Prevalence of discourse on public engagement with science in ecology literature

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Scientists are increasingly encouraged to engage with the public about science. Key to normalizing and advancing "public engagement with science" (PES) is the dissemination of such activities within the science literature. We developed a classification scheme to assess the extent and type of PES articles in ecology-themed scholarly journals. Our review indicated that although many ecologists interact with the public and intend to maintain this interaction, only a small minority publish about PES efforts, perspectives, strategies, successes, and challenges in ecology journals regularly read by their peers. We suggest that publication of PES in disciplinary journals offers a means of both providing professional credit and improving engagement practices. Thus, we encourage ecologists to write articles about their PES efforts, urge editors and reviewers to be responsive to such submissions, and recommend more consistent use of common PES keywords in science articles.

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In August 2010, *Frontiers* published a special issue on science communication (https://bit.ly/3G0eREs), which included a call for a "wholesale reconsideration of the ways scientists communicate with society" (Groffman *et al.* 2010). Since then, scientists have been increasingly encouraged to engage with the public in ways that can shift beliefs, build trust, and deepen understanding for both groups (eg Bauer and Jensen 2011; Holt 2015; NAS Engineering Medicine 2016). This form of communication has been coined by some as "public engagement with science" (PES), and this term has grown in use since a seminal article was published in the journal *Science* (Leshner 2003) and subsequent creation of the American Association for the Advancement of Science (AAAS) Center for Public Engagement with Science and Technology. However, no single definition of PES exists, and there is not a clear distinction between PES and other related terms (eg outreach, education, and communication). McCallie *et al.* (2009) and the AAAS defined PES as bidirectional interactions that support mutual learning, whereas Besley *et al.* (2018b) used a broader definition that encompassed any effort by members of the scientific community to engage with people outside their research area. Such communication does not necessarily involve symmetric exchange but it does have the potential to alter beliefs. For example, it could promote a public participant to think, "this scientist really cares about the same things that I care about", and a scientist to think, "the public can make valuable contributions to my research" (see Besley *et al.* 2018a,b). Storksdieck *et al.* (2016) proposed a wide range of activities that promote PES, including in-person dialogue, such as conversations after a "meet-a-scientist" event (eg Woods-Townsend *et al.* 2016; Nadkarni *et al.* 2019) and online exchanges via sharing and commenting (eg Hara *et al.* 2019; Lai *et al.* 2020), as well as collaborative efforts like citizen science and co-production of knowledge involving stakeholders and scientists (eg Nel *et al.* 2016). Although mutual learning may be possible through all of these approaches, this cannot be assumed (Martin 2017).

Resources have emerged to support science researchers as they interact with public audiences in PES activities (eg via university outreach offices). Engagement training programs, both standalone and university-based, are also increasingly available to scientists, and include the National Academies Science Ambassador Program, the AAAS Leshner Leadership Institute for Public Engagement, and the Alda Center for Communicating Science. In 2019, the US National Science Foundation (NSF) invested $5.2 million in the Center for Advancing Research Impact in Society (ARIS) to work with "scientists and engagement practitioners to build capacity, advance scholarship, grow partnerships and provide resources

In a nutshell:

- Many ecologists engage regularly with the public about science and in scientific investigations
- One measure of scientists' public engagement is to apply a classification scheme to determine the extent and types of communication about these efforts within scholarly literature
- Application of this scheme indicated that public engagement efforts are infrequently communicated in professional ecology journals (comprising ~1% of articles published)
- Increasing the number and type of public engagement articles in ecological and other scientific publications is one small but important way to expand and improve understanding and practice of these science–society interactions

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to help them engage with and demonstrate the impact of research in their communities and society" (https://researchinsociety.org/about). Science communication and education researchers are providing a sound foundation for these efforts by reporting on scientists' attitudes and perceptions of impact, as well as approaches and training associated with scientists and public engagement activities (eg Besley *et al.* 2018b; Stylinski *et al.* 2018; Llorente *et al.* 2019). Despite this growth in practice and understanding, much remains unknown about scientists' involvement in public engagement.

