

RESEARCH ARTICLE

The Impact of Heterogeneity in a Global Knowledge Commons: Implications for Governance of the DNA Barcode Commons

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The extent of actor heterogeneity is known to influence the outcomes in natural resource commons, and scholars have recently begun address the impact of heterogeneity on knowledge commons creation and sustainability. There is increasing evidence to challenge the dominant theory that heterogeneity is uniformly disadvantageous, but little is known about heterogeneity in knowledge commons. Here, we analyse heterogeneity as it applies to rules for governing a knowledge commons – the DNA barcode commons. DNA barcodes are short, standardized gene regions that can be used to inexpensively identify unknown specimens, and proponents have led international efforts to make DNA barcodes a standard species identification tool. The dominant actors in the commons are researchers in diverse fields, and the global scope of barcoding means these researchers work in countries with varying levels of biodiversity, research infrastructure, and financial resources for scientific endeavours. This cultural and wealth heterogeneity among actors results in challenges for constructing and governing the commons, including its supporting infrastructure of databases and biorepositories. We interviewed participants in DNA barcoding, and collected organizational documents. We applied the grammar of institutions to identify institutional statements, and categorized each statement based on institutional logics theory. We found that institutional logics theory is an effective applied research tool to study heterogeneity in knowledge commons. Our analysis also suggested that heterogeneity is a challenge to developing shared expectations in global knowledge commons, but participants can design institutional statements to bridge gaps in expectations.

Keywords: knowledge commons; global; heterogeneity; institutional logics; grammar of institutions; DNA barcoding

Introduction

The impact of heterogeneity on successful outcomes for natural resource commons has been well studied, but scholars have only recently addressed the impact of heterogeneity on knowledge commons creation and sustainability (Mishra and Bubela 2014; Frischmann et al. 2014; Bubela et al. 2012, 2017; Dedeurwaerdere 2010). Empirical studies and theoretical models of natural resource commons demonstrate that heterogeneity can result in collective action challenges for commons governance, as diverse individuals participate with different expectations about what constitutes appropriate behaviour (Ruttan 2006). However, increasing evidence challenges the assumption that heterogeneity is uniformly disadvantageous (Agrawal and Gibson 2001).

Here, we analyse heterogeneity as it applies to rules for governing a global knowledge commons – the DNA barcode commons, which we described in Geary and Bubela (2019). The actors who participate in the DNA barcode commons exhibit heterogeneity in their access to biodiversity infrastructure and funding; the extent that biodiversity laws are implemented in their country of origin; and their inclusion in governance structures of the DNA barcoding commons. Specifically, DNA barcoding infrastructure and funding are

concentrated in high income countries, while much of the world's biodiversity is concentrated in low and middle-income countries.

The behaviours of individual actors who participate in DNA barcode commons are determined by regulations, instructions, precepts, and principles (Black 1962), collectively referred to as 'rules' and, in the commons literature, as "institutional statements" (Basurto et al. 2010). Rules established by an authority are labeled "rules-in-form". For the DNA barcode commons, rules-in-form derive from international treaties, such as the *Convention on Biological Diversity (CBD)* that governs the use of genetic resources (including biological materials and sequence data), funding agency requirements, and organizations like the Consortium for the Barcode of Life (CBOL) and the International Barcode of Life (iBOL). However, the "rules-in-use" that individuals follow in their day-to-day behaviour are often different from rules-in-form, and institutional theorists have argued that understanding these rules-in-use is central to deeper institutional analysis of commons (Crawford and Ostrom 2005).

Crawford and Ostrom (1995) introduced the grammar of institutions in 1995 to facilitate analysis of human action within institutional settings. Identification of this grammar in text or speech is a tool for systematically differentiating between types of institutional statements (*Rules* with consequences, conditional *Norms*, and simplistic shared *Strategies*¹) (Crawford and Ostrom 1995). Scholars have employed this tool extensively to examine the institutional statements that are 'in use' (Basurto et al. 2010; Siddiki et al. 2011). However, we lack methodological tools to understand the relationship between heterogeneity, expectations of behaviour, and institutional statements used to govern a commons. We posit that the application of institutional logics theory may address this gap. Institutional logics focus on the importance of overarching institutional orders that shape how individuals behave and expect others to behave (Friedland and Alford 1991). Many empirical studies draw on the concept of institutional logics to examine and understand organizational behaviour (Thornton and Ocasio 2008; Thornton et al. 2012).

