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Network Embedding for Understanding the National Park System through the Lenses of News Media, Scientific Communication, and Biogeography

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The U.S. National Parks encompass a variety of biophysical and historical resources important for national cultural heritage. Yet how these resources are socially constructed often depends on the beholder. Parks tend to be conceptualized according to their (fixed) geographic context, so our understanding of this system of systems is dominated by this geographic lens. To expose the systemic structure that exists beyond their geographic embedding, we analyze three representations of the National Park System using park–park similarity networks according to their cooccurrence in (1) about 423,000 news media articles; (2) about 11,000 research publications; and (3) about 60,000 species inhabiting parks. We quantify structural variation between network representations by leveraging similarity measures at different scales: park level (park–park correlations) and system level (network communities' consistency). Because parks are governed and experienced at multiple scales, cross-network comparison informs how management should account for the varying objectives and constraints that dominate at each scale. Our results identify an interesting paradox: Whereas park-level correlations depend strongly on the representative lens, the network communities are remarkably robust and consistent with the underlying geographic embedding. Our data-driven methodology is generalizable to other geographically embedded socioenvironmental systems and supports the holistic analysis of systems-level structure that might elude other approaches. *Key Words: national parks, National Park Service, network analysis, protected area systems, system of systems.*

The U.S. National Parks (NPs) are representative pieces of North American natural and cultural heritage, where managers, visitors, and many other stakeholders can experience the NPs' wonders and contribute to their conservation. Ecological complexity and its geographical embedding are frequently seen as keystone elements of NPs management, whereas social complexity is often overlooked despite the challenges it poses for NPs managers, especially in light of the NPs' dual mandate to preserve nature and facilitate visitation (Sellars 1997; Earle 2009; Jenkins 2022). Addressing social complexity involves considering the multiplicity of attitudes of diverse stakeholders (Ogunjinmi, Onadeko, and Ogunjinmi 2013; Mangachena and Pickering 2021). For example, decision-making in NPs should consider the "best available science" and social concerns (Harmon 1999; Manning et al. 2016; Jenkins et al. 2021), even when they contradict each other. Although studies have addressed attitudes' multiplicity regarding NPs by evaluating how NPs are framed in social media (Simeunovic-Bajic 2011; Mangachena and Pickering 2021; Marcotte and Stokowski 2021), they seldom evaluate systemically how framings and representations vary across stakeholders, a valuable resource to inform NP policy and communication. This study leverages network analysis to explore the interrelation of three different NP representations (i.e., scientific research, mass media, and biodiversity) and their implications for NP management.

Historically, NPs management has been challenged by different societal sectors given that NPs' dual mandate rarely implies satisfactory outcomes for everyone (Lemons 2010). The diversity of management preferences regarding NPs might promote

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disagreement and controversy, which could explain long-lasting division between NPs management, science, and the public (Sellars 1997; Franklin 2001; Arroyave, Romero, et al. 2021). For instance, some NPs policies (e.g., predator control) might satisfy the interests of some publics while being scientifically unsound, whereas others (e.g., prescribed fire) might adhere to the best available science and nevertheless invoke societal discomfort (Sellars 1997). We argue that such divergence in preferences underlays how different stakeholders frame NPs.

How phenomena such as NPs are framed depends on internal (e.g., preconceptions, experiences, interests) and external conditions (e.g., funding, institutional agendas, bureaucratic barriers). Such conditions steer how NPs are experienced, known, and felt (Simeunovic-Bajic 2011; Brossard 2013; Peters 2013; Lazer et al. 2018; Toivonen et al. 2019). For instance, framing NPs from a particular academic lens is influenced by existing knowledge, physical and financial capabilities, scientific hierarchies, and agendas (Arroyave, Romero, et al. 2021). Although experiencing NPs, as a primary way of knowing and framing NPs, was restricted to a portion of the population (Sellars 1997; Simeunovic-Bajic 2011), communication systems have opened NPs up to the broader public. Communication systems, such as online social networks, mass media, and scientific communication, enable the emergence of new frames and geographies where NPs can be experienced and reimagined (Simeunovic-Bajic 2011; Brossard 2013; Stinson 2017; Marcotte and Stokowski 2021). For instance, scientific publications and mass media are rich sources of information and intertwined communication channels for catalyzing action, but there is a disconnect between the priorities and prominence of discourses between both forms of communication as they might differ on how a phenomenon is framed (Brossard and Scheufele 2013; Petersen, Vincent, and Westerling 2019). Studies have largely focused on how NPs are framed in online social networks (Ogunjinmi, Onadeko, and Ogunjinmi 2013; Toivonen et al. 2019; Mangachena and Pickering 2021; Marcotte and Stokowski 2021), yet such consumer-oriented approaches do not bring insights regarding the NP system structure seen through the lenses of multiple audiences and the frames used by other stakeholders.