As part of their appraisal of science communication, Groffman *et al.* (2010) recommended a review of the "barriers and bottlenecks" that interfere with science–society exchanges. Such a review would benefit from a formal assessment examining impacts, such as changes in beliefs, that result from public engagement activities. To that end, researchers have developed evaluative instruments to measure scientists' beliefs in their ability to succeed with PES activities and the effectiveness of these activities (Peterman *et al.* 2017; Robertson Evia *et al.* 2018). Here, we propose that another useful measure is to determine the extent and types of communication about PES efforts, strategies, perspectives, successes, and challenges within the academic science literature. Entire journals are devoted to theories and practices associated with communication and pedagogical practices. For example, the scope of *Public Understanding of Science* includes "public communication of science and scientific expertise in traditional and social media" (https://journals.sagepub.com/aims-scope/PUS), while the scope of *International Journal of Science Education Part B* includes "perspectives on communication about science and technology of individuals and groups of citizens of all ages, scientists and engineers" (https://bit.ly/3FVHJgI). These and other journals publish many articles related to PES and scientists' training, attitudes, objectives, and more (eg Besley *et al.* 2018b; Stylinski *et al.* 2018; Copple *et al.* 2020). However, many researchers within science disciplines rarely or never read these publications, as they are aimed at social scientists and educators. One way to normalize and advance PES activities by scientists is for them to discuss their efforts within their own professional disciplinary journals. Some prominent examples exist, such as calls for greater emphasis on two-way exchanges (eg Agre and Leshner 2010) and special issues related to PES activities in *Frontiers* (eg special issues focused on science communication, citizen science, and translational ecology). However, it is unknown how regularly researchers and others publish about PES in the science literature of their own disciplines.

To begin to address this, we sought to quantify the prevalence of PES discourse in the ecology literature and changes in frequency over time. We wanted to capture any discourse about PES efforts regardless of format or whether the activity was evaluated. Thus, building from Besley *et al.* (2018b), we used the broadest possible definition of PES for this study: "any time a scientist communicates about a scientific topic outside of a university setting and with people outside of their area of research". Our definition includes any communication with public audiences, K–12 teachers and students, and other stakeholders, but excludes undergraduate or graduate education and dissemination to other scientists. We selected the field of ecology as the focus of our study because socioenvironmental factors affect phenomena regularly studied in ecological research, and ecologists often interact with stakeholders. Consequently, ecology journals should be likely venues to discuss PES efforts, strategies, perspectives, successes, and challenges. We asked three questions: (1) to what extent do ecologists participate in PES activities; (2) are ecologists publishing about their PES activities; and (3) what type of PES articles are published in the ecology literature? On the basis of our findings, we provide recommendations to advance scientists' exchanges about PES endeavors in peer-reviewed science publications.

To what extent do ecologists participate in PES activities?

We drew from a 2016 survey in which Ecological Society of America (ESA) members were asked about their PES experiences with adults (data provided by J Besley, A Dudo, and S Yuan [pers comm]; key findings in Besley *et al.* 2018a,b). The survey was limited to US and university-based ESA members (4867). A total of 779 of these members (16%) completed the survey. Respondents were primarily white (92%), a mix of males and females (58% and 42%, respectively), whose mean age was 51 years. They represented diverse career levels, research funding sources, and publication records. Although only 38% had moderate to a great deal of training associated with PES activities, nearly 80% had been involved in face-to-face public engagement at least once in the previous year. Just over one-half had also participated in interviews with media professionals (56%); online exchanges through websites, blogs, and/or social networks (57%); and direct interactions with policy makers (53%). The survey respondents reported positive attitudes about prior PES experiences and expressed high willingness to maintain their involvement in PES activities (5.8 and 6.0, respectively, on a scale from 1 [negative or low] to 7 [positive or high]). Nearly three-quarters of the ecologists also reported that they did not require approval from their supervisors to pursue PES, and just over one-half received no credit for these activities. Although survey respondents do not necessarily represent the entire field of ecology, overall the findings revealed that many ecologists are conducting PES activities and intend to continue to participate in these experiences. This aligns with other studies that have reported that scientists' participation in engagement activities is becoming more common (eg Pew Research Center 2015). We therefore propose that at least some scientists are positioned to submit manuscripts on their successes, challenges, and impacts within the ecology literature.

