

6&6: A Transdisciplinary Approach to Art–Science Collaboration

SARAH E. CLARK, ERIC MAGRANE, THOMAS BAUMGARTNER, SCOTT E. K. BENNETT, MICHAEL BOGAN, TAYLOR EDWARDS, MARK A. DIMMITT, HEATHER GREEN, CHARLES HEDGCOCK, BENJAMIN M. JOHNSON, MARIA R. JOHNSON, KATHLEEN VELO, AND BENJAMIN T. WILDER

Despite an historical connection between the arts and sciences, in the past century, the two disciplines have been greatly siloed. However, there is a renewed interest in collaboration across the arts and sciences to support conservation practice by understanding and communicating complex environmental, social, and cultural challenges in novel ways. 6&6 was created as a transdisciplinary art–science initiative to promote a deeper appreciation of the Sonoran Desert. Six artists and six scientists were paired to create work that explored conservation issues in the Sonoran Desert and the Gulf of California. In-depth interviews were conducted with the artists and scientists throughout the 4-year initiative to understand the impact of 6&6 on their personal and professional behaviors and outlook. The findings from this case study reveal the role that intensive, place-based, and transdisciplinary art–science programs can play in shaping narratives to better communicate the patterns and processes of nature and human–environment interactions.

Keywords: art–science, transdisciplinary, Sonoran Desert, conservation practice, science communication

Prior to the twentieth century, art and science were inextricably linked. For example, the Renaissance was a period of philosophical, artistic, and scientific rebirth exemplified by the works of Leonardo Da Vinci, which were equal parts art and science. Emphasis was placed on observation and careful documentation. Field notebooks captured careful observation, where discovery and insights were gained—depicted in words, formulas, and drawings alike (Canfield 2011). Careful observation and presentation also coursed through the formative experiences of Darwin, Wallace, and Humboldt, leading to works that shaped the foundation of our modern understanding of the natural world. For example, Humboldt’s (Humboldt and Bonpland 1807) *Tableau Physique*, one of the most visually stunning and influential diagrams in the history of environmental sciences, depicts the altitudinal distribution of vegetation zones on Mount Chimborazo, which has been recently reinvestigated to track vegetation shifts in response to climate change (Morueta-Holme et al. 2015, Moret et al. 2019). Similarly, the journals of nineteenth century naturalist and writer Henry David Thoreau have been studied to understand shifts in the phenology of flowering plants (Willis et al. 2008).

At their core, both science and art are inspired by our basic observations of the world around us. Despite the inherent bonds and historical connection between the two, by the twentieth century, a collaborative understanding had mostly gone silent as academia moved away from an overt

partnership between the arts and sciences. As a result, the arts and sciences have largely become entrenched in siloed disciplines. It is in this context that, in a famous 1959 lecture, C. P. Snow ([1959] 2012, p. 3) pointed out the “two cultures,” in which “the intellectual life of the whole of western society is increasingly being split into two polar groups.”

However, in recent years, there has been a reawakening of the collaborative spirit and growing interest in art–science collaboration, as well as inspiration drawn from antecedents to such work. For example, there is a renewed focus in Humboldt’s bridging of scientific inquiry and aesthetics (Dixon et al. 2013, Straughn et al. 2013, Wulf 2015). Outlets for and engagement with the processes and products of art–science collaborations appear to be on the rise, with journals such as *SciArt Magazine* and *Leonardo*, academic centers such as the Stanford Art + Science program, the University of California Los Angeles’s ArtSci Center, the Art and Science program of the Desert Laboratory on Tumamoc Hill, and other institutions such as the Nevada Museum of Art’s Center for Art + Environment and the Search for Extraterrestrial Intelligence (SETI) Institute to name a few examples. There has also been a long tradition of artist-in-residence programs at prominent scientific research institutions such as the European Organization for Nuclear Research (CERN) and National Aeronautics and Space Administration (NASA). An awareness is growing that if human society is to maintain a vibrancy of culture and

biodiversity through the Anthropocene, it needs new ways of seeing the world and what stands to be lost.

Art-science collaborations can help to understand and communicate intertwined environmental, social, and cultural challenges in novel ways. The arts may play an important role in drawing connections between social and ecological challenges at the heart of conservation practice, in turn fostering socioecological transformation (Hawkins et al. 2015). In the context of climate change, “Art is much more than a means of transmitting scientific information; art also expresses and catalyzes culture” (Sassor 2015, p. 2). In addition, literature within the social sciences, and in particular, human geography, has recently engaged with the epistemological aspects of art-science collaboration (Dixon et al. 2013, Woodward et al. 2015), pointing to how art and science often do not fit neatly into distinct categories. Indeed, the discipline of *art-science* (or *sci-art*) has emerged as a potent and viable tool for generating knowledge, going beyond simply harnessing art as a means to assemble audiences for scientific findings (Born and Barry 2010).