Emerging frames and geographies are socially constructed by different stakeholders (e.g., scientists, journalists, media editors) based on existing imaginaries, value systems, and mental shortcuts that facilitate making sense of the problem (Nisbet et al. 2002; Brossard and Scheufele 2013) and developing representations of the system and their interdependences. In this study, we develop a method that quantifies the systems' representation by analyzing the similarity between NP–NP pairs. When aggregated, the entire set of NP–NP relationships render a systematic representation of the NP system structure. Moreover, to assess how representations depend on the lens used, we construct three different NP networks based on biodiversity, scientific research, and news media data specific to each NP. We then apply network comparison methods to assess the similarities between the representations themselves. The advantage of embedding the system of NPs within a network is to facilitate the evaluation of structural properties from the local (NP unit) to global (system) scales (Borgatti et al. 2009; Newman 2018), which could inform management about differences in NPs framing between stakeholders.

In what follows, we first introduce the data set built to evaluate the different representations of the U.S. NP system and the networks methods used for analyzing the interrelation between representations at different scales. We then analyze a paradox of scales, namely a weak local consistency in the NP–NP relationships that nevertheless translates into robust system-level structure largely corresponding to the system's geographical embedding. We conclude by discussing how local versus global information contained in the network embedding informs management.

Methods

This study evaluates three different representations of the U.S. NP system by identifying relational configurations between NPs as they appear in two types of public communication: scientific publications (research) and mass media (media). Research and media representations are indicative of how scientific and public stakeholders frame the system. Additionally, a third representation accounting for biogeographical features of NPs (biodiversity) is included as a benchmark for comparison. In what follows we introduce the data used to reconstruct the NP representations, and then we describe how network representations are analyzed.

Data

We collect data specifically designed to address each dimension. First, the biodiversity dimension is evaluated through the species inhabiting each of the NPs as reported in the Integrated Resource Management Applications (IRMA). Such species lists, including animals, plants, fungi, and bacteria, contain 153,534 entries referring to 59,588 species. It is expected that NPs with similar biogeographical characteristics share a significant number of species. Hence, the NP system representation based on cooccurring species reflects the most traditional representation of the system according to its intrinsic geographic embedding.

Second, the information regarding scholarly research was collected through Web of Science (WoS), a long-standing and widely used index of scientific research published in established peer-reviewed journals (Leydesdorff, Carley, and Rafols 2013). By searching the publications containing the phrase "National Park" and limiting the search to the United States and the years 2010 through 2020, we gather information from nearly 11,000 research publications. Records for each publication comprise information regarding authors, title, abstract, keywords, and discipline. We then identify 8,941 publications mentioning one or more specific NPs by string matching NP names with the content of publication (i.e., title, abstract, keywords).

Third, we recover media articles mentioning NPs by way of the MediaCloud project, which is a system that indexes and curates information derived from articles published in newspapers and magazines, blogs, and other (print and online) sources. A keyword-based query of the MediaCloud returns a list of articles featuring that specific entity, which facilitates analyzing a wide-ranging set of voices, including scientists, journalists, politicians, and the general public (Petersen, Vincent, and Westerling 2019). Over the same period of 2010 through 2020, we identify 423,002 media articles corresponding to mainstream sources that specifically mention at least one NP by its official name. We limit our search in MediaCloud to mainstream news media and similar sources to reduce heterogeneity (i.e., multiple communicative interests and topical emphases) and therefore produce a more consistent representation of the system in the media domain. The articles were disambiguated as some of them could be the same article but with small variations in their URLs or title (Petersen, Vincent, and Westerling 2019). Also note that among these three representations, we can only evaluate the temporal dynamics of research publications and media articles, as species lists do not account for time-related variations.

The distribution $P(n)$ that quantifies the relative frequency of exactly n NPs cooccurring within the same dimension (research or media) indicates that most communications only mention a single NP unit, yet a nonnegligible fraction of each corpora mentions various NPs simultaneously (Figure 1). Interestingly, the distribution $P(n)$ calculated for both research and media follows a remarkably similar statistical regularity, evidenced by the inverse-linear decay when the frequency distributions are plotted on logarithmic axes; these distributions are also invariant when evaluated across nonoverlapping time windows. Such statistical regularities are distinctive of complex systems and describe the atypical and disproportionate importance of rare elements in the system (Newman 2018; Thurner, Hanel, and Klimek 2018). In our case, the distribution is indicative of the inherent limitation of mentioning several NPs simultaneously given, for example, human communicative restrictions and optimizations deriving from bounded context (Baixeries, Elvevåg, and Ferrer-I-Cancho 2013).

