Communicating Environmental Science through Art: Scope, Applications, and Research Agenda

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Abstract

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Traditionally science and art have been distinctly separate disciplines rarely practiced in concert, despite substantial evidence that art enhances understanding of science, technology, engineering and mathematics (STEM). Recently, art has been a means of communicating science, including environmental research. However, this movement of using art to communicate science has yet to be examined on a large scale. This study describes the key characteristics of the environmental science art movement by creating a database of 252 artworks and corresponding artists, coding for key data, and using a grounded theory approach to text analysis of artwork's purpose statements. Results of the analysis show that environmental science art is a recent and increasingly prevalent phenomenon. Environmental science artists are gender balanced, reflect the age of environmental scientists and artists, and are trained in the arts 95% of the time and trained in the sciences 48% of the time. Catalogued science artworks date back four decades, with a majority of the artwork occurring since 2007. The artworks typically address issues of climate change, biodiversity, and highlight the connection between humans and the environment. Stated applications of the artworks include their artistic value, ability to increase awareness and educate, opportunity for interdisciplinary collaboration, ability for political commentary and activism, engagement and simulating experiences and connections to the environment, ability to foster dialogue towards a solution, and ability to be utilitarian. Overall, this study provides an overview of the scope and state of environmental science art, providing background and a foundation for future studies on how art could be used to communicate science and research about the environment.

Key Words: Science Communication, Science Art, Science Outreach, Environmental Science, Science Education

1 Introduction

1.1 Environmental Science Communication and Outreach

A key responsibility of scientists is effectively communicating scientific research to the public [1-8]. Scientists also consider public outreach and communication integral and beneficial to their scientific research [4,8,9]. Additionally, leading scientific organizations have made numerous efforts to educate scientists in science communication, such as the Leopold Leadership Program[10] or the American Association for the Advancement of Science tools for communicating science[11].

Despite these efforts, public outreach and science communication participation rates are still low among scientists [12-14]. These low rates are influenced by several different factors. For instance, there is no institutional award system for scientists that demonstrate exemplary, innovative outreach and communication. Also, there remains a pervasive belief among scientists that scientific terms and concepts may be too difficult to communicate to the public [3,7,15-17].

Art and science have typically operated as distinct disciplines, rarely practiced in concert. Despite this separation, there is substantial evidence that art enhances people's understanding and learning of specific and technical subject matters in the science, technology, engineering, and mathematic (STEM) fields[18-21]. Art also has the ability to create emotional connections between its subject and the public and empower communities by fostering consciousness and agency of environmental issues through direct and passive engagement [18,20-23]. Simulating experiences emotionally connects the public to the environment, which is crucial for public awareness and caring about environmental issues [24-27].

1.2 Environmental Science Communication and Outreach through Art

One potential solution to improve science communication and outreach efforts is to foster interdisciplinary collaboration between the sciences and the arts. Although there has been a recent increase in interdisciplinary collaboration among the scientific disciplines, there is limited documented collaboration between the sciences and the arts[28,29]. However, collaboration between scientists and artists has recently emerged, serving to create awareness, educate, and engage the public about environmental science.

Several case studies document the use of art in the environmental sciences. For instance, a 2014 study published by Schneller and Irizarry documented that environmental science portrayed in murals fostered a community's pro-environmental attitudes and encouraged an awareness of sea turtle conservation issues in Mexico. This attitudinal change arose from the mural's ability to educate and engage the community's collective consciousness [20]. However in general, researchers have not studied many environmental science art efforts even though some are well documented in the media, such as the annual Dance Your PhD contest hosted by the American Association for the Advancement of Science (AAAS)[30], AAAS Art Gallery[31], and various articles in the journal Nature[31,32]. Subsequently, there has yet to be a large study that examines many artworks and artists, in order to describe the science art movement.

1.3 Research Questions

This descriptive study aims to address three fundamental questions about the environmental science art movement: 1) who is doing environmental science art, 2) what are the characteristics of environmental science artworks, and 3) what are the topics and benefits of environmental science art. In order to explore these questions, we collected data for nine categories: environmental science artist's gender, year of graduation, education or training in the science or arts, employment and environmental science artwork's medium, production dates, characteristics, topics, and applications.

2 Methodology

2.1 What is Environmental Science Art?

For this study's purpose, environmental science art is the creative expression of environmental science that produces works that appeal to the human senses, intellect, or emotions. The criteria for environmental science art was twofold. Firstly, the artwork had to be considered art. Secondly, the artwork had to be within the environmental science realm. These two definitions were applied with the following protocol:

The criteria for art were:

- The work was explicitly labeled as art.
- OR represents a traditional artistic medium in the eye of the viewer that includes, but not limited to, photography, painting, sculpture, digital art, drawing, etching, poetry, dance, theater, performance art, or public art.
- AND its primary purpose is the creative expression that appeals to the human senses (i.e. visually, olfactory, auditory) in order to influence the intellect and/or emotions, and the artwork provides a space for interpretation for the viewer.

The criteria for environmental science were:

- The topic (as determined based on artwork descriptions and/or the perceptions of the data coder) of the artwork is in the environmental science realm, based on the definition given by the National Science Foundation[33]: the multidisciplinary study of processes and interactions among the atmosphere, biosphere, cryosphere, hydrosphere, lithosphere, and socio-economic systems[33]. This field includes, but is not limited to, ecology, biology, chemistry, zoology, environmental and public affairs, mineralogy, oceanography, limnology, soil science, geology, atmospheric science, environmental economics, environmental justice, environmental policy and management, and geography.

An example of environmental science art could be a photo series depicting communities impacted by climate change or a musical composition addressing albedo[34], an atmospheric process that affects climate and weather. However, an installation that addresses light's refraction properties would not be considered environmental science art, since the light's physical properties are not framed in the context of the environment.

Similarly, the scope of art is also limited. The architecture of a LEED certified building, however visually appealing, is not considered art in this study because the primary purpose of the art is structural.

Other examples of environmental science art included in the database included a painting of penguins drifting on ice platforms[35] and park sculptures made out of landfill waste[36]. These two examples are considered environmental science art because their topics are within the realm of environmental science (climate change and waste pollution, respectively), and are represented through traditional visual art media (painting and sculpture, respectively). However, an example of art that was excluded from the database was the architectural design of the Yale School of Forestry, Kroon Hall[37]. This building's design has won an Excellence in Design + Construction Award, and was designed to be a no-waste sustainable building. Although sustainability would fall into the realm of environmental science, the primary purpose of this building was for structure and to create space for offices and classrooms. Because the primary purpose of this building's architecture was not the creative expression of sustainability but rather the support and structure for its department, it was excluded from the database of environmental science art.

Only modern environmental science art, or art produced in the 20th or 21st century, was included. This limitation was imposed because this study aims to address the environmental science art movement within the context of the modern environmental movement. Despite the historical relationship between nature and art, this modern temporal limitation enables the research question to be more focused and relevant. As supporting evidence for the validity of this decision, the search efforts resulted in art produced exclusively within the specified temporal range.

2.2 Data Collection and Coding

This descriptive study's objective is to describe the field of environmental science art and to develop a basic understanding of how environmental science is communicated through art. This study coded for data for four variables for environmental science artists (gender, year of graduation, education or training, employment) and five variables for environmental science artworks (medium, production date, topic, characteristics, applications) in the database. This study also used a grounded theory approach to textual analysis of the purpose statements given by the artists to code for topics and applications of the art[38,39]. In addition, an initial pilot study was conducted with 86 artworks and 64 science artists to refine the initial codes and process.

2.2.1 Database Creation

We collected data between September 2014 and March 2015 by searching Google, Google Scholar and Web of Science for the keywords: environmental science art. The collection of data was enhanced with opportunistic recommendations of environmental science art provided by colleagues. Environmental science art was the only search term used, rather than a variety of search terms such as environmental science poetry, environmental science dance, or environmental science sculptures.

We followed each search through the twentieth page of results, and followed embedded links within the result pages through to the third level. The artwork of each relevant artist was represented at least once, but no more than five times. If an artist had multiple environmental science artworks, we included every fifth artwork in the database. This search concluded at the data saturation point, which is the point when three consecutive searches yielded the same science artists.

Each artwork was determined to be environmental science art based on the definition provided, which yielded 203 artists and 252 artworks. Artistic mediums like poetry, dance, and performances constitute only 4% of the artworks in the database based on the search term: environmental science art. We concluded that these media were likely under-represented in the database, so we subsequently decided to exclude non-visual artists and artworks from the final database and focus this study exclusively on the visual arts. After excluding the non-visual artists and artworks, we have a total of 196 visual artists and 242 visual artworks in the database. The National Endowment for the Arts defines the visual arts as an aesthetic piece through painting, sculpture, photography, printmaking, drawing, craft, and public art[40].

