"How's Shelby the Turtle today?" Strengths and Weaknesses of Interactive Animal-Tracking Maps for Environmental Communication

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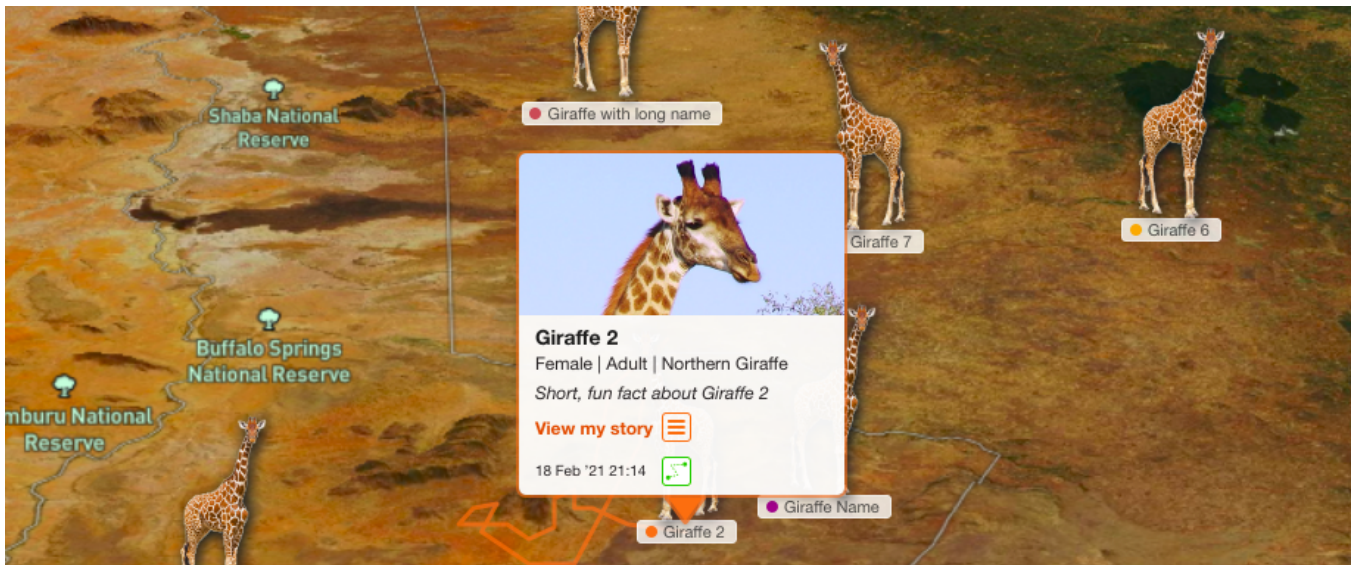**Kurtis Heimerl**
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Figure 1: Example design mockup for an interactive animal-tracking map

ABSTRACT

Interactive wildlife-tracking maps on public-facing websites and apps have become a popular way to share scientific data with the public as more conservationists and wildlife researchers deploy tracking devices on animals. Environmental organizations engage with the public for a variety of reasons: to raise awareness of environmental causes, build relationships with potential partners, and encourage people to take political and personal actions. However while there is a large body of work comparing different media strategies for environmental communication goals, the effectiveness of interactive data visualizations for these purposes remains unclear. This work examines the strengths and weaknesses of interactive wildlife-tracking maps for environmental communication. We interview conservationists about their aspirations for using these maps with their own data, and conduct a study gauging lay users' reactions to different designs. Many conservationists aspire to create deep, immersive user engagements with these maps—letting users relate to data-driven stories about individual animals and freely explore the nuances of the tracking data. Our findings show potential for the most highly-motivated users to deeply engage with these

data and stories, but more casually-interested audiences struggle with the maps' complexities. However for casual audiences, wildlife tracking maps can still superficially but effectively showcase the organizations' work to protect the species; perhaps inspiring hope for their future, attracting audiences to other communication channels to learn more, and adding to the organizations' credibility. Following these insights, we present a set of design considerations for further development of similar wildlife-tracking map applications; emphasizing their needs for user onboarding, context for data interpretation, and integration with relatable media.

KEYWORDS

wildlife tracking, environmental communication, data visualization

1 INTRODUCTION

Wildlife researchers and conservation institutions need to communicate with the public for a variety of reasons: to promote awareness of their projects, raise awareness of environmental issues, build political support, raise funds, and encourage environment-friendly behavior [63]. Similarly, many organizations and conservation parks look to new digital media to provide immersive natural experiences while avoiding the environmental harms of overtourism [7, 44]. To these ends, many environmental organizations are experimenting with interactive data visualizations in their outreach efforts [1, 72], showcasing data from their research projects and conservation operations. These organizations aspire to provide more interactive, engaging experiences than reading static articles, let viewers see the data and science behind environmental research claims, and allow users to freely explore for personally motivating information.

Interactive maps visualizing wildlife tracking data have become popular over the last decade as technology improvements allow wildlife researchers to gather vastly greater quantities of positional data for individuals and populations [22, 51]. Dozens, perhaps hundreds, of interactive maps featuring wildlife-tracking data have been published to the web (Fig 2). The most common designs show animals' locations with markers and use lines to trace their locations over time (Fig. 1). They also commonly incorporate text, pictures, and videos that give context to the data, showing information about the animals and research projects (Fig. 3). However, these interactive visualizations' effectiveness remains unclear for environmental communication goals, and they are often expensive and time-consuming for organizations to produce [3, 6].

The field of *environmental communication* emerged around the 1960's to examine media strategies for improving environmental outcomes. This large, multidisciplinary body of work addresses the challenge from a variety of angles, such as the psychological effects of emotion on environmental behaviors [12, 58]; and the effects of various advertising strategies on voters in environmental policy referendums [40]. Meanwhile, scholars of interactive data

visualizations have characterized the affordances that distinguish them from other media like print and video [62, 66], but interactive visualizations' unique strengths and weaknesses remain unexplored in the context of environmental communication.

Addressing these questions, this paper presents formative design work for public-facing wildlife tracking maps in collaboration with EarthRanger (a geospatial domain awareness system for parks and protected areas), the Giraffe Conservation Foundation (GCF), and the Atlantic White Shark Conservancy (AWSC); as described in Section 3. First we contextualize this work with a review of research on environmental communication and interactive data visualizations, and explore the designs of existing wildlife tracking map applications (Section 2). We examine conservationists' aspirations for these interactive visualizations via focus groups with GCF and AWSC (Section 4). Then, we investigate lay audiences' experiences of these maps with a qualitative user study (Section 5).

We contribute a set of design considerations for future animal-tracking maps in Section 7. Most of our study participants struggled to find meaning in the maps' geospatial data, so special attention is needed to integrate media that explains the tracking data and environmental context. Highly-directed introductory sequences can help to "onboard" new users, helping them quickly learn to interpret the data and navigate the interface. Additionally, incorporating real-time, frequently-updated tracking data opens up an additional affordance to continuously engage users in the long term, encouraging them to check back for updates and develop connections to their favorite animals.

Synthesizing our results, in Section 6 we explore the strengths and weaknesses of wildlife-tracking maps for various environmental communication goals, with implications for other types of interactive data visualization. These interactive maps can excel at providing immersive, open-ended experiences for the most highly-motivated audiences—such as AWSC's dedicated "sharkies" who enthusiastically follow their social media— allowing them to connect with stories of individual animals and deeply explore the data. However, these interactive maps struggle to meaningfully engage more casually-interested users due to their complexity in today's era of fast internet browsing and short attention spans; and often fall short of the immersive, relatable experiences that conservationists hope for. Other more-relatable media like short videos can be more effective for engaging these audiences. Though casual users most-often will not deeply engage with the maps' data, they show potential to begin conversations with new audiences through other communication channels as many participants voiced that the maps made them want to learn more. They can help conservation organizations establish credibility by showing the scope of their work and showing that their missions are evidence-supported. Wildlife-tracking maps can also still potentially make an emotional impressions on casual audiences by illustrating the efforts to protect each species, perhaps inspiring hope for the future.

