Integrative and Comparative Biology

Integrative and Comparative Biology, volume 58, number 1, pp. 103–112
doi:10.1093/icb/icy016

Society for Integrative and Comparative Biology

SYMPOSIUM

Species Loss: Exploring Opportunities with Art–Science

Jennifer Harrower,[1,*] Jennifer Parker[†] and Martha Merson[‡]

*Department of Environmental Studies, University of California—Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA; [†]Department of Art, University of California—Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA; [‡]TERC, 2067 Massachusetts Avenue, Cambridge, MA 02140, USA

From the symposium "Science in the Public Eye: Leveraging Partnerships" presented at the annual meeting of the Society for Integrative and Comparative Biology, January 3–7, 2018 at San Francisco, California.

[1]E-mail: jharrower@ucsc.edu

Synopsis Human-induced global change has triggered the sixth major extinction event on earth with profound consequences for humans and other species. A scientifically literate public is necessary to find and implement approaches to prevent or slow species loss. Creating science-inspired art can increase public understanding of the current anthropogenic biodiversity crisis and help people connect emotionally to difficult concepts. In spite of the pressure to avoid advocacy and emotion, there is a rich history of scientists who make art, as well as art–science collaborations resulting in provocative work that engages public interest; however, such interdisciplinary partnerships can often be challenging to initiate and navigate. Here we explore the goals, impacts, cascading impacts, and lessons learned from art–science collaborations, as well as ideas for collaborative projects. Using three case studies based on Harrower's scientific research into species interactions, we illustrate the importance of artists as a primary audience and the potential for a combination of art and science presentations to influence public understanding and concern related to species loss.

Introduction

Societal activities that dramatically alter the planet and lead to species loss will continue, without key changes to policy and human behavior (Newbold et al. 2015). The frightening rate of species loss is galvanizing some into action, but possibly not enough to make a difference (McKibben 2011). Environmental organizations raise funds, file legal challenges, and apply political pressure, while most scientists will diligently continue their work, documenting species responses, quantifying species decline, monitoring habitat change, and destruction. This work is undeniably important. Nevertheless, without changes to policy and human behavior, societal activities that dramatically alter the planet and lead to species loss will continue (Daily and Ehrlich 1999; Novacek 2008; Newbold et al. 2015). Interdisciplinary collaborations are recognized as an important approach to address complex environmental problems (Frodeman et al. 2017) and are compatible with the emphasis on broader impacts that funders want to see scientists achieve. For those scientists who have no interest in stepping into politics, policy, or citizen science, but who can imagine motivating others to do so, we describe art (art making, art exhibits, art-led outreach) as one vehicle for spurring societal change.

Scientists do communicate their findings, typically publishing and presenting once data are in and analyzed. However, Harrower has initiated several outreach projects before completing her fieldwork, desiring to engage people now in attending to ecosystem health and communicating the urgency of species decline. This unorthodox approach is viable for projects that rely on discussions of species interaction and species loss, rather then specific findings about research sites. Further, by gathering feedback from audiences and art-collaborators during the research process, she ensures the development of engaging products and experiences for a variety of audiences. It is worth noting that such projects can qualify for institutional support—residencies that lend credibility to the effort and facilitate research permit approval, funding to support artists'

Advance Access publication May 19, 2018

involvement, and, in Harrower's case, approval from her dissertation committee to pursue outreach alongside her scientific research.

Art can connect people to complex concepts at an emotional level and could be used to increase public understanding of the current anthropogenic biodiversity crisis (Harrison and Harrison 1993; Jacobson et al. 2007; Ballengée 2015; A'Bear et al. 2017; Curtis 2017). Art has the potential to influence values, beliefs, knowledge, and the development of societies (Belfiore and Bennett 2006) which are the same factors driving the environmental behavior of citizens (Jackson 2005). Art can create a space for dialogue around important issues, and harness the power of narrative and imagery to deliver educational messages that could inspire aesthetic appreciation and emotional response (Carlson 2000; Curtis et al. 2014). Interdisciplinary teams can tap into a variety of professional and personal networks, enabling access to more diverse audiences for whom the science work alone may not have emotional resonance (Curtis et al. 2014; Ballengée 2015). The art making process can also enable a deep emotional connection to the subject being studied, and can build empathy and understanding around science concepts, organisms, and ecological systems (Kay 2000; Curtis et al. 2014; Ballengée 2015). As influential as art can be, as enormous as the potential rewards are, scientists have cause to be wary.

