

Letter to the Editor

Comment on “Resilience of Complex Systems: State of the Art and Directions for Future Research”

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Fraccascia, Giannoccaro, and Albino (hereafter FGA) recently reviewed research on the resilience of complex systems [1]. They identified several different fields in which research on the resilience of complex systems is commonly undertaken but found that the literature is highly compartmentalised with few citations between these fields. This result matches previous cross-disciplinary reviews of resilience that have found a similar pattern [2, 3]. While we would hope that interdisciplinary collaborations are helping to bridge this gap, we agree with FGA that the literature on the resilience of complex systems is highly fragmented. FGA's demonstration of this fragmentation through citation analysis is a valuable contribution.

Here, we would like to caution that the 154 papers that FGA identified (their Table 1) are a far from comprehensive reflection of research on the resilience of complex systems. While the limited selection of literature might not affect FGA's main conclusions, the literature identified gives the reader a narrow and biased impression of research on the resilience of complex systems. We will illustrate how the search terms chosen by FGA (resilience AND “complex system*”) led to this narrow selection of the literature and roughly estimate to what degree the literature on the resilience of complex systems has been underrepresented.

In perhaps the most telling evidence of the limitations of FGA's literature search, three of the four references they used to introduce research on the resilience of complex systems (their references 2-5) were not then found during

their literature search (their Table 1). The search did not find Folke et al.'s review of resilience in ecosystem management [4] because that article's abstract refers to their object of study as “complex adaptive ecosystems” and “complex adaptive systems,” not “complex systems.” Walker et al. [5] in their perspective on the resilience of social-ecological systems omitted the word “complex” from their abstract altogether and referred instead to their object of study as “social-ecological systems” (though in the body of the article, which is not in the Web of Science database, they refer variously to “complex adaptive systems,” “complex, coupled SESs,” and “complex, multi-scalar SESs”). Vogus and Sutcliffe [6] used neither “complex” nor “system” in their entire article on organisational resilience and it was therefore not found by FGA's search, referring instead to organisations as their object of study.

These three examples illustrate how variations in language for the same concept need to be taken into account when designing a systematic literature review [7] and lead to the following modifications to FGA's search. First, while opinions may differ on whether complex adaptive systems are a subset of complex systems [8] or complex systems are actually complex adaptive systems with the word “adaptive” understood as implied, both interpretations support including complex adaptive system literature in any review of complex systems. Second, the label “social-ecological system” omits the word “complex,” but social-ecological systems are commonly acknowledged to be examples of

complex adaptive systems [9]. Third, when analysing the resilience of organisations it is clear that complex systems concepts such as structure and rigidity are likely to be involved [6]. Complex adaptive systems, social-ecological systems, and organisations are therefore all either types of complex systems or synonymous with complex systems and should be included in a literature review on complex systems.

We begin by taking into account the first of these insights. We performed a new search on ISI Web of Knowledge from 1900 to 2017 using the search term (resilience AND (complex NEAR/2 system*)). The term (complex NEAR/2 system*) finds articles where “complex” and “system*” are separated by at most 2 words and therefore captures cases such as “complex adaptive systems” and “complex social-ecological systems.” The number of articles returned almost doubled, with 957 articles identified compared to 490 using FGA’s original search terms (before they postprocessed their results down to 154 papers). (FGA reported 458 papers before postprocessing; our additional 32 papers are presumably due to papers published after FGA’s search date of September 2017). The top five articles within the subject areas of ecology and environmental science using this search were not within the top five listed by FGA, indicating that key literature was not captured by FGA’s search.

One of the five top-cited papers found by our search, by Elmqvist et al. [10] on the role of response diversity on the resilience of ecosystems, was also captured by FGA’s search terms but was not included in their list of literature (their Table 1). The paper was presumably excluded by FGA because it “did not really address the topic” or did not “explicitly [study] complex systems” [1]. We respectfully disagree; the main point of Elmqvist et al. that a diversity of responses amongst elements of an ecosystem can promote resilience is an important insight for understanding the resilience of complex systems more generally. We suspect the reason for omission was simply that ecosystems are outside FGA’s usual area of research and therefore they could not appropriately judge this article’s relevance. Their specific disciplinary background may also have contributed to the narrow choice of search terms. Such a narrow approach risks ignoring literature with relevant insights into the topic, especially for a topic as interdisciplinary as resilience. Recent reviews by Xu and Kajikawa [2] and Baggio and Brown and Hellebrandt [3], which it appears FGA did not consult, have highlighted the interdisciplinary nature of resilience and even its status as a boundary object for integrating disciplines.

Expanding the search further, we conjecture that ecosystems [4], social-ecological systems [11], communities [12], and organisations [6] are also complex systems whose resilience is frequently studied. Using the search term (resilience AND ((complex NEAR/2 system*) OR “social-ecological system*” OR communit* OR organisation* OR ecosystem*)) yielded 16,157 papers, more than 30 times FGA’s initial search results. An inspection of the highest 20 cited papers yielded by this search found at least 7 where the resilience of a complex system is the main subject of the paper [4, 5, 11, 13–16]. Even though the search term is more complicated and possibly admits less relevant papers, at 35%

this is a very similar rate to FGA’s postprocessing rate of 32%. Complicated (and iteratively developed) search terms are in fact common when conducting systematic literature reviews, in order to capture the different ways in which a chosen topic is discussed [7, 17]. We conclude that the literature on the resilience of complex systems is likely to be much larger than FGA’s 154 papers.

