Our Wastewater Footprint: *Protecting Water Quality Through Comprehensive Coproduction of Knowledge*

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ABSTRACT Collaboration among scientists and stakeholders is increasingly valued in research to coproduce knowledge and research products that better inform decision making and enact meaningful change. We present an example of effective coproduction of knowledge to protect water quality along the Mississippi–Alabama coast using a comprehensive approach that tracked progress from initial research through product assessment. We coproduced an education and decision support tool known as "Our Wastewater Footprint" and engaged communities through a variety of public outreach efforts, adapting the product to meet the needs of individual end users. We assessed the effectiveness of our efforts by tracking attendance at outreach activities, measuring website traffic, and collecting survey data from end users after product use. Data from >9,900 users indicated that presentations at community events and print and social media posts most efficiently reached large audiences using limited resources, and social media posts were most effective in promoting changes in behavior and attitudes on a social level. This case study exemplifies how involving stakeholders in research and product development can increase community engagement in stewardship and prompt change to enhance water quality. Our results tangibly demonstrate that meaningful assessment of the administrative and social impacts of coproduced knowledge is feasible and can be accomplished in a short period of time. KEYWORDS coproduction, adaptive research, ecotour, outreach, science transfer, stakeholder, education, end user

INTRODUCTION

In recent years, there has been a shift toward coproduction of scientific knowledge through collaboration among scientists and stakeholders [1–3]. Coproduction enables researchers to better address specific concerns and objectives of stakeholders and customize research outcomes to appropriate temporal and spatial scales for use [4, 5]. Traditional dissemination of scientific research has followed a "loading dock" approach where knowledge is produced and delivered from scientists to a designated depository or "loading dock" (e.g., peer-reviewed journal, technical report) where it can be retrieved by end users [4, 6]. Increasingly, researchers have acknowledged the limitations of this one-way transfer of knowledge to inform decision making and result in meaningful action or "actionable science" [2, 6, 7]. In turn, research has shown that stakeholders involved in the collaborative process have greater understanding and acceptance of research results and are more likely to use coproduced knowledge in decision making [5, 8, 9]. Some best practices and guiding principles have been developed for coproducing knowledge [e.g., 5, 7, 10, 11]; however, little information is available to evaluate the effectiveness of these efforts for researchers or the likelihood of coproduced knowledge to result in decision-making outcomes or actions [3, 8, 12–14].

Demonstrating the success of coproduction through assessment will be essential to propagate widespread investment and participation by researchers and stakeholders in future collaborative efforts. Assessment is

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increasingly required to determine the social or broader impacts of scientific research and for accountability of research funding [15–17]. Many researchers, however, are not familiar with approaches and metrics for assessing outreach activities that lead to broader impacts from coproduction, and resources have been limited for ready integration into traditional research practices [3, 16]. Researchers also may be discouraged from assessment of coproduction outcomes if it is perceived as too difficult or time consuming, detracting from primary research activities, or unachievable due to unrealistic goals and expectations, particularly with regard to the pace or level of impact [16, 18]. Narratives and case studies can be powerful ways to tangibly demonstrate the feasibility and value of assessment and can be readily customized to targeted stakeholders, but such studies are limited for coproduction [18]. Hence, there is demand for researchers to share their experiences engaging in and assessing coproduction activities to fuel sustained application and realize societal benefits [3].

Wastewater inputs and associated declines in water quality are an environmental issue of concern to coastal communities globally for which management can materially benefit from coproduction of knowledge. Sources of wastewater, including agricultural, chemical and industrial, stormwater, and human sewage can impair water quality by delivering anthropogenically derived nutrients and pathogens to coastal waters [19–21]. Nutrient loading contributes to cascading effects that ultimately result in loss of ecosystem services and ecologically and economically important species [22]. Wastewater also can convey viral and bacterial contaminants such as fecal coliforms, *Escherichia coli*, norovirus, *Vibrio*, *Salmonella*, *Shigella*, and *Listeria* that pose human health risks, resulting in beach and fishing area closures and reducing income to local communities [23, 24]. Wastewater, therefore, has potential for pervasive and long-lasting effects on the function of coastal ecosystems and the economy of communities that depend on those resources [25, 26]. Fortunately, management of ecological and human health risks associated with wastewater can be influenced and mediated by informed stakeholder feedback. In the United States, estuaries such as Narragansett Bay, Rhode Island, and Tampa Bay, Florida, saw water quality improved after wastewater treatment facilities updated infrastructure and technology based on community pressure [27, 28]. Stakeholder participation in decision making and implementation is increasingly valued in water resource management, and some international regulations require participation in water quality initiatives [29–32]. Protecting water quality, therefore, requires coordinated knowledge, awareness, management, and decision making among researchers and diverse groups of stakeholders [31, 33]. Despite the pervasiveness of water quality concerns and recent management advances, this level of collaboration in support of wastewater management has not previously been demonstrated and assessed as an example of coproduction [3].

