Iceland's migratory birds in changing environmental conditions: An interactive synthesis

Frances J. Duncan
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Iceland’s migratory birds in changing environmental conditions:
An interactive synthesis

Frances J. Duncan
fduncan@smith.edu
SIT Iceland and Greenland
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Abstract

Human-driven changes to environmental conditions alter the habitats, behaviors, and migration patterns of migratory species. Changes in temperature, vegetation, and precipitation are just some of the factors contributing to shifts in phenology, demography, and distribution of migratory birds. These changes are driven by anthropogenic climate change and amplified by human land-use change, and are especially intense at high latitudes. This project creatively communicates the effects of environmental changes on three species of migratory birds in Iceland—the northern wheatear, the Greenland white-fronted goose, and the black-tailed godwit—using principles of storytelling and game design. The resulting interactive product is a game that can extend the reach of scientific information on migratory species to non-expert audiences and, by enabling players to engage with their observations and investigate further questions, increases accessibility of the scientific process.

Keywords: communication, migratory birds, climate change, land-use change, games

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Introduction

In an essay on science through storytelling, paleontologist Sara ElShafie describes communication as bridging differences in understanding (ElShafie, 2018). Despite this, science is often communicated in ways that fail to open the door to non-expert learners. Experts and non-experts have different bases of contextual knowledge for understanding new information (Carlton & Jacobson, 2016), and this difference should guide the development of science communication methods. Communicating science solely through the publication of formal scientific papers limits the accessibility of information contained in scientific studies to mostly experts. It is valuable to extend the reach of science information beyond only experts, since groups of people with varied knowledge backgrounds are more able to come up with creative problem-solving approaches (Pearson & Schuldt, 2015). On issues related to climate change, which requires complex solutions and thorough understandings of multiple interconnected systems, this broadening of scientific participation is even more essential. Different backgrounds give people unique “mental models” of context, perhaps because their experiences with climate and environmental change vary based on their experiences with specific local factors (Carlton & Jacobson, 2016). People’s experiences shape what they put the most importance on, which is perhaps why interactive communication—often in the form of “dialogue” communication (Priest, 2016, p. 7)—is more effective than simply telling people new information.

With this in mind, I sought to communicate this issue of both local and global importance—climate and environmental change—in an interactive format focused on three species of migratory birds in Iceland. Icelandic migratory birds are a subject of local importance: bird watching is common in Iceland, and citizens contribute to scientific bird data through the widespread Christmas Bird Count and other reporting opportunities (Christmas Bird Count, n.d.). It is also a topic that connects distant regions of the globe since migratory birds travel seasonally between wintering and breeding grounds (CAFF, 2013, p. 144). Because migratory birds in Arctic and sub-Arctic regions like Iceland also inhabit other areas of the world during winter seasons, they face the effects of human-driven climate change and land-use change in multiple environments (CAFF, 2013, p. 56). These environmental changes may alter or destroy their habitats (a common example is the development of the East Asian coastal wintering habitat of the spoon-billed sandpiper, which caused complete habitat destruction; CAFF, 2013, p. 54), and trigger changes in the timing of life-history events such as migration, nesting, and chick fledging.
(CAFF, 2013, p. 147). Therefore, understanding the impacts of human-driven climate and land-use changes on migratory birds in Iceland requires understanding the factors they encounter in non-Icelandic wintering and breeding grounds as well as in Icelandic habitats.

The experiences of migratory birds in changing environmental conditions provides an excellent focus for creative communication of scientific studies because these birds are well studied throughout their movements over time and space. They face numerous environmental obstacles, and extensive study of their experiences reveals interrelationships between environmental changes and changes to bird population phenology, distribution, and breeding and survival successes. Abundant scientific studies on migratory birds in Iceland have informed my work, which is focused on three species: the northern wheatear, the Greenland white-fronted goose, and the black-tailed godwit. These three species each use Icelandic habitats differently, and have unique interactions with changing environmental conditions. This paper will provide background information on each species and detail the development of an interactive mode of creative communication that allows multiple players to gain insight, through personal connection, into migratory bird populations in changing environmental conditions.

Literature Review:
The effects of changing environmental conditions on three migratory birds in Iceland

I. Northern wheatear

The northern wheatear (*Oenanthe oenanthe*) is a small migratory songbird that spends its summers in sub-Saharan Africa and travels a long distance north in the early spring to breed in various places across the high latitudes surrounding the Northern polar region, including in Iceland (Maggini & Bairlein, 2013). Because the wheatear breeds in multiple locations in the Northern Hemisphere, it has been possible to study wheatear populations in different environmental conditions and draw connections between these conditions and variation in population characteristics.

One such study found that wheatears that breed in Iceland have a higher metabolic rate than wheatears that breed in Norway, despite wintering in the same region for half the year, when taken out of their habitats and subject to controlled temperature testing (temperatures between 0-30°C; Maggini & Bairlein, 2013). A major difference in these two breeding populations is the temperature of their breeding grounds, with the lower latitudes of Norway
experiencing a warmer spring than Iceland; this difference led the researchers to hypothesize that the lower temperature in Iceland is a driver of the higher metabolic rates of Icelandic-breeding wheatears because the cold requires a higher rate of energy expenditure to maintain body heat (Maggini & Bairlein, 2013). If this is true, and the temperature difference motivates this difference in metabolic rate, it is likely that as temperatures increase with climate change, northern wheatears will experience a shift in their metabolic rates and food consumption due to changes in energy expenditure.

