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Biosphere Reserves research: a bibliometric analysis

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Abstract

The Lima Action Plan, approved in 2016, stresses the important role of research and international collaborations within the World Network of Biosphere Reserves for societal transformation. This article aims to contribute to the LAP objectives by providing an up-to-date publication- and citation-based review of the literature, covering research related to biosphere reserves published between 1970 and 2016 and indexed by the Web of Science. Its general aim is to provide an overview, based on bibliometric data, of publications and major topics in Biosphere Reserve research and its international research network. The results show that there have been increased scientific output and citations in recent decades. Studies in various fields of natural, social and human-environmental research highlight that the World Network serves as a forum for the co-production of knowledge for sustainable development.

Introduction

Protected areas are subject to change (Hammer et al. 2016; Mose 2007; Radkau 2014). While motives for the implementation of protected areas vary (see e.g. Mose & Weixlbaumer 2007), their primary goal for a long time was conservation alone. During recent decades, however, protected areas have been increasingly considered as drivers of (or obstacles to) sustainable regional development (Coy & Weixlbaumer 2009; Kraus et al. 2014; Weber 2013). In this new paradigm for protected areas, the conservation and utilization of the environment have to be coordinated and integrated (Hammer 2007; Phillips 2003). In the face of present persistent problems that threaten the *safe operating space for humanity* (Steffen et al. 2015), protected areas are undergoing reassessment by scientists, activists and political actors alike. Now, they function as living labs or model regions for new forms of human-environmental relationships. They are seen as tools for *pioneer knowledge* (Schneidewind 2016) in order to adapt societies to global environmental changes, abandon current *unsustainable* trajectories, and foster societal transformation (Kratzer 2018; Stoll-Kleeman & O'Riordan 2017).

The change of goals and functions of protected areas are especially true for the UNESCO Man and Biosphere Programme (MAB). This started in the 1970s as an intergovernmental scientific programme and aims to establish a scientific basis for a better relationship between people and the environment (UNESCO MAB 2017). The implementation of the programme, from 1976 onwards (for its history, see e.g. Batisse 1982, 1993, 1997; Ishwaran et al. 2008; Köck & Arnberger 2017; La Vega-Leinert et al. 2012.), is carried out via a worldwide network of protected areas called Biosphere Reserves (BR). There is ongoing discussion about whether or not BRs are protected areas as such (see e.g. Bridgewater et al. 1996; Bridgewater & Babin 2017; Shafer 2015). The International Union for Conservation of Nature (IUCN) even removed BR in 1994 from its system of protected area management categories. In line with other authors like Shafer (2015), Gillespie (2007) or Bridgewater and Babin (2017), however, I argue that BRs are protected areas that use a different approach to protection: they are an example of the paradigm shift from a segregated to an integrated approach in area protection that has happened in recent decades (Batisse 1997; Mose & Weixlbaumer 2007; Phillips 2003, 2004; Shafer 2015), representing a *shift towards more accountable conservation* (Coetzer et al. 2014, p. 90). As a consequence, in this article BRs are considered protected areas.

The World Network of BRs is a complex multilevel organization coordinated by the UNESCO MAB International Coordinating Council, and is organized into various spatial and thematic subnetworks (see Schliep & Stoll-Kleemann 2010). Today, this network consists of 669 BRs in 120 countries (Figures 1 and 6).

Three interrelated zones are characteristic of their integrated approach (see e.g. UNESCO MAB 2017):

- one or more core areas used for long-term protection of ecosystems,
- a buffer zone surrounding the core areas, used for sound ecological practice,
- a transition area where most activities are allowed, and where sustainable development is promoted and developed.

Thus, BRs fulfil the three interconnected functions of conservation (preserving genetic resources, species, ecosystems and landscapes), development (fostering sustainable economic and human development), and logistic support (demonstration projects, environmental education, research and monitoring) (Batisse 1997). Each BR is subject to a review process every ten years to guarantee that the standard criteria and functions are being met (Price 2002). Most of the earlier BRs, however, fulfilled neither the functions nor the *spatial framework* criteria (Price 1996). In many cases, BRs were implemented in existing protected areas, e.g. national parks, like Yellowstone or the Rocky Mountain National Park (Batisse 1997; Ishwaran et al. 2008). In

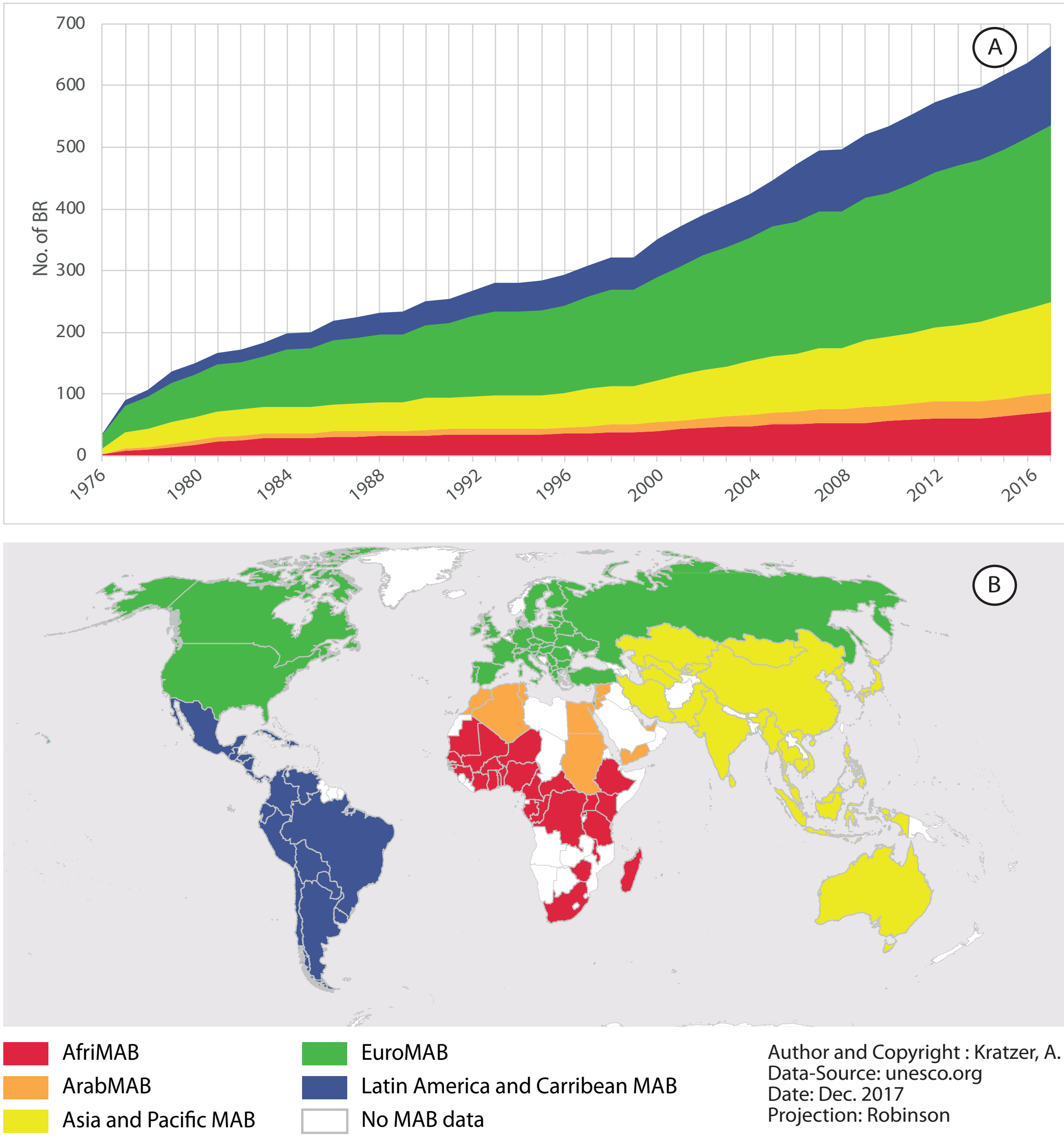

Figure 1 – Development (A) and mapping (B) of spatial MAB sub-networks 1976–2017.