In this study, we describe and assess a comprehensive approach to coproduction of knowledge based on research to improve water quality along the Mississippi–Alabama coast. We provide tangible examples of how: (1) stakeholders were integrated into research and product development to coproduce knowledge, (2) knowledge was transferred in support of environmental decision making, and (3) the impacts of coproduction activities were assessed in terms of reach, efficiency, and effectiveness to result in social change. Our results provide insight to encourage and enable other researchers to engage stakeholders in research and science transfer projects and coproduce knowledge and products that will prompt change.

CASE EXAMINATION

Setting

On the Mississippi–Alabama coast, freshwater, estuarine, and marine ecosystems support a wide range of natural resources that overlap with human activities [34]. The northern Gulf of Mexico coast is globally recognized as a biodiversity hotspot, having high biological richness and facing major conservation threats [35, 36]. Local economies in the region are closely linked to natural resources including commercial and recreational fisheries, aquaculture, ecotourism, and a beach destination tourism industry. For example, Mississippi–Alabama coastal tourism brought in an estimated 16.4 million travelers in 2013 and yielded US$17.6 billion in sales revenue, US$5.9 billion in labor income, and ∼200,000 full- and part-time jobs [37]. These regional ecosystems and industries rely on good water quality, which is impacted by a variety of human activities and wastewater sources [34]. Mobile Bay, which comprises most of the Alabama coast, is one of the largest freshwater discharges in the United States, draining wastewater from upstream inputs including

65% of Alabama's land mass, as well as parts of Tennessee, Mississippi, and Georgia, to the Mobile Bay watershed [38]. It is estimated that more than 26 million gallons of raw sewage entered Mobile Bay waters in 2017 alone [39]. Additionally, population growth along the Mississippi–Alabama coast is among the highest in the United States, with four of the top 10 fastest growing cities in Alabama located adjacent to Mobile Bay and eight within the Mobile Bay watershed [40]. Public awareness of water quality concerns and how to address them remain an important issue as coastal areas are subjected to an expanding human footprint, making this area an excellent benchmark system to assess the effectiveness of adaptive research and coproduced knowledge and products to raise awareness and promote change to protect water quality.

APPROACH

Stakeholder Integration Into Research and Product Scoping (2008–2014)

To connect findings from scientific research to intended end user interests and decisions, we used a joint fact finding (JFF) approach [41, 42]. We initiated this approach during spring 2008, 2 years prior to the start of the research study, in collaboration with stakeholders including personnel at the Grand Bay National Estuarine Research Reserve, which is located on the Mississippi–Alabama border, the U.S. Food and Drug Administration Seafood Safety Laboratory in Alabama, and Ecotours of South Mississippi, a locally owned and operated nature tour business. We discussed research priorities and defined a preliminary list of community interests and additional stakeholders to guide proposal development (JFF Step 1: Prepare). We then invited collaboration by partners whose expertise and interests dove-tailed with the identified research needs and management concerns of the community. We developed the scope of work for the research project and wrote the research proposal with this collaborative group (JFF Steps 2–3: Scope and Define). Throughout the research study (2009–2013), we regularly interacted with stakeholders, received feedback, and integrated stakeholder perspectives during semi-annual working group meetings (JFF Steps 4–6: Conduct Study, Evaluate, Communicate). All meetings were moderated by a professional integration lead with research and extension experience who employed a structured decision-making (SDM) framework [e.g., 43, 44] to set objectives, review alternatives, evaluate costs and benefits, and reach consensus. The combined JFF and SDM approach was selected as the most suitable method for stakeholder integration and coproduction based on similarity to the scientific method commonly used by researchers.

TABLE 1. Participants Who Attended the Data Sharing and Product Vetting Workshop in 2014 and the Subsequent "Our Wastewater Footprint" Product Unveiling and Stakeholder Feedback Workshop in 2018.

	Number of Participants	
Role	2014	2018
Utilities	3	0
County government	0	5
State government	19	10
Federal government	9	4
Regional government	0	2
Local government	1	2
Nonprofit/community-based organization	3	4
University/academia	7	3
Private business	6	1
Total	48	31

Stakeholders self-identified their role as a participant at each workshop.

To translate research outputs to useful products for stakeholders, we hosted a stakeholder workshop that included more than 40 researchers, managers, and members of the public to share results and coproduce outreach products (table 1). Stakeholders reviewed four example products suggested for development in earlier stakeholder meetings: (1) land-use change predictive assessment tool, (2) website informational clearinghouse, (3) interactive educational game for ecotours, or an "edutainment packet," and (4) traditional printed education and outreach materials. Stakeholders were separated into three focus groups based on their self-defined roles and interests (land-use change, water quality/shellfisheries, outreach/education) to review and discuss the products. From these discussions and a subsequent anonymous survey, stakeholders identified the products they thought would be most useful to promote water quality protection in the community. Favored products included predictive tools, a centralized web-based resource to share data and other relevant resources with the community, and interactive educational materials to broadly transfer knowledge to local citizens, from ecotourists to municipal officials.