The growth in art-science is also linked with a growing awareness that the great environmental challenges of the twenty-first century need to be addressed with a *transdisciplinary* approach. Transdisciplinarity is concerned with the unity of intellectual frameworks beyond individual disciplinary perspectives, or in other words, approaches that transcend traditional boundaries to generate knowledge (Stember 1991, Choi and Pak 2006, Stokols et al. 2018). This holistic approach differs from *interdisciplinarity*, which Choi and Pak (2006, p. 351) describe as an interactive approach that “analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole,” and *multidisciplinarity*, an additive approach that “draws on knowledge from different disciplines but stays within their boundaries.” It is important to recognize that instead of having clear demarcations, these three frameworks exist along a continuum through which teams made up of multiple disciplines may flow during different periods of their work together (Choi and Pak 2006, Klein 2008).

The present article is a case study of a transdisciplinary art-science collaboration called 6&6. We provide an inside view of an experiment in which six artists and six scientists were paired to create work that explored science and conservation issues in the Sonoran Desert and Gulf of California.

6&6 within art-science collaborations

In 2012, a community of researchers focused on the Sonoran Desert region coalesced to establish the Next Generation Sonoran Desert Researchers or N-Gen (Wilder et al. 2013, Wilder and O’Meara 2015). N-Gen is a network of individuals committed to the rich social and ecological landscape that spans the mainland Sonoran Desert, the Baja California peninsula, the Gulf of California, Indigenous Nations, and the US-Mexico borderlands. Dedicated to the spirit of this region, N-Gen catalyzes research and biocultural collaboration, develops capacity for innovative transdisciplinary action, and influences decisionmakers in both countries to

promote a conservation ethic that matches the grandeur of the landscape (www.nextgensd.com).

Toward the realization of this vision and to harness the power of the synergy of art and science, in 2015, N-Gen launched a call for artists and scientists to participate in 6&6. The announcement read,

“Six artists and six scientists whose work aims to portray and better understand the Sonoran Desert will unite. We are soliciting applications from scientists from all disciplines and artists of any media to be part of a cohort that will cross-pollinate and create new ways to see the Sonoran Desert. Twelve individuals will collaborate with their counterparts to create a shared vision of life in the Sonoran Desert.”

Although the intention from the outset was to create a collective exhibition, there was no specific plan, timeline, or model followed in precisely *how* to do so.

Twenty-one artists applied to participate along with four scientists. The discrepancy in the number of applicants from each discipline is noteworthy as this endeavor largely fell outside the traditional boundaries of time and work permitted of most scientists, fitting better within the artists’ realm. Indeed, incentives for scientists in academia to go outside of traditional boundaries of collaboration or to produce outputs other than the peer-reviewed scientific papers are limited. With some directed recruitment efforts, six scientists were identified, and six artists were selected by a review committee. Likewise, there was a discrepancy in the composition of the participants. The final cohort was made up of white US participants, which did not reflect the multinational, multiethnic nature of the United States, Mexico, and Indigenous Nations that make up the Sonoran Desert landscape. It became clear that not only do connections to artistic communities in Mexico and Indigenous Nations need to be strengthened, but that barriers also exist to working on long-term transdisciplinary projects of this nature across the US-Mexico border.

The cohort first met in March 2015 for an all-day picnic in the Tucson Mountains, where each participant shared their creative philosophy and work approach. Next, the group went on a camping trip to Punta Cirio, Sonora, Mexico, in May 2015, where the goals of the collaboration were solidified, including the 6&6 name and the model of six artists and six scientists working in six pairs as part of a cohesive larger group. At the outset, it was also determined that the pairings would revolve around new scientific questions and works of art, within which art and science would be mutually influential and visible. Collectively, the 6&6 mission statement was crafted: “A collaboration between artists and scientists to explore the patterns and processes of the Sonoran Desert and Gulf of California to impart a deeper appreciation of this region.”

The next couple of months were used by the participants to explore possible pairings, which were established in August 2015. From that point, each artist-scientist pair worked



Figure 1. Typical group meeting among 6&6 participants in the Sonoran Desert. Photograph: Sarah E. Clark.

independently in the development of their project with occasional group gatherings (figure 1). A collaborative exhibition of their work took place at the University of Arizona Museum of Art from 22 December 2018 through 31 March 2019 (table 1).

Art–science collaborations might be generalized into three different but overlapping categories, including art–science collaboration focused on conservation issues or field research (Swanson et al. 2008, Ingram 2013, Swanson 2015, Januchowski-Hartley 2018, McDermott 2019), works generated within the research lab or bioart (Stracey 2009, Yetisen et al. 2016), and art–science collaborations that focus on specific issues, most prominently climate change (Thornes 2008, Buckland 2012, Sassor 2015).