2.2.2 Database Coding

After we created the database of environmental science artists and artworks, we collected data and coded for certain categories. We collected data on an artist's gender, year of undergraduate graduation, education or training in the arts, and place of employment.

Gender determination was based on the used pronouns in the artist statements or artwork purpose statements, gender affiliation of a name, or the apparent gender from a photograph. Any ambiguity resulted in an exclusion from this analysis.

The year of undergraduate education served as a proxy for age. We used data from the National Center for Education Statistics to find the age of undergraduate graduation[41]. The average age of students entering college was 18[42]. To find the average age of college graduation and the age of environmental science artists, we used the following formulas, with 0.337, 0.502, and 0.161 being the proportion of students graduating in 4 years, 5 years, or 6 years, respectively:

$$\text{Average age of college graduation} = \frac{[(0.337)(22\text{ years}) + (0.502)(23\text{ years}) + (0.161)(24\text{ years})]}{(0.337+0.502+0.161)} = 23\text{ years}$$

Current age of environmental science artist = 2015 – (Year of college graduation) + (Average age of college graduation)

Age of environmental science artist at art production = (Year of art production) – (Year of college graduation) + (Average age of college graduation)

We defined education or training as the attainment of an official degree in a subject, post baccalaureate classes, or an artistic apprenticeship. Apprenticeships in the arts have been a method of education for artists by having a mentor that teaches a craft to the student artist[43]. This definition tried to be inclusive of all formal and informal methods of training in the sciences and the arts.

Since 82% of the environmental science artists in the database specified working for an institution or organization in the U.S., and 75% of the environmental science artworks were exhibited in the U.S., we concluded that U.S. comparison data was reasonable and appropriate. So the comparison data used in this study came from the U.S. Department of Education, U.S. Department of Labor, and the National Science Foundation.

We used the R programming package to conduct all data analysis. Any data that was not available was recorded as such and that data point was excluded from its respective analysis.

2.2.3 Grounded Theory Approach to Text Analysis

To describe the topics and applications of an artwork, we used a grounded theory approach to textual analysis using the artworks' purpose statements. Grounded theory is an approach to text analysis that requires systematic iterations of coding[44]. These multiple rounds of coding allows the inductive construction and refinement of themes[44]. In this case, the themes were about the topics and applications of the art derived from the artwork's purpose statement. Any artworks without an accompanying purpose statement were excluded from this portion of the analysis.

3 Results and Discussion

3.1 Environmental Science Artist Population Estimate

In order to estimate the population size of environmental science artists, we conducted a preliminary scoping exercise in which we used the trial search terms: environmental science poetry, environmental science dance, and environmental science sculpture. We chose these terms because poetry, dance, and sculpture represent three different artistic mediums. The search results yielded a 5% repetition with the results yielded for the database search term: environmental science art. This indicates that the database is only encompassing a small portion of the environmental science art movement.

To estimate the potential size of the population of environmental science artists, we used the following proportion:

$$\frac{\text{203 environmental science arts in database}}{\text{Total number environmental science artists}} = 0.05$$

If the database accounts for approximately 5% of all the science artists documented online, then the population of environmental science artists include at least 4000 individuals. This estimate assumes that the discovery rate of environmental science artists is equal between the trial search terms and the search term used in this study. This estimate does not account for artists, whose work is not available online or is posted on non-English websites. Also, artists who use media specific terms other than "art" to describe their work are likely not thoroughly accounted for in this estimate, with the exceptions of dancers, poets, and sculptors.

In order to generate an estimate of the population size of environmental science visual artists, we also conducted this scoping exercise with the terms: environmental science art installations, environmental science paintings, and environmental science photography. These terms were chosen because they were three different mediums of visual arts. This second scoping exercise yielded a 30% repetition with the results from the database search term: environmental science art. We conducted the same calculation:

$$\frac{\text{196 environmental science visual arts in database}}{\text{Total number environmental science visual artists}} = 0.3$$

This yielded a total of approximately 650 environmental science visual artists.

The assumptions and limitations of the previous calculation hold true for this one as well. If we expanded this scoping exercise of visual artists to include other search terms, such as environmental science drawings or environmental science sculptures, it could have uncovered a larger population of environmental science artists. Future studies should target the performing, written, and other art forms in order to more fully construct a picture of the environmental science art movement.

3.2 Who?: Environmental Science Artists

3.2.1 Gender Distribution

Out of the 197 environmental science visual artists in the study, 49% of environmental science artists were female and 51% were male. In comparison, the gender distribution of environmental scientists in the United States which is 28% female and 72% male and the gender distribution of artists is 52% female and 48% male[45] (Table 1).

This equal gender distribution of people with science training is noteworthy because of the historical unequal gender distribution of the environmental science field[45-47]. A historical underrepresentation of women would suggest that we would see this same underrepresentation of women with science training in the environmental science art population, which is not the case. However, these gender distributions of people with art or science training could also reflect the artist workforce, which is gender balanced (Table 1). Future research into the nuance of the gender distribution in the environmental science art population, and why the gender distribution of people with science or art training seem to reflect the gender distribution of the art workforce and not the environmental science workforce, is necessary to draw any further conclusions.

We also examined gender distribution in relation to education and place of work. These descriptors were chosen since the gender gap in environmental science fields, particularly in academic and research institutions, is a persistent concern in many professions[46,47].

Group	**Female**	**Male**
Entire environmental science art sample (n=197)	49%	51%
People with science training/education (n=79)	49%	51%
People with art training/education (n=158)	52%	48%
People who work in art departments at academic institutions (n=21)	81%	19%
People who work in science departments at academic institutions (n=17)	41%	59%
Environmental scientists*	28%	72%
Artists*	52%	48%

Table 1: Gender distribution of the environmental science population and its subsets from the database, as compared to environmental scientists and artists (asterisk indicates data from U.S. Department of Labor).

Mostly there was gender balance along the lines of education or workplace (Table 1). The exceptions were in art and environmental departments within academia.

People who worked for art departments had substantially more representation of women than men. In science, social science, and interdisciplinary science departments there were more men than women (Table 1). Despite this skew towards men in science departments, this gender distribution is more balanced than the gender distribution of the environmental science workforce.

Both of these subgroups have a higher representation of women than their respective average gender representations. These differences could possibly be explained because women have been shown to be more engaged in interdisciplinary research collaborations[28,48]. Although the environmental science field is interdisciplinary, its status quo has women substantially underrepresented. Therefore, further cross-discipline collaborations, such as the collaboration of science and art, could be explained by women's increased likelihood for interdisciplinary collaboration[28,48]. Similarly, women in art departments may be more willing to collaborate across disciplines than their male counterparts. A study reported by Rhoten and Pfirman (2007) reports 13% more women collaborate across disciplines than men, which could partially explain why we see such a stark difference between female representation in environmental science artists and average female representation in artists. However, this suggests that there could be other factors influencing female artists in the environmental science movement, such as female environmental science artist displacement into art departments, which could provide the grounds for future studies.

Another explanation of the gender difference is that the people who work for science, social science, and interdisciplinary science departments reflect the art workforce rather than the environmental science workforce, which is suggested by the fact that 82% of people who work for science departments also specify art training or education.. Finally, 24% of the people who work in science departments and 14% of people who work in art departments in the database are undergraduate or graduate students. Statistics from the U.S. Department of Labor only use data from people who officially work in staff or faculty positions at science departments, suggesting that the inclusion of these students may have also influenced the observation of better gender balance in science departments.

This analysis provides a basis for future research. There could be a more focused study on why women and men are represented equally in the environmental science art movement and how the mechanisms of gender balance here might be extended to environmental science in general. Also, it would be important to expand this analysis to include racial diversity of the environmental science art movement. Many studies and databases have documented the racial diversity of environmental science fields, similar diversity analyses with the environmental science art movement is needed[45,49,50].

3.2.2 Age Distribution

The year of undergraduate degree served as a proxy for the age distribution of environmental science artists. The average year of graduation is 1993. Since the data was normally distributed, the average year of graduation was the only measure of central tendency we used. Using college graduation statistics from the U.S. Department of Education reports for the years 1996, 2000, and 2002-2006, we used a weighted average to find that average undergraduate graduation age is consistently 23 years for each of these datasets. Since no other statistics were reported from the U.S. Department of Education, we assumed that graduation age before 1996 was the same as after 1996. Assuming age of graduation is 23 years, the average current age of environmental science artists is 46 years and the average age of an environmental science artist at the time of art production is 40 years.