Product Development (2017–2018)

To develop and vet the selected products, we sought and obtained additional funding specific to science transfer that allowed for continuation of the coproduction process to provide tangible and usable materials to stakeholders [45]. We continued use of the JFF process by conducting an initial planning meeting with the expanded group of stakeholders established during the research and product scoping. This team drafted the core content of products including (1) the "Our Wastewater Footprint" website (https://www.disl.edu/research/wastewaterfootprint), which featured a general introduction to wastewater pollution; summary of the research project setting, methods, and findings; resources and recommendations to improve water quality; and electronic copies of printable outreach materials; 2) Edutainment packets, consisting of 2-page full color factsheets featuring an interactive educational game and instructions for use as a handout for ecotour operators, classroom instructors, and others. Draft products were reviewed and vetted by stakeholders during an unveiling workshop (table 1). To promote use of the web page and information packets, we also produced informational flyers to be broadly distributed within communities.

Product Refinement, Dissemination, and Assessment (2018–2019)

Product refinement and dissemination activities fell into five major categories with different target audiences and outreach goals, including (1) professional meetings, (2) tourism, (3) static displays, (4) print and social media, and (5) community events (table 2). These categories were then used to assess the reach, efficiency, and effectiveness of outreach efforts.

TABLE 2. Types of Outreach Activities Through Which "Our Wastewater Footprint" Was Disseminated, Including Audiences Reached and Interaction Goals for Each Activity.

Activity	Description	Examples	Audience Type	Interaction
Professional meetings	Presentations at scientific and business meetings	Coastal and Estuarine Research Federation biennial meeting, Bays & Bayous Symposium, National Conference on Ecosystem Restoration, Evonik Industries, Osprey Initiative, LLC.	Small and large groups; short-term; (two-way communication)	Active interaction with peers and other professionals engaged in science transfer; shared ideas, received feedback
Tourism	Use of edutainment packets or factsheets	Boat-based (power, kayak) ecotour or nature-immersive groups (e.g.; WildNative Tours, Delta Airboat Express)	Small groups; short-term (one-way communication)	Active training; personalized programs for product use and public education
Static display	Poster or electronic display in a museum or business	Evonik Industries closed circuit campus television, Dauphin Island Sea Lab aquarium display, WildNative Ecotour lobby poster display	Large groups; short or longer term; repeated exposure (one-way communication)	Passive interaction with employees and interested visitors for product use and public education
Print and social media	Electronic and hardcopy news items	Newsletter, magazine, newspaper articles; Facebook posts; links shared on partner websites (e.g., Alabama Coastal Foundation, Dog River Clearwater Revival)	Large groups; short-term; repeated exposure (one-way communication)	Passive public advertising and participation by local environmental organizations for product use and dissemination
Community events	Traveling displays, presentations, outreach booths	Dauphin Island Sea Lab's Discovery Day open house, K–12 STEM events, fishing tournaments (e.g., Evonik Fishing Rodeo)	Small and large groups; short-term (two-way communication)	Active interaction with interested members of the public for product use and education

Small group refers to fewer than 30 people, and short-term indicates a single interaction or event.

Product refinement involved updating and reviewing the "Our Wastewater Footprint" website and other materials based on stakeholder feedback, adapting factsheets to create different versions specific to local waterways and user groups, and adding website linked QR codes to all printed products. We also expanded our products by translating written materials to PowerPoint presentations for professional meetings, electronic displays, and community events. For ecotours and similar groups, a representative at each partner organization was trained by the "Our Wastewater Footprint" team and given materials to distribute as appropriate. Each organization's representative could then teach their tour groups, classes, or employees about wastewater influence in their area.

Product dissemination was accomplished by reaching out to existing stakeholders to share products and establishing new relationships with potential end users along the Mississippi–Alabama coast. New partnerships were made by contacting ecotours and other local organizations or businesses identified by existing stakeholders or team members as having programs or products related to the content of "Our Wastewater Footprint." We opportunistically participated in outreach events and further modified outreach materials and activities as needed to meet the needs of new end users. All users were invited to download materials from the website for individual modification and allowed to repost modified materials to benefit future users.

Product assessment considered three common types of metrics typically used to assess the impacts of outreach projects: (1) administrative metrics (total number of people reached), (2) social metrics (number of people that learned something new or indicated they would change behaviors based on information), and (3) environmental metrics (actual changes in community behavior or resource quality), a longer term metric not directly measured in this study [46].

Reach and efficiency (administrative metrics)—We recorded the reach of "Our Wastewater Footprint" for individual events under each dissemination category. For professional meetings, community events, and tourism venues, we recorded reach as the number of attendees or participants. Static display reach was determined as the number of people passing through (e.g., a business lobby) or attendance at each location during the time the display was posted. For print and social media, reach was calculated as the number of views of a given post or documented distribution (number of subscribers) to the specific media outlet (e.g., newsletter, magazine). To quantitatively define the efficiency of each type of dissemination activity, we calculated "efficiency scores" by dividing the total reach by the average number of person-hours invested in planning and executing activities for each dissemination category.