Another study, by Low et al., used the different sites of wheatear breeding to analyze the effects of vegetation height on wheatear survival; they found that wheatears had more trouble finding food and that survival was lower in areas of tall vegetation (>15cm; 2010). This is likely because it is harder for wheatears to find the insects that they eat in longer grass, and the resulting extra effort on the part of adult wheatears to feed their young results in decreased survival to adulthood (Low et al. 2010). With trends of increasing temperatures due to climate change, especially in polar regions, it is likely that vegetation growth will increase and occur earlier in the spring. This may result in decreased food availability in wheatear habitats, because the wheatears will have a reduced time-window to find their food. On the other hand, an increasing trend of land-use change by people converting previously unfarmed land into farm and pastureland may increase the availability of short grasses and allow wheatears to forage more successfully and efficiently support their young. Farmland is a preferred wheatear habitat during the breeding season (Seward et al. 2013), likely because of the short vegetation maintained by frequent grazing and resulting insect-hunting potential (Seward et al., 2013).

The additional climatic variable of precipitation may have an impact on vegetation availability, but also has direct associations with wheatear breeding success and survival. Öberg et al. found significant correlations between the occurrence and intensity of precipitation in wheatear breeding grounds and various demographics of wheatear populations: in breeding seasons with high precipitation, the fledgling survival rate (young birds surviving through their first flight, represented by the number of young post-fledging versus the number of young in the nest earlier in the season), chick recruitment rate (chicks surviving to adulthood, represented by survival to the next year, and male survival (to the next year) all decreased significantly (2014). Additionally, adult birds fed their young 22% less frequently in seasons years with high precipitation, possibly because it is harder to find food or because females spend more time
keeping their chicks warm in the nest; this is likely related to the decreased survival rates, especially of males who face increasing challenges as a major provider of food for their offspring when precipitation is high (Öberg et al., 2014). Öberg et al. point out that increased rainfall in temperate regions is a predicted effect of climate change, and therefore wheatear populations may struggle as the effects of climate change intensify (2014).

These studies of the associations between environmental conditions and the overall success of wheatears imply that climate changes have some effects on northern wheatear populations that will increasingly become apparent: as temperatures increase, wheatear metabolic rates may decrease to adjust to decreased energy demands; however, decreased energy demands does not necessarily mean that wheatears will have excess food, as vegetation changes due to climate or land-use change may change the ease of insect predation and alter food sources. Precipitation may compound the effects of these changes by presenting new challenges in food availability and increasing the energy demands on adult wheatears to provide for their young.

II. Greenland white-fronted goose

The Greenland white-fronted goose (*Anser albifrons flavirostris*) does not breed in Iceland, but instead passes through on its way to western Greenland breeding grounds (Fox et al., 2012). The staging period in Iceland usually lasts 3-5 weeks and allows the geese to recover after their flight from western European wintering grounds in Ireland and the United Kingdom and to refuel before the second portion of their spring migration (Fox et al., 2012).

Because Greenland white-fronted geese migrate in two flights, their springtime survival and breeding success are dependent on environmental conditions and seasonal timing in multiple locations. First, their wintering grounds must provide sufficient food for the geese to depart for Iceland in a healthy state. Second, their timing of arrival in Iceland must coincide with the spring availability of resources like food and appropriate habitat. Greenland white-fronted geese eat the underground organs of grasses and plants including common cotton-grass and Lyngbye’s sedge; their ability to feed therefore depends on the ground having thawed by the time of their arrival in Iceland (Fox et al., 2012). Finally, once the geese have accumulated fat reserves for their migration to Greenland, they must time their flight to breeding grounds to coincide with seasonal availability of habitats. If they arrive too early, they may face frozen habitats (Fox et al., 2014) and their breeding success will decline as a result; this has occurred recently in years with high spring snowfall in western Greenland (Fox et al., 2012).
Despite the sensitivity of timing for the migration of the Greenland white-fronted goose, the multi-step migration has actually enabled the goose to adjust to environmental changes (Fox et al., 2014). The three regions of habitat—Ireland and the United Kingdom, Iceland, and Greenland—have all been experiencing changes to climatic and land-use variables at different rates and in various manners. In the wintering grounds of the Greenland white-fronted goose, changes to human land-use have created an earlier availability of food, allowing the geese to accumulate appropriate stores earlier and leave for their staging period in Iceland earlier in the spring (Fox et al., 2012). The land-use change has occurred since the mid-twentieth century, when a trend of increased cultivation of land for livestock feed commenced during the second World War; the conversion of uncultivated land to farmland especially increases the availability of food for geese in winter, since the lands are managed year-round (Fox et al., 2012).