We compared the age of the environmental science art population to the average age of environmental scientists and collected by the National Science Foundation (NSF). The NSF collects age data in five categorical ranges (<30 years, 30-39 years, 40-49 years, 50-59 years, 60-75 years). Due to this fact, we used the youngest and oldest possible age in each range. The youngest age for the <30 category was 22 years, since we used the youngest possible age of a person could be at the time of undergraduate graduation. We used the following formula to calculate the average age range of environmental scientists and of artists[49]:

$$\left[\frac{\sum_{i=1}^{5} \text{Youngest age per range}_i * \text{Number of people in range}_i}{\sum_{i=1}^{5} \text{Number of people in range}_i}, \frac{\sum_{i=1}^{5} \text{Oldest age per range}_i * \text{Number of people in range}_i}{\sum_{i=1}^{5} \text{Number of people in range}_i}\right]$$

Using this calculation, the current average age range of environmental scientists is 40-49 years. The current average age range of artists is 40-49 years. The average current age of the catalogued environmental science artists falls within both of these age ranges. This result suggests that current age and age at art production of environmental science artists in the database is similar to the average age of environmental scientists and artists. However, given that the age at art production corresponds with the low age in the range, this might indicate that active science artists are younger than their environmental scientist and artist peers. Obtaining more specific age distribution data for environmental scientists and artists is a needed next step for elucidating this further.

We used the same subgroups from the gender analysis, and found that all the subgroups reflect the average current age of environmental scientists and artists. There were two potential noteworthy findings. The average age of people at science, social science, interdisciplinary science departments at academic institutions and the age of art production of people with science training and education have an average current age of 37 years, which is 3 years below the average current age range of environmental scientists and artists. However, these sample sizes were only 12 individuals in science, social science, and interdisciplinary science departments, and 10 individuals with science training and education. Both of these subgroups included undergraduate, graduate, and post-doctoral students. This could have lowered the average age below the range reported by NSF, which only includes faculty and staff in their data collection.

3.2.3 Education and Training

In the environmental science art sample, 86% of the environmental science artists specified their art or science training. From this subset of environmental science artists who specified their education or training, almost all of them had training in art (95%) and almost half had training in science and art (Figure 1). These results suggest that the environmental science art population is not equally trained in science and art. While a substantial portion of the artists have training in both areas (43%), by far the most dominate training among science artists is that 95% of them have training or education in the arts.

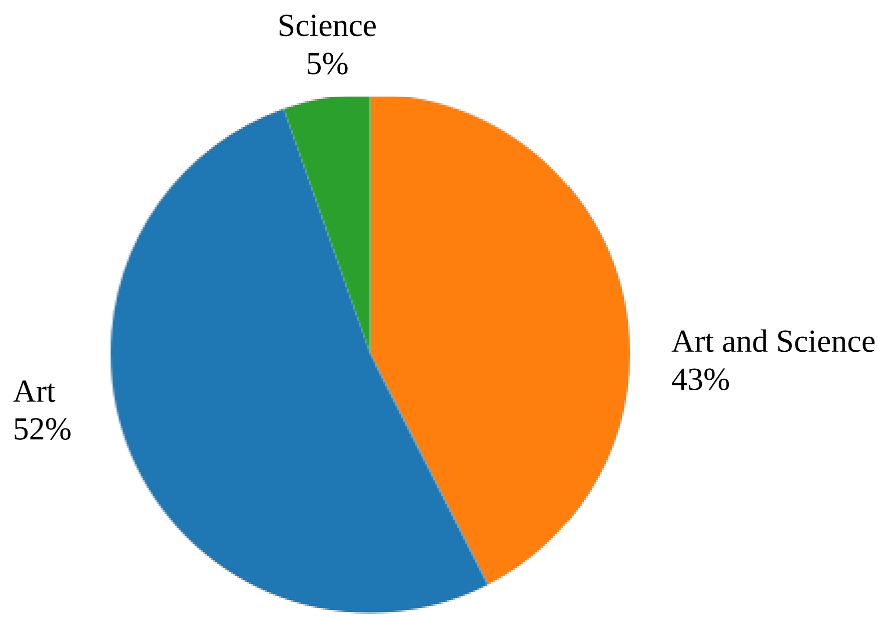


Figure 1: Percentage of environmental science artists who have training or education in science and/or art.

These results indicate that without prior exposure or training in the arts, a person is not likely to partake in the environmental science art movement. This idea is supported by many psychological theories that state that exposure or familiarity of a subject will increase a person's tendency to perform it[51,52]. In this study's case, it seems like training or education in art is an overwhelmingly predominant indicator whether a person is more likely to partake in the environmental science movement.

These results suggest that for environmental science art to grow in the environmental science departments at academic institutions, these institutions need to provide training in art or a forum where scientists can find artist collaborators.. This recommendation aligns with conversations among top environmental scientists. For example, Dr. Jane Lubchenco, the former Administrator of NOAA and a prominent leader of environmental science and communication, stated that scientists need to better communicate their science to the public[4,8]. Furthermore, the environmental science community has recognized the need to include the humanities and social sciences[4,29,53,54]There are already initiatives that provide training, such as COMPASS, to improve scientist's ability to communicate to the public at various academic institutions[55]. Furthermore, large research institutions, such as the University of Washington, have already addressed the need to improve science communication[56]. Specifically, the University of Washington has highlighted science art as a method of improving communication in a science communication report and supported a graduate student-faculty group, Sandbox: Science, Arts, and Engineering collaborative, focusing on science, engineering and art collaborations.

3.2.4 Employers and Work

This analysis observes environmental science artists' employers, which will suggest what employment conditions are most conducive for environmental science art production. Overall, 39% of the environmental science artists reported their place of employment. Of the people who reported their place of employment, 65% work for an academic institution, 20% work for art studios, 4% work for museums, and 11% work for other organizations (Figure 2). Additionally, 6% of all of the environmental science artists produced their artworks when commissioned by other organizations, such as the United Nations or UNESCO, produced environmental science art as part of a class, or produced their artwork while on specific fellowships, such as a NSF fellowship or a Fulbright Fellowship.

In terms of environmental science artists at academic institutions, we observed that 71% work in an arts department, 24% work in a science, social science or interdisciplinary science department and 5% are unreported. The lower percentage of environmental science artists in science departments at academic institutions can possibly be explained by science academia's lack of adequate incentives in science departments for innovative communication and outreach strategies[7,57,58].

One potential reason for this difference in representation of science and art departments is that the nature of art requires an artwork to have a topic, which can range from aesthetics, abstract concepts, or even nature and conservation[59,60]. On the contrary, there is limited opportunity for art to be incorporated into the scientific process. This contrast between science and art suggests that art has a better capacity to connect itself with the sciences than science's ability to incorporate art into its research process.

Overall, an environmental science artists will most likely be employed by an art department in an academic institution. However, it is also evident that environmental science art production can also be supported through other avenues such as art studios, organizations' art commissions, fellowships and museums.

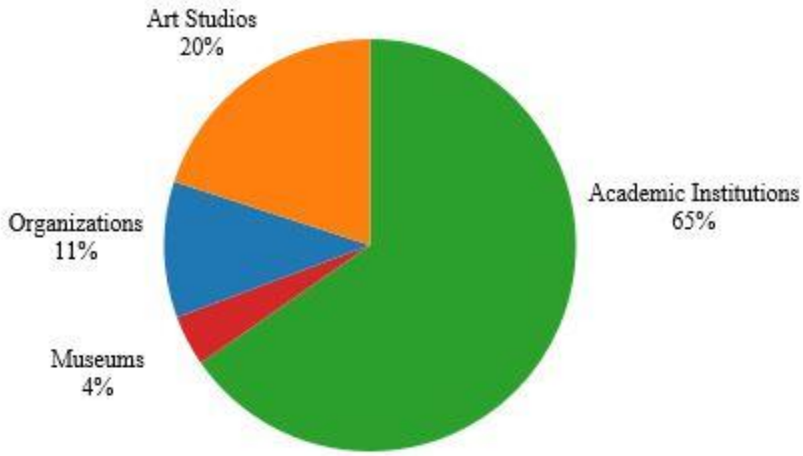


Figure 2: Percentage of environmental science artists employed at different types of institutions.