Using the DNA barcode commons as a case study, our goals are twofold: 1) to describe the relationship between institutional statements and institutional logics in a global knowledge commons, and 2) to contribute to the development of an expanded, theoretically grounded method for the study of heterogeneity and knowledge commons, using the concept of institutional logics. We first briefly describe our knowledge commons case study (see Geary and Bubela 2019), followed by an introduction to heterogeneity in the commons and our two approaches to study it, namely, the grammar of institutions and ideal types of institutional logics.

Case Study: The DNA Barcode Commons

The process and promise of DNA barcoding

In 2003, a team led by Paul Hebert at the University of Guelph in Canada proposed DNA barcoding as a tool to accelerate the documentation of life on earth – a pre-requisite for studying anthropogenic and other impacts on biodiversity (Hebert et al. 2003). The tool to differentiate species required the sequencing of a small region of an organism's DNA – the DNA barcode. Previous efforts at classifying organisms were inefficient (requiring highly specialized taxonomists), expensive (requiring extensive DNA sequencing), and not scalable due to lack of standardization (Tautz et al. 2003). Hebert et al. (2003) proposed using short, highly conserved, and ubiquitous DNA sequences to enable high-throughput analyses by way of a barcoding pipeline with attendant economies of scale.

This DNA barcode pipeline remains dependant on taxonomically classified specimens (**Figure 1**), both as the source of DNA barcodes and as reference specimens against which to compare unknown specimens. Biological materials, therefore, are an integral component of the DNA barcode commons. Specimens are collected from the field or sampled from existing collections. These specimens can be shipped to locations capable of performing other tasks associated with creating barcode records, including isolating DNA, DNA barcode sequencing, and storing the reference specimen. The result of the barcoding process is an open access, comprehensive database of DNA barcode sequences linked to metadata (data that describes barcode), and a collection of reference specimens.

The effort to build the DNA barcode commons, which comprises both data and biological specimens, quickly gained momentum because of its utility to taxonomy and a range of practical applications dependent on species identification (e.g., biodiversity research and product regulation) (Hebert et al. 2003). Access

¹ We have used capitalization and italics to indicate when referring to the specific *Rules*, *Norms* and *Strategies* as defined in the syntax of the grammar of institutions. Otherwise, the term rules is referring generally to any statement that could be understood as rules-in-form or rules-in-use.