Effectiveness (social metrics)—To determine whether reach resulted in increased product use, website traffic in terms of main page views during the outreach time period (November 1, 2018, to November 30, 2019) was monitored daily via Google Analytics [e.g., 47]. To quantify the duration of influence (longer term impact), we compared website traffic for 2-, 5-, and 10-day windows following each outreach activity. To determine how viewers were using resources available on the website, we recorded total and unique viewers and calculated the average amount of time spent on each web page per viewing day. To assess the effectiveness and social impact of products, online and in-person (paper) surveys were provided to ecotour operators to administer to participants. The online survey also allowed independent website viewers to provide feedback (https://www.disl.org/research/wastewaterfootprint/ourwastewater-footprint-survey).

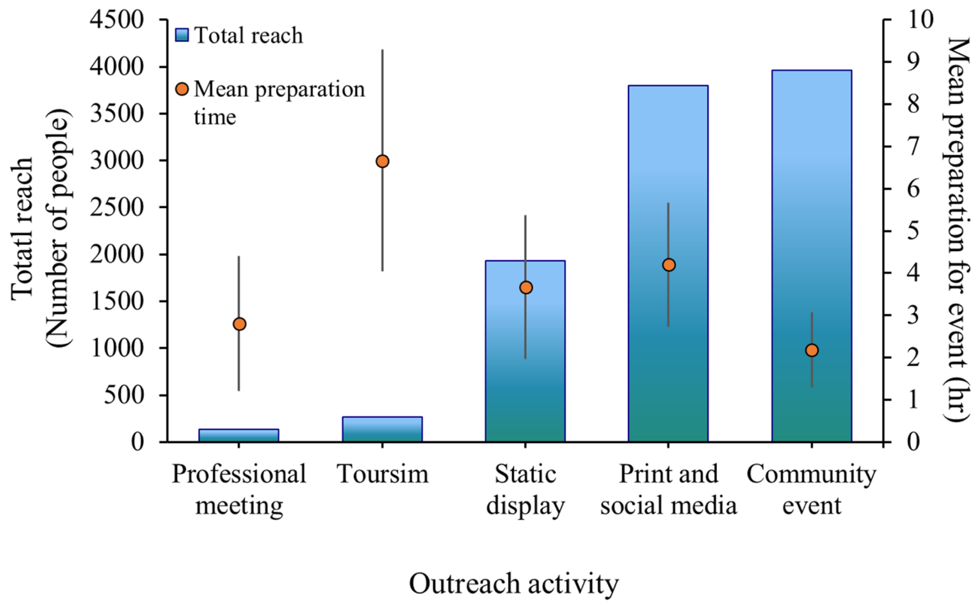
RESULTS

Research Outcomes Overview

Our research study found that historical and present-day land use, particularly increased wastewater and stormwater, has affected estuarine water quality on the Mississippi–Alabama coast [48, 49]. With input from stakeholders who helped to define sampling locations and the scope of data collection, we identified one location with particularly poor water quality (considered impaired by some metrics) and demonstrated that wastewater treatment helped alleviate water quality impairment throughout the region [50]. We concluded that to sustain water quality and associated living resources, communities must balance land use with water quality priorities, which should include implementing suitably designed wastewater treatment and promoting communication among researchers, local residents, and management authorities.

Stakeholder Engagement

Representatives from a variety of community groups participated in the coproduction process at the product vetting (2014) and unveiling (2018) workshops. At both workshops, ~60–70% of attendees identified as



Efficiency score: 47 41 527 905 1817

Figure 1. The total reach of "Our Wastewater Footprint" in terms of number of people participating or receiving information during each type of outreach activity compared to the mean ($\pm$standard deviation) number of person-hours invested in preparing for each activity. Efficiency scores were calculated as the ratio of total reach to preparation time.

government workers from local to federal levels, with most participants from state agencies (table 1). The remaining ~30% of participants were based in academic, nonprofit, or commercial institutions. A closing survey taken by participants at each workshop (SI. 1 and 2) found >80% of attendees agreed or strongly agreed that they gained new information from the research or products, which they would directly use or share, and participants felt engaged and invested in the research and products. During the 2014 workshop that included use of the SDM approach with breakout group discussions of product alternatives, reported collaborative engagement was >96% (SI. 1). All respondents indicated they trusted the knowledge of the presenters (2014) and derived products (2018). Survey results also yielded suggestions for expanded end users, applications, and content to improve reach and likelihood of use.

Assessment of Reach and Efficiency (Administrative Metrics)

During the 13-month assessment period, we conducted 27 outreach and product dissemination activities (5 professional meetings, 3 tourism-based activities, 3 static displays, 5 print and social media posts, and 11 community events; table 2). "Our Wastewater Footprint" reached at least 9,900 people. Some categories may have reached a larger audience than can be reasonably determined due to views outside of our assessment period (static displays or tourism) or on a platform we did not have access to, such as a personal Facebook page (print and social media). Reach within individual activity categories ranged from a total of 131 people at professional meetings to nearly 4,000 people at community events and through print and social media (figure 1). Together, community events and print and social media categories comprised 78% of the total reach of product dissemination activities.

