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**‘Of course, data can never fully represent reality’: Assessing the Relationship between Indigenous Data and IK, TEK, and TK**

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Short Title: Assessing the Relationship between Indigenous Data and IK, TEK, and TK

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## **Abstract**

Multiple terms describe Indigenous peoples' creative expressions, including Indigenous knowledge (IK), traditional ecological knowledge (TEK), traditional knowledge (TK), and increasingly Indigenous data. Variation in terms contributes to disciplinary divides, challenges in organizing and finding prior studies about Indigenous peoples' creative expressions, and intellectually divergent chains of reference. A decolonial digital feminist ethics of care approach to citation analysis of records about Indigenous peoples knowledge and data, including network analyses of author-generated keywords and research areas, and content analysis of peer-reviewed studies about Indigenous data, reveals ambiguous uses of the term 'Indigenous data,' the influence of ecology and environmental studies in research areas and topics associated with IK, TEK, and TK, and the influence of public administration and governance studies in research areas and topics associated with Indigenous data studies. Researchers of Indigenous data would benefit from applying a more nuanced and robust vocabulary, one informed by studies of IK, TEK, and TK. Researchers of TEK and TK would benefit from the more people-centered approaches of IK. Researchers and systems designers who work with datasets can practice relational accountability by centering the Indigenous peoples from whom observations are sourced, combining narrative methodologies with computational methods to sustain the holism favored by Indigenous science and the relationality of Indigenous peoples.

Many terms describe Indigenous peoples' creative expressions. These include *Indigenous knowledge* (IK), *traditional ecological knowledge* (TEK), *traditional knowledge* (TK), *local knowledge* (LK), *Native ways of knowing*, and *Native systems of knowledge* among others. A new generation of policy advocates also apply the term *Indigenous data* to identify “any facts, knowledge, or information about a Native nation and its tribal citizens, lands, resources, cultures, and communities” where data is defined as “information ranging from demographic profiles, to educational attainment rates, maps of sacred lands, songs, and social media activities,” as well as “information and knowledge about our environments, tribal citizens and community members, and our cultures, communities, and interests.” (Nickerson 2017; Rainie et al 2017) Previous studies identify the challenges caused by a scientific discourse bearing multiple competing signifiers to describe IK. (Ngulube and Onyancha 2017; Ocholla and Onyancha 2005; Onyancha 2018 et al; Ramos 2018) A disparate terminology deepens disciplinary divides, and makes peer-reviewed publications difficult to organize and find in research databases. Meanwhile, as Indigenous peoples argue for relationality and holism, the techniques of Western science reduce, data-fy, and objectify Indigenous peoples and their biomes. (Agrawal 2002) We thus ask, 1) *How is the term ‘data’ used in the published scientific literature about Indigenous peoples and communities? How do uses of the term ‘data’ relate to established uses of the term ‘knowledge’ as defined in the literature about Indigenous peoples and communities? What patterns and trends are associated with these uses?* and 2) *Is there observable disciplinary divergence in usage of the terms ‘data’ and ‘knowledge’? Is there observable disciplinary divergence in patterns and trends associated with usage of the terms ‘data’ and ‘knowledge’?*

Through a decolonial digital feminist ethics of care approach to topical analysis of records about Indigenous peoples knowledge and data—including network analyses of author-

generated keywords, associated noun phrases, and associated research areas—and content analysis of peer-reviewed studies about Indigenous data, we reveal patterns and trends shaping definitions of Indigenous knowledge and data across research domains. Social graphs show patterns in the convergences and divergences of associated research topics and areas. We interpret results as domain experts, and contextualize the limitations of Indigenous data work and Indigenous knowledge work.

## **Literature Review**

IK is a scientific construct, and as such, depends on a scientific definition of data. As a construct, data is designed to be constantly transformed toward increasing clarity around a line of inquiry. Any single observation is a datum, and, once synthesized into a decodable string of meaning, ‘data’ becomes ‘information,’ indicating an increasing level of mathematical and qualitative complexity. Once parsed, valued, and legitimized, ‘information’ becomes ‘knowledge’, and is most recognizable in their marketable forms as intellectual property. Metadata maintains this life cycle of information; its purpose is to transmit information. This characterization of the relationship between data, information, knowledge, and metadata is best known as the Data-Information-Knowledge (DIK) model, and is integral to the theory and practice of information science (Liew, 2007; Zins, 2007). The DIK model reveals the role of institutions, computing, and individuals in transforming datasets toward increasing degrees of complexity.

Datasets have become ubiquitous in our society. The FBI uses them to track criminal behaviors and suspects. Stockbrokers, advertisers, and entrepreneurs use them to boost sales. Social media platforms gain revenue by selling users’ ‘data doubles.’ Governments and private corporations invest in information and communication technologies to transmit signals. Fields of

study, including genetics, epidemiology, social media studies, machine learning, and artificial intelligence rely on the pervasiveness of datasets for computational methodologies, including datasets created by, for, and about Indigenous peoples.

Prior to the rise of big data, Indigenous thinkers have interrogated bio-colonialism: the techno-scientific habit of categorizing Indigenous ways of relating and being as items, documents, artefacts, relics, or products—kinds of intellectual property—that abet capitalist erasure of Indigenous life. (Harry, 2006) More recently, Indigenous researchers assert Indigenous peoples’ rights to own, access, and regulate datasets made about them, arguing that Indigenous peoples have an inherently data-fied way of being (Carroll et al, 2019). This is a paradigmatic shift from previous arguments that establish Indigenous ways of being as holistic and relational rather than categorical (Archibald 2008; Cajete 2000; Littletree 2019; Meyer 2008; Smith 2012; Wilson 2008). In 2015, a group of Indigenous scholars convened in Australia to discuss Indigenous data sovereignty: “the legal and ethical dimensions around data storage, ownership, access and consent, to intellectual property rights and practical considerations about how data are used in the context of research, policy, and practice.” (Taylor and Kutakai, 2015: 2) Their contributions reflect the experience of Indigenous peoples confronting the technocratic habitus of the English-speaking technologically advanced countries—Canada, Australia, New Zealand, and the United States—where the knowledge theory of value has created a market for all kinds of information packaged and repurposed as ‘data.’

Understanding Indigenous peoples’ historical relationships with the life cycle of information suggests a close relationship between intellectual practices of science and technology and Indigenous peoples’ tactics for navigating technoscientific industries and institutions. It indicates the continuing malleability of ‘data,’ in particular when Indigenous

peoples interpret ‘data,’ ‘information,’ and ‘knowledge’ across technical, political, practical, epistemic, and ontological domains. Indigenous information scientists are keenly aware of the practical implications of these terms (Lee, 2011; Nakata et al, 2005). Ngulube and Onyanchi (2017) identify the inadequacy of indexing and retrieval tools for IK. Onyanchi (2018) attribute this structural inadequacy to “Western rooted knowledge organisation systems [that] do not embrace the contextual, dynamic, holistic and harmonious nature of indigenous knowledge such that often the used terms or information used to describe it compromises it to the extent of the loss of its uniqueness among others.” (157) Researchers who utilize these systems to search for and learn about IK find that they are unable to comprehend the depth of Indigenous peoples’ lived reality as the systems decontextualize Indigenous relationality. This is particularly challenging as research databases are an integral means to trace accounts of Indigeneity (Cooper et al, 2019).

## **Materials and Methods**

We are a team of four Indigenous information and computer scientists with over 15 years apiece of professional and scholarly experience. We conducted this research in accord with a feminist ethics of care, that is, a reliance on our situated knowledge to interpret the systematic and structural impact of colonizing knowledges in which critical analyses of “different kinds of data—implicated at different registers of engagement over time—can ‘turn’ us in practical ways to critically rethink the ongoing intersectional networks of relations, values, and ethical commitments that undergird our research and those of others.” (Gilligan, 1982; Haraway, 1988; Luke and Millette 2018: 4; Tuhiwai Smith, 2012) Unlike retributive justice theories, Gilligan’s (1982) formulation of a feminist ethics of care is relational: to gather the most relevant

information undergirding an unjust scenario one must immerse and locate oneself in it, and then discern the nature of the relationships between relevant actors and issues in order to ascertain corrective responsibility. Our approach is thus inductive and iterative, with our methods functioning like a multi-lensed probe sensing and revealing traces of bodies of literature.

### ***Phase I: Framing Indigenous Information Scientific Constructs of Data and Knowledge***

For over a century, scholars have written about the facets of IK. (Berman, 1971; Hajibayova and Buente, 2017; Lilley, 2015; Littletree and Metoyer, 2015; Moorcroft, 1997; Szekely, 1997) Indigenous approaches to data represent a recent area of investigation, and include critiques of scientific misuses of datasets and the need for tribal research review processes, uses of consumer genetic testing to make claims to Native American ancestry, studies of digital infrastructures and systems, surveillance studies, decolonial approaches to computational methods, and studies of tribal data governance. (Tallbear, 2013; Liboiron, 2015; Murphy, 2016; Vigil-Hayes et al, 2017; Marley et al, 2019; Duarte, 2017; Pulley, 2014; Walter and Anderson, 2013; Tsosie, 2019) For this study, we developed a framework identifying facets of ‘data’ as we have observed its application in projects relating to Indigenous peoples, depicted in the first three columns of Table 1. Through this method, we conceptualized how scholars discursively use the term ‘data’ to signify methodological processes and social and technical phenomena.

