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When disasters strike environmental science: a case–control study of changes in scientific collaboration networks

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Abstract

Studies of scientific collaboration networks reveal the social structure of scientific disciplines. Most of these studies assume scientists work under conditions of institutional stability. What happens to science when disaster strikes and research practice is disrupted? This study examines structural changes in a scientific collaboration network after serial exposure to major disasters. We analyze the collaboration network of wetlands scientists publishing research related to the marshes of the Louisiana Gulf Coast between 1996 and 2015, along with a control network from a wetlands setting in a different geographic area that did not experience any disasters over the same time span. Hurricanes Katrina and Rita (2005) and the Deepwater Horizon oil spill (2010) offer the opportunity to compare the Gulf wetlands collaboration network before and after the disasters. Results indicate changes in size, research activity, and connectivity in periods following the major hurricanes and oil spill.

Keywords Authorship networks · Network change · Disasters · Gulf wetlands

Introduction

Scientific collaboration is a fundamental feature of science; the growth of knowledge depends on it. Scientific networks can be large or small, they can marshal resources of many institutions or only a few, and their principles of organization can differ (Moody 2004). Some, like the early *Drosophila* geneticists (Kohler 1994), are organized around the development of new research tools. Other scientific networks develop and advance lines of theory—e.g., oncogene theory in cancer research (Fujimura 1996), or rational choice theory in the social sciences (Becker 2013). Other networks of scholars form around specialty areas devoted to the investigation of empirical phenomena such as gravity waves (Collins 1992) or bacteriophages (Mullins 1972).

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The primary product of science is the publications that appear in peer-reviewed journals (Crane 1972). Networks based on these publications can be formed by considering connections between the authors. When two or more scientists publish together, their coauthorship connects them to one another and to a larger scientific collaboration network (Newman 2001b; Beaver and Rosen 1978). These networks define scientific communities whose patterned activities knit together social structures that support the creation and sharing of research (Crane 1972; Whitley 2000; Knorr-Cetina 1999).

Our study offers a novel contribution to the existing literature on coauthorship networks. We approach the question of how networks change under extreme social and ecological disruption by way of a longitudinal, quasi-natural experiment (Cook and Campbell 1979). Our case is the collaboration network of scientists publishing research related to the ecological conditions of wetlands along the Louisiana Gulf coast between 1996 and 2015.

We examine structural changes in the Louisiana wetlands coauthorship network before and after serial exposure to two major disasters: the hurricane season of 2005, which included the major hurricanes identified as Katrina and Rita, and the 2010 Deepwater Horizon oil spill. The two-decade span provides the opportunity to observe the collaboration network before and after the environmental disasters. Additionally, we consider a control case from a different wetlands setting in the northwest United States, far from the Gulf coast, over the same time period. The control case allows us to observe how a similar collaboration network changes under generally similar social and scientific conditions, but in the absence of major disasters.

Because their capacity for destruction is so great, disasters have long been a focus of scientific and social scientific research. However, research on dramatic events and influences from outside a system has generally ignored disasters' impacts on scientific production itself. This omission is important because exogenous shocks influence nearly every aspect of society, including science. We do not yet know whether author collaboration networks impacted by exogenous shocks shrink, remain in a stable state, or expand. Nor do we know if exogenous events correspond to change in the connectivity of authors in the network, or if they coincide with changes in scholarly activity.

Collaboration networks

One way to view the social network underlying a scientific field focuses on the connections among the authors of publications. A series of papers by Newman (Newman 2001a, b, 2004) examined large, cross-sectional collaboration networks in broad academic disciplines such as physics, biomedicine, computer science, and mathematics. Recent research on the structure of collaboration networks has explored smaller collaboration networks representing narrower subfields and scholars working in a specific geographic region. Examples include studies of the collaboration networks of management scholars from China (Zhai et al. 2014) and Turkish academics working in nursing (Damar et al. 2018).

Research on scientific collaboration networks has started to consider network evolution and temporal dynamics in larger academic fields. In early work, Barabasi et al. (2002) analyzed networks from mathematics and neuroscience over an 8 year period. Moody (2004) used longitudinal data on collaboration networks from nearly 40 years of publications to test a set of theoretical questions about social integration within the field of sociology. More recently, Prosperi et al. (2016) examined surname nepotism in five decades of health science publications and researchers have explored the growth of scientometrics by analyzing the collaboration network (Zhao and Zhao 2016).

Most examinations of collaboration networks assume the system operates under relatively stable social conditions. Few studies investigate the impact of an unplanned and disruptive exogenous event such as a natural or human-made disaster on collaboration networks. An important exception is the work of Mryglod et al. (2016), who are some of the first researchers to demonstrate that disasters have the potential to influence the collaboration network. Arguing that scientific communities respond to the identification of important problems that need solutions, these authors showed that the 1986 Chernobyl nuclear power plant disaster greatly stimulated research interest in the topic. As part of their study, Mryglod et al. (2016) examine a collaboration network of countries whereby two nations share a tie if authors from the countries coauthored a paper. They report important changes to the structure of the international network following the disaster, including an increasingly connected network and a noteworthy increase in the size of the largest component.

This research sets the stage for our consideration of network dynamics in the face of serial exogenous disasters. Following Mrygold et al. (2016), we argue that the collaboration network of environmental scientists who study processes related to the ecological decline of the Gulf marsh system was influenced, in part, by the hurricane season of 2005 and the major Gulf oil spill in 2010. These disaster events represent exogenous shocks related to increased storm activity and technologically risky energy production and they have attracted substantial attention from the scientific community. Under most current climate-change scenarios, catastrophic disruption is expected to increase and intensify (Hoegh-Guldberg et al. 2018). It is unsurprising that researchers have been drawn to the Louisiana hurricanes and Gulf oil spill, publishing a large body of research and commentary dedicated to the two disasters in top, peer-reviewed science journals. According to *Web of Science* data, scientists have published over 3000 research articles relating to the 2005 hurricanes and more than 900 articles relating to the 2010 oil spill. However, the impact of these disasters on the structure of scientific collaborations remains unstudied.[1]

A focus on the dynamics of scientific communities is important because much of the work on the philosophy of science describes the evolution of science only in terms of the consistent, gradual, endogenous change that Thomas Kuhn (1962) described as "normal science." This frame resonates with the work of Charles Darwin, who proposed that species evolved slowly and gradually from one form to the next. In contrast, Eldredge and Gould (1972) proposed that new species develop quickly, when gradual change is suddenly interrupted or "punctuated" by "rapid and episodic events". Here, we apply the idea of punctuated change to the study of collaboration networks in science. We propose that when major exogenous shocks occur, they generate important problems that require solutions (Mrygold et al. 2016). As we explain below, the severe storms and oil spill significantly damaged Gulf coastal marsh areas in ways that likely captured the attention of environmental scientists. Additionally, the hurricanes and oil spill may have influenced the structure and production of scientific research by disrupting or destroying the social and ecological conditions under which collaborative scientific work normally occurs.