Preparation time for these activities ranged from 2 to 7 h, with community events (2.2 h) and professional meetings (2.4 h) requiring the least amount of preparation time and tourism (6.7 h) requiring the most (figure 1). Less preparation time was necessary for community events and professional meetings largely because these required only copying or updating premade materials, while tourism required time to prepare materials, meet with ecotour operators, train them on product use, and follow up on use and for assessment. As a result, community events had the highest efficiency scores followed by print and social media, professional meetings, static displays, and tourism.

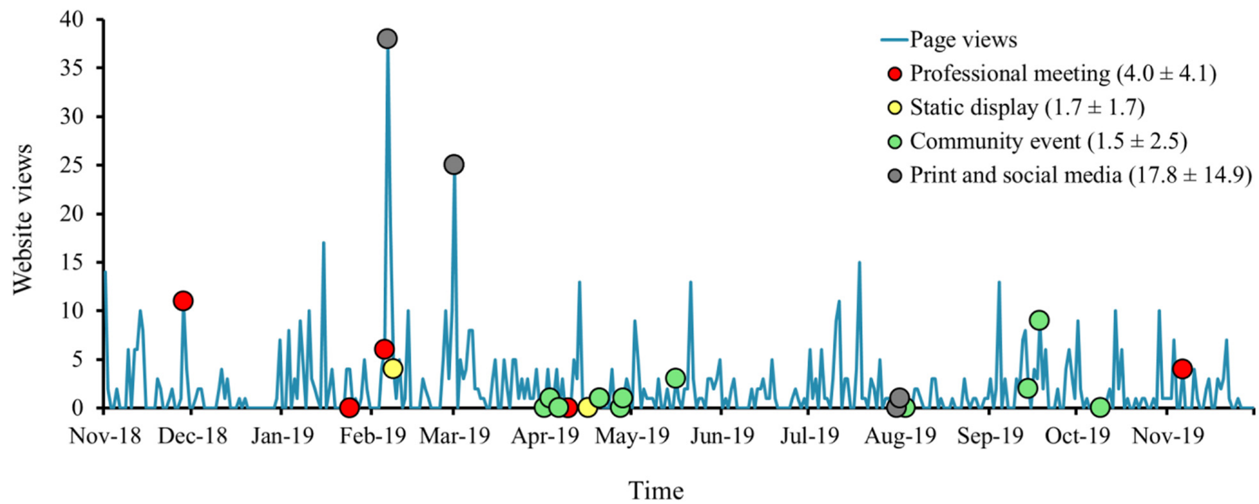


Figure 2. Website traffic for "Our Wastewater Footprint" during November 2018–2019 (month-year) when the website and other products were disseminated at different outreach activities. Each dot indicates the date of an outreach event, and the blue line indicates continuous daily website views, including the dates of events and periods between events. Tourism (ecotours) was not included because dates of specific ecotours were not reported. The numbers following category titles in the legend represent the mean ± standard deviation day of website views for each activity category.

Assessment of Effectiveness (Social Metrics)

The "Our Wastewater Footprint" website had 733 total views during the 13-month study (figure 2). Daily views ranged from 0 to 38, with a mean ± standard deviation of 2.1 ± 3.7. The two highest days of views occurred on February 6 and March 1, 2019, following highly viewed social media posts. As a result, print and social media activities generated the highest daily mean of 17.8 (figure 2, inset table) and median (25) number of website views. Median values for all other types of activities were ≤4.

When quantifying longer term influence, in all cases, the mean number of daily website views did not significantly differ from 2 to 10 days following an event (figure 3, top; analysis of variance: 2-day: $F_{3,20} = 2.82$, $p = .07$; 5-day: $F_{3,20} = 2.15$, $p = .13$; 10-day: $F_{3,20} = 1.77$, $p = .19$). For professional meetings and print or social media posts, average daily views tended to be higher within 2 days following the event and decreased with time but still remained higher after 10 days than other activities after 2 days. For example, print and social media posts generated an average of 11 views during the 2-day window, with views declining to an average of four views during 10 days, possibly due to ongoing ease of access for these types of activities.

While on the website, most viewers visited the main page (figure 3, bottom), and 47% of these viewers continued to other major pages, primarily visiting pages focused on the study system (Grand Bay) and overall wastewater influences ("Our human footprint"). The longest average viewing time (∼3.5 min per viewing day) was spent reviewing methods and results from the research study. When considered together, pages that offered tangible recommendations and access to products such as the edutainment packet, factsheets, or surveys ("What you can do," "Take it with you," "Resources," "Other links") were the most engaged, having more views (173 unique, 198 total viewers) and cumulative mean viewing time (∼8.5 min per day) than other individual pages.

In all, 10 ecotour survey responses were received (∼4% of tourism reach) from participants following three ecotour activities, including eight paper and two online surveys. All ecotour survey participants noted that they would somewhat or definitely incorporate water quality improvement recommendations into their lifestyles (SI. 3). In areas known to have wastewater sources, 60% of ecotour participants recognized sources of wastewater they previously had not noticed and learned something new about those sources. These results support use of ecotour surveys as representative social metrics.