2 RELATED WORK

In this section we contextualize our work by discussing the popular public-facing wildlife-tracking maps developed by conservation organizations, and relate them to research on environmental communication and interactive data storytelling.
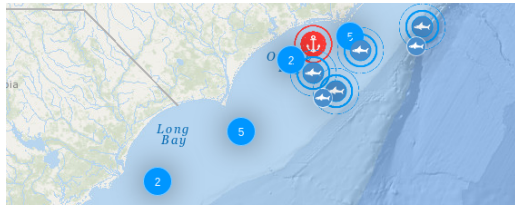
(a) Icons show individual sharks. The animals with live, real-time incoming data are marked with a radial "ping" animation. The red marker shows the current location of a research vessel.
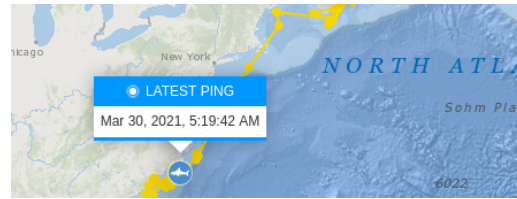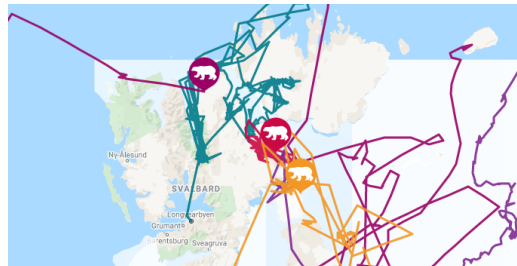

(b) Users select one shark at a time to see the vast distances it moves up and down the coast. Each transmission is marked by a dot, and users can mouse over for timestamps.

The *OCEARCH shark tracker* [55] maps hundreds of sharks, many in near-real-time. © OCEARCH

(c) The user starts with a map of WWF's tracking projects, and can click icons for information about each project.

(d) Zoomed into one project, the map shows GPS tracks for a few individuals alongside text and media about the research.

The *WWF Wildlife Tracker* [27] showcases several of the organizations' tracking projects. © WWF
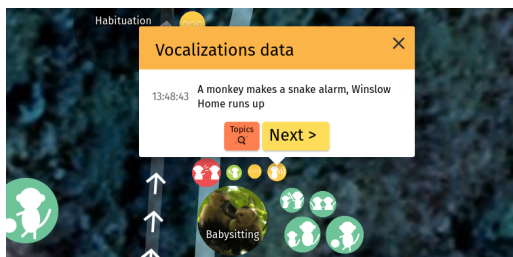
(e) *How to Be A Monkey* shows a day of behavioral data for just one individual plotted on its GPS track. The interface directs the user between points-of-interest with a "next" button [26].
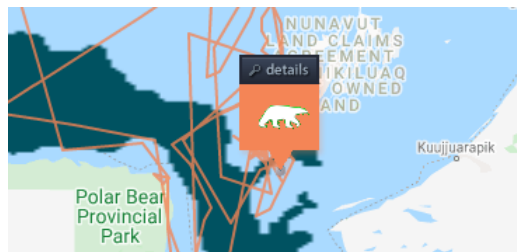
(f) *Polar Bears International*'s tracker [36] animates the bears' movement in response to the changing ice coverage, shown in dark blue [36]. © Polar Bears International
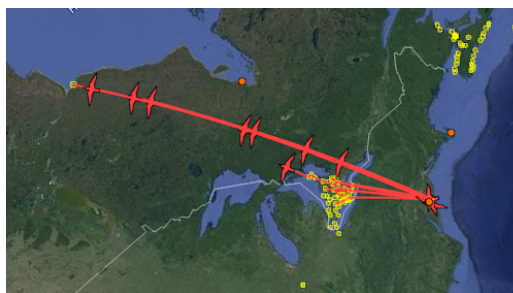
(g) The *MOTUS tracking system*'s website [69] shows migration patterns by animating hundreds of individual icons. © MOTUS
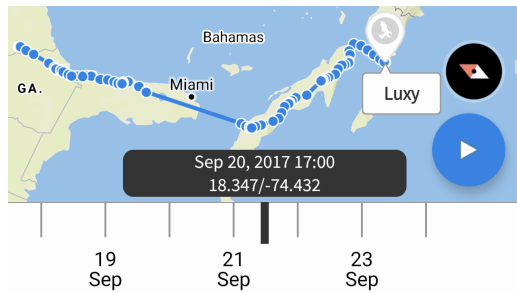
(h) Movebank's *Animal Tracker* app [35, 52] lets users animate animals' locations by dragging a timeline widget. © Movebank

Figure 2: Selected screenshots from wildlife-tracking apps and websites illustrating a variety of designs for data presentation and user-interaction modalities.

2.1 Wildlife tracking

The past decade has seen a monumental increase in wildlife tracking projects, and conservationists have amassed vast quantities of positional data. For example, the popular animal-tracking-data repository Movebank grew from 61 million records in 2014 to 2.4 billion in 2021, and currently gains 3 million new records every day [51]. This expansion has mostly been driven by cost reductions and technology improvements including cheaper tracking devices, improved battery life, cheaper satellite communications, and the advent of LoRa and Sigfox networks. Tracking technologies continue to progress rapidly, with innovations like improved transmission frequency and battery life, increased device lifespans (to minimize disturbing the animals for replacement), and trackers with new additional capabilities like acoustic sensors, cameras, and accelerometers. There are now a variety of well-developed use cases: conservationists employ tracking systems for basic behavioral research [38], advocacy to protect ranges and migratory routes [29], anti-poaching security and monitoring [70], and promotion of human-wildlife coexistence [67, 74].

All such tracking data mainly consists of geographic coordinates paired with time stamps, but the data still has considerable heterogeneity among projects. There is wide variation in projects' time resolutions—for example, underwater or dense jungle environments have fewer transmission opportunities, whereas security applications require data much more frequently. Larger animals can carry bigger batteries. Ethical and health considerations also contribute to the variety in tracking system designs; e.g. elephants cannot use sub-cutaneous trackers because they cause health issues.

2.2 Wildlife tracking maps

Public-facing wildlife-tracking maps have become a common fixture online and in mobile app stores as more organizations seek to share their data with the public for education, outreach, fundraising, and political advocacy. Parks, research labs, and NGO's commonly feature their animal tracking maps prominently on their websites and promote them heavily via social media and press releases [2, 15, 20, 54].

Nearly all such websites share a core set of features: the locations of animals are plotted as markers on a map, and lines show the trails of their previous locations (Fig. 2). The maps incorporate prose, pictures, and videos in a variety of ways (Fig. 3) to contextualize the data, explain the purpose of the research (Fig. 3b), and give information about individual animals (Fig. 3a).

Wildlife tracking maps vary significantly in the ways that users can interact with the data. Some interfaces direct the user around a "guided tour" of points-of-interest (Figs. 2e, 3d); some show the user vast quantities of data to explore with minimal direction (Figs. 2a, 3c); and many find a middle path between these two approaches, guiding the user through curated sets of data where they can drill down to interesting examples as they desire (Figs. 2c, 2d, 2f). Map designers combine various strategies to avoid visual clutter, like using icons to represent clusters of individuals and showing only one individual track at a time (Figs. 2a, 2b). Additionally, the maps employ a variety of portrayals and interactions for the data's temporal dimension: some show the animals' movement over time with animations (Figs. 2f, 2g), many show timestamps under a tooltip

for each individual transmission (Figs. 2b, 2e), and some provide controls for time manipulation (Fig. 2h).