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[1] Abbasi and colleagues studied how fire events and natural disasters affect response team networks (Abbasi et al. 2013; Abbasi and Kapucu 2016), but not scientific networks.

Louisiana wetlands

Louisiana's three million acres of wetlands account for 40% of wetlands in the continental U.S., provide a third of the nation's commercial fish and seafood, and protect critical energy infrastructure for a third of oil and natural gas supplies (Mendelssohn et al. 2012). Since 1985, Louisiana wetlands have disappeared at a rate of 16.57 mi^2 annually (Couvillion et al. 2011). Environmental scientists often characterize wetlands destruction in terms of two processes, subsidence and erosion. Subsidence relates to land sinking. Erosion refers to the removal of surface material from one area to another. These two general processes are associated with various proximal sources of wetlands loss, including marsh canalization, barrier island erosion, infilling for agriculture, stabilization of the Mississippi River, and eutrophication from fertilizer nutrient runoff (Mendelssohn et al. 2012).

Hurricanes are another source of wetlands loss. Hurricanes devastate wetlands because high-speed winds and tidal surges scour out marsh beds. Large storms can also have longer-term impact on vegetation by weakening plant structures (Steyer et al. 2007). An estimated 152 mi^2 of wetlands were lost to open water during the 2005 hurricane season (Couvillion et al. 2011).

For scientists who study wetlands, hurricanes Katrina and Rita fundamentally altered the field conditions of their research in the most literal sense, by destroying research field sites. The storms also disrupted the social and institutional conditions of scientific research (Bellotti 2012). The levee failures following Katrina in 2005 produced significant displacement among residents of New Orleans. Area universities and colleges were temporarily closed, equipment was damaged, experiments were scuttled, data were lost, and scientists and graduate students abandoned their homes and offices as the residents of the region were displaced after the disaster (Fussell 2015; Sastry and Gregory 2014). The 2005 storm season marks a key point for our analysis of the Louisiana wetlands science collaboration networks. Then, another disaster struck the Gulf.

In April 2010, a fire and explosion on the Deepwater Horizon oil-drilling rig located approximately 40 miles off the Louisiana coast initiated another major environmental disaster. The worst oil spill in US history flowed for 87 consecutive days and released an estimated 4.9 million barrels of oil into the Gulf of Mexico until a temporary cap was on the well (National Resource Defense Council 2015). A permanent cap was completed 5 months later (Weber 2010). Adding to its impact on coastal plant and marine life (Graham et al. 2010), the spill affected 796 km of shoreline marsh (Michel et al. 2013); 95% of oiled marshes are in Louisiana (DeLaune and Wright 2011). Wetlands scientists have documented wide-ranging, short-term impacts to shoreline vegetation and soils, seabed sediments, benthic organisms, marsh fish populations, and ecosystem services (Mendelssohn et al. 2012; DeLaune and Wright 2011). Longer-term ecological consequences of the spill are expected but currently not well understood (MacDonald et al. 2014).

The Deepwater Horizon spill marks a second environmental disaster in our observation period. Like the 2005 hurricanes, the spill radically altered the field conditions of wetlands science in the area, but it did not similarly displace researchers or damage research infrastructure. Instead, the spill generated a major funding infusion when British Petroleum, PLC committed $500 million over 10 years to study the consequences of the spill through the through the Gulf of Mexico Research Initiative (GoMRI). In the spring and summer of 2010, GoMRI held a series of public meetings, where research themes related to the oil spill were identified. A series of initial, fast-track grants were awarded for the first period, June 2010–May 2011 and the program has continued to fund research activities through

2018–2019 (Gulf of Mexico Research Initiative 2017). Response to the 2005 hurricanes generated no comparable source of non-federal research funding.

Hurricanes and tropical storms are reoccurring meteorological events in the Gulf of Mexico. During the study period, eleven hurricane-strength storms and several less powerful tropical storms struck Louisiana's Gulf Coast.[2] None produced the type or scale of damage that was delivered by Katrina and Rita in August and September of 2005. The levee failures following Katrina in 2005 produced significant displacement among residents of New Orleans and storm damage to surrounding areas forced residents to relocate (Sastry and Gregory 2014; Fussell 2015) Oil spills are also endemic to the region. Approximately 1500 oil spill notifications are filed with the Louisiana Oil Spill Coordinator's Office each year (Louisiana Department of Public Safety and Corrections 2010). The average amount of oil spilled in Louisiana annually is 330,000 gallons, or 7857 barrels, some of which will affect wetlands. This amount represents about 20% of the total average volume of oil spilled in the U.S. every year but less than 0.2% of the volume of the Deepwater Horizon event. Even in a region accustomed to hurricanes and oil spills, the 2005 storms and the 2010 oil spill have no precedents in recent history.

Methodology

Data for this study consist of research articles from peer-reviewed journals listed in *ISI Web of Science* Science Citation Index and Social Science Citation Index. We identified articles belonging to the network of interest published between 1996 and 2015 using the search string "[Louisiana AND (wetland OR erosion OR subsidence)]". This search string casts a wide net around topics related to Louisiana coastal wetlands and underlying geological processes associated with coastal land loss and the disappearance of coastal marshes. Louisiana ensures geographic accuracy. The term "wetland" ensures that the research considers wetlands in Louisiana instead of a different geological feature. A search limited only to "wetland" misses some research that contributes to wetland ecosystem health and loss, such as geologically oriented studies of processes impacting the coastal sea bed. The other keywords—subsidence and erosion—are general processes that we included to capture relevant research that uses terms other than "wetlands" (e.g., marsh, estuary, swamp, delta, etc.).