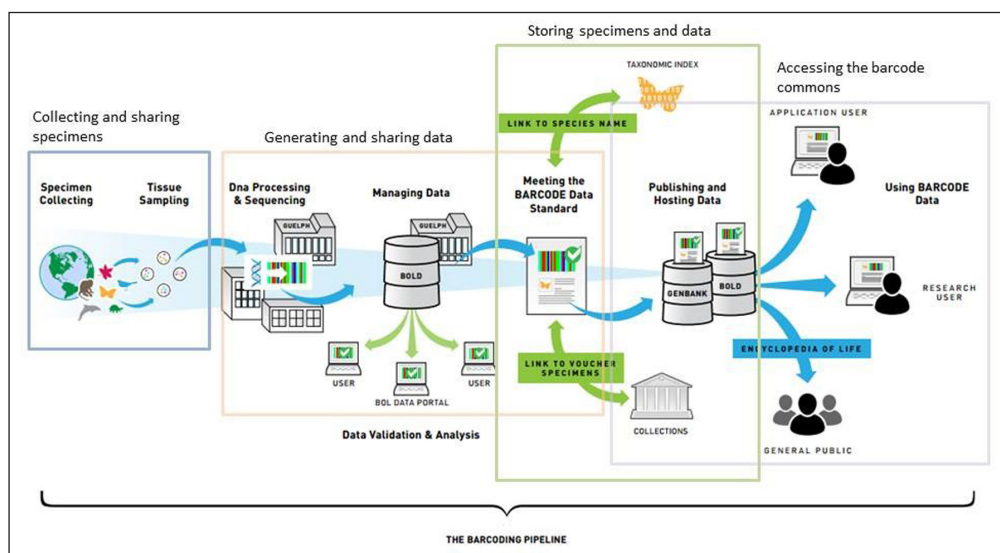


Figure 1: The DNA barcoding pipeline. Adapted from CBOL website (Consortium for the Barcode of Life 2016).

to the commons facilitates rapid identification of unknown specimens in situations where morphological identification is impossible. Such situations arise in many contexts, for example, where the necessary expertise to make identifications is unavailable, or the specimen needing identification is indistinguishable from other similar species, such as butchered meat or insect larvae (Costa and Carvalho 2007). Identifications are made by matching the DNA barcode from an unknown specimen to the known barcode record linked to the reference specimen. DNA barcodes from unknown specimens may be generated by sending: (1) the entire specimen; (2) the specimen's whole genome extract; or (3) only the DNA barcode extract from the specimen to a laboratory equipped to produce DNA barcodes.

Barcoding as an organized global effort

The creation of a comprehensive DNA barcode commons is necessarily a global endeavor, and scientists quickly organized to generate international participation through two main organizations: the Consortium for the Barcode of Life (CBOL) and the International Barcode of Life (iBOL). CBOL was founded in 2004 at the Smithsonian Institution with support from the Alfred P. Sloan Foundation, and focused on promoting the DNA barcode system and developing global standards. In 2009, Dr. Paul Hebert led an international initiative to build a barcode reference library for global biodiversity; this initiative resulted in the launch of the iBOL Project in 2010. Funded through Genome Canada's International Consortium Initiative, iBOL included 26 nations as iBOL 'nodes' partnered through formal agreements (iBOL 2015a). Genome Canada originally committed \$25 million from 2009 until 2015, along with 35 international sponsors from 15 countries (iBOL 2015c). iBOL's main mission was to build a publicly accessible database including 5,000,000 barcodes representing 500,000 species by 2015 (iBOL 2015d). The Barcode of Life Datasystem (BOLD), housed at the informatics unit of the Biodiversity Institute of Ontario (described in more detail in the next section), grew from 102 users in 2005 to over 14,000 users from 94 countries in 2015 (Ratnasingham 2015).

The formal governance structures of CBOL and iBOL established standards for participating in the DNA barcoding effort, but other overarching policies and norms influenced these standards and the behaviours of participants. At the international level, sharing genetic resources is governed by the *CBD* and the related *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (Nagoya Protocol)*. The most direct influence on the organizational rules of iBOL derived from Genome Canada; as with all Genome Canada projects, the agency appointed a Board to oversee and direct how the funding was used.

In 2013, leaders within the DNA barcoding community proposed a new international coordinating organization to sustain the functions of CBOL and iBOL (Li et al. 2013). The organization, the International Society for the Barcode of Life (ISBOL), was launched in 2015 at the 6th International Barcode of Life Conference in Guelph, Ontario. The authors of the Kunming Declaration (Li et al. 2013) and representatives from key regions and organizations formed an Interim Governance Council to develop a governance structure for the new organization and establish its practices.

The heterogeneous DNA barcoding community

The DNA barcode commons, therefore, involves a heterogeneous set of actors from countries that differ in their ability to participate. Participation requires a researcher to have access to specimen collections, DNA extraction and sequencing equipment, and infrastructure to store reference specimens and to process and share data. Many of the countries that possess the greatest biodiversity within their borders (Australian Government 2008) have few resources for such research participation, including The Democratic Republic of the Congo, Madagascar, India, Colombia, and Venezuela.

