

Paradox incentive structures and rules governing sharing of coastal and marine data in Kenya and Tanzania: Lessons for the Western Indian Ocean

Désirée Schwindenhammer^{1,2*}, Julius Francis³, Mishal Gudka⁴, Hauke Kegler², Christopher Muhando⁵, Hauke Reuter^{1,6}, Rushingisha George⁷, Nina Wambiji⁸, Achim Schlüter²

¹ University of Freiburg, Faculty of Environment and Natural Resources, Dekanat der Fakultät für Umwelt und Natürliche Ressourcen, 79085 Freiburg, Germany

² Leibniz Centre for Tropical Marine Research (ZMT), Fahrenheitstrasse 6, 28359 Bremen, Germany

³ School of Aquatic Science and Fisheries Technology (SoAF), University of Dar es Salaam, P.O. Box 60091 Dar es Salaam, Tanzania

⁴ Coastal Oceans Research and Development - Indian Ocean (CORDIO), PO Box 10135, Mombasa 80101, Kenya

⁵ Institute of Marine Sciences (IMS), University of Dar es Salaam, PO Box 668, Buyu, Zanzibar, Tanzania

⁶ University of Bremen, Faculty for Biology and Chemistry, Bibliothekstrasse 1, 28359 Bremen, Germany

⁷ Tanzania Fisheries Research Institute (TAFIRI), PO Box 9750, Dar es Salaam, Tanzania

⁸ Kenya Marine and Fisheries Research Institute (KMFRI), PO Box 81651-80100, Silos Road, English Point, Mkomani, Mombasa, Kenya

* Corresponding author: desiree.schwindenhammer@envgov.uni-freiburg.de

Abstract

Comprehensive and timely data-sharing is essential for effective ocean governance. This institutional analysis investigates pervasive data-sharing barriers in Kenya and Tanzania, using a collective action perspective. Existing data-sharing rules and regulations are examined in respect to boundaries, contextuality and incentive structures, compliance and settlement mechanisms, and integration across scales. Findings show that current institutional configurations create insufficient or incoherent incentives, simultaneously reducing and reproducing sharing barriers. Regional harmonisation efforts and strategically aligned data-sharing institutions are still underdeveloped. This article discusses proposals to increase capacities and incentives for data-sharing, as well as the limitations of the chosen analytical framework. The debate is extended to aspects beyond institutional issues, i.e., structural data-sharing barriers or ethical concerns. Key recommendations include the establishment of more compelling incentives structures for data-sharing, increased funding of capacity-building and sharing infrastructure, and further awareness creation on the importance of data-sharing.

Keywords: data-sharing, ocean governance, collective action, institutional design, knowledge commons

Introduction

Coastal and oceanic ecosystems in the Western Indian Ocean (WIO) region sustain millions of lives and are characterised by their abundant biodiversity, which renders them immensely valuable in socio-economic and ecological terms (UNEP, 2015a). At the same time, they face various pressures related to anthropogenic activities and climate change (Diop *et al.*, 2016;

Hollander *et al.*, 2020). Decision-makers are challenged with mitigating these pressures while settling space-use conflicts and considering the interests and needs of a diverse range of stakeholders. Local and national coastal management strategies also need to be harmonised to meet transboundary conservation goals in the region (UNEP, 2020). To this end, sustainability-oriented decision-making and integrated

coastal area management would greatly benefit from accurate, up-to-date, and comprehensive marine biodiversity data (Pendleton *et al.*, 2020; UNEP, 2020; Satterthwaite *et al.*, 2021). However, the amount of available biodiversity data as well as processing and interpretation capacities are limited in East Africa and the larger WIO region (UNEP, 2015a). Effective data-sharing among researchers, policy-makers, and stakeholders is thus critically important. Efforts to make more data available and develop common sharing strategies are undertaken at various levels of operation, including data-sharing policies, regulations, and voluntary initiatives within and among state agencies, research institutes, and environmental organisations (UNEP, 2020). Despite these endeavours, further barriers to data-sharing persist and urgently need to be addressed by scientists, decision-makers, and environmental managers (Pendleton *et al.*, 2019; Satterthwaite *et al.*, 2021).

This article aims to examine prevailing institutional barriers to data-sharing, building on findings of a qualitative exploratory study which was conducted to investigate data-sharing practices in coastal East Africa (Schwindenhammer, 2020). Data-sharing is a complex activity and involves various forms of information exchange among actors, within or across different sectors, i.e., research, politics, industry, and civil society. Findings from the exploratory study suggest that considerably different and even contrasting normative views of *what* data-sharing should entail and *how* it should be organised exist. This, despite a common understanding of its importance in general. Effective, equitable, and harmonised sharing practices in East Africa and the larger WIO region are yet to be further developed and refined (Ibid., Schwindenhammer *et al.*, 2021). This analysis focuses on rules regulating data-handling practices in academia and research, and ways in which the current institutional design might prevent or complicate data-sharing. Implications of data-sharing for marine ecosystems sustainability and regional ocean governance are discussed. A collective action theory perspective (Ostrom, 1990) is used to investigate these issues and propose options for more productive exchange at the nexus of science, policy, and management. With this analysis, the authors intend to contribute to existing data-sharing recommendations for decision-makers and scientists in the WIO region (UNESCO-IOC, 2019; Schwindenhammer *et al.*, 2021). This article mainly focuses on data-handling practices in science and academia, while remaining conscious that these may differ in interaction with other sectors.

Background on data-sharing in the WIO region

Data and information concerning the state of key species and ecosystems in coastal and marine environments of the WIO region are important to inform decision-making (UNEP, 2020; Satterthwaite *et al.*, 2021). As such, the sharing of scientific products (data, information) with policy-makers is essential for ocean governance. Generally, many researchers are motivated to share their findings, e.g., to expedite scientific advancements, for collaborative purposes, to inform and educate, to increase the impact of their work, to generate funding, or to advance their career (Schmidt *et al.*, 2016; Figueiredo, 2017; Schwindenhammer, 2020). Such collaboration is vital to enhance research in data-poor countries, which have limited capacities to collect, process, and analyse data (Hollander *et al.*, 2020). Local researchers and practitioners with long-standing experience are well aware of blind spots and limiting factors for data-sharing in the WIO region. During expert workshops¹, they have underlined the need for more uniform data collection and handling approaches, increased fostering of sharing skills and capacities, and taxonomy training for non-academics working with marine biodiversity data (Schwindenhammer *et al.*, 2021). Furthermore, numerous initiatives exist to provide data and increase information flows. For example, the Nairobi Convention's Coral Reef Task Force (CRTF), which consists of two nodes of the Global Coral Reef Monitoring Network (GCRMN), has successfully compiled complementary ecological data from multiple contributors into consolidated datasets (Obura *et al.*, 2017; Gudka *et al.*, 2018). These datasets have been pivotal to recent regional reef status reporting (Ibid.) and other analyses (Obura *et al.*, 2021). Another important regional initiative is the Clearinghouse Mechanism² introduced by the UNEP Nairobi Convention³, which aims to provide a regional data reference centre, facilitating data-sharing for Contracting Parties and their stakeholders in the WIO region.

¹ Workshops took place in the context of the NeDiT project, led by the Institute of Marine Sciences at the University of Dar es Salaam (IMS) and the Leibniz Centre for Tropical Marine Research (ZMT). The international partnership project aims to create a collaborative network of researchers using innovative digital technologies to inform marine resource management.

² Available at <https://www.nairobiconvention.org/clearinghouse/>

³ The Nairobi Convention is an intergovernmental partnership between states, private sector, and civil society.