### ***Phase II: Curating Sources from Web of Science for Qualitative and Quantitative Analysis***

To get a sense of how our terms appear in the published scientific literature, we searched the Web of Science (WoS) Core Collection for records on the topics of ‘indigenous data,’ ‘indigenous knowledge,’ ‘traditional knowledge,’ and ‘traditional ecological knowledge.’ We



recognize the limitations of using the WoS for citation analysis of an Indigenous subject, in that it reflects a Western representation of IK, and does not index sources integral to Native American and Indigenous studies. Nevertheless, the WoS has been used extensively in previous studies using quantitative citation analysis and is recognized as an essential academic research database as it contains over 20,000 peer-reviewed scholarly journals across the life sciences, biomedical sciences, engineering, social sciences, arts and humanities. The WoS has robust citation analysis capabilities, particularly the ‘Analyze Results’ feature, which we used to identify trends in subject categories, research areas, and journal titles. We considered other citation analysis tools, such as Google Scholar, but these do not have a formal API (application program interface) and block web scraping tools, resulting in incomplete datasets.

Two members of the research team independently searched the WoS Core Collection using the ‘topic’ search field, which includes author-generated keywords, abstracts, titles, and Keywords Plus. The author-generated keywords field is populated by words that authors of articles choose to describe the content of their articles. The Keywords Plus field is populated by a WoS algorithm that identifies noun phrases that frequently occur in each article’s bibliography. The WoS Core Collection does not use a controlled vocabulary except for institutional names. We discussed our results with regard to the number of records per search, trends in journal titles, topical coverage, and associated fields. Three of the datasets (TEK, TK, IK) yielded thousands of records for each search and provided a sufficient number of records for quantitative network analysis. Because ID yielded substantially fewer records - twenty-six total records were found - we decided to instead conduct a content analysis of selected articles from that set of records, which later helped us discern patterns between uses of the terms ‘data’ and ‘knowledge.’ Table 2 depicts the results of our queries and is discussed in the results section below.

### ***Phase III: Modeling Networks of Terms, Research Areas, and Keywords***

We created charts, models, and visualizations produced through statistical and network analyses to inform our interpretation of results produced through the qualitative content analysis of articles about ‘Indigenous data,’ as well as our interpretation of overall findings. To begin, we wrote a script to be able to collect specific sets of records from the WoS through their API. We collected records containing the query terms ‘traditional ecological knowledge,’ ‘traditional knowledge,’ ‘indigenous knowledge’ and ‘indigenous data’ as these were found in the author-generated keywords, abstracts and titles fields of WoS records. This resulted in a total of 8,470 records, which we detail in Table 2. We applied statistical and social network analyses to identify patterns in the uses of TEK, TK, IK, and ID in records obtained from the WoS Core Collection, including a measure of topical overlap, measures of co-occurrence of terms, and a measure of similarity (Jaccard similarity) of uses of terms across fields. To analyze the topics that researchers related to ID, IK, TK, and TEK, we quantified author-generated keywords that co-occurred with noun phrases that appeared in article abstracts, and identified the top 10 noun-phrases in records matching our query terms.

To quantify the extent of topical overlap among datasets garnered through each query, we calculated the Jaccard coefficient for each dataset, that is, the ratio of records that contained one of the query terms as an author-generated keyword over the sum of records that resulted from each query. We further quantified the overlap between the areas of research captured by our queries by calculating the Jaccard similarity (JS) between query terms used in each of the datasets. We then applied the JS to construct relational networks in Gephi, an open source graph visualization software, based on the co-occurrence of several features of the datasets including

author-generated keywords, noun phrases in the abstract, and related areas of research. Specifically, the JS aids in the construction of the distance—or length of the links—between nodes in our relational networks, with the nodes indicating, alternatively, frequency of noun phrases associated with author-generated keywords, and areas of research associated with author-generated keywords.

In order to model how the query terms use different keywords to refer to different topics (as inferred by noun phrases used in the abstract) in our datasets, we constructed a bipartite network using two disjoint sets of nodes: 1) noun phrases used in the abstract and 2) author-generated keywords. A link exists between a keyword and a noun phrase if they co-occur in the same article. We then used the Python NetworkX package to create a projection on the keyword nodes by calculating the JS between the sets of noun phrases associated with each pair of keywords. The more similar the keywords, the more heavily weighted the link between them. We then used the Louvain method for community detection to separate the keywords into classes by maximizing the number of connections between nodes within a class than between nodes of different classes, which, with the aid of Gephi, resulted in a visualization of statistically significant communities of nodes (Blondel 2008). We then used Gephi's palette to color-code nodes according to their class labels, resulting in explorable visual social graphs for each dataset. In addition, we also calculated the betweenness centrality for each node, which represents the probability that a node lies on the shortest path between any pair of nodes in the network. Keywords with a high betweenness centrality represent keywords that are often used alongside a variety of other keywords. Because Gephi is a tool for exploration of social graphs, it was possible for us to run our cursor over the visualizations in Gephi to gain more detail about certain sub-structures within the larger network structures, including specific node features such as

associated noun phrases and research areas. Exploring our graphs (Figure 2 and Figure 3) as a team helped us characterize, narrativize, and prioritize observable and measurable patterns in our datasets. When creating images of the graphs, we used the PageRank algorithm to make nodes with a higher levels of connectivity appear larger (Page et al, 1998).

#### ***Phase IV: Characterizing Uses of ‘Data’ through Content Analysis***

Three members of the research team independently reviewed 17 of the 26 total articles that contained the phrase ‘Indigenous data’ and that claimed to be about ‘Indigenous data’ with a focus on research about Indigenous issues in North America. We co-created a list of uses of the term ‘data’ as they appeared across this dataset, and noted relevant fragments such as phrases, sentences, institutional affiliations, methodologies, and values statements. We discussed our findings as a group, and fitted these into the framework identifying facets of ‘data.’ (Table 1) This helped us discern features shaping the ontological relationship between uses of the term ‘data’ and uses of the term ‘knowledge’ as defined in the literature about Indigenous peoples.

#### ***Phase V: Interpretive Comparison of Qualitative and Quantitative Approaches***

Finally, we compared the results of overall quantitative analyses with qualitative content analysis of uses of the term ‘indigenous data.’ We interpreted results in light of relationality as an Indigenous way of knowing, as well as domain knowledge in the fields of information science and computer science.

## **Results**

We cycled through the phases of our methods iteratively, continuously shaping and refining our results, as we isolated the most significant findings with regard to our research questions. The results of our analyses are therefore presented in the order of their statistical significance and most impactful qualitative meaning.

*With regard to Indigenous peoples, the term 'data' is used ambiguously and inconsistently in the published scientific literature.*

Qualitative review of 17 peer reviewed research papers about 'Indigenous data' reveal data, information, and knowledge are used interchangeably. 'Data' is often conflated in meaning, and can refer to objects such as datasets, processes such as communication flows, and historical conditions. It is used in relationship to the concept of sovereignty, but without contextualizing how it relates to specific governance processes in the case of legal and political sovereignty or relationality in the case of inherent sovereignty.

Content analysis of the term 'data' throughout the 17 articles reveals at least 29 distinct and nuanced uses of the term, which are detailed in the last column of Table 1. When we fit the uses of the term 'data' from the 17 articles in with the facets of data and characteristic features noted by Indigenous and decolonial scholars, we note that many of the terms relate to six facets of data. Table 1 provides an overview of the six facets we found in the 17 articles along with the associated uses of the term 'data.' *Data as object* uses signify the isolation of observations into malleable objects intended for further scientific analysis. *Data as property* uses signify a piece of property that pertains to, is sourced from, or originates from a polity, whether that be an Indigenous people or a nation-state government, and which requires that context to be precisely and accurately deciphered. *Data as structural element* uses signify the cyclical complexification of message and meaning leading to the crystallization of knowledge. *Data as historical condition*

uses signify social, historical, and political conditions. *Data as surveillance* uses signify the acquisition and preparation of observations through the use of informants or other intermediaries for the purpose of creating context-specific frameworks to aid in governmental tracking. *Data as process of analysis* uses signify statistical and social scientific methods to manipulate datasets for the purpose of answering research questions. We also note that none of the 17 articles use the term ‘data’ as characterized by eight of the facets of data in our framework: data as research, data as a way of knowing, data as technology, data as infrastructure, data as story, data as kinship, and data as subject.