We restricted attention to research articles published in English language natural and social science journals. The initial extraction produced 925 articles representing a wide range of disciplines. We examined titles and abstracts to ensure topical relevance. We removed 19 publications because they did not involve Louisiana wetlands, resulting in a total of 906 articles that we used to construct the coauthor database.

To construct a collaboration network for a comparison-case, we assembled publication data on wetlands science in Washington state over the same period, from 1996 to 2015. We used similar search procedures, but changed geographic location from "Louisiana" to "Washington," and again reviewed articles to ensure topical relevance. This regional network, which includes Puget Sound, did not experience any significant disasters during the study period.

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[2] These storms included the hurricanes Opal (1995), Danny (1997), Georges (1998), Lili (2002), Ivan (2004), Katrina (2005), Rita (2005), Humberto (2007), Gustav (2008), Ike (2008) and Isaac (2012).

Previous examinations of much larger scientific collaboration networks identify two complications when computing the number of authors in a field (Newman 2001b). Different authors may share the same name. Alternatively, the same author may use different names on different papers. The smaller network allowed us to cross check author names for accuracy. To guard against double counting, we clarified whether authors listed on different articles with slight differences in name (e.g., the addition of a middle initial) were the same person. We examined biographical detail about the authors, such as institutional affiliation, and electronic information such as department web pages and curricula vitae to ensure that authors in the collaboration networks are unique individuals, coded with consistent identifiers.

Following other research on large author collaboration networks (Newman 2001b, 2004; Zhang et al. 2018; Mryglod et al. 2016) we use five-year publication periods to standardize comparisons. We separated articles based on year of publication into four periods: T1 (1996–2000), T2 (2001–2005), T3 (2006–2010) and T4 (2011–2015). This division allows us to observe how the network appeared in two earlier periods (T1 and T2) before the significant disasters occurred.

An advantage of these five-year intervals is that the hurricanes and oil spill occurred 5 years apart, so the disasters occurred in the final year of the T2 and T3 periods. The hurricanes struck in the second half of 2005, so there was insufficient time for the disasters to influence publications in that year. Ending T2 in 2005 allows us to examine changes in the network in the decades prior to and after the 2005 hurricane season. While the Deepwater Horizon oil spill (DH) began in April of 2010 the wellhead was not capped until mid-September. As such, T4 represents articles published after the oil spill.

We examine the network with respect to several general properties relating to research activity and network structure in each period. For research activity, we report the number of authors in the network and two measures of research activity, the number of published articles and the mean number of articles published by each author. For network structure, we consider average degree, subgroup structure, and network robustness. We present results for the Louisiana case first, followed by the Washington network results.

Results

Table 1 presents the properties of the coauthorship network by period. The first part of the table displays summaries of research activity. Characteristics of network structure are shown in the second part of the table.

Research activity

Prior to the 2005 storm season, the size of the collaboration network was under 400 authors. After the hurricane season, in T3, the collaboration network increased by 152% to 491 authors. In T4, the collaboration network grew 185% to reach its maximum observed size of 908 authors. Across all periods, the collaboration network triples in size. While other unmeasured factors likely influenced growth in the Louisiana wetlands science network, the 2005 hurricane season and the 2010 oil spill corresponded with major increases in network size.

We consider two measures of research activity: the total number of published articles in a period and the mean number of papers published per author in a period. The

Table 1 Summary of network statistics for Louisiana wetlands scientific collaboration networks

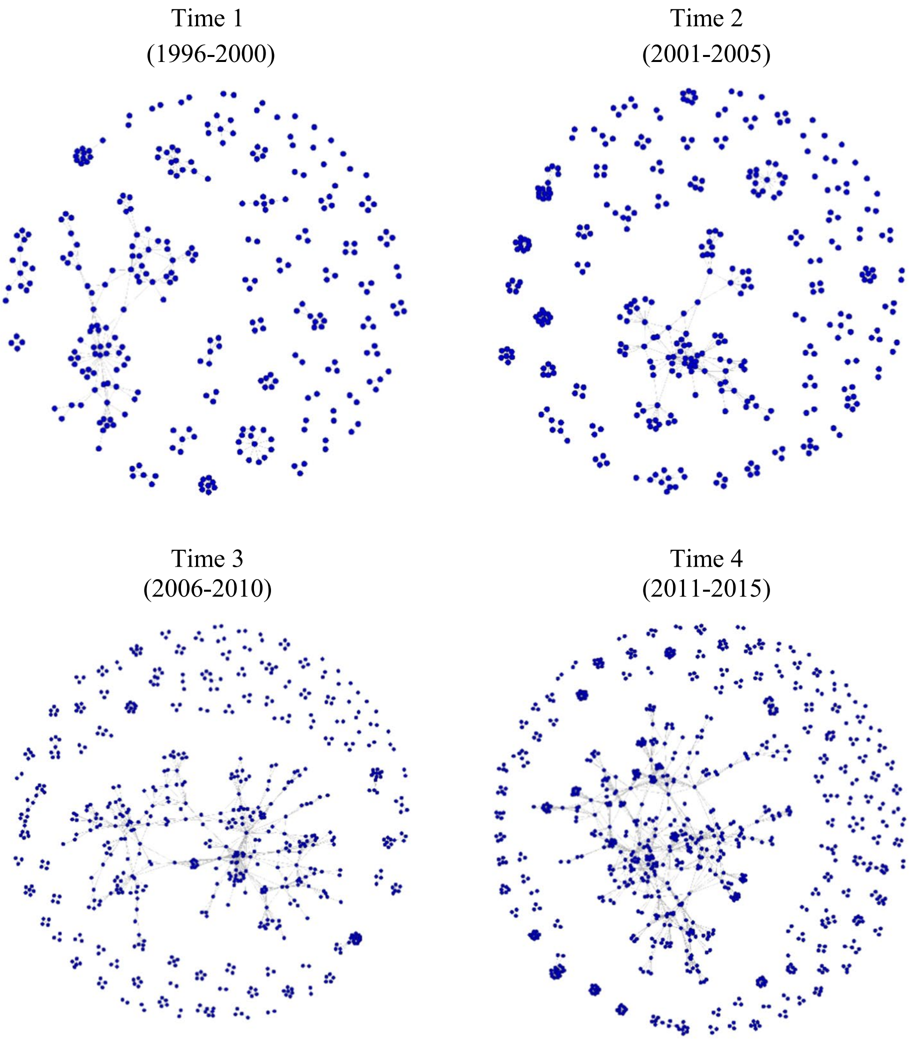
	Time 1 (1996–2000)	Time 2 (2001–2005)	Time 3 (2006–2010)	Time 4 (2011–2015)
Number of papers	158	150	265	333
Number of authors	307	367	659	904
Papers per author	1.56	1.37	1.44	1.45
Authors per paper	3.01	3.34	3.58	3.93
Collaborators per author (average degree)	3.60	4.29	4.77	5.49
Number of components	58	70	96	119
Largest component	90	97	287	412
As a percentage	29.6%	26.4%	43.6%	45.6%
Second largest component	14	16	19	19
As a percentage	4.6%	4.4%	2.9%	2.1%
Number of Isolates	15	16	20	14
As a percentage of components	25.9	22.9%	20.8%	11.7%
Assortativity	0.06	0.37	0.32	0.27