Although aspects of 6&6 intersect with each of the aforementioned categories, 6&6 can be largely situated within the category of art–science collaborations focused on conservation issues. These collaborations are often place-based, which is at the core of 6&6 (figure 2). The collaboration's particular place, the Sonoran Desert and Gulf of California, has a history of art–science collaboration, perhaps most notably the writer John Steinbeck and marine ecologist Ed Ricketts' scientific literary expedition in the Gulf of California (Steinbeck and Ricketts 1941), as well as more recent art and literature collaborations built around conservation and place (McMahon et al. 2012, Mirocha et al. 2015, Magrane and Cokinos 2016).

Exploring the transdisciplinary approach to art–science collaborations

A unique characteristic of 6&6 was its emphasis on a transdisciplinary approach to art–science collaborations. The artists and scientists involved were invited to not only create the mission of the overall initiative together but also to cocreate

their individual projects (i.e., the specific scientific-artistic question they would pursue together) from scratch. This holistic approach contrasts with other more interdisciplinary (interactive) or multidisciplinary (additive) art–science collaborations in which the artist is given scientific data, with the goal being to communicate the science in an artistic way.

Also at the core of 6&6 was an overt effort to document the process of what is involved in transdisciplinary art–science collaboration. The lead author (Clark), who was not a member of one of the pairings, led the documentation effort to create a behind-the-scenes look at the 6&6 process through interviews, compilation of artistic and scientific content generated during the initiative, and ultimately the creation of an interactive touchscreen installation at the final 6&6 exhibition (available for viewing at <http://ngen6and6.com>).

Clark conducted in-depth interviews over the phone with each of the participants at the beginning (spring 2016), middle (spring 2017), and end of the project (spring 2019) after the final exhibition opened. The interview questions were consistent across the three time periods to track any changes over time (see the supplemental material). The participants were also given the option to submit written answers.

Over the course of the project the lead author became thoroughly involved with 6&6, as both a documentarian and an observer. This led to an autoethnographic sensibility (Butz and Besio 2009), in which critical reflexivity of all of the 6&6 participants informed the analysis of the project. Clark read through the interview transcripts in MS Word, creating a codebook of key themes and then noting by hand which themes appeared most frequently and were consistent across all or most of the 6&6 artist-scientist pairs. This informal qualitative assessment, alongside Clark's own experience within the 6&6 initiative, informed the key findings presented in the present article, which were shared with the 6&6 participants for their review and feedback. Clark, Magrane (artist participant), and Wilder (scientist participant and project lead), led in writing and shaping the direction of the present article. Although each 6&6 pair's experience was of course unique, as a whole, we present 6&6 as a case study of the various facets of transdisciplinary art–science collaboration. The following key findings arose largely during the final interviews conducted after the opening of the exhibition, once the participants had the time and perspective to digest and reflect on their experience.

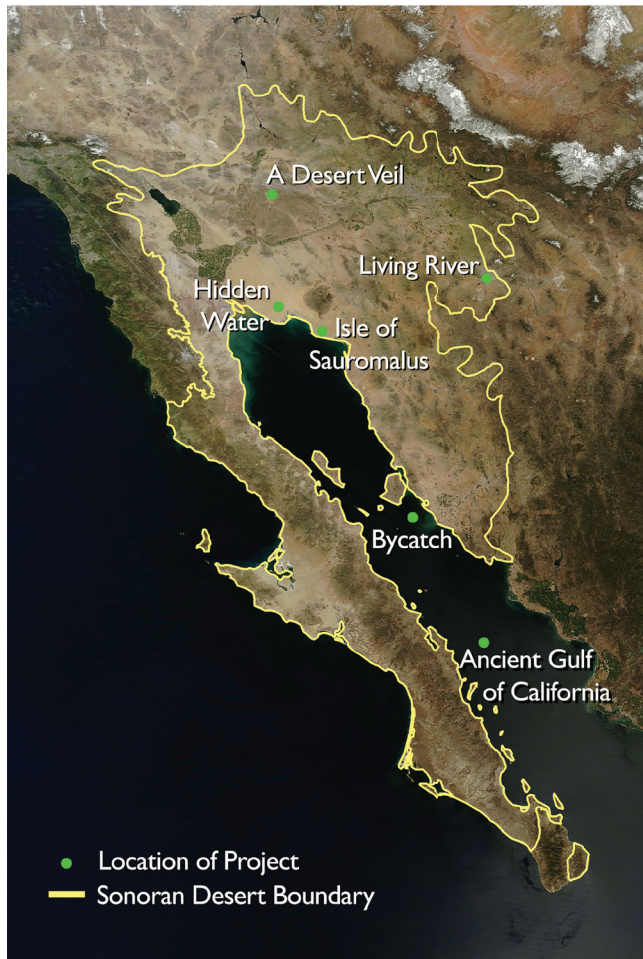
Finding common ground between artists and scientists

The artists and scientists came together in 6&6 with a shared love of the Sonoran Desert and a desire to understand this unique biome and communicate its wonders to others. Where

Table 1. 6&6 artist–scientist pairings and artwork.

