **66**: 315. DOI: <http://dx.doi.org/10.1037/a0023253>.
- Wigley, T.M., Raper, S.** 1987. Thermal expansion of sea water associated with global warming. *Nature* **330**: 127–131. DOI: <http://dx.doi.org/10.1038/330127a0>.
- Wolsko, C, Ariceaga, H, Seiden, J.** 2016. Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors. *Journal of Experimental Social Psychology* **65**: 7–19. DOI: <http://dx.doi.org/10.1016/j.jesp.2016.02.005>.

How to cite this article: Bonanno, A, Ennes, M, Hoey, JA, Moberg, E, Nelson, S-M, Pletcher, N, Tanner, RL. 2021. Empowering hope-based climate change communication techniques for the Gulf of Maine. *Elementa: Science of the Anthropocene* 9(1). DOI: <https://doi.org/10.1525/elementa.2020.00051>

Domain Editor-in-Chief: Alastair Iles, University of California, Berkeley, CA, USA

Guest Editor: Andrew Pershing, Climate Central, Princeton, NJ, USA

Knowledge Domain: Sustainability Transitions

Part of an Elementa Special Feature: Gulf of Maine 2050: Visioning Regional Resilience and Sustainability

Published: July 30, 2021 **Accepted:** June 3, 2021 **Submitted:** May 14, 2020

Copyright: © 2021 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>.