These websites and apps are designed with a variety of foci and messaging, but a few common themes prevail. Many focus mainly on the researchers and conservation projects, describing their purposes, showcasing the organizations' work, or commonly telling stories about how each animal was tagged. In one example, *Into the Okavango* mapped a month-long research expedition live as it happened [54, 71]. Other maps focus their narratives on the animals themselves, trying to personally connect with the user (Fig. 3a). Some maps focus on threats to a species, stressing the need for conservation efforts (Figs. 2f, 3d); for example, Polar Bears International shows the bears' movement over changing ice coverage to show their vulnerability to climate change. Additionally, many of the websites provided worksheets and curricula for classrooms, teaching students to analyze and interpret the tracking data and learning about the underlying conservation issues [14, 50].

2.3 Environmental communication

Environmental communication studies the various ways individuals, corporations, politicians, environmental organizations, journalists, and other groups attempt to influence the policies that affect our planet's health. Fundamentally, the field explores media strategies for culture change: starting from an idea that nature is something to dominate, and moving towards a notion of nature as something that we need to share for our own survival. Many attribute Rachel Carson's 1962 book *Silent Spring* as the the fields' beginning, whose vivid and provocative depiction of pesticides' environmental harms brought widespread public attention to environmental issues and led to new regulations in the USA [13, 63].

Scholarly research on media, communication, and the environment developed into the 1970s and subsequent decades, shaped by the key environmental issues of each era, and influenced by foundational early works like Anthony Downs' 1972 study of the environment as a social problem [21], Harvey Molotch and Marilyn Lester's 1975 study of news reporting following a major oil spill [47], and David Sachsman's 1976 study of source influence [59]. Developments in the 1980s focused largely on the media's impact on nuclear power narratives [33]. Recently as climate change has become the main environmental issue in the media, research has focused on building consensus towards large collective actions.

Through the 1990s and 2000s, environmental communications research continued to grow in relevance as university professors in the United States dedicated course material to environmental communications analysis. These decades also marked the rise of international environmental communication associations and societies, like the International Association of Media and Communication Research (1988), The Society of Environmental Journalists (1990), and the Science and Environment Communication section within the European Communication Education and Research Association. The International Environmental Communication Association formed in 2011, working to broaden the global cache of environmental communications beyond the United States and Europe [33]. Today, the study of environmental communications plays a pivotal role in advancing equitable ecological policies worldwide.

2.3.1 Environmental communications and best practices for real-world impact. As the academic discipline of environmental communication developed, conservation practitioners look to harness the lessons learned to promote societal or behavioural change and maximise conservation impact.

Emotions. Emotions strongly impact audiences' attitudes towards environmental issues and their willingness to take action [75, 76], and there remains an open discussion on the long-term effects of positive and negative feelings. For example, anxiety around environmental issues can cause people to seek more information [34], and many campaigns try to motivate behavior change by evoking "eco-guilt" and "eco-shame" [46, 48].

However, newer work increasingly focuses on positivity amid an emerging consensus that decades of scare tactics have done more harm than good. Audiences disengage with environmental topics when they feel hopeless [34]. Many environmental communication efforts thus deliberately seek to cultivate hope for the future—hope and other positive emotions can motivate audiences as strongly as negative ones [56, 76]. In today's political landscape, practitioners commonly avoid using controversial terms to avoid scaring audiences away from uncomfortable topics and increasingly drive positive narratives that emphasize progress and solutions [37, 41].

Continuous conversations. Ongoing, continuous conversations are important to sustain attention for environmental issues and build consensus towards collective actions. Environmental issues tend to move slowly—rarely the urgent, pressing issue of the day—and are prone to slip out of the mind. Communication practitioners have long worked to repeatedly bring them back to public attention [10]. The media's *"issue-attention cycle"* complicates this work, whereby public attention rarely stays sharply focused on one issue for long before moving on, unresolved, to the next issue [21].

Ongoing conversations play an important role towards building consensus and taking collective actions. For example, the 2020 Yale Climate Opinion Maps [42] show that most Americans believe that global warming is happening (72%) and support regulation of CO2 as a pollutant (75%), but very few hear about global warming at least once a week (25%) and most rarely or never discuss it (64%). These results show there is not an issue with consensus on climate change in the United States, but rather the problem is a reluctance from Americans to discuss or take action on the subject.

Recent environmental communications work explores media strategies to open spaces for such conversations. For example, a 2019 case study analyzed Twitter data to show the importance of online interactions between water professionals, activists, and the general public to construct a consensus around new paradigms of water management [8].

To this end, environmental organizations seek to build lasting relationships with their audiences, continue conversations, engage people over social media, and show them how to get involved. Communication practitioners stress the importance of knowing the audience in depth to tell stories they relate to [37, 41]. Organizations can additionally use interpersonal communication strategies to make science communication more relatable and effective, encouraging conversational engagement using elements like selfies and first-person pronoun-rich captions [43].

Relatability. Relatability has been central to environmental communications for decades, as audiences generally respond much more strongly to relatable media [31, 33, 37]. For example, a study that measured participants' reactions to polar bear messages found that participants were more likely to donate money when presented with empathetic portrayals of bears harmed by climate change, and found no benefit to messaging with a more objective approach [68]. Telling stories is critical: the aphorism *"one death is a tragedy, a million deaths is a statistic"* is especially true in this case.

Practitioners have recently began a shift to human-centered and place-based stories, instead of centering a particular issue [37]. Stories about familiar places resonate more strongly than vague ideas and far-away lands, and practitioners increasingly recognize the important role of local media [30, 37, 61]. Some of the most successful recent efforts have utilized human-centered stories [31, 37], which can be especially effective in communities that are skeptical of environmentalism. For example, it is difficult to draw attention to the negative effects of climate change on shellfish populations, but telling stories about dying fishing communities provokes emotion and draws attention. Human-based stories are some of the most tangible; they are a real thing that you can see today.

Connection to nature. A long thread of research addresses *connection to nature* as a catalyst for pro-environmental actions. Natural experiences help to cultivate this feeling, but as urbanization and industry make us less connected to nature than ever before, can media help to re-connect us? Studies with films and virtual reality have yielded mixed results [5, 9] and the extent to which this is possible remains unclear. For example, can we digitally re-create the experience of a safari? This remains an important question for parks and wildlife conservancies as they look towards virtual experiences to reduce their dependency on tourism and its ecological harms [32, 39].

2.4 Data visualization and narrative

This work also draws from research on interactive data visualizations for journalism and storytelling. These media have surged in popularity over the last decade as more news articles incorporate interactive elements and designers create immersive experiences centered around the data visualizations themselves. Compared to purely-linear narratives, these interactive data stories can allow users to explore on their own, verify claims, and ask their own questions of the data [62, 66].