Analyses of art–science work have found both the quality of the art and the representation of the science lacking, which can do damage to the reputation of art–science projects (Ballengée 2015), and to the reputations of those who are involved in them. The default model for art–science collaborations can leave either or both parties unsatisfied, with a lingering sense of missed opportunities. In a common scenario, artists are hired help, carrying out an illustration of someone else's vision (Glinkowski and Bamford 2009). Or in some cases, scientists find their work becomes watered-down or misrepresented in the final art form (Glinkowski and Bamford 2009; Curtis et al. 2014; Miller 2014). However, if collaborators can achieve interdependence, the work can flourish. Interdependence refers to a clear understanding of roles, and dependence on the other to fulfill those roles (Bronstein 2003). Acknowledging that in a collaboration, individuals will not necessarily have full autonomy over timeline, team members, tasks, and technique, we wondered to what extent these could or should be negotiated. Pink's description of these four ts (team, time, task, and technique) is the basis for understanding intrinsic motivation. With autonomy over these areas, many people will feel motivated to produce at a high level (Pink 2011). By giving collaborators autonomy over two or more ts could lead to increased motivation and better collaborative outcomes. Avoiding the pitfalls requires high levels of engagement from all partners, a commitment to identifying a shared goal and buy-in for a shared aesthetic and oversight by scientist experts.

In this article, we describe scientist and artistic partnerships through three case studies of Harrower's eco-art projects, with additional supporting literature. There is a rich history of ecological and social practice artists who make provocative work that challenges people to care for their environment (Gablik 1991; Harrison and Harrison 1993; Miller 2014; Curtis 2017). Ecological artists utilize symbols and narratives of the nature/culture interface to actively engage the public to reckon with current social and environmental issues. These artists work across multiple disciplines to collaborate and utilize different cultures of practice through research, maker ecologies, scholarly publications, and art exhibitions.

Since navigating collaborations for purposes of communication science to public audiences is a high-risk, high-reward endeavor, we look at three case studies to answer the following questions: What features of the collaboration insure both scientific integrity and satisfying, creative roles for participating artists? What cascading impacts resulted from campus-initiated art–science collaborations? What are the benefits to soliciting feedback from the public during the creative process?

Case studies

Harrower's research explores the species interactions of Joshua trees and their mutualists—fungi and moths—and how the outcomes of those relationships could shift with the changing climate, resulting in population declines of the charismatic Joshua tree. Working as an ecologist, and multi-media eco-artist, she is interested in exploring through art how to visually communicate the complexity and ecological importance of symbiotic interactions (www.JuniperHarrower.com). Harrower is not alone in deriving inspiration for her scientific and artistic projects from national parks. The US National Parks have a long history of attracting and inspiring artists, from the early painters in the 19th century who were instrumental to establishing National Parks and attracting visitors, to the more recent widespread establishment of numerous artists residencies (Winfree and Dunaway 2011).

Harrower's work examines if we can influence education, empathy, and human desire to care for natural systems and organisms through art. She uses current science methods and multi-media art practices to investigate the outcomes of human influence on ecological systems. By approaching her study system through art and science, she hopes to better understand the form and function of the organisms as well as to share with others the hidden beauty of these threatened species interactions. Through this work she aims to encourage dialogue around social and environmental issues, to contribute to science theory, and to make thoughtful recommendations for policy and management.

The following three case studies from Harrower's interdisciplinary research were chosen to highlight examples of art–science collaborative work: a collaboration between artists and scientists in developing an educational art–science project for the classroom; an educational multimedia animation collaboration between artists and a scientist; and a large participatory art collaboration between artists, a scientist, park rangers, and the public to populate an online dating site for Joshua trees. An important measure of the impact of art–science projects can be gathered from participant and audience experiences (Neff et al. 2010; Curtis 2017). We include data and feedback that were gathered from surveys with 121 people across these studies. Surveys were a mixture of close-ended and open-ended questionnaires administered by Harrower on paper directly following an event or class, or conducted online with SurveyMonkey within days of the event. Open-ended responses were categorized and coded for further analysis (Mason 2017).