Similar land-use change has been occurring in Iceland: farmers have converted vast areas of land to hayfields to produce hay for their animals, and the management of these lands means there is above-ground food for geese even if they arrive when the soils in Iceland are still frozen (Fox et al., 2012). Additionally, as temperature increases in the early spring, vegetation growth advances; this combination of climatic and land-use factors is generally increasing the early spring availability of grasses for geese to feed upon and enabling them to begin their migration from Ireland earlier (15 days earlier since 1973; Fox et al., 2012). Iceland’s temperatures have so far been stable and not shown dramatic trends of increase, though this is predicted to change as climate change progresses, which has led Fox and Walsh to conclude that the earlier spring migration is primarily driven by changes to climate in the geese’s wintering grounds (2012) and is only enabled by the changes to Icelandic vegetation that allow for goose survival even when the ground has not yet thawed (Fox et al., 2012). If farming of hayfields had not increased to its current extent, early-migrating geese would likely not survive the spring; as it happens, however, the geese have demonstrated a 10-day advance in their arrival in Iceland (Fox et al., 2012).

Despite their survival through this early arrival in Iceland, the Greenland white-fronted geese arriving in Iceland early do not demonstrate the same rates of fat accumulation as they did when migration was delayed in previous decades. Rather, Fox et al. found that geese accumulated fat at a slower rate than they did in 1969 (2012). Possibly as a result, the geese have not begun to depart for Greenland earlier, so their early migration from their wintering grounds means that their staging period in Iceland is increasing in duration, seemingly in response to
changing environmental conditions; because they have not adjusted the timing of their migration to Greenland, the geese do not gain any benefits in breeding success due to early breeding (a common phenomenon among birds; Fox et al., 2012). While early breeding may be dangerous in Greenland currently due to cold temperatures and a lack of available food, the amplified warming trends of climate change in the polar region are warming Greenland and rapidly melting the ice sheet that covers the land mass. This warming may lead to earlier available habitats, and could therefore enable the advance of the second half of the Greenland white-fronted goose migration.

III. Black-tailed godwit

The black-tailed godwit (*Limosa limosa islandica*), unlike both the Greenland white-fronted goose and the northern wheatear, is a wading bird that only breeds in Iceland (Gunnarsson et al., 2005), though it spreads across western Europe during the winters. Interest in the recent increase in godwit populations and range expansion across Iceland has led to numerous studies investigating the effects of temperature changes and habitat quality on godwit survival and breeding success (e.g. Alves et al., 2019; Gunnarsson et al., 2005; Gunnarsson et al., 2006). Godwit populations have been especially easy to study since 1-2% of the population is identified with rings, and godwits have been carefully tracked for the past 20 years since ringing began in 1999 (Gunnarsson et al., 2006).

Climate changes, especially changes to temperature that may impact vegetation growth and resource availability, can often drive shifts to the phenological timing of life-history events in animal populations; godwits have been observed to both arrive in Iceland (Gunnarsson et al., 2006) and lay their eggs (Alves et al., 2019) earlier in warmer springs. Earlier nesting also corresponds to earlier hatching and the first flight of godwit chicks, which occurs at around 25 days after hatching, so these events were observed earlier in warmer springs as well (Alves et al., 2019).

Advance in phenological timing for godwits has been associated with increased chances that chicks will survive, and therefore has implications for the demographic traits of godwit populations. Alves et al. conducted a study that found that early-hatched godwit chicks had a 60% chance of surviving to adulthood, in contrast to the 35% recruitment rate of chicks that hatched later in the season (2019). When chicks survive their first year, they have an increased likelihood of survival since adult godwits have higher survival rates than chicks (Alves et al.,
Because of the increased rates of survival year to year associated with early breeding and hatching, the climatic changes that drive shifts in phenological timing may be contributing to population growth of godwits; the godwit population has grown by a factor of 10 since the early twentieth century (Alves et al., 2019).

Along with growing in number, black-tailed godwits are expanding their breeding ranges across Iceland’s coast to inhabit more lowland breeding areas (Alves et al., 2019). This may be tied to the increasing population, since a dramatic increase in the number of godwits could crowd existing habitats and require expansion to new areas. Alves et al. (2019) and Gunnarsson et al. (2006) have established that migrating godwits consistently arrive in older breeding sites (colonized before 1970; Gunnarsson et al., 2006) first, and as the season progresses, later arrivals fill in the more recently (since 1970; Gunnarsson et al., 2006) colonized breeding grounds.

“Old” and “new” breeding sites are not of equal quality: Gunnarsson et al. studied the differences between historically and recently colonized godwit breeding sites and found that more recently colonized areas are of much poorer quality than those sites godwits have used for over fifty years (2005). Black-tailed godwits thrive in marsh habitats, where invertebrate prey is abundant and there are plenty of pools of water (Gunnarsson et al., 2005). Historically colonized sites tend to be these preferred marsh habitats, while new sites are predominantly birch bogs with fewer pools and less invertebrate prey (Gunnarsson et al., 2005).

