A Case Study of the Importance of Publicly-Funded Research to Coastal Regions

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Introduction

Around the world, public funds are used to support research that accrues environmental benefits while also improving social and economic well-being. Examples include improved weather forecasts, natural hazard preparedness, improvements in public health, and decision-support for policy-makers in the agriculture, transportation and energy sectors. In the United States (U.S.), the Land Grant System, established by the Morrill Acts of 1862 and 1890, provided for state and federal funds to be given in support of institutions across the country. In return, these institutions conduct research, education, and technology transfer to benefit their surrounding communities. The result of this was the beginning of publicly-funded Land Grant Colleges, of which there are now more than 112 in the U.S. and its territories (*1*).

In the 1960s, oceans were high on the public agenda (*2-4)*. Capitalizing on this societal context, in 1963, geophysicist and oceanographer Athelstan Spilhaus proposed a marine analog of the Land Grand System (*2,5*). Three years later, Congress passed the original National Sea Grant College Program Act of 1966 (*6*). The resulting program, henceforth "Sea Grant", is a highly leveraged federal and state partnership which harnesses the intellectual capacity of the nation's research institutions to solve problems and generate opportunities in coastal communities. With an initial budget of $6 million, Sea Grant, then part of the National Science Foundation (NSF), distributed its first major awards in 1968 (*3,4*). Sea Grant was transferred to the newly-created National Oceanic and Atmospheric Administration (NOAA) in 1970 (*3*), and remains there today. In total, there are now 34 Sea Grant programs across the nation.

In 2018, Sea Grant invested $76.5 million in federal dollars with state Sea Grant programs leveraging an additional $93 million (*7,8*). A portion of these investments supported over 1,500 researchers and 1,000 graduate students, (*8,9*). In general, research supported by Sea Grant follows an ethic defined by King (*1970*) as, "(…) a commitment to several fundamental ideas: that ocean issues can be most effectively tackled by many disciplines; that skills and resources in the nation's universities are the keys to expanded use of the oceans and their resources; that success in the oceans requires the full spectrum of basic, problem-oriented, and applied research; that these opportunities are best tackled cooperatively by scientists, government officials, industrial and commercial firms, and civic groups; that knowledge is not the exclusive province of academic scientists but should be widely shared and used; and that the country's ability to develop, use, and manage its marine resources depends on nurturing talent in all fields of study."

Much like the Land Grant model, Sea Grant accomplishes its mission through a three-pronged approach of research, outreach and education (*7,10*). The Sea Grant network establishes and coordinates research agendas in topic areas including coastal and estuarine dynamics,

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aquaculture, recreational and commercial fisheries, ocean and water resource law and policy, marine- and Great Lakes-related social science, and aquatic biotechnology. The synergistic interplay of use-inspired research (*7,11,12*), conducted by many of the nation's finest scholars, with sustained and timely delivery of that knowledge to a variety of stakeholders to help solve problems and inform decision-making, is key to the success of the Sea Grant model.

In addition to generating scientific knowledge and understanding, Sea Grant helps prepare the next generation of marine, coastal, and ocean scientists. For many early career researchers, Sea Grant funding helps launch their academic careers. Researchers use Sea Grant funds to conduct innovative place-based research, which can often be scaled up and developed into larger research projects (J. Downing, pers. Comm). While there are many ways to share research-based information, the primary method for Sea Grant funded researchers to communicate results is through peer-reviewed publications. These publications lend credibility to extension and education programs, serve as a basis for grey literature (i.e., abstracts, technical reports, outreach and extension bulletins, policy briefs, etc.), and provide a mechanism to transfer innovative, relevant, and timely information to natural resource managers (*12,13*). Publishing peer-reviewed research in high impact journals is also the primary measure of scientific productivity for academics in all career stages.

Academic benefits of scientific research can be quantified by analyzing citation indices (CI) and journal impact factors (JIF) (*14,15*). Citations are the references to previous work that researchers relied on while conducting their own scientific investigation (*15)*. JIF is a journal-level metric designed to compare the CI of one journal to others. JIF could be an indicator of success in that an article was accepted by a prestigious journal in an academic discipline (*16*). It could also be a surrogate for a more carefully derived direct measure of CI. There are some shortcomings to using JIF and CI. In particular, JIF limitations include concerns with asymmetry between the numerator and the denominator, differences across disciplines, an insufficient citation window, and skewness of the underlying citation distributions (*17*). CI is often used to describe overall 'research quality' which is a multidimensional concept; and while CI may reflect important aspects of scientific impact and relevance, there is no evidence that citations reflect other key dimensions of research quality (*15,16*). Nevertheless, bibliometric indicators for assessing scientific performance are still widely used.