Content analysis reveals that the term ‘data’ is often used to refer to ‘datasets,’ and that the field of demography strongly influences usage of the phrase ‘Indigenous data.’ ‘Data’ is often qualified, making it a signifier for a process, rather than an object. It is also not uncommon to find sentences that use the term multiple times to signify different meanings, such as in the following: “Another important element of the data regime is to recognise that ‘data’ is both qualitative and quantitative and both must be considered valid and equally important data sources.” (Wilks, 2018: 11)

Content analysis of articles about ‘Indigenous data’ also reveals infrequent citation of the scholarly literature on American Indian sovereignty and almost no citation of scholars of IK or Native ways of knowing.

*‘Indigenous data’ is a relatively new construct designed to support informed governance of Indigenous peoples.*

Content analysis also revealed a range of social values about the construct of ‘data.’ There appeared to be an assumption that datasets pre-exist and need only to be gathered by an Indigenous informant. The assumption is that once gathered, the datasets can be fitted into a kind

of framework that a government or non-governmental organization can apply to determine factors shaping the lives of Indigenous peoples at scale resulting in better ‘data outcomes.’ There are assumptions that ‘Indigenous data’ helps national governments assess services for resident Indigenous peoples, allowing Indigenous peoples to ‘speak back’ to the state with statistical evidence. There are assumptions that ‘Indigenous data’ is a counter to the “colonizing and deficit-based narratives” that further marginalize Indigenous people (Walter et al 2018; Wilks et al 2018). There are assumptions that national governments and supranational organizations need Indigenous data to guide decision-making and inform policy, and that supranational organizations such as the World Health Organization and the United Nations best establish indicators of wellbeing. On the other hand, there were also strong statements about how Indigenous people distrust data collection due to Western scientific practices of extraction. In sum, qualitative analysis reveals that ID is a euphemism for ‘national demographic measures about resident Indigenous populations as comparable to existing demographic measures about resident non-Indigenous populations.’ (Abu-Saad, 2016; Anderson et al, 2016; Davis, et al, 2009; Liebler, 2018 ) We also noted that ID is most often used to describe data that has been collected *about* a population rather than data that has been collected through the application of Indigenous research methodologies.

*With regard to Indigenous peoples, uses of the terms ‘data’ and ‘knowledge’ are strongly influenced by differences in disciplines and fields, with ecology and environmental studies relying on the term ‘knowledge.’ IK and TK function as a paradigmatic boundary-spanners, allowing for convergences across disparate research areas.*

Qualitative review of records based on queries in WoS revealed that TK (3,266), IK (2,907), and TEK (453) appeared in abstracts and titles at far greater rates than ID (52). Table 3

shows the top 5 journals retrieved from WoS queries on the topics of TEK, IK, TK, and ID. TEK, IK and TK appeared far more in titles associated with biology, environmental studies, ecology, ethnobotany, and pharmacy studies; further qualitative review of the titles and abstracts show the influence of economic development, capitalist enterprise, and modernization studies associated with these terms. ID appears to be a term emerging in titles associated with policy and governance with titles and abstracts reflecting association with the fields of public administration and governance.

Review of the top author generated keywords co-occurring with IK, TK, and TEK reveals the influence of ethnobotany and sustainability sciences, whereas the top keywords co-occurring with ID reveals the influence of public policy studies and quantitative social science (Figure 1, and Supplemental Materials Figures 4, 5, and 6). For all query terms except ID, the query term was also the top author-generated keyword. We observed differences in topical focus as well, with IK, TK, and TEK associated more often with issues such as climate change, conservation and biodiversity, and ID associated more with public administration.

We observe significant overlap with respect to our query terms matching up with the top author-generated keywords associated with each of the records. To get a better sense of how authors might be using these terms in a more intentional manner, and to remain consistent with our iterative method of analysis, we further filtered records in each dataset to include only records that include the query term in the author-generated keywords. This reduces the ID dataset to 2 entries; the IK dataset to 1,067 entries; the TK dataset to 941 entries; and the TEK dataset to 417 entries. That the ID dataset is reduced so dramatically points to the relative novelty of the term.



To further quantify the extent of topical overlap, we calculated the portion of records that contained any of our query terms in the body of the article record and that also contained one of the query terms as an author-generated keyword (Figure 2). While our calculation shows that the most frequent keyword/query term coincidence occurs when the query term matches the author-generated keyword, we also note significant overlap between IK, TK, and TEK with very little coincidence between ID and any of the other query terms, indicating the relative isolation of the term ID in the broader literature. Figure 2 depicts side-by-side comparisons of the structural differences among social graphs comprised of author-generated keywords associated with ID (80), TEK (3,313), IK (7,556), and TK (9,154).

Figure 2 also represents the author-generated keywords in the records associated with ‘Indigenous data’ as well as the top five keywords associated with the search (‘indigenous,’ ‘indigenous data sovereignty,’ ‘american indian and alaska native,’ ‘indigenous people,’ ‘qualitative data’). For the ID dataset, we note that the emphasis on the word ‘indigenous’ contrasts significantly with the other datasets, also detailed in Figure 2, which rather emphasize issues such as climate change, environmental governance, and health. We also note that the ID dataset emphasizes populations of indigenous human beings more than the other datasets. (Supplemental Figure 4) Unlike the IK dataset, the TEK dataset of the author-generated keywords in the records associated with ‘traditional ecological knowledge’ is less densely clustered, although betweenness is more evenly dispersed among topics that comprise the TEK body of literature. (Supplemental Figure 5) Interestingly, ‘indigenous knowledge’ did not appear with much influence, though ‘traditional ecological knowledge’ did appear in the IK dataset. (Figure 2) This indicates topical difference in the terms IK and TEK, where TEK has less

overlap with Indigenous methodologies and Indigenous studies, and more overlap with matters of governance.

The structure of the graph representing the author-generated keywords associated with TK, 'traditional knowledge,' is similar to the structure of the graph associated with TEK, indicating similar degree of cohesion and integration of satellite topics. (Figure 2) Similar to the TEK graph, the TK graph centers on climate issues, but is noticeably lacking in reference to issues of governance. (Supplemental Figure 6)

We also used the bipartite network methodology to examine how *different research areas* use similar author-generated keyword groupings. By visually and collectively comparing the networks for each dataset, we were able to identify critical differences in the research areas that tend to use the query terms, and how research areas cluster together based on how closely their keywords align. In these networks, nodes represent research areas which tend to be closely related to many other fields in terms of using similar author-generated keywords (i.e., they have a significant overlap in the author-generated keywords used by papers in other research areas) *and* they tend to be linked to research areas that also have significant author-generated keyword overlap with other areas.

The ID research areas, as shown in Figure 3, form separate groupings with no overlap between the distinct research areas, which is perhaps an indication of the newness of the topic of 'indigenous data,' such that no one field or discipline represents a sizable amount of records about the topic and that various fields and disciplines have not yet had time to collaborate around the ID research area. The earliest article related to ID is dated 2009 (Davis et al), with the bulk of scholarship being published beginning in 2015. We examine the top research areas that emerged in the bipartite network projection between the topic of IK and affiliated research areas (the

largest image in Figure 3). We observe several discernable clusters, with the top five clusters including sociology, engineering, development studies, public administration, and social sciences—other disciplines, and smaller clusters distributed across a range of research areas, from microbiology to women’s studies to physical geography and demography. This is an indication of the relevance of IK as a paradigm--a way of seeing phenomena about the known universe--rather than as a discrete subject or discipline, and is also an indication of the boundary-spanning function of studies of IK, as the topic stimulates unexpected convergences across otherwise divergent disciplines.

Comparatively, the research areas affiliated with the TEK dataset are dispersed across fewer fields and disciplines. SM Figure 2 shows that the research areas affiliated with TEK are largely shaped by environmental studies in combination with social sciences such as anthropology and sociology. The network model of research areas affiliated with the TEK dataset, reveals the relative influence of the fields of sociology, anthropology, and development studies.

Interestingly, the network model showing research areas affiliated with TK, again, detailed in SM Figure 3, is more similar to the network model of research areas affiliated with IK, with a densely clustered core of research areas. Similar to the IK model, the topic of TK appears to function as a boundary-spanner, with a wide range of research areas applying TK, from biotechnology to behavioral science and zoology. Unlike the records gathered through the IK query, the records gathered from the TK query are not necessarily about Indigenous peoples or their creative expressions, but rather signify a kind of knowledge that is either not yet automated or technicized, or that, due to its process of manifesting is dependent on pre-industrial, pre-technological, or non-industrial or non-technological ways of life. It is thus not

surprising to see ‘public administration’ and ‘development studies’ in the highly ranked TK research areas, as the pursuit of many nation-states in the technologically advancing countries is to ‘modernize’ the pre-industrial ways of life of its denizens. Similar to the TEK research areas, TK is shaped by environmental studies, though not to the same degree, as the network model reveals the relatively stronger pervasiveness of social science in the literature.

In sum, these results reveal the interplay of literature on the topics of IK, TEK, and TK, with the relatively new sub-field of ID emerging through the increasing availability of statistically significant datasets *about* Indigenous peoples, and occurring alongside larger more cohesive bodies of literature about the relationship between environmental changes and human ways of knowing, Indigenous ways of knowing, and non-industrial ways of knowing. The thread of industrialization, governance, and development theory winds through the entire corpus of records.