Black-tailed godwit individuals tend to inhabit the same breeding grounds year after year, in accordance with a characteristic known as “philopatrizm”; this tendency holds for both their wintering grounds and Icelandic breeding grounds (Gunnarsson et al., 2006). Because of their philopatric patterns, the same godwits may be experiencing high quality habitats every year, while their late-arriving counterparts inhabit low quality breeding sites every year, potentially compounding the imbalance in breeding success (Gunnarsson et al., 2006).

Older habitats contribute to godwit breeding success through more than just habitat structure; they also tend to experience warmer temperatures earlier in the spring, which allows for more rapid vegetation growth (Alves et al., 2019). Because godwits lay their eggs in tall vegetation to conceal their nests from predators, increased vegetation growth in the early spring allows for earlier and more successful nesting (Alves et al., 2019). Additionally, the warmer temperatures may increase food availability early in the season as well as the godwits’ ability to
find it, and reduce the amount of energy needed to maintain body temperature so that chicks may grow more efficiently, increasing survival (Alves et al., 2019).

The early arrival, breeding, and hatching that is enabled through higher temperatures may reduce competition for godwits and contribute to their breeding success through temperature, vegetation, and resource advantages (Alves et al. 2019); however, the resulting population growth is not always to the birds’ advantage. Black-tailed godwits that arrive later in the breeding season are increasingly pushed into lower-quality habitats, where they are among less fit individuals and there is an imbalance in the male-to-female ratio (Gunnarsson et al., 2005). For this reason, Gunnarsson et al. have proposed that a “buffer effect” may soon hit godwit populations and stem the current population growth, because the increasing number of godwits in low quality birch bog habitats will have less breeding success (2005).

Godwits face another challenge as land-use change continues to spread across Iceland: increased drainage and cultivation of wetland habitats disrupts breeding sites and eliminates pools on which wading birds like the black-tailed godwit rely (Jóhannesdóttir et al., 2017). With intentions for continued expansion of farmlands, though resulting mosaic habitats can suit the preferred habitat structure of breeding waders well, godwits may face further disruption of ideal breeding sites and management of vegetation that threatens effective nest protection (Jóhannesdóttir et al., 2017).

In conclusion, black-tailed godwits, like Greenland white-fronted geese and northern wheatears, are experiencing shifting climatic conditions and changes to their familiar habitats. As temperatures warm, and continue to increase at different rates in different regions, migratory birds in Iceland will experience shifts to the structure of vegetation and food availability in their habitats, as well as to the climatic conditions they experience upon arrival. These changes are driven by human actions, both in the form of greenhouse gas emissions and in the form of wetland drainage and agricultural expansion. Some seem to increase the flexibility of timing for species like the Greenland white-fronted goose, while others present challenges to breeding success and survival. Regardless of the apparent effect, migratory birds will likely need to continue to shift the timing of their migration, nesting, and breeding in order to survive in these changing environmental conditions.
Literature Review:

Accessible science through creative communication

“Communication...is about building understanding between different perspectives. To do this, we cannot assume that objectivity will be appealing or that scientific evidence will speak for itself.” –Sara ElShafie (2018).

Studies on “mental models” in topics related to climate change reveal that the connections people draw between ideas to create a web of context for a given topic differ between experts and non-experts (Carlton & Jacobson, 2016). When taking into account that learner understanding and interest relies on communicators establishing context for new information (Bruine de Bruin & Bostrom, 2013; ElShafie, 2018), the importance of this observed difference in mental models is apparent. Pearson and Schuldt point out the value in different backgrounds of experience and education in science; while it may be an obstacle to simple communication, the potential for creative problem-solving that is presented by diverse learners working together is well worth cultivating (Pearson & Schuldt, 2015). It is not a hassle, then, but an opportunity, to work towards developing methods of science communication that draw on the values people share (Pearson & Schuldt, 2015) and overlap in expert and non-expert contextual understandings (Carlton & Jacobson, 2016) while recognizing the different learning needs of a broad range of learners.

ElShafie (2018) and Smol (2018) both address the criticism of scientists who have attempted to communicate their work in engaging and accessible formats to increase public interest and understanding. Known as the Sagan effect after scientist Carl Sagan, this criticism is based on the idea that scientists have introduced bias into their work by shaping it into a format so easily understood and broadly interesting that it becomes publicly popular (ElShafie, 2018). Science, though, should not be presented solely as a sterile white-lab-coat practice; to do so misrepresents the process of observing, questioning, and hypothesizing that is the natural scientific method and a practice humans perform daily. To develop engaging methods of communicating science, as long as the resulting communication is carefully built on fact and represents the uncertainties that accompany scientific results, simply extends the accessibility of science to a broader audience and enhances the potential for innovation that Pearson and Schuldt (2015) address. Criticism of creative communication therefore threatens the very accessibility of science (Smol, 2018).
Science communication must undergo repeated processes of review in order to maintain accuracy while assessing efficacy of conveying information (Bruine de Bruin & Bostrom, 2013). Tools such as metaphors and images are used most effectively in careful balance: if a metaphor is catchy but misrepresents or overstates the results of scientific observation, it has the potential to deepen misunderstandings or narrow the interpretation of results (Kueffer & Larson, 2014). Metaphors can undermine efforts to recognize the range of values Pearson and Schuldt discuss as beneficial to advancing scientific efforts (2013); instead, because metaphors often unconsciously tie specific values to an explanation and offer only one interpretation of results, their use can reinforce dominant values and politicize scientific questions (Kueffer & Larson, 2014). The politicization of climate change in the United States illustrates the dangers of this issue, and shows the importance of selecting communication methods, since as Kueffer and Larson point out, the method of communication can affect the crafting of responses (2014).