Project: seeking symbiosis

Seeking symbiosis grew out of Harrower's interest in increasing visibility for her ecology research among undergraduates enrolled in University of California, Santa Cruz (UCSC). Harrower and art faculty member Geoffrey Thomas co-led an undergraduate digital arts and storytelling class, teaching students about the symbiotic interactions of Joshua trees. As part of the class, Harrower introduced students to her laboratory, protocols and methods, as well as to the experimental seedlings. Students spent time in the greenhouses observing and sketching. Students created triptychs of the Joshua trees and processes of the symbiosis, with the goal to emotionally connect with viewers about tree loss (Fig. 1). Harrower and Thomas planned a showing of students' work on campus in both science and art spaces at the (UCSC), at a sustainability festival at UCSC, and shared via local press.

Cascading impacts

The outcomes from this collaboration include student and instructor art, an art/science education model, and exploratory art themes of Joshua trees and climate change that influenced collaborators work trajectories. The student artwork was exhibited in both the science and art departments, and Harrower and Thomas shared their collaborative model for art–science education at the California College of the Arts, art and science conference. This led to lively conversation with over 80 educators, scientists, and artists, who were interested in incorporating this education model into their classrooms and practice. These works were also presented and discussed at the 2015 UCSC social fiction conference. Images from this collaboration are now being used by park interpretive rangers in JTNP for educational outreach to teach Harrower's research to the public. With over 3 million visitors per year at JTNP there is great potential for wide exposure to these materials. Thomas created a series of images to consider social–political impacts of Joshua trees and climate change. One striking image of tarantula inspired mobile robots that housed Joshua tree saplings that was further developed and later influenced the creation of a stop motion animation about Harrower's research in JTNP.

Impact

Through anonymous feedback (end of class evaluations and an online survey), a majority of students reported that they gained a deeper understanding of the human forces driving biodiversity loss and climate change ($n = 19$). All students found the inclusion of science to be important and useful in their arts training (on a rating scale with strongly agree to strongly disagree). A number of students expressed the desire for a deeper understanding of the science and science methodology than we had the ability to cover in the class time, and felt that it would have greatly improved their ability to make meaningful art. In spite of the several hours invested in science content, some students remarked that their ability to engage with the concepts was limited to just illustrating the science.

Lessons learned

Harrower and Thomas articulated an assignment for their students' art projects that would grow out of learning about Joshua trees and stretch beyond

Fig. 1 Four examples of the projects from Harrower's art–science collaborations. (**A**) Seeking Symbiosis: Thomas' ghostly Joshua tree depictions with missing limbs reference the trees that we are loosing to climate change using the format of a triptych to commemorate death and dying. (**B**) Joshua Tree Love Story: Image still from the stop-motion animation that follows Harrower and her son on a research expedition through JTNP, to understand why the trees are dying. (**C**) Hey JTree: Online dating site to meet Joshua trees aimed at connecting the public to ecology research and to inspire love and stewardship for the trees. (**D**) Joshua Tree Love Story: Two backdrops used in the animation painted by Harrower's unique art process that combines elements of her research organisms into the painting process (such as Joshua tree seed oil and fibers) to achieve a deeper connection to the study system.

illustrating the symbiotic relationships. Once students were steeped in the factors affecting Joshua tree loss, and particularly the impact of climate change on key symbionts, students were encouraged to explore larger themes. They explored theories of the nature/culture divide, linking them to the current disconnect between human activities and their impact on species and ecosystems through visual imagery as desert caretakers. They invoked technological imagery and the cultural perception that in the end science will save us, and we don't need to dramatically change our behaviors (Jackson 2005). Students' responses confirmed the value of the approach Harrower and Thomas took to jointly develop a course rather than limit Harrower's science to a one-time guest lecture. As identified in other art–science projects, a reoccurring theme is some need for artist autonomy over the final project, to build intrinsic motivation and emotional investment (Glinkowski and Bamford 2009). To address students' feedback, future courses will allocate more time to exploring science content and give students a chance to propose projects inspired by the science that they work on throughout the length of the course.

Project: Joshua tree love story

The goal of Joshua tree love story is to increase the knowledge of an all-ages audience that might not attend a science talk or ranger program, with an animated, short film (available online and in classrooms) on species interactions. Additionally, to move artist collaborators and viewers to consider issues of species loss and motivate sustainable behaviors. We asked: can involvement in a science-rich animation project deeply connect artists to complex science concepts and motivate sustainable behavior? Can an animation convey key knowledge about science issues and motivate an emotional response

among viewers? How does a pilot audience react to a science talk vs. animation?