In this paper, we present results of a quantitative and qualitative bibliometric analysis of all Sea Grant publications from 2001 to 2015 that were submitted to the National Sea Grant Library (NSGL) (*18*). The NSGL is a digital library and official archive for all Sea Grant publications, including peer-reviewed journal articles, extension bulletins, technical reports, policy briefs, and educational curricula. While the NSGL includes documents submitted since Sea Grant's inception in 1966, JIFs were only available from year 2001 onwards. Per the NSGL, Sea Grant-funded research generated 6,531 peer-reviewed publications between 2001 and 2015. These publications were from more than 1,450 different sources, including peer-reviewed journals, books, and conference proceedings. This analysis serves as a case-study for how support of publicly-funded research benefits the greater scientific community, by producing a body of research that supports future work. It also showcases how providing support to thoughtfully crafted public research institutions can lead to directed research outcomes that benefit communities.

Materials and Methods

We determined the JIF and CI for each peer-reviewed research publication, and then summarized these by publication year. Custom R code *(19)* was used to extract the JIF for each

peer-reviewed research publication from the Thomson Reuters InCites Journal Citation database, Science edition *(20)*. JIFs were matched to the journal title and publication year of the article. Citation indices were web-scraped from Google scholar with a combination of open-source R package (rvest) and custom R code *(19)*.

Given potential drawbacks of using JIF and CI only, we included additional analyses of research publications. For two publications that were cited more than 5,000 times, we assessed their reach with the ISI Web of Science "Analyze Results" feature, summarizing the top 25 countries and top 25 Web of Science topic categories, respectively, for all citing articles *(21)*. For all publications, we assessed the most common topics of investigation by conducting a word cloud analysis of publication titles. We used a modified version of the rquery.wordcloud function for words that showed up a minimum of 150 times across titles. To ensure clarity in the resulting word cloud, we set the maximum number of words to be displayed to 500, and modified the source code to not allow words to be rotated. We also summarized the 20 most common words found via this analysis, as well as all journals that published at least 50 Sea Grant-funded research publications between 2001-2015.

Results

Table 1 lists the top 20 journals in which Sea Grant-funded research publications were published. JIFs were extracted for 5,096 of the 6,531 records. Some of the journals included in the current analysis are not part of the InCites database (e.g., some open access journals; many law journals). For publications that could be analyzed, the overall mean JIF was 2.5 (range 0.027-42.351). Generally, the mean JIF increases each year over the course of our study (Fig. 1A, B). Between 0 and 7 publications in each year of our study were published in journals with JIF of twenty or higher (Fig. 1A). Most Sea Grant-funded research has been published in journals with impact factors of approximately 2. Sea Grant publications from 2001-2015 were typically published in journals with JIF between 2-3, with minimal changes from year-to-year (Fig. 1B).

Table 1. Top 20 journals in which Sea Grant publications were published between 2001-2015.

Journal Title	Number of Publications
Marine Ecology Progress Series	208
Journal of Shellfish Research	148
Journal of Great Lakes Research	134
Canadian Journal of Fisheries and Aquatic Sciences	120
Environmental Science and Technology	108
Aquaculture	106
Estuaries and Coasts	97
Journal of Experimental Marine Biology and Ecology	89
Applied and Environmental Microbiology	80
Transactions of the American Fisheries Society	79
Estuaries	72
Limnology and Oceanography	71
Marine Biology	70
Journal of Coastal Research	65
Estuarine, Coastal and Shelf Science	63
North American Journal of Fisheries Management	62
PLoS ONE	61

Journal of Geophysical Research	57
General and Comparative Endocrinology	54
Fisheries Research	52

Sea Grant-supported publications are also consistently accepted in journals with high JIFs (for example, the journals Nature, Nature Immunology, and Science have impact factors >20). The two highest-cited publications were by Sala et al. (*22*) entitled, "Global biodiversity scenarios for the year 2100", and by Jackson et al. (*23*) entitled, "Historical overfishing and the recent collapse of coastal ecosystems." For the top 25 citing countries (Fig. 2), Sala et al. (*22*) was cited 6,918 times, while Jackson et al. (*23*) was cited 5,468 times. These papers were also cited across a broad variety of subject areas (Table 2). Taken together, these results suggest that Sea Grant-supported publications are accessible to subject matter experts as well as the broader scientific community, and that Sea Grant-supported publications are valuable to researchers outside of the original field of study.