Data Analysis

Network representations are formed from the aggregate composition of dyadic $NP_i - NP_j$ interrelations, that quantify the NP–NP similarity based on their cooccurrence in scientific publications and media articles, or the species featured by them. Networks are composed of nodes (NP units) and links connecting each pair of nodes if, for example, there is at least one media article mentioning both (see Figure 2). For each NP–NP link, we quantify the degree of similarity using the Jaccard similarity index, defined as $J_{ij} = {}^{R_i \cap R_j}/_{R_i \cup R_j}$. This index evaluates the fraction of shared elements (i.e., species, research publications, or media articles) between two NPs ($R_i \cap R_j$), with respect to the whole set of elements associated with both ($R_i \cup R_j$). The Jaccard index varies from zero (no shared elements) to one (complete overlapping of elements) and appropriately accounts for differences in the respective sample sizes.

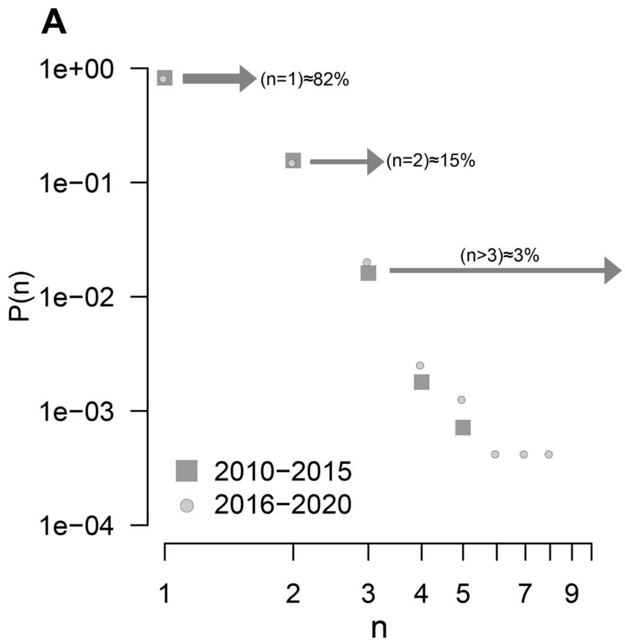

Figure 1. Frequency distribution of the number of national parks (NPs) mentioned per (A) research publication and (B) media article. The probability (P) of finding n NPs mentioned together in a single document using two time windows is shown, as denoted by the color tones. The extremely skewed distributions indicate that the vast majority of communications feature just a single park. There is a statistical regularity exhibited, however, where infrequent but nonspurious occurrence of communications that feature two or more parks is indicative of the system-level structure that extends well beyond the geographic embedding.

We are interested in evaluating the similarities across network representations at two different scales: microscopic (node level) and mesoscopic (network structure level). At the mesoscopic scale we infer similarity based on a direct comparison of each network's community structure obtained using Louvain's algorithm (Blondel et al. 2008). At the node level, various methods for comparing networks have been developed (e.g., Schieber et al. 2017; Martínez et al. 2018; Tantardini et al. 2019; Wills and Meyer 2020). Given the networks' characteristics, a suitable method must consider that (1) networks being compared contain the same set of nodes; (2) the links are weighted; and (3) the network can be fragmented. Unfortunately, according to Tantardini et al. (2019), only distance-based methods satisfy these three conditions. To address this methodological gap, we develop a nodal correlation as a distance-based metric to evaluate the differences between networks at the microscopic (node-level) scale. One advantage of this method is it can identify those nodes that contribute the most to the similarity between the two networks.

Nodal correlation is based on comparing the ego network of a given node i between the two networks a and b being compared, while considering the set of link weights for a node $\{J_{ij}\}_a$ (resp., $\{J_{ij}\}_b$). The nodal correlation for node i is defined as the Pearson's correlation R_{ab} between the pairs. As such, R_{ab} values approaching $+1$ indicate reinforcing similarity across the two networks or dimensions; negative R_{ab} values approaching -1 indicate opposing similarity, such that if a link is strong in one network then it is weak in the other; and R_{ab} values close to 0 indicate no similarity for node i across the two networks.

By way of example, Figure 2D shows a portion of the ego network for Yosemite NP (YOSE) for the three dimensions. Note that there is a positive correlation in corresponding link weights of biodiversity and research networks, largely attributable to the cooccurrence of YOSE with its geographic neighbors King's Canyon NP (KICA) and Sequoia NP (SEQU). When comparing biodiversity and media, however, we observe asymmetric link weights, which contributes to more negative nodal correlation values than in the previous case.