To address disparities in scientific infrastructure among participating countries, iBOL established regional and central nodes. The aim of regional and central nodes was to provide scientific infrastructure and support to national nodes that lacked the necessary resources (iBOL 2015a). Canadian national and provincial funders supported additional infrastructure – the Canadian Center for DNA Barcoding (CCDB) housed within the Centre for Biodiversity Genomics (CBG) at BIO in Guelph. CCDB is the largest contributor of DNA barcode records, and CBG includes operating units to manage biological collections, production of genomic data, informatics, international development, and education and outreach (Centre for Biodiversity Genomics 2016).

Despite available resources, however, national laws and institutional policies may limit the extent to which researchers can transfer the genetic resources required to produce barcodes, including biological specimens, DNA extracts, and DNA sequences. Many biodiverse countries have implemented the *Nagoya Protocol* through national legislation on access and benefit sharing (ABS), exercising their sovereignty over genetic resources (United Nations 2010) with the intent to prevent misappropriation. In contrast, high income countries like Canada, the United States (US), and Australia had not, as of January 2019.² Researchers from countries with ABS laws may be prohibited from sending specimens or DNA extracts out of country or depositing sequence data into databases.

Actors also vary in their ability to influence Barcode of Life (BOL) efforts. The two main BOL organizations that create standards and protocols for creating and sharing DNA barcodes, iBOL and CBOL, are based in Canada and the US. While iBOL included an International Scientific Steering Committee, participation was limited to individuals who had secured large amounts of local funding for BOL projects (iBOL 2015b).

Finally, the ability to benefit from an open-access barcode database varies substantially. Researchers and regulators in countries with better scientific infrastructure are more likely to be able to utilize a barcode database (Yancy et al. 2008). Professional benefits are also more likely to accrue to researchers with training in bioinformatics, access to computers and broadband internet connections, English language competence for publications and presentations, and funding to travel to scientific venues to develop collaborative networks.

Literature Review and Background

Heterogeneity in the commons

Substantial research has focused on understanding how heterogeneity impacts commons governance. Emerging consensus suggests increased heterogeneity is a challenge for communities to overcome, rather than a necessary determinant of failure (Ostrom 2005). Evidence also suggests that institutional arrangements are more impactful for heterogeneous than homogenous communities (Brito et al. 1997) where institutional arrangements are defined as rules-in-use by a community to determine the nature of the use of and access to a resource, including enforcement (Ostrom 1987). Further, the governance of commons is more successful when actors are involved in rule-making (Varughese and Ostrom 2001).

Increasingly, scholars have focused on the impacts of specific sources of heterogeneity in natural resource commons. Most studies are quantitative and assess one narrowly defined variable as a source of heterogeneity, for example, knowledge (Lindahl 2012), resource dependence (Sakane et al. 2014), social caste (Shiferaw et al. 2012), resource contributions (Burlando and Guala 2005), social preferences (Fischbacher and Gaechter 2006), and productivity (Brito et al. 1997). However, conclusions on how heterogeneity impacts a commons depend on the source of heterogeneity that is examined as the independent variable and whether the study measured collective action or the provision of a collective good as the dependant outcome variable (Ruttan 2008). For example, social heterogeneity negatively impacts collective action because it is associated with lower levels of trust (Poteete et al. 2010a). In contrast, wealth heterogeneity may positively affect provision of goods because wealthy actors are highly motivated to maintain provision of a good that provided them with benefits (Ruttan 2006).

² See Convention on Biological Diversity, Parties to the Nagoya Protocol. <https://www.cbd.int/abs/nagoya-protocol/signatories/>.