order to improve the quality of the programme and to differentiate BRs from other protected areas, the Seville Strategy (UNESCO 1996) and the Madrid Action Plan (UNESCO 2008) were implemented. The 2016 Lima Action Plan (UNESCO MAB 2017) builds on the Seville Strategy and highlights the importance of BRs for societal transformations and their experimental character. Through the promotion of scientific cooperation and the testing of policies, technologies and innovations, BRs should act as model regions to achieve the Sustainable Development Goals (see United Nations 2015) and to address the important challenges of our time (see Reid et al. 2010), such as biodiversity loss and climate change.

Recent reviews have shown that the gap between the concept and practice still remains[1] (see e.g. Ishwaran et al. 2008; Price 1996, 2002; Price et al. 2010; Stoll-Kleeman & O'Riordan 2017). Some authors (e.g. Stoll-Kleeman & O'Riordan 2017) see countries' sovereignty as a major problem because they are not obliged to provide any support for BRs. Another reason for the gap could be that scientists have not provided the necessary knowledge to reduce the concept-practice gap. Research and the development of BRs influence each other. Research and monitoring are part of the logistic function of BRs and the basis for the management of them. In order to cover the wide range of tasks and to meet the expectations and goals related to today's BRs, different forms of research and cooperation are required. The Lima Action Plan (LAP) follows this line of thought in terms of sustainability science and internationality. Sustainability science is *"an integrated, problem-solving approach that draws on the full range of scientific, traditional and indigenous knowledge in a transdis-*

[1] Consequently, 38 sites that did not match the criteria have been withdrawn from the global network since 1997.

ciplinary way to identify, understand and address present and future economic, environmental, ethical and societal challenges related to sustainable development […]. *Biosphere reserves, particularly through their coordinators, managers and scientists, have key roles to play in operationalizing and mainstreaming sustainability science and ESD* [Education for Sustainable Development; author's note] *at local and regional levels, in order to build scientific knowledge, identify best practices, and strengthen the interface between science, policy and education and training for sustainable development*" UNESCO MAB 2017, p. 19). UNESCO MAB also refers to the World Network of BRs as a *"unique forum for the co-production of knowledge for sustainable development between the inhabitants of biosphere reserves, practitioners and researchers"*" ibid., p. 22). Therefore, the strengthening of research and exchange of knowledge in this global network of model regions is a high priority.

The intention of this article is to contribute to the LAP objectives by providing a publication- and citation-based state-of-the-art review. For this, the article studies BR-related research published from 1970 to 2016 and indexed by the Web of Science (WoS). Its general aim is to provide an overview of Biosphere Reserve research (BRR) and its international research network, based on bibliometric data. The paper discusses:

- The scientific production in BRR. What are the key publications and journals in terms of citations?
- Internationality and collaborations. Is BRR dominated by certain countries? Does the amount of scientific literature in a country correlate with the number of BRs in that country?
- Major research fields. What are the main topics within BRR?

Methods

Bibliometric analysis

Bibliometric analysis studies the statistics of publications and citations (Newman 2010). It goes back to the 1960s and the famous study by Derek de Solla Price (1965), and since then has gained attention in various scientific fields (e.g. Bakker et al. 2016; Chiu & Ho 2007; Martyn 1964). A bibliometric method characterizes a scientific field by highlighting research hotspots and trends (Zhang et al. 2016). To the best of my knowledge, there are no publications to date which examine in a quantitative manner the link between BRs and publications, other than for Rawat and Rawal's (2016) analysis of Himalayan BRR, and for Shaw et al. (2017), who outline an ongoing research project for a EuroMAB (see Figure 1) research database.

Any bibliometric analysis is challenging because the assumptions and decisions made influence the results highly. Following Markard et al. (2012, p. 959), this paper therefore *provide*[s] *full transparency* about the choices made regarding the selection criteria. Two assumptions apply to most bibliometric studies. First, scientific progress is a result of knowledge creation through publications. The quality of these publications is steered by a peer review process, funding and ethics (Chappin & Ligtvoet 2014). The second assumption is that the citation of a paper is an indicator of the relevance of an article or book. As Newman (2010) points out, there are many reasons why one paper cites another, but whatever the reasons are, the more citations a publication receives, the more its subject matter is relevant in the particular field. Figure 2 shows the data collection and analysis process.

Data collection

Authors usually conduct bibliometric studies using one of three standard databases (Belter & Seidel 2013). Here, the data was extracted from the WoS Core Collection, which covers natural and social sciences, as well as arts & humanities. On 21 December 2017, a topic search with a timespan from 1970 to 2016 was conducted. BRR includes research that has biosphere reserve* or its translations in the title, abstract, author keywords or KeyWords Plus. There have been concerns about the bias of WoS, especially concerning the preference for publications in English language (Mongeon & Paul-Hus 2016). However, this only concerns bibliographical information (Testa 2016). Furthermore, as success within the neoliberal scientific system is based on the number of reads and citations, most articles are written in, or translated into, English anyway. Although WoS covers book reviews and book chapters, no books are listed per se. This of course excludes important works such as those by Mose (2007), Gillespie (2007) or Moreira-Muñoz and Borsdorf (2014).

Cleaning the downloaded dataset with openrefine (openrefine.org) led to some changes in authors (e.g. merging of Devine, Jennifer A. and Devine, Jennifer), but not to a reduction in the amount of data. The final dataset contained 2742 publications.

Data analysis

Information pertaining to individual documents, including authors, journals, titles, all keywords, citations and WoS categories, was retrieved from the final dataset. For some descriptive findings, e.g. the number of articles or the most important journals, the data was exported to MS Excel 2016. The bibliometric analysis itself was conducted using the open source tool CiteSpace (see Chen 2014). This software uses a co-occurrence matrix to analyse and map the institutions that contribute to the publications, as well as the keywords, WoS categories and so forth.

Geographic distribution and collaborations

The information on the institutions involved in publications was used to describe and map the impact of certain countries on BRR. The information provided by CiteSpace was visualized using the open source software Gephi (gephi.org) into a circular chart of collaborating countries. In addition to this, the geographical mapping of the number of publications per country was carried out using ArcMap 10.4.1.