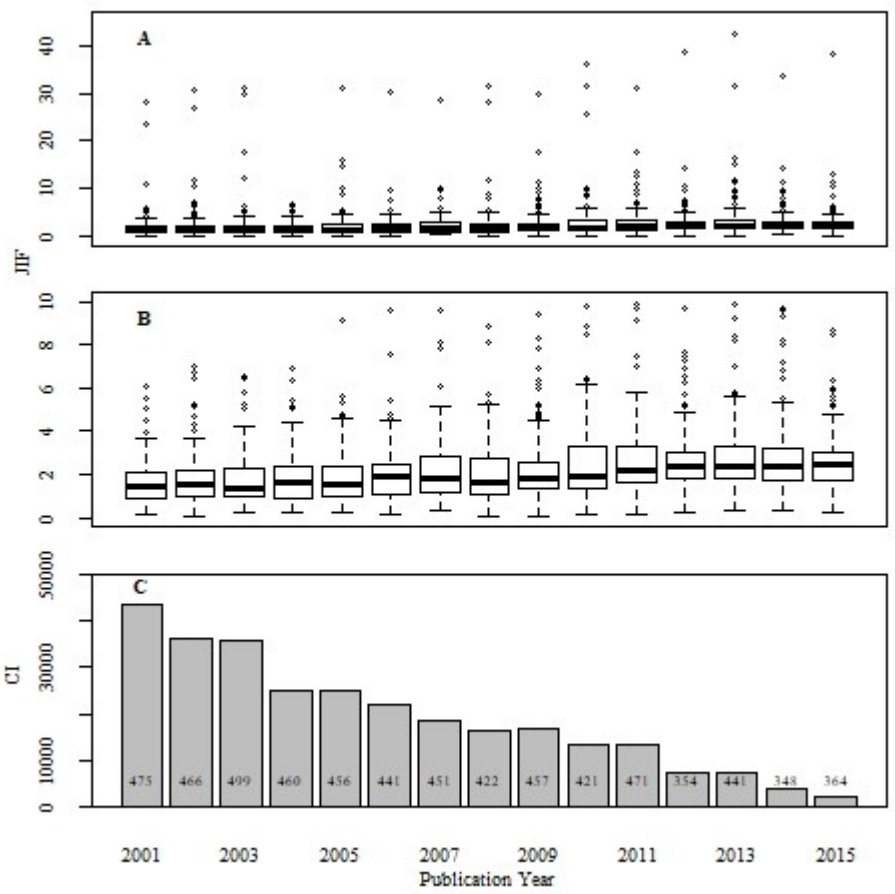

Fig. 1. *Journal impact factor (JIF) and citation indices (CI) summarized by year. The JIF plots depict minimum, maximum, median, first and third quartiles, and outliers for each year. All publications (n=5,096) are included in (A), while (B) includes only publications from journals with an impact factor of less than 10 (n=5,019). The CI plot (C) depicts total values. The number of publications submitted to the NSGL for each year are noted inside each bar.*