3.3 What? Where? When?: Environmental Science Artworks

3.3.1 Artistic Mediums

We found nine different media amongst the visual artwork with photograph, sculpture, and site installations being the most common (Figure 3).

The use of photography was the most predominant visual medium. This could be because – as many artists cited – photography can capture what is seen naturally in the environment, without much filtering. For instance, photographer Albert Flynn DeSilver quoted that one can “simply document the drawing out of the ocean” and observe “how things are drawn organically in the landscape… rather than impose [the] human self upon them[61]”. Photography might also be the most prevalent of the mediums because it is an easily accessible medium to produce art[62]. This is especially true in an age where digital cameras, cell phone cameras, and social media are prevalent[63-65].

Eighteen percent of the visual artworks also used alternative materials, particularly for installations and sculptures. These alternative materials for construction included plastic pollution, trash, organism's bones, and organic and natural material. In all instances, the artist chose a particular alternative material due to its relation to the artwork's topic and the materials' ability to enhance the artwork's message. For instance, artist Pam Longobardi used plastic pollution found in the ocean to create a sculpture commenting on the problem of marine plastic pollution[66].

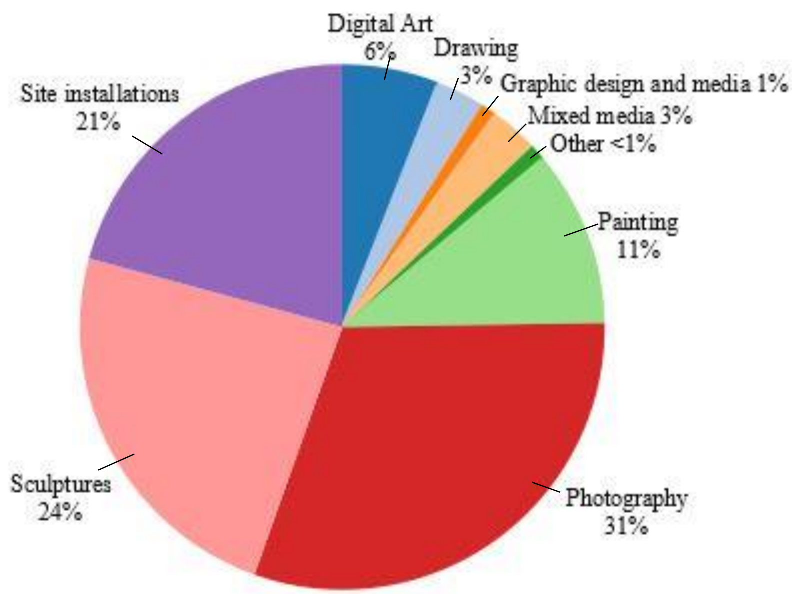


Figure 3: Proportion of various mediums of the visual artworks.

3.3.2 Characteristics

There were two major characteristics of the artworks in the database that rose to the level of an identifiable motif. Both of these speak to issues of accessibility, which is an important issue if art is being used as a method of science communication. Firstly, 44% of the artworks are site specific. Oftentimes, these sites were chosen specifically for their relationship to the art's topic.

For example, an installation addressing water usage for lawns in the desert would aptly be installed in the desert[67]. Thus, even though the artworks were restricted in geography, they were located in areas where people were well primed to contemplate the message of the artwork. Nine percent of these site-specific artworks are also ephemeral, creating a temporal window of access. However, in this case only one artwork stated that the time limitation was intentionally related to the message of the artwork. So in this case, temporal limitations create accessibility restrictions with no additional benefits in terms of communication to the viewer.

Secondly, 20% of the artworks identified itself as abstract art. This abstraction of environmental science could intellectually restrict the audience's connection to the artwork without specialized knowledge. However, 92% of the abstract artworks resolve this restriction by having descriptions of the artwork's topic.

3.3.3 Production Dates

Environmental science artworks in the database were produced between 1974 and 2015, with a median year of production in 2009 and an average year of production in 2007 (Figure 4). The first catalogued environmental science artwork in the database, "Burning Oil Sludge" by Robert Adams in 1974[68], coincides with the birth of the modern environmental movement in the 1970s[69]. To determine whether the trend in artwork production is an artifact of the growth of the internet, we compared the artworks' date of production against the number of internet host sites and their growth based on data gathered by Netcraft, an internet analyst company[70]. We log-transformed the data to be comparable to the data that Netcraft provided. We then adjusted the production of environmental science art for internet growth by dividing the number of produced art per year by the number of internet host sites per year (Figure 5).

We observed a slope of 0.003 ($p<0.05$), which shows that production of environmental science art production is increasing slightly, yet significantly, over time independent of the increase in the number of internet sites.

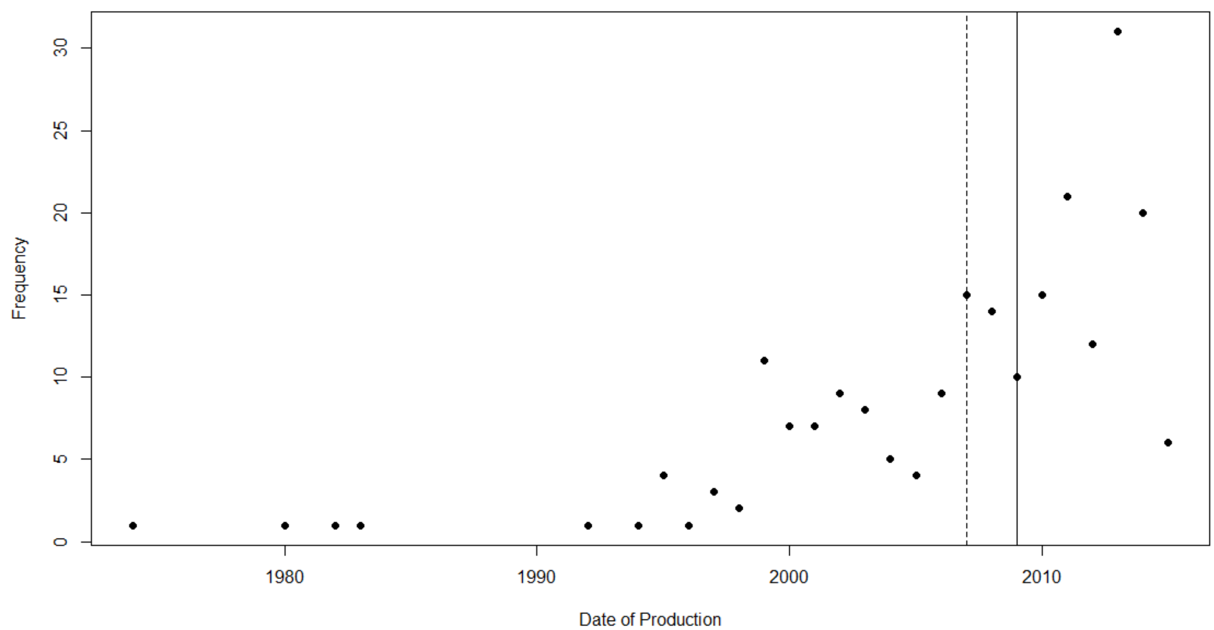


Figure 4: Number of environmental science artworks per year, n=220. Median year of production is 2009 (solid line) and mean year of production is 2007 (dashed line).

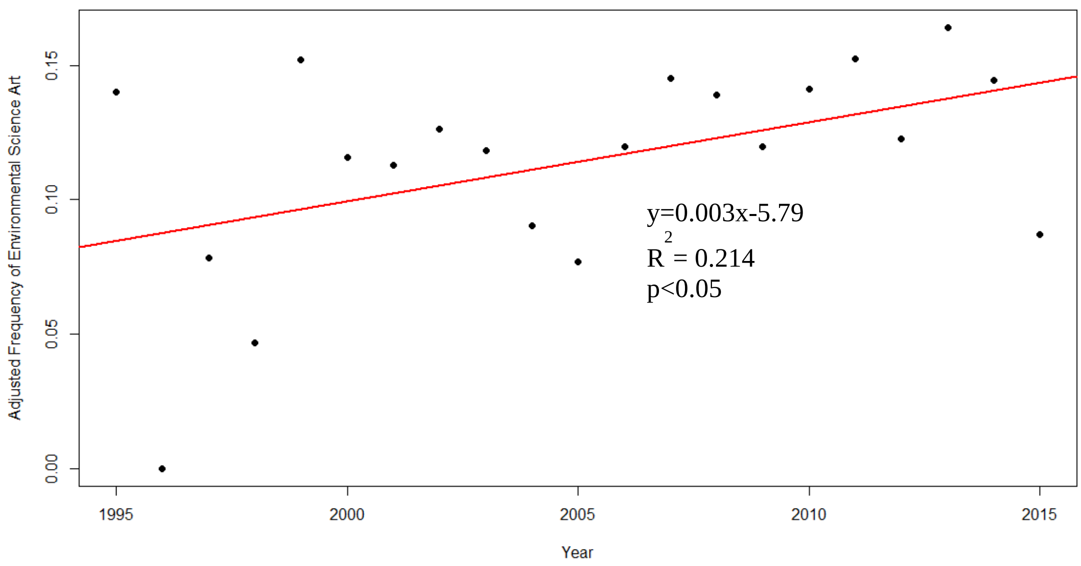


Figure 5: Adjusted number of environmental science artworks per year as a proportion of the number of internet host sites per year.