The use of images in environmental communication, especially regarding climate change, present a similar challenge to the use of metaphors. Lewandowsky and Whitmarsh address the importance of using images that represent trends rather than instances in order to more accurately reflect scientific findings (2018). They use the example of a snowball versus a time series of a melting glacier: while a snowball may show the occurrence of snow in one particular moment, it cannot disprove climate change; on the other hand, a melting glacier shown over time illustrates a trend that provides evidence for changes to climate over time (Lewandowsky & Whitmarsh, 2018). Lewandowsky and Whitmarsh see images as a potential mode for connecting with learner experiences, which is important in communication since experiential learning more effectively communicates an issue that does not fit within a learner’s established contextual knowledge than analytic learning (2018). This relates back to the idea of mental models used by Carlton and Jacobson (2016) and provides a framework for making new information compatible with a learner’s existing mental model.

Another danger that accompanies the selection of images to represent climate change-related issues is that some pictures can induce a sense of separation between the learner and the problem: if the images used are all unfamiliar to the learner, it may misrepresent the immediacy of climate change as an environmental concern (Lewandowsky & Whitmarsh, 2018). It is therefore prudent to focus climate communications on local and present issues in order to accurately communicate information and establish a connection of relevance through the
learner’s own experiences (Carlton & Jacobson, 2016). Carlton and Jacobson found through their mental models that local concerns are often most relevant in non-expert thinking on an issue, and pointed out that in order to understand climate change in a way that accurately reflects the immediacy of the issue, it is essential to portray it as current; framing climate change as a problem humans will really only begin to face in the future distances it from among current concerns where it belongs (Carlton & Jacobson, 2016). By focusing on what is immediate and local, it will be possible to draw connections between changes that are happening right now, which can be observed directly, and how those changes may increase into the future.

Priest addresses a change in approach to scientific communication that has occurred recently: “deficit” communication, which focuses specifically on giving learners more information, has been increasingly replaced as a dominant framework for effective communication by “dialogue” communication, which focuses on the manner of communicating with learners (2016, 7). Dialogue communication revolves around interaction between learners (the non-experts) and experts, which increases engagement with the subject material (Priest, 2016, p. 7). While dialogue communication is time consuming and limited, since it generally requires personal interaction to enable an exchange of ideas (Priest, 2016, p.7), it centers the learner in the experience of learning and establishes a personal connection that can serve to strengthen the importance of the information learned.

ElShafie (2018) and Kipnis (2018) offer two methods of communicating information that steer away from the impartiality of deficit communication and engage the learner in a way that is personal, but is perhaps less limited than dialogue communication. ElShafie presents the idea of communicating science as a story, and draws direct parallels between the standard format of a scientific paper and the story arc children learn in elementary school (ElShafie, 2018). In this comparison, the introduction sets the stage for the story, the methods introduce the action until the climax is reached with the results, and the analysis settles the action towards the discussion and conclusion, which represent the resolution of the story (ElShafie, 2018). By crafting a narrative around scientific information, ElShafie says, scientists can convey the context and importance of their work, and why it is interesting (2018). By using the elements of a story, including a plot where a protagonist is confronted with obstacles, and an overarching theme, scientists can “distill” the information they want to convey to a specific audience, and this effort
to communicate the relevant information in a relatable format will engage the audience (ElShafie 2018).

This is not to say, however, that shaping science information into stories requires manipulating facts. Kipnis addresses this clearly when she discusses the communication of science through games (2018). A game often has rewards, incentives, and consequences, and Kipnis makes clear that in a game communicating information from a scientific study, any such outcomes should accurately reflect the responses of variables in the study (2018). On a similar note, the rules of the game should represent natural constraints related to the study; unrelated concepts should not be introduced because to do so would mislead the player’s understanding of the concept (Kipnis, 2018). A similar approach can be taken with storytelling; the obstacles faced by a protagonist should accurately reflect the challenges and constraints confronted in the study, and the stakes of not overcoming these obstacles should represent real consequences in the natural world. While it is important to avoid personifying a protagonist that is not human (ElShafie, 2018), portrayal of species as “charismatic” can spark a deeper interest in learning about a species (CAFF, 2013, p. 154).

Using stories, games, and other creative communication methods in science is a necessary task to extend the accessibility of science to wider audiences. Improved understanding of differing contextual understandings between experts, non-experts, and people of different backgrounds will contribute to innovative methods of communicating and solving environmental problems. Communicators must aim to create learning through experiences, and develop engaging and interactive methods of communication to establish personal connections between learners and science information.