Results

Network representations of the U.S. NP system offer several insights regarding how the system is structured around its biodiversity, how it is

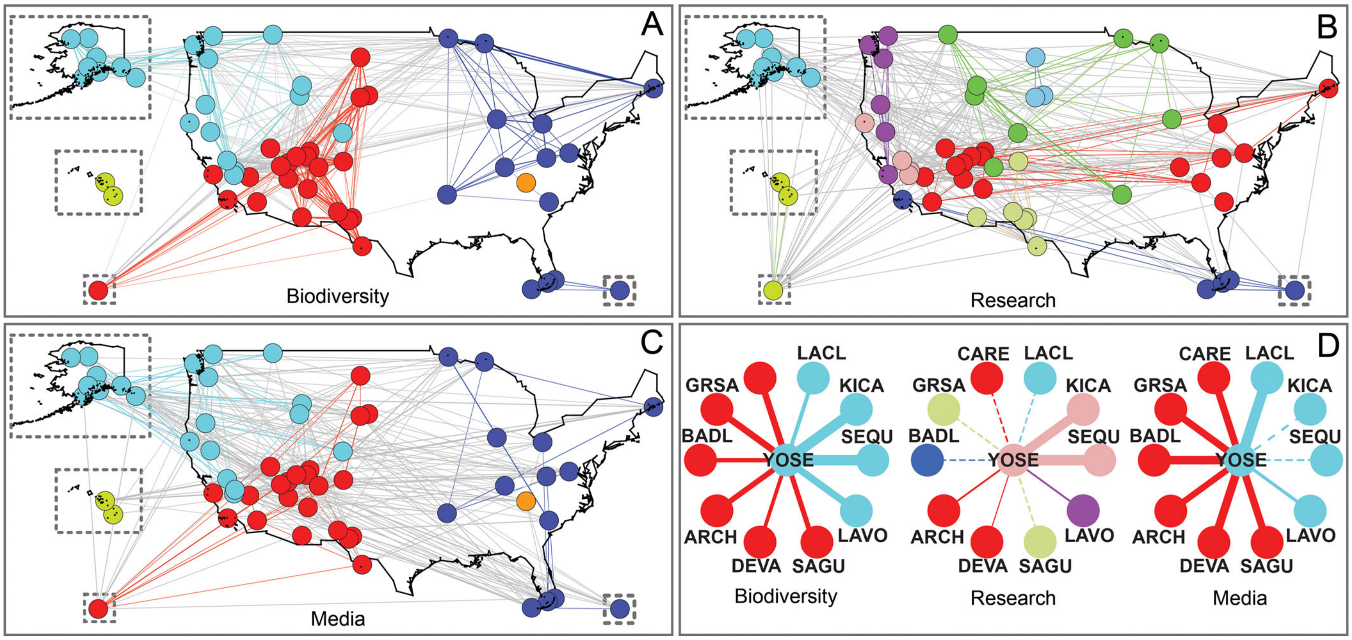

Figure 2. Network representation of the U.S. national parks (NPs) according to (A) their biological similarity, (B) their cooccurrence in research publications, and (C) their cooccurrence in media articles. Nodes represent individual NPs connected by links indicating their similarity. Colors denote communities specific to each individual network visualized in (A–C), and so there is no relation implied by communities of the same color across (A–C). NP communities were identified using the Louvain algorithm, an unsupervised clustering algorithm that groups nodes into communities by maximizing network modularity, resulting in groups featuring stronger connections within community than without. Biodiversity and media networks are clustered and visualized using only a portion of the strongest links. Boxes in dashed lines are relocated and the box corresponding to Alaska is downsized by 25 percent. (D) Example ego networks of Yosemite National Park (YOSE). Line thickness is proportional to NP–NP similarity where dashed lines correspond to values close to or equal to zero and node colors are the same as the network communities highlighted in A–C.

researched, and how it is imagined (Figure 2A–C). Network representations include sixty-two out of sixty-three NPs (Gateway Arch NP was excluded because species are not reported for this NP). All networks are completely connected when aggregating observation data over the period from 2010 through 2020, but at the annual level the networks are fragmented to varying degrees. Interestingly, the networks are dense and have a high abundance of weak links. In what follows, we present the results of nodal correlations (microscopic analysis) and then the results of communities' structure (mesoscopic analysis).

Microscopic Analysis

The ego network illustrated in Figure 2D shows the local network that is representative of an NP-specific management perspective. This microscopic perspective is contrasted with a mesoscopic (i.e., community-level, addressed in the next session) and even system-level perspective (associated with the global connectivity of all nodes). Qualitatively, the nodal correlation measures to what degree a given NP is framed in similar ($R_{ab} \approx 1$), unrelated ($R_{ab} \approx 0$), or opposing ($R_{ab} \approx -1$) ways by different stakeholders. The latter could be source of conflicting imaginaries, governance priorities, and a host of other challenges.