3.3.4 Topics

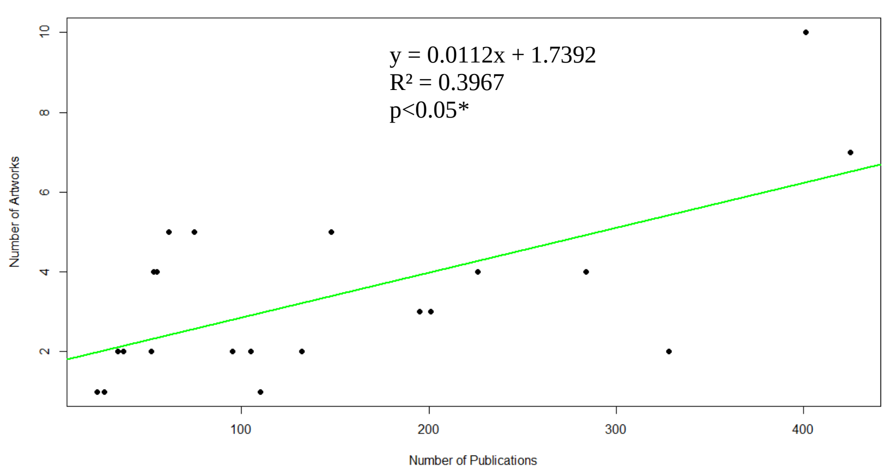
It is apparent that environmental science art can address a broad range of topics and issues. Topics were inductively identified using a grounded theory approach to text analysis of artist's purpose statements. We have reported all topics that occurred in 5% or more of the artworks (Table 2).

- Climate change or sea level rise, 13 %
- Anthropogenic environmental effects, 12%
- Biodiversity, 11%
- Pollution, 8%
- Beauty of nature and its interconnectedness with humans, 6%
- Changing landscapes or habitat degradation, 5%
- Climate change effects on people, 5%

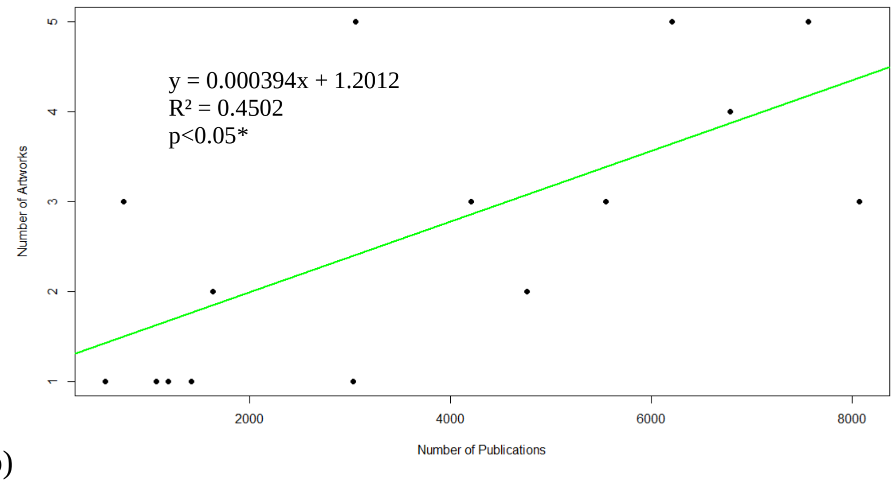
Table 2: Frequency of the most common topics of environmental science art.

We expected that environmental science art's topics would be germane to the period's environmental issues. For each topic, we compared artworks' production year against articles' publication year. For example, the production year of all climate change artworks were compared against the publication year of all articles containing the word climate change. We used Web of Science topic searches, to find a topic's number of publications. A topic search in Web of Science searches through a publication's title, abstract, and keywords for matches[71]. We excluded the topic of beauty of nature and its interconnectedness with humans from the Web of Science search, since it was a general topic theme rather than a specific environmental issue, such as the other topics.

Four of the six topics exhibited a significant direct variation between the number of artworks and the number of publications (Figure 6). This suggests that the topic of environmental science art is often being motivated – at least in part – by the prominence of that topic in the scientific literature.

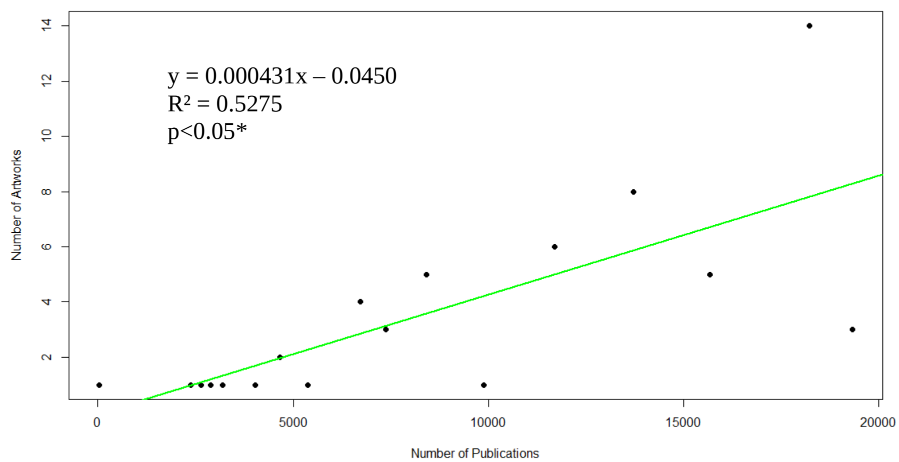


(a)



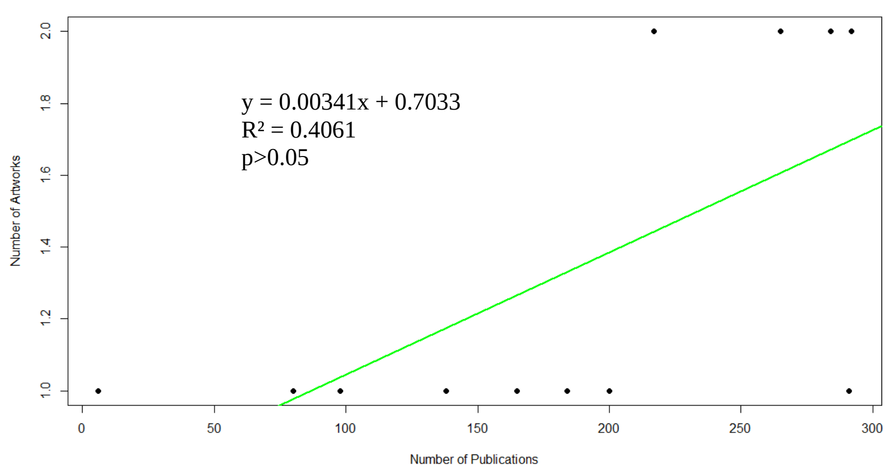
y = 0.000394x + 1.2012
R² = 0.4502
p<0.05*
Number of Artworks
Number of Publications

(b)