time and energy of scientists are finite and relatively unchanging quantities, so we would not expect a disaster to alter rates of article productivity for authors. Increasing institutional and disciplinary pressures to publish, along with the development of the internet may lead to increased numbers of publications in a field. However, there are reasons to expect productivity decreases along other lines following a disaster. The hurricanes disrupted the personal lives of local scientists and some were forced to turn attention away from their research. Additionally, “new” authors attracted by the disasters may have incurred start-up costs to conduct research in the area and this might delay research publication.

The number of published articles remained relatively stable between T1 and T2, from 157 to 151 articles. Following the hurricanes, the number of articles increases to 265 publications. Another substantial increase is observed after the oil spill, with 334 articles published in T4. From the observed low in T2, the number of articles increased by a factor of nearly 3.0 after the hurricanes and oil spill occurred.

Authors published slightly more than one paper in each period. Some slight variation in the typical number of papers published by authors exists across the periods, but the observed differences are small. Despite the increasing size of the collaboration network and the increased number of publications, neither the 2005 storms nor the 2010 oil spill seems to correspond to changes in the productivity of individual authors.

On average, articles published in this area are written by approximately three coauthors, although the average increases steadily across all four periods until it reaches nearly four coauthors per article in T4. This trend is consistent with the idea that as more scientists enter a field, opportunities to collaborate will increase. Additionally, as the number of coauthors increases, the network may become more interconnected as scientists are more likely to be tied through intermediaries. In the earliest period, papers averaged fewer than three collaborators while in the most recent period, the average increased to over four coauthors on each paper.



Time 1
(1996-2000)

Time 2
(2001-2005)

Time 3
(2006-2010)

Time 4
(2011-2015)

Fig. 1 Louisiana wetlands research collaboration network across four periods, 1996–2015

Network structure

Figure 1 presents graphs of the collaboration network in each period. The graphs were constructed using the Fruchterman-Reingold algorithm with the R igraph package (Csardi and Nepusz 2006). Nodes represent authors and lines connecting nodes indicate that two authors have published at least one paper together in the period. The circles encapsulating the networks encompass the same area to allow comparisons between the networks. The position of the nodes in the graphs is arbitrary.

The top row of Fig. 1 shows the network prior to the impact of the 2005 hurricane season. These two periods are very similar, with no distinguishing features from one period to the next. The graphs from T2 and T3 show the collaboration network before and after the hurricanes. The graphs from T3 and T4 display the network after the hurricanes and oil spill. The presence of a large subgroup (component) distinguishes T3 from T2. In T4, the number of nodes increases further, and a single, giant component starts to dominate the network. The graphs show the serial disasters coincide with a growing and more connected network. We find an abundance of relatively small, simple network structures (dyads, triads) in the first two periods. After the 2005 storms at the end of T2, the network grows and develops more complex structures in T3. The network undergoes further changes in size and structure in T4, after the oil spill disaster occurs at the end of T3.

We now turn to an examination of network properties that are not immediately evident through inspection of the graphs: average degree, subgroup structure, and network robustness. The bottom sections of Table 1 present information on these network properties. We discuss these summary computations below, focusing on comparisons before and after the disasters.

The average number of authors collaborating with each other in a period is the average degree in the network. In many types of social networks, the degree of a node provides an indicator of importance or prestige. Here, the average degree represents a key measure of research activity. Scientific collaboration requires communication. Publishing research with others indicates ideas are being shared and disseminated. Collaboration networks with high average degree suggest that scientists are engaging in collaborative publication activities. Isolates are omitted from the average degree computation.

For average degree, the collaboration network shows an increasing trend over time. In the earliest period, the average degree is approximately 3.6, indicating that Louisiana wetlands scientists have, on average, between three and four collaborators. In T2, the average degree increases to over four collaborators. Following the hurricanes, the average degree increases again to 4.5 collaborators, and it exceeds five collaborators in T4. Over the two-decade span, environmental scientists are engaging in work that involves more collaborators. The trend toward increasing average degree observed prior to the hurricanes continues after the serial disasters. Thus, where we might expect productivity to decrease because of ecosystem disruption, researchers' physical dislocation, or start-up costs for new research, the disasters coincide with a network that produces more articles rather than fewer ones.

We examine subgroups in the collaboration network by considering components and isolates. A component is defined in a collaboration network when at least two scientists are connected directly by a coauthor tie or indirectly connected through two or more intermediate ties. If Scientist A publishes with Scientist B, Scientist A becomes indirectly connected to everyone with whom Scientist B has published. In addition, Scientist B is tied to Scientist A's coauthors. A disconnected scientific network contains many small, isolated components. The existence of even one highly productive researcher who collaborates with other scientists provides a bridge between two or more scientists who do not directly publish with each other. As researchers connect with others via intermediate ties, the network becomes characterized by a giant component—a vast collection of scientists who reach each other by following paths of collaborative ties.

If an author publishes at least one paper with someone else, a component is created. Not all papers involve coauthors and some authors never publish with anyone else. Isolates are generated in the network when a scientist publishes only single-authored papers. The definition of a component requires the presence of a coauthor. However, isolates form the simplest type of subgroup and their presence indicates a disconnected structure. We analyze the tendency for isolates to form in a separate discussion below.

Some of the most striking changes relate to the component structure following the two disasters. The number of components increases by about 37% after the hurricanes and jumps another 23% after the oil spill. In T1, the largest connected group of ninety coauthors includes nearly one-third of all scientists in the network. The second-largest component (fourteen authors) includes less than five percent of the network. The other coauthors are clustered in smaller, isolated groups, with approximately 80% in components with five or fewer coauthors.