Theoretical Framework

Governing the commons

Resources can be conceptualised as different kinds of goods, e.g., public and accessible to everyone, or private and only accessible to few (Ostrom and Ostrom, 1977; Ostrom, 1990). When natural resources are shared by one or several groups, dilemmas of appropriation and provision are bound to occur. This is particularly true for *common-pool-resources*, which are freely accessible and at the same time highly subtractable, i.e., using the resource or extracting units from it will leave less for others. *Commons* are resource systems which may include several types of goods and are used by more than one individual or entity (Ibid.). For many years, commons researchers proposed that self-interested individuals were incapable of achieving collective benefits as a group, i.e., using it sustainably. This rather fatalistic assumption, most famously described by Hardin's *Tragedy of the Commons* (1968), has long served as a rationale to prescribe approaches for the governance of natural resources, i.e., through state and market instruments (Gordon, 1954; Olson, 1971; Demsetz, 1974). However, empirical findings have repeatedly indicated that communities are capable of aligning individual and group interests with regards to the use of shared resources (Ostrom, 1990; Gautam and Shivakoti, 2005; Cox *et al.*, 2010). *Collective action theory* aims to understand how such communities cooperate through self-organisation, and why some succeed in overcoming commons dilemmas whereas others do not. One of the most prominent scholars in this field, Elinor Ostrom, has identified social and ecological variables which influence self-organisation for community-based resource governance (Ostrom, 1990; McGinnis and Ostrom, 1992; Hess and Ostrom, 2007).

Data as a shared resource

Although collective action concepts generally describe dilemmas of natural resource use, for example fish stocks or forests, they may also apply to *knowledge commons* (Hess and Ostrom, 2007, p. 4). Knowledge can be understood as 'intelligible ideas, information, and data' and implies varying degrees of accessibility and possibilities for appropriation (Ibid., p. 8). Publicly available scientific data and information, which are analysed holistically across geographical and disciplinary borders, could potentially bear great societal benefits (Figueiredo, 2017). Advocates of the open science movement emphasise the increased transparency, quality, and impact that could be achieved, and stress the societal obligations of science (Elliott and Resnik, 2019; Krishna, 2020). In an ideal world,

one may be inclined to envision scientific data as public goods, which are freely accessible and non-subtractable (i.e., one individual's use of data does not reduce the value to others using the same resource). Conversely, data are often understood as a common-pool resources which are rivalled in use and may be affected by collective issues such as freeriding, congestion, overuse, and conflict (Hess and Ostrom, 2007). Knowledge commons face issues such as 'commodification or enclosure, pollution and degradation, and nonsustainability', similarly to natural resources (Hess and Ostrom, 2007, p. 5; Krishna, 2020). Technological advancement throughout the last decades has rendered data a highly complex resource, creating new possibilities for sharing and collaboration, while simultaneously increasing the (perceived) risk of abuse and stealing (Hess and Ostrom, 2007, p. 14). In social environments characterised by high rivalry, i.e., competition for innovation and publications, incentives to withhold data often outweigh those for sharing. Cooperation may further be impeded by a lack of recognition and due credit, fear of data misuse, or additional efforts associated with sharing (Schmidt *et al.*, 2016; Figueiredo, 2017; Chawinga and Zinn, 2019). Researchers who have invested personal and financial resources into data collection and analysis may find themselves in a dilemma of wanting to share their findings while also collecting the rewards of their hard work (Ibid.). Even if they decide to share data, further issues may arise due to the incompatibility of different datasets that were collected under a variety of methodologies, equipment, time scales, details, or insufficient data quality (Schmidt *et al.*, 2016). When researchers lack the time and capacity to use the findings to their full extent, some data may remain unused on private servers or repositories. Such 'data loss' may also occur with digitally stored information on short-lived webpages and databases (Waters, 2007) or because of the lack of metadata describing these datasets (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021). Scholars have stressed the importance of preventing data loss and enclosure (Heller, 1998; Boyle, 2007; Krishna, 2020), as it may leave scarce scientific resources underused. This is particularly problematic in the context of coastal and ocean governance, in which knowledge is both scarce and urgently needed to address complex and pressing social and environmental challenges (UNEP, 2020; Satterthwaite *et al.*, 2021). Efforts are currently in place to mitigate against losing datasets by making global databases more robust to accept all data types and formats, e.g., the Ocean Biogeographic Information System (OBIS) (De

Pooter *et al.*, 2017) and the World Register of Marine Species (WoRMS) (Vandepitte *et al.*, 2018). Given this state of data-sharing, investigating underlying institutional structures may help to better understand barriers to data-sharing and how to overcome them (Hess and Ostrom, 2007; UNESCO-IOC, 2017).

Institutional design for collective action

Collective action, such as preventing the deterioration of common-pool resources, relies on trust and reciprocity among members of a community or group (Ostrom, 1990). Social interactions are organised by *institutions*, commonly understood rules which shape responsibilities, procedures, and payoffs for individuals (Ibid.), helping them to reduce uncertainty in social environments (North, 1990). Formal rules are officially documented and enforceable, sometimes legally binding, for example laws, contracts, or directives. Informal rules are based on social norms and interpersonal agreements, usually imposed through social repercussions, e.g., affecting an individual's reputation, access to certain social spheres,

or collaboration opportunities (Ostrom, 1990). In the context of data-sharing, institutions provide incentives and disincentives for individuals or entities to make their data available to others. From a multitude of empirical studies, Ostrom and her colleagues identified eight design principles for 'robust, long-enduring' institutions (Hess and Ostrom, 2007, p. 7). These principles may help explain under which conditions trust and reciprocity can be built and maintained for the sustainable use of common-pool resources. Such collective action is also relevant in the context of data-sharing. Data in shared knowledge systems often involve different usage rights and opportunities for access for various user groups, which requires appropriate institutional arrangements to foster its equitable, efficient, and sustainable use (Ibid., p. 6). This is particularly relevant in the WIO region, where decision-makers from ten countries draw on their collective marine biodiversity knowledge to govern shared ecosystems. In the following sections, Ostrom's design principles will serve as a point of reference to assess select institutional arrangements for data-sharing in

Table 1. Design principles of robust institutions for data-sharing, based on Ostrom (1990) and McGinnis and Ostrom (1992).

Principle	Meaning for Data Sharing
1. Clearly defined boundaries: Individuals or entities who have rights to withdraw units from the resource must be clearly defined, as must the boundaries of the resource itself.	Clear definition of who may access and/or use specific sets of data, as well as the extent to which these data may be used, modified, and/or shared.
2. Context-specific rules: Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labour, materials, and/or money.	Rules affecting the distribution of costs and duties in data-sharing arrangements are closely related to the distribution of benefits and rights. These rules are tailored to the situational conditions, i.e., type of data or capacities of involved parties.
3. Collective-choice arrangements: Most individuals affected by operational rules can participate in modifying operational rules.	Those involved may participate in creating and/or revising rules of data-sharing arrangements.
4. Monitoring of compliance: Monitors, who actively audit resource conditions and participant behaviour, are accountable to the participants or are the participants.	Those monitoring data-sharing activities are accountable to other members of data-sharing arrangements or are members themselves.
5. Graduated sanctions: Participants who violate operational rules are likely to experience assessed graduated sanctions (depending on the seriousness and context of the offense) from other participants, by officials accountable to these participants, or by both.	Those who violate rules of data-sharing arrangements face sanctions which are proportional to severity and context (e.g., repetition) of the offense. These sanctions are carried out by other members or monitors of the violated data-sharing arrangement.
6. Conflict-resolution mechanisms: Participants and their officials have rapid access to low-cost, local arenas to resolve conflict among participants or between participants and officials.	Spaces and procedures exist to easily resolve conflicts related to data-sharing arrangements, i.e., among members or between members and external officials.
7. Minimal recognition of rights to organise: The rights of participants to devise their own institutions are not challenged by external governmental authorities.	Involved parties can create and enforce their own rules for data-sharing arrangements without interference from government authorities.
8. Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises.	Rules, monitoring, sanctions, and governance activities related to data-sharing arrangements need to harmonise and complement each other among user groups and across scale.