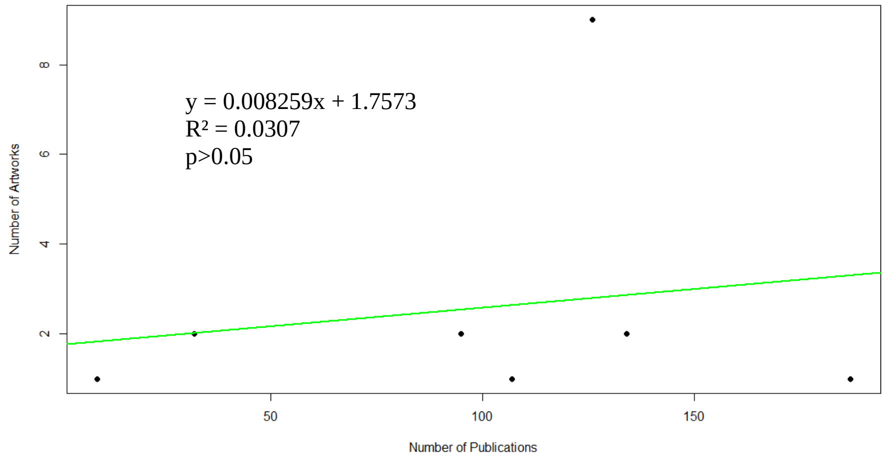
y = 0.000431x – 0.0450
R² = 0.5275
p<0.05*
Number of Artworks
Number of Publications

(c)

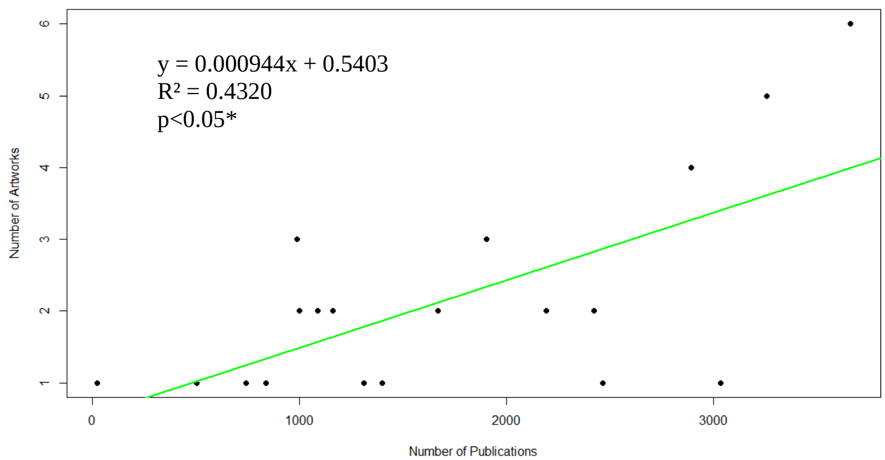


y = 0.00341x + 0.7033
R² = 0.4061
p>0.05
Number of Artworks
Number of Publications

(d)



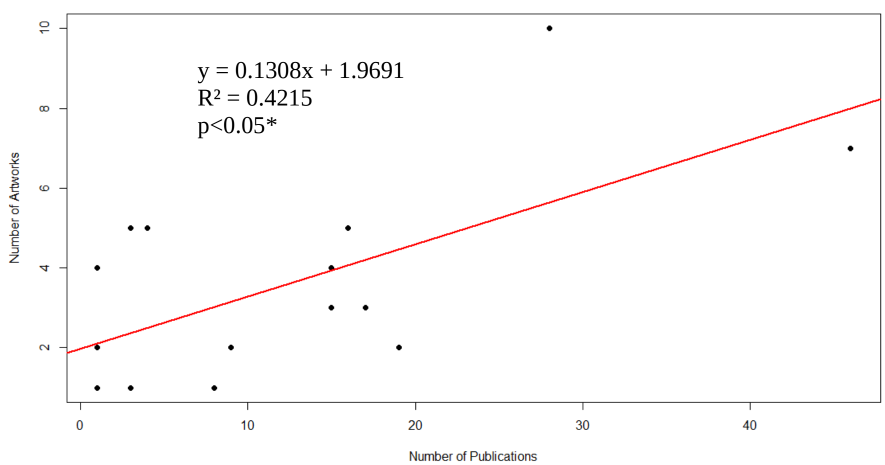
(e)



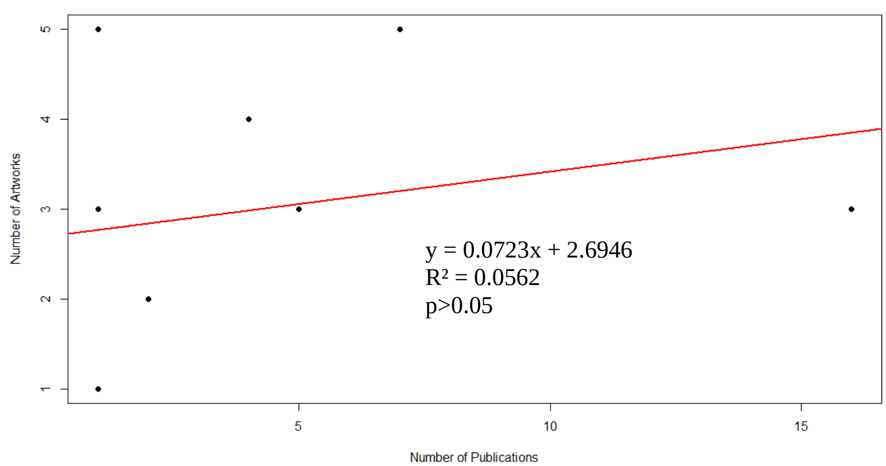
(f)

Figure 6: The number of artworks against the number of publications for each topic: (a) Anthropogenic environmental effects, (b) Biodiversity, (c) Climate change, (d) Habitat degradation, (e) Climate change's effect on people, and (f) Pollution. A significant p-value was noted with an asterisk.

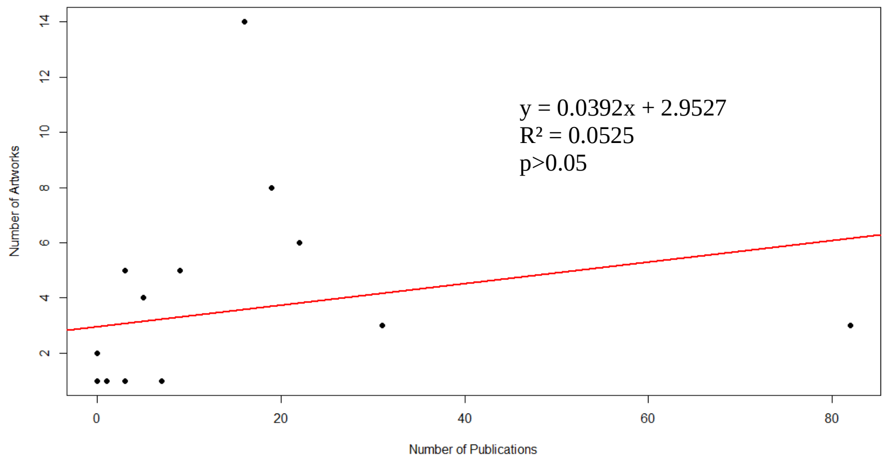
We repeated this analysis using LexisNexis, which searches for newspaper articles, magazines, and other news media, in order to examine how the topic of environmental science relates to the topics in news media. If topics were germane to the period's environmental issues, we would expect that artwork's addressing that topic will be directly correlated to its coverage in the media. Again, this analysis was limited to U.S. news, cases, and companies since 82% of the environmental science artists in the database are employed in the U.S. and 75% of the artworks in the database were exhibited in the United States. However, only one of the six topics exhibited a significant direct variation between the number of artworks and the number of instances of media coverage (Figure 7). This suggests that the topic of environmental science art is rarely motivated by the prominence of that topics in the news media.