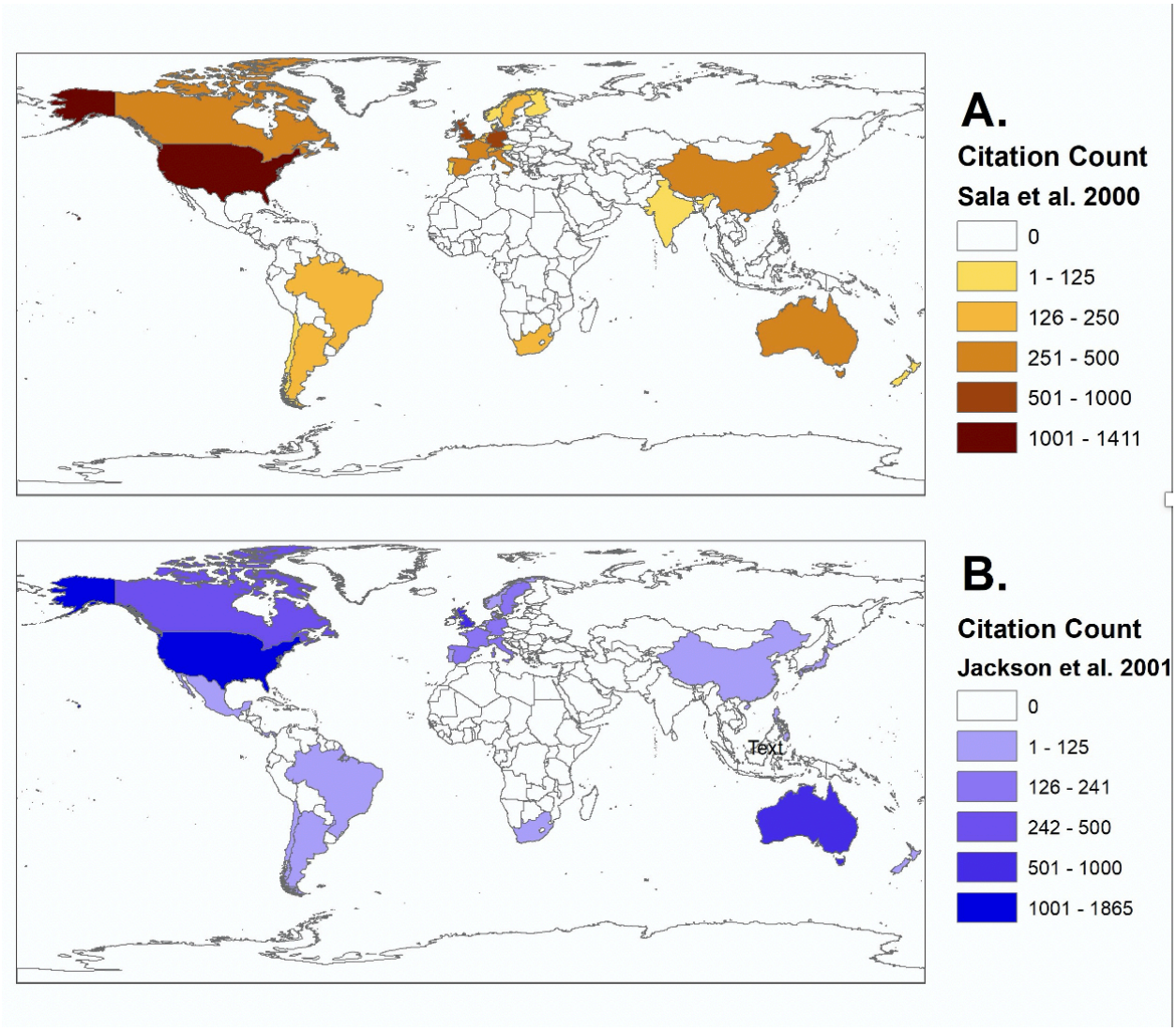

Fig. 2. *Geographic distribution of citations for the two highest-cited publications analyzed in the current study (top 25 citing countries). Darker colors represent more citations. (A) depicts the citation distribution for Sala et al. (18), while (B) depicts the citation distribution for Jackson et al. (19).*

CIs were collected for 6,218 of the 6,531 records. The median number of citations per year was 16,907 (range 2,234 - 43,398). Older publications have been cited more often than newer ones (Fig. 1C); however, there was a fairly consistent number of publications submitted each year (range per year 348 to 499, median 451). The shape of the curve (Fig. 1C) suggests that over time, Sea Grant publications are consistently being consulted and utilized by other scientists to support their research, and therefore have lasting value to the scientific community.

Table 2. Top 25 citing Web of Science categories for the two highest cited research publications. Journals could fall into more than one category as defined by the database.

Web of Science Journal Category	Sala et al. (*18*)	Jackson et al. (*19*)
Ecology	2,214	1,217
Environmental Sciences	1,265	747

Biodiversity Conservation	1,003	361
Marine Freshwater Biology	427	1,289
Plant Sciences	368	32
Multidisciplinary Sciences	354	397
Evolutionary Biology	199	133
Environmental Studies	198	264
Forestry	198	
Geography Physical	186	58
Zoology	160	94
Geosciences Multidisciplinary	130	113
Water Resources	108	131
Engineering Environmental	83	44
Agriculture Multidisciplinary	74	
Biology	127	134
Fisheries	121	513
Entomology	97	
Soil Science	88	
Limnology	86	51
Meteorology Atmospheric Sciences	74	
Geography	60	
Agronomy	65	
Remote Sensing	61	
Oceanography	60	620
International Relations		84
Archaeology		62
Genetics Heredity		56
Economics		48
Anthropology		58
Biochemical Molecular Biology		36
Green Sustainable Science		37
Paleontology		31

The most common words found in titles of Sea Grant-funded publications reflect the mission of Sea Grant, locations where Sea Grant research is taking place, and the audiences that Sea Grant serves (Fig. 3). In addition, the most commonly used words imply the applied nature of Sea Grant research (effects, new, management, development, use). This analysis also shows that Sea Grant-funded research being conducted on key species or life stages of aquatic organisms (fish, oyster, juvenile, salmon).