Many of these smaller groups represent cliques, a subgroup structure where every node in the subgroup is tied to every other node. Cliques form in a coauthorship network when multiple coauthors publish a paper. Tightly-knit clique structures are indicative of network effectiveness because they may involve multiple (and possibly overlapping) linkages (Provan and Sebastian 1998; Ngamassi et al. 2014). In a coauthorship network, members of a clique are more likely to be directly working together on research, as opposed to those sharing an indirect tie through an intermediary.

The component structure in T2 is similar to T1. The largest component is nearly the same size as T1 (ninety-seven authors), comprising approximately 26% of the wetlands scientists. The second-largest component is sixteen authors, about the same size as the second-largest component in T1 and constituting about the same percentage (4%) of the network. The network continues to be characterized by relatively small, isolated groups, again with about 80% of authors tied to components of size five or smaller. In the two periods prior to Katrina and Rita, most Louisiana wetlands scientists were publishing in small groups.

Immediately after the hurricanes, the network becomes dominated a relatively large component, encompassing over 40% of all researchers. Before the hurricanes, a smaller proportion of the network is connected. Following 2005, nearly half of the network falls into a connected subgroup.

In T4, the trend toward a single, giant component characterizing the network continues. The largest component connects more than four hundred scientists, over 45% of the network. This giant component is as large as or larger than the entire network before the disasters. As the field experienced two major disasters, the network structure of Louisiana wetlands science moved from a set of unconnected, small research teams (cliques) to a much larger and more fully connected collaboration network characterized by a single, linked group of researchers. These changes in the component structure of the network are consistent with results reported by Mryglod et al. (2016), who report increases in the size of the largest component in their collaboration network after the Chernobyl incident.

Isolates are authors who publish only sole-authored research, represented by single, unconnected nodes in the graphs. The percentage sole-authored publications declines steadily over the observation period. This decrease is reflected in the component structure. In T1, 26% of the nodes are isolates and in T2, 23% are isolates. While the total number of articles published increased after both disasters, single-node components in each period decreased. The percentage of isolates in T3 is about 21% and this drops to under 12% in T4. Thus, collaborative research in the form of multi-authored publications became more common after the disasters.

The final network property we consider is network robustness. We measure this property with assortativity. Assortativity measures the correlation between the degrees of connected nodes. Isolates are not included in the assortativity computation because they are not connected to any authors (i.e., degree equals zero). High assortativity indicates that high-degree nodes tend to be linked to high-degree nodes while low-degree nodes share ties with low-degree nodes (Newman 2002). In a scientific collaboration network, a network characterized by assortative mixing on degree is comprised of highly collaborative scientists who are likely to work with other highly collaborative scientists.

Networks with high assortativity are robust to the removal of a high-degree node because other high-degree nodes that are similarly connected can compensate for the disappearance of a node (Newman 2002). An isolated group of coauthors publishing a single paper might withstand the loss of a single contributor. In contrast, networks with low assortativity are vulnerable to destruction because there is no way to compensate for the removal of a high-degree node. Low assortativity implies the removal of a node has the potential to disconnect one group of authors from another connected set of authors in the network.

Assortativity is an important network characteristic to consider in a small scientific field because the network might be susceptible to the removal of a key scientist through retirement or death. Alternatively, as was the case for many Gulf-area academics in 2005, disruption of family and career, as well as geographic displacement from a hurricane like Katrina, can force scientists out of the network, at least temporarily. On the other hand, in small systems, a paper with many coauthors has the potential to significantly reduce assortativity if the coauthors collaborate with a different, smaller group of authors on another paper. The situation resembles a scatterplot with a few observations, where a single outlier can unduly influence the correlation.

Assortativity fluctuates nonlinearly across the period. The network always displays positive assortativity, with a low of 0.06 in T1 and a maximum of 0.37 in T2. While the number of authors and papers in T1 and T2 are similar, T2 exhibited a much stronger tendency for high degree authors to be tied to other high degree authors, and low degree authors to be tied to other low degree authors. Assortativity decreases slightly in T3 after the hurricanes and again in T4 after the oil spill. The lower assortativity in these periods suggests authors with few collaborators (low degree nodes) are tied to authors with a large number of collaborators (high degree nodes). Thus, while we observe a tendency for highly collaborative scientists to be connected to other highly collaborative scientists in T2, this proclivity was reduced slightly after the disasters.

The relatively high assortativity in T2 indicates that this period exhibits the most robust network. As we might expect, the explosive growth of the network in size and complexity after the disasters reduced assortativity, however it was not decreased to the low level observed in the earliest period. The positive assortativity values in T3 and T4 remain consistent with the idea that major disruptive events, such as the 2005 hurricanes and the 2010 oil spill, connected some prominent scientists together in research activities. Such collaborations may have been aimed at evaluating the disasters' impacts, outlining new research agendas, producing policy statements, and pooling resources in response to newly issued RFPs.

However, these highly collaborative scientists are also connected to authors who did not collaborate with many others, as the lower, positive assortativity values indicate. Ties between highly connected scientists and less collaborative researchers may reflect links between established wetlands researchers and experts from other areas without wetlands science backgrounds (e.g., climate scientists), or an influx of new researchers attracted to the substantial federal grant money following the oil spill. Articles written by professors and graduate students may, in some cases, also produce lower assortativity values. Nevertheless, the trend suggests that Louisiana wetlands research has slowly developed a structure that is increasingly able to withstand the removal of a single, productive scientist, much like larger and more established scientific fields.

Control case

Disaster research and other studies exploring the influence of exogenous events often suffer from a lack of baseline comparisons or research designs that allow for controls. In the absence of the possibility of such controls, we take the next best approach. We consider a control case that allows us to examine whether another regional wetlands coauthor network experienced similar changes in the before and after disaster periods. The Washington state wetlands collaboration network offers data from a similar field, but the wetlands areas in this region did not experience any major disasters. We expect the Washington network will change over the observation period because science in general is growing and the internet and other computer technologies have made collaboration more efficient. What matters for our study, though, is the pattern of change we observe in both networks. The Louisiana network showed clear and significant distinctions between T1/T2 and T3/T4. It tripled in size after T2 and developed a giant component containing over 40% of the entire network. If the Washington network exhibits similar network dynamics, our interpretation of the data becomes complicated. Factors other than the disasters may be influencing the observed changes in both networks or the Gulf disasters may have affected wetlands research more generally, including the Washington network. On the other hand, if the Washington network changes in ways that do not correspond to timing of the disasters, this lends additional support to the claim that the Louisiana network dynamics are, in part, related to the disasters.