We first consider how the distribution of R_{ab} values calculated for each NP varies over time. Figure 3A–C shows the average R_{ab} value, along with an error bar indicating the 10th through the 90th percentile range of R_{ab}. Considering first Figure 3A, which shows the relation between research and media representations, we observe two distinct periods. Between 2010 and 2012, R_{ab} values are mostly negative, and from 2013 to 2020 they are distributed around zero. In other words, in the first period, NPs frequently researched together rarely coincide simultaneously in media communication, and vice versa. From 2013 onward, this antipodal relationship diminishes to the point that there is little relationship between the two frames. Moving next to Figure 3B comparing research and biodiversity dimensions, R_{ab} values are mostly positive with no significant

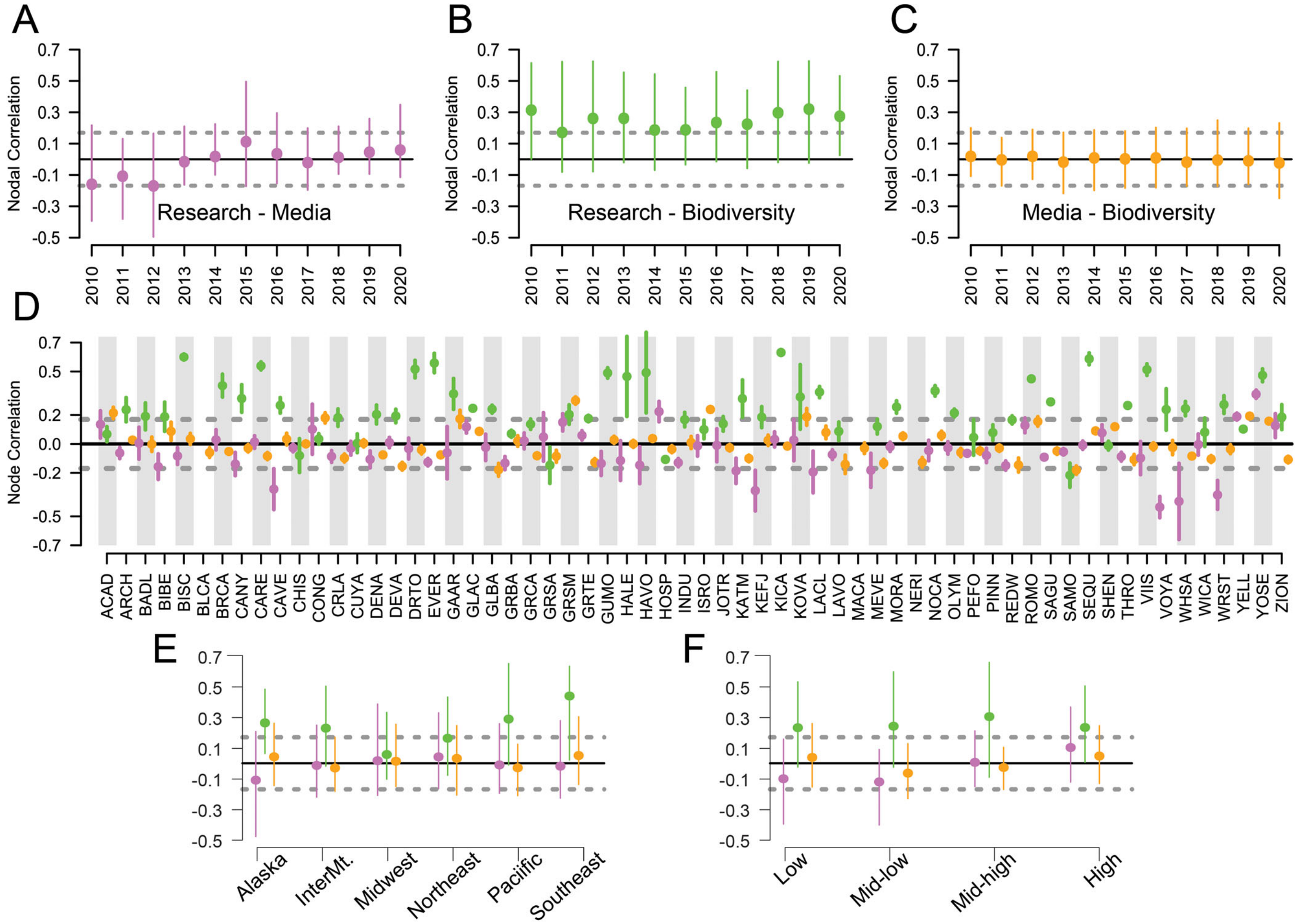

Figure 3. Nodal correlations measure the (dis)similarity in park-level connectivity between different network embeddings. The nodal correlation (R_{ab}) of a single national park (NP) measures to what degree the connectivity of that park is similar in network representations *a* and *b*, and is calculated according to Pearson's correlation coefficient. R_{ab} is calculated to all pairs of homologous ego networks (see, e.g., Figure 2D) existing in research–media (purple), research–biodiversity (green), and media–biodiversity (orange) networks. Average R_{ab} values are indicated by each circle, and error bars show the 10th to 90th percentile interval. Dashed gray lines are indicative of R_{ab} being significantly different from 0 with 90 percent1 confidence according to Student *t* distribution with 60 degrees of freedom. (A–C) System-level temporal variation in R_{ab} and (D) temporal R_{ab} aggregates for individual NP units, (E) for NP groups defined according to official geographic regions defined by the National Park Service, and (F) across four (quartile) NP groups based on visitor popularity. Taken together, the variation in R_{ab} values across different data partitions indicates that the information contained in the research and biodiversity network embeddings are the most similar, whereas the information contained in the media network embedding is the most distinct.