Kenya and Tanzania and to identify potential areas for improvement. Table 1 contains an overview of the eight design principles, their definitions, as well as their meaning in the context of data-sharing.

Methodology

Data collection and previous analysis

An exploratory, qualitative study was conducted for the purpose of a Master thesis in the context of the NeDiT⁴ project (Schwindenhammer, 2020). In November and December 2019, thirteen interviews were conducted in Kenya (Mombasa and Nairobi) as well as Zanzibar, Tanzania. Interview partners were chosen through a combination of criterion and snowball sampling (Patton, 2002), mostly involving partners of the NeDiT project network. Professional involvement with marine biodiversity data, such as using, providing, or producing it, was the main selection criterion. Potential interview partners were either approached in person or contacted via email before arranging conversations. Data were collected through semi-structured interviews, using the ‘romantic conception of interviewing’ (Roulston, 2010). This interview method served to build trust and rapport between researcher and participant, encouraging a high degree of openness and self-revelation by the latter. A semi-structured interview guide granted flexibility and conversational flow while covering all topics of interest (Patton, 2002) and allowed participants to express ideas in their own words (Flick, 2015). Interview questions were informed by previous experiences of the NeDiT project, as well as Ostrom’s institutional design principles and assumptions (1990), contributing to six research objectives. These objectives were to: 1) understand the current situation of actors who produce, process, analyse, or use marine biodiversity data; 2) identify motives for sharing marine biodiversity data in different formats; 3) identify existing formal and informal rules related to the handling and sharing of marine biodiversity data and analysing the mediating role they play; 4) explore patterns of interactions between involved actors and investigate the mediating role of social norms and trust; 5) determine the willingness and capacities of involved actors to share marine biodiversity data among each other and with others in different formats; and 6) to explore which new rules and norms could be established to increase collaboration among actors (Schwindenhammer, 2020). Prior to beginning the interview, participants were informed about the procedure, the pur-

pose of the study, and about their rights to withdraw from the interview at any time. They were advised to sign the consent form and asked permission to record the conversation on a private mobile phone. Afterwards, interviews lasted between 34 and 96 minutes. Recordings were complemented by extensive notes taken during the interview, which were reviewed and annotated with further personal impressions after each session (Patton, 2002).

After the completion of field interviews, a two-fold qualitative text analysis was conducted to identify common themes around data-sharing. Interview recordings were transcribed as post-scripts, which included a detailed account in the form of paraphrased statements while remaining close to a participant’s choice of language and expressions. Whereas parts of little relevance to the research topic were shortened or omitted, particularly relevant or interesting statements were transcribed as full citations, based on the judgment of the researcher. In another step, paragraphs within these post-scripts were re-ordered by topic to facilitate coding. A free version of the qualitative data analysis software f4analyse⁵ (Evers, 2018) was employed for two rounds of coding, using a combination of deductive and inductive coding. For the first round, an initial coding frame was developed according to the interview guide and findings from the Belmont Forum Open Data Survey (Schmidt *et al.*, 2016). The initial coding frame was tested using a line-by-line method and subsequently revised to include additional categories and three *in-vivo* codes which emerged from the second round of inductive coding. The final coding frame included five main categories which encompassed statements related to: 1) motivation for sharing; 2) descriptions of what makes shared data valuable; 3) accounts of how data are shared; 4) institutions and rules; and 5) conditions which may impede data-sharing. In addition to the content analysis, a comparison of institutional contexts was conducted, using a different framework⁶ which is beyond the scope of this paper. The main purpose of this additional analysis was to understand how varying institutional configurations in seemingly similar contexts could produce vastly different outcomes regarding data-sharing.

⁴ More project information available at <https://www.leibniz-zmt.de/en/research/research-projects/nedit.html>

⁵ Version 1.0.0-beta.26 FREE for Windows, available at <https://www.audiotranskription.de/english/f4-analyse>

⁶ The framework used was the Institutional Analysis Development (IAD Framework). More detailed information about the study may be requested from the corresponding author.

Present article

Aggregated findings of the study were systematically re-examined according to Ostrom's eight institutional design principles (1990), which were thematically grouped into four clusters, i.e., '*boundaries*', '*congruence of context, costs, and benefits*', '*compliance and settlements*', and '*integration across scales*'. Specifically, *operational rules*, which organise daily activities around resource appropriation and provision, their monitoring, as well as the enforcement of sanctions, were investigated (Hess and Ostrom, 2007).

Findings

An abundance of operational rules affects scientific data-sharing practices in Kenya and Tanzania. This section relates these rules in view of Ostrom's institutional design principles (1990). In each cluster, the interpretation of these principles in the context of data-sharing is elaborated prior to specifying examples from the study.

Boundaries

This first cluster includes findings related to principle 1 (see Table 1), which is understood as the necessity to define explicit boundaries in operational data-sharing rules. Appropriation rules indicate individuals or groups who may access certain datasets and specify ways in which these data may be used, modified, or shared with others. Whereas some datasets may be freely available to anyone, e.g., in open access formats, others may be reserved for users of a certain professional background, employees or affiliates of an institute, agency, or organisation, or for individuals involved in a project. Moreover, financial boundaries restrict data access via subscriptions or once-off payments. Limitations for data use include restrictions for specific purposes, determine the level of aggregation which may be accessed and modified (i.e., primary or compiled data), or state the appropriate form of acknowledgement given to data collectors and owners. Sustainable data use implicates sensible information-handling, with boundaries in place to protect original ideas or vulnerable species from exploitation.

Participants of the study consider boundaries established in formal sharing rules important to prevent conflict, reduce ambiguity, and create a sense of control over the data. Yet, boundaries around shared data often appear unclear and non-transparent in practice, especially in the case of openly accessible databases or repositories. In such open formats, data contributors may anticipate loss of control and authority over

their data, not knowing who can access them and how they are used. Concerns about data misuse, i.e., use and reproduction without permission, for unintended purposes, or without acknowledgement, may prevent researchers from sharing data to open platforms. Alternatively, sharing information about data, e.g., via metadata declarations or data papers⁷, enables contributors to establish more explicit boundaries and maintain transparency. This form of sharing is popular among contributors and data users alike, as it creates data visibility while retaining control over access and use. Direct sharing of datasets, i.e., from one person or entity to another, also allows for an unambiguous communication of boundaries through verbal or written agreements. Overly strict boundaries, on the other hand, may also constitute data-sharing barriers. Some individuals may struggle with legal constraints on data-sharing, e.g., restrictive contracts which prevent sharing or use beyond the scope of specific projects. In the WIO region, a substantial amount of data is dispersed across specialised databases of government departments, research institutes, or organisations, only accessible to employees and affiliates. Moreover, sensitive data may be confined within national borders, e.g., data containing genetic information.