Network graphs for the Washington network are shown in Fig. 2, while Table 2 presents the research activity and network measures. Compared to the Louisiana case, the Washington network is smaller and less dynamic. When systematic changes in research productivity and network structure appear, they tend to occur gradually across the entire period, as opposed to the Louisiana network which exhibits stronger contrasts between the before and after disaster periods. Between T1 and T3, the Washington network exhibits gradual changes in many of the measures. Large increases in the number of articles, authors, and components occur only in T4. However, the proportion of authors included in the largest component of shrinks in T4. Unlike the Louisiana network, the network does not exhibit large changes in the scale of its component structure in the post-disaster periods, nor does a single giant component develop after the disasters. The proportion of isolates in the Washington network varies greatly, in part because the number of articles published is relatively low. In periods T1, T3, and T4, fewer than five articles in each period are published by only one author.

Assortativity shows no linear trend across the Washington periods but overall, it is consistently higher than the Louisiana network. In T1 and T2, we observe high assortativity because most of the subgroups represent one article. In T1, 13 of 15 components in the network represent authors producing only one article; in T2, 23 of 24 components represent a single paper. In T3, assortativity decreases because one scientist published three papers, each with at least four coauthors and one of the coauthors published with a unique coauthor. If this component is removed, assortativity increases to 1.0, indicating that all scientists published only one paper with a unique set of collaborators. In T4, assortativity returns to a high level because 85% of the components are generated by authors producing only one article. The structure of the network is resistant to the removal of a node because authors tend to publish with the same coauthors. Despite slight increases in size and the

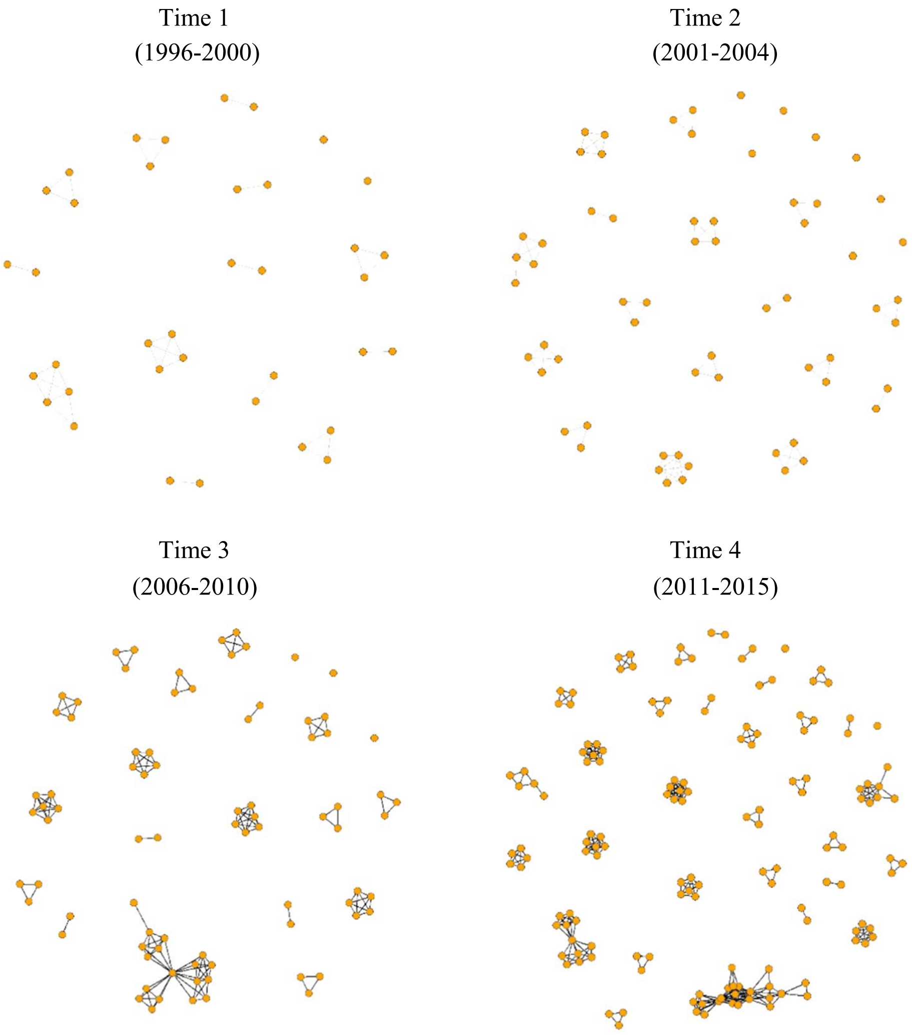


Fig. 2 Washington wetlands research collaboration network across four periods, 1996–2015

number of components, assortativity suggests that the removal of a node in any period would not change the network.

Overall, we observe a relatively disconnected Washington wetlands coauthor network that shows an increase in the number of authors, articles, and components across the entire observation period. In T1–T3, very few authors produce more than one paper and when they publish, they rarely collaborate with different coauthors. When comparing T1 and T2 (pre-disaster periods) to T3 and T4 (post-disaster periods) in the Washington network, we do not observe the same pattern of changes in research activity and network characteristics that we find in the Louisiana network over these periods. The dynamics we observe in the Washington case suggest that disasters correspond with changes only in the Louisiana collaboration network.