However, recent work has shed light on interactive visualizations' limitations as storytelling media. Despite the field's initial excitement, recent discourses have noted their often-underwhelming user engagement and debated their value. For example, around 85%-90% of viewers do not engage with interactive graphics on New York Times articles [3, 45]. Published usage statistics from popular interactive data articles have shown that visits are often short, with most users spending under two minutes [16]. Designers need to consider that users often do not have time to explore interactive visualizations in depth, their levels of motivation vary substantially, and the visualizations' user interfaces are often not self-explanatory enough [6]. There has been significant controversy and debate about interactive data visualizations' effectiveness for
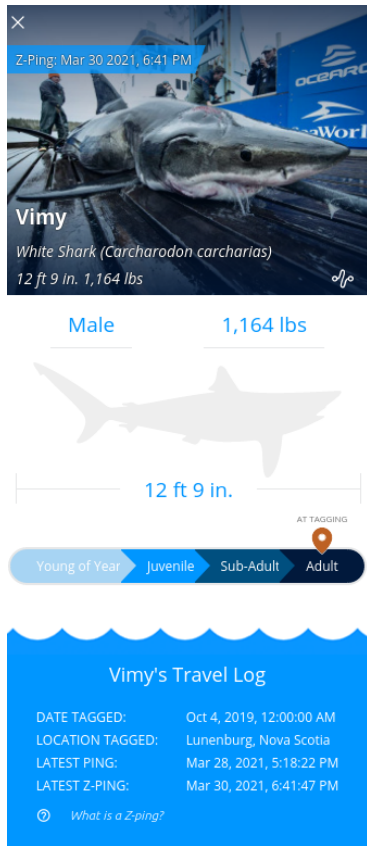
(a) *OCEARCH Shark Tracker* [55] shows individual photos of each animal with biographical metrics and a short paragraph about how it was tagged. © OCEARCH
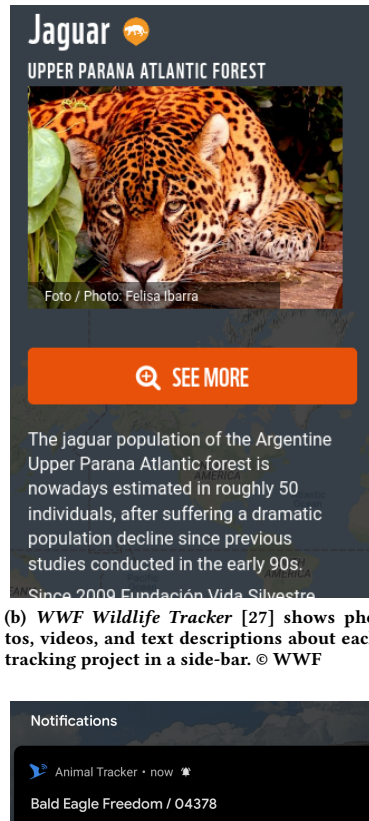
(b) *WWF Wildlife Tracker* [27] shows photos, videos, and text descriptions about each tracking project in a side-bar. © WWF
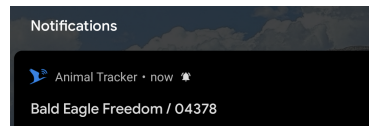
(c) Movebanks' *Animal Tracker* [35, 52] sends mobile notifications with news about animals. © Movebank

(d) *Elephant Story* [65] features a long-form written article and a map that animates to show different data as the user scrolls through the story. © Save The Elephants

(e) *How to Be a Monkey* [26] shows text popups, pictures, and videos describing monkey behaviors interspersed with behavioral data markers on the map.

Figure 3: Selected screenshots from wildlife-tracking showing various common design patterns for integrating contextual media and text with wildlife tracking data.

storytelling and journalism, and whether they are worth their considerable expenses and effort to make compared to other media like articles or videos.

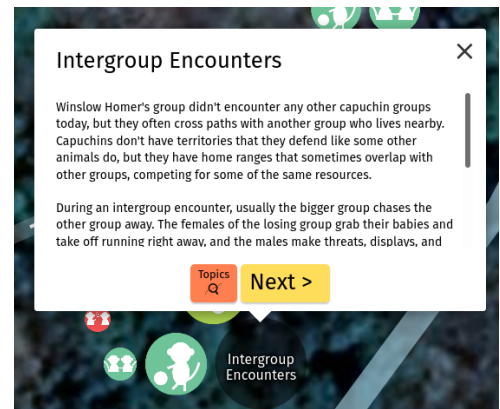However, while interactive data visualizations often engage a more narrow audience than other digital media, they can excel for allowing the most-motivated users to dig deeper [4]. Design patterns have emerged that combine different narrative techniques and feature different degrees of direction and interactivity for the user, including some with linear, directed paths through the data; "random access" interfaces that do not direct users into any particular path but encourage them to explore freely; and "choose your own adventure" structures where users select a path from many options [62, 66]. A burgeoning community of data visualization enthusiasts is still continuously developing new interaction techniques and narrative methods.

3 PROJECT BACKGROUND

We address these open questions about interactive data visualization and environmental communication through the lens of product design, as we work towards implementing a toolkit for conservation organizations to deploy their own wildlife tracking maps through EarthRanger. This section describes our projects' objectives and partnerships to contextualize the formative design work in this paper.

EarthRanger is a secure domain awareness system used by dozens of wildlife conservancies, protected areas, and other conservation organizations to manage their operations. Its core is a software platform that organizes real-time geospatial data over large areas, such as incident reports, locations of tracked animals, locations of ranger and vehicles, and data from various sensors and camera traps. EarthRanger was originally developed for anti-poaching security but has since expanded its scope to include ecological monitoring and has found increasing use by trans-boundary organizations other than parks and protected areas. Several conservation organizations

now use it to track animal migrations across vast areas, including our two partners the Atlantic White Shark Conservancy (AWSC) and the Giraffe Conservation Foundation (GCF).

EarthRanger currently has no public-facing component, being designed fundamentally for private-facing use-cases by conservancies. However, many EarthRanger clients have requested a feature to selectively share some of their animal-tracking data with the public to display in their visitors' centers and websites. To this end, our research team has begun developing a customizable extension of EarthRanger to accommodate these communication goals with public-facing wildlife-tracking maps.

Here we briefly describe AWSC and GCF to contextualize and motivate this project, providing them as examples of organizations hoping to deploy these interactive maps.

3.1 Atlantic White Shark Conservancy

The Atlantic White Shark Conservancy (AWSC) is a small non-profit organization on Cape Cod, USA born from a collaboration of academics and local community leaders working to conserve vulnerable white sharks around the cape. After suffering an estimated 73% population decline into the 1970's and 80's, subsequent fishery management plans have recently seen their numbers start to rise [19]. AWSC's mission is to *"Support scientific research, improve public safety, and educate the community to inspire white shark conservation."* As the sharks' numbers increase, AWSC works to increase public awareness for the safety of both the public and the sharks—chance human encounters are becoming one of the sharks' main conservation threats. AWSC concentrates their outreach efforts on Cape Cod where they have developed relationships with local lifeguards, beach managers, government leaders, and schools.

AWSC works closely with the Massachusetts Division of Marine Fisheries who have tagged over 200 white sharks with location-tracking acoustic receivers. The tags are used for basic research on shark behaviors, public safety, and conservation management; estimating the population size and profiling sharks' predatory behaviors. GPS and long-distance data transmissions do not work well underwater because of the radio waves' high attenuation, so it is not possible to get continuously-updated GPS data for the animals. Instead, the researchers use a network of acoustic receivers up and down the coast that log when a tagged shark passes by. This leads to much sparser data than most terrestrial animal-tracking projects.

3.2 Giraffe Conservation Foundation

The Giraffe Conservation Foundation (GCF) is a small organization with 19 staff working for giraffe conservation through strong international partnerships with governments of 16 African countries, park-management organizations, genetics experts, academic institutions, local stakeholders, and large research organizations like the Smithsonian. GCF works through research and advocacy to create more public interest for giraffe conservation and secure government buy-in to increase giraffe's chances of survival. All 4 species face considerable conservation threats; they have lost 30% of their population in the last 30 years and 90% of their habitat in 300 years. One species, the northern giraffe, is down to 5,600 individuals. However, the giraffe's decline has been dubbed the "silent extinction" due to the lack of public awareness, government action, and research.