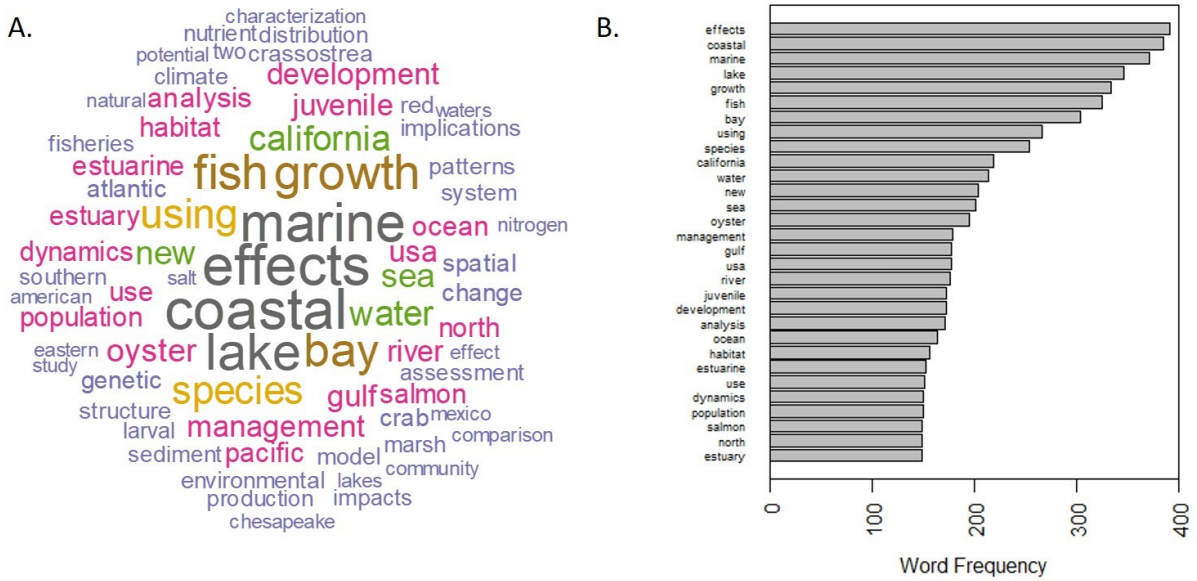

Fig. 3. *The most common words found in titles of Sea Grant publications published between 2001-2015. For (A), size and color denote the frequency, where words with larger font showed up more often. All words listed showed up a minimum of 100 times. (B) depicts the ranking of the top 30 most common words.*

Discussion

The diversity of journals in which Sea Grant-supported research is published suggests that Sea Grant funded researchers are advancing the goals of Sea Grant, i.e., to share timely information with the most relevant end user groups. Publication in primarily aquatic journals, as was observed, is to be expected given the broader goals of the Sea Grant program. Publication in societal journals, or even regional or state journals (e.g., the Alaska Fishery Research Bulletin, the Texas Water Journal, or the Ohio Journal of Science), is likely a means of ensuring that results are used by those who stand to benefit most from them. In addition, early in their careers, scientists may be publishing in lower impact journals as they establish themselves and generate a strong reputation as a credible source of information (*15*). That Sea Grant-supported research publications are consistently cited over time suggests high quality research is being produced regardless of where it is published, benefitting both local end-users and the broader scientific community.

The sheer number of peer-reviewed publications by Sea Grant funded researchers is striking given the relatively small investment in this research (*7,24)*. We recognize that while the publications analyzed herein received at least some support from a Sea Grant program, not every project was entirely funded by Sea Grant. As a boundary organization, partnerships and leveraging plays an integral role in the operations and framework of the Sea Grant network. For example, our analysis suggests that the some of the most impactful work published by Sea Grant funded researchers was conducted with leveraged support from other publicly-funded institutions, such as NSF, the U.S. Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, other NOAA line offices, and countless state agencies (e.g., *22,23*).