## **Discussion**

In their application of a feminist ethics of care to the study of big data, Luka and Millette (2018) assert that, “data can never fully represent reality, although data analyses provide pathways to help understand the world within which we live.” (Luka and Millette, 2018: 2) In this investigation, we discerned scholarly uses of the term ‘data’ with regard to Indigenous peoples, and then depicted those findings against the backdrop of much larger bodies of literature on the topic of ‘knowledge’ in Indigenous contexts. Our analyses reveal how researchers evoke nebulous uses of the word ‘data’ to fit the conventions of their respective fields of study and the needs of their research projects, especially as it pertains to the measurement and surveillance of Indigenous populations. Biocolonialism appears in the literature around IK, TEK, and TK as

author-generated keywords referencing the extraction of natural resources and methods from Indigenous peoples while Indigenous peoples continue to experience displacement and dispossession due to industrialization, climate change, and economic wars. As such, we suggest that even the most comprehensive datasets cannot represent the complex realities of Indigenous peoples; instead, they represent the questions that researchers ask.

Researchers of ID may benefit from additional grounding in the IK and TEK bodies of literature, as these relate to environmental change and as ID bears more of a focus on the governance of Indigenous populations. Researchers of IK would also benefit from examining the co-creation and management of TK by non-Indigenous populations, in particular with regard to the outcomes of development theory and the treatment of biomes. Similarly, researchers of TK and TEK would benefit from investigating how Indigenous sovereignty movements pursue rights and ownership of *knowledge as property* and *data as property*, as well as claims to privacy, security, and ownership of *knowledge as process* and *data as process*. Proponents of Indigenous data sovereignty would also benefit from applying a more nuanced vocabulary, one that effectively places the Indigenous data sovereignty movement into conversation with the discourse and policies that already shape the IK and TK paradigms, especially regarding intellectual property practice and law. A refined vocabulary would also allow the Indigenous data sovereignty movement to become more ontologically robust, contributing to the epistemic stakes of Indigenous science, a paradigm that redefines how we think we know the universe around us, especially as we find ourselves in landscapes shaped by climate change, industrialization, and technicization.

## **Perspectives**

One aspect of Indigenous science that is not revealed through our methodological lens is that of relationality. According to relationality, all phenomena can be investigated through consideration and thick description of the relationships that form the ecology of belonging around all objects, ideas, and beings. (Wilson, 2008). Through Indigenous methodologies, we are accountable to the relationships we make as we ask questions on behalf of, collect observations from, and disseminate knowledge about Indigenous communities. Accordingly, Tsosie's (2019) conclusions regarding "tribal data," indicate the importance of practicing cultural sovereignty as we make plans for protecting our land, resources, and culture for the benefit of the seventh generation.

That 'drought' is the most prominent author-generated keyword in the TK dataset offers an unexpected insight (Figure 2). More than a node in a graph, the keyword 'drought' represents thousands of hours of research, millions of dollars in grant funding, and many researchers working through their institutions to solve the world's water crisis through the application of TK. When it comes to wicked problems like climate change, environmental damage, and disproportionate numbers of missing and murdered Indigenous women, we cannot expect datasets alone to generate solutions. We need conscientious deliberation with individuals and groups from the most affected communities.

Relationality demands accountability and responsiveness. For a system designer or researcher working with datasets, this would mean being accountable to the communities and landscapes from which observations were acquired. Scientists, information professionals and programmers need to humanize their processes, creating relationships to discern reality rather than depicting reality through rendering the trace evidence. Advocates of 'Indigenous data' in particular would benefit from Indigenous approaches to library and information management,

where care is taken to consider the relationality embedded in creating, storing, using, protecting, and preserving the creative expressions of Indigenous peoples particularly as these expressions move from our families and communities into institutions through various formats.

Methodologically, to avoid reductivism, such an approach means combining narrative techniques such as storywork with statistical and computational methods, and practicing a critical reflexive approach to the ‘silver bullet’ ethos shaping solutions informed by access to large datasets.

Still, in its very malleability, *data as structural element* offers scientists hope in the form of empirical evidence; there is persuasive power in the dataset. A sophisticated understanding of the semantic and ontological relationship between data, information, and knowledge as these emerge in the context of Indigeneity will likely produce new conceptual frameworks, methodologies, and metatheory. Next steps include tracing the theoretical collaborations of scholars who work with data and knowledge for the advancement of Indigenous peoples and biomes. Investigating their trajectories could shine a light on their reasons for pursuing certain constructs, reasons which may be tactical and strategic given the power of the techno-scientific industry.

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**Table 1. Facets of Data and Characteristic Features as Noted by Indigenous and Decolonial Scholars**

<b>Facet of Data</b>	<b>Definition</b>	<b>Indigenous and Decolonial Scholars</b>	<b>Uses of the terms that included ‘data’ as identified in 17 WOS articles</b>
<i>Data as object</i>	A set of scientific observations, plural for datum, shorthand for datasets	Walter and Anderson, 2013	data items; local data
<i>Data as property</i>	A set of information that an authorized community of users recognizes as IK, TK, TEK; proprietary, commensurate with intellectual property and private property claims	Harry and Kaneche, 2006; Dei, 1999; Marley et al, 2019; Taylor and Kukatai, 2016	data sources; data collection dependency [on local knowledge]; decolonized Indigenous data framework; data analysis dependency [on local knowledge]; data interpretation dependency [on tribal participation]; Indigenous data identifiers; data ownership; data stewardship; Indigenous data jurisdiction; data protocols; local data; data usefulness [for

			Indigenous communities]; administrative data
<i>Data as structural element</i>	A part of a cycle of increasing complexity tending toward the construction and circulation of information, the co-construction of knowledge, and the emergence of metadata	Shannon and Weaver, 1963	data quality; data consistency; data integrity; data accuracy; data aggregation/disaggregation; culturally-informed data quality framework; decolonized Indigenous data framework; data analysis dependency [on local knowledge]; data interpretation dependency [on tribal participation]; local data; historical data; modern data; accessible sources of data
<i>Data as research</i>	A field of study, i.e. data science, Indigenous data science, Indigenous informatics	Dei, 1999; Ngulube and Onyancha, 2011; Onyancha et al, 2016	None found

<i>Data as way of knowing</i>	A haptic, sensory or phenomenological relationship with data, i.e. Indigenous design experience of videogaming, coding, augmented reality, Indigenous user experience	LaPensee, 2017; Pulley, 2014	None found
<i>Data as technology</i>	A feature of a techno-scientific industry, a social construct of a particular era and assemblage of actors	Duarte, 2017; Murphy, 2016	None found
<i>Data as historical condition</i>	A shorthand for a particular historical and ideological moment; 'Big Data'	Duarte, 2017; Carlson, 2019	historical data; modern data
<i>Data as infrastructure</i>	An integral feature in the material structure of	Duarte, 2017	None found

	telecommunications devices, ie. ‘data plan’		
<i>Data as surveillance</i>	The discrete parts of human intelligence and signals intelligence labor, tending toward the construction of actionable information by governments or organizations	Browne, 2015; Noble, 2018	data sources; data availability; data accessibility; data collection dependency [on local knowledge]; data collection frameworks; culturally-informed data quality framework; decolonized Indigenous data framework; data interpretation dependency [on tribal participation]; Indigenous data identifiers; Indigenous data jurisdiction; local data; data usefulness [for Indigenous communities]; data risks; historical data; modern data; administrative data; data regime
<i>Data as process of analysis</i>	A methodological approach, such as a dataset or a process of datafication needed to conduct Indigenous	Walter and Anderson, 2013; Vigil-Hayes et al, 2017	benchmark data; data consistency; data accuracy; data definitions; data comparability; data collection frameworks; culturally-informed data quality framework;



	network analysis or Indigenous statistical analysis		decolonized Indigenous data framework; data analysis dependency; data interpretation dependency; Indigenous data identifier; local data; data gaps (Feir and Handcock, 2016)
<i>Data as story</i>	A crafting of narratives of the world through data	Pulley, 2014	None found
<i>Data as kinship</i>	A mapping of ways we relate to one another; genetic information; genealogy	Tallbear, 2013	None found
<i>Data as subject</i>	The data in itself tells us something beyond its use as an object of manipulation; meta- analysis of data types, datasets, and information	Doyle, 2013; Liboiron, 2015; Nakata, 2007	None found

**Table 2. Overview of Datasets Used for Quantitative Network Analysis**

	<b>Number of articles</b>	<b>Number of authors</b>	<b>Number of journals</b>	<b>Number of affiliations</b>	<b>Number of topics</b>
<b>Indigenous Data</b>	31	128	26	28	25
<b>Indigenous Knowledge</b>	3,420	7,930	1,310	3,263	113
<b>Traditional Knowledge</b>	3,860	10,387	1,570	3,711	131
<b>Traditional Ecological Knowledge</b>	1,159	3,252	384	1,128	71