The author collaboration network under our search is also substantially different to FGA’s for at least the environmental science and ecology subject areas (Figure 1; compare FGA’s Figure 3). Carl Folke and Brian Walker, who FGA themselves identified as authoring key publications on resilience, become the first and second most productive authors in our new search. These results further demonstrate bias in FGA’s selection of literature.

While our expanded search terms reveal a significantly larger body of literature, we have not expanded the search to include all literature on resilience. We recognise value in FGA’s novel focus on specifically the resilience of complex systems. For such a review, not all literatures on resilience may be relevant. For example, research into psychological resilience as the ability of a person to withstand and recover from stress [18] does not necessarily feature a systems perspective. FGA’s finding that there is comparatively little research within psychological on the resilience of complex systems may be an accurate result.

We have shown how synonyms for and subtypes of “complex systems” should be included in a review of research on the resilience of complex systems. The same argument could be made for resilience, depending on whether the target of the review is (a) the evolution of the concept specifically named resilience or (b) literature that delivers insights on the resilience of complex systems regardless of whether the name resilience is actually used. For example, under some definitions robustness is synonymous with resilience [19] and vulnerability in some literature is considered the opposite of resilience [20]. Expanding the search term to ((resilience OR robustness OR vulnerability) AND ((complex NEAR/2 system*) OR “social-ecological system*” OR community* OR organisation* OR ecosystem*)) yields 32,734 records, more than 65 times FGA’s results before postprocessing.

While FGA delivered useful evidence of the fragmentation of literature on the resilience of complex systems, we conclude that the 154 papers they identified are likely a massive underestimate of the literature. Using the postprocessing rate identified above, we tentatively estimate $32,734 \times 35\% \approx 11,400$ papers in the literature. As well as being an underestimate, FGA’s review was likely biased towards technical and business fields and underrepresented research on the resilience of complex human systems. In conducting future systematic literature reviews on resilience and complex systems, we suggest researchers take heed of the call—made by FGA themselves—to look across disciplines, engage with other researchers, and build upon the previous work of others.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

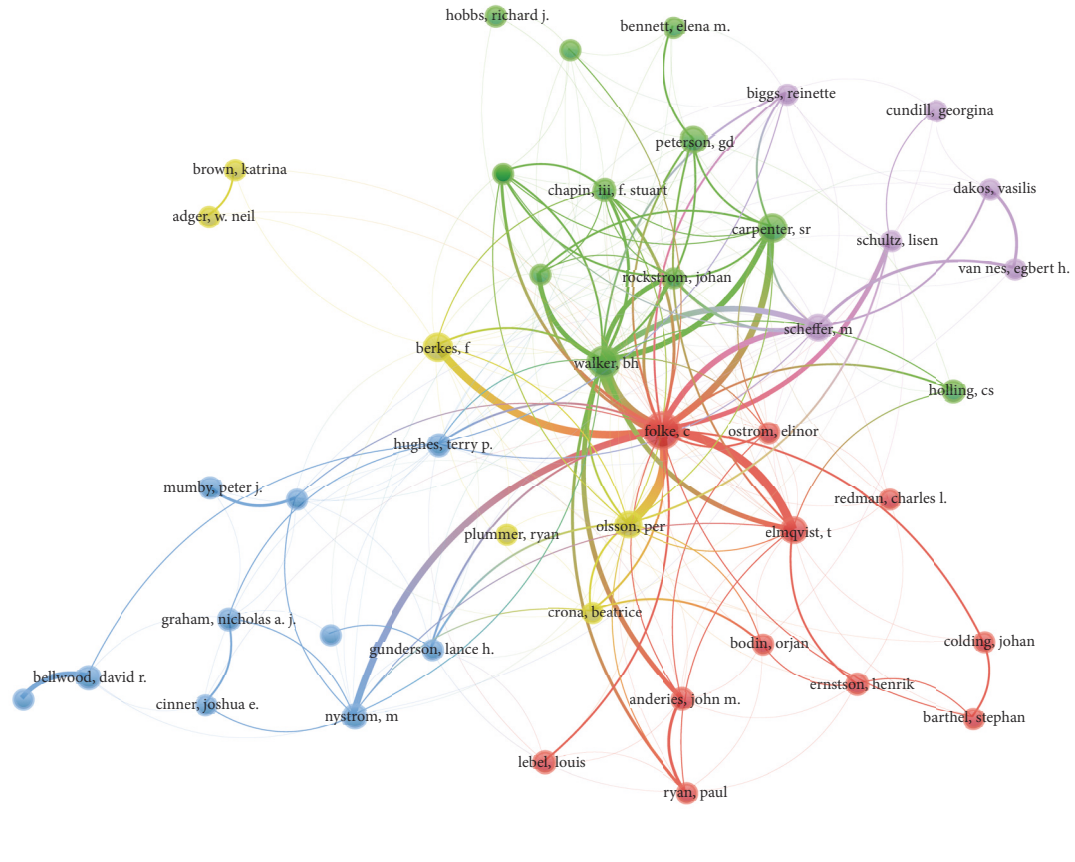
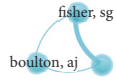


FIGURE 1: **Updated author collaboration network for Environmental Science and Ecology.** Collaboration network of those authors with 5 or more papers in the 1000 most cited papers using the topic search (resilience AND ((complex NEAR/2 system*) OR "social-ecological system*" OR community* OR organisation* or ecosystem*)), filtered by subjects "environmental science" and "ecology." Colours represent clusters of authors.

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