Congruence of context, costs, and benefits

This cluster reports on findings with respect to design principles 2, 3, and 7 (see Table 1). Appropriation rules are suitable in the context of application, e.g., considering the appropriate extent of data accessibility, the intended group of users and their capacity to adhere to given rules, as well as local culture and customs. Moreover, provision rules assigning costs and duties in data-sharing arrangements are closely aligned with the distribution of benefits and rights, promoting rule adherence from a cost-benefit perspective and conveying equity. For example, those investing time and financial resources into the collection, treatment, or provision of data profit from their findings or receive credit when these data are used by others. Equity is promoted by applying sharing rules to everyone while considering variations according to individual needs and abilities. If possible, affected users and contributors are involved in the creation or modification of operational rules. They may possess profound information and experience to devise effective and context-specific rules, contrary to externally imposed statutes which may neglect local conditions.

⁷ Searchable metadata documents, which describe a particular dataset or a group of datasets and may be published in peer-reviewed journal articles.

Furthermore, locally devised data-sharing rules may be more potent in the absence of interference from external authorities, i.e., governments.

In the study cases, scientific data-handling is often regulated by rules created in local contexts, e.g., through internal policies or directives of research institutes, organisations, or journals. For instance, researchers are frequently required to contribute data declarations or entire datasets to internal repositories of their affiliated institute upon completion of a project. These operational rules are generally appropriate for affected employees and affiliates, matching their capacities to comply and securing sensitive information. Incentives for sharing are created by making it a prerequisite for research licenses, field-work permissions, project funding, or publishing. In some situations, general data-sharing rules require some flexibility on an individual basis, e.g., for projects involving longitudinal data collection. In absence of guaranteed data protection and credit for data contributors, individuals may perceive risks and burdens of sharing as larger than its benefits, especially in highly competitive research environments. This may reduce their willingness to share data unless attribution or authorship is strictly enforced.

Creating context-specific provision and appropriation rules is often a challenge for open access databases, which have a broad user base and mostly rely on voluntary contributions. Instead, some global databases provide additional sharing incentives, such as the DOI service⁸ offered by the Flanders Marine Institute (VLIZ) which hosts the World Register of Marine Species (WoRMS), African Register of Marine Species (AfReMaS) and the Ocean Biodiversity Information System (OBIS) databases. This service enables researchers to formally publish their data, so they can be traced and cited. For projects or bilateral agreements, contracts are commonly used to establish formal data-sharing rules, e.g., creating a memorandum of understanding about when, how, and with whom data collected within a funded project should be shared. Projects involving multiple partners may employ initiative-specific data-sharing agreements with each data owner to facilitate sharing, as was the case for the Nairobi Convention's CRTF ecological data compilation (Obura *et al.*, 2017; Gudka *et al.*, 2018). Assigning data coordination and management responsibilities to a trusted non-governmental intermediary in the region

sustains perceived impartiality and fairness in such large projects. Rules are also commonly established informally, i.e., through interpersonal verbal agreements. Due to direct and clear communication among involved parties, contracts and informal agreements often result in high contextuality and a fair distribution of benefits. Incentives to share data are high to avoid legal or social repercussions.

Compliance and settlements

This cluster includes findings regarding principles 4, 5, and 6 (see Table 1). Compliance with operational data-sharing rules is monitored to identify and address rule violations. Ideally, compliance monitors belong to the group affected by these rules or are in some way accountable to its members, rather than uninvolved external authorities. Known and observable monitors are more likely to establish rapport with the people they oversee, fostering trust and cooperation. Moreover, monitors who benefit from sustainable data-handling practices have additional incentives to ensure rule compliance. Sanctions for violations of operational data-sharing rules are fair and enforceable, which means they are proportional to the severity and context of the offense, avoiding excessively harsh or unreasonable punishments. Disciplinary measures include the limitation or withdrawal of permissions, e.g., to publish, conduct field-work, or access repositories. Consequences could also be of a financial nature, i.e., fines or retraction of funding. Finally, spaces and procedures exist to resolve conflicts around data-sharing at low costs.

Participants in this study generally perceive a high adherence to data-sharing rules. Ample accountability exists among people who directly interact and can observe each other's behaviour, e.g., colleagues and project partners. As data-sharing is often required prior to obtaining funding or permissions, monitoring automatically becomes a by-product of approval processes, and rules are easily enforced. Executives in research institutes have a strong interest to ensure that all scientific data are shared into their respective repository, particularly those serving a double-function as National Oceanographic Data Centres (NODCs). However, in absence of formalised rules, comprehensive monitoring and successful enforcement of data-sharing is less likely. Moreover, in settings in which data contributors and users seldom interact or stay anonymous, e.g., open access databases, individuals may attempt to avoid accountability. Monitoring through strong peer review systems

⁸ Flanders Marine Institute, available at <http://www.vliz.be/en/publish>

may complement formal rules and create additional incentives to share, especially in competitive professional environments. For instance, the peer review screening by the WIO Journal of Marine Science (WIOJMS) enables regional reviewers acquainted with current research activities to detect plagiarised ideas or data. Disputes around data-sharing may emerge between or among individuals, organisations, or authorities. Breaching of contracts is usually followed by established protocols to settle conflicts, whereas disciplinary boards may conciliate violations of internal directives and codes of conduct. Data are often shared informally, rendering conflict resolution dependent on the personal relationship of involved parties. Although these arrangements often involve a high degree of accountability and are easily monitored, they are unsuitable to serve as reliable long-term understandings and lack standardised procedures to deal with disagreements, e.g., when relationships or conditions change.

Integration across scales

This cluster involves aspects related to the principle 8 (see Table 1), which translates to the need for data-sharing rules, monitoring, sanctions, and governance activities to harmonise and complement each other among user groups and across scale. Like puzzle pieces, different rules and regulations between individuals, organisations, authorities, and regional coordination bodies interlock and engage in the bigger picture of the data-sharing institutional landscape.

Operational data-sharing rules in the WIO region are often influenced by higher-level institutions such as national laws, e.g., decrees which require reporting of scientific data to government authorities or regulate data-sharing across borders. In Kenya, for instance, guidelines for data-sharing are provided by the National Commission for Science, Technology and Innovation (NACOSTI), which manages research activities in the country. Moreover, international data-sharing standards and obligations may prompt the creation of operational rules, e.g., through mandates of the Nairobi Convention (UNEP, 2015b), the Convention of Biological Diversity (Secretariat of the CBD, 2010, 2012, 2020) or the United Nations (UNESCO-IOC, 2014, 2019; United Nations, 2015). Norms for data-sharing in research and academia are further shaped by international frameworks, such as the 'Findable, Accessible, Interoperable, and Reusable' (FAIR) principles (Wilkinson *et al.*, 2016) or the

'CARE' principles for indigenous data sources⁹. Overall, various influences and interests have resulted in the large number and diversity of data-sharing rules and regulations in the region. Sometimes, these rules are inconsistent or even contradict each other. For instance, NACOSTI obliges researchers to report data collected in Kenya to the respective affiliation institute, including full datasets, metadata forms, research articles, or dissertations. NACOSTI further prohibits the sharing of certain findings across national borders. At the same time, these researchers may be bound to different sharing policies at their workplace or must uphold contract agreements with project donors and partners. Such legal constraints especially affect international and inter-organisational projects which conduct research on transboundary ecosystems.

Moreover, international or regional attempts to harmonise data-sharing often fall short of integrating across scale. A regional data-sharing protocol by the Nairobi Convention, for instance, would rely on voluntary commitments of signatory states. However, it may be incompatible with existing protocols in some of these states. Further, a considerable amount of research data never reaches national repositories, e.g., due to inconsistent sharing rules in institutes and organisations, or because of a shortage of data collection capacities.