Artist–scientist pair	Final artwork
Benjamin M. Johnson and Benjamin T. Wilder	<i>Hidden Water: Pozos of the Gran Desierto</i>
Charles (Chip) Hedgcock and Mark A. Dimmitt	<i>A Desert Veil: Soft Plants in a Harsh Landscape</i>
Heather Green and Taylor Edwards	<i>Isle of Sauromalus</i>
Kathleen Velo and Michael Bogan	<i>Living River: Flow of Life in the Santa Cruz</i>
Maria R. Johnson and Eric Magrane	<i>Bycatch</i>
Thomas (Tom) Baumgartner and Scott E.K. Bennett	<i>Paleogeographic Rendering of the Ancient Gulf of California</i>

Note: Complete descriptions and images of the final artwork as well as biographies of the participants can be found at <http://ngen6and6.com>.

**Figure 2. Geographic focus of each 6&6 pairing.**

there were differences in professional approach or worldview between the artists and scientists, a personal connection or friendship between the 6&6 artist–scientist pairs was important for the longevity, strength, and success of their individual collaborations. For example, one pair formed a strong personal bond over their shared fascination with a river running through Tucson despite their very different ways of conceiving of the river and its flow, i.e., the visual or artistic form of the water versus its chemical quality or ecological profile.

Within the first year of the project, a couple original members withdrew for personal or professional reasons and

new participants joined and were paired up. Especially at the beginning of 6&6, group camping trips, outings, and pot-lucks promoted personal connections and supported overall group cohesion. The establishment of this shared 6&6 culture also supported the group’s resilience and flexibility, so that changes in 6&6 pairs early on did not threaten the overall success of the project. One participant who joined after a year into the project expressed disappointment in not being able to participate in the early formative group events, but felt they were nonetheless able to hit the ground running with their partner.

The 6&6 pairings were allowed to unfold organically on the basis of natural (personal and professional) affinities, and this iterative process ensured that the artist–scientist pairs were on the path of discovery together from the beginning. As was described by one participant,

“I really appreciated that the idea was the paired artists and scientists would actually define the project and the question and the inquiry part of it together from the beginning rather than that already being defined and one of the collaborators being brought on.”

The participants also highlighted the importance of flexibility, openness and curiosity when connecting with their partner and developing their project together. In the words of one participant,

“I think that we were both curious about the other person’s process and we were both really open to learning about the topic, about how the other person approached it, and we also enjoyed seeing things from another person’s perspective.”

Importantly, the 6&6 approach did not place more emphasis on science over art (or vice-versa), which ensured, as one participant explained, “that anything that came out of [the project] was going to be both visually dynamic and interesting but also quite scientifically accurate.” The artist and scientist participants felt equally valued and were on the same footing from the beginning, empowering them to drive the formation of their art–science projects together.

Embracing the rub: Friction as a driver of creativity

The 6&6 participants quickly learned that transdisciplinary art–science collaboration is about friction, the rub between professional approaches, communication styles and vocabulary, and different ways of looking at the world. One participant reflected,

“Us bringing these very different perspectives to the same task... I feel like that’s the real value. And by artists knowing how scientists work and by scientists knowing how artists work. That’s gold right there.”

Although a collaborative process of this depth and duration (i.e., time commitment) was challenging at times, working with someone very different from themselves on a shared product over years—and committing to work together to see the project through—brought tremendous rewards. Almost all the participants highlighted the value of being forced to think outside the box and get outside their comfort zone. For example,

“Number one [value of an art–science collaboration] is essentially to shake us out of our own rut that we get in sometimes... trying to step back from the science a bit and think about where your science might interact or intersect with art... I think [that] naturally forces you out of that narrow groove you might be in and makes you look at the area or region in a much broader way.”

Many participants also described 6&6 as the first time they worked in such an in-depth or extended way with someone outside their usual professional field. One participant described the positive impact of working through the tension they confronted while collaborating with someone operating within a different methodology or mindset:

“It’s the first time I’ve been working so closely with somebody who is coming from a very different mindset and that was really unique and interesting to me... it definitely challenged me in ways not only to explain my intentions in a different way or more in-depth way but it challenged me also to widen my thoughts or expectations about [what] the project was or is.”

In order to overcome any barriers to collaboration, another participant realized the importance of framing the transdisciplinary work as being mutually supportive despite having differing areas of expertise:

“I think I’ve always tried to make an effort to do interdisciplinary and cross-disciplinary work, it’s something I’ve always been really open to and thought I was doing this sufficiently... But this definitely took it into a new level, which breaks into this more transdisciplinary approach... This was very different because we started together and finished together, so we were a supporting team entirely despite having our own areas of expertise.”

The transdisciplinary approach required a tremendous amount of time and effort, much more than any of the participants were expecting. Because the initiative lasted longer than expected (in total about four years), some of the participants experienced burnout at various points, taxed by the total number of hours required for their project’s completion. Although the ebb and flow of activity differed for each 6&6 pair, taken all together, most of the participants were grateful for the extended timeline however, pointing to the space it allowed for the collaboration to evolve and unfold. In the words of one participant,

“One [successful component of 6&6] was that the timeframe was very open. When we started we didn’t know what we were going to do, how it was going to work, and we weren’t locked in. If we had to do this in a year we wouldn’t have done anything nearly as meaningful.”