In contrast to natural resource commons, few studies have explored the relationship between heterogeneity and the governance of knowledge commons, such as the DNA barcode commons. Knowledge commons require separate study and theory development because they differ from natural resource commons (Frischmann et al. 2014). Because knowledge commons typically comprise non-rivalrous resources, the focus of successful knowledge commons governance is not overuse, but under-use. Governance, therefore, needs to promote use, re-contribution of value-added information, and fair distribution of the costs and benefits among geographically distributed actors. Many institutional arrangements for knowledge commons provide free and open access. In theory, open access makes use more efficient, but in practice, it may create additional challenges. Open access leaves the resource vulnerable to free riders – those who take from the commons without contributing to it. Free riders reduce trust in the commons and negatively impact the ability to establish shared community norms. As such, heterogeneity in a knowledge commons may have different impacts on governance than in natural resource commons. Here, we employ a mixed-methods approach to study a heterogeneous knowledge commons, which avoids assumptions about the dimensions that should be selected for study (Jansen 2010).

Grammar of Institutions

Institutional statements are the *Rules*, *Norms*, and *Strategies* that are either formally documented (rules-in-form) or employed by actors in their day-to-day behaviours (rules-in-use). The grammar of institutions was developed as a common syntax to aid empirical study of institutional statements (Crawford and Ostrom 1995). The focus on rules is useful because they are modifiable, unlike other commons characteristics (Crawford and Ostrom 2005).

The grammar of institutions includes five working parts summarized by the acronym “ADICO” (Crawford and Ostrom 1995). *Attributes* (A) refer to the subset of community members to which the particular statement applies, ranging from a single individual to the entire group. The *Deontic* (D) distinguishes prescriptive (must, forbidden) from non-prescriptive (should, may). The *Aim* (I) is the specific action or outcome intended by the statement. *Conditions* (C) set out the situations when an institutional statement is applied and are especially important in defining the situations in which a specific behaviour is permitted or forbidden. The *Or Else* (O) of the statement defines a consequence for the actor if s/he does not comply with the statement.

Researchers can use the ADICO syntax to classify institutional statements, either written in organizational documents or articulated by individuals, as *Rules*, *Norms*, or *Strategies*. *Strategies* (AIC) are the least constraining and represent a general guideline without conditions that allow or forbid the particular behaviour, and without consequences for non-compliance. *Norms* (ADIC) are more specific and lay out the conditions under which a behaviour occurs, although *Norms* do not specify the consequences for non-performance of the behaviour. *Rules* (ADICO) are enforceable statements with specific conditions and consequences.

Institutional Logics

Institutional logics are a concept within institutional theory developed to account for the interrelationship between societal structures and individual and organization behavior (Friedland and Alford 1991). They were originally developed and have largely been studied in the context of Western societies. The concept suggests that the behaviours of actors are guided by central logics of societal structures, providing a basis for actors to interpret what is appropriate behaviour and to determine how to succeed within a given context (Thornton 2004).

Theorists have identified seven societal-level logics that interact with each other: family, community, religion, state, market, profession, and corporation (Thornton et al. 2012). These logics often co-exist, although one may dominate (Goodrick 2002; Lounsbury 2002; Thornton 2002; Thornton and Ocasio 1999). Empirical work is mostly focused on how multiple logics jointly guide behaviour.

Initial work to explain how logics co-exist focused on mechanisms of competition for dominance (Hensmans 2003; Hoffman 1999), unresolved conflict requiring ‘uneasy truces’ between competing logics, (Reay and Hinings 2005), and the various ways in which segmentation allows for multiple logics to co-exist without interacting (Reay and Hinings 2009; Lounsbury 2007; Thornton et al. 2005). However, none of these explanations allowed for the reality that multiple logics guide behaviour of single actors, an idea introduced by Goodrick and Reay (2011). These authors studied pharmacists, who faced pressure from four different logics: corporation (work within large organizations), market (sell product), profession (obligation to professional standards), and state (adhere to government regulations). Their analysis resulted in a rich description of how multiple societal level logics collectively influence professional work (Goodrick and Reay 2011).

Recent research has suggested that specific contexts can act as filters that alter how logics inform behaviours within an organization (Jaskiewicz et al. 2016; Lee and Lounsbury 2015). These filters can be organizational attributes that impact how the organization draws on the relationship between institutional logics and behaviour; they can help explain organizational success (or failure) in managing competing logics. For example, Jaskiewicz et al. (2016) found that while family and market logics informed family businesses, how these logics informed behaviour depended on the filters of family culture and leadership style within each business.