Film is one of the US's widest-reaching art forms. Exported globally, a giant in the economy, the film industry touches millions of people. In spite of the popularity of homegrown videos such as YouTube, scientists rarely create educational videos about their work. But with reasonable fears of Joshua tree extinction, Harrower was interested in using film as a means to achieve her goals of increasing awareness and motivating action to mitigate climate change. Harrower found she could both control the storyline and trust collaborators to carry through on a vision that didn't dilute the science content or overly-dramatize the science process.

In order to make viewers feel the impact of species loss, the film rapidly portrays Joshua tree loss using illustrated and animated imagery. The animation written and directed by Harrower explores the unseen world of species interactions and challenges stereotypes of what science and scientists look like (Fig. 1) through the character of a scientist and mother (Harrower) doing field research with her baby. To motivate sustainable behaviors, the story connects with the viewers on a human level, through the relationship of a mother and her child. The narrative follows Harrower and baby on a research expedition across her field sites in JTNP to investigate if the rapidly changing climate is having an impact on tree survival, and to explore the intricacies of the species interactions that the tree depends on. Tiny yucca moths (as large stop motion puppets) appear in magnified detail. Viewers witness the moths stuffing pollen gathered in one blossom into the blossoms of another tree. The microscopic web of fungal interactions in the Joshua tree root system comes alive with clay and glass beads, symbolizing nutrient transfer from the soil via the fungi to the plant, in exchange for plant sugars. Viewers see trees across the set wither and die. The impact of the loss is heightened by the parallel aging of the baby into an old man, to emphasize that species loss can occur within a human lifetime. One way the film stays close to the science is by incorporating Harrower's highly detailed paintings that mimic the microscopic complexities of the underground Joshua tree and fungal symbiosis. The paintings are created from fibers and oils from the Joshua trees, matching the data collected in JTNP along a climate gradient from low to high elevations. The paintings give viewers a way to see how relationships change with local climate and soil conditions (Fig. 1).

Significant time was put into sharing knowledge about the science and the art needed to create the work. Harrower led visits to the field, laboratory, and greenhouses, and shared knowledge verbally and informally, through written reports, and used conceptual models and drawings. This fueled the interdependence of team members. The long hours shared together generated friendship and respect. Harrower clarified expectations at the beginning, such as a general timeline, baseline pay, and individuals' roles. These necessarily evolved throughout the project, with some team members having to take on more work, but additional funds were secured so participants felt their time was respected. Work was most productive when the team met together, otherwise momentum was maintained by weekly email reports and occasional small group meetings.

Impact

Informal educators struggle to capture the impact of widely shown or televised media projects. Can a film affect viewers' understanding of complex ecology and motivate behavioral shifts? To begin to answer these questions, Harrower convened a focus group that heard a science talk about the research and watched an early release version of the animation.

Joshua tree love story was screened at SymbioStudio (Oakland, CA, USA), following a science talk about the same research to 45 people. During the event, Harrower collected feedback via an anonymous survey (10 questions, close-ended, and 1 open ended question). Ninety-five percent ($n = 45$) of respondents felt the animation was more successful than the science talk at conveying the ecological information. Sixty-eight percent of those surveyed reported that they were moved to change their own potentially environmentally destructive behaviors after seeing the animation. Hundred percent of respondents agreed that the science talk was more powerful with the accompanying animation, and that likewise, the animation was more powerful having followed the science talk. Twenty-nine respondents provided thoughtful and lengthy descriptions for ways to improve the flow of the animation, identified areas needing improvement, or pointed out unclear artistic metaphors that were at odds with the scientific principles. Participants expressed that the emotional messages conveyed through the art connected with them on a deeper level than the science alone, and that this resulted in a stronger sense of urgency and need to do something about human behaviors that contribute to species decline.

Cascading impacts

Scenes from Joshua tree love story are part of a visual library that was created by Harrower during her iSWOOP residency at JTNP, to provide park interpretive rangers with materials for use in public education and outreach. The animated film will be shown at the JTNP Visitor Center, which during peak visitation serves as many as 4500 people in 1 day (personal communication from park staff). Park rangers may use film artifacts: dioramas, puppets, dolls, and props in a Visitor Center exhibit or as props during programs. We are also currently developing Common Core ecology and art lesson plans for educators to use in conjunction with this animation.