Are ecologists publishing about their PES activities?

We conducted a literature review using the Web of Science online subscription-based citation indexing service. Given our focus on ecology, we selected the five peer-reviewed journals of ESA: *Ecology*, *Ecological Applications*, *Ecological Monographs*, *Frontiers in Ecology and the Environment*, and *Ecosphere* (hereafter, "the five ESA journals"). Within these journals, we searched for evidence of PES in titles, abstracts, and keywords of research papers, reviews, editorials, and letters published in the 20-year period 1998–2018. Many terms can be linked to public engagement, including participation, deliberation, dialogue, learning, science café, science festival, public presentation, citizen science, and others. To ensure a manageable search while casting as wide a net as possible, we used five overarching terms related to PES activities: engagement, communication, education, outreach, and broader impact. We also searched for two specific PES activities, citizen science and co-production, because they have a long history in ecology, are gaining attention, and provide opportunities to write about PES in the science literature (eg Miller-Rushing *et al.* 2012). Each search term returned articles with associated usages (eg the search term "engagement" generated articles using "public engagement with science"). We also used "wild cards" (denoted by an asterisk) to capture all grammatical forms of the search terms (eg "engag*" included engage, engages, engaged, and engagement).

In the five ESA journals over the selected time period, a total of 14,814 research papers, reviews, editorials, and letters were published, of which 368 contained our search terms. We read the abstracts of the 368 articles to remove any documents that did not meet our definition of PES; this included articles on animal communication and university-based education (206 articles). This left 162 articles that referred to PES; this was 44% of the 368 returned articles and 1% of the 14,814 total articles. A linear regression of the percentage of PES articles versus publication year indicated that such articles in the five ESA journals significantly increased from 1998 to 2018 (Figure 1), although the relationship was relatively weak ($F[1,19] = 12.96$, $P = 0.002$, adjusted $R^2 = 0.37$, slope = 0.08).

What types of PES articles are published in the ecology literature?

To categorize the types of PES articles, we created a classification scheme using a collaborative qualitative analysis process (Richards and Hemphill 2018). After a planning meeting, we individually composed notes on possible article types based on a review of a subset of manuscript abstracts, and then reconvened to discuss the notes. From these notes, one team member drafted a preliminary classification scheme, which was discussed and refined by all team members. We piloted this by independently classifying a common set of abstracts and then meeting to discuss and resolve any discrepancies, the outcome of which produced the final classification scheme. We applied this scheme to all manuscript abstracts using consensus coding, which involved having two team members independently classify each abstract, compare results, discuss differences, and come to agreement about the final classification of each abstract. In several instances, adjustments and clarifications had to be made to the classification scheme; when this occurred, we re-coded all previously coded articles as needed.

Overall, this collaborative process of coding, discussion, and refinement produced a final classification scheme with five article types – PES Reflection, PES Synthesis and Opinion, PES Embedded in Ecology Research, PES Research, and PES Training and Resources – plus descriptions and examples (Table 1), which we used to classify the 162 returned PES articles. Because we limited our review to article abstracts, we missed any descriptions of PES activities in the body of these articles; however, this approach ensured that all articles in which these activities were important