Methods

Literature Review

I conducted two literature reviews in order to inform this project. For the first, on migratory birds in Iceland, I started my research with broad information on birds in the Arctic and then narrowed my focus around the three species I selected: the northern wheatear, the Greenland white-fronted goose, and the black-tailed godwit. I chose to focus on these three species because of the depth of information available on each of them with regard to a variety of environmental factors, and because of their different uses of Icelandic habitats.
The second literature review centered around communication of scientific information, especially related to climate. I investigated methods of communicating climate change through books and studies published on the topic, and looked into creative science communication. My work was informed by previous accounts of creative pieces, especially by sources from the 2018 symposium on “Science Through Narrative: Engaging Broad Audiences” (as published in *Integrative and Comparative Biology*, 58(6); e.g. Kipnis, 2018; ElShafie, 2018) which gathered scientists and artists together in collaboration towards extending the reach of scientific information through creative methods.

*Synthesis and Design*

I mapped out webs of connecting information for each bird species in order to link related findings and expand on inferences (for an example see Appendix C). I used these webs, sketched over a map of Iceland and surrounding areas, to inform the visual and conceptual design of an activity board. These sketches also helped me to identify the environmental variables included in the activity.

*Construction*

Using self-hardening modeling clay and acrylic paint, and relying on reference images, I sculpted and painted multiple small (2-5cm) bird figurines of three species: northern wheatears (6), Greenland white-fronted geese (5), and black-tailed godwits (9). On a 24x36 cm plastic cutting board, I painted a stylized map: I placed Iceland in the middle, with Greenland and the United Kingdom and Ireland on either side. To show that Greenland and the United Kingdom and Ireland were not to scale, I darkened both the land masses themselves and their blue ocean surroundings, leaving Iceland magnified in the middle. Using paper, cardboard, and acrylic paint, I constructed sturdy and movable pieces to represent environmental variables, each with a simple image.

Realizing that the game was not self-explanatory, I developed a set of cards using the same images to depict environmental variables, and wrote a set of instructions and an introduction to the game. Additionally, I created a map and chart for each player to track environmental effects on their species over time. Because I wanted a component of interaction between communicator and learner, I added a submissions box where players can submit proposals for further study, give feedback on the game itself, or offer additional interpretations of the variables and responses at play (for pictures of all game components, see Appendix A).
Testing

In order to assess the comprehension and efficacy of the activity, I ran trial runs of the game and noted potential improvements, such as switching the mode of environmental determination from a coin flip to a dice roll with increasing probability of environmental change over time, to improve representation of climate trends over random weather variability. Observing volunteers trying to comprehend the game helped me understand where I needed to offer more explanation.

Ethics

While developing this science communications project, I was careful not to introduce my own biases into the information I conveyed. The creative method of communication I developed, through a game, required simplification of complex relationships. In representing interconnected factors, I was conscious of communicating associations rather than causal relationships where causality had not been established through scientific study. Thoughtless science communication has the potential to mislead audiences and undermine scientific credibility; I therefore was very careful to base each image and representation in fact, and to convey trends and uncertainties where appropriate. By offering more detailed explanations of variables and associated behavioral changes to species on the cards and charts, I hoped to give the players a more complete understanding of the scientific studies that informed the development of the game.

Results

Through my project, I attempted to establish a context for the information on migratory birds I am presenting that can fit into non-expert mental models while maintaining the accuracy required to align with expert models. I approached this by simplifying the connections between changing environmental variables and the associated changes in migratory bird phenology, demography, and distribution. I recognized the danger of stating causality where none has been established; therefore, the game I created allows the player to observe associations as researchers have done in the studies that informed this project and does not declare causal relationships.

The game I created draws heavily on the principles set forward by ElShafie (2018) regarding storytelling in science, though it tells a story predominantly through actions,
interactions, and responses rather than words (for full instructions, see Appendix B). The player establishes a personal connection with a “protagonist” of sorts through a game piece; this reflects not only ElShafie’s components of storytelling (2018) but also the principles of developing a character identity that guide game design as discussed by Kipnis (2018). The game pieces represent the three species of birds this project focuses on, so a player can select to be either a northern wheatear, a Greenland white-fronted goose, or a black-tailed godwit.

The birds, and therefore the players, confront the obstacles (ElShafie, 2018) presented by human-driven environmental changes, including habitat disruption from land-use change and changes to climatic variables that alter the availability of resources. Following the advice of Kipnis (2018), I ensured that both the obstacles and the consequences of failing to overcome those obstacles (the stakes; ElShafie, 2018) reflected the reality of the overarching theme (ElShafie, 2018) of migratory bird adaptations to environmental change. I was careful to have the only objectives of the game be survival and breeding success, like the objectives of these species in nature. The birds are not competing for resources, since there is not interspecies competition between these three species in nature. Since the sole aim of the birds is survival, successful adaptation results in the player gaining more birds or allows the player to advance migration earlier, while failure to adapt to environmental change costs the player birds or delays migration. These details address the frequently voiced concerns (identified by Smol, 2018; ElShafie, 2018) that creative science communication will introduce bias and aim to influence policy in one direction or another (Priest, 2016, p. 15).

