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NSF Supported Socio-Environmental Research: How Do Crosscutting Programs Affect Research Funding, Publication, and Citation Patterns?

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Insight

NSF supported socio-environmental research: how do crosscutting programs affect research funding, publication, and citation patterns?

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ABSTRACT. Recognizing the continued human domination of landscapes across the globe, social-ecological systems (SES) research has proliferated, necessitating interdisciplinary collaborations. Although interdisciplinary research started gaining traction in academic settings close to 50 years ago, formal frameworks for SES research did not develop until the late 1990s. The first National Science Foundation (NSF) funding mechanism specifically for interdisciplinary SES research began in 2001 and the SES-specific Coupled Natural Human (CNH) Systems program began in 2007. We used data on funded NSF projects from 2000 to 2015 to examine how SES research was funded, where the research is published, and the scholarly impact of SES research. Despite specific programs for funding SES research within the NSF, this type of research also received funding from non-SES mission programs (e.g., Ecosystem Science constituted 19% of grants in our study, and Hydrology constituted 16% of grants). Although NSF funding for SES research originates from across programs, the majority of products are published in journals with a focus on ecological sciences. Grants funded through the Coupled Natural Human Systems programs were more likely to publish at least one paper that was highly interdisciplinary (Biological Sciences [BE-CNH] constituted 70% of grants in program, and Geosciences [GEO-CNH] constituted 48% of grants) than the traditional disciplinary programs (Ecology [ES], 35% and Hydrology, 27%). This result highlights the utility of these cross-cutting programs in producing and widely disseminating SES research. We found that the number of citations was higher in BE-CNH and ES than other programs, pointing to greater scholarly impact of SES research in these NSF programs. Through our research, we identified the need for institutions to recognize research products and deliverables beyond the "standard" peer-reviewed manuscripts, as SES and interdisciplinary research and unconventional research products (e.g., popular press articles, online StoryMaps, workshops, white papers) continue to grow and are important to the broader societal impact of these types of research programs. This project demonstrates that the outcomes and products of grants awarded through the NSF CNH programs are important to furthering SES research and the programs should be valued and expanded in the future.

Key Words: *funding; interdisciplinary; NSF; research impact; social-ecological systems*

INTRODUCTION

Humans have altered the majority of Earth's landscapes (Hooke et al. 2012, Williams et al. 2015, Ellis et al. 2021), leading to increasing recognition of the pervasiveness of human impacts on environmental systems around the globe. This awareness gave rise to the need for a new framework that couples humans, our institutional structures, and decision making with environmental systems as integral parts of an interconnected whole. Although not the first discipline to tackle these issues, the growing field of socio-environmental systems and the coupled-human and natural systems framework (henceforth discussed as "SES") arose in response to this need, promoting understanding of the interconnections, feedbacks, and drivers between environmental and human systems (Liu et al. 2007, Bodin and Tengö 2012, Chen 2015, Turner et al. 2016).

SES research is inherently interdisciplinary, requiring integration and fusion of knowledge, concepts, and approaches from a range of academic disciplines (Holzer et al. 2018, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2005, Serlet et al. 2020). Many of the grand challenges we currently face (e.g., climate change, health, pollution) are embedded in coupled socio-environmental systems, requiring interdisciplinary research to advance understanding of the controls and feedbacks in these systems (Ledford 2015). Interdisciplinary research efforts face unique challenges and tensions related to the complexity of problems considered and differences in perspectives, norms, and language that can stymie communication (Pohl and Hirsch Hadorn 2008, Lang et al. 2012, Pricope et al. 2020). Yet, interdisciplinarity is increasingly considered a standard approach to SES research (Chen 2015, Thompson et al. 2017, Serlet et al. 2020).

In the more than 20 years since SES was first formalized as an analytical framework (Berkes and Folke 1998), the application of the concept has spread across multiple disciplines (Colding and Barthel, 2019). The SES framework was modified to fit a variety of systems such as fisheries, cities, and forestry, and has been integral to studying resilience and sustainability by providing a common foundation for researchers with different approaches, backgrounds, and research traditions (Folke 2006, Pickett et al. 2016, Partelow 2018). In addition, SES models and frameworks underpin massive research efforts such as long-term social-ecological research (LTSER) sites in Europe (Mauz et al. 2012, Dick et al. 2018) and some long-term ecological research (LTER) sites (particularly the Central Arizona-Phoenix, Baltimore Ecosystem Study, and new Minneapolis-St. Paul) in the U.S. (Redman et al. 2004).

Despite the growing prominence of the SES framework as an approach to understanding coupled socio-environmental systems, funding programs specifically targeted at this type of

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integrative research generally lagged behind the application of this approach by the scientific community. In recognition of this, the NSF, one of the primary funders of environmental research in the U.S., initiated a program for funding research that integrates social and environmental understanding. This program, (previously Coupled Natural Human Systems [CNH]; as of 2020 Dynamics of Integrated Socio-Environmental Systems [DISES]; National Science Foundation 2020), supports interdisciplinary research on both the human and natural system components, processes, integration, and interactions of a coupled human natural or socio-environmental system (National Science Foundation 2018, 2020). It is a multi-directorate program, managed by Biological Sciences, Geosciences and Social, Behavioral and Economic Sciences since 2007. Before 2007, the program was a special competition in the Biocomplexity in the Environment emphasis area from 2001 to 2005.

NSF promotes interdisciplinary research as a funding goal, which provides opportunities for major directorates (large scale thematic units in the NSF, including those previously named), to fund SES research in addition to the cross-cutting CNH/DISES program. For example, the Ecosystem Science (ES) Cluster within the Directorate for Biological Sciences accepts research proposals on "managed, and disturbed ecosystems...and human-dominated environments"(https://beta.nsf.gov/funding/opportunities/ecosystem-science-cluster-0). Although interdisciplinarity is a larger agency goal, certain programs emphasize interdisciplinary proposals more than others and collaborative projects are often just two principle investigators (PIs) or integration of two fields (Kardes et al. 2014). Although broader impacts create opportunities for communicating the societal implications of a given proposal, NSF's mission is frequently thought of as the funder of "basic" or "fundamental" science, leaving out ideas or fields that are perceived as more applied or anthropocentric in nature. Therefore, there are distinct directorate and programmatic differences in the solicitation and funding of SES and interdisciplinary grant proposals. As NSF and other funding agencies continue to support these types of research efforts through new and existing funding mechanisms, it will be valuable for them to consider how the outcomes of their funded projects align with their stated objectives and potentially re-assess their criteria of success. It is also valuable for the community of SES researchers to understand patterns of funding and the outcomes of research supported by these programs in order to build successful interdisciplinary research programs (e.g., choosing which programs are most suitable for researchers to develop and submit proposals).

Here, we explore the state of SES research funded by the NSF. Specifically, we examine NSF-supported SES research funded through the CNH program and through other NSF programs (which are not specifically targeted toward integration of social and environmental systems), characterizing the amount of funding, interdisciplinarity, and citation rate of the products produced from grants funded through these programs. Using information reported about NSF grants, we ask:

1. Funding

- What are the main programs funding SES research at the NSF?
- How many projects are funded through each program/directorate and to what extent?

2. Productivity

- How many manuscripts do NSF-supported SES research grants produce, and does this differ among grants funded by different programs/directorates?

3. Interdisciplinarity

- What disciplinary audience(s) is/are being targeted by publications that arise from NSF-supported SES research? Does this differ across programs/directorates?
- At what scale (individual publications vs. population of publications produced from a grant) can the products of SES research be considered interdisciplinary?

4. Scholarly Impact

- How much is NSF-supported SES work cited? What is the relationship between interdisciplinarity and citation rate? How does citation rate differ across funding programs?

To address these questions, we gathered data about grants that have funded SES research across multiple NSF directorates, used NSF Award search to record the number of peer-reviewed publications associated with each grant, and assessed the interdisciplinarity and scholarly impact of publications (using citations as a proxy metric, albeit limited, Fig. 1). Given the limited (but growing) funding opportunities designated specifically for SES research and the diversity of disciplines from which this work (and funding for it) may come, these questions have bearing on the future of funding and success of interdisciplinary SES research, and how reporting mechanisms can be improved or adapted to highlight the unique contributions made by SES researchers.