The title analyses again emphasize the specific role Sea Grant plays in the broader publicly-supported research landscape. Many of the most common words in Sea Grant-funded publication titles are related to location or taxonomic group. The analyses reveal where work has been conducted, and support the notion that Sea Grant-funded research is tackling relevant issues for

local stakeholder groups. For example, two regions wherein Sea Grant-funded research has played a pivotal role in leading use-inspired research on locally relevant topics include: the Chesapeake Bay in the Mid-Atlantic region of the U.S., which has been the site of nutrient runoff cleanup efforts since the 1990s; and the Gulf of Mexico, which touches the southeastern U.S., and supports a strong fishery but has suffered impacts such as oil spills or large hypoxic events. It is appropriate that Sea Grant-funded research should contribute to knowledge of these important aquatic ecosystems. Similarly, salmon are important fishes across the nation, but are key to commercial and recreational fisheries along the Pacific and Atlantic coasts, as well as in the Great Lakes. Other words suggest the research is being conducted on complex issues facing aquatic systems, e.g., stressors (climate, development, nutrient), survival of aquatic species (larval, juvenile, distribution, dynamics). Thus, Sea Grant-funded researchers are providing key science-based information that can shared with local and regional community members.

While Sea Grant funding is specifically directed to meet state specific goals and needs, our findings suggest these place-based, locally relevant research projects have scientific impacts that are global in scale (*6,9*). Sea Grant is well known for funding research topics in their infancy, as these problematic issues and concerns become globally relevant, for example, harmful algal blooms, aquatic invasive species, and microplastics. In all instances, Sea Grant was supporting stakeholder concerns at the local level and investigating causes of these phenomena before they because widespread topics of focus. The seminal research projects and subsequent peer-reviewed papers supported by Sea Grant provided foundational understanding to tackle these global issues. Even though the financial investments in Sea Grant research projects are relatively low (*24*), Sea Grant funded research yields big impacts, including a consistent stream of high-impact, well-cited peer-reviewed publications.

Conclusions

Publicly-funded research is meant to help improve the quality of life, and the Sea Grant program is doing just that. For example, in 2018, the Sea Grant program helped generate an estimated $624 million in economic benefits; created or supported 7,621 jobs; provided 34 state-level programs with funding that assisted 269 communities improve their resilience; helped nearly 23,741 fishers adopt safe and sustainable fishing practices; helped restore an estimated 207,773 acres of coastal ecosystems; worked with about 1,300 industry and private sector, local, state and regional partners; and supported the education and training of 1,994 undergraduate and graduate students (*9*).

State Sea Grant programs are recommended to invest a minimum of 40% of their budget into competitive research, and the average investment in competitive research by state Sea Grant programs (36.5%) has remained relatively static over the past decade (*7*). This relatively small investment in research by the Sea Grant programs has led to the development of a network of researchers who produce thousands of papers and tens of thousands of citations, all representing knowledge that is being co-produced and used by diverse individuals in U.S. coastal and Great Lakes communities. This analysis is a small snapshot (~15 years) in a period of over five decades of Sea Grant's investments in research. If one were to scale up this impact to include the entire period of research investments by Sea Grant, it would not be surprising to note the innumerable contributions that Sea Grant has made to enhance the quality of life and livelihood in America's coastal communities and Great Lakes region whilst advancing the state of scientific knowledge and understanding (*11, 24*).

Back in 1980s, as is the case now, drastic cuts and/or termination of Sea Grant has been proposed by the Administration (*4*). Sea Grant is not alone in facing potential or realized funding decreases *(e.g., 25).* Through sustained outreach to Congress and robust constituent support, Sea Grant has been able to survive budgetary shocks over decades, but other publicly-supported institutions have not fared as well *(25).* Even for Sea Grant, static investments in research, combined with climbing personnel and equipment costs, limit the program's ability to support a more comprehensive portfolio of research ranging from short-term problem-solving to long-term investigation of basic processes. A few strategies to increase investments in publicly-supported research program include reallocation of funds from base budgets, closer collaborations between agencies, and additional federal investments to base budgets (*4,7,11, 24*). What King (*4*) noted in 1986, continues to stay relevant even now: "the key to Sea Grant's continued success is an expansion of its research base." This statement is relevant for all publicly-funded research, particularly when it supports user-driven needs and community well-being.

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Conflict of Interest

The authors declare no conflict of interest.

Availability of Data and Material

Data and metadata are available at https://purr.purdue.edu/publications/3539/1.

Authors' Contributions

All authors contributed to the Conceptualization, Methodology, Resources, Writing, Visualization, and Project Administration of the project. MB and CJF were primarily responsible for Investigation and Formal Analyses.

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