Through an anonymous survey and informal interview, collaborators ($n = 10$) reported that participation in an art–science project had inspired new methods and insights in their own work, and had also provided them with a deeper understanding and appreciation for current issues surrounding biodiversity loss and climate change, as well as appreciation for the science process. All participants felt their career was positively enhanced through this work. Following this experience, seven of the artists went on to participate in other art–science collaborations.

Lessons learned

All collaborators agreed on the goals to emotionally connect the viewers to issues of species loss and motivate sustainable behaviors. The techniques for art making, animation, and style (dolls and set design) evolved with artists' input. Artists also shaped the timeline and recruited colleagues to join the project as needed. So the shared vision or task, timeline, techniques, and even team were a joint effort. Because Harrower wrote the screenplay and gave orientations on the science, she controlled the accuracy and integrity, while granting artists freedom to create something beyond her original vision.

Significant effort was put into teaching all team members the science processes that informed the art, allowing for greater discourse between collaborators on design elements and the ability to brainstorm techniques for animating some of the complex biology. Unanimously, participants agreed that the voice of the artist was respected through the collaborative process.

Institutional support was critical to the creative and financial aspects of the project. Harrower credits Parker who advocated for outreach as and arts research as an academically important complement to her ecology research. Parker provided critical feedback on different elements of the work and access to resources, funding, connection to collaborators and space. The design team from iSWOOP, where Harrower works as artists-in-resident as well as a featured scientist, also contributed feedback and financial support to the project. These many different support structures gave the project academic validity and resources.

Gathering audience feedback was pivotal in guiding our final editing process. Further, the feedback that the animation was enjoyable and enhanced when paired with a scientist's talk has shaped how we think about disseminating the film. We intend to create a recorded talk as an alternative to an in-person presentation.

Project: Hey JTree

Hey JTree is an ongoing participatory art research project using social media, and an on-line dating site for meeting Joshua trees (Fig. 1). The goal of Hey JTree is to actively enhance interaction between research, visitors to the park, and on-line audiences with collected data from individual trees using text, photographs, art, and short video clips of charismatic Joshua trees set to music. Social media takes the notion of adopting a tree or an animal to a whole new level. Rather than being assigned a tree or adopting a generic wolf, the concept of online-dating enables people to emotionally adopt a specific Joshua tree that lives in JTNP. The need to counteract irresponsible social media posting by visitors is vast and urgent. Visitors show violations of rules that are intended to promote conservation. Images such as drone usage, feeding/touching animals, rock or tree graffiti, and climbing Joshua trees have been described by park staff as one of the most difficult challenges they currently face as managers (personal communication).

This project was envisioned by Harrower, who advertised through social media artistic networks and selected 53 visual artists, musicians, and writers to collaborate. This is the first cohort of citizen artists, by which we mean those who express ideas through the arts to achieve societal change, but who are not by training or vocation professional artists. But in time elementary students and others will take a turn at contributing art to this project. As citizen artists, they will create poems, prints, and record songs specific to their chosen Joshua tree.

A project website (www.heyjtree.com) details the ecological tree information for each individual, shows on a map where each tree lives, art, and music

created for each tree, and includes a dating style profile (similar to on-line dating sites) written by professional writers. Collected data include details on tree height and branch number, to link with the moth and fungal data collected by Harrower from her research sites in JTNP. Each tree's location is given in latitude and longitude, but also recorded as a "scavenger hunt" and given in miles to drive and number of steps from identifiable locations in the park. The public can also participate as "citizen artists" by submitting "love letters," poetry, music, or art to their tree, which will be uploaded to the project site generating a collective shared love and experience for individual trees.

Lessons learned

The collaborative process was predominantly researcher driven, but benefited from space made to discuss possibilities and to let the project evolve with collaborators. Harrower hosted an art–science event at SymbioStudio where she gave a research talk and invited all collaborators to meet each other, learn about the research, and to brainstorm ideas. At this event, new ideas were born, that included: working with students through a creative writing class at UCSC to build additional tree correspondences, choosing a tree to promote that is on an educational tour led by JTNP interpretive rangers so they can describe and promote the project to the public, and other ideas for future art show displays that highlight the art, music, education, and tree ecology.

Citizen artists met with Harrower in her field sites and were trained to collect data for the trees, including height, branch numbers, location, photos, and video. This information was passed to the writers who then developed a character description for each tree. Writers were given almost complete freedom to create this work, as long as the writing was family friendly. Musicians each chose a tree, and were given complete freedom to create music for a 1-min tree video for their tree.