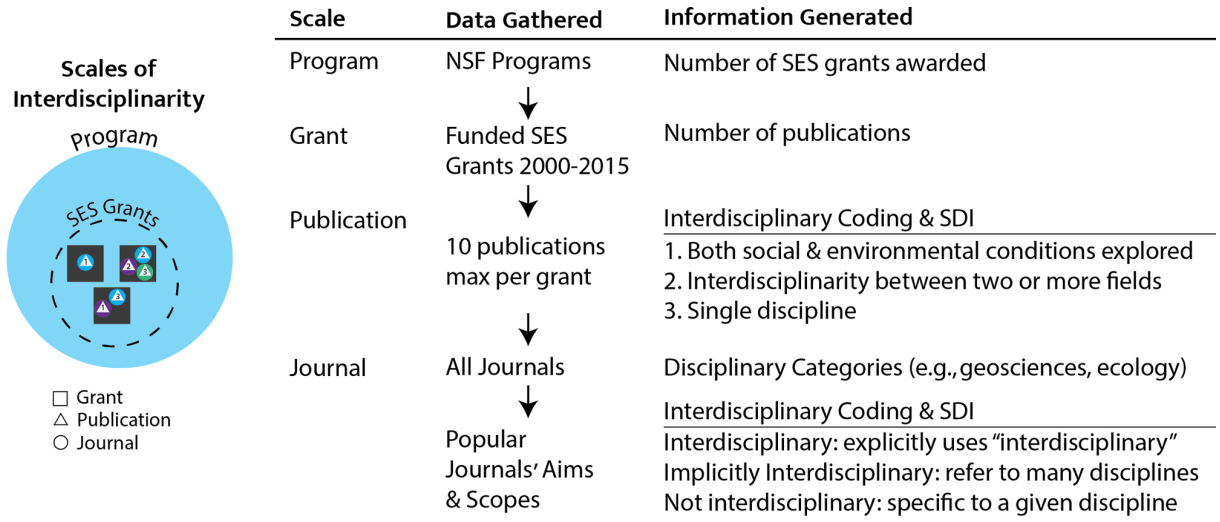
METHODS

Data acquisition and cleaning

To assess how SES is funded, we collected data on grants with a possible SES focus or component. We used DimensionsPlus (Digital Science 2018) to query grants from the NSF. DimensionsPlus is a comprehensive database of publications, grants, books, chapters, and conference proceedings. We searched for funded projects from 12 grant programs in the Geosciences, Biological Sciences, Engineering, Computer & Information Science & Engineering, and Social, Behavioral & Economic Sciences Directorates that might include SES grants (Table A1.1) on 7 June 2019. We exported those results to csv files that contained 9381 individual entries (grants or collaborative grants). We then narrowed this list by retaining only grants with start and end dates between 2000 and 2015 (n = 4170) and eliminating duplicate collaborative grants for a final total of 3384 individual grants. We then screened for grants with a focus on SES by examining the grant title (retaining those that included both a human and natural component). We included Research Experience for Undergraduate (REU) sites and Research Collaboration Networks (RCNs), because they often produce publications, but we did not include funding for workshops, infrastructure, or educational programming. This process left us with a data set of 137 funded grants across nine programs.

After curating this list of grants that funded SES research between 2000 and 2015, we used the NSF Award Search (https://www.nsf.gov/awardsearch/) to record the number of scholarly products

Fig. 1. Conceptual figure and flow chart of data collected for analysis. At the program scale, specific programs that might fund SES research were identified, SES grants awarded from that program were then subset from the full list of funded projects (dashed circle). Black squares denote a given grant and the diversity (or lack thereof) in journals and diversity index of each publication resulting from the grant.



produced as the result of each grant (i.e., "Publications Produced as a Result of this Research"). For each grant, we then recorded bibliographic information (title, year, authors, journal) for no more than 10 publications. If there were over 10 publications listed with the award, we randomly sampled 10 publications (the total number of publications reported ranged from 0 to 329, mean: 18, median: 5). Books or publications that were not subject to peer review (which were infrequently reported) were not included in our further analyses. We then collected additional data about each publication, including the number of citations and the text of the abstract, using Google Scholar. If we were unable to find a given publication using Google Scholar we removed it from our data set. It is important to note that we encountered a few discrepancies in what was reported on the NSF award information pages (e.g., papers associated with a given grant number despite the NSF award information listing no publications, title/journal information that differed from the published version, conference abstracts listed as publications, the same manuscript listed multiple times). In these cases, we made a good-faith effort to identify and include the paper in our final dataset, excluding those we could not find in the search, and then updated the associated total publication count.

Metrics of scholarly impact and interdisciplinarity

For each publication in our final list (n = 570 of 2482 total reported papers) we coded the degree of interdisciplinarity of each publication based on both the paper abstract and the departmental affiliations of the authors. Our interdisciplinarity code had three levels: "1" indicated social and natural science interdisciplinarity where both social and environmental conditions are measured or explored and/or author affiliations included departments across these disciplines; "2" indicated general interdisciplinarity between two or more different fields (that may both be within natural or social science); and "3" indicated single-disciplinarity. Although this categorization is inherently subjective, we controlled for differences among members of the author team: each member coded a subset of the publications individually, and then switched subsets to code a second time. Once all publications had been coded twice, we discussed discrepancies (of which there were few) to come to a consensus evaluation. We assumed that the large number of publications we coded represented the diversity of programs, grants, and associated publications related to SES research being funded by NSF.

To capture another angle of interdisciplinarity of these products, we evaluated the interdisciplinarity of the journals in which they were published. We categorized each journal as publishing in the natural sciences, social sciences, or interdisciplinary/SES. For journals that had three or more of the publications in our data set, we collected the journal aims and scope to determine whether the journal focused on publishing interdisciplinary or SES research. We coded the journals by whether they explicitly used "interdisciplinary" in their aims and scope (e.g., Journal of Environmental Management), implicitly referred to interdisciplinary research (e.g., Global Environmental Change), or did not refer to interdisciplinarity at all (e.g., Geophysical Research Letters).

Finally, we calculated a diversity index for the publications that resulted from each grant. After recording the academic discipline of each journal in our dataset (e.g., geoscience, biology/ecology, human health; see Table A.1.2 for full list), we used the Shannon Diversity Index (SDI; Shannon 1948) to assess the abundance and evenness of journal disciplines for each grant, controlling for differences in the total number of papers. The SDI takes on greater values for grants with manuscripts published across a wider variety of disciplines and with more evenness among disciplines. For example, consider the SDIs of four hypothetical grants: Grant A (10 papers total: 3 in geoscience journals, 3 in biology/ecology, and 4 in human health; SDI = 1.089), Grant B (10 papers total: 8 geoscience, 1 biology/ecology, and 1 human health; SDI =

Table 1. Total number of grants funding SES research by NSF program, total publications, and total and average funding amounts for grants included in this analysis.