Discussion

This investigation guided by Ostrom's design principles (1990) sheds light on the intricate web of social norms and formal rules for data-sharing in Kenya and Tanzania, as well as the institutional barriers which persist.

Paradoxes and payoffs

In their current constellation, institutional arrangements create incentives both for and against sharing, simultaneously reducing and creating data flow barriers. Given the pressing demand for scientific data, devising rules that are fair, realistic, and effective seems to constitute a delicate balance between creating incentives for voluntary sharing while also employing compulsory means. Although similar principles of institutional design may be applied, organising collective action for the sustainable use of shared data fundamentally differs from sharing natural resource commons. For instance, defining appropriate boundaries of access and use is often more difficult for a

⁹ Global Indigenous Data Alliance, available at <https://www.gida-global.org/care>

dataset than for physical places, such as lakes or forests. Whereas data may be collected and processed in a specific place and by a closed group of people, boundaries become increasingly intangible as such data are shared and further handled in digital spaces. This is apparent in the difficulty to establish context-appropriate and enforceable sharing rules in large open access databases, which store data from a variety of places and contributors and have a broad, sometimes anonymous, user base. Although open sharing practices are often encouraged to reduce bureaucracy and accelerate research processes, highly contextual rules may actually produce additional administrative burdens, e.g., when specific contracts are needed for each alternative use of the same datasets.

The dispersion of scientific information across specialised databases is another example of such bureaucratic hindrances, as outsiders need to obtain permissions for data access and use. Whereas these boundaries may seem reasonable from an organisational perspective, they can impede essential collaborations and efficient data-reporting to national or regional regulatory bodies. A payoff between contextualised boundaries and streamlining of information seems inevitable if regional and international conservation goals are to be effectively supported. Informal sharing based on trust and personal relationships is frequently used to circumvent data accessibility issues and plays an important, yet ambiguous role. On one hand, these unofficial sharing pathways may serve as a foundation to develop formal agreements and build long-term professional relationships. At the same time, they can reduce transparency and awareness of existing data, reproducing the exact issues which data-sharing aims to reduce, i.e., research redundancy and information gaps. Furthermore, agreements bound to personal relationships are vulnerable to change and may even result in ownership conflicts. Thus, depending on the context, informal rules can both strengthen and undermine formal institutions.

Moreover, the incongruence of time horizons in science and governance poses another contradiction. Research and publishing are lengthy processes and scientific data may only become available after several years, whereas the information is needed immediately. Requiring data-sharing within shorter time frames would often be unattainable, as stages of data collection or processing may still be incomplete or because of inadequate personal capacities. Furthermore, premature sharing may contradict other obligations researchers have, e.g., with

donors or project partners. Due to these discrepancies, research findings might become significantly delayed and cannot be used to inform policy and management decisions in a timely manner.

Perspectives for ocean governance

To facilitate regional ocean governance, i.e., achieving the Sustainable Development Goals (United Nations, 2015), the Aichi Biodiversity targets (Secretariat of the CBD, 2010), and milestones defined in the UN Decade for Ocean Science (UNESCO-IOC, 2019), data-sharing is imperative. Otherwise, the measurement of relevant indicators and mobilisation of the necessary political and financial capital to implement decisions is unattainable. In the WIO region, numerous approaches to counter the issues outlined above are starting to develop or already exist, albeit inconsistently. For instance, the growing use of metadata declarations, both for obligatory and voluntary sharing, is highly promising. Sharing metadata can constitute a valuable compromise, increasing the visibility of scientific data and transparency of their origin, while contributors retain control over access and use. This could be an especially fruitful option to encourage sharing to open access databases or from ongoing research projects.

Publishing and funding bodies possess considerable levers to shape and enforce data-sharing rules, and thus play a central role in fostering metadata availability (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021). Targeted policy adjustments could grant greater legal authority to NODCs and increase their capacity to act as intermediaries for the implementation of data-sharing mandates. Additionally, the inclusion of feedback mechanisms, e.g., tracing access and purpose of use, could further reduce fears of data misuse and increase voluntary sharing (Pendleton *et al.*, 2019; Chawinga and Zinn, 2019). Sharing could further be encouraged with a simplified publishing process, i.e., promoting data papers and attributing them the same significance as traditional research articles (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021).

Providing traceable and citable DOIs for datasets is another auspicious approach to reward frequent and swift data-sharing, especially for time-sensitive research needed to inform indicator-based conservation strategies (Pendleton *et al.*, 2019; Chawinga and Zinn, 2019). Such data citations further ensure that the data cannot be manipulated and anyone claiming them as their originators can be confirmed

by the citations. Authorship crediting mechanisms in journals could further be adapted to better acknowledge the contributions of individual authors in large collaborations, contrary to the current focus on first and last authors (Li *et al.*, 2021; Devriendt *et al.*, 2022). Moreover, attention should be paid to create equitable, collaborative, and inclusive environments in diverse research teams, as a cordial work climate may positively impact data-sharing practices (Settles *et al.*, 2019). Currently, some researchers in the region have embraced collaborations for publishing global papers or regional assessments. Shared skills from these experiences spur the creation of new networks and can ultimately attract more funding as a wider group of donors and collaborators become involved. This is particularly relevant in instances in which no historical precedence for data-sharing policies exists and uncertainty about the benefits of sharing prevails.

Leonelli *et al.* (2018) stress the need to sensitise global data-sharing efforts to diverse research environments, pointing out global differences in access to digital infrastructure and highlighting the distinct challenges, concerns, and goals of African researchers. They further criticise the unequal power relations in global standards of scientific rigour and data quality, which are usually determined by countries with privileged access to technical and financial resources (Ibid.). Contextual considerations may increase the accessibility of international data-sharing spaces for researchers from low-resourced environments. To this end, donors and funding bodies could consider more flexible financing options, e.g., in the form of micro-funding for routine research activities (Rappert, 2017). Researchers should receive comprehensive data-sharing training, ideally early in their career (Chawinga and Zinn, 2019; Tanhua *et al.*, 2019; Schwindenhammer *et al.*, 2021). Chawinga and Zinn (2019) propose that researchers are educated to spend equal efforts toward data management as to research publications. Some scholars caution against imprudent data-sharing or absolute interpretations of openness (Leonelli *et al.*, 2018). Instead, they underscore the need to provide researchers with data-sharing tools that enable them to include a variety of considerations and make ethical, safe choices (Levin and Leonelli, 2017; Leonelli *et al.*, 2018). Examples for African-led initiatives prioritising ethical and adequate data-sharing include the African Open Science Platform (Boulton *et al.*, 2018) or H3Africa and H3BioNet (Leonelli *et al.*, 2018).