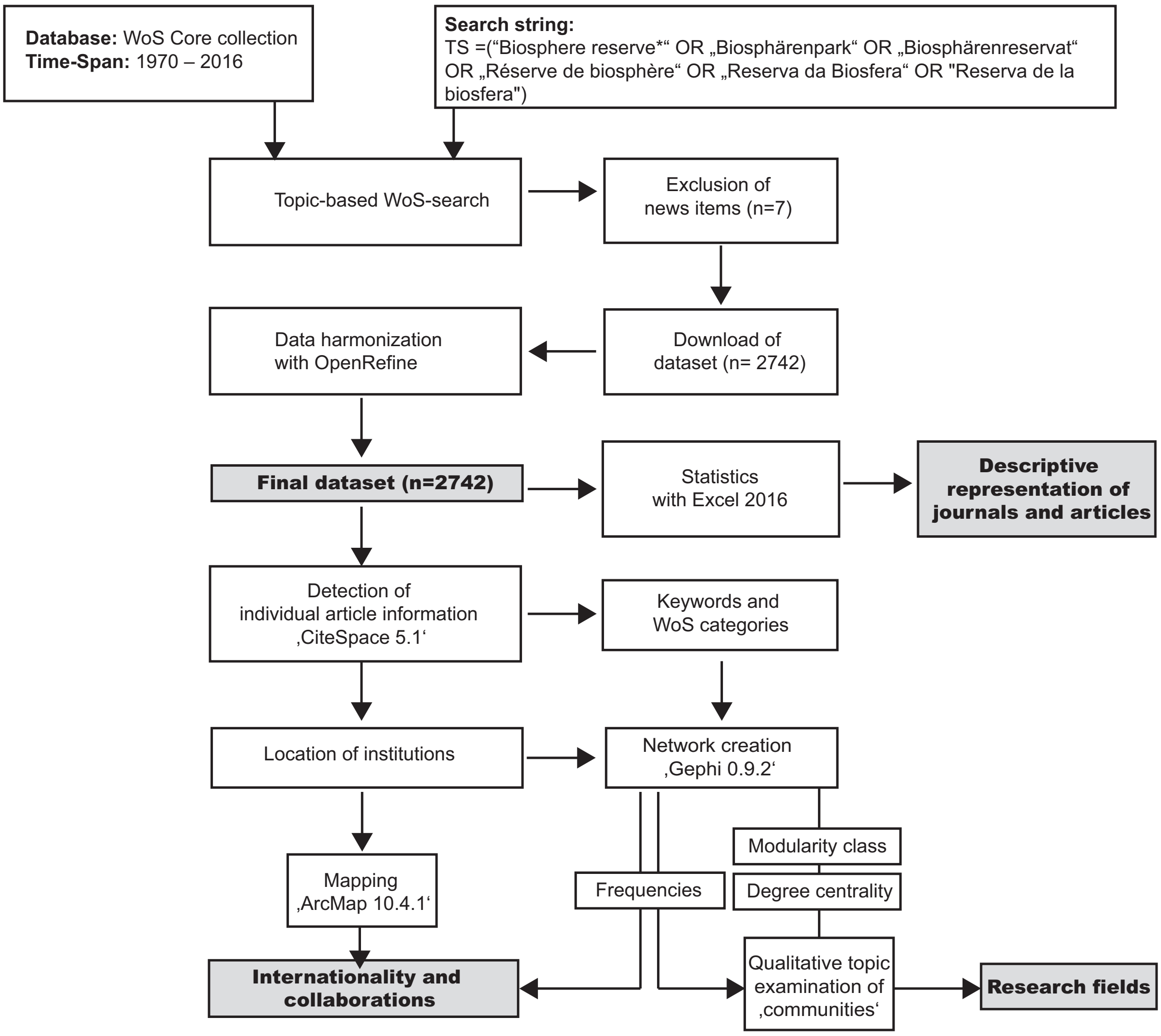

Figure 2 – Mapping of the research process.

Networks and co-word analysis

Publications in scientific fields form a network where the nodes are, for example, articles, while the edges represent citations. The co-occurrence of words together with the detection, counting and interpretation of terms as well as of clusters reveal the structure and meaning of research fields (An & Wu 2011; Callon et al. 1983; Newman 2006). In the present paper, network graphs of co-occurring keywords and WoS categories were studied. If, for example, a keyword A and a WoS Category B appear in three or more articles, an edge is drawn between A and B. These networks were also analysed and visualized using Gephi. Cluster detection and interpretation took several steps. First, the social network metric modularity class (Blondel et al. 2008; Newman 2006) identified components that are more connected to each other than others, thus representing big thematic fields or research hotspots in a more detailed way than the original WoS categories. Second, degree centrality was calculated to measure the number of relations between categories and keywords (see Popescu et al. 2014). A node with high degree centrality has many connections in the network and connects papers with similar ideas or approaches. In the final step, a manual topic examination of the most-cited articles in a cluster defined the topics qualitatively.

Results and discussion

Publications and journals

The search revealed 2742 publications[2], with a clear bias towards journal articles, English language and collaborative authorship (Figures 3 and 4). The first scientific paper appeared in 1977. The amount of published literature and its citations have increased considerably, especially since the middle of the 2000s. The annual scientific output has almost quintupled from 62 articles in 2005 to 299 in 2016, with more than 50% of all studies being published in the period 2010–2016 (n = 1503). Overall, by the end of 2016, the total number of citations was 25400. In the last ten years, the number of annual citations has increased almost eightfold, from 510 (2005) to 3978 (2016).

The relation of citations to the number of published articles shows that the increase in citations is

[2] The words *publication*, *paper* and *article* are used synonymously in this article.