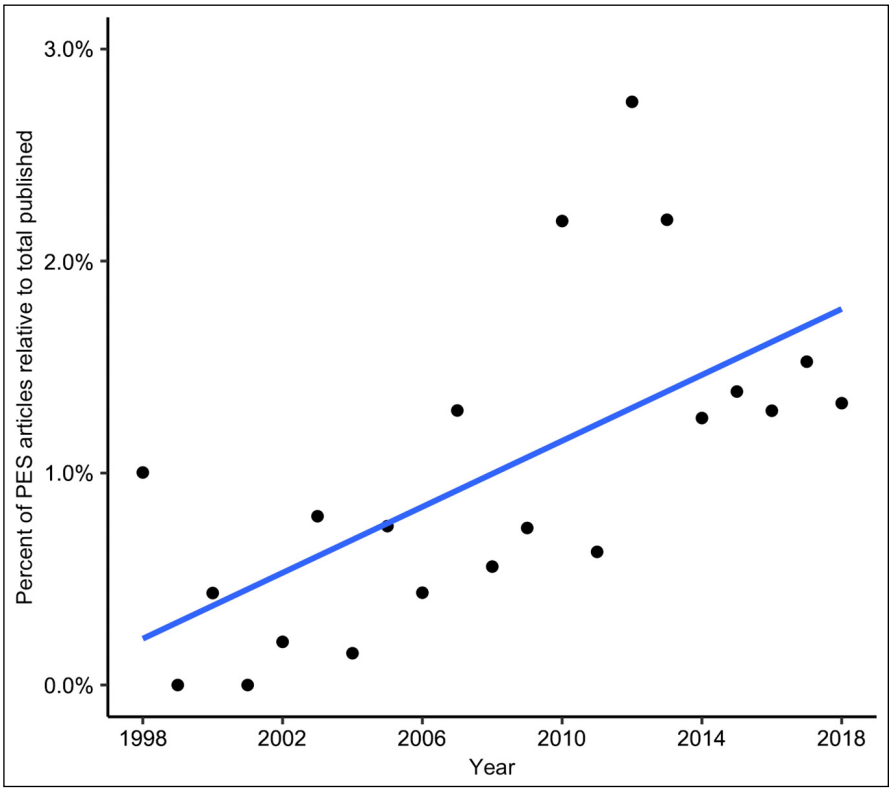

Figure 1. Publication year versus percentage of "public engagement with science" (PES) articles (relative to total articles in each journal) over a 20-year period for five journals published by the Ecological Society of America (ESA). The solid blue line is the regression line (see text for details).

Table 1. Classification scheme of articles that include "public engagement with science" (PES) activities

PES article type	Definition	Example
PES Reflection	Descriptions of authors' personal experiences participating in PES, which may include recommendations	An ecologist reflected on his experience as a US Congressional Science Fellow and the importance of personal relationships in policy (Pouyat 2007)
PES Synthesis and Opinion	Descriptions of concepts, frameworks, or best-practices relevant to PES, such as synthesis or opinions of existing PES-related work, or introduction of new ideas	A team of ecologists introduced the concept of "translational ecology" and associated effective communication practices (Enquist *et al.* 2017)
PES Embedded in Ecology Research	Descriptions of PES' role in ecological research (often within Introduction or Methods sections), such as involving citizen-science volunteers; the unit of analysis of this research is not humans and their learning; this can include accessing and using data collected by citizen-science volunteers	A team of ecologists outlined working with hunters to collect data on beaver (*Castor canadensis*) winter lodges (Brommer *et al.* 2017)
PES Research	Descriptions of original qualitative and quantitative research addressing questions about PES (not ecology); the unit of analysis of this research is humans and their learning	Two ecologists investigated "broader impact activities" within abstracts of the National Science Foundation Ecosystem Studies Program (Nadkarni and Stasch 2013)
PES Training and Resources	Descriptions of an existing instructional program to support PES	A team of ecologists presented challenges of developing the CoralWatch citizen-science program (Marshall *et al.* 2012)

Notes: PES is defined here as "any time a scientist communicates about a scientific topic outside of a university setting and with people outside of their area of research (not including undergraduate or graduate education)".

enough to state within the abstract were identified. Note that for editorials and letters (which by design do not have abstracts), we read the full text.

Using our final classification scheme, we found that the majority of PES articles (57%) were published in *Frontiers in Ecology and the Environment*, followed by *Ecosphere* (20%), *Ecological Applications* (17%), and *Ecology* (6%), with none in *Ecological Monographs*. This variation among the five journals is not surprising given their different emphases (eg *Frontiers* addresses "all aspects of ecology", whereas *Ecology* focuses on "important ecological phenomena"), but PES articles appear to be appropriate for any one of these journals.