Program	Number of grants	Percent of total grants	Papers from program	Percent of total papers	Funding per program (US$1000)	Percent of total funding	Average funding per grant
Biological Sciences CNH (BE-CNH)	37	27.01%	361	14.54%	$24,690	26.87%	$667,297
Critical Resilience (CR)	5	3.65%	41	1.65%	$2390	2.60%	$478,000
EPSCOR	2	1.46%	39	1.57%	$1300	1.41%	$650,000
Ecosystem Science (ES)	26	18.98%	407	16.39%	$18,480	20.11%	$710,769
Geosciences - CNH (GEO-CNH)	35	25.55%	411	16.55%	$19,870	21.63%	$567,714
Humans, Disasters, and the Built Environment (HDBE)	2	1.46%	3	0.12%	$1330	1.45%	$665,000
Hydrology (Hydro)	22	16.06%	96	3.87%	$16,390	17.84%	$745,000
Long-Term Ecological Research (LTER)	7	5.11%	1125	45.31%	$6930	7.54%	$990,000
Machine Learning (ML)	1	0.73%	0	0%	$500	0.54%	$500,000
TOTAL	137	100%	2483	100%	$91,880	100%	$670,657

0.639), Grant C (6 papers total: 2 geoscience, 2 biology/ecology, and 2 human health; SDI = 1.099), and Grant D (6 papers total: 4 geoscience, and 2 biology/ecology; SDI = 0.637). This measure allowed us to determine whether the products from a given grant are reaching various audiences by publishing different types of manuscripts, an assessment of interdisciplinarity at the grant rather than at the publication scale. To meet the data needs of the analysis, we used a subset of grants from the programs/directorates with the largest numbers of grants in our final dataset: Hydrology, Ecosystem Science (ES), Dynamics of Coupled Natural and Human Systems - Biological Sciences (BE-CNH), and Dynamics of Coupled Natural and Human Systems - Geological Sciences (GEO-CNH). We used the same SDI analysis to determine the evenness of interdisciplinary scores across papers within grants in each program.

We emphasize that although our analysis assesses the scholarly impact of research through citations and publications, these are not the only measures of impact, scholarly or societal (Bornmann 2012). Because we are using the publicly reported information collected by NSF, we are limited by the measures that NSF uses to assess the impact and performance of the grants it funds.

Data analysis

To query, analyze, and visualize data, we used R (3.6.2) tidyverse packages ggplot2 (3.3.2) and dplyr (1.0.2). First, the number of SES grants funded under each program was calculated. We then calculated the number of resulting publications, funding, and citations by grant, program, and journal. Creating summary statistics and distributions, we compared the main moments (i.e., mean and standard deviation) across granting programs. We also tallied within each grant the number of 1, 2, and 3 codes from the interdisciplinary coding.

RESULTS AND DISCUSSION

Funding

The two CNH programs funded over half of the SES projects captured in our review of grants from 2000–2015 (Fig. 2a, Table 1). Given the mission of the CNH program to "support interdisciplinary research that examines human and natural system processes and the complex interactions among human and natural systems at diverse scales" (National Science Foundation 2018), we expected CNH programs to be the dominant funding stream for SES projects. However, there were many SES projects funded by other programs within NSF (e.g., Ecosystem Science: 19% of projects, and Hydrology: 16%). These high proportions may be because of the increased recognition of the importance of studying SES within these disciplines, the perceived challenge of being awarded a CNH (and thus a tendency among researchers to seek funding for SES research from other programs), or it may highlight a need for greater funding or additional special programs like CNH (now DISES).

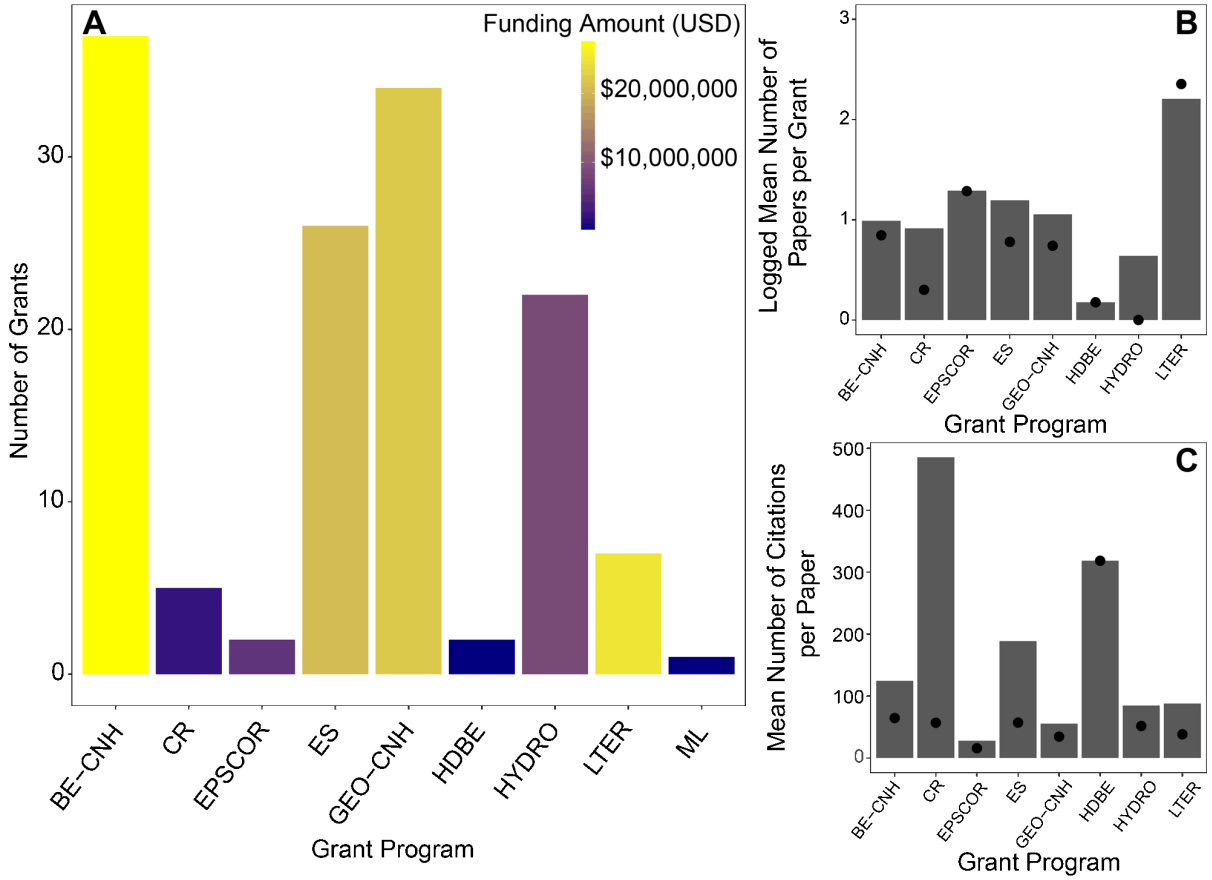
Although the percentage of total grants and the percentage of total funding among programs are highly correlated, there are some notable divergences. For example, CNH awards receive less funding on average than grants awarded under their equivalent disciplinary programs (GEO-CNH awards are on average US$43,000 less than Hydrology awards; BE-CNH averages US$177,000 less than Ecosystem Science grants; Table 1). These differences in the average award amounts among programs have implications for both where researchers choose to submit proposals and the scope of SES research that can be accomplished within a given project.

Productivity

Grants awarded through the LTER Network program produce the highest number of papers per grant (161 papers per grant, on average; Fig. 2b). This highlights the value of funding for long-term research, where enduring research infrastructure and long-term, consistent, ongoing datasets can produce significant returns in terms of productivity (among myriad other benefits; Likens 1989, Lindenmayer et al. 2012). Although individual grants supported by most of the programs produce around 10 publications on average, the average productivity of grants supported by the Critical Resilience (CR) and Hydrology programs is skewed by a few grants that produced many papers, whereas the majority produced only a few or no papers.