Limitations and further considerations

This paper highlights a few examples of data-sharing issues in the WIO region. However, these findings are not necessarily representative or generalisable for the entire region, as the empirical basis is a small qualitative sample from selected locations in Kenya and Tanzania (Schwindenhammer, 2020). Another limitation may have been the exclusive use of collective action as a theoretical perspective, as it only encompasses institutional aspects of data-sharing issues. Recalling the FAIR principles (Wilkinson *et al.*, 2016), sharing rules and directives often address data findability and accessibility, while omitting dimensions of interoperability and reusability. Comprehensive harmonisation of data-sharing efforts across scales thus exceeds the coordination of rules and should also consider structural barriers. Such obstacles include, for instance, inadequate quality, comprehensibility, or applicability of data shared for decision-making (Fisher *et al.*, 2010; Tanhua *et al.*, 2019; Schwindenhammer *et al.*, 2021); or navigation issues for other researchers wanting to use shared data (Pendleton *et al.*, 2019). Tanhua *et al.* (2019) suggest building interoperable data management systems based on existing structures, i.e., databases and open sharing infrastructures. A practical example for this is the European Marine Observation and Data Network (EMODnet)¹⁰ effort, which provides access to European marine data from local, national, regional, and international repositories (Ibid.). Additional efforts to increase the robustness of global databases, i.e., compatibility with all data types and formats, are currently in place to mitigate against losing datasets, e.g., in OBIS (De Pooter *et al.*, 2017), WoRMS (Vandepitte *et al.*, 2018), and AfReMaS (Odido *et al.*, 2022).

Others propose a combination of technical and cultural solutions, drawing from various sectors to address sharing barriers (Pendleton *et al.*, 2019). This could be in the form of ‘ocean data combinatory machines’, i.e., technology platforms which draw lessons from commercial online marketplaces to bring together data, researchers, and users (Ibid., p. 6). Data management systems should be built in anticipation of an increased volume of data in the near future, e.g., due to technological advances and facilitated data capture through sensors (Tanhua *et al.*, 2019). Close collaborations with sensor manufacturers could result in direct communication of metadata according to standards and conventions of the respective research community (Ibid.). Additionally, several scholars suggest incorporating

¹⁰ More information available at https://emodnet.ec.europa.eu/en/about_emodnet#inline-nav-3.

user experience-testing when developing digital data-sharing infrastructure (Hermes *et al.*, 2019; Tanhua *et al.*, 2019; Volentine *et al.*, 2021).

Furthermore, a holistic reassessment of research priorities may be needed to avoid a mismatch of research efforts and conservation needs (Fisher *et al.*, 2010), or a lack of research data use in policy-making (Aggestama and Mangalagiu, 2020). Such insights could be yielded from a focus on the co-production of knowledge and expertise (Wyborn *et al.*, 2019). Participatory methods, i.e., collaborative or transdisciplinary research designs, could highlight the perspectives of all relevant stakeholders, create more equitable data collection processes, and produce actionable data for decision-making (Berkes *et al.*, 2000; Cinner *et al.*, 2009; Glass and Newig, 2019; Norström *et al.*, 2020). Lastly, a substantial amount of financial capital is necessary to build and maintain data-sharing capacity-building and infrastructure. This should be considered when allocating financial priorities in projects, as well as in organisational, national, or international budgets (Leonelli *et al.*, 2018; Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021).

Conclusion

This article intends to contribute to a more profound understanding of institutional data-sharing barriers in the WIO region and their implications for regional ocean governance. For this purpose, a collective action theory lens was applied, using Elinor Ostrom's institutional design principles (Ostrom, 1990) as an analytical framework to review existing data sharing-rules and how they interact. Data-sharing is commonly believed to be a matter of ethical obligation, fairness, and proper scientific conduct. However, this social norm does not always translate into the routines of people who work with marine biodiversity data. Current institutional configurations often create insufficient or incoherent incentives for sharing. In absence of clear, enforceable, and fair rules, competitive professional contexts tend to promote non-collaborative data-handling practices. Existing initiatives to harmonise data-sharing practices in the region still have little directly measurable effects on more effective coordination, as links to strategically align data-sharing institutions across governance levels are still underdeveloped. Overall, three key messages emerged from the findings of this paper. Firstly, more compelling incentives for individual and organisational data-sharing must be established. A transformation of the reward system in scientific professional circles

could tie benefits and career advancement to timely and transparent sharing, e.g., promoting data papers or DOIs for datasets. Measures to make project funding or publishing contingent on data-sharing have also proven successful in encouraging open data practices. Secondly, capacity-building and infrastructure for data-sharing should be considered more prominently when allocating fiscal budgets for projects, institutes and organisations, or constituencies. Thirdly, further awareness creation on the importance of data-sharing among researchers, publishers, and funding bodies is essential. A sharing culture should be nourished in all research environments, with lessons learned from successful regional collaboration examples.

Acknowledgements

Data used in this publication was collected by D. Schwindenhammer in the context of the NeDiT project, under the supervision and guidance of A. Schlüter, H. Reuter, and H. Kegler. This article was developed in cooperation with project partners from the Leibniz ZMT in Germany, KMFRI and CORDIO in Kenya, as well as the IMS, TAFIRI, and WIOMSA in Tanzania. We would like to express our gratitude toward the interview partners who gifted us with their time and experiences. Acknowledging any use of our collaborators' own work, we assume there is no conflict of interest. For any inquiries, the main author may be contacted.

References

- Aggestama F, Mangalagiu D (2020) Is sharing truly caring? Environmental data value chains and policymaking in Europe and Central Asia. *Environmental Science and Policy* 114: 152-161 [doi: 10.1016/j.envsci.2020.07.012]
- Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications* 10 (5): 1251-1262 [doi: 10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2]
- Boulton G, Hodson S, Serageldin I, Qhobela M, Mokhele K, Dakora F, Veldsman S, Wafula J, participants of African open science platform stakeholder workshop, September 2018, participants of African open science platform strategy workshop, March 2018, advisory council, African open science platform project, technical advisory board, African open science platform (2018) *The Future of Science and Science of the Future: Vision and Strategy for the African Open Science Platform (v02)*. Zenodo [doi: 10.5281/zenodo.2222418]
- Boyle J (2007) Mertonianism unbound? Imagining free, decentralized access to most cultural and scientific material. In: Hess C, Ostrom E (eds.) *Understanding*