**Table 3. Top 5 Journals Retrieved from WoS Queries**

‘Traditional Ecological Knowledge’ (453 records)	‘Indigenous Knowledge’ (2907 records)	‘Traditional Knowledge’ (3266 records)	‘Indigenous Data’ (52 records)
<i>Ecology and Society</i> (11.5%); <i>Human Ecology</i> (5.5%); <i>Journal of Ethnobiology and Ethnomedicine</i> (3.4 %); <i>Arctic</i> (2.8%); <i>Ecological Applications</i> (2.8%)	<i>Indian Journal of Traditional Knowledge</i> (4.6%); <i>Journal of Ethnobiology and Ethnomedicine</i> (3.3%); <i>Journal of Ethnopharmacology</i> (3.2%); <i>Ecology and Society</i> (2.1%); <i>Human Ecology</i> (1.8%)	<i>Indian Journal of Traditional Knowledge</i> (7.4%); <i>Journal of Ethnopharmacology</i> (7.3%); <i>Journal of Ethnobiology and Ethnomedicine</i> (6.3%); <i>Economic Botany</i> (1.8%); <i>Arctic</i> (1.6%)	<i>Lancet</i> (2.7%); <i>Aboriginal Policy Studies</i> (3.9%); <i>Agroforestry Systems</i> (3.9%); <i>American Behavioral Scientist</i> (3.9%); <i>American Journal of Public Health</i> (3.9%);

## Figure Captions

**Figure 1.** Top 10 co-occurring keywords associated with records that matched each of our search terms.

**Figure 2.** Author-generated keywords in records containing ID, IK, TK, and TEK. The graphs for IK, TK, and TEK reveals densely clustered centers surrounded by an array of smaller, disconnected satellites of keyword clusters, indicating cohesion in the topics comprising the central body of literature about IK, TK, and TEK orbited by a loosely associated set of topics influenced by environmental studies. For IK, top 5 keywords are ecosystem services, indigenous methodologies, karnataka, traditional ecological knowledge, and indigenous studies. For ID, the largest node forms around the keyword ‘indigenous.’ The high betweenness associated with ‘indigenous’ and its position as a bridge between nodes from different classes demonstrates its role as a term that is used to connect what might be disparate topics. We report basic statistics for each network in gray boxes, including the number of nodes ( $N$ ), number of links ( $L$ ), density ( $D$ ), modularity ( $M$ ), average clustering coefficient ( $\langle C \rangle$ ), average degree ( $\langle k \rangle$ ), and standard deviation of degree.

**Figure 3.** Top research areas that emerged in the bipartite network model between the selected topics (ID, IK, TK, and TEK) and affiliated research areas. Here we note a well-defined core of research areas for IK, TK, and TEK, with IK demonstrating tight integration between topics such as sociology, medicine, public administration, and engineering. For IK, top research areas are sociology, engineering, development studies, public administration, and social sciences—other disciplines. Conversely, ID has relatively few affiliated research areas, most of which are

focused on medicine. Top keywords and node sizes are determined using the PageRank algorithm. We report basic statistics for each network in gray boxes, including the number of nodes ( $N$ ), number of links ( $L$ ), density ( $D$ ), modularity ( $M$ ), average clustering coefficient ( $\langle C \rangle$ ), average degree ( $\langle k \rangle$ ), and standard deviation of degree.

**Supplementary Figure S1.** Graph of the top research areas that emerged in the bipartite network model between ID and affiliated research areas.

**Supplementary Figure S2.** Graph of the top research areas that emerged in the bipartite network model between TEK and affiliated research areas.

**Supplementary Figure S3.** Graph of the top research areas that emerged in the bipartite network model between TK and affiliated research areas.

**Supplementary Figure S4.** Graph of the author-generated keywords in records containing ID.

**Supplementary Figure S5.** Graph of the author-generated keywords in records containing TEK.

**Supplementary Figure S6.** Graph of the author-generated keywords in records containing TK.

Figure 1.

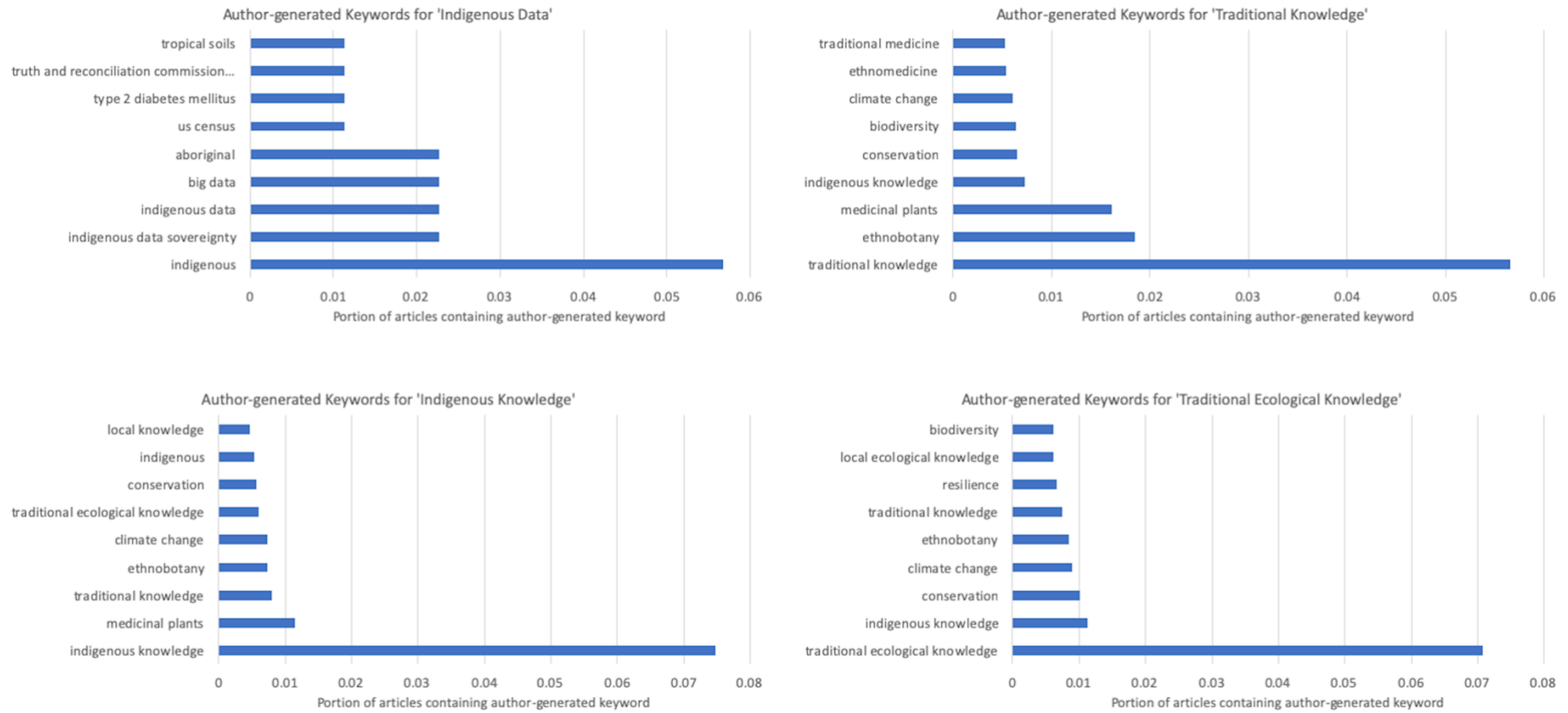


Figure 2.