One major challenge with assessing "productivity" in SES research is the limitation of counting only peer-reviewed publications. SES research, particularly transdisciplinary projects where local stakeholders are involved, often produce work that is meant for audiences beyond academia, including local policy makers, managers, and/or the general public, such as popular press articles, online StoryMaps, white/gray literature, open

Fig. 2. Funding, productivity, and impact of National Science Foundation (NSF) grants awarded between 2000 and 2015 for social-ecological systems (SES) research projects. Total count of grants (height of bar, A) was highest in the two Coupled Natural Human (CNH) Systems programs (Biological Sciences BE-CNH] and Geosciences [GEO-CNH]), although the greatest total funding was awarded through the BE-CNH and long-term ecological research (LTER) programs (color of bar, A). The mean number of papers published per grant (height of gray bar, B) was similar among programs (except LTER and Humans, Disasters, and the Built Environment [HDBE]), although the median number of papers per grant (black circles, B) was more variable. The mean number of citations per paper from grants (height of gray bar, C) varied among programs, with the highest mean citations from papers resulting from ER and HDBE program funding. In contrast, the median number of citations per paper (black circles, C) was similar across programs, with the exception of HDBE which may be high given only having three papers.



datasets and/or visualizations, workshops, or fact sheets. This scholarly work is an extremely valuable way to communicate the results of the project to the individuals that stand to benefit the most from the research, but academia does not yet have a widespread, broader set of evaluative methods for acknowledging and recording these types of contributions (Holzer et al. 2019). Indeed, these contributions were only infrequently recorded in the NSF Award Search system. The process of creating interdisciplinary work itself may provide valuable insights to future work, and the societal impacts may have significant lag times (Arnott et al. 2020). In fact, entirely new ways of measuring success in SES research may be necessary to evaluate the myriad of tangible and intangible impacts that interdisciplinary, actionable, or place-based science has on these systems (Bornmann et al. 2012, Balvanera et al. 2017).

Impact

We evaluated the number of citations per publication in each program to assess if NSF supported SES research has greater scholarly impact when it is more interdisciplinary. The median number of citations per paper are similar across most programs, suggesting a similar impact for the majority of SES work in Hydrology and CNH programs in both Biology and Geosciences (Fig. 2c). Some programs had a few papers (CR: total papers = 41, Humans, Disasters, and the Built Environment (HDBE): total papers = 3) that are highly cited, which inflate the mean citation number, illustrated by the difference between the mean and the median (Fig. 2c). Overall, our results show a similar impact of papers, as assessed by citations, across programs. Similar to the challenges with evaluating productivity based on the number of published peer-reviewed articles, citations are not ideal for evaluating the true societal, or broader impact of SES work

because they do not reflect the impact of the non-peer reviewed publications and other outputs that are not included in NSF reporting (e.g., open data, code, and software), nor do they provide a measure of long-term societal impacts (Balvanera et al. 2017, Arnott et al. 2020).

Interdisciplinarity

We evaluated whether the interdisciplinarity of products resulting from these grants differed between CNH and traditional programs. One challenge in doing this was determining how to characterize interdisciplinarity. For example, an individual paper may have authors from across disciplines and/or may publish in a journal that has diverse readership. At the scale of the grant, the products may be published across a range of disciplinary and interdisciplinary journals, creating different routes to reaching interdisciplinary audiences.

To understand what disciplinary audiences SES research is targeting, we determined the broad discipline (natural science, social sciences, interdisciplinary/SES) for each journal with a publication across the NSF programs evaluated. Assessing all grants, natural science journals captured the largest percentage of publications across NSF programs (63%, Table 2). The CNH programs had almost double the percentage of interdisciplinary and SES journals than their ES/Hydrology counterparts. Publications in the social science journals remained low, only capturing 6% of publications across programs. Given the importance of social science in SES research, the low percentage of work published in social science journals is unexpected. Although we do not have the information to know why this is the case, we could imagine a few alternative scenarios. Social scientists could be getting a smaller percentage of the larger grant, limiting their ability to publish findings in social-science specific outlets, their work could be more time intensive (e.g., conducting and analyzing interviews vs. modeling climate simulations),thereby limiting their ability to publish as many articles within the grant cycle, or their input is so critical to the collective grant goals they are time-limited in developing independent research products that would fall specifically in social science journals (rather than interdisciplinary ones). This also highlights the need to broaden participation of social scientists beyond having one "token" social scientist on a team of environmental scientists, which may increase their ability to publish more articles in social science specific journals. In any case, this finding is particularly relevant for the CNH program, which specifically sought to have findings in each side of the natural-human spectrum as well as the integrated components.

Table 2. Journal categories in which NSF-funded SES research is published, by program.

Program	Natural Science Journals, count (%)	Social Science Journals, count (%)	Interdisciplinary & SES journals, count (%)	Total grant count
BE-CNH	82 (50.6)	15 (9.26)	65 (40.1)	162
ES	77 (70.6)	7 (6.42)	25 (22.9)	109
GEO-CNH	96 (65.8)	7 (4.79)	43 (29.5)	146
Hydrology	29 (80.6)	1 (2.78)	6 (16.7)	36
All Programs	327 (63.0)	33 (6.36)	159 (30.6)	519

To further understand publication outlets, we identified a subset of journals with higher numbers of publications (i.e., those journals in which three or more publications from our dataset appeared, n = 23) to determine the most common outlets and audiences reached by these projects. Of this subset, 78% of the journals included interdisciplinarity (explicitly or implicitly) in their aims and scopes and 52% of them included human/social institutions and processes (Fig. A1.1). These results show that journals with an interdisciplinary or SES scope are more likely to be targeted by researchers with CNH grants.

To gain insight on the different bodies of publications resulting from grants that fund SES research, we characterized interdisciplinarity of papers at the program and grant scale across ES, Hydro, GEO-CNH, and BE-CNH programs. At the program scale, the CNH programs have a high percentage of SES grants that contain at least one paper that is coded as highly interdisciplinary (GEO-CNH: 49%, BE-CNH: 70%; Table 3). Comparatively, the SES grants that came from ES and Hydrology programs are less likely to have at least one highly interdisciplinary paper (Hydro 27%: ES: 35%). This result highlights the importance of these cross-cutting programs and the requirements in their solicitations that mandate interdisciplinary proposals and teams.

To evaluate interdisciplinarity of products at the grant scale, we calculated the diversity of the interdisciplinarity index among papers within each grant by program (Fig. 3). In these distributions, the higher the SDI value of the peak, the higher the average richness and evenness of interdisciplinarity scores of papers within grants funded by a given program. In other words, a higher SDI value means that the grant has publications across a greater range of interdisciplinary and disciplinary outlets, pointing to the interdisciplinary success of the grant level, rather than the publication level. Grants in CNH programs are more likely to produce papers across the spectrum of interdisciplinarity, which highlights the importance of looking at the grant as a whole instead of just individual products (Fig. 3a). This high diversity score produces publications that deepen work within individual disciplines as well as establishing connections across disciplines. Interestingly, ES also has a relatively high proportion of grants that represent a range of interdisciplinary products. In the Hydrology program, the distribution has two modes with either mostly disciplinary or interdisciplinary publications, suggesting that the products of SES hydrology proposals are either more disciplinary than those in ES or also publish papers across the whole spectrum of interdisciplinarity. We find that CNH programs tend to have more diverse products across grants than the traditional disciplinary programs when considering the interdisciplinary index.

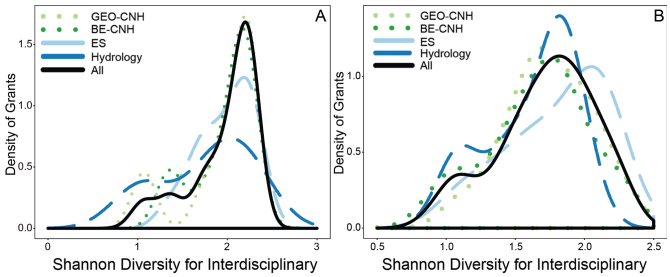
We also assessed interdisciplinarity at the grant scale by calculating SDI of the disciplines of the journals in which products were published (Fig. 3b; Table A1.2). The distributions of SDI scores across grants show a consistent picture across programs. The relatively high SDI scores for each program suggest that the population of papers produced from grants are generally published in a set of journals with high richness and evenness of disciplines. ES shows the most highly skewed distribution, suggesting even greater average diversity of journal disciplines for grants in this program. These results show that regardless of

Table 3. Interdisciplinarity of products from grants funding SES research across NSF programs. Across all grants in our study, we coded peer-reviewed manuscripts associated with grants as "1" (interdisciplinary across social and natural sciences), "2" (interdisciplinary within, but not across, social or natural sciences), or "3" (not interdisciplinary).