In support of their mission, GCF has placed over 200 GPS trackers on giraffe across 11 countries with a main goal of scientific research. Little is currently known about giraffe's movements and the distances they cover, which is particularly important for conservation as their habitats are increasingly fragmented by fences and human development. The data allow researchers to investigate the connectivity between different protected areas and collect evidence to strategically advocate for policies that support migration corridors. The large geographic scale of the tracking project allows for examination of behavioral differences in different landscapes; as it currently is unclear whether conservation lessons learned in certain habitats apply to others. Additionally, the GCF uses automatic immobility alerts to investigate when a giraffe stops moving, and sometimes sends a team to investigate.

4 CONSERVATIONIST FOCUS GROUPS

To better understand conservationists' communication goals and their aspirations around public wildlife-tracking maps, we conducted focus groups with staff of two conservation organizations who use EarthRanger: the Atlantic White Shark Conservancy [17] (AWSC), and the Giraffe Conservation Foundation [25] (GCF). Each remote session lasted one hour and included 2-3 members of each organization with our research team. Discussion questions were framed by earlier meetings with the clients, and included their intended audiences, motivations for sharing their animal tracking data, intended user experiences, and other communication strategies. The sessions were recorded, transcribed, and then underwent thematic analysis by the authors. Each focus group participant was then provided with a copy of this manuscript to review for accuracy.

4.1 Motivation for public animal tracking map

Both organizations were excited to augment their existing communication strategies with interactive maps. They each had prior experiences showing their tracked GPS data and receiving strong reactions; and they cited this as a main motivation to share it with the wider public:

> *"You pull the [EarthRanger] app on your phone and show them the movements of a couple of giraffe, and people get really excited and engaged and they love seeing that. You can show and say, look: this is a female and she moves in this really small area back and forth, and her home range is really small. But then this male moves vast distances overnight, and people get really animated and excited about it. So we just wanted to share this excitement with a with a bigger group and really use it to draw attention to giraffe; to our work."*

Each had started using maps in their communications already: GCF had showed animated GIF's of giraffe movements on social media posts with very positive responses. Similarly, AWSC had considerable public interest in their Sharktivity mobile app [18] which maps shark sightings and has been downloaded over 100,000 times.

The conservationists were also motivated by a notion that *"people inherently understand maps"*—that the general public will not

read research papers, for example, but can intuitively see a track on a map and understand how the animal is traveling through its home range to find what it needs to survive. Both groups hoped to keep audiences continuously engaged over time by frequently updating the data; so the map would be different, new, and interesting each time they returned. They all shared a hope that the maps' interactivity and visual appeal would help them broaden their audiences and reach more people.

Additionally, the conservationists simply loved exploring the data themselves and wanted to share their experiences with others:

> *"When I'm not in the field, opening this is a part of my morning routine, and I'll have my cup of coffee and see where the giraffe are. In the absence of actually seeing giraffe in the field, it's just a spark of joy."*

4.2 Communication goals

The conservationists all hoped to inspire an appreciation of the animals, raise a general awareness of conservation, showcase their own organizations' work, and encourage audiences to get involved and engage with them further. They each wanted to boost the public profiles of their animals: raising attention for giraffe conservation, and increasing public awareness of sharks as their numbers recover for both humans' and sharks' safety. Each organization already used a variety of channels for public engagement: photo contests, frequent public talks, mobile apps, websites, and various social media campaigns.

4.2.1 Audience. Both GCF and AWSC hoped to use the public animal-tracking maps to reach new audiences and interact broadly with the general public. Additionally though, they sought new ways to engage audiences who were already highly involved with their organizations: the *"sharkies:"*

> *"There's some people who are just kind of shark groupies. There are a lot of people in the public who are really interested in these sharks and what they're doing, and just want to learn more about them."*

and the *"giraffe lovers:"*

> *"They just love giraffe, they love reading anything we do, they love seeing different things, and they would love seeing something like this."*

Additionally, both specifically hoped that the wildlife tracking maps could be a tool for building relationships with other organizations, researchers, and donors: *"you want to get people interested in your work, because you don't want them only to donate once."* The AWSC, who concentrate their shark outreach programs on Cape Cod, also hoped the interactive website would help broaden their outreach efforts to new places.

4.2.2 User experience.

Visual appeal. Both groups hoped to create an eye-catching experience with the interactive maps and viewed the visual appeal as a key for attracting audiences' attention: *"most people don't want to read scientific reports; they don't want to read long stories; they just want to see something that is visually attractive."* Towards this strategy, they each cited prior success with visual communications before: *"They just eat up a couple of pictures... it's worth a thousand*

words, right?" One participant had previously used mobile apps for public outreach, but thought it would have been more effective if the app were less visually "clunky."

Connecting with individual animals. The conservationists agreed that their most important goal was to tell stories of individual animals and inspire empathetic connections. By providing a window into the animals' lives through their GPS tracks, pictures, and stories, they hoped to use the personal connections as a vehicle to teach users about the animals and their conservation: *"You know, I think of all these giraffe that are tagged... they're all individuals. So they all have their own story. And I think sometimes when you look at the [GPS] track—at least as a scientist—you just want to ask why, right?".* They spoke about this at length:

> *"...just allowing people to get to know these sharks as as individuals. You know, relating to them as animals that have a tough life, that struggle. We have a lot of white sharks that have been hit by boats. They have fishing gear—I was just looking at video footage of one, right before we got on this call, where it looked like it got caught in a gill net and made it out. People don't tend to think of these animals that way a lot of times. "*

Both groups already used animal stories to relate with audiences in their other outreach efforts, and anticipated that people would be eager to see them on the maps: *"Some of these sharks are locally kind of famous, because they've heard about them. We've had sharks strand on the beach and get tags, and then everybody wants to know that shark has come back."* The giraffe researchers also wanted to link directly to certain animals on the map, so they could feature their stories in social media posts.

Additionally, GCF wondered about ways to visualize environmental context, like elevation and protected area boundaries. The giraffe's environments were key to the stories they hoped to tell:

> *"These giraffe are moving across these crazy diverse landscapes, and we're just trying to figure out ways to communicate this to the public to show there's lots of really interesting places that giraffe live... It just seems like a really ripe opportunity for an engaging website."*

Real-time data. Both groups were enthusiastic to use the animals' real-time data to connect with audiences, albeit for different reasons. GCF researchers hoped to engage users with regular scheduled updates about certain individuals, giving people *"some kind of update once a week; they'll get something [like] Simon the giraffe has moved 1400 kilometers in the past 30 days and it's now in this habitat."* They hoped to use these updates to start conversations on their social media; as well engaging with donors as part of their adopt-a-giraffe program, showing how their donation had made a tangible difference. (Similarly, AWSC hoped to use their map for their adopt-a-shark program.)

The AWSC, however, plans to share sharks' near-real-time data for public safety, alerting beach users when sharks are nearby. They already have a phone-tree system alerting lifeguards and surfers to shark sightings, and they hoped their map could also disseminate this information. They hoped to trigger the audiences' general awareness that there could be sharks around if they knew that the data was live: *"if you're here in the summer and the fall, just assume*

that there's a shark somewhere in the vicinity, and you know, consider that when you decide how you're gonna use the water."