Of the five article types, Synthesis and Opinion was the most common for PES articles published in the five ESA journals (46% of the 162 PES articles, Figure 2). This type appeared in all but 4 years throughout the 20-year time period (1–10 articles each year). The preponderance of Synthesis and Opinion articles is perhaps unsurprising, as scientists may just be beginning to consider the relevance and application of public engagement within ecology. Consequently, authors have primarily focused on calls for shifts in mindsets about communication with broader audiences, as well as frameworks and recommendations to bolster changes in tactics. For example, in 2017, a group of ecologists promoted and expanded the concept of "translational ecology" and associated principles that include collaboration among diverse stakeholders, engagement via deep dialogues that build trust, and communication that embraces respect for diverse viewpoints and applies strategies to elicit these viewpoints (Enquist *et al.* 2017).

The other PES article types appeared much less frequently: PES Research (14%), PES Embedded in Ecology Research (26%), PES Reflection (7%), and PES Training and Resources (7%). At least one article has been published every year within the article types PES Research and PES Embedded in Ecology Research since 2012 and 2007, respectively. This small but regular presence may be because ecologists are gaining expertise with PES activities, and view engagement through a research lens to test approaches and impacts on stakeholders. For example, PES Research articles in ecology journals have investigated education campaign impacts on zoo and aquarium visitors' understanding of biodiversity (Moss *et al.* 2015), metacognitive ability of 7th-grade students in the context of skills associated with social–ecological system-resilience thinking (Spellman *et al.* 2016), scientists' policy-related activities and beliefs (Singh *et al.* 2014), and factors affecting interactions between ecologists and rural Indigenous communities (Castillo *et al.* 2018). Likewise, the persistent presence of PES Embedded in Ecology Research articles provides evidence that some ecologists are embracing public engagement as an essential component for developing, conducting, or disseminating their investigations. These efforts include collaborative ecological studies between scientists and professional stakeholders (eg Miller *et al.* 2009) or citizen-science volunteers (eg Mazer *et al.* 2015). They also include data validation studies, which assess the quality of data collected or produced by citizen-science volunteers (eg Cox *et al.* 2012).

Summary and recommendations

Our review indicated that, even though ecologists often lack formal PES training and may not receive professional credit within the academic system for PES endeavors, many interact with the public and intend to continue their participation in public engagement activities. This participation is likely influenced by the NSF requirement of "broader impacts" in every grant proposal submission, although this requirement

expands well beyond PES (for example, it includes graduate education and dissemination to other scientists). However, despite this high level of involvement, only a very small proportion of ecologists contribute articles about their PES activities to journals regularly read by their peers. Although rising slightly in number over the past two decades, PES articles still remain a minor component, representing less than 1% of all articles published in the five ESA journals.

As we are not aware of any analogous analyses on the communication of PES activities, we do not know how the field of ecology compares to other science disciplines. Although we cannot determine the "right" percentage of PES articles in ecology journals, we suggest that 1% of the total body of knowledge is far too low. We therefore urge that the number and types of PES articles published in ecological and other scientific journals be increased based on the following rationale: (1) such publications can offer a form of professional credit within the academic system to help normalize and increase PES by scientists; and (2) because these publications are regularly read by scientists, they serve as an avenue to improve engagement practices as scientists share and discuss their efforts, strategies, perspectives, successes, and challenges associated with participating in and reflecting on PES. For example, more PES Reflection articles could enhance scientists' awareness of innovative ways to inform the public about ecological research, while additional PES Embedded in Ecology Research articles could provide specific strategies for involving stakeholders in scientific studies (eg informing study design and supporting collection of field data). Our study developed and refined a classification scheme, which we offer as a way to assess the extent and ways in which these different types of PES activities are communicated in peer-reviewed scientific journals; additional studies can apply it further in ecology and to other science disciplines.