The visual artists' work, however, was more constrained. During the group meeting session at SymbioStudio, collaborators decided that a united image would be the most powerful for a future exhibition setting, and that all visual artists would create carvings of their chosen tree from tree silhouettes that were sized in relation to each other. A similarity in style allows the prints to be exhibited next to each other with a unified aesthetic, and maximizes the viewers' ability to distinguish differences in size, form, and branch number between the different trees. We felt this was an important aesthetic choice.

Impact

The art making process connects people to the environment in a powerful and emotional way. Through an anonymous closed-ended survey administered by Harrower at the end of the event, and online to other participants, all collaborators ($n = 51$) strongly agreed that the art making process was more important for building emotional attachment to the science, than the importance of creating a finished artwork. Ninety percent of collaborators felt an enhanced emotional connection and personal responsibility to the issue of biodiversity loss than they had before working on this project. Eighty-two percent of collaborators reported that participation in this art–science project had inspired them to reconsider ways that their behavior negatively impacted the environment, and to make modifications. All participants surveyed felt that an in-depth science description, given both in written form and as a verbal talk, was very important to enhancing their understanding about the system, leading to an enhanced ability to make art. All participants agreed that participation in this art–science project provided them with a deeper understanding and appreciation for current issues surrounding biodiversity loss and climate change, as well as appreciation for the science process.

Cascading impacts

This project will continue to grow. As of April, 2018, the social media site is not yet open to public interaction, but once in place, viewers will be able to post directly to tree profiles by submitting letters and art. We will show the art in conjunction with science talks, a printmaking workshop at the JTNP visitors center art gallery, at art galleries, and museum exhibitions. In March 2019, as part of the art residency, we will be working with elementary school students to collect data on the trees. Participating students will create their own Joshua tree art and writings. This work has already inspired a ranger at Indiana Dunes National Lakeshore to begin plans for a local tree-dating project.

Discussion

Scientists who seek to have broader impacts, to influence the public's engagement and behavior can benefit from collaborations with artists whose creative expressions reach audiences, often evoking an emotional response. Emotions are increasingly credited with playing a central role in the decisions we make and the information we take in (Jacobson et al. 2007). In Harrower's case studies, we found that art

has the potential to evoke a strong emotional response that could inspire new behaviors. As these projects are recent and ongoing, we have yet to follow up with respondents to gather evidence of long-term changes in beliefs or behavior. If the art making experience effects a strong emotional connection, it could potentially influence a person's values and habits (Matarasso 1997; Jackson 2005; Curtis 2017).

Successful collaborations require strategies that enable us to connect with collaborators, collaborate successfully, and create meaningful science inspired art works that connect with the intended audience (Nielsen-Pincus et al. 2007; Glinkowski and Bamford 2009). Harrower has tapped into opportunities for collaboration that are widely available to grad students or professors associated with a university: collaborations with art faculty, leveraging video, and social media to promote broad exposure. Interdisciplinary collaborations have shaped her outreach efforts, and the message about Joshua tree decline and species loss has taken a different form in each project. With artists' input, each of these interdisciplinary projects has given the research and topic of species loss a visual form, reaching new audiences. Interdisciplinary collaborations are recognized as an important approach to address complex environmental problems (Daily and Ehrlich 1999; Newbold et al. 2015; Frodeman et al. 2017). How those interdisciplinary partnerships are nurtured affects the product and the experience for collaborators—is the project ultimately rewarding, inspiring, or draining or even worse, embarrassing? Art–science collaborations have to wrestle with articulating an appropriate level of autonomy to artists and maintaining scientist's engagement. Extrapolating from the projects Harrower has initiated and co-led, a variety of strategies can set a project on a path to positive cascading impacts, such as treating artists as a primary audience; seeking input from public audiences; structuring public events that offer a combination of science talks and art experiences; working with a theme such as species loss as well as specifics of a scientific investigation. Cascading impacts can be achieved when a scientist integrates multiple dimensions of their identity into their professional life (Risien and Storksdieck 2018).