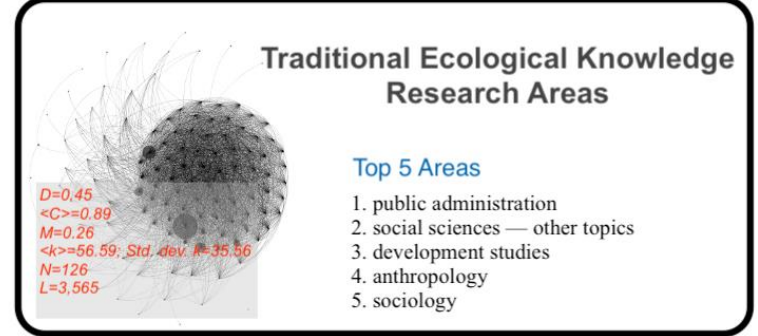
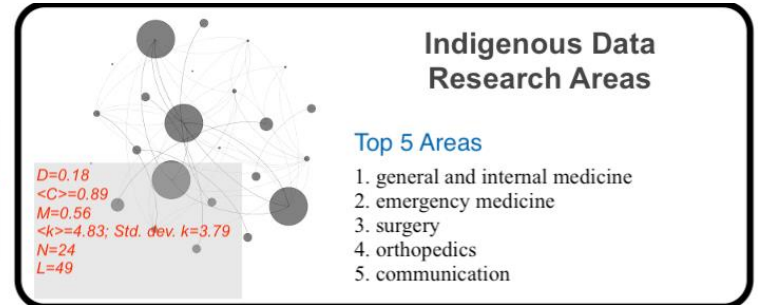
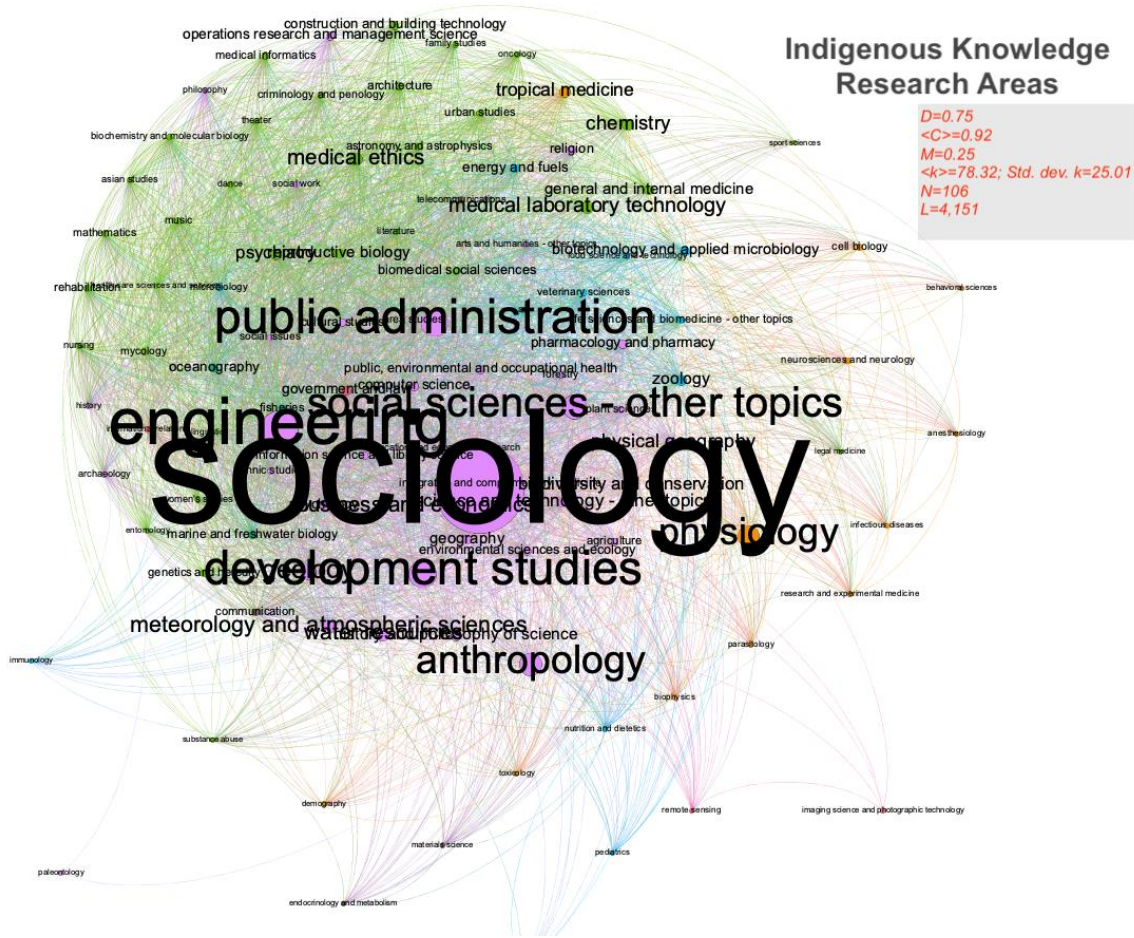
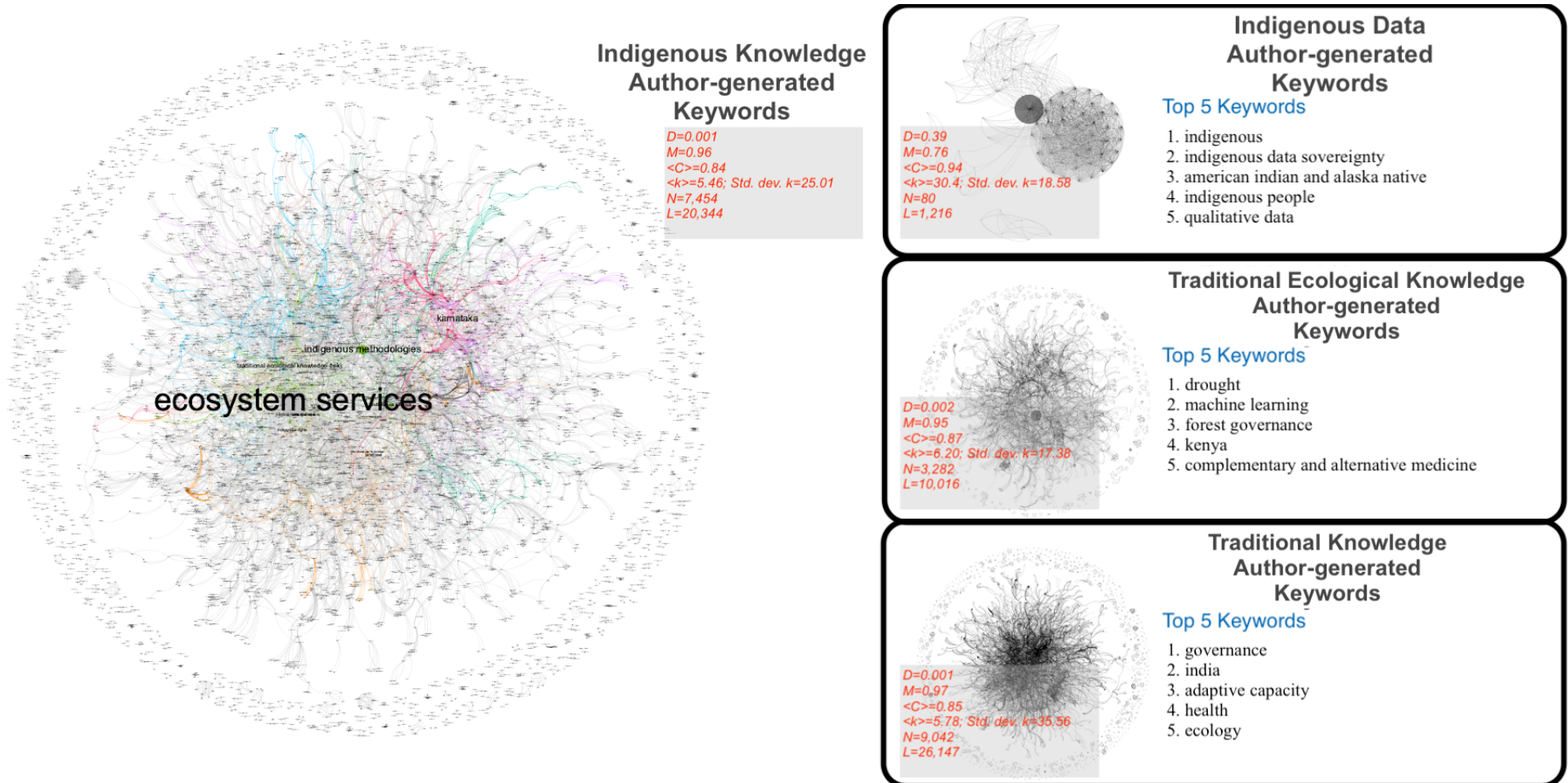
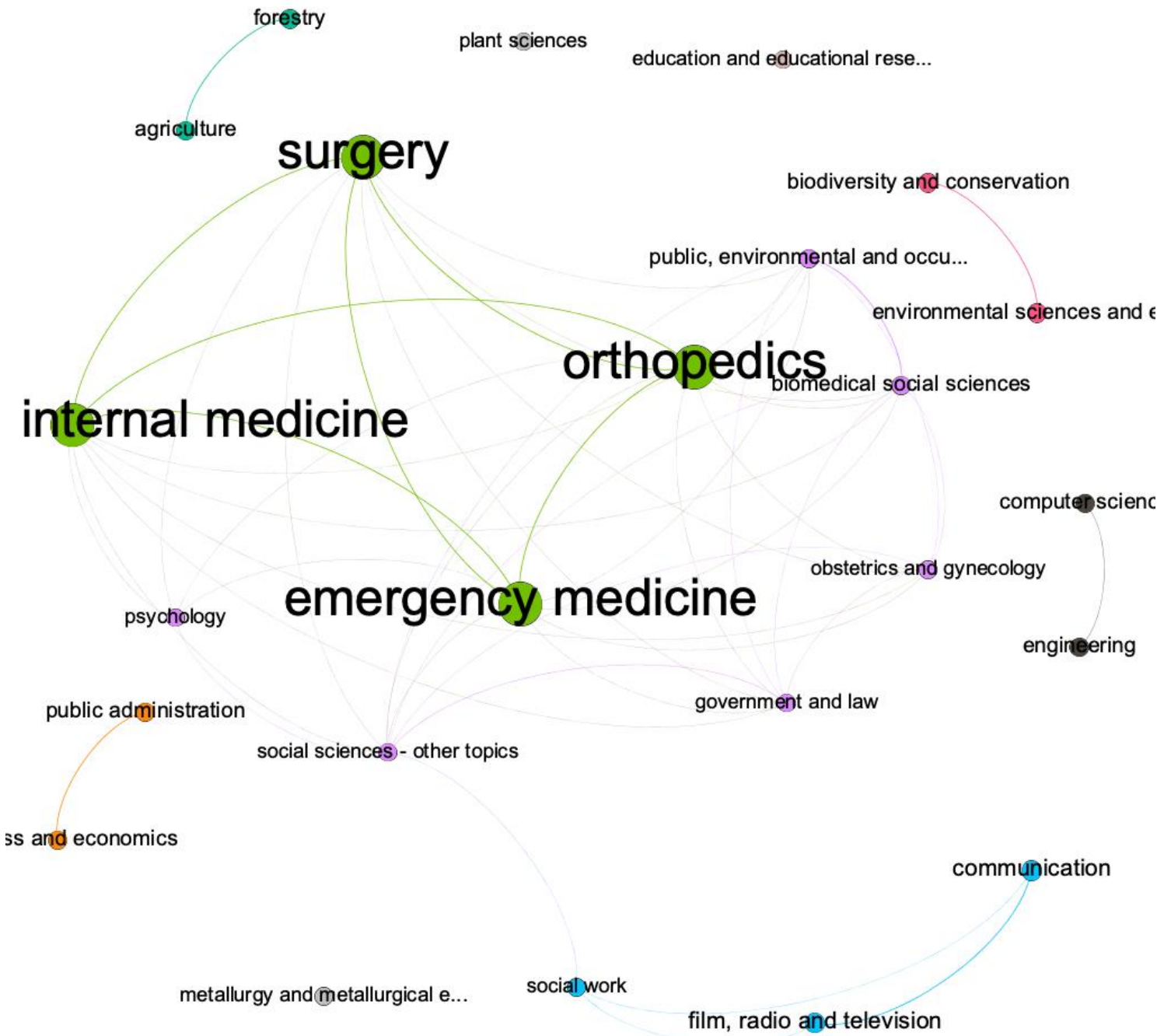