Players determine current environmental conditions by rolling the dice. At the beginning of the game, one player selects the time period during which the game will take place. If the selected time period is before 1970, the probability of experiencing warm springs, increased vegetation growth, and early snowmelt is low (rolling 1-5 maintains standard conditions, rolling a 6 represents the previously-mentioned “abnormal” conditions associated with human-driven environmental change). As time goes on, the probability of experiencing these abnormal conditions increases, so that between 1970-2030 rolling 1-3 maintains standard conditions while 4-6 represents abnormal conditions, and after 2030 rolling a 1 maintains standard conditions, while 2-5 leads to effects of environmental change. The added factor of changing probability through time distinguishes the trends of climate change from the random chance of weather, and also gives the players the option of playing multiple rounds to witness the potential changes in
environmental conditions and associated changes in timing and success for the bird species over time.

The game represents complexity in changing environmental conditions because no outcome is exclusively positive or negative for the player; for example, gaining too many godwits (representing massive population growth) crowds the godwit habitats and may trigger a buffer effect that leads to a decline or stabilization in population size. Early departure from Ireland by Greenland white-fronted geese may seem lucky, unless the ground in Iceland has not yet thawed (which is determined by dice roll). Through these various possibilities, the player can get a sense of the complexity of climate change and how trends of climate change increase the probability of certain outcomes, but do not rule out exceptional years.

In order to make this game especially relevant to players in Iceland and minimize a sense of distance and separation (a concern brought up by Carlton and Jacobson, 2016), I focused specifically on Iceland and centered the island on the game board. Greenland and the United Kingdom and Ireland are depicted on the board to give a sense of broader importance, since migratory birds act as links throughout different habitats and regions of the world, but they are not to scale so that the focus remains locally on Iceland.

The layout of the board mirrors, in some sense, the visualization of a mental model as depicted by Carlton and Jacobson (2016). The squares, where players draw cards, are related to specific environmental variables. They are tied together with the links of the three migration paths of the birds, and in some cases these paths meet at variables of shared importance to two different bird species. Additionally, each player receives a copy of this map detailing the potential outcomes for their bird species based on environmental changes. Not only does this add a level of engagement with the game, since players can then anticipate certain outcomes, but it also increases comprehension of the interconnected variables at play.

By representing the connections between human-driven environmental changes and changes to the physical forcings (phenology, distribution, metabolism, demography; Lewandowsky & Whitmarsh, 2018) of three migratory bird species in Iceland in the form of a game, I aimed to create an interactive format for communicating a synthesis of scientific information. As Priest points out, science is thought to be most effectively communicated through dialogue rather than through a simple presentation of information (2016, p. 7). There are limits in space and time to communicating science information through dialogue personally, and
the format of a game may allow for a similar manner of interactive engagement with the material. Movable game pieces, and the connections shown between different environmental variables and associated obstacles faced by the bird populations give feedback similar to that of a conversation as players engage with the game; they may be left to figure out different possibilities of their own. Priest discusses the value of engagement in a back-and-forth dialogue between scientists and the public (2016, p. 7), and Carlton and Jacobson address the importance of allowing interviewees to first exhaust their own connections before asking specific follow-up questions in interviews to inform mental models (2018); following these two principles, I decided to create a submissions box to accompany my final product. This box will allow players to fully engage with the game, knowing that their learning can continue past their experience with the game. The submission box is intended for follow-up questions, proposals for further research, and feedback on the game itself to continue to improve learning about migratory bird species in Iceland.

Analysis

The design of this game represents a balance between presenting thoroughly accurate information from scientific research on bird populations and crafting a simplified product that allows players to grasp the basics without getting overwhelmed. In her book *Communicating Climate Change*, Priest refers to this balancing act as “satisficing,” a term that encompasses the idea that simplifications necessarily sacrifice some of the complexity in relationships, but that a certain extent of such sacrifice is necessary to convey information in a digestible format (2016, p. 5). This is certainly true of my final product: while I was careful to not explicitly declare causality of any relationship in which it had not been established, the simplifications I found necessary to create an accessible design may imply causal relationships where causality has not been supported. I attempted to mitigate any misunderstanding by providing details of associated changes on the cards and maps players receive.

Priest also addresses the limitations of person-to-person communication, an ideal mode of getting information across to a learner in a comprehensible manner (2016, p. 8). The format of this project—a game—allows for reproduction and therefore has the potential to become widespread, reaching learners who may not have access to personal communication with experts on the topic of migratory birds in Iceland.
This game would be best used in a school or museum, especially in Iceland because of the local ties (Carlton & Jacobson, 2016) formed through regional focus of this project. In an educational environment, this game can either be used as a brief overview of some effects of environmental change on three of Iceland’s migratory birds, or as an introduction or supplement to improve comprehension of more in-depth study. To fully understand the best uses of this game would require further studies, using this game in educational settings on its own or in parallel with other materials. It would also be wise to test its efficacy in communicating the basic connections it aims to convey by comparing it to reader comprehension of a written overview like the one provided in the literature review section of this paper.