“I’m a different person now”: Impact on the 6&6 participants

6&6 affected the participants beyond their professional lives, often in ways that surprised them. All the participants highlighted the new friendships and community they formed during the four years, and many spoke about how fun it was to connect with people outside their usual personal and professional circles. One participant commented, “Artists and scientists out together in nature is just SO FUN!,” highlighting the importance of play in creative collaboration. The participants also spoke about how the initiative cultivated for them an even deeper love or appreciation of the Sonoran Desert.

Of course individuals, like disciplines, cannot always be siloed, and many of the participants talked about how they felt like they could more fully embrace the artistic or scientific side of themselves after participating in 6&6. Several of the artists and scientists also reflected on how they are more open to an artistic or scientific framework or approach in their current work. This transformation is illustrated by the following two quotes from scientist and artist participants:

“After going through this experience... I would be much more prone to think about integrating an artistic approach with my science, or from the start of a scientific project thinking about how I might be able to communicate either the process of doing the science or the results of the science in a much more artistic way.”

“You know, artists out there, we have a lot of personality and we brand ourselves. Every piece of artwork is like our brand, and we’re trying to grow our brand. And when I started working with my [scientist] partner I realized that I started to get this sense of responsibility that’s kind of like greater than myself.”

Several of the participants (especially the scientists) reflected that they are now more likely to engage in

transdisciplinary work in the future, even while recognizing the potentially significant time and energy commitment involved. As described by one participant,

“It has definitely empowered me and made me feel even more comfortable to work with what on the outset are really foreign disciplines and foreign approaches... it kind of feels like some barriers are falling away in terms of the approaches I feel like I can take and pursue in fundamental, robust projects.”

Complex problems require complex solutions: Art–science as knowledge generation

The world itself is complex and cannot be neatly organized into the arts and the sciences, i.e., disciplines and epistemologies are themselves human attempts to frame and interpret the world. The participants in 6&6 found that the transdisciplinary art–science approach better supports understanding the complexity of their work and the questions they ask. As one participant reflected,

“We can’t possibly understand something in the world just through science or art, we can understand a piece of it, and I don’t think we can ever understand the full picture of something, that’s beyond human capability, but we can certainly get closer both to understanding and finding knowledge and creating that connection and sense of place through this [transdisciplinary] work.”

Similarly, many of the participants reflected that the transdisciplinary approach supports more effective communication of hard-to-grasp complexities. In other words, merging artistic and scientific perspectives tells a more complete and impactful story than what would have been possible with only a scientific or artistic approach. Several participants also spoke about how art–science collaborations are effective ways to get people to care about particular issues or regions. As one participant explained,

“[The transdisciplinary approach] makes the [art–science] products more potent... I feel like the reach is a little stronger, that connection you make with an individual is deeper, and that the message is clearer. It strengthens the product in terms of that narrative that comes out of the work.”

Finally, several of the participants highlighted the way in which the transdisciplinary approach is particularly well suited for developing innovative solutions to increasingly complex problems. For example,

“The state of the world right now, and the grand challenges we face environmentally, culturally, and socially are not going to be able to be adequately addressed in siloed disciplines or siloed ways of thinking.”

Both the arts and the sciences generate meaning in their own unique ways. Combining the two schools into the practice of *art–science* can be a radical and transformative approach to engaging with the world and its inhabitants. In the words of one participant,

“Scientists pursue knowledge and artists pursue beauty. And sometimes a lot of art won’t have substance to it, and sometimes science won’t be so beautiful. And I think when those two disciplines collaborate together then it can create more of a clear message. Beauty that has meaning. Data, or maybe important research, is communicated in a more personal way.”

The dash in art–science: Science shapes art, and art shapes science

The six art installations that were presented at the final exhibition (<http://ngen6and6.com>, 6&6 catalogue) represented a diverse range of final products; some works were more art forward, and others more science forward (figure 3). Each installation explored different aspects of the Sonoran Desert and Gulf of California with the intention of having the viewer take something away from each pairing, feeling more connected to the magnificence of the desert and sea, and their place in it (figure 4). In some of the 6&6 pairings, the artist and the scientist played clearly defined artistic and scientific roles, and in other collaborations there was great fluidity around who exactly was the scientist (i.e., doing science) and who was the artist (i.e., doing art) at any given time.