4.2.3 User takeaways. Conservationists from both groups waxed at length about the astonishing beauty of their animals and hoped audiences would learn to appreciate them by learning about their complexities and challenges: the vast distances they they traveled, the dangers they face, and their skillfulness. Additionally, they shared the secondary goal of teaching users about their organizations' work and their challenges: *"we want them to see this and be impressed by the scope, and realize... the problems may be more complicated than I imagined."*

Although many people are shocked disheartened to learn about the threats to the animals, the conservationists stressed that they did not want to dwell on doom and gloom: *"We really like to share good news stories, and how the partnerships work that we are engaged in, and how that works well."* They hoped to get users excited about the conservation work, and realize that people are working to figure it out: *"Giraffe are in trouble, but together we can make a difference."*

Uniquely for conservation organizations, AWSC has additional messaging goals around public safety. They work to raise awareness that sharks are often nearby in the water, helping people *"get an idea of where they occur; where the hot spots are,"* and consider the sharks when using the beaches.

Actions. Both groups hoped to inspire users to get involved in wildlife conservation: *"trying to, you know, promote action. Be it more direct engagement with us as partners, or donations, or just asking questions."* They all acknowledged, though, that it's difficult for people to know what actions to take, or to know how to get involved.

Both organizations hoped the maps would make people want to learn more. GCF particularly wanted to use the map to drive users to their website and social media channels: *"What I would hope that they're really interested in, is that they want to read more. You know, like redirecting to GCF's website and actually seeing what's being done on the ground. If that's the progression, I think that's a great end point."*

4.3 Summary of conservationist focus groups

Both groups were excited to deploy public-facing maps with their wildlife tracking data, hoping to create eye-catching experiences that were east to understand, and draw attention to their organizations. They each discussed getting strong positive reactions from showing people their geospatial data before. They felt strongly connected and excited about the data themselves, and wanted to share their own experience with others.

They hoped to use the data to inspire personal connections with individual animals and give the users vivid windows into their lives, helping people learn to appreciate the animals and want to take action. Although acknowledging the difficulty for most people to get involved in conservation, they hoped users would want to learn more about the animals and engage further with their organizations via donations, their websites, or social media. Both groups planned to integrate the maps with their other communication efforts, like telling stories about individual animals on social media and linking to their GPS tracks.

5 USER STUDY

We conducted user sessions to better understand lay peoples' experiences with these wildlife-tracking maps. We sought to understand their likes and dislikes, their experiences navigating the interfaces, and the messages and knowledge they took away.

5.1 Methods

We recruited 10 participants for 30-minute video calls where they explored two wildlife-tracking maps. We then asked them for their impressions of each map and comparisons between the two, explaining their thoughts and reasoning. The purpose of the comparisons was not to evaluate the maps, but rather to solicit more critical feedback. Our questions included which map they liked better, which they would be more likely to use again, which they learned more from, and which made them feel stronger emotions; among others. We sought participants with varying interest levels in wildlife conservation, and recruited them by posting on an email list for college students in environmental management programs, a discussion board for graduate students in evolutionary biology, and a discussion board for computer science students.

With each participant, we showed two wildlife-tracking maps and asked them spend 5-7 minutes exploring each map in whatever way they they wanted. (Five to seven minutes is significantly longer than the median time of 1-2 minutes that web visitors will typically spend [16], but typically less time than the most dedicated users.) We asked participants to share their screens so we could observe their behavior. To diversify participants' responses, the maps were randomly drawn from this list of 4 maps chosen for their markedly different designs:

- *OCEARCH Shark Tracker* [55] (Figs. 2a, 2a, 3a), with an open, fairly undirected interface to explore data for hundreds of individual sharks and a storytelling emphasis on the individual animals;
- *WWF Wildlife Tracker* [27] (Figs. 2c, 2d), with a narrative centered around WWF's research projects, and a more guided approach that lets users explore curated data about several different tracking projects;
- *How to Be a Monkey* [26, 79] (Figs. 2e, 3e), focusing on behavioral data for only one individual, and having a directed interface with a "guided tour" of key data points.
- Polar Bears International's *Bear Tracker* [36] (Fig. 2f), which animates the bears' movements against changing ice coverage.

5.2 Results

Our participants had mixed levels of background knowledge about wildlife conservation. Most cited social media as a main source of environmental news and information; roughly half followed specific organizations like wildlife rescue hospitals or animal sanctuaries, and roughly half mainly saw news shared by their friends. A few participants named newspapers as sources for environmental news, and one read journal articles. Three of the ten participants said they had seen wildlife tracking data before.

5.2.1 User experience. We observed a notable variety in the ways that participants explored the applications. Some focused mainly

on the integrated text and media; some opted to read pages on the organizations' websites before diving into the map; and others looked mainly at the many GPS tracks, usually spending a few seconds on each track.

Some participants voiced that they preferred the sites with modern, more visually exciting designs. Asked which map they would be more likely to revisit, a majority explained that they would choose the one with more data and variety. About half said they probably would not revisit either map: *"Well, I might send them to my 12-year-old cousins."*

Learning curve. Even though the websites generally had well-polished and thought-out user interfaces, most participants spent the first couple minutes clicking around to see how the maps worked and familiarizing themselves with the interface before they could start exploring the data. It took time to understand the many different types of data, controls, and layers of navigation. Most of the participants commented on this: *"The structure is … confusing. There were so many different ways to redirect from the animal;"* and *"I could have gotten a better sense on how to navigate with more time."*

Data interpretation. By looking at the tracking data, most participants noted the animals' large ranges, and sometimes observed that they seemed to have territories: *"this whale has a nice home fjord."* Many complained that the maps were too visually noisy, the data were hard to see, and they lacked context to explain the animals' behaviors. Two described the GPS tracks as "hairballs:" big confusing blobs that were hard to make sense of. Most maps incorporated text and media about the animals, but one participant complained it did not help to explain the GPS data: *"I guess what I got out of it, I think I could have also gotten out of a PowerPoint… I don't think that the actual geospatial component was integrated into the other component."*

Some participants were disoriented by noise in the data: many GPS tracks had outlier points that a familiar researcher would recognize as errors, but confused some users. A few were confused by combinations of new and old data shown together the map: *"…did some of the bears die? Why are they not moving any more?"*

Unprompted, a majority of the participants complained that they wanted to better understand the timescales of the animals' movements: *"I didn't know the time period. Is all the movement for one year or many years?"* Many expressed that the missing time component was key for understanding the animals' stories:

> *"I wonder if there's some way to visualize … how much time he spent here. Like, did he spend months there and then decide to move on? Or maybe he came from the other direction and found that was a good spot and was like 'I'll just stay here?'"*

Several participants wanted to know which seasons the animals were moving, as well as movements by night and day. A few voiced their appreciation of the the Polar Bear Tracker's animations to show time scales. Other example maps showed time data in more subtle ways, but participants were generally unsatisfied.