changes in the characteristic level over time, indicating that NPs similar in their biological composition tend to also be researched together. The magnitude of R_{ab} values is relatively low, however, suggesting that the biodiversity dimension captures only a fraction of the connectivity in the research dimension. Finally, comparison of the media and biodiversity networks in Figure 3C indicates little relation between these two dimensions, with relatively small variation within year and across time.

Figure 3D shows the characteristic value and range of R_{ab} for each NP. Results indicate that trends in Figure 3A–C are consistent at the individual NP level. Downscaling to NP units facilitates identifying those NPs with particularly large R_{ab} values. For instance, in the research–media network comparison, three NPs with significant negative R_{ab} values are Wrangler-St. Elias (WRST), White Sand Dunes (WHSA), and Voyageurs (VOYA). Interestingly, these three parks simultaneously feature significant positive R_{ab} values for the research–biodiversity comparison, and $R_{ab} \approx 0$ values for the media–biodiversity comparison. Together, this information suggests that the connectivity of these NPs in the media dimension is not driven by research or geographic contexts and is thus likely related to other important park-system frames such as governance and travel.

To further understand the variation in R_{ab} values, we tested how the distributions relate to NP characteristics associated with administrative region and visitation. Region is defined according to the spatial and administrative division defined by the NPs system, and popularity is defined as quartile groups of NPs according to their 2010 through 2020 mean number of recreational visits reported in IRMA. We apply analysis of variance to test for differences in the mean R_{ab} values calculated for the research–media and the research–biodiversity comparisons, separately. Results (Figure 3E) identify statistical differences in the research–media dimensions ($F = 2.283$, $p = 0.046$), specifically for NPs belonging to the Alaska region. For the research–biodiversity comparison we identify the Midwest region as being statistically distinct ($F = 27.043$, $p < 0.001$).

Figure 3F shows the analog analysis grouping instead by visitation intensity, which captures both popularity and proximity to large cities. For the research–media comparison, the most and least visited NPs feature statistically significant deviation from the population average ($F = 13.515$, $p < 0.001$). For the research–biodiversity comparison, none of the visitation groups are statistically distinct, so the variation in R_{ab} values for this comparison can be attributed to NP-level idiosyncratic factors exhibited in Figure 3D that are not related to visitation intensity.

Mesoscopic Analysis

Results from the microscopic analysis suggest that network representations of NPs in research and biodiversity dimensions conserve some degree of similarity, and the media dimension seems to be the most distinct of the three. Mesoscopic analysis shows a contrasting pattern, however.

First, the biodiversity representation shows a distinction between NPs in the East, Midwest, and Northwest (Figure 2A). Such distinction is based on the communities identified by the (unsupervised) Louvain algorithm (Blondel et al. 2008), which identifies clusters of nodes by maximizing the connectivity (i.e., links) within clusters and minimizing the connectivity between clusters. Although there are several strong links connecting the clusters internally, there are also several links connecting NPs located in the northern regions, indicating that biological composition follows both latitudinal and longitudinal gradients. Second, the research network is structured in several communities that are largely associated with a geographical partitioning (Figure 2B). For instance, there is a community distributed in the Pacific coast (purple), one encompassing the Alaska region (cyan), and one containing the Pacific islands (light green). There are some communities (e.g., red) that do not follow a strict geographical pattern. Importantly, a large number of NPs (75 percent) are found together in the same community in the research and the biodiversity networks. As such, research communities are largely subcomponents of communities that highly correlate with common biodiversity. These results indicate that research addressing multiple NPs tends to be developed in proximal NPs with ecological similarities, which might be associated with the fact that much of the research developed in NPs could be related to conservation and biodiversity, as opposed to visitor use management for example, and therefore is centered around species ranges or ecosystems. Indeed, further investigation in this regard (see Supplemental Material Figure A) shows that most of the publications correspond to research on natural sciences (91 percent), and the network representation of research as a whole is largely captured by the network of natural science research. Nevertheless, it is important to mention that social or multidisciplinary sciences contribute to shaping the mesoscopic structure of the system as they constitute meaningful links in the research network (Supplemental Material Figure A). Third, the network representation based on media cooccurrence (Figure 2C) shows an identical partitioning in communities of what is shown by the biodiversity representation. Nevertheless, there is little correspondence between the dominant links in the biodiversity and media networks. For instance, looking at the blue community located in the East it is notable that the number of strong links within the community in the media network is smaller than the number of links within the same community in the biodiversity network.