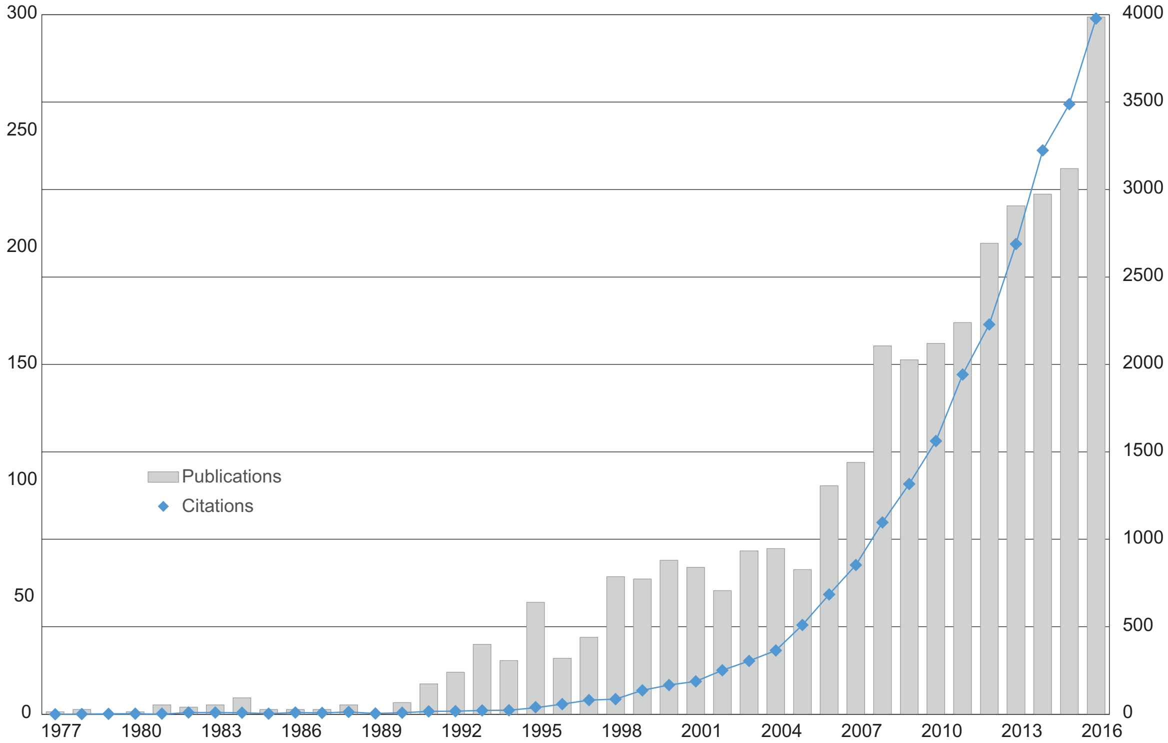

Figure 3 – Numbers of citations (line, right-hand scale) and publications (columns, left-hand scale) per year.

very uneven (Figure 5). The data follows a power law in which most papers get few citations, while a few articles receive most citations (Barabasi & Bonabeau 2003; Newman 2010). Nearly 26.6% of all papers in BRR have never been cited; conversely, the top 20% of all BR papers ($n_{p20} = 548$) receive about 73% of all citations. This is similar to other studies of citation networks, e.g. the famous one by Solla Price (1965), where 35% of the papers examined were not cited at all.

The role of BR in the most-cited papers varies (Table 1). Papers 1, 2 and 9 are review articles and use several studies of BR to draw conclusions for protected areas in general. The same is true for paper 5b, which is a meta-analysis of empirical case studies. In papers 3, 4 and 7, BRs simply act as research areas without a connection to the BR concept. The articles most and least closely related to BRs are articles 8 and 5 respectively. Olsson et al. (2007) analyse their empirical work in a Swedish BR regarding the role of bridging organizations, like BR management, in the governance of socio-ecological systems. Paper 5a only cites BR studies; it has no direct relation to any particular BR.

A change from a thematic to a title-based search in WoS (Table 2), which generates all articles with BR in the title (n=1 079), reveals a slightly different picture. Five out of the top ten papers have a clear connection to a BR as a case study and analyse the BR's inherent processes and effects in relation to different fields. Here again, four publications use a BR as a research area without having a connection to it. The remaining article among the five, Batisse (1982), is a state-of-the-art publication in which the author presents the genesis of BRs and gives good examples of how BRs can be implemented and managed. BR articles published after the Seville strategy (1996) achieve higher

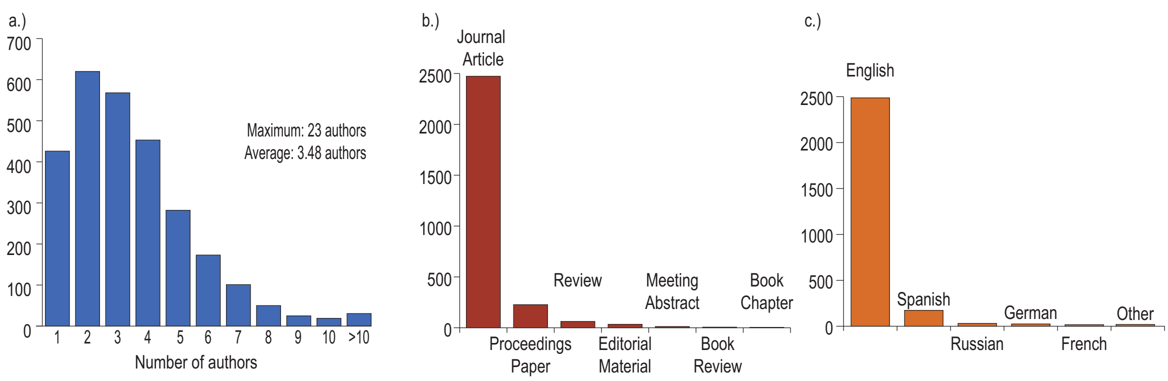

Figure 4 – Number of authors per article, article type and language for Biosphere Reserve Research.

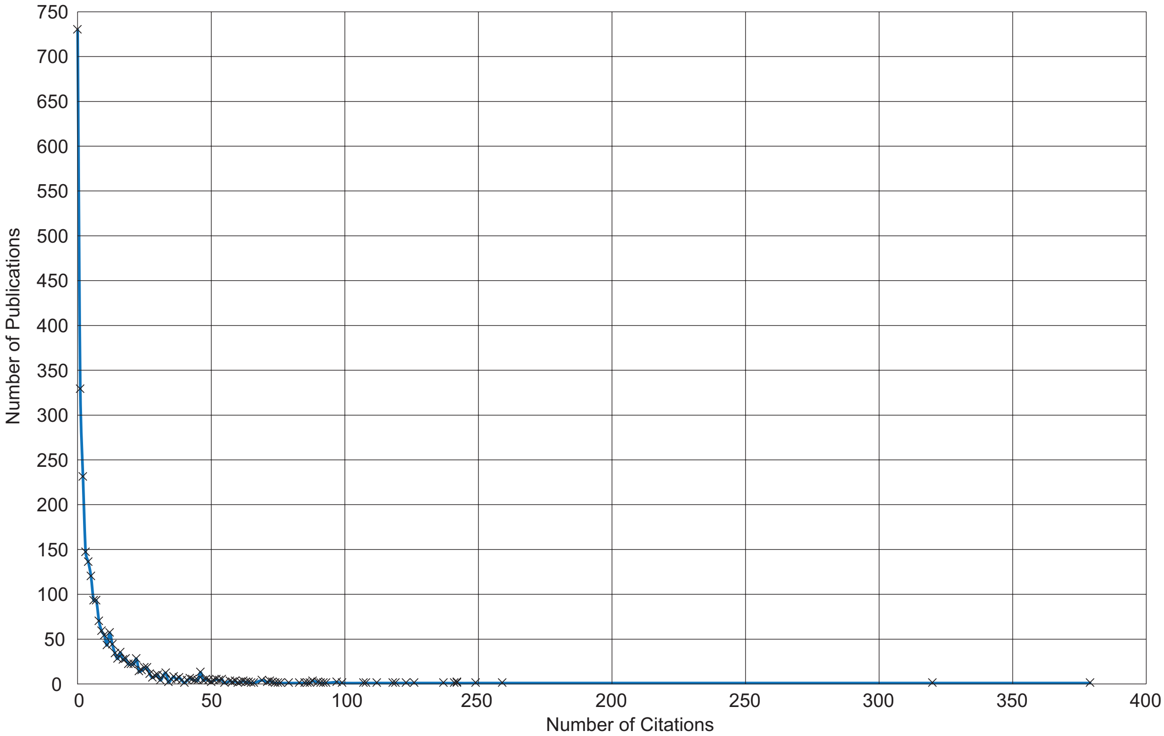

Figure 5 – Relationship between number of publications and their citations. The black crosses stand for single publications; the blue line indicates the power law or 80/20 rule.

numbers of citations than those from before that date. This seems to be in line with Wang et al. (2009), who found that the likelihood of a paper being cited is time-dependent.