In representing changes to environmental obstacles for three migratory birds in Iceland, the structure of this game does not frame human-driven climate and land-use change as entirely a threat; this is both a strength and a weakness of this game. It is a strength because it is true that climate change and other environmental change are complex issues that affect different species and habitats in varied ways. However, this framing of human-driven environmental changes may weaken the truth that climate change and land-use change are extreme threats to the survival of many species.

An expansion upon this game could provide a more thorough understanding of this complexity: the format of this game has the potential to be applied to the migratory patterns and changing environmental obstacles faced by other migratory species across the globe. Similar games could highlight other regions on separate boards and add more species to existing boards, and could even be placed alongside this board of Iceland to broaden understanding of the effects of environmental change on migratory species. This expansion could also clarify any misunderstanding arising from the scale manipulation on the map, since each board would clearly highlight a specific region.

Due to the limited time-frame I had to complete this project, my game design was built around concepts I assumed to be widely accessible. Study into what people already know about migratory birds and environmental change, for example by using the mental model interviewing framework provided by Carlton and Jacobson (2016), would better inform this project so that the information provided could fit into common contextual understandings of this topic. This strategy could be used in the development of similar games for other migratory species. Additionally, future efforts could go towards modifying the existing game based on feedback
from players and follow-up studies on player comprehension. A method of providing feedback is already built into the game in the form of a submissions box. This is intended to give players an opportunity to ask questions, propose further studies, and offer suggestions for improvements to the game itself. The contents of the submissions box can inform future design, and would be especially useful in a museum or classroom setting, where follow-ups to questions or studies could be posted publicly on a board or website, and may lead to enhanced learning through personal communication between learners and experts.

**Conclusion**

Informed by extensive studies into migratory birds, this project has addressed relationships between human-driven environmental changes and the migratory behavior and population dynamics of three migratory bird species in Iceland: the northern wheatear, the Greenland white-fronted goose, and the black-tailed godwit. My goal throughout this project was to synthesize this information in an interactive and accessible manner. Guided by principles that aid storytellers and game designers in creating engaging material, I developed a game that allows players to form a personal connection with a single species of bird and anticipate changes to its breeding and migratory success as it faces changing environmental obstacles. The format of this game can be easily applied to communication about other migratory species around the world and their interactions with environmental change.

A game is an experiential form of learning, making it comprehensible to people with diverse contextual backgrounds, and the simplifications employed in creating it condense information so that it is digestible while reflecting scientific accuracy. Interactive forms of learning like games can supplement formal scientific research and provide a basis for deeper learning. Communicating science through the reproducible format of a game allows this learning experience to spread broadly, since it does not confront the obstacles of space and time that limit in-person communication.

My project can inform future creative communication of species interactions with changing environmental conditions, especially for other migratory species. Expansions on this concept could investigate specific mental models of their target audiences to best inform the design of the game. Studying player comprehension of the existing game could also provide a
useful basis for improving representation of the ways in which migratory species interact with human-induced changes to their environments.
References


Appendix A: Game components

Figure 1: Game board.

Figure 2: Environmental variables.
Figure 3: Bird figurines, from left to right: Greenland white-fronted goose, northern wheatear, black-tailed godwit.

Figure 4: Decade cards, detailing probability of rolling for “standard” or “abnormal” variables.
Figure 5: Map and chart for black-tailed godwit.
Figure 6: Map and chart for Greenland white-fronted goose.
Figure 7: Map and chart for northern wheatear.
Figure 8: Cards 1-4.
Figure 9: Cards 5-8.
Appendix B: Instructions

**INTRODUCTION:**

Anthropogenic (human-driven) changes to the environment occur through climate change and land-use change, resulting in altered habitats and conditions for species across the globe. Migratory species experience these changes in multiple locations, since they travel seasonally between different habitats. In this game you will investigate the relationships between the migratory patterns and population dynamics of three migratory birds in Iceland as they experience increasing intensity of environmental change over time.

**INSTRUCTIONS:**

- **Set up:**
  - Place snow (❄️) on Iceland. Leave all other environmental variables to the side.

- Each player should choose 1 species of bird and place 1 figure of that species on the first matching color circle or square to the far right of the board. All players should start with an additional 2 figurines of their chosen species (off the board), and should receive the matching map and chart of outcomes for their species.

- The youngest player should choose a decade between 1900 and 2100. Play will continue with respect to that decade through the round. See decade cards for resulting dice rolls.*

*Note: The increasing probability of rolling for "abnormal" conditions through time represents trends of environmental change. While "outlier" years always occur against the trend, generally temperatures are increasing, and use change is expanding, and temperate regions will experience increased precipitation.

- **Play:**
  - Players take turns advancing 1 space at a time. Wheatcar goes first. When a player lands on a square, that player should follow directions on the corresponding numbered card to determine environmental conditions, either by rolling dice or observing factors already at play. Then, all players should examine their charts for any associated changes for their species. Once an environmental variable has been determined, it remains in play for the rest of the round. Play multiple rounds in different decades to notice the effects of environmental change over time!

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Figure 10: Game instructions.
Figure 11: Sketches and webs used to synthesize information.