Program	Grants with at least one paper coded as "1," count (%)	Grants with at least one paper coded as "2," count (%)	Grants with at least one paper coded as "3," count (%)	Total grant count
BE-CNH	26 (70.3)	15 (40.5)	16 (43.2)	37
ES	9 (34.6)	8 (30.8)	16 (61.5)	26
GEO-CNH	17 (48.6)	12 (34.3)	12 (34.3)	35
Hydrology	6 (27.3)	7 (31.8)	7 (31.8)	22
All programs	66 (48.2)	48 (35.0)	60 (43.9)	137

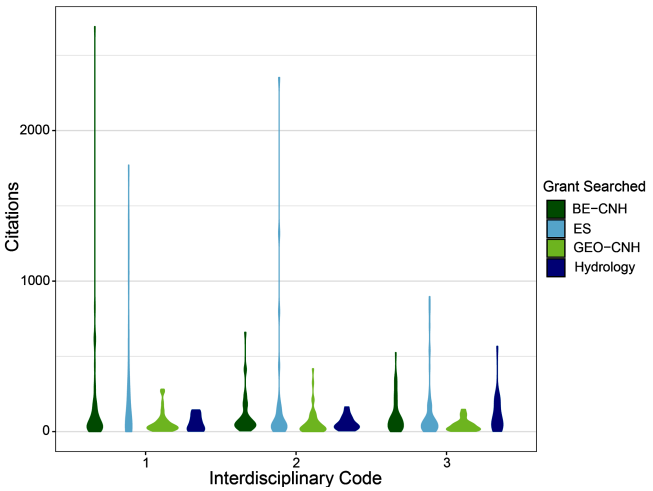
granting program, SES grants tend to publish manuscripts across diverse outlets, both discipline specific and interdisciplinary journals. A second peak at lower SDI value across many of the granting programs demonstrates a set of less diverse publication outlets for some grants funded through GEO-CNH and Hydrology programs.

Fig. 3. Distributions of Shannon Diversity Index of publication Interdisciplinarity scores and journal discipline for grants awarded by four NSF programs. Grants with higher richness and evenness in interdisciplinary index codes will have a higher Shannon Diversity Index number (n(BE-CNH) = 361, n(ES) = 407, n(GEO-CNH) = 411, n(Hydrology) = 96).



Although determining the publication outlets is relevant for determining where and to what audience a given team is disseminating their work, we were also interested in evaluating which publications receive the most attention from the scientific community (Fig. 4). Publications with a high interdisciplinarity score had the highest number of citations from the BE-CNH programs. Publications from the GEO-CNH program had fewer highly cited outliers than BE-CNH publications across all interdisciplinarity levels. Despite being identified as SES grants, the most highly cited publications from the Hydrology program were those categorized as single-discipline. Except for the Hydrology program, the distributions of total citations for papers were different for highly interdisciplinary to less interdisciplinary groups. The number of highly cited outliers decreased across BE-CNH, GEO-CNH, and ES programs. This result could show that the most highly cited publications are coming from interdisciplinary work published in high-impact interdisciplinary journals (e.g., *Nature* and *PNAS*). Although BE-CNH and ES grants had highly cited papers in each category, the GEO-CNH and Hydrology grants had many papers that were cited by few to no other publications.

Fig. 4. Distributions of citations for publications from grants funded by each of four NSF granting programs, grouped by interdisciplinarity index. Papers coded as "1" are interdisciplinary across social and natural sciences (n(BE-CNH) = 88, n(ES) = 33, n(GEO-CNH) = 88, n(Hydrology) = 14); papers coded as "2" are interdisciplinary within, but not across, social or natural sciences (n(BE-CNH) = 33, n(ES) = 18, n(GEO-CNH) = 26, n(Hydrology) = 13); papers coded as "3" are not interdisciplinary (n(BE-CNH) = 65, n(ES) = 77, n (GEO-CNH) = 39, n(Hydrology) = 27).



CONCLUSIONS

Our work shows that CNH programs are better at funding interdisciplinary and SES projects that create interdisciplinary products, while still often deepening disciplinary knowledge. SES research carries a number of additional challenges and requirements that come with the interdisciplinary nature of SES work. Additional financial resources are critical for creating successful interdisciplinary collaborations that enable research teams to successfully undertake SES research, yet SES-focused programs award less funding per grant on average than their equivalent disciplinary grants. This corresponds with other findings that show funding favors more disciplinary work over interdisciplinary work between cognitive science and educational research (Kwon 2017). Although scholarly impact was relatively similar across programs, it is challenging to assess the true impact of SES research without consistent and widespread reporting and

tools for evaluating products and broader impacts beyond peer-reviewed publications.

SES research is more often published in journals with interdisciplinary scopes than those with a narrower focus. At the program scale, there was a greater likelihood that grants funded through CNH programs (in comparison to their natural science counterparts) produced a highly interdisciplinary paper, highlighting the value of these cross-cutting programs. One purported challenge to interdisciplinary work is the need to simultaneously deepen knowledge in a given field while broadening to incorporate knowledge from other fields. Our analysis of the variability of interdisciplinarity of publications from a given grant show that peer reviewed products within grants are often representative across the range from disciplinary to interdisciplinary subject matter. Analyzing interdisciplinarity of products from individual publications to the grant and program scales is necessary to encapsulate the variability of knowledge that is created through these efforts.

The future of funding and evaluating SES research

Our findings lead to many questions about how we might improve the funding and dissemination of SES research. The following are a short list of relevant questions important for the community of SES researchers to consider:

- Are there unique norms or concepts within ecology that allow ecology programs to create more products in diverse and interdisciplinary journals and receive more citations?
- What strategies can other fields adopt to increase the breadth and interdisciplinarity of their research products?
- How can we train scientists to effectively conduct SES research that includes and reaches a broad audience?
- How can we better quantify the value of the range of products resulting from SES research (e.g., Porter et al. 2006)?
- How can NSF create additional cross-cutting programs that fund SES research or extend the degree to which traditional programs fund SES projects?
- How can NSF be more nimble in incorporating novel ideas about and approaches to conducting interdisciplinary science from the research community into NSF programs and incentive structures (e.g., National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2005)?

As SES research moves forward, we should expand the recognition of research products and deliverables beyond the "standard" peer-reviewed manuscripts. In conducting our analysis, peer-review publications were the most consistently reported and discoverable outcomes of funding for SES research within the NSF Awards Search system. This reporting is likely because the evaluation system for researchers primarily counts and rewards these types of contributions. To ensure a robust future for SES research, we need to develop a culture and system of reporting and including other products and outcomes in our evaluation of researchers (Bell et al. 2011, Huutoniemi 2016, Arnott et al. 2020). Products of co-developed and interdisciplinary SES research such as popular press articles, online StoryMaps, workshops, white/gray literature, fact sheets, open datasets, and analytical code, etc. should be valued not as "extras" but as valuable outcomes in their own right. These types of products are particularly important and increasingly expected as outcomes of transdisciplinary research, which incorporates stakeholder knowledge. Explicitly considering how these types of research products might be valued across multi-, inter-, and transdisciplinary research would not only be beneficial for researchers but also for strengthening connections and communication with stakeholders and communities. By changing how we value products beyond peer-reviewed articles published in high-impact journals, we will incentivize solution-based SES research with positive impacts on communities and the environment in addition to research careers.

Our analysis of the outcomes of grants awarded through the NSF CNH programs highlights that these funding mechanisms are important in furthering SES research. The NSF CNH programs, together with other funding mechanisms and research initiatives designated for SES research, (e.g., NSF Coastlines and People (CoPe), European Long-Term Ecosystem and Social Ecological Research Infrastructure, USGS Climate Adaptation Science Centers, National Center for Atmospheric Research Innovator Program, among many others), incubated the field of SES from a conceptual model to a thriving interdisciplinary research area (Ledford 2015). These programs are critical for the advancement of interdisciplinary SES research, making their continued support and growth by NSF imperative for the field. Indeed, the legitimacy and support provided by these research support mechanisms allows researchers to take risks, permitting SES to flourish.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13281

Author Contributions:

All authors (K.E.K., A.E.B., M.L.F.) contributed equally to the idea generation, approach, data analysis, writing, and editing of this manuscript.