In addition to fluidity existing between who was performing artistic and scientific functions at certain points along the project implementation, the pairs’ work together would also flow along the spectrum from interdisciplinarity and multidisciplinary to transdisciplinarity. For example, the pairs worked closely in a transdisciplinary manner at the beginning of their collaboration by shaping the project goal and methods or approach together. After the initial phase, the collaborations would go through phases of working independently to generate content that they would share with their collaborator once completed. Then their efforts would reunite to create the final, integrative artwork for the exhibition. Some artists reflected that the collaboration had a very “transdisciplinary feel” (especially during times when artist–scientist pairs were collecting scientific data together or creating an artistic product together) up until the creation of the final artwork and installation when the artists took a much stronger lead and did the heavy lifting. The ebb and flow of the type of collaboration throughout the multiyear process demonstrates the varying ways that an art–science collaboration operating within an overall transdisciplinary framework can unfold.

Although the final 6&6 exhibition illustrated the ways in which the science shaped or was incorporated into the art, the art influenced the scientific process as well. To name a few examples, data was collected in the field that would not have been otherwise (e.g., the use of camera traps), scientists



Figure 3. Mosaic of 6&6 final artwork. Photographs: Tim Fuller. Clockwise from upper left: *Hidden Water: Pozos of the Gran Desierto* (Johnson and Wilder), *Isle of Sauromalus* (Green and Edwards), *Bycatch* (Johnson and Magrane), *A Desert Veil: Soft Plants in a Harsh Landscape* (Hedgcock and Dimmitt), *Living River: Flow of Life in the Santa Cruz* (Velo and Bogan), and *Paleogeographic Rendering of the Ancient Gulf of California* (Baumgartner and Bennett). Complete artwork descriptions, biographies, and supplemental materials can be found at <http://ngen6and6.com>.

have presented on the fruits of the art–science collaborations at conferences, and several scholarly papers have resulted from the collaborations (Edwards and Green 2019, Magrane and Johnson 2017, Zamora et al. 2019). In at least two cases, the scientists reflected that they would have not followed particular lines of inquiry had it not been for the art–science collaboration.

Although it is impossible to define exactly what a transdisciplinary art–science collaboration is or looks like, 6&6 demonstrated that the *bi-directionality* between the two disciplines (the dash in the term *art–science*) is of utmost importance. The quality and depth of the back and forth and the commitment to engage beyond individual disciplines is what helped shape the ultimate outcome of 6&6. Through participation in 6&6, the artists and scientists strengthened both their willingness and capacities for transdisciplinary collaboration in conservation practice.

Conclusions

Inspired by the precedents of art–science thinking, 6&6 was a contemporary experiment in taking the time to co-create a shared vision for the Sonoran Desert. Although we began 6&6 without any predetermined model or design, over the course of the initiative our experience shaped several key insights that we hope will provide guidance for future transdisciplinary art–science collaborations. To that end, the following recommendations are organized by project phase.

Recruitment. (1) Clearly state the overall goal or focus of the art–science collaboration including the specific topic, place, or organizing concept. (2) Consider open calls for participation with strategic recruitment efforts to increase participation from diverse individuals and networks. Targeted recruitment may also be needed for scientists given reduced academic incentivization for non-traditional scientific outputs.



Figure 4. Public enjoys the 6&6 exhibition. Photograph: Tim Fuller.

Design. (1) Schedule social events (e.g., dinners or potlucks, hikes, camping trips) where artist or scientist participants can get to know each other and their work and develop overall group cohesion. (2) Designate a project leader who helps maintain momentum, serves as a point person for group decisions, and addresses internal (e.g., cohort dynamics) and external (e.g., funding, gallery space) communications. The project leader may be an outside facilitator, or may be chosen from within the cohort of artist or scientist participants. The project lead may also rotate. (3) Invite artist or scientist participants to choose their own collaborator on the basis of shared interests and rapport (e.g., artist or scientist participants may determine the pairings collectively in a group or submit their preferred partners privately to the project leader who then makes the pairings). (4) Empower the artist or scientist participants to shape the overall goal, structure, and timeline of the overall project (e.g., development of a vision statement, development of initiative design principles, setting clear expectations regarding time commitment and final products). (5) Establish expectations, needs, and guidelines for compensation at the outset. (6) Undertake some form of documentation to track what may be an unpredictable progression of the effort (e.g., designating a note-taker at all meetings, creating a website or blog with updates on the group's progress, photographing group events and individual artist-scientist work sessions in the field, lab or studio).

Implementation. (1) Support overall group teambuilding and cohesiveness by scheduling regular social events or check-ins (e.g., quarterly or bi-annually) in which participants can give updates on their work together, receive feedback from the group, and discuss any challenges. (2) Schedule regular check-ins (e.g., quarterly) between the project leader and individual artist or scientist pairings to discuss progress on their collaboration, identify the ways in which both the art and science perspectives or approaches are being integrated, and brainstorm solutions to any challenges. (3) Set and follow

internal deadlines to keep momentum going. Deadlines can be flexible on the basis of the realities of the effort needed and preferences of the group; however, they are essential to keep the participants focused over a long-term project given other personal and professional commitments and responsibilities.