Notably, while most participants' takeaways from the GPS data were fairly superficial, two of the participants with environmental backgrounds were able to perceive a lot more from the data:

> *"I can see that narwhals like to be closer to the coasts, rather than in the open ocean; and I learned that polar bears travel on both water and land… and [the fish] made a lot of jagged, erratic movements; they stayed in one area and then traveled in a straight line."*

5.2.2 User takeaways. We asked participants if they had learned anything from the maps. Many of the participants were impressed by the large distances that the animals traveled: *"Right off the bat, I didn't realize there were sharks that went literally from Miami to Maine."* A few participants said that they learned more from the integrated media than from the geospatial data itself:

> *"I probably learned more from the first one, just because they had those informational blurbs. So I learned how the monkeys interact with each other, and how they learn to eat by imitating their elders, and how they groom each other. With the second one I learned where each animal is located in the world, but nothing more past that."*

Some appreciated learning about the organizations, research projects, and methodology: "I learned a lot about how tracking animals works… I saw that you get a ping when they come to the surface and data is transferred!?" A few also felt that they did not learn anything, or were not sure what they learned: *"I don't know if I had a specific nugget that I took away, other than these things exist."*

Emotions. Asked what emotions they felt while using the maps, participants responded a variety of ways. Many first said they were just excited to see the animal-tracking maps, this being a new experience for them: "I was just excited to use it… it was a fun thing to volunteer for!" A few felt a new admiration of the animals, especially from seeing how far they traveled. A few remarked that the animals were cute: *"…and I don't know what emotion that is. Like, adoration a little bit maybe?"*

Some participants expressed that the maps made them feel optimistic for the animals' futures, seeing how the organizations were working to conserve them: *"It's nice to know with the WWF that they're doing a lot of work around the world… so that's a little bit of optimism."* One felt sad and frustrated that the animal tracking was necessary. For the polar bear map in particular, some users felt sad for the bears:

> *"I was pessimistic going into the polar bear one… It's nice to see that they're being followed, but I don't know that I felt any worse or better by the end of it."*

A few users, though, did not feel much emotion: *"It was interesting, but I didn't feel anything about the animals."* Also, many expressed disappointment when realizing the data on the map was old, perhaps dampening their reactions: *"it's very clearly not up to date.'*

Relatability. Asked what made them feel connected to the animals and researchers, most participants cited the websites' text, pictures, and videos rather than the mapped data itself: for example, *"I felt like I was getting a ground view… I'm seeing real life pictures, and the videos that the researchers and observers took;"* and *"If you click a specific animal, you can see the scientist or divers installing the devices on them, and you feel more connected to the people behind the tracking."* A couple participants voiced that they felt more

connected when the data was real-time, and they could see where the animal was today. Unprompted, several also exclaimed that it would be fun to adopt an animal and receive continuous updates about it: *"it would be fun if you had a favorite shark or animal!"*

Actions. We asked participants if the maps made them want them to take any actions. Most said that the map did not make them particularly want to do anything, or that they did not know what to do:

> *"I don't really know what I could have done by looking at this. Like, I don't know if these animals are endangered, or what steps I could take. So I feel like it would take a lot of external research on my part to figure out what I could do, if I did feel like I wanted to do anything."*

However, half of the participants said the maps made them want to learn more about the animals and the conservation organizations: *"I honestly don't feel like I need to do anything right now except for learn more about what these projects are. I don't feel like I know enough to make any kind of action."*

5.2.3 Summary of user sessions. Most participants were excited to see the vast distances the animals traveled, and noted that some moved around territories, but struggled to find other meaning in the maps' geospatial data because they lacked context. Most also complained that they wanted to better understand the timing of the animals' movements. Some were excited to see real-time data about the animals and felt more connected when data was recent, and expressed disappointment when data was old. Most participants also felt that they learned more from the maps' integrated text, pictures, and videos than from the geospatial data itself, and felt more connected to the animals from these supporting media.

Many participants were impressed by the animals' long distances traveled, and felt like they learned more about the research and conservation efforts; although some were not sure if they learned anything. Most were just excited to see the map and the animals movements, and some reported other emotions like optimism from seeing the conservation efforts, adoration of the cute animals, and sadness and frustration that the conservation efforts were necessary. Most users did not know what actions to take after seeing the maps though; however many said that they wanted to learn more about the animals and conservation projects.

6 INTERACTIVE DATA VISUALIZATIONS AND ENVIRONMENTAL COMMUNICATION

Here we synthesize our results to examine wildlife tracking maps' strengths and weaknesses for environmental communication goals. Many of our findings are generalizable to other interactive data visualizations, hinging on their unique affordances that allow users to ask their own questions of the data and freely explore [62].

Deepening relationships with dedicated audiences. Interactive data visualizations are most effective when users are highly motivated to explore, willing to overcome the inherent learning curves to take advantage of their interactive affordances. Therefore one of the strongest potentials for wildlife-tracking maps is to meaningfully interact with their most dedicated audiences: their sharkies and

giraffe lovers. These audiences are environmental organizations' champions, and sustaining these relationships is crucial.

The conservationists hoped to provide immersive windows into individual animals' lives—this requires the users to be driven by their curiosity to comb the tracking data for interesting nuances. When audiences are already engaged and already have knowledge about the animals, they also are much better positioned to find more meaning in the maps' data. For example, while some participants voiced that all the GPS tracks looked the same, a couple with stronger wildlife backgrounds speculated excitedly about the animals' behaviors.

Connecting with new audiences. Broadening participation is one of environmental communication's most important goals, but it is significantly more difficult for casually-interested users to have immersive experiences these applications: *'I had a hard time understanding the geospatial component of the map."* Their learning curves present a considerable barrier, especially as typical internet browsers tend to visit for only a minute or two [16]—many of our participants took longer than this just to get oriented with the interfaces and data before they could start confidently exploring. Many participants' main takeaways from the maps did not utilize the interactive affordances; instead they talked more about the pictures and descriptions; and could find only superficial meaning in the data, appreciating the animals' large ranges but seldom more than that.

However, these maps can still serve as a starting point to engage these casually-interested audiences in conservation issues, even while most will not interact deeply with the individual animals' data. Brief visits can still advance some communication goals. Many participants voiced that the maps made them want to learn more about the animals and the organizations. They were still excited to see something stimulating and new. Some were impressed by the large scales of the projects and conservation efforts. Used effectively, these reactions could begin new conversations and relationships with users and serve as entry points for organizations' other communication channels—their apparent potential to begin relationships with new audiences may be one of their key strengths.

Relatability. Most participants reported that the applications' pictures and videos made them feel more connected to the animals and researchers, rather than the GPS data as they lacked the context to interpret it; for example: *"I didn't learn much from the GPS data itself, it was the pictures and stories."* For these casual users, other media like articles or videos can be more effective to create personal connections than dots on a map.

Many animal tracking maps try to achieve relatability by featuring stories of individual animals, but many of our participants found it easier to learn about the research projects than the animals themselves. This opens a door for telling relatable human-centered stories featuring the researchers: explaining why they are tracking the animals, how they use the data, their personal stake in the project, how it can help the animals, and how it can help humans.

Additionally, maps can be particularly strong for reaching local audiences and telling relatable stories about familiar places. For example, white shark sightings already receive a lot of media attention and public excitement on Cape Cod, and AWSC's map can contextualize and localize them for these audiences.

Continued conversations. Because modern environmental problems are so collective by nature and people do not know how to take meaningful actions individually, modern environmental communication theory stresses the need to keep conversations continuously alive [37]. Wildlife tracking maps have promising potential to engage users in the longer term by bringing them back for updates on their favorite animals, especially when continuously updated with real-time data. Many participants noted this, unprompted: *"If it was an organization that had an 'adopt an elephant or whatever' program, then that would be* so awesome *if you could track your elephant."* Many participants cited the animals' real-time locations as a factor that helped them feel more connected, seeing what the animal was doing right now and knowing that the tracking projects were still active.

These continuous updates on favorite animals present a great opportunity for interactions between the tracking maps and other channels like social media or email lists, allowing organizations to tell detailed stories about the animals and link to the maps, and allowing audiences to respond and participate in the conversations. (As noted, these affordances also lend themselves particularly well to adopt-an-animal campaigns which are some of conservation organizations' most popular and successful fundraisers.)

7 WILDLIFE MAP DESIGN CONSIDERATIONS

From our findings, here we outline design considerations for future wildlife-tracking maps.