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Data Availability:

The data and code that support the findings of this study are openly available at dataverse.harvard.edu and will be made accessible upon acceptance.

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Appendix #1 Additional information on granting programs and journals that papers were published in.

Table A1.1 NSF granting programs that funded SES research between 2000-2015.

NSF Directorate	Grant Programs
Engineering	Real-time Machine Learning, Environmental Sustainability, Humans Disasters and the Built Environment
Computer & Information Science & Engineering	Smart Connected Communities
Biology	LTER, Ecosystem Sciences, Ecology and Evolution of Infectious Disease
Geosciences	Hydrology, Geomorphology and Land Use Dynamics, EPSCOR
Social, Behavioral & Economic Sciences	Critical Resilience Infrastructure Systems and Processes, Science of Learning Collaborative Networks
Crosscutting	Coupled Natural Human

Table A1.2: List of all journals that were published in and associated disciplinary categories. If the journal had three or more publications from our dataset, we evaluated whether the mission of the journal explicitly or implicitly included “interdisciplinary”. If the description / mission of the journal explicitly included the word “interdisciplinary” we coded that as “yes”, if the word was not used but was implicit in the description of the types of papers in the journal this was considered “implicit”, and if neither of those conditions were me then it was “no”. If there were less than three papers published in a given journal they were not evaluated and given a “N/A”.

Journal	**Discipline**	**Number of Papers**	**Interdisc?**
Ecology and Society	ses	13	Yes
Ecosystems	ecology /biology	11	Yes
Landscape ecology	ecology /biology	10	Yes
Urban ecosystems	ses	10	Implicit
Global change biology	ecology /biology	9	Implicit
Landscape and Urban Planning	ses	9	Yes
Water resources research	hydrology	9	Yes
PLoS One	multi-disciplinary	8	Yes
Science	multi-disciplinary	8	Yes
Ecology letters	ecology /biology	8	No
Ecological applications	ecology /biology	7	Yes

Environmental management	ses	7	Yes
Ecological modelling	ecology /biology	7	Implicit
Journal of geophysical research-atmospheres	geoscience	7	No
Ecological economics	ses	6	Yes
Proceedings of the National Academy of Sciences	multi-disciplinary	6	Implicit
Frontiers in Ecology and the Environment	ecology /biology	5	Yes
Ambio	multi-disciplinary	5	Implicit
Bioscience	ecology /biology	5	Implicit
Environmental Modelling and Software	multi-disciplinary	5	Implicit
Forest Ecology and Management	ses	5	Implicit
Canadian journal of fisheries and aquatic sciences	ecology /biology	5	No
Conservation biology	ecology /biology	5	No
Environmental research letters	multi-disciplinary	4	Yes
Human ecology	ses	4	Yes
Nature	multi-disciplinary	4	Yes
Population and Environment	social science	4	Yes
Global environmental change	ses	4	Implicit
Journal of Geophysical Research -Earth Surface	geoscience	4	Implicit
Biogeochemistry	biogeochemistry	4	No
Biological invasions	ecology/biology	4	No
Ecology	ecology /biology	4	No
Fisheries oceanography	marine science	4	No
Geomorphology	geoscience	4	No
Geophysical research letters	geoscience	4	No
Journal of Medical Entomology	ecology /biology	4	No
Diversity	ecology /biology	3	Yes
Environmental Science and Technology	multi-disciplinary	3	Yes
Journal of Environmental Economics and Management	ses	3	Yes
Occasion: Interdisciplinary Studies in the Humanities	social science	3	Yes
Soil science society of america journal	geoscience	3	Yes
Hydrogeology journal	geoscience	3	Implicit
Applied geochemistry	geoscience	3	No
Bulletin of Marine Science	marine science	3	No
Bulletin of the Ecological Society of America	ecology /biology	3	No
Environmental pollution	ses	3	No
Hydrobiologia	ecology /biology	3	No
Hydrology and Earth System Sciences	hydrology	3	No
International Journal of Geographical Information Science	geography	3	No
Journal of Ecology	ecology /biology	3	No
Journal of geophysical research-biogeosciences	biogeochemistry	3	No
Limnology and oceanography	multi-disciplinary	3	No
Oecologia	marine science	3	No
Parasites and Vectors	health/disease	3	No

Transactions of the American Fisheries Society	ecology /biology	3	No
Tree physiology	ecology /biology	3	No
A Matter of Spirit: Journal of the Intercommunity Justice and Peace Center	social science	< 3	N/A
Acta ecologica sinica	ecology /biology	< 3	N/A
Advances in Complex Systems	multi-disciplinary	< 3	N/A
Advances in Infectious Diseases	health/disease	< 3	N/A
Advances in marine biology	ecology /biology	< 3	N/A
Advances in Water Resources	geoscience	< 3	N/A
African Journal of Agricultural and Resource Economics	ses	< 3	N/A
Agriculture and Human Values	ses	< 3	N/A
Agriculture ecosystems & environment	ag	< 3	N/A
Agriculture, Ecosystems, and Environment	ag	< 3	N/A
Agronomy	ag	< 3	N/A
American antiquity	humanities	< 3	N/A
American fisheries society	ses	< 3	N/A
American fisheries society symposium	ses	< 3	N/A
American journal agricultural economics	ses	< 3	N/A
American Journal of Tropical Medicine and Hygiene	health/disease	< 3	N/A
American naturalist	ecology /biology	< 3	N/A
American prospect	social science	< 3	N/A
Animal behaviour	ecology /biology	< 3	N/A
Animal Feed Science and Technology	ag	< 3	N/A
Annals of Botany	ecology /biology	< 3	N/A
Annals of Glaciology	geoscience	< 3	N/A
Annals of the Association of American Geographers	geography	< 3	N/A
Annals of the New York Academy of Sciences	multi-disciplinary	< 3	N/A
Annual Meetings of the Population Association of America, Los Angeles	social science	< 3	N/A
Annual Review of Environment and Resources	multi-disciplinary	< 3	N/A
Anthropology news	humanities	< 3	N/A
Applied geography	geography	< 3	N/A
Aquaculture research	ag	< 3	N/A
Aquatic ecology	ecology /biology	< 3	N/A
Aquatic mammals	ecology /biology	< 3	N/A
Archiv für Hydrobiologie	ecology /biology	< 3	N/A
Arizona law review	law	< 3	N/A
Atmos. Ocean	geoscience	< 3	N/A
Auk	ecology /biology	< 3	N/A
Australian Journal of Agricultural and Resource Economics	ses	< 3	N/A
Automatica	multi-disciplinary	< 3	N/A
Biogeosciences	biogeochemistry	< 3	N/A
Biological conservation	ecology /biology	< 3	N/A
Biological sciences	ecology /biology	< 3	N/A

Biology letters	ecology /biology	< 3	N/A
Biotropica	ecology /biology	< 3	N/A
Bmc public health	health/disease	< 3	N/A
Boreas	geoscience	< 3	N/A
Bull. Amer. Meteor. Soc.	geoscience	< 3	N/A
Bulletin of the american meteorological society	geoscience	< 3	N/A
California archaeology	humanities	< 3	N/A
Canadian journal of zoology-revue canadienne de zoologie	ecology /biology	< 3	N/A
Capitalism, nature, socialism	multi-disciplinary	< 3	N/A
Caribbean Journal of Science	multi-disciplinary	< 3	N/A
Castanea	ecology /biology	< 3	N/A
Choices	ag	< 3	N/A
Cities	ses	< 3	N/A
Climate change	geoscience	< 3	N/A
Climate research	geoscience	< 3	N/A
Climatic change	geoscience	< 3	N/A
Computers and Electronics in Agriculture	ag	< 3	N/A
Computers and Geosciences	geoscience	< 3	N/A
Computers Environment and Urban Systems	geography	< 3	N/A
Conservation ecology	ecology /biology	< 3	N/A
Conservation letters	ecology /biology	< 3	N/A
Crustaceana	ecology /biology	< 3	N/A
Current anthropology	humanities	< 3	N/A
Current Opinion in Environmental Sustainability	ses	< 3	N/A
Current zoology	ecology /biology	< 3	N/A
Die erde	geography	< 3	N/A
Diseases of Aquatic Organisms	ecology /biology	< 3	N/A
Earth interactions	geoscience	< 3	N/A
Earth system dynamics	geoscience	< 3	N/A
Ecohealth	health/disease	< 3	N/A
Ecohydrology	hydrology	< 3	N/A
Ecological indicators	ecology /biology	< 3	N/A
Ecological research	ecology /biology	< 3	N/A
Ecologies and Politics of Health	ses	< 3	N/A
Ecology of freshwater fish	ecology /biology	< 3	N/A
Economics	social science	< 3	N/A
Economics and Management	social science	< 3	N/A
Ecosphere	ecology /biology	< 3	N/A
Electrical power systems research	engineering	< 3	N/A
Energy strategy review	social science	< 3	N/A
Environmental engineering science	engineering	< 3	N/A
Environment	multi-disciplinary	< 3	N/A
Environment and Behavior	ses	< 3	N/A