Final product. (1) Set the final outcome or end product target (e.g., art exhibition, scientific paper, public conservation action or event) and deadline as early in the initiative as possible. (2) If the goal is to exhibit in a gallery, work with gallery spaces at least 2 years in advance of the desired show date. Find curators who are willing to take risks on work for which they cannot yet see the final products but

believe in the overall concept and caliber of project participants. (3) Provide funding to artist-scientist pairings to at least cover costs associated with creation of the final product (e.g., art supplies, printing costs). (4) Support public impact of the art-science collaboration by planning educational or participatory community events (e.g., art shows, citizen science events) and harnessing local or national media.

Reflection. (1) Enable participants to provide feedback to the organizing entity or project lead regarding the process with the overall group as well as their individual artist-scientist pairing. (2) Host a final celebration or meeting in which participants can discuss lessons learned and share the ways in which this collaboration will shape their work moving forward.

We hope that the recommendations above may be useful for others in designing transdisciplinary art-science collaborations. Although we acknowledge that there are many different ways that art-science collaborative projects could be conceptualized and organized, we believe these recommendations are open and adaptable. Our 6&6 experiment found that artists and scientists unravel the stories of nature through different but surprisingly complementary means. United in the creative process, the two can be a powerful force with an even greater capacity to connect, engage, and deepen our understanding and appreciation of the world we live in, and in turn improve conservation practice.

Supplemental material

Supplemental data are available at *BIOSCI* online.

Acknowledgments

The authors acknowledge the University of Arizona Museum of Art (UAMA) for hosting the 6&6 exhibition, including special thanks to James Burns and UAMA staff Olivia Miller and Nathan Saxton. The 6&6 interactive touchscreen website was created by Sarah E. Clark, Lauren Moffatt, and Jarrod

Henderson. The 6&6 catalogue was designed by Amanda Gonzalez. 6&6 was made possible through the support of the Agnese Nelms Haury Program in Environmental and Social Justice, Cox Communications, The Confluentcenter for Creative Inquiry (University of Arizona), Sarah Smallhouse, and anonymous supporters, with administrative support by the International Community Foundation. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US government. We thank the anonymous reviewers of an earlier version of the present article for their detailed and helpful comments.