Figure 3.

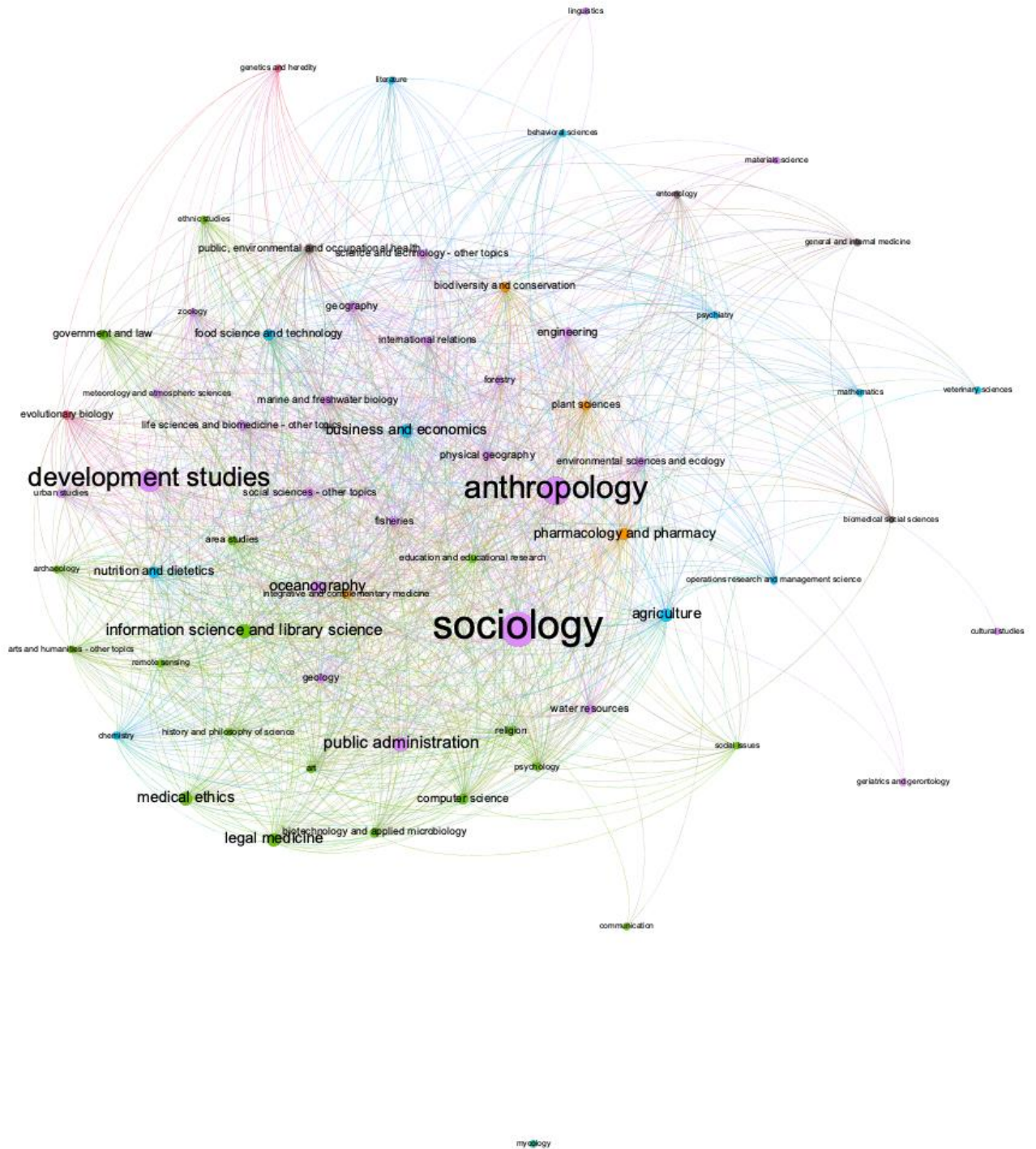




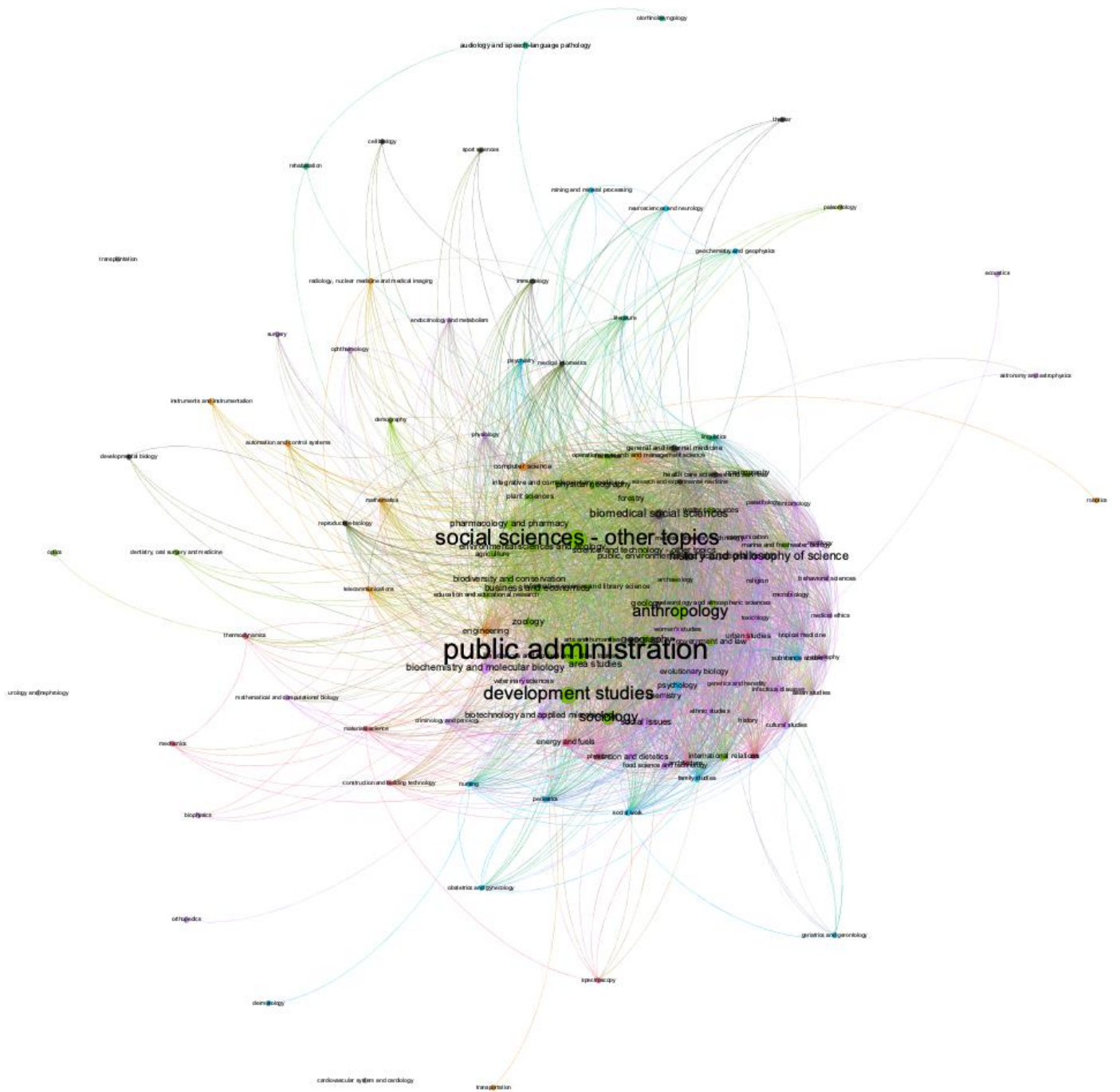
Supplementary Figure S1.