Table 2 Summary of network statistics for Washington wetlands scientific collaboration networks

	Time 1 (1996–2000)	Time 2 (2001–2005)	Time 3 (2006–2010)	Time 4 (2011–2015)
Number of papers	17	27	26	45
Number of authors	37	62	81	148
Papers per author	1.11	1.10	1.06	1.10
Authors per paper	2.41	2.52	3.38	3.77
Collaborators per author (average degree)	1.78	2.29	3.41	4.20
Number of components	15	24	21	33
Largest component	5	6	18	23
As a percentage	13.5%	9.7%	22%	15.5%
Second largest component	4	5	6	12
As a percentage	10.8%	8.1%	7.4%	8.1%
Number of Isolates	2	9	4	3
As a percentage of components	13.3%	37.5%	19.0%	9.1%
Assortativity	0.80	0.94	0.24	0.63

Conclusion

This study compares the structure of a scientific collaboration network before and after the ecological and social impacts of serial environmental disasters—events that are likely to increase with increasing climate uncertainty. A loosely connected collaboration network focused on Louisiana wetlands underwent changes following two exogenous shocks. At the end of our observation period, the network had nearly tripled in size, produced twice as many articles, and started to exhibit a structure like larger disciplinary networks. The collaboration network became more connected, more productive, and potentially more resilient. In contrast, a topically similar collaboration network in the state of Washington, a region with sizable and economically important wetlands acreage that was not buffeted by major environmental disasters did not exhibit patterns of change that corresponded to the timing of the disasters.

While the Washington network offers a comparison-case in the sense of a quasi-experimental design, it does not have the benefits of random assignment that a true experimental design offers, nor does it allow statistical control of other potential influences. The Washington network is smaller and less productive across the entire period. However, the control network is not stable across the observation period. This suggests there are unmeasured factors influencing both coauthorship networks that we fail to consider here. We note the number of authors in the Louisiana and Washington networks increases over time. We also observe a tendency in both networks for multi-authored papers to increase, as the proportion of isolates declines. While the pattern of these changes remains consistent with the idea that the disasters influenced the Louisiana wetlands network, other factors may be operating. Future studies should attempt to account for other influences that likely impact collaboration within a scientific field.

Despite these limitations, our study extends earlier cross-sectional research on larger collaboration networks (Newman 2001b) in several important ways. We analyze the collaboration network from a smaller, more topically focused academic subfield than typically considered. We show that collaboration networks are not static entities, underscoring the importance of exploring the evolution of networks over time. More importantly, our examination of the Gulf wetlands network demonstrates that changes in the collaboration network occur after exogenous shocks. These changes are consistent with the contention that disasters generate problems requiring solutions (Mryglod et al. 2016).

The observed changes in the component structure are important to consider. It appears that the component structure may be among the most malleable network properties. These changes in the component structure of the network are consistent with results reported by Mryglod et al. (2016), where immediately following the Chernobyl disaster, the largest component in their country network contained 38% of the nodes, but two decades later, the largest component included 82% of the nodes.

In addition to considering other factors that could influence coauthorship networks, future analysis might consider a more comprehensive examination of individual and article-level attributes of the components in the wetlands coauthor network. For instance, do components form around larger social organizations such as authors' academic affiliations or researchers working in academic or government institutions? Furthermore, it would be interesting to consider how different types of exogenous shock might produce changes to the component structure of scientific networks in different fields, such as the impact of recent active wildfire seasons in the western United States on forestry collaboration networks.

Large-scale exogenous shocks have the potential to influence collaboration networks of entire scientific fields, however these effects may operate in complex ways. The finding that the technological life-cycle within a scientific field correlates with the collaboration network (van der Pol and Rameshkoumar 2018) suggests an interesting opportunity to explore how endogenous changes from within a field may interact with an exogenous shock to intensify or attenuate an effect. Network boundaries with respect to the scope or reach of the particular exogenous event (Laumann et al. 2017) will be important to consider in future research.

The enormous destructive capacity of disasters such as Hurricanes Katrina and Rita and the Deepwater Horizon oil spill for a local area are matched only by their capacity to generate new empirical information. Whether and how such information is transformed into scientific knowledge, shared among researchers, and circulated into society are questions of increasing consequence and depend on the social resiliency of science to environmental change. The author collaboration network provides insight into these issues.

More fundamentally, this study contributes to the literature that suggests science is not disconnected from the environments it studies. Scientists respond to the shocks generated by a rapidly changing world. Whether these shocks come from exogenous events such as a nuclear power plant meltdown, severe weather, or some other unforeseen event, the structure of scientific collaboration networks will likely change as scientists attempt to solve problems that those disasters bring to the fore.

References

Abbasi, A., & Kapucu, N. (2016). A longitudinal study of evolving networks in response to natural disaster. *Computational and mathematical organization theory, 22*(1), 47–70.

Abbasi, A., Owen, C., Hossain, L., & Hamra, J. (2013). Social connectedness and adaptive team coordination during fire events. *Fire Safety Journal, 59,* 30–36.

Barabasi, A. L., Jeong, H., Neda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica a-Statistical Mechanics and Its Applications, 311*(3–4), 590–614.

Beaver, D., & Rosen, R. (1978). Studies in scientific collaboration: Part I. The professional origins of scientific co-authorship. *Scientometrics, 1*(1), 65–84.

Becker, G. S. (2013). *The economic approach to human behavior*. Chicago: University of Chicago Press.

Bellotti, E. (2012). Getting funded. Multi-level network of physicists in Italy. *Social Networks, 34*(2), 215–229.

Collins, H. (1992). *Changing order: Replication and induction in scientific practice*. Chicago: University of Chicago Press.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-Experimentation: Design & analysis issues for field settings*. Boston: Houghton Mifflin Company.

Couvillion, B. R., Baras, J. A., Steyer, G. D., Sleavin, W., Fischer, M., Beck, H., et al. (2011). Land area change in coastal Louisiana from 1932 to 2010: U.S. Geological Survey Scientific Investigations Map 3164, scale 1:265,000. https://pubs.usgs.gov/sim/3164/. Accessed June 26 2017.

Crane, D. (1972). *Invisible colleges; diffusion of knowledge in scientific communities*. Chicago: University of Chicago Press.

Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal, Complex Systems, 1695*(5), 1–9.

Damar, H. T., Bilik, O., Ozdagoglu, G., Ozdagoglu, A., & Damar, M. (2018). Evaluating the nursing academicians in Turkey in the scope of Web of Science: scientometrics of original articles. *Scientometrics, 115*(1), 539–562.

DeLaune, R. D., & Wright, A. L. (2011). Projected Impact of Deepwater Horizon Oil Spill on U.S. Gulf Coast Wetlands. *Soil Science Society of America Journal, 75*(5), 11.

Eldredge N., & Gould, S. J. (1972). Punctuated equilibria: An alternative to phyletic gradualism. In T. J. M. Schopf (Ed.), *Models in paleobiology* (pp. 82–115). San Francisco: Freeman, Cooper & Company.