Environment and Society	ses	< 3	N/A
Environmental and Development Economics	social science	< 3	N/A
Environmental Biology of Fishes	ecology /biology	< 3	N/A
Environmental biosafety research	ecology /biology	< 3	N/A
Environmental conservation	ses	< 3	N/A
Environmental Hazards: Human and Policy Dimensions	ses	< 3	N/A
Environmental health perspectives	health/disease	< 3	N/A
Environmental history	humanities	< 3	N/A
Environmental resources economics	ses	< 3	N/A
Estudos avancados	multi-disciplinary	< 3	N/A
European Conference on Computer Vision	engineering	< 3	N/A
Europhysics letters	physics	< 3	N/A
Evolution	ecology /biology	< 3	N/A
Evolutionary applications	ecology /biology	< 3	N/A
Fish and fisheries	ses	< 3	N/A
Fisheries	ses	< 3	N/A
Fisheries research	ses	< 3	N/A
Food policy	social science	< 3	N/A
Forest Policy and Economics	ses	< 3	N/A
Forests	ses	< 3	N/A
Freshwater biology	ecology /biology	< 3	N/A
Functional ecology	ecology /biology	< 3	N/A
General technical report nrs-138	NA	< 3	N/A
Genetic and Evolutionary Computation Conference (GECCO 2009)	ecology /biology	< 3	N/A
Geoforum	geoscience	< 3	N/A
Georgia Journal of Ecological Anthropology	ecology /biology	< 3	N/A
Giscience and Remote Sensing	remote sensing	< 3	N/A
Global change	geoscience	< 3	N/A
Ground Water Monitoring and Remediation	hydrology	< 3	N/A
Hazard management	ses	< 3	N/A
Heredity	ecology /biology	< 3	N/A
Hydrol. Processes	hydrology	< 3	N/A
Hydrological processes	hydrology	< 3	N/A
IAHS Proceedings from Cold Region Hydrology in a Changing Climate	hydrology	< 3	N/A
ICES Journal of Marine Science	marine science	< 3	N/A
ICES Journal of Marine Sciences	marine science	< 3	N/A
IEEE Conference on Computer Vision and Pattern Recognition	engineering	< 3	N/A
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	remote sensing	< 3	N/A
IEEE Transactions on Pattern Analysis and Machine Intelligence	engineering	< 3	N/A
Inside agroforestry	ag	< 3	N/A
Integrated Environmental Assessment and Management	ses	< 3	N/A
Internat. J. Climatology	geoscience	< 3	N/A

International forestry review	ecology /biology	< 3	N/A
International Journal of Biometeorology	geoscience	< 3	N/A
International Journal of Biostatistics	mathematics	< 3	N/A
International Journal of Computer Vision	engineering	< 3	N/A
International Journal of Digital Curation	social science	< 3	N/A
International journal of environmental research and public health	health/disease	< 3	N/A
International Journal of Environmental Research and Public Health	health/disease	< 3	N/A
International Journal of Forestry	ecology /biology	< 3	N/A
International Journal of Geo-Information	geography	< 3	N/A
International Journal of Health Geographies	health/disease	< 3	N/A
International Journal of Remote Sensing	remote sensing	< 3	N/A
International Journal of Sustainable Development	ses	< 3	N/A
International Journal of Wildland Fire	geoscience	< 3	N/A
J. Geophys. Res.	geoscience	< 3	N/A
J. Geophysical research-biogeosciences	biogeochemistry	< 3	N/A
Jgr-biogeosciences	biogeochemistry	< 3	N/A
Jgr-oceans	marine science	< 3	N/A
Journal of Geophysical Research	geoscience	< 3	N/A
Journal of Archaeological Science	humanities	< 3	N/A
Journal of Theoretical Biology	ecology /biology	< 3	N/A
Journal of Agricultural and Applied Economics	ses	< 3	N/A
Journal of American Water Resources Association	ses	< 3	N/A
Journal of Animal Ecology	ecology /biology	< 3	N/A
Journal of Applied Ecology	ecology /biology	< 3	N/A
Journal of Applied Meteorology and Climatology	geoscience	< 3	N/A
Journal of Archaeological Method and Theory	humanities	< 3	N/A
Journal of Arid Environments	geoscience	< 3	N/A
Journal of Climate	geoscience	< 3	N/A
Journal of Coastal Management	ses	< 3	N/A
Journal of Coastal Research	marine science	< 3	N/A
Journal of Development Studies	social science	< 3	N/A
Journal of Earth Science	geoscience	< 3	N/A
Journal of environmental engineering-asce	engineering	< 3	N/A
Journal of Environmental Indicators	ses	< 3	N/A
Journal of Environmental Management	ses	< 3	N/A
Journal of evolutionary biology	ecology /biology	< 3	N/A
Journal of Extension	ag	< 3	N/A
Journal of fish biology	ecology /biology	< 3	N/A
Journal of Fish Biology	ecology /biology	< 3	N/A
Journal of Forestry	geoscience	< 3	N/A
Journal of Geophysical Research	geoscience	< 3	N/A
Journal of Glaciology	geoscience	< 3	N/A
Journal of Great Lakes Research	multi-disciplinary	< 3	N/A

Journal of Human Evolution	ecology /biology	< 3	N/A
Journal of Hydrology	hydrology	< 3	N/A
Journal of Land Use Science	ses	< 3	N/A
Journal of Latin American Geography	geography	< 3	N/A
Journal of Marine Research	marine science	< 3	N/A
Journal of Natural Resource Policy	social science	< 3	N/A
Journal of North American Benthological Society	ecology /biology	< 3	N/A
Journal of Northwest Atlantic Fishery Science	ecology /biology	< 3	N/A
Journal of Physical Oceanography	marine science	< 3	N/A
Journal of Planning Education and Research	social science	< 3	N/A
Journal of Soil and Water Conservation	geoscience	< 3	N/A
Journal of Sustainable Forestry	ses	< 3	N/A
Journal of the American Water Resources Association	ses	< 3	N/A
Journal of the North American Benthological Society	ecology /biology	< 3	N/A
Journal of the North Atlantic Fisheries Science	ecology /biology	< 3	N/A
Journal of Theoretical Biology	ecology /biology	< 3	N/A
Journal of Transportation Engineering	engineering	< 3	N/A
Journal of Urban Health: Bulletin of the New York Academy of Medicine	health/disease	< 3	N/A
Journal of Young Investigators	multi-disciplinary	< 3	N/A
Journal of Zoology	ecology /biology	< 3	N/A
Kiva Journal of Southwestern Anthropology and History	humanities	< 3	N/A
Korean Journal of Remote Sensing	remote sensing	< 3	N/A
Land	ses	< 3	N/A
Land use policy	social science	< 3	N/A
Limnology and Oceanography Methods	ecology /biology	< 3	N/A
Malaria journal	health/disease	< 3	N/A
Marine and Freshwater Research	ecology /biology	< 3	N/A
Marine ecology progress series	ecology /biology	< 3	N/A
Marine policy	ses	< 3	N/A
Marine resource economics	ses	< 3	N/A
Molecular ecology	ecology /biology	< 3	N/A
Natural resource modeling	ses	< 3	N/A
Nature and Culture	ses	< 3	N/A
Nature climate change	geoscience	< 3	N/A
Nature geoscience	geoscience	< 3	N/A
Nature scientific reports	multi-disciplinary	< 3	N/A
Neuron	health/disease	< 3	N/A
New phytologist	ecology /biology	< 3	N/A
New Zealand Journal of Marine Science and Freshwater Research	marine science	< 3	N/A
Nonlinear Processes in Geophysics	geoscience	< 3	N/A
North American Journal of Fisheries	ecology /biology	< 3	N/A
North american journal of fisheries management	ecology /biology	< 3	N/A