User onboarding. Interactive data visualizations, even when designed well, tend to have fairly complex user interfaces—in the first moments each user needs to piece together context to understand what the data are, how to interpret them, and how they can interact. In our user study, we watched many participants flounder to understand the maps before they were comfortable enough to explore. To reduce this friction, interactive data visualizations require special attention to "user onboarding" [6] to lower the cognitive burden of understanding the data. Interfaces for user onboarding commonly take the form of a graphic or an introductory sequence of screens explaining how to interpret and manipulate the data, for example.

Quick impressions. Given the reality of short online attention spans, there will always be a large fraction of users who do not try to substantially interact with the data. We encourage implementers to think carefully about their messaging for these 30-second visitors. For this segment, designers can consider approaches that circumvent the learning curve of interactive elements, like a splash-screen with a short video, or a highly-directed introductory sequence highlighting key takeaways, or a story of just one individual.

Giving meaning to geospatial data. Most participants in our study could not find much meaning in the geospatial data, except for seeing animals' far travel distances or observing that they had territories. The difficulty of interpreting tracking data is a key shortcoming for this mediums' ability to convey the vivid impressions of the animals' lives that many conservationists hope for. Conservationists might struggle to appreciate this problem, though, because they relate to their own data so vividly.

Visually encoding information about animal behaviors and the environmental context is one way to make the maps' data more meaningful. For example, maps can prominently show habitat types, rivers, vegetation, weather, or shifting ice coverage (Figure 2f [36]); visually distinguish the animal movements' during day and night or in different seasons; or highlight sudden changes in travel speeds. However it is still a challenge to effectively communicate what these additional contexts mean for the animals; e.g. some example maps in our study showed vegetation in satellite images and marked rivers, but participants did not react to them.

Maps can also explain the data more directly with textual descriptions, photos, and videos about the animals' behaviors. This approach lends itself well to integration with other media types, like long-form articles or narratives on social media.

Time component. Most existing wildlife-tracking maps do not emphasize the time component of the tracking data. Most of our participants, though, wished that they could better understand the timescales of the animals' movements and voiced that this would help them understand the data better. Time data can be incorporated in a number of ways: animations, tooltips, or varying the tracks' color. One participant suggested a particularly interesting approach: a tooltip for each GPS transmission calling out the time since the last transmission, how far the animal traveled, and its average speed.

Participants were excited to see real-time live data about the animals, but also frequently expressed disappointment and confusion upon realizing the data was old. Implementers ought to creatively balance the display of time data to keep the website feeling fresh.

Relatability. A large majority of our participants reported feeling more connected to the animals through pictures, videos and text rather than the dots and lines on the map. It is difficult to empathize with data alone, so thoughtful integration with more-relatable forms of media should be central to application designs.

Visual appeal. Lastly, users generally wanted the applications to be visually exciting with a high-quality, modern finish. Visual appeal is one of the most important elements for the users' excitement, often underestimated by software developers. Sites with less-polished interfaces shook some participants' confidence, unsure if it would work on their computers.

8 DISCUSSION

Here we provide additional thoughts on data security and access limitations of these maps, discuss our study's limitations and future work directions.

8.1 Data security

Though not the focus of this paper, data security is a fundamental design problem for wildlife-tracking maps when sharing animals' location data. GCF and AWSC conservationists both shared concerns for the animals' safety: for example, tourist boats might use the data to find and crowd sharks. In another case, the International Wolf Center had offered tracking data as a part of a school program but withdrew the data for fear of the wolves being killed [14].

More work is needed to understand the range of security threats. Especially when providing continuously-updated data, not all risks are easy to predict ahead of time; e.g. it is potentially dangerous when an animal stops moving. There is also a risk that animals' current locations might be predicted from past locations, perhaps

even by co-opting some of the predictive models developed for anti-poaching efforts [24, 28]. Publishing tracking data to the web may also draw attention to the server infrastructure as a hacking target, where other sensitive non-pubic data are hosted.

There are many potential mitigation strategies, and more work is needed to understand their necessity, efficacy, and impacts on the user experience. Most projects will not share locations for the most threatened or poached animals, though they are frequently the most charismatic and draw the biggest audiences. GCF is choosing to delay their published data by two weeks for the giraffe's safety; the AWSC shares these safety concerns but is cautiously opting to publish data in near-real-time for public safety reasons and hope that live data will be more exciting for audiences. Differential privacy techniques may applicable to the unknown threat of predictive algorithms, by adding a jitter to the data, for example. Especially for live data, some commitment to human monitoring is unavoidable.

8.2   Access limitations

Interactive wildlife-tracking maps are typically made for international audiences and donors; best suited to audiences with computers, internet access, and prior science education. However, many conservation projects are located in remote, low-income areas where local people often face access barriers like device ownership, poor connectivity, language, and education. Organizations strive to engage these local audiences because their engagement is critical for conservation projects' successes [53, 57], and the role of interactive technologies is becoming a salient open question as technology access increases around the world [80]. There are opportunities for mediated access [60] to wildlife tracking maps whereby conservancy staff provide demonstrations or encourage communities to experience the maps together in collective settings [49, 77]. Interactive data applications also lend themselves well to community science approaches, potentially helping conservancies deepen their bilateral interactions with communities [73]

Maps and data visualizations are notoriously inaccessible for people with visual impairments [11]. Map implementers can mitigate this to a certain extent by ensuring the maps' incorporated videos and text are accessible by screen-readers. Sometimes other media like audio recordings are better suited. Recent waves of research on interactive data experiences for visually-impaired users also present new opportunities for wildlife-tracking maps [23, 64, 78].

8.3   Study limitations

This study presents formative design work, and there is more to learn from a full deployment and observation of user behaviors in the real world. However, we expect similar patterns documented by other systems, having a small group of highly-engaged users and a long tail of short and minimally-interactive visits [4].

To present the conservationists' perspective we have worked with small, fairly technically-capable organizations with successful communication efforts. We have not included perspectives of other organizations using these maps, many having less technical capacity. In our user study, participants explored each map for 5-7 minutes, which is longer than most typical visits but not representative of the most dedicated users who visit repeatedly. Our

sample contained some participants who are very passionate about wildlife, but we cannot be confident that our study represented the experiences of internet audiences who engage with these these conservation organizations online and we can only interpolate about them from the conservationists' descriptions. We intend to focus on these dedicated audiences in future work.

8.4   Future work

Our work suggests that interactive data visualizations can be most effective with audiences who are already highly-interested in conservation, and these audiences are crucial for environmental organizations as their biggest supporters. However, one of the most important, impactful questions for environmental communication how to get casually-interested audiences more deeply engaged. Therefore, adapting interactive data visualizations for broader audiences is a key objective. There are opportunities for design research on new interface approaches that integrate data with more relatable media types. We need to develop new, interactive narrative styles that draw on best-practices from environmental communication; such as using relatable, interpersonal communication styles and cultivating hope [43].

For wildlife-tracking maps specifically, more design work is needed to help users find deeper meaning in the animals' geospatial data—a key shortcoming of the current prevalent designs. We hope to find creative new ways to meaningfully incorporate other environmental and contextual information into the experience.

Lastly, better tools are needed as more conservation organizations collect wildlife tracking data and seek ways to share it. Many smaller organizations lack the technical capacity to develop effective wildlife tracking maps. Based on the formative work for this project, our team is working to develop a toolkit that allows organizations to easily deploy wildlife-tracking maps for their own projects, accommodating the heterogeneity between each organizations' data and communication goals.

9   CONCLUSION

Conservation organizations are increasingly investing in wildlife tracking maps and other interactive data visualizations for various communication goals. Through user sessions and focus groups with conservationists, we have explored this medium's unique strengths and weaknesses for environmental communication and outlined a set of design recommendations for future implementations.

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