Fujimura, J. H. (1996). *Crafting science: A sociohistory of the quest for the genetics of cancer*. Harvard: University Press.

Fussell, E. (2015). The long-term recovery of New Orleans' population after Hurricane Katrina. *American Behavioral Scientist, 59*(10), 1231–1245.

Graham, W. M., Condon, R. H., Carmichael, R. H., D'Ambra, I., Patterson, H. K., Linn, L. J., et al. (2010). Oil carbon entered the coastal planktonic food web during the Deepwater Horizon oil spill. *Environmental Research Letters, 5*(4), 045301. https://doi.org/10.1088/1748-9326/5/4/045301.

Gulf of Mexico Research Initiative (2017). Synopsis of Gulf of Mexico Research Initiative. http://gulfresearchinitiative.org/request-for-proposals/. Accessed November 21, 2017.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., et al. (2018). Impacts of 1.5 °C global warming on natural and human systems. In: Global warming of 1.5 °C an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. Intergovernmental Panel on Climate Change.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge: Harvard University Press.

Kohler, R. E. (1994). *Lords of the fly: Drosophila genetics and the experimental life*. Chicago: University of Chicago Press.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Laumann, E. O., Marsden, P. V., & Prensky, D. (2017). The boundary specification problem in network analysis. In L. C. Freeman, D. R. White, & A. K. Romney (Eds.), *Research methods in social network analysis* (pp. 61–87). New York: Routledge.

Louisiana Department of Public Safety and Corrections (2010). Facts about Oil Apills in Louisiana. http://www.losco.state.la.us/about.html. Accessed June 26, 2017.

MacDonald, I. R., Kammen, D. M., & Fan, M. H. (2014). Science in the aftermath: investigations of the DWH hydrocarbon discharge. *Environmental Research Letters, 9*(12), 125006. https://doi.org/10.1088/1748-9326/9/12/125006.

Mendelssohn, I. A., Andersen, G. L., Baltz, D. M., Caffey, R. H., Carman, K. R., Fleeger, J. W., et al. (2012). Oil impacts on coastal wetlands: implications for the Mississippi river delta ecosystem after the deepwater horizon oil spill. *BioScience, 62*(6), 562–574. https://doi.org/10.1525/bio.2012.62.6.7.

Michel, J., Owens, E. H., Zengel, S., Graham, A., Nixon, Z., Allard, T., et al. (2013). Extent and degree of shoreline oiling: deepwater horizon oil spill, Gulf of Mexico, USA. *PLoS ONE, 8*(6), e65087.

Moody, J. (2004). The structure of a social science collaboration network: Disciplinary cohesion from 1963 to 1999. *American Sociological Review, 69*(2), 213–238.

Mryglod, O., Holovatch, Y., Kenna, R., & Berche, B. (2016). Quantifying the evolution of a scientific topic: reaction of the academic community to the Chornobyl disaster. *Scientometrics, 106*(3), 1151–1166.

Mullins, N. C. (1972). The development of a scientific specialty: The phage group and the origins of molecular biology. *Minerva, 10*(1), 51–82.

National Resource Defense Council (2015). Summary of information concerning the ecological and economic impacts of the BP Deepwater Horizon spill disaster. https://www.nrdc.org/sites/default/files/gulfspill-impacts-summary-IP.pdf. Accessed June 26, 2017.

Newman, M. E. J. (2001a). Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. *Physical Review E, 64*(1), 016132.

Newman, M. E. J. (2001b). The structure of scientific collaboration networks. *Proceedings of the National Academy of Sciences of the United States of America, 98*(2), 404–409. https://doi.org/10.1073/pnas.021544898.

Newman, M. E. J. (2002). Assortative mixing in networks. *Physical Review Letters, 89*(20), 208701–208704. https://doi.org/10.1103/PhysRevLett.89.208701.

Newman, M. E. J. (2004). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the United States of America, 101,* 5200–5205. https://doi.org/10.1073/pnas.0307545100.

Ngamassi, L., Maitland, C., & Tapia, A. H. (2014). Humanitarian interorganizational information exchange network: how do clique structures impact network effectiveness? *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations, 25*(6), 1483–1508.

Prosperi, M., Buchan, I., Fanti, I., Meloni, S., Palladino, P., & Torvik, V. I. (2016). Kin of coauthorship in five decades of health science literature. *Proceedings of the National Academy of Sciences of the United States of America, 113*(32), 8957–8962. https://doi.org/10.1073/pnas.1517745113.

Provan, K. G., & Sebastian, J. G. (1998). Networks within networks: Service link overlap, organizational cliques, and network effectiveness. *Academy of Management Journal, 41*(4), 453–463.

Sastry, N., & Gregory, J. (2014). The location of displaced New Orleans residents in the year after Hurricane Katrina. *Demography, 51*(3), 753–775.

Steyer, G. D., Perez, B. C., Sariai, P., & Suir, G. (2007). Potential consequences of saltwater intrusion associated with Hurricanes Katrina and Rita. In S. G. S. Farris, G. J., Crane, M. P., Demas, C. R., Robbins, L. L., Lavoie, D. L. (Eds.), Science and the storms—the USGS response to the hurricanes of 2005: U.S. Geological Survey Circular, 1306 ed. (pp. 137–146): U.S. Department of the Interior. U.S. Geological Survey.

van der Pol, J., & Rameshkoumar, J.-P. (2018). The co-evolution of knowledge and collaboration networks: the role of the technology life-cycle. *Scientometrics, 114*(1), 307–323.

Weber, H. R. (2010). Blown-out BP well finally killed at bottom of Gulf. http://archive.boston.com/news/nation/articles/2010/09/19/blown_out_bp_well_finally_killed_at_bottom_of_gulf/. Accessed 20 March 2018.

Whitley, R. (2000). *The intellectual and social organization of the sciences* (2nd ed.). Oxford: Oxford University Press.

Zhai, L., Yan, X., Shibchurn, J., & Song, X. (2014). Evolutionary analysis of international collaboration network of Chinese scholars in management research. *Scientometrics, 98*(2), 1435–1454.

Zhang, Z., Rollins, J. E., & Lipitakis, E. (2018). China's emerging centrality in the contemporary international scientific collaboration network. *Scientometrics, 116*(2), 1075–1091.

Zhao, Y., & Zhao, R. (2016). An evolutionary analysis of collaboration networks in scientometrics. *Scientometrics, 107*(2), 759–772.