Overall, our systemic, cross-scale, and cross-dimension analysis indicates the existence of common mesoscopic characteristics of the NPs network representations in the biodiversity, research, and media dimensions, even though such characteristics are mostly absent at the microscopic level. In other words, regional clustering is an emergent property of the NPs that is recognizable in multiple dimensions and cannot be fully explained by the properties of it composing NPs. As such, although local or NP-based framings in scientific research and mass media largely differ, even involving opposing relationships ($R_{ab} < 0$), upscaling to collective perspectives indicates a large degree of agreement in NP system framing, owing to its principal biogeographical embedding.

Discussion

Managing NPs requires addressing both ecological and social complexity by harmonizing nature protection and public's enjoyment (Sellars 1997; Harmon 1999; Jenkins 2022). The multiplicity of stakeholders and their perspectives around NPs lead to conflicts, however, between NPs managers and different societal sectors such as the public or academics (Sellars 1997; Arroyave, Romero, et al. 2021; Jenkins et al. 2021). Although NPs management strategies have evolved toward more inclusive and adaptive forms of governance (Franklin 2001; Mangachena and Pickering 2021), reconciling managerial preferences of multiple stakeholders remains fundamentally problematic given the dual mandate of keeping NPs unimpaired and accessible for the public (see Organic Act 1916). Understanding how stakeholders frame the system is therefore informative for NPs policy and communication design (Shanahan, McBeth, and Hathaway 2011).

Our analysis of network representations of NPs in biodiversity, research, and media dimensions shows an interesting paradox regarding collective forms of organization: Although the NP–NP similarities appear to be highly dependent on the lens used to construct the representation, mesolevel network structures nevertheless are robust and converge toward a geographically localized perspective—independent of the communication channel or the interests of those producing the message (e.g., ecological issues, outdoor recreation). In other words, although NP–NP similarities are indicative of lacking coordination between dimensions, mesolevel community structure suggests that research and media frame NPs in a similar way, resembling the biogeographical structure of the system defined by their species composition and geographical embedding. Such a paradox might be originated by (1) differences in constraining factors affecting science (e.g., funding, experimental design, disciplinary culture) and media (imagination, editorial policy), and (2) the importance of intermedium NP–NP similarities and similarities with second neighbors. Such mechanisms are beyond the scope of our analysis and require further investigation. Although we explored some of the disciplinary differences on the research dimension (see Supplemental Material) identifying the dominance of natural sciences in the network representation, it is necessary to evaluate how general properties of the NP network representations vary when multiple disciplinary (e.g., physical sciences, life sciences, humanities) and topical (e.g., species ecology, tourism, climate change, transportation, and visitation) emphases are considered for the research and media domains. Similarly, it is necessary to further explore the mechanisms causing R_{ab} differences at a regional level, and popularity grouping of NPs could bring insights regarding how common mesoscale properties of NPs emerge and how they can be most effectively and efficiently managed.

In particular, and owing to the expansion of digital communication, the nexus between science and media has become an active area for studying various social processes. Most of the studies, though, have focused on what information is distributed and how (Nisbet et al. 2002; Ogunjinmi, Onadeko, and Ogunjinmi 2013; Toivonen et al. 2019; Mangachena and Pickering 2021), thereby overlooking other cognitive processes such as collective understandings of the problems at hand (Weingart 1998; Brossard 2013; Lazer et al. 2018) that originate from bottom-up and top-down significations. We argue that further investigation is needed regarding how stakeholders leverage communication channels and topical emphases at system levels and how their framing resonates with specific audiences as they create a sense of place and meaning (Marcotte and Stokowski 2021).

The identification of structural properties at a mesoscale in networks is not new (Blondel et al. 2008; Borgatti et al. 2009; Newman 2018), nevertheless it brings insights for geographic studies and protected area management. First, the identification of physical spaces that are mimicked by emergent geographies (research and media) at the intersection of systems that transcend digital and material space is notable by itself and highlights the need for system-level approaches for characterizing complex social phenomena. Second, our results suggests that policy and communication strategies emphasizing focal entities (e.g., NP units) might be less effective than strategies based on upper level forms of organization because local spaces could bring further room for disagreement (Lemons 2010). Moreover, system-level approaches could facilitate cross-scale coordination, knowledge circulation, and scientific literacy (Peters 2013; Schot and Steinmueller 2018; Nisbet et al. 2002; Romero et al. 2022) as they leverage systemic similarity for fostering consensus (Arroyave, Romero, et al. 2021). In this way, our results shed new light on the nuanced systemic structure that exists beyond the traditional geographic embedding of the U.S. NP system.