- knowledge as a commons: From theory to practice. MIT Press, Cambridge. pp 123-143
- Chawinga WD, Zinn S (2019) Global perspectives of research data sharing: A systematic literature review. *Library & Information Science Research* 41 (2): 109-122 [doi: 10.1016/j.lisr.2019.04.004]
- Cinner J., Wamukota A, Randriamahazo H, Rabearisoa A (2009) Toward institutions for community-based management of inshore marine resources in the western Indian Ocean. *Marine Policy* 33 (3): 489-496 [doi: 10.1016/j.marpol.2008.11.001]
- Cox M, Arnold G, Villamayor Tomás S (2010) A review of design principles for community-based natural resource management. *Ecology and Society* 15 (4): 38 [doi: 10.5751/es-03704-150438]
- De Pooter D, Appeltans W, Bailly N, Bristol S, Deneudt K, Eliezer M, Fujioka E, Giorgetti A, Goldstein P, Lewis M, Lipizer M, Mackay K, Marin M, Moncoiffé G, Nikolopoulou S, Provoost P, Rauch S, Roubicek A, Torres C, van de Putte A, Vandepitte L, Vanhoorne B, Vinci M, Wambiji N, Watts D, Klein Salas E, Hernandez F (2017) Toward a new data standard for combined marine biological and environmental datasets - expanding OBIS beyond species occurrences. *Biodiversity Data Journal* 5: e10989 [doi: 10.3897/BDJ.5.e10989]
- Demsetz H (1974) Toward a theory of property rights. *Classic Papers in Natural Resource Economics*: 163-177 [doi: 10.1057/9780230523210_9]
- Devriendt T, Borry P, Shabani M (2022) Credit and recognition for contributions to data-sharing platforms among cohort holders and platform developers in Europe: Interview study. *Journal of Medicinal Internet Research* 24 (1): e25983 [doi: 10.2196/25983]
- Diop S, Scheren P, Machiwa JF (2016) *Estuaries: A lifeline of ecosystem services in the western Indian Ocean*. Springer. 322 pp [doi: 10.1007/978-3-319-25370-1]
- Elliott KC, Resnik DB (2019) Making open science work for science and society. *Environmental Health Perspectives* 127 (7): 075002 [doi: 10.1289/ehp4808]
- Evers JC (2018) Current issues in qualitative data analysis software (QDAS): A user and developer perspective. *The Qualitative Report* 23 (13): 61-73 [doi: 10.46743/2160-3715/2018.3205]
- Flick U (2015) *Introducing research methodology: A beginner's guide to doing a research project*. SAGE Publications. 271 pp
- Figueiredo AS (2017) Data sharing: Convert challenges into opportunities. *Frontiers in Public Health* 5: 327 [doi: 10.3389/fpubh.2017.00327]
- Fisher R, Radford BT, Knowlton N, Brainard RE, Michaelis FB, Caley MJ (2010) Global mismatch between research effort and conservation needs of tropical coral reefs. *Conservation Letters* 4 (2011): 64-72 [doi: 10.1111/j.1755-263X.2010.00146.x]
- Gautam AP, Shivakoti GP (2005) Conditions for successful local collective action in forestry: some evidence from the hills of Nepal. *Society and Natural Resources* 18 (2): 153-171 [doi: 10.1080/08941920590894534]
- Gordon HS (1954) The economic theory of a common-property resource: The fishery. In: Gopalakrishnan C (ed) *Classic papers in natural resource economics*. Palgrave Macmillan, London. pp 178-203 [doi: 10.1057/9780230523210_10]
- Glass L-M, Newig J (2019) Governance for achieving the sustainable development goals: How important are participation, policy coherence, reflexivity, adaptation and democratic institutions? *Earth System Governance* 2: 100031 [doi: 10.1016/j.esg.2019.100031]
- Gudka M, Obura D, Mwaura J, Porter S, Yahya S, Mabwa R (2018) Impact of the 3rd global coral bleaching event on the Western Indian Ocean in 2016. *Global Coral Reef Monitoring Network (GCRMN) / Indian Ocean Commission* [doi: 10.13140/RG.2.2.32306.71365]
- Hardin G (1968) The tragedy of the commons. *Science* 162 (3859): 1243-1248 [doi: 10.1126/science.162.3859.1243]
- Heller MA (1998) The tragedy of the Anticommons: Property in the transition from Marx to markets. *Harvard Law Review* 111 (3): 621 [doi: 10.2307/1342203]
- Hermes JC, Masumoto Y, Beal LM, Roxy MK, Vialard J, Andres M, Annamalai H, Behera S, D'Adamo N, Doi T, Feng M, Han W, Hardman-Mountford N, Hendon H, Hood R, Kido S, Lee C, Lee T, Lengaigne M, Li J, Lumpkin R, Navaneeth KN, Milligan B, McPhaden MJ, Ravichandran M, Shinoda T, Singh A, Sloyan B, Strutton PG, Subramanian AC, Thurston S, Tozuka T, Ummenhofer CC, Unnikrishnan AS, Venkatesan R, Wang D, Wiggert J, Yu L, Yu W (2019) A Sustained ocean observing system in the Indian Ocean for climate related scientific knowledge and societal needs. *Frontiers in Marine Science* 6: 355 [doi: 10.3389/fmars.2019.00355]
- Hess C, Ostrom E (2007) *Understanding knowledge as a commons: From theory to practice*. MIT Press, Cambridge. 382 pp
- Hollander J, Linden O, Gudka M, Duncan MI, Obura D, James N, Bhagooli R, Nyanapah J, Onyango C, Duvane J, Louis Y, Ngotho D, Mvungi E, Mamboya F, George R, Hamisi M, Adeleke B, Ngoa E, Harlay J, Oduor N, Fondo E, Wambiji N, Raharinaivo L, Winkler A, Okemwa G, Karisa J, Madi Bamdou M, Mtaki K, Randrianandrasana J (2020) Marine organisms response to climate change effects in the Western Indian Ocean. *Journal of Indian Ocean Rim Studies* 3 (1): 33-59

- Krishna VV (2020) Open science and its enemies: Challenges for a sustainable science–society social contract. *Journal of Open Innovation: Technology, Market, and Complexity* 6 (3): 61 [doi: 10.3390/joitmc6030061]
- Leonelli S, Rappert B, Bezuidenhout L (2018) Introduction: Open data and Africa. *Data Science Journal* 17: 5 [doi: 10.5334/dsj-2018-005]
- Levin N, Leonelli S (2017) How does one “open” science? Questions of value in biological research. *Science, Technology, & Human Values* 42 (2): 280–305 [doi: 10.1177/0162243916672071]
- Li X, Cheng G, Wang L, Wang J, Ran Y, Che T, Li G, He H, Zhang Q, Jiang X, Zou Z, Zhao G (2021) Boosting geoscience data sharing in China. *Nature Geoscience* 14: 541–542 [doi: 10.1038/s41561-021-00808-y]
- McGinnis M, Ostrom E (1992) Design principles for local and global commons. Paper presented at the Linking Local and Global Commons Conference, Cambridge
- Norström AV, Cvitanovic C, Löf MF, West S, Wyborn C, Balvanera P, Bednarek AT, Bennett EM, Biggs R, de Bremond A, Campbell BM, Canadell JG, Carpenter SR, Folke C, Fulton EA, Gaffney O, Gelcich S, Jouffray J-B, Leach M, Österblom H (2020) Principles for knowledge co-production in sustainability research. *Nature Sustainability* 3 (3): 182–190 [doi: 10.1038/s41893-019-0448-2]
- North DC (1990) *Institutions, institutional change and economic performance*. Cambridge University Press, Cambridge. 152 pp [doi: 10.1017/CBO9780511808678]
- Obura D, Gudka M, Rabi FA, Gian SB, Bijoux J, Freed S, Maharavo J, Mwaura J, Porter S, Sola E, Wickel J, Yahya S, Ahamada S (2017) Coral reef status report for the Western Indian Ocean. Global Coral Reef Monitoring Network (GCRMN) / International Coral Reef Initiative (ICRI) [doi: 10.13140/RG.2.2.20642.07366]
- Obura D, Gudka M, Samoilys M, Osuka K, Mbugua J, Keith DA, Porter S, Roche R, Van Hooidonk R, Ahamada S, Araman A, Karisa J, Komakoma J, Madi M, Ravinia I, Razafindrainibe H, Yahya S, Zivane F (2021) Vulnerability to collapse of coral reef ecosystems in the western Indian Ocean. *Nature Sustainability* [doi: 10.1038/s41893-021-00817-0]
- Odido M, Appeltans W, BelHassen M, Mussai P, Nsiangango SE, Vandepitte L, Wambiji N, Zamouri N, Jiddou AM (eds) (2022) African register of marine species [https://www.marinespecies.org/afremas on 2022-01-31]
- Olson M (1971) *The logic of collective action: Public goods and the theory of groups*. Harvard University Press, Cambridge. 208 pp
- Ostrom E (1990) *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press, Cambridge. 279 pp
- Ostrom V, Ostrom E (1977) Public goods and public choices. In: Savas ES (ed) *Alternatives for delivering public services. Toward improved performance*. Westview Press. Reprinted in McGinnis, 1999. pp 7-49
- Patton MQ (2002) *Qualitative evaluation and research methods* (3rd ed.). SAGE Publications. 598 pp
- Pendleton LH, Beyer H, Estradivari, Grose SO, Hoegh-Guldberg O, Karcher DB, Kennedy E, Llewellyn L, Nys C, Shapiro A, Jain R, Kuc K, Leatherland T, O’Hainnin K, Olmedo G, Seow L, Tarsel M (2019) Disrupting data sharing for a healthier ocean. *ICES Journal of Marine Science* 76 (6): 1415–1423 [doi: 10.1093/icesjms/fsz068]
- Pendleton L, Evans K, Visbeck M (2020) Opinion: We need a global movement to transform ocean science for a better world. *Proceedings of the National Academy of Science* 117 (18): 9652–9655 [doi: 10.1073/pnas.2005485117]
- Rappert B (2017) Fostering data openness by enabling Science: A proposal for micro-funding. *Data Science Journal* 16: 44 [doi: 10.5334/dsj-2017-044]
- Roulston K (2010) Considering quality in qualitative interviewing. *Qualitative Research* 10 (2): 199–228 [doi: 10.1177/1468794109356739]
- Satterthwaite EV, Bax NJ, Miloslavich P, Ratnarajah L, Canonico G, Dunn D, Simmons SE, Carini RJ, Evans K, Allain V, Appeltans W, Batten S, Benedetti-Cecchi L, Bernard ATF, Bristol S, Benson A, Buttigieg PL, Gerhardinger LC, Chiba S, Davies TE, Duffy JE, Giron-Nava A, Hsu AJ, Kraberg AC, Kudela RM, Lear D, Montes E, Muller-Karger FE, O’Brien TD, Obura D, Provoost P, Pruckner S, Rebelo L-M, Selig ER, Kjesbu OS, Starger C, Stuart-Smith RD, Vierros M, Waller J, Weatherdon LV, Wellman TP and Zivian A (2021) Establishing the foundation for the global observing system for marine life. *Frontiers in Marine Science* 8: 737416 [doi: 10.3389/fmars.2021.737416]
- Schmidt B, Gemeinholzer B, Treloar A (2016) Open data in global environmental research: The Belmont forum’s open data survey. *PLOS ONE* 11 (1): e0146695 [doi: 10.1371/journal.pone.0146695]
- Schwindenhammer D (2020) Knowledge commons in East Africa: Relevant institutions for marine biodiversity data handling and sharing practices. MSc thesis, Faculty of Environment and Natural Resources, University of Freiburg, Freiburg. 136 pp
- Schwindenhammer D, Kegler H, Reuter H, Muhando C, Msagameno D, Rushingisha G, Tuda A, Mwangi T, Obura D (2021) Fostering marine biodiversity data sharing for decision-making in the Western Indian Ocean region. *Policy Brief* 10. [doi: 10.21244/zmt.2021.001]