The cases described above illustrate how vital it is to treat artist collaborators as a primary audience for increasing knowledge, not as a necessary steppingstone to the true target audience. Time spent for knowledge sharing between disciplines is important, as a basis for building mutual respect, a sense of joint ownership, generating empathy and interdependence (Steinheider and Legrady 2004; deLahunta 2006; Glinkowski and Bamford 2009; Curtis et al. 2014). Harrower's strategic moves of involving the artists in shaping the message and elevating that message from specific details about her study to larger social implications have allowed her artist collaborators autonomy of task, team, time, and technique within the parameters of rigorous science and agreed upon aesthetics. This approach sets the stage for greater buy-in and high levels of intrinsic motivation according to research (Glinkowski and Bamford 2009; Pink 2011; Curtis et al. 2014).

Harrower and her collaborators found that utilizing conceptual models and focal themes to highlight the science issues served as an important communication device for teams to break down language barriers and frame complex interdisciplinary problems. Identifying language commonalities, metaphors, and drawing diagrams to communicate the vision greatly facilitated the process. This agrees with other work that found conceptual models to be a valuable tool for bypassing jargon and sharing knowledge between disciplines (Heemskerk et al. 2003; Frodeman et al. 2017).

In Seeking Symbiosis, Joshua tree love story, and Hey Jtree, Harrower found that collaborators reported valuing the opportunity to understand the science deeply. Unanimously, all recruited completed the projects and demonstrated a high level of investment, were personally moved to examine habits, and reported high levels of interest in further art–science collaborations. Survey data from Harrower's projects support findings from other studies describing the outcomes of successful art–science collaborations in which time invested in the artists education about the science research both enhances the artistic outcome and feeling of mutual respect for different research methodologies (Glinkowski and Bamford 2009; Miller 2014).

Across Harrower's work, all collaborators reported an enhanced connection to the science process and an increase in their emotional response to species loss that was gained through the art making process. Rather than rotely fulfilling an obligation, they became conversant in symbiotic relationships, mycorrhizal fungal networks, and aspects of phenology. This finding agrees with other work that has demonstrated group art making experiences have the potential to alter people's attitudes and beliefs (Jackson 2005; Glinkowski and Bamford 2009; Ballengée 2015). The process of research, creation, and self-reflection inherent to the art making process can assist with knowledge and identity building (Harrison and Harrison 1993; Curtis 2017).

Seeking input from public audiences through surveys and focus group discussion, Harrower keyed in to the value of pairing her science talks with artistic media. Audience feedback is an often overlooked component during the art making process (Glinkowski and Bamford 2009), but to maximize emotional impact, we found it useful. Audience feedback on a version of the animated film helped the team clarify central ideas/concepts. Scientists who have an interest in outreach and advocacy could benefit from asking an audience for feedback on a talk or art–science collaboration. To best prepare and develop materials for a diverse public, researchers could take special note on questions and comments to better understand audience's prior knowledge and areas of interest.

We found that the emotional impact of the art making process (across all three case studies) and the art viewing process (Joshua tree love story) was strongest when paired with a science talk. This finding aligns with the theory of using multiple modalities to influence knowledge acquisition, which could lead to personal changes in attitudes and beliefs (Jackson 2005). Pairing a science talk and art will be part of our way of working in the future. We can use audience feedback to determine what the advantages and disadvantages are to leading with the art experience or the science talk, as well as to determine how the audience responds if the talk is given by a participating artist or the scientist. This fusion may be a new take on science cafes, a format that opens up new venues for discussion about science and society.

As a final note, Harrower's impulse to initiate outreach projects early on in a study is somewhat unconventional. While scientists might wonder about the value of talking about their research before results are in, Harrower has found that the outreach and research efforts nourish each other. Securing funding and accessing residencies all lend credibility and support to both the research and outreach efforts.

Harrower will continue to investigate Joshua tree ecology at her research sites, assess the impact on stewardship and perceptions of beauty, urgency, as well as understanding of species interactions among her target audiences—those who are involved as citizen artists, professional artist collaborators, or public audiences in park settings and beyond. With partners from informal education, Harrower will explore how artists who have a high level of science understanding function might participate, lead, or facilitate in-person presentations paired with art exhibits or film screenings or citizen art workshops.

As evidenced by our current environmental state, we cannot assume resilience of species and their habitats. To secure a sustainable future we need to develop collaborative interdisciplinary approaches that engage the public and motivate people to protect our resources. The potential for social change through art/science goes far beyond translating science for public consumption. By forming intentional art/science collaborations like the ones described above, scientific researchers have the potential to turn information into inspiration for further learning and action to support species conservation and sustainable approaches to life on our planet.