At the end of 2016, there were 917 journals publishing research about BRs. The number of publications per journal ranges from just 1 to 47. Table 3 gives an overview of the fifteen journals that are the most active (number of publications) and most important (number of citations). A power law distribution (see above) is also true for the total number of citations in specific journals. Here, the top 20% of all journals

Table 1 – The ten most-cited publications, their authors and journals containing Biosphere Reserve as a topic *published 1977 to the end of 2016. Data: Web of Science 2017*

No.	Title	Authors and journal	Year	Cit.	Role of BR
1	Parks and peoples: The social impact of protected areas	West, P., J. Igoe, & D. Brockington *Annual Review of Anthropology*	2006	379	Cited examples
2	The role of protected areas in conserving biodiversity and sustaining local livelihoods	Naughton-Treves, L; M.B. Holland & K. Brandon *Annual Review of Environment and Resources*	2005	320	Cited examples
3	In situ conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community	Louette, D, A. Charrier & J. Berthaud *Economic Botany*	1997	159	Locality of research
4	Assessing, mapping, and quantifying cultural ecosystem services at community level	Plieninger, T., S. Dijks, E. Oteros-Rozas & C. Bieling *Land Use Policy*	2013	149	Locality of research
5a	Cultural importance indices: A comparative analysis based on the useful wild plants of southern Cantabria (northern Spain)	Tardio, J. & M. Pardo-De-Santayana *Economic Botany*	2008	142	Reference
5b	Community managed forests and forest protected areas: An assessment of their conservation effectiveness across the tropics	Porter-Bolland, L. et al. *Forest Ecology and Management*	2012	142	Cited examples
7	Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed	Millward, A.A. & J.E. Mersey *Catena*	1999	141	Locality of research
8	Enhancing the fit through adaptive co-management: Creating and maintaining bridging functions for matching scales in the Kristianstads Vattenrike Biosphere Reserve, Sweden	Olsson, P., C. Folke, V. Galaz, T. Hahn & L. Schultz *Ecology and Society*	2007	137	Case study
9	Spatial attributes and reserve design models: A review	Williams, J.C., C.S Revelle & S.A. Levin *Environmental modelling and Assessment*	2005	126	Cited examples
10	Trends, drivers and impacts of changes in swidden cultivation in tropical forest–agriculture frontiers: A global assessment	Van Vliet, N. et al; *Global Environmental Change-Human and Policy Dimensions*	2012	123	Cited examples

Table 2 – The ten most-cited publications, their authors and journals containing Biosphere Reserve in the title *published 1977 to the end of 2016. Data: Web of Science 2017*

No.	Title	Authors and journal	Year	Cit.	Role of BR
1	Enhancing the fit through adaptive co-management: Creating and maintaining bridging functions for matching scales in the Kristianstads Vattenrike Biosphere Reserve, Sweden	Olsson, P., C. Folke, V. Galaz, T. Hahn & L. Schultz *Ecology and Society*	2007	137	Case study
2	The biosphere reserve – a tool for environmental conservation and management	Batisse, M. *Environmental Conservation*	1982	99	State of the art
3	Losing knowledge about plant use in the Sierra de Manantlan biosphere reserve, Mexico	Benz, B.F., J. Cevallos, F. Santana, J. Rosales & S. Graf *Economic Botany*	2000	97	Locality of research
4	Herpetofauna diversity and microenvironment correlates across a pasture-edge-interior ecotone in tropical rainforest fragments in the Los Tuxtlas Biosphere Reserve of Veracruz, Mexico	Urbina-Cardona, J., M. Olivares-Perez & V. Reynoso *Biological Conservation*	2006	89	Locality of research
5	Ngo landscapes in the Maya Biosphere Reserve, Guatemala	Tardio, J. & M. Pardo-De-Santayana *Economic Botany*	1998	73	Case study
6	Use of non-crop food vascular plants in Montseny biosphere reserve (Catalonia, Iberian Peninsula)	Bonet, M.A. & J. Valles *International Journal of Food Sciences and Nutrition*	2002	73	Locality of research
7	Local people's perceptions as decision support for protected area management in Wolong Biosphere Reserve, China	Xu, J.Y., L.D Chen, Y.H. Lu & B.J. Fu *Journal of Environmental Management*	2006	69	Case study
8	Designing effective marine protected areas in seaflower biosphere reserve, colombia, based on biological and sociological information	Friedlander, A. et al. *Conservation Biology*	2003	64	Case study
9	Bovine Tuberculosis in Donana Biosphere Reserve: The Role of Wild Ungulates as Disease Reservoirs in the Last Iberian Lynx Strongholds	Gortazar, C. et al. *PLOS ONE*	2008	62	Locality of research
10	Land change in the southern Yucatan and Calakmul Biosphere Reserve: Effects on habitat and biodiversity	Vester, H. et al. *Ecological Applications*	2007	59	Case study

(n_{j20} = 183) represent 84.5% of all citations. It is noticeable that these n_{j20} are not identical to the journals that publish the most articles. In comparison to this, the Annual Review of Anthropology published only one paper, but this was the most-cited paper.

Table 3 – Number and ranking of the most important journals in Biosphere Reserve research in terms of citations and publications

Journal	Citations		Publications	
	Number	Ranking	Number	Ranking
Forest Ecology and Management	1 009	1	36	4
Conservation Biology	955	2	23	12
Biodiversity and Conservation	771	3	47	1
Biological Conservation	717	4	35	6
Economic Botany	652	5	17	28
Environmental Conservation	585	6	36	4
Biotropica	462	7	18	25
Ecology and Society	460	8	29	9
Journal of Environmental Management	438	9	19	23
Journal of Ethnopharmacology	433	10	13	36
Annual review of Anthropology	376	11	1	404
Landscape and Urban Planning	342	12	23	12
Ecological Applications	332	13	7	74
Journal of Arid Environments	319	14	23	12
Annual review of Environment and Resources	317	15	1	404
eco.mont	40	148	34	7

Internationality and collaborations

This analysis shows how often and with whom researchers cooperate internationally, and the number of publications per country. If an article has more than one author from the same country, it is credited as one article for that country. An article with authors from more than one country counts as one article for each country. In sum, 98 countries are involved (Figure 6). Researchers from universities in Mexico were involved in the production of 660 articles or 24% of all publications, followed by the USA (n = 560; 20.4%) and India (n = 253; 9.2%). Before the Seville strategy, the USA, Slovakia and Mexico were the top three countries. Since 1997, the geographical distribution of published articles has changed, with Mexico coming out top, and India and China also being in the top five. Figure 6 also shows that there is a strong linear correlation between the number of BRs in a country and the number of BR-related articles of the same country. This suggests that BRs have an important function as research sites for research institutions in the countries where the BRs are located. However, it goes beyond the scope of this paper to verify this assumption. Nevertheless, an exemplary analysis of Mexican BR articles showed that almost 90% of them were written by people from Mexican research institutes.