Discussion

We found continuous interaction with stakeholders was important to guide scientific research, coproduce research products, and assess outcomes. Allowing stakeholders to provide feedback throughout the research and product development process gave insight into how different

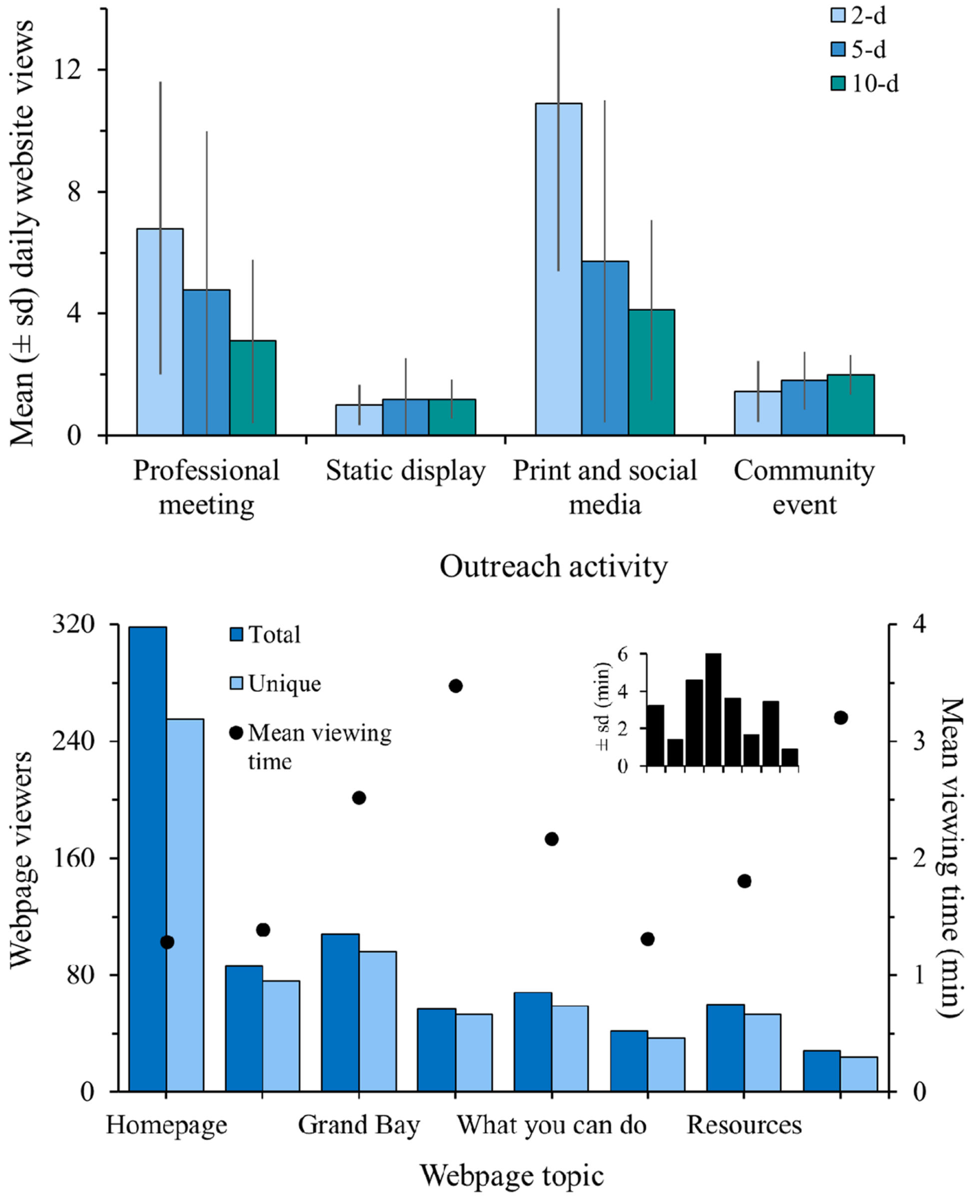


Figure 3. Mean (± standard deviation) website views per day for 2, 5, and 10-day windows following four types of outreach activities (top) and total and unique viewers of the "Our Wastewater Footprint" website compared to the mean viewing time for each of the main webpages, separated by topic (bottom) during the 13-month study period. Mean viewing time was calculated as the total time spent on each web page per viewing day divided by the total number of viewing days during the study. Due to high variation in mean viewing time, the standard deviation (±standard deviation) is shown in the same order as an inset to the bottom panel.

members of the community would use research products and helped invest stakeholders in product use. During design and implementation of research and throughout product vetting and development, most stakeholder interactions occurred during in-person meetings, with coproduced research products guiding subsequent outreach and broader community engagement. Most importantly, during this project, we were able to successfully quantify the impacts of these efforts using administrative and social metrics that we anticipate will affect environmental metrics in the future. By providing tangible examples of a successful comprehensive approach to coproduction that included assessment, we can facilitate participation in coproduction activities by other researchers and promote sustained application through evidence of benefits [3, 16].