Acknowledgments

The data that support the findings of this study are available in Web of Science (WoS) at www.webofknowledge.com and in the Integrated Resource Management Applications (IRMA) of the U.S. National Park Service at https://irma.nps.gov. Further information, including NPs classification and code for reproducing our results, can be found at https://doi.org/10.5061/dryad.stqjq2c8n.

Supplemental Material

Figure A shows the multiple network representations of the U.S. NPs based on the cooccurrence of research publications according to their WoS classification. This article can be accessed on the publisher's site http://dx.doi.org/10.1080/24694452.2023.2277808 and at https://doi.org/10.5061/dryad.stqjq2c8n.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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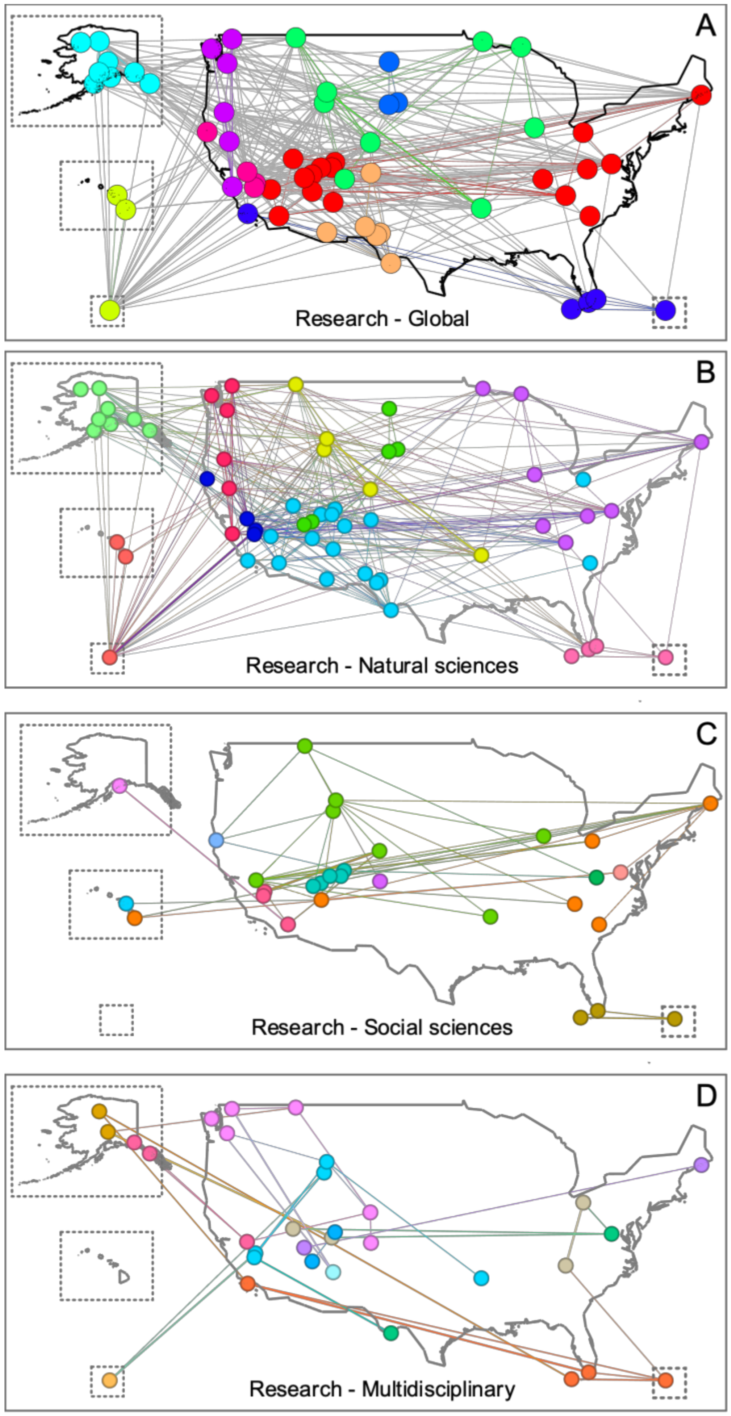
SUPPLEMENTARY MATERIALS



Supplementary Figure A. Network representations of the U.S. national parks according to (A) the co-occurrence of research publications in general, and the co-occurrence of publications classified by Web of Science as (B) Natural sciences (91% of publications), (C) Social sciences (6%), and (D) Multidisciplinary science (i.e., both natural and social sciences. 3%). Nodes are colored according to the communities detected using Louvain algorithm and might vary between panels. Boxes in dashed lines are re-located and the box corresponding to Alaska is downsized to a 25%. Note that when the representation of research is disaggregated into disciplines, the resulting networks could contain less links and nodes, particularly in the cases where there is a smaller amount of information. Importantly, disaggregated networks coincide to a great extent with the aggregated network.