Figure 7 complements the results by illustrating two indicators for international collaborations: first,

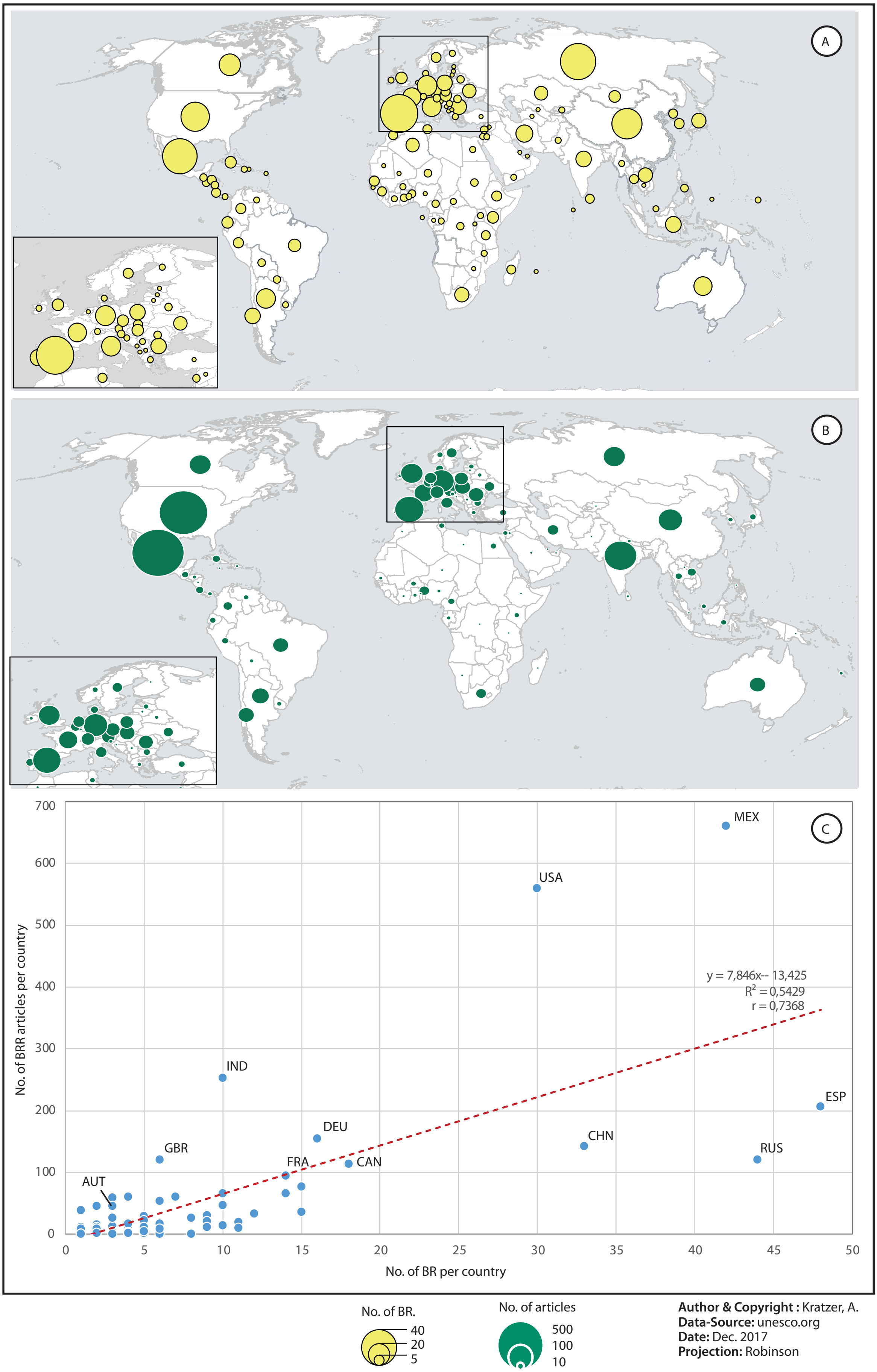

Figure 6 – Number of (A) biosphere reserves per country, and (B) Biosphere Reserve research articles per country published 1977–2016; (C) scatter plot of the correlation between A and B.