Reach and Efficiency (Administrative Metrics)

Use of a range of assessment methods enabled our study to rapidly identify practices to maximize the reach and efficiency of coproduced knowledge and products within the stakeholder community. Administratively, "Our Wastewater Footprint" had a high estimated minimum total reach to more than 9,900 individuals. Comparison of reach to preparation time along with website traffic and survey data indicated that active community events and passive print and social media posts were the most efficient methods to reach large audiences. Other studies have found strategic use of a variety of social media tools to be effective for engaging end users and building collaborations [47, 51]. The increasing popularity of social media applications, availability of a wide and growing range of platforms, declining costs of basic technology for access and use, easily accessible metrics for quantifying use, and increased awareness of high return on investment are likely to make informed and targeted social media posting a particularly useful tool to facilitate distribution of coproduced knowledge and enhance assessment of coproduction activities in coming years [52, 53]. Furthermore, social media platforms are increasingly dedicated to active interactions (e.g., Facebook Live, Instagram, TikTok), giving additional capacity to communicate with a range of audiences [54]. Overall, we found that a combination of active (community interactions) and passive (print and social media) approaches were most efficient and effective for dissemination of "Our Wastewater Footprint" materials to engage a large and diverse audience in a short period of time.

Effectiveness (Social Metrics)

To be meaningful, administrative metrics must translate to social or environmental changes. As with reach and efficiency, we found that print and social media were the most effective means to motivate social responses (e.g., prompt end users to seek additional information or identify lessons learned). Greater social responses for print and social media may be in part facilitated by end users encountering articles or posts while already using a device with internet access, allowing them to immediately use a link to other web-based resources. Participants engaged in other activities such as professional meetings, community events, and tourism may be delayed in accessing the internet and lose motivation to follow up online, contributing to reduced likelihood of seeking additional knowledge (fewer website views) immediately following these events. Static or declining website views on days following outreach events emphasize the need for resharing passive information through time to maintain social responses. Hence, while community events involved active interaction with end users and had a similar administrative reach to print and social media posts, they did not result in the same evidence of social engagement with products. From team member experience, however, these direct interactions were beneficial in allowing two-way communication between stakeholders and the "Our Wastewater Footprint" team to mutually enhance knowledge of water quality concerns. It is possible that stakeholders attending meetings and community events, where they were able to directly communicate with the team, take hard copies of materials such as factsheets, and ask questions firsthand, did not need to visit the website for additional information, particularly within the 2- to 10-day window following events. These stakeholders may refer to outreach materials and visit the website in the future when needed, potentially resulting in a longer term investment in product use that is not immediately captured in the metrics we assessed. Similarly, static displays, such as in the lobby of a building, reached fewer people per day but did so over a longer period of time (the duration of the display), providing a less immediately trackable but potentially longer term impact on viewers. When strategically planning product dissemination, it is important to consider that each category of outreach activity has a different type of audience and duration of impact. Depending on the specific outreach goals and available resources of a project, our data suggest the most effective approach for turning administrative results into immediate and longer term social impacts may be to engage in a variety of active and passive outreach activities (e.g., table 2).

Surveys following targeted outreach activities provided an additional but more labor-intensive means of assessing stakeholder engagement with coproduced knowledge on a social level. Our survey results indicated that stakeholders valued and trusted coproduced research knowledge and products, intended to use or share these products, and felt integrated and invested in the coproduction process. These social outcomes are highly promising, and they align with and build on results from other studies that have shown potential for improvement in water quality through collaboration with stakeholders

[31, 32]. While none of the surveys had 100% participation, we found in-person surveys (e.g., at workshops) had much higher response rates than remotely implemented surveys (ecotours, website). Limited survey responses following ecotours may, in part, be due to tourists who were uninterested or unwilling to take the surveys or ecotour operators who did not request or encourage survey participation after each tour. Because ecotour operators received training to independently use "Our Wastewater Footprint" content to add value to their operation but received no direct benefit from subsequent survey participation, there was no way to ensure they would follow through on the survey (assessment) component following training. Similarly, website viewers may have been unwilling to invest time to participate in online surveys or may not have known about the survey if they did not visit the survey-linked page within the website. Of all product dissemination activities, integration with ecotourism relied most heavily on stakeholder partners and their effectiveness in using and communicating coproduced knowledge, making it the most labor-intensive, difficult to quantify, and arguably least efficient coproduction assessment method. Ecotourism, however, has been rapidly growing worldwide as an economically beneficial approach to sustainable tourism [55, 56] and therefore has potential to be a powerful tool in the coproduction process to increase public education and promote environmental change. Our experiences working with ecotour operators suggest that these efforts will take time investment and business-focused integration efforts to balance oversight of product dissemination with priorities of ecotour operators and their clients. Operators must perceive value, particularly economic value, in use and assessment of coproduced knowledge to motivate their participation in coproduction and application of products [57, 58]. Further study is needed to develop best practices for collaboration with ecotourism to produce administrative, social, and environmental impacts.