References cited

- Born G, Barry A. 2010. Art-science: From public understanding to public experiment. *Journal of Cultural Economy* 3: 103–119.
- Buckland D. 2012. Climate is culture. *Nature Climate Change* 11: 1–4.
- Butz D and Besio K. 2009. Autoethnography. *Geography Compass* 3: 1660–1674.
- Canfield MR, ed. 2011. *Field Notes on Science and Nature*. Harvard University Press.
- Choi B and Pak A. 2006. Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine* 29: 351–364.
- Dixon DP, Hawkins H, Straughan ER. 2013. Wonder-full geomorphology: Sublime aesthetics and the place of art. *Progress in Physical Geography* 37: 227–247.
- Edwards T and Green H. 2019. Chuckwallas of Punta La Cholla. *Sonoran Herpetologist* 32: 19–26.
- Hawkins H, Marston SA, Ingram M, Straughan E. 2015. The art of socio-ecological transformation. *Annals of the Association of American Geographers* 105: 331–341.
- Humboldt A, Bonpland A. 1807. *Essai sur la géographie des plantes, accompagné d'un tableau physique des régions équinoxiales*. Levrault and Schoell.
- Ingram M. 2013. Ecolitics and aesthetics: The art of Helen Mayer Harrison and Newton Harrison. *Geographical Review* 103: 260–274.
- Januchowski-Hartley SR, Sopinka N, Merkle BG, Lux C, Zivian A, Goff P, Oester S. 2018. Poetry as a creative practice to enhance engagement and learning in conservation science. *BioScience* 68: 905–911.
- Klein JT. 2008. Evaluation of interdisciplinary and transdisciplinary research: A literature review. *American Journal of Preventive Medicine* 35(suppl. 2): S116–S123.
- Magrane E, Cokinos C, eds. 2016. *The Sonoran Desert: A Literary Field Guide*. University of Arizona Press.
- Magrane E, Johnson M. 2017. An art-science approach to bycatch in the Gulf of California shrimp trawling fishery. *Cultural Geographies* 24: 487–495.
- McDermott A. 2019. Artists and scientists come together to explore the meaning of natural sound. *Proceedings of the National Academy of Sciences* 116: 12580–12583.
- McMahon E, Monson A, Weinstein BM, eds. 2012. *Ground/Water: The Art, Design, and Science of a Dry River*. Confluentcenter for Creative Inquiry, University of Arizona.
- Mirocha P, Magrane E, Terkalian B, Soria M, Coleman DL, Milstead M, Koopman K. 2015. The Tumamoc Hill arts initiative: A portfolio of site-based art and writing inspired by a history of Sonoran Desert science. *Journal of the Southwest* 57: 265–303.
- Morueta-Holmea N, Engemann K, Sandoval-Acuña P, Jonas JD, Segnitz RM, and Svenning J. 2015. Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. *Proceedings of the National Academy of Sciences* 112: 12741–12745.
- Moret P, Muriel P, Jaramillo R, Dangles O. 2019. Humboldt's *Tableau Physique* revisited. *Proceedings of the National Academy of Sciences* 116: 12889–12894.
- Sassor RR. 2015. Envisioning a climate for change. *Stanford Social Innovation Review* (18 March 2015). http://ssir.org/articles/entry/envisioning_a_climate_for_change.
- Snow CP. [1959] 2012. *The Two Cultures*. Cambridge University Press.
- Steinbeck J, Ricketts, EF. 1941. *Sea of Cortez: A Leisurely Journal of Travel and Research*. The Viking Press.
- Stember M. 1991. Advancing the social sciences through the interdisciplinary enterprise. *Social Science Journal* 28: 1–14.
- Stokols D, Misra S, Moser RP, Hall KL, Taylor BK. 2018. The ecology of team science: Understanding contextual influences on transdisciplinary collaboration. *American Journal of Preventive Medicine* 35(suppl 2): S96–S115.
- Tracey F. 2009. Bio-art: The ethics behind the aesthetics. *Nature Reviews Molecular Cell Biology* 10: 496–500.
- Straughn E, Nicholson PJ, Magrane E. 2013. *Curating the cosmos*. Cargo Collective. <https://cargocollective.com/curatingthecosmos>.
- Swanson FJ, Goodrich C, Moore KD. 2008. Bridging boundaries: Scientists, creative writers, and the long view of the forest. *Frontiers in Ecology and the Environment* 6: 499–504.
- Swanson FJ. 2015. Confluence of arts, humanities, and science at sites of long-term ecological inquiry. *Ecosphere* 6: 132.
- Thornes JE. 2008. A rough guide to environmental art. *Annual Review of Environment and Resources* 33: 391–411.
- Woodward K, Jones III JP, Vigdor L, Marston SA, Hawkins H, Dixon DP. 2015. One sinister hurricane: Simondon and collaborative visualization. *Annals of the Association of American Geographers* 105: 496–511.
- Wilder BT, O'Meara C, Medel A, Narchi N, Aburto-Oropeza O. 2013. The need for a next generation of Sonoran Desert researchers. *Conservation Biology* 27: 243–244.
- Wilder BT, O'Meara C. 2015. The continuum of desert research. *Journal of the Southwest* 57: 163–186.
- Willis CG, Ruhfel B, Primack RB, Miller-Rushing AJ, Davis CC. 2008. Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change. *Proceedings of the National Academy of Sciences* 105: 17029–17033.
- Wulf A. 2015. *The Invention of Nature: Alexander von Humboldt's New World*. Knopf.
- Yetisen AK, Coskun AF, England G, Cho S, Butt H, Hurwitz J, Kolle M, Khademhosseini A, Hart AJ, Folch A, Yun SH. 2016. Art on the nanoscale and beyond. *Advanced Materials* 28: 1724–1742.
- Zamora HA, Wilder BT, Eastoe CJ, McIntosh JC, Welker J, Flessa KW. 2019. Evaluation of groundwater sources, flow paths, and residence time of the Gran Desierto Pozos, Sonora, Mexico. *Geosciences* 9: 378.

Sarah E. Clark (sarah@imageandsoundgroup.com) is the founding director of Image and Sound Group, in Redlands, California. Eric Magrane is an assistant professor in the Department of Geography at New Mexico State University, in Las Cruces. Thomas (Tom) Baumgartner is the creative director for AlphaGraphics Commercial Printing Services, in Tucson, Arizona. Scott E. K. Bennett is a geologist, tectonicist, and earthquake scientist with the US Geological Survey's Geology, Minerals, Energy, and Geophysics Science Center, in Moffett Field, California. Michael Bogan is an aquatic ecologist in the School of Natural Resources and the Environment at the University of Arizona, in Tucson. Mark A. Dimmitt is a botanist and vertebrate biologist formerly affiliated with the Arizona-Sonora Desert Museum, in Tucson. Taylor Edwards is a herpetologist, evolutionary biologist, and conservation geneticist at the University of Arizona Genetics Core, in Tucson. Heather Green is an assistant professor of book arts at Arizona State University, in Tempe. Charles (Chip) Hedgcock is a black and white fine art photographer and a professional photographer in life sciences and medicine, working most recently in the Department of Entomology at the University of Arizona, in Tucson. Benjamin M. Johnson is a visual artist and curator in Tucson, Arizona. Maria R. Johnson is a visual artist and a master of science candidate in marine resource management at Oregon State University, in Corvallis. Kathleen Velo is a photographic artist and fine art studio artist in Tucson, Arizona. Benjamin T. Wilder is the director of the Desert Laboratory on Tumamoc Hill at the University of Arizona and director and cofounder of the Next Generation Sonoran Desert Researchers, in Tucson, Arizona.