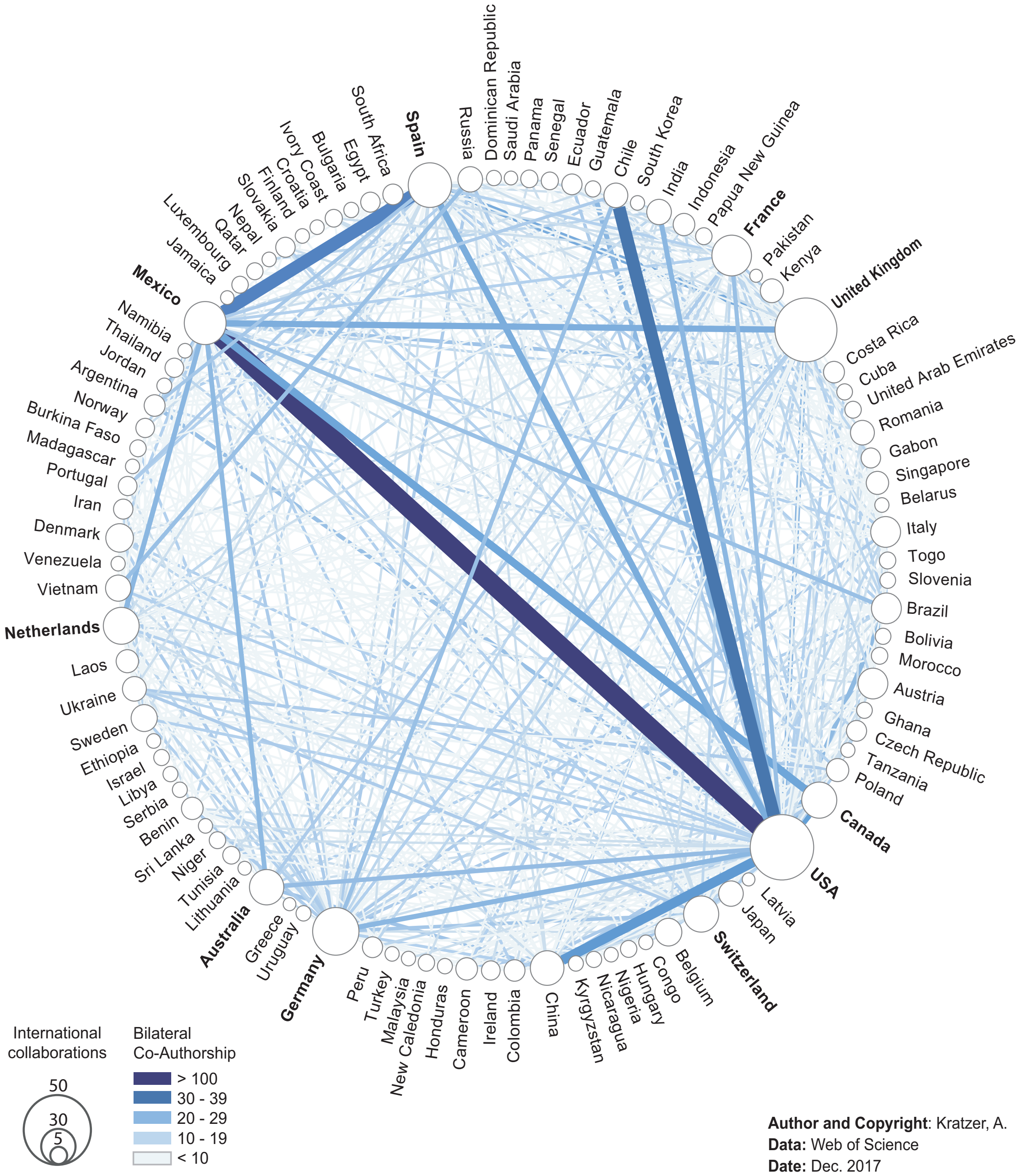

Figure 7 – Circle chart of international collaboration. Node size indicates with how many other countries a country collaborated (degree); edge colour stands for the number of instances of co-authorship between two countries. Bold letters indicate the top 10 collaborators.

with how many other countries a country collaborates; second, how often a collaboration took place with another country. USA (n = 68), United Kingdom (n = 66) and Germany (n = 45) account for most of the instances of cooperation. The most frequent collaboration took place between Mexico and the USA (n=128), followed by Mexico and Spain (n = 39), and Chile and the USA (n = 36).

Major research fields

BRR covers 119 WoS categories. A further 11 021 unique keywords, which occur 37 077 times, are used to give a more detailed description of the research conducted (see Figure 8). 8 251 or 74.9% of these keywords appear only once. *Conservation* is the most frequently used keyword (n = 430), followed by *biosphere reserve* (n = 385) and, not surprisingly given the results above, *Mexico* (n = 261). However, the categories are vague in what they cover, and the keywords can be ambiguous, for example *community*, which is used in both ecology or planning.

The network of keywords and WoS categories results in the identification of research fields. To concentrate the network on the most important clusters

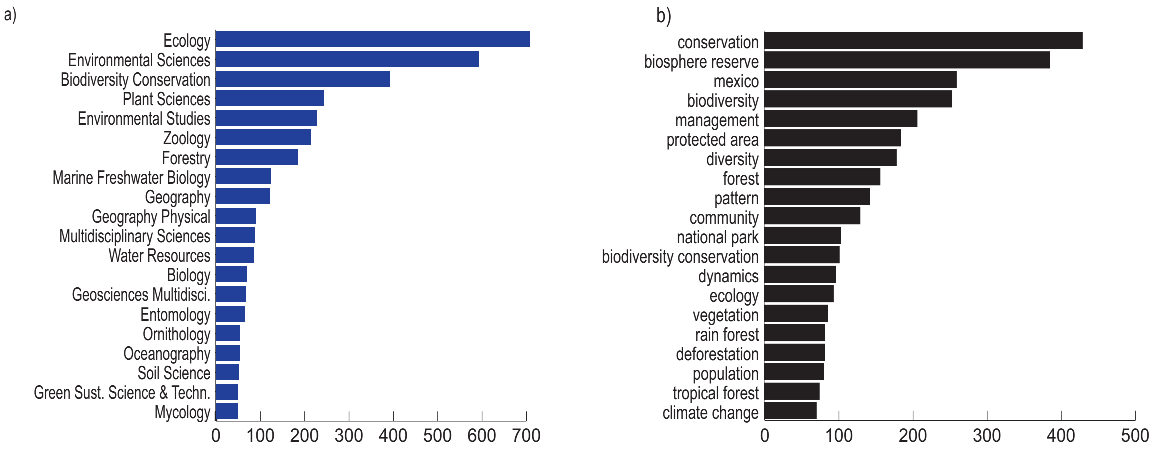

Figure 8 – Most frequent Web of Science categories (a), and keywords (b) in Biospere Reserve research 1977–2016.

and to improve the visualization, only publications cited a minimum of three times were used. The final network consists of 322 nodes (WoS categories and keywords) and 1 772 edges. The keywords with the highest degree centrality, which are therefore the most important ones, are general concepts like *protected area, conservation or biosphere reserve*. The density of a network is an indicator of the network's connectedness, where a value of 1 indicates a fully connected network. A density of 0.034 for this network suggests that the publications tend to be quite diverse. However, all keywords and categories are interconnected through a shortest-path length that averages 2.826. This measure points to how close words in the network are. The relatively low value of the shortest-path length and the low density of the network imply that, while there are quite different research fields, the research is based on a closely related set of words. This is known to be an effect of the power law distribution (see above), where new authors tend to use keywords of already highly cited papers (Amaral et al. 2000).

The calculation of modularity classes resulted in the identification of 7 research clusters or main research fields (see Figure 9; Table 4). Clusters with more nodes do not represent more frequently occurring fields but rather more differentiated ones. While the field *economy* is quite distinct, *biodiversity* covers all types of animals, plants, biomes or regions. The diversity of this cluster is also visible in the different WoS categories. No research field can be seen as an isolated island. Sometimes, there are also strong connections to other clusters, for example from *economy* to *governance and policy*, or from *agriculture, forestry and fishery* to *environmental changes*.

Table 4 – Characteristics of BR research fields 1977–2016. Web of Science categories and keywords are ranked by degree; topic examples are based on manual inspection of papers.

Research fields	Nodes	Web of Science categories	Keywords	Topics (examples)
Economy	15	Green & Sustainable Science & Technology; Economics; Hospitality; Leisure; Sport & Tourism	tourism, ecotourism, natural resources, perspectives, environmental impact	Effects of tourism; value chains; local products and resources; tourist's perceptions
Governance and policy	64	Geography; Planning & Development; Sociology; Law; International relations; Ethics	protected area, biodiversity conservation, sustainable development, resilience, comanagement, people, perception, participation	Concepts; people and BR; acceptance studies; governance approaches; conflicts and decision making; role of BR for regional development; participation
Agriculture, forestry and fishery	68	Environmental Studies; Soil Science; Forestry; Fisheries; Agriculture, multidisc.; Horticulture	conservation, tropical forest, forest, restoration, impact, eutrophication, coral reef, wetland	Effects of forestry and fishing; conflicts between human activities and conservation; sustainable agriculture
Environmental changes	40	Environmental Sciences; Geography, phys.; Water resources; Toxicology; Geosciences, multidisc.; Engineering, environm.	climate change, model, sediment, scale, river, water quality, salinity, trend, precipitation, lead, fish, seabird	Effects of e.g. climate change on resources and water; human impacts (other than cluster above), e.g. contamination; methods to minimize environmental degradation
Land-use and land Cover change	40	Remote sensing; Imaging Science & Photographic Technology	deforestation, land use change, forest transition, benefit, illegal logging, indigenous people	Different methods of change detection; monitoring land use/land cover especially in tropical forests; provide baselines for development
Pharmacy, medicine and health	25	Plant Sciences; Anthropology; Pharmacology & Pharmacy; Integrative & Complementary Medicine	medicinal plant, ethnobotany, traditional knowledge, antibacterial activity, pulmonary syndrome, rodent	knowledge, substances, use and medicinal effects of (tropical) plants; pharmaceutical studies; nutrition & diets; alternative medicine
Biodiversity	70	Ecology; Marine & Freshwater Biology; Zoology; Ornithology; Entomology; Mycology; Evolutionary Biology	biodiversity, species richness, abundance, population, mammal, habitat, taxonomy, new species, community structure	Biodiversity in core and (to a lesser degree) buffer zones; detection and classification of species; hot spots of biodiversity