- Secretariat of the CBD [Convention on Biological Diversity] (2010) Decision adopted by the Conference of Parties to the Convention on Biological Diversity at its tenth meeting. X/2. The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. Nagoya, Japan [https://www.cbd.int/decision/cop/?id=12268]
- Secretariat of the CBD [Convention on Biological Diversity] (2012) Ecologically or biologically significant marine areas (EBSAs): Scientific collaboration among dedicated experts to better understand marine biodiversity and support country efforts to achieve the Aichi Biodiversity Targets [https://www.cbd.int/marine/doc/ebsa-brochure-2012-en.pdf]
- Secretariat of the CBD [Convention on Biological Diversity] (2020) Global biodiversity outlook 5. Montreal [https://www.cbd.int/gbo5]
- Settles IH, Brassel ST, Soranno PA, Cheruvilil KS, Montgomery GM, Elliott KC (2019) Team climate mediates the effect of diversity on environmental science team satisfaction and data sharing. *PLoS ONE* 14 (7): e0219196 [doi: 10.1371/journal.pone.0219196]
- Tanhua T, Pouliquen S, Hausman J, O'Brien K, Bricher P, de Bruin T, Buck JJH, Burger EF, Carval T, Casey KS, Diggs S, Giorgetti A, Graves H, Harscoat V, Kinkade D, Muelbert JH, Novellino A, Pfeil B, Pulsifer PL, Van de Putte A, Robinson E, Schaap D, Smirnov A, Smith N, Snowden D, Spears T, Stall S, Tacoma M, Thijssse P, Tronstad S, Vandenberghe T, Wengren M, Wyborn L, Zhao Z (2019) Ocean FAIR data services. *Frontiers in Marine Science* 6: 440 [doi: 10.3389/fmars.2019.00440]
- UNESCO-IOC [Intergovernmental Oceanographic Commission] (2014) IOC medium-term strategy. UNESCO, Paris [https://unesdoc.unesco.org/ark:/48223/pf0000216743]
- UNESCO-IOC [Intergovernmental Oceanographic Commission] (2017) Global ocean science report: The current status of ocean science around the world. UNESCO Publishing. 277 pp
- UNESCO-IOC [Intergovernmental Oceanographic Commission] (2019) Summary report of the first global planning meeting: UN decade of ocean science for sustainable development. Copenhagen [https://www.oceandecade.org/decade-publications/]
- United Nations (2015) Transforming our world: the 2030 Agenda for sustainable development. A/RES/70/1. United Nations, General Assembly [https://sdgs.un.org/2030agenda]
- UNEP [United Nations Environment Programme] (2015a) The amended Nairobi convention for the protection, management and development of the marine and coastal environment of the Western Indian Ocean (Amended Nairobi Convention). Mahe, Seychelles [https://www.nairobiconvention.org/clearinghouse/node/206]
- UNEP [United Nations Environment Programme] (2015b) Regional state of the coast report: Western Indian Ocean. UNEP, Nairobi. 546 pp [https://wedocs.unep.org/handle/20.500.11822/9700]
- UNEP [United Nations Environment Programme] (2020) The state of ocean governance in the Western Indian Ocean. SAPPHERE Project, Secretariat of the Nairobi Convention, UNEP, Kenya. 65 pp [https://www.unep.org/resources/report/state-ocean-governance-western-indian-ocean-region]
- Vandepitte L, Vanhoorne B, Decock W, Vranken S, Lanssens T, Dekeyzer S, Verfaillie K, Horton T, Kroh A, Hernandez F, Mees J (2018) A decade of the World Register of Marine Species – General insights and experiences from the Data Management Team: Where are we, what have we learned and how can we continue? *PLOS ONE* 13 (4): e0194599 [doi: 10.1371/journal.pone.0194599]
- Volentine R, Specht A, Allard S, Frame M, Hu R, Zolly L (2021) Accessibility of environmental data for sharing: The role of UX in large cyberinfrastructure projects. *Ecological Informatics* 63: 101317 [doi: 10.1016/j.ecoinf.2021.101317]
- Waters D (2007) Preserving the knowledge commons. In: Hess C, Ostrom E (eds) *Understanding knowledge as a commons: From theory to practice*. MIT Press, Cambridge. pp 145-166
- Wilkinson MD, Dumontier M, Aalbersberg IJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten JW, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, 't Hoen PAC, Hoofst R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B (2016) The FAIR guiding principles for scientific data management and stewardship. *Scientific Data* 3: 160018 [doi.org/10.1038/sdata.2016.18]
- Wyborn C, Datta A, Montana J, Ryan M, Leith P, Chaffin B, Miller C, van Kerkhoff L (2019) Co-producing sustainability: Reordering the governance of science, policy, and practice. *Annual Review of Environment and Resources* 44 (1): 319-346 [doi: 10.1146/annurev-environ-101718-033103]