CONCLUSION

There are many obstacles faced by researchers who are dedicated to coproduction of knowledge. Much of the information available on coproduction, adaptive research, and science transfer is theoretical or top-down (originating from policy or management needs; [e.g., 3]). There are few specific published examples of how to comprehensively transfer products from the ground up (from research to application) and assess impacts at the social and community levels. Creating tangible resources from research results historically has not been a priority, and the application of coproduction of knowledge to research products is still in many ways in its infancy [3]. Traditional metrics most often used by funders and scientists (e.g., peer-reviewed publications, citations) to measure research outcomes are not designed to facilitate or evaluate the success of coproduction efforts [18, 59]. Many scientific communication and outreach assessments also are exclusively released to funding agencies or kept in companies' internal databases [60], which makes finding background knowledge on outreach and assessment methods difficult. Continued development and availability of practical guidance for multi-collaborator input to produce evidence-based materials that can be interactive, and eventually evaluated, will be critical to success for future adaptive research and science transfer projects that result in coproduction of knowledge [8, 12].

Arguably the major obstacle that may be encountered by researchers is deciding how to engage in coproduction activities with limited resources [3, 61]. While there has been a push for scientists to consider how others such as managers and policy makers may use their information, there are very few funding opportunities that support the flexibility in timing and funding to allow research projects to meaningfully adapt to stakeholder feedback after a project is initiated or that support development and vetting of coproduced materials or tools. Interactions among scientists and stakeholders can be required by funding agencies [3], but without flexibility in budgeting and time frames for work, responsiveness to end user needs may still be limited. After primary research is conducted, funders will also need to consider additional funding and time for product development, vetting, use, and assessment to determine the best forms of outreach to facilitate transfer and whether those efforts lead to behavioral or policy changes or, at minimum, enhanced awareness of a concern [62, 63]. A project like "Our Wastewater Footprint" illustrates the value of dedicated funding to turn research results into coproduced, publicly usable resources and recommendations. We tangibly demonstrate that meaningful assessment of the administrative and social impacts of coproduced knowledge is feasible and can be accomplished in a short period of time. While we were not able to assess environmental-level outcomes of the coproduction process as part of this project, engaging and incorporating stakeholders in research and product development improved both research and outreach outcomes that we hope will translate to meaningful improvements to local water quality in the future.

Recommendations

- A combination of active (community interactions) and passive (print and social media) approaches were most efficient for dissemination of "Our Wastewater Footprint" materials to large and diverse audiences in a short period of time, with use of print and social media having the most potential for further development and creative applications in the future.
- Print and social media posts were most effective in turning administrative results into social responses that could be assessed.
- Development of partnerships with relevant businesses, nongovernmental organizations, and community-based conservation groups helped to build a network of stakeholders to use and further disseminate information.
- Surveys following outreach activities were useful to assess stakeholder participation in coproduction of knowledge and product use but required considerable time investment and oversight.
- Ecotourism has potential to be a powerful tool for coproduction and public education that can lead to environmental change but will require business-focused integration efforts to balance outreach goals with priorities of business operators and their clients.
- Continued development and availability of practical guidance for coproduction of evidence-based materials that can be interactive and eventually evaluated will be critical to success for future adaptive research and science transfer projects.
- To enable development and vetting of coproduced materials derived from adaptive research, funding agencies must support flexibility in timing and funding to facilitate coproduction, including assessment.

CASE STUDY QUESTIONS

1. What are optimal methods to transfer research findings into products that will benefit end users and how can you engage stakeholders in the coproduction process?
2. What are the more effective and efficient forms of outreach and dissemination when trying to reach a large audience using limited resources (personnel, time, funding)?
3. How do you balance efficiency and effectiveness to translate research findings to diverse audiences and provide solutions to environmental concerns?
4. How can you assess use of coproduced knowledge and products to prompt social and administrative changes that can eventually lead to environmental changes?

AUTHOR CONTRIBUTIONS

TMG: Conceptualization, data curation and analysis, methodology of outreach and assessment, product creation, writing–original draft. EEH: Conceptualization, methodology and preparation for outreach products, support for outreach activities, writing–editing and reviewing. ESD: Conceptualization, investigation and methodology for original research study, preparation for outreach products, writing–editing and reviewing. RHC: Conceptualization, methodolgy, product preparation, funding acquisition, project administration, analysis, writing-editing and reviewing.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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SUPPLEMENTAL INFORMATION

SI 1: 2014 Workshop Survey Results: Attendee survey results for the 2014 product vetting workshop held following completion of the research project. Approximately 56% of attendees completed the survey. (PDF)

SI 2: 2018 Workshop Survey Results: Attendee survey results following the 2018 "Our Wastewater Footprint" product unveiling workshop. Participant demographics shown in table 1. Approximately 65% of attendees completed the survey. (PDF)

SI 3: Eco-tour Survey Results: Survey results from ecotours conducted in Mobile Bay, AL during peak tourism season (April–August) 2019. (PDF)

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