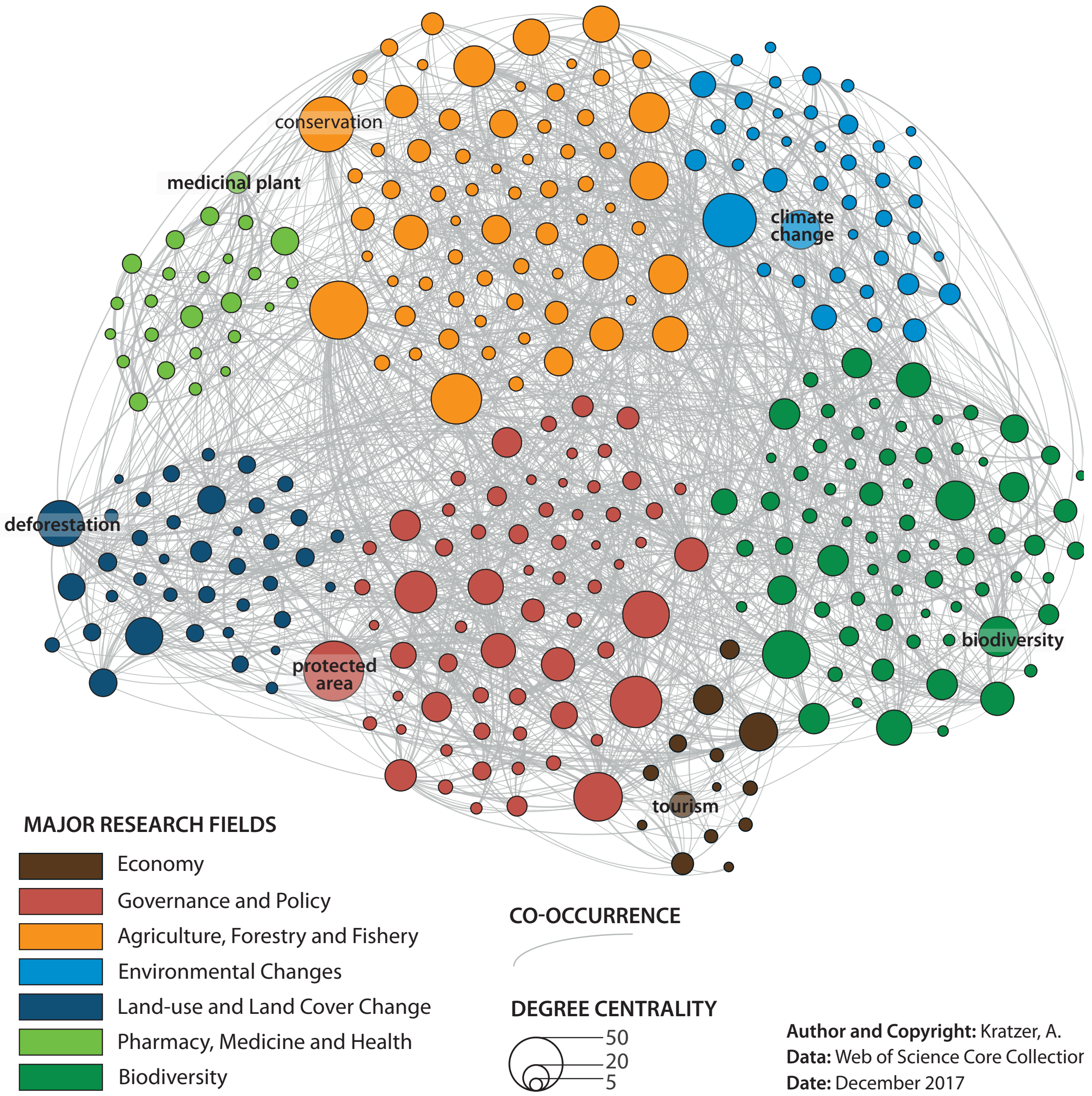

Figure 9 – Co-word network of Biosphere Reserve research keywords and World of Sciences categories 1977–2016. Node diameters are proportional to degree centrality. The cluster location results from the circle pack *layout algorithm. Labelled are keywords with the highest degree centrality.*

Conclusion

With the Lima Action Plan (LAP), the UNESCO MAB underlined the important role of research to support the management and sustainable development of BRs. The aim of this study was to contribute to the objectives of the LAP by providing an overview of BRR and its international research network based on bibliometric data. The findings show that there has been an increase in scientific output and citations in recent decades. This also points to increased awareness of, and knowledge about, BRs in general. The results highlight the most cited papers and journals related to BRs. This, however, does not necessarily mean that these are the most important publications. It simply reflects what researchers refer to in order to answer certain scientific questions or to solve *real-world problems*. The research reported in many papers takes place in just one BR and is not *about* BRs. This leads to two conclusions. First, that BRs fulfil their role as research sites. Second, that future research needs to address further the connection between the concept and its various implications.

The LAP statement that the World Network of BRs serves as a unique forum for the co-production of knowledge for sustainable development has been further underpinned by this review. Different research topics and high numbers of participating countries and international collaborations reflect the global science network on the one hand and global challenges like biodiversity loss or climate change in BRs on the other. There are no dominating countries; research efforts are combined, particularly by researchers from Mexico, USA, India and China, as well as other developed and some developing countries. The correlation of publications and BR by country also highlights the regional embeddedness of research. Research is used to analyse and solve problems in local contexts and to improve the relationships between people and their environment.

This is the first study to provide an overview of BRR. All findings are of course biased and constrained by the criteria of the WoS database and the way in which BRR was defined. The study's strengths lie in its transparent approach and detailed quantitative analysis. The paper provides a baseline for further collaborations and potential research fields. However, as Shaw et al. (2017) have stated, investigations into current research relating to BRs are complex and multifaceted. In order to refine the information of the present paper, more quantitative and qualitative research is needed, because quantitative studies alone are not able to determine the true meaning of papers. First, a bibliometric analysis based on a different database in order to compare and verify the results would be useful. Another approach could switch the perspective from keywords and categories to citations. What is relevant for authors? What and whom do they cite? Last but not least, qualitative studies of different timeframes are needed to identify such things as the causes of research trends and the role of strategies like the LAP.

The present paper hopefully contributes to the goals of the LAP and should be valuable to all researchers and governance actors who work in or with BRs. It will help them to make better decisions about what to research and with whom to cooperate in order to improve the global network.

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