North American Journal of fisheries Management	ecology /biology	< 3	N/A
Northwest science	multi-disciplinary	< 3	N/A
Oceanography and Marine Biology: An annual review	marine science	< 3	N/A
Oikos	ecology /biology	< 3	N/A
Parasitol research	health/disease	< 3	N/A
Pedobiologia	ecology /biology	< 3	N/A
Peer Reviewed Proceedings of Digital Landscape Architecture	humanities	< 3	N/A
Permafrost and Periglacial Processes	geoscience	< 3	N/A
Phil. Trans. Royal society	multi-disciplinary	< 3	N/A
Physical review e	physics	< 3	N/A
Places	humanities	< 3	N/A
Plant and Soil	ecology /biology	< 3	N/A
Plant ecology	ecology /biology	< 3	N/A
Polar geography	geography	< 3	N/A
Population ecology	ecology /biology	< 3	N/A
Procedia environmental sciences	geoscience	< 3	N/A
Proceedings of the 23rd International Conference on the Systems Dynamics of Society	social science	< 3	N/A
Proceedings of the Environmental Information Management Conference, Santa Barbara, CA	geography	< 3	N/A
Proceedings of the Royal Society B	ecology /biology	< 3	N/A
Proceedings of the Royal Society B - Biological Sciences	ecology /biology	< 3	N/A
Proceedings on the second conference on the Human Dimensions of Wildland Fire U.S. Department of Agriculture	ses	< 3	N/A
Proceeds of the 8th Annual Conference on Communication and Environment	ses	< 3	N/A
Progress in Human Geography	geography	< 3	N/A
Progress in Oceanography	marine science	< 3	N/A
Quarterly j. Royal meteorological soc.	geoscience	< 3	N/A
Regional environmental change	geoscience	< 3	N/A
Remote sensing	remote sensing	< 3	N/A
Remote Sensing of Environment	remote sensing	< 3	N/A
Research and Applications	NA	< 3	N/A
Resource and Energy Economics	ses	< 3	N/A
Restoration ecology	ecology /biology	< 3	N/A
Review of Agricultural Economics	ses	< 3	N/A
Review of Economics and Statistics	social science	< 3	N/A
Revista economãa Sociedad y Territorio	social science	< 3	N/A
Scientific reports	multi-disciplinary	< 3	N/A
SIAM Journal on Control and Optimization	mathematics	< 3	N/A
Society and Natural Resources	ses	< 3	N/A
Sound Science: Synthesizing Ecological and Socioeconomic Information about the Puget Sound Ecosystem	ses	< 3	N/A
Southern Journal of Applied Forestry	ecology /biology	< 3	N/A
Survey of Geophysics	geoscience	< 3	N/A
Sustainability: science, practice and policy	ses	< 3	N/A

The holocene	geoscience	< 3	N/A
The professional geographer	geography	< 3	N/A
The social science journal	social science	< 3	N/A
Theoretical ecology	ecology /biology	< 3	N/A
Tinro	NA	< 3	N/A
Transactions in GIS	geography	< 3	N/A
Transactions of the Institute of British Geographers	geography	< 3	N/A
Trends in Ecology and Evolution	ecology /biology	< 3	N/A
Tropical conservation science	ecology /biology	< 3	N/A
UGEC viewpoints	ses	< 3	N/A
Urbanization and Global Environmental Change Viewpoints	ses	< 3	N/A
Verhandlungen der Internationale Vereiningung Theoretische und Angewandte Limnologie	ecology /biology	< 3	N/A
Water resources	hydrology	< 3	N/A
Weed science	ecology /biology	< 3	N/A
World development	ses	< 3	N/A
Zoologia	ecology /biology	< 3	N/A
Zoonoses and Public Health	ecology /biology	< 3	N/A

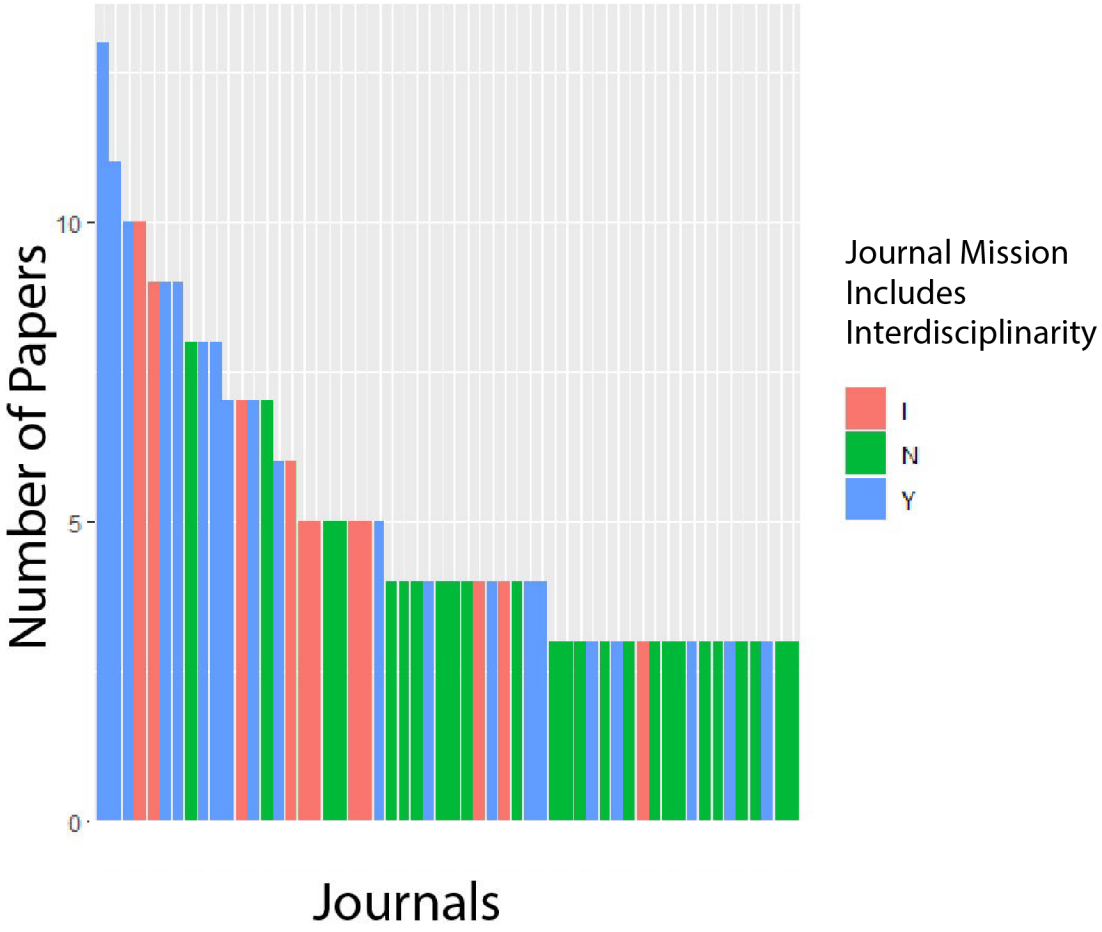

Figure A1.1. The number of papers published in each journal with 3 or more papers and details on inclusion of interdisciplinarity in the mission statement of that journal.