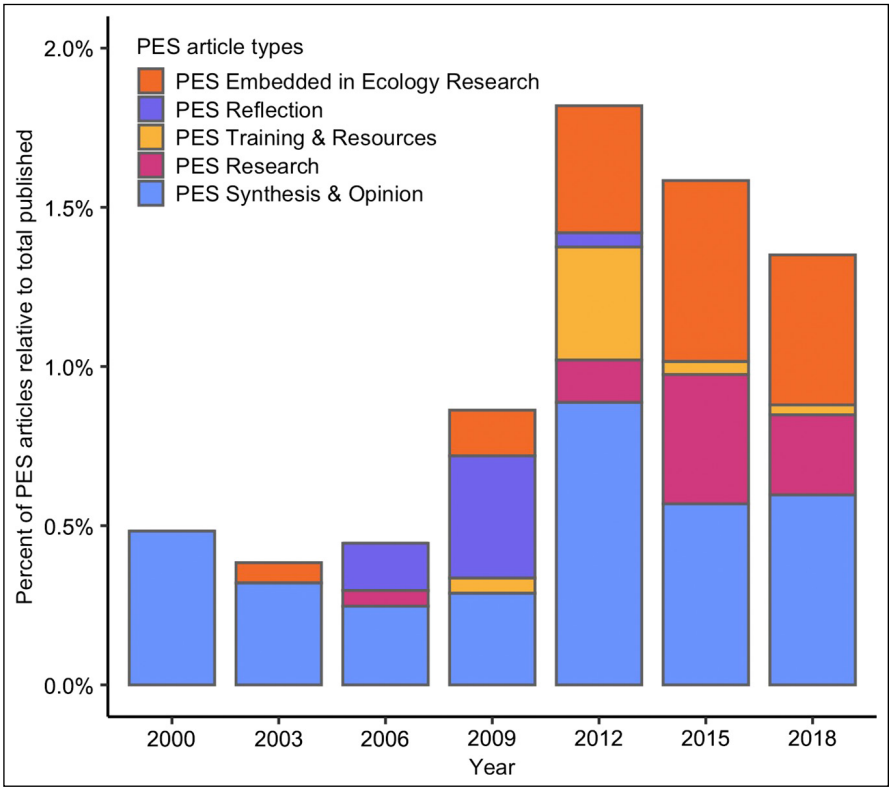

Figure 2. Percentage of each PES article type (relative to the total articles in each ESA journal) published from 1998 to 2018 (organized into 3-year groupings as depicted on the x axis, where, for instance, "2000" collectively represents all PES articles published in 1998, 1999, and 2000). See Table 1 for descriptions of article types.

Scientific organizations and prominent researchers have called for major changes in how science is communicated. As part of this movement, we encourage ecologists to write articles about their efforts to engage the public and stakeholders in ecological topics and investigations. We also encourage journal editors to promote and be responsive to PES-related submissions, and for reviewers to maintain a broad view of discussions about PES activities in scientific manuscripts. Special issues provide venues for delving deeper into specific topics, such as PES, but we also urge editors to consider publishing PES articles in regular issues of their journals to further normalize and embed PES into scientific practice. Finally, to improve access to this work, we recommend more consistent use of common PES keywords in science articles. To conduct our search, we could not include the multitude of words that could be associated with PES activities, and instead used several broad search terms, which returned many articles (56%) that lacked a connection to PES. Furthermore, articles on PES that used different PES-relevant terms were likely overlooked (eg an article on science cafés may not include "educate", "engage", "communicate", "co-production", "broader impact", "citizen science", or "outreach"). Overall, it is challenging for ecologists to find existing articles linked to PES because multiple labels are applied to this practice. We therefore suggest that journals update pre-populated lists with common PES keywords, such as "public engagement with science", and encourage authors to use these shared terms.

Although our findings provide evidence of the presence of articles on PES activities in ecology journals, many questions remain about the quality of PES. Are scientists open to mutual learning? Do they have opportunities to pursue PES and particularly co-production of knowledge? How effective are their PES efforts? Others have also highlighted the need to better understand and address the lack of incentives and rewards associated with participating in PES, as well as the challenge of balancing such work with other professional obligations (eg American Academy of Arts & Sciences 2020). We must also

acknowledge and address the often outsized workload placed on scientists from minority groups who are disproportionally asked to participate in service activities, including PES, to promote diversity (Akin 2020). Addressing issues of credit, incentives, and workloads will require an approach that includes resources, training, shifts in university policies and culture, and more research. Because publications serve as currency within the academic community, one component of this approach is increased publication of articles on PES efforts, perspectives, strategies, successes, and challenges in science journals. Such publications can serve as a form of "credit", while also helping to normalize and advance the practice of PES by scientists.

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Data Availability Statement

Data used in this Review are not publicly available because they are human subject data. Data can be obtained by researchers with appropriate credentials from J Besley (jbesley@msu.edu).

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