Acknowledgments

We would like to thank Greg Gilbert, and Brent Haddad for comments on early versions of this manuscript. We thank our many arts and science collaborators who participated in the different case studies, and the supportive staff from Joshua Tree National Park for their help with fieldwork and educational outreach. We would also like to give thanks for the financial support from OpenLab, iSWOOP, SymbioStudio, and the Norris Center for Natural History.

References

A'Bear L, Hayward JC, Root-Bernstein M. 2017. Conservation science and contemporary art. Leonardo 50:27–30.

Ballengée B. 2015. Ecological understanding through transdisciplinary art and participatory biology [dissertation]: Plymoth University.

Belfiore E, Bennett O. 2006. Rethinking the social impact of the arts: a critical-historical review. Centre for Cultural Policy Studies, University of Warwick.

Bronstein LR. 2003. A model for interdisciplinary collaboration. Soc Work 48:297–306.

Carlson A. 2000. Aesthetics and the environment. the appreciation of nature, art and architecture. New York (NY): Routledge.

Curtis D. 2017. Building sustainability with the arts. In: Building sustainability with the arts: proceedings of the 2nd national EcoArts Australis Conference. Cambridge Scholars Publishing. p. 3.

Curtis DJ, Reid N, Reeve I. 2014. Towards ecological sustainability: observations on the role of the arts. S. A.P. I. E.N. S., Surveys and Perspectives Integrating Environment and Society.

Daily GC, Ehrlich PR. 1999. Managing earth's ecosystems: an interdisciplinary challenge. Ecosystems 2:277–80.

deLahunta S. 2006. Willing conversations: the process of being between. Leonardo 39:479–81.

Frodeman R, Klein, JT Pacheco RCDS. 2017. The Oxford handbook of interdisciplinarity. Oxford University Press.

Gablik S. 1991. The reenchantment of art. New York (NY): Thames and Hudson.

Glinkowski P, Bamford A. 2009. Insight and exchange: an evaluation of the Wellcome Trust's Sciart programme. London: Wellcome Trust.

Harrison HM, Harrison N. 1993. Shifting positions toward the earth: art and environmental awareness. Leonardo 26:371–7.

Heemskerk M, Wilson K, Pavao-Zuckerman M. 2003. Conceptual models as tools for communication across disciplines. Conserv Ecol 7:8.

Jackson T. 2005. Motivating sustainable consumption. Sustain Dev Res Netw 29:30.

Jacobson SK, Mcduff MD, Monroe MC. 2007. Promoting conservation through the arts: outreach for hearts and minds. Conserv Biol 21:7–10.

Kay A. 2000. Art and community development: the role the arts have in regenerating communities. Community Dev J 35:414–24.

Mason J. 2017. Qualitative researching. London: Sage.

Matarasso F. 1997. Use or ornament. The social impact of participation in the arts. London: Comedia/Arts Council. p. 4.

McKibben B. 2011. Eaarth: making a life on a tough new planet. Canada: Vintage Books.

Miller AI. 2014. Colliding worlds: how cutting-edge science is redefining contemporary art. WW Norton & Company.

Neff M, Sumner D, Bawden GW, Bromberg E, Crutchfield JP, Davidson D, Gilbride S, Kellogg LH, Kreylos O. 2010. Blending art and science: collapse (suddenly falling down). Leonardo 43:274–81.

Newbold T, Hudson LN, Hill SLL, Contu S, Lysenko I, Senior RA, Börger L, Bennett DJ, Choimes A, Collen B, et al. 2015. Global effects of land use on local terrestrial biodiversity. Nature 520:45–50.

Nielsen-Pincus M, Morse WC, Force JE, Wulfhorst J. 2007. Bridges and barriers to developing and conducting interdisciplinary graduate–student team research. Ecol Soc 12: 8.

Novacek MJ. 2008. Engaging the public in biodiversity issues. Proc Natl Acad Sci U S A 105:11571–8.

Pink DH. 2011. Drive: the surprising truth about what motivates us. Penguin.

Risien J, Storksdieck M. 2018. Unveiling impact identities: a path for connecting science and society. Integr Comp Biol. (doi: 10.1093/icb/icy011).

Steinheider B, Legrady G. 2004. Interdisciplinary collaboration in digital media arts: a psychological perspective on the production process. Leonardo 37:315–21.

Winfree RA, Dunaway F. 2011. The nature of art: communicating park science, nature and culture through art. Alaska Park Sci 10:53–63.