## Supplementary Figure S2.

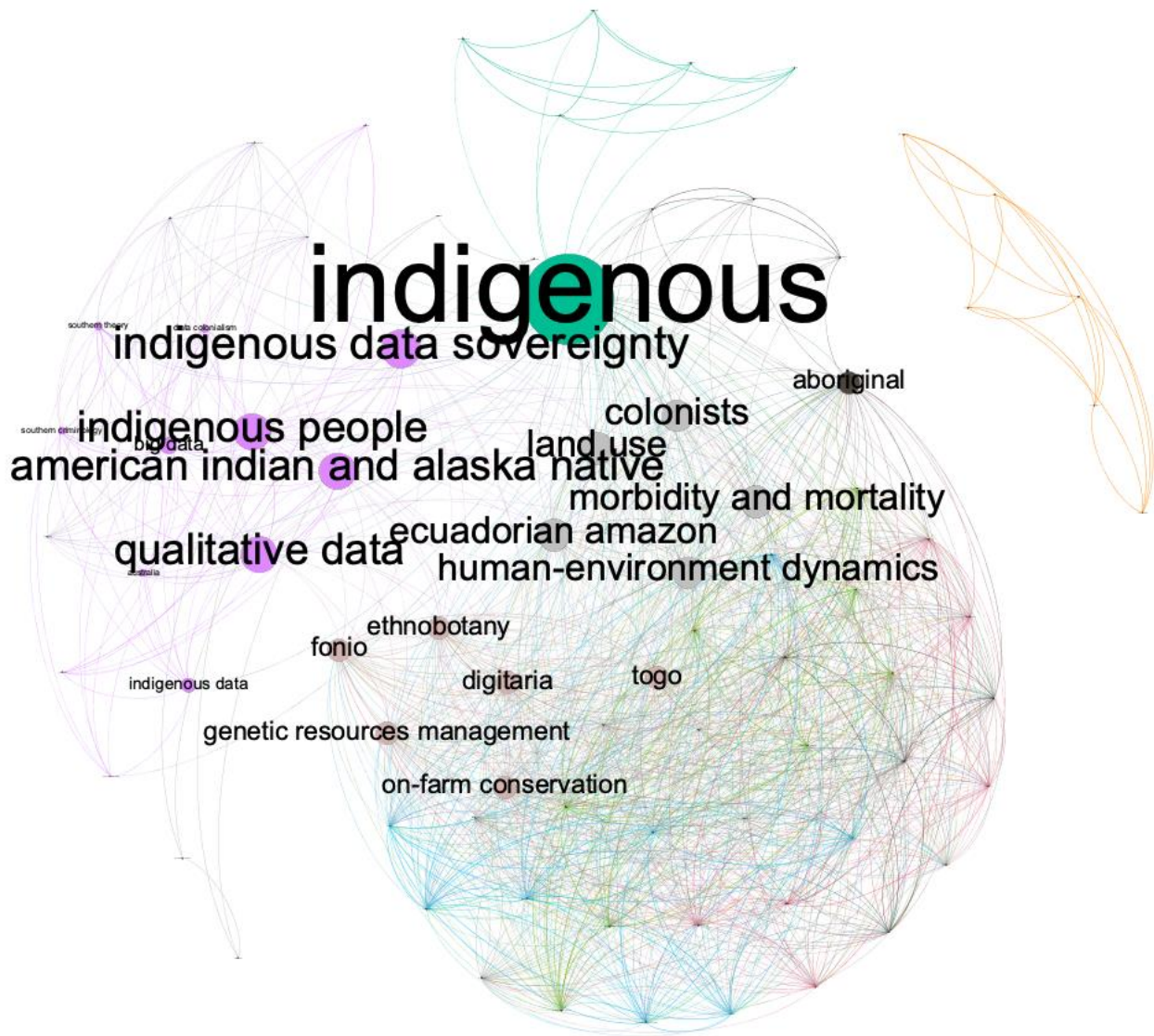


# Supplementary Figure S3.

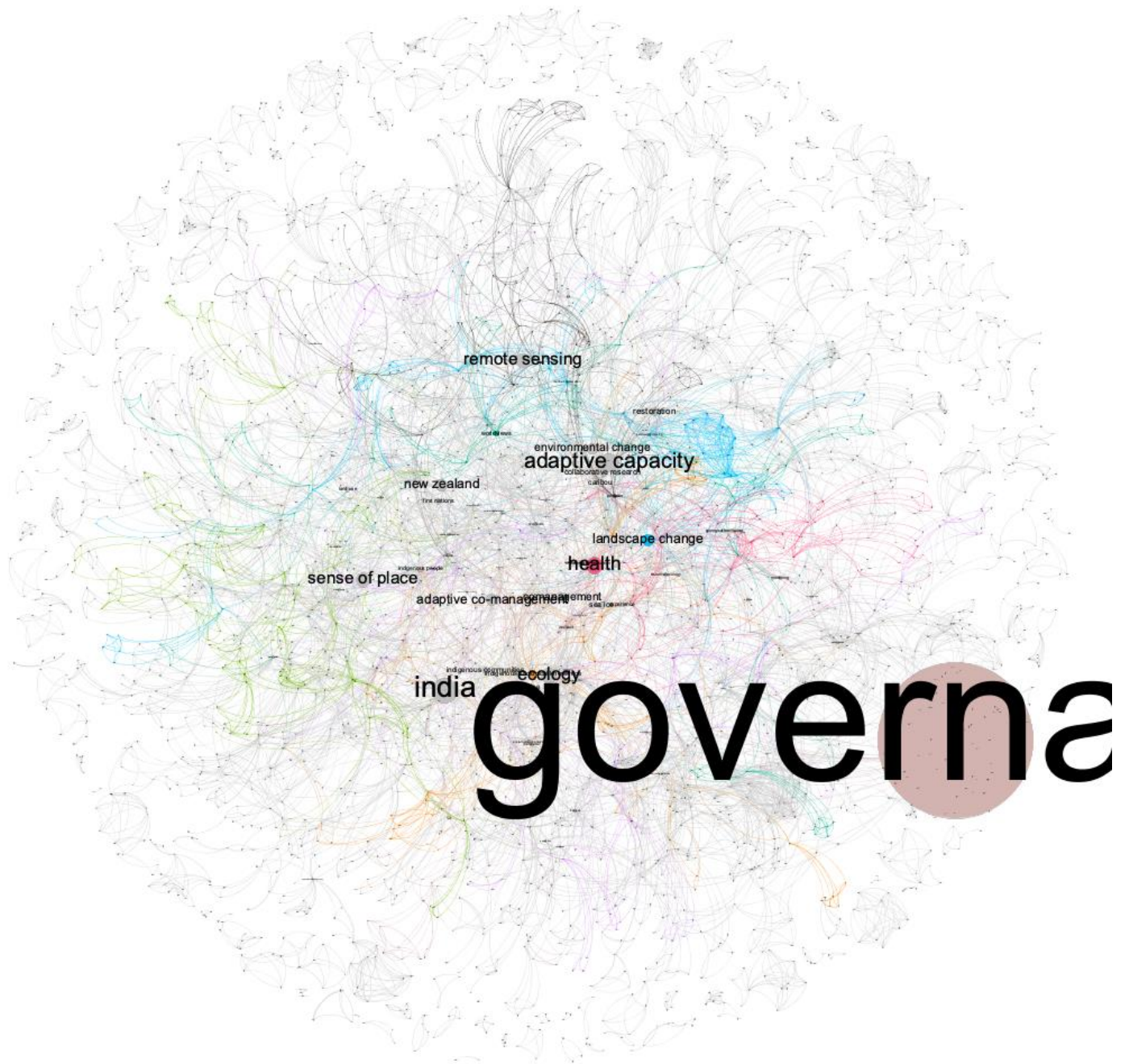




Supplementary Figure S4.



Supplementary Figure S5.





Supplementary Figure S6.