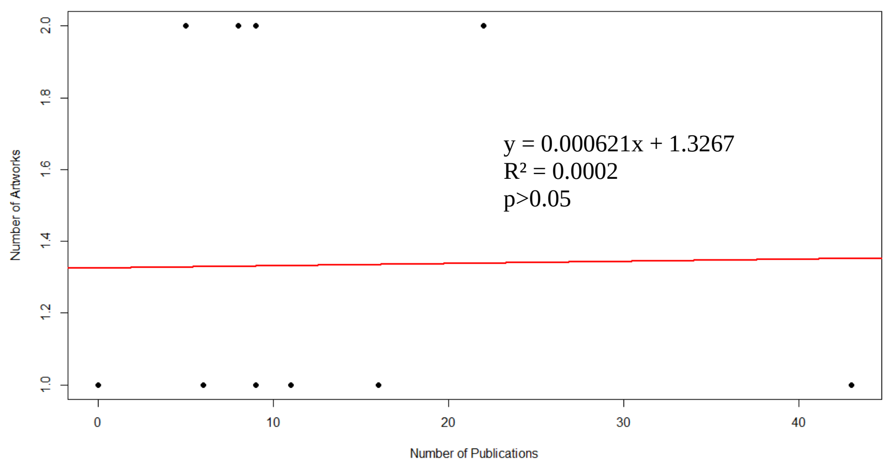
(a)



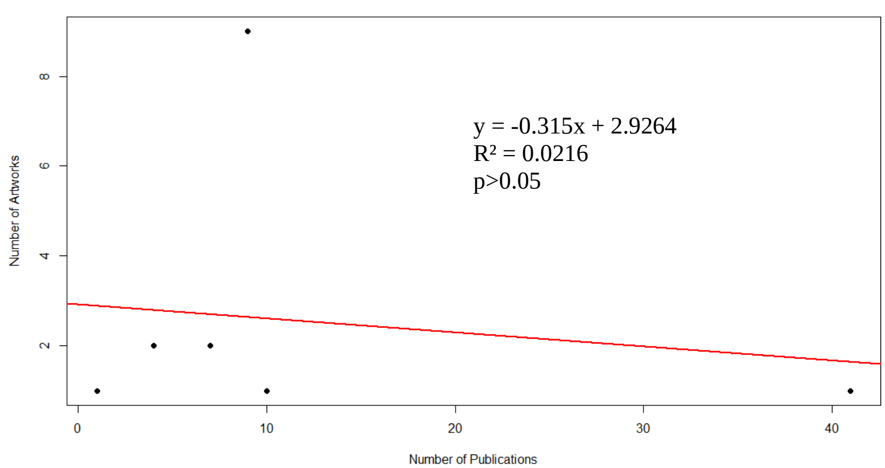
(b)


y = 0.0392x + 2.9527
R² = 0.0525
p>0.05
Number of Artworks
Number of Publications

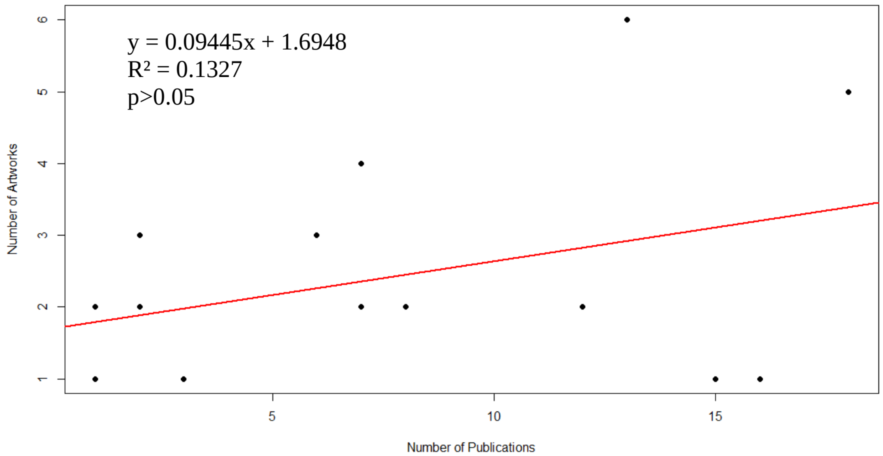
(c)


y = 0.000621x + 1.3267
R² = 0.0002
p>0.05
Number of Artworks
Number of Publications

(d)


y = -0.315x + 2.9264
R² = 0.0216
p>0.05
Number of Artworks
Number of Publications

(e)



(f)

Figure 7: The number of artworks against the number of newspaper articles, law cases, law reviews, and company profiles for each topic: (a) Anthropogenic environmental effects, (b) Biodiversity, (c) Climate change, (d) Habitat degradation, (e) Climate change's effect on people, and (f) Pollution. A significant p-value was noted with an asterisk.

Finally, we wanted to see if people with art training or people with science training were more likely to be motivated by a topic's number of scientific publications. We found that only one topic, climate change, shows a significant direct correlation between the number of artworks produced by people with science training and the number of science publications (Figure 8). However, three of the six topics show a significant direct correlation between the number of artworks produced by people with art training and the number of science publications (Figure 9). This result is surprising because it demonstrates that people with art training, and not science training, in the database are more motivated by a topic's number of science publications. This result can possibly be explained by the fact that artists may consult with scientists for guidance but not list the consulted scientist as one of the artwork's producer. For instance, artist Andrea

Polli stated that she “works with urban planners, atmospheric scientists, and pollution experts to look at the relationships between humans and local and global climate change[72].” Another artist, Joseph Emmanuel Ingoldsby, “documents landscape pattern and color change using traditional and new technologies to explore the coastal landscape and collaborates with scientists to explain how the coastal landscape is adapting to a warming climate, higher seas and armored development along the fragile shores[73].” Despite both stating that their art were products of direct collaboration with scientists and planners, both artworks did not cite the scientists as one of the artwork’s producers. One area of future study to strengthen this study is to account for the scientists that were part of the art collaborations, since the scientists were not referenced by names in the artwork’s purpose statements.

Overall, we can conclude that topics addressed by environmental science art correlate with the topic’s coverage in the scientific literature most of the time and rarely correlate with the topic’s coverage in the news media. This pattern provides valuable insight into how environmental science artists choose their artwork’s topics. This analysis suggests that an increasingly popular topic in the scientific literature could provide opportunities for environmental scientists to collaborate with artists in order to communicate their research to the public.

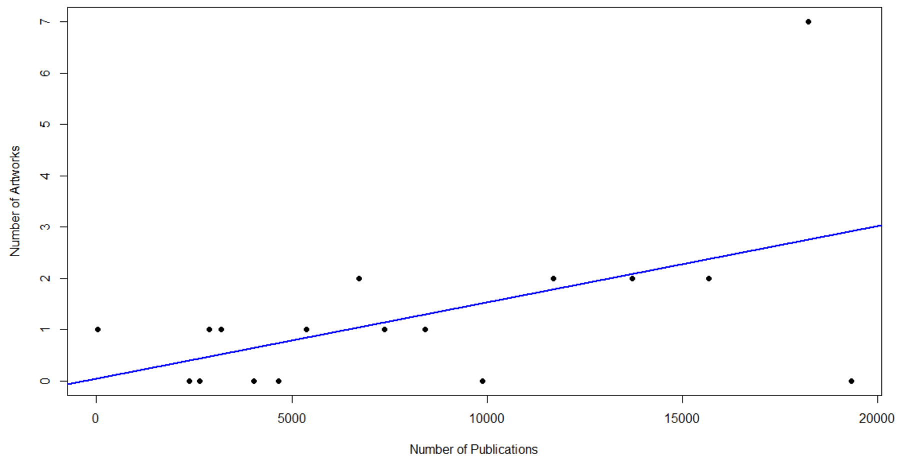
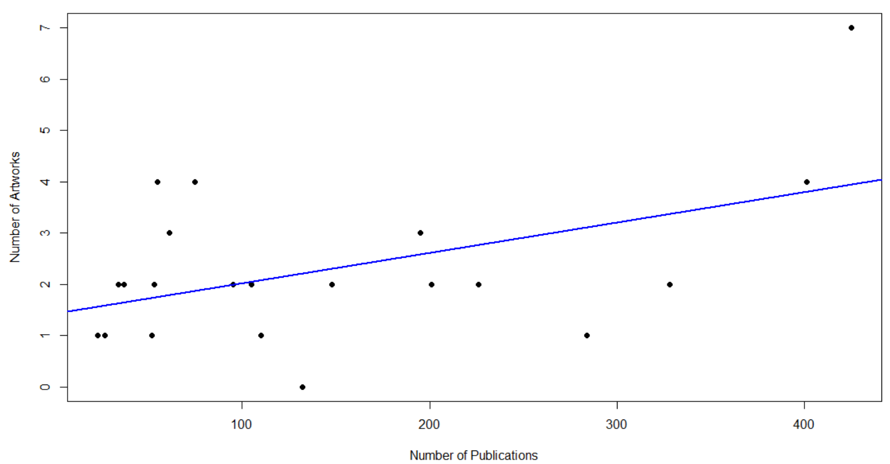


Figure 8: The number of artworks produced by people with science training compared against the number of publications for climate change.



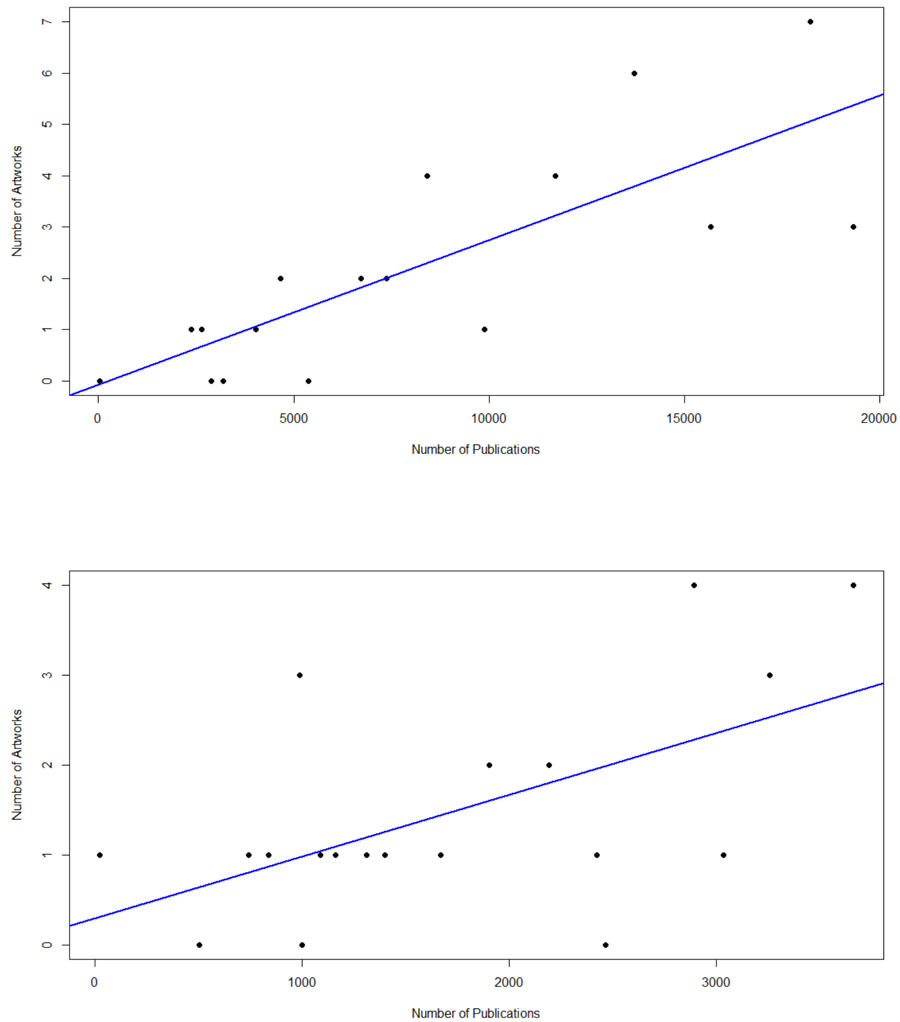


Figure 9: The number of artworks produced by people with art training compared against the number of publications for: (a) Anthropogenic environmental effects, (b) Climate change, and (c) Pollution.

3.4 Why?: Characteristics and Themes of Environmental Science Art

3.4.1 Applications

There are many documented applications of environmental science art, including its ability to educate, increase awareness, communicate technical scientific information, and enhance the scientific process [18-23,74]. These results are consistent with the current scientific literature on applications of environmental science art while also yielding new applications not listed in the literature (Table 3). We defined applications as direct purposes stated in the artwork's purpose statement or how the artwork has been used.

1. Awareness or education, 93%
2. Artistic and cultural value, 90%
3. Advocacy or activism, 39%
4. Interdisciplinary scientific collaboration, 32%
5. Social or political commentary, 24%
6. Passive engagement, 19%
7. Active engagement or empowerment, 10%
8. Utilitarian art, 8%
9. Outreach or dialogue towards a solution, 7%

Table 3: Frequency of most common applications of environmental science art.

Overall, environmental science art's most prevalent applications are artistic and cultural value and the ability to educate and increase awareness of a topic. Using art to help educate and increase awareness of topics and issues has been applied not only for the environmental sciences, but also in other scientific fields[75,76]. For instance, HighWaterLine was a public artwork and performance by Eve Mosher that communicated scientists' and statisticians' predictions of sea level rise from climate change. She created an artificial tide line that marked over 70 miles of coastline in New York City. The HighWaterLine communicates and educates the public about sea level rise and statistical predictions while emotionally connecting its audience to sea level rise by indicating the dramatic effects that sea level rise will have on coastal communities. This artwork also created dialogue and conversation with locals about how climate change affects their livelihoods, and created a direct call for policy action when the HighWaterLine predictions came true after Hurricane Sandy in 2012[77].

Another prevalent application of environmental science art is interdisciplinary scientific collaboration. Having art be rooted in scientific concepts and collaborating with scientists is important to increase the art's credibility to the public as a source of scientific information[78-80].

Environmental science art is also used for advocacy, activism, or social and political commentary. Some artists have had their work applied for advocacy and activism of environmental issues. For instance, Subhankar Banerjee's photograph of Arctic drilling's effects on caribou migration routes was used to directly lobby the United States Congress to defeat an exploratory Arctic drilling effort in 2002[81].

Art can also provide a space for education and dialogue about issues ranging from stormwater runoff and pollution to climate change[82]. For instance, "Cascading Memorials" from artist Ruth Wallen, an installation of photography and sketches about the urbanization and climate change effects in San Diego county, aims to "foster discussion about the future by bringing to public memory both recent and predicted losses brought about by rapid urbanization coupled with climate change[83].

Environmental science art can also be utilitarian for humans and the environment such as by creating new habitat for animals or filter and purify rainwater for human use. For example, public sculptures can create aesthetics for a park while filtering stormwater runoff and releasing it into a river[82]. The artwork, "Santuario" by artist Yolanda Gutierrez provides a commentary on anthropogenic effects on bird habitat and how hurricanes led to the devastation of an island ecosystem. This devastation inspired the artist to create site installations that was utilitarian by providing a habitat for the native birds[84].

Finally, environmental science art is used to engage the audience through direct participation or passively engage the audience. Direct participation and active engagement will empower certain communities and groups of people[20]. Active and passive participation increases awareness, simulates experiences, and creates emotional connections between the audience and the art's topic, which is crucial for the public and their awareness about environmental issues [24,25,27,85]. Active engagement of art directly allows the audience to participate in the artwork. For example, Lisa Steele and Kim Tomczak's artwork, "The Unsolicited Reply", gives its audience a choice: whether to light up their exhibit and appreciate the exhibit as it was intended with lights and extravagance, or to let the exhibit stand idle and not consume energy, and thus not experience the full aesthetics of the artwork[86]. This direct engagement educates and increases awareness of energy and fossil fuel consumption. Passive engagement includes art that does not require direct participation such as public art or graffiti, and could convey messages of politics, morality, and sustainability[82,87-89]. For instance, public sea turtle murals in Mexico have actively enhanced a conservation conscience within a community[20].

Overall, communicating environmental science through art has many perceived applications and benefits. Art's ability to create awareness, educate, engage, advocate, collaborate, be utilitarian, and provide cultural and artistic value makes it a powerful tool for science communication.

4 Conclusion

The objective of this study was to describe the environmental science community and its art, extract topics and applications through inductive coding and grounded theory, and create a preliminary picture of the environmental science movement.

In terms of describing the environmental science artist population, the community has an equal gender distribution between men and women, and the community's age distribution reflects the age of environmental scientists and artists. Furthermore, almost all environmental science artists have training or education in the arts, and about half have training or education in the sciences. Environmental science artists typically work in academic institutions or art studios. The artworks were produced on average in 2007 and serve to create awareness and educate its audience about an environmental issue that is germane to its time period.

Overall, this study is one of the first to detail the environmental science art movement. There is ample opportunity to continue studying the interface between environmental science and art. Using art to communicate environmental science, or science in general, is increasing in popularity among science academia. Large research universities have begun to provide outlets for science communication through art and well known scientists and science organizations support initiatives to use art as a tool for outreach and communication. For instance, the University of Washington recently put together a science communication task force and has different science art initiatives, such as Sandbox, a student-faculty group that facilitates collaboration among scientists, engineers, and artists[56]. Dr. Bill Chameides, former dean of the Duke University's Nicholas School of the Environment, contributes a blog to Conservation magazine about the connection between the arts and the sciences[90]. The AAAS also has several initiatives to use art as a tool for outreach and communication, such as the AAAS Art Gallery and the annual AAAS Dance Your Ph.D. contest[30,91]. Nature has also highlighted science art in their journal[31,32].

This study documents the scope of using art to communicate environmental science and research and its applications and benefits. Overall, environmental science art aims to do what all art strives for – to emotionally connect its audience with its topic, an essential tool for creating awareness around environmental issues. As environmental science art continues to grow in popularity, art can become an established method for scientific outreach and communication.

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