Ideal types as an empirical tool to study logics

Empirical study of logics is often grounded in the concept of ideal types (Thornton 2004; Thornton and Ocasio 2008), which represent a fictionalized description of how behaviour would be organized if each logic was the only influence on behaviour (Thornton et al. 2012). As an analytical tool, defining the ideal types of logics allows researchers to systematically cluster behaviours into categories to facilitate comparison (Thornton et al. 2012). As part of empirical analysis, researchers must identify the relevant logics for the study and define how behaviour would be organized if guided solely by each logic (Reay and Jones 2016). As per Goodrick and Reay (2011), we described the ideal types of four logics from the set of seven institutional logics that we determined were relevant to the DNA barcode commons because of the attributes of the actors within the barcode commons: corporation, market, profession, and state. Here we define the four institutional logics used in our study, and it is important to note that the definition of each ideal type is distinct from the common usage of that logic's label.

The *corporation logic* places emphasis on organizational hierarchy and administrative control of actions. The relevant organizations in DNA barcoding are CBOL and iBOL, which established rules, standards, and project targets for participants. Administration controls actions to standardize production and processes for decision making, which flow through managerial reporting systems. The aim associated with a corporation logic is to increase organizational size and diversification.

In the ideal type *market logic*, individuals compete in an open system free of regulation, whether produced through a state actor or a professional association. Any individual could produce DNA barcodes, and user preferences determine acceptable standards. The aim of the market logic is to increase efficiency and maximize individual gains, either reputational or profit-based. Even in a market logic-dominated DNA barcode commons, professionals (biologists) would be the main actors producing DNA barcodes, resulting in some overlap between personal and professional reputational benefits. However, a logic is market rather than profession when professional standards favour the maximization of individual benefits. While specialized knowledge may be valued, it is available to anyone and not necessarily obtained through formal education (Goodrick and Reay 2011).

The ideal type *profession logic* is characterized by the specialized knowledge gained through professional education (Freidson 2001). For DNA barcoding, the associated professions derive from taxonomy and biology, as individuals trained in these fields have the expertise to create DNA barcodes and to use them. Thus, professionals alone determine DNA barcoding goals and standards. These goals and standards are enforced by professional associations or by academic journals that require sequence data release as a prerequisite for publication. While state legislation may provide authority to enable professional associations, the state is not involved in determining or enforcing professional standards.

In contrast, the ideal type *state logic* involves government control through either legislation or state actors. State actors include public funding agencies and regulatory bodies. These may determine the DNA barcode projects that receive resources and/or promulgate the data or materials sharing requirements for DNA barcoding. The aim of state actors is to use DNA barcoding to increase public good.

Summary

Actors in the DNA barcode commons, an exemplar global knowledge commons, are highly heterogeneous. Commons resources comprise multiple forms of data, metadata and biological materials, the sharing and utilization of which are governed by a complex rules structure. Both iBOL and CBOL established formal institutional arrangements for participating in the DNA barcode commons, however, these groups are largely centralized in North America and represent a small subset of the global barcoding community. Such institutional arrangements have the potential to encourage collective action to create and maintain the commons, but collective action may be impacted by socio-cultural and wealth heterogeneity among actors. Current empirical approaches to study heterogeneity fail to consider multiple forms of heterogeneity, or provide insight into which institutional arrangements might best overcome the problems arising from heterogeneity, especially those that arise in a global context. Our empirical analysis addresses the

study of heterogeneity through combined use of the grammar of institutions to identify rules-in-use and institutional logics to understand the relationship between heterogeneity and institutional statements within the global DNA barcode commons.

Methods

Our empirical work aimed to broaden research on heterogeneity and rules-in-use beyond the impact of single variables. We employed a mixed-methods approach to combine theoretical frameworks and methods to analyse a single case study, using multiple data sources (Poteete et al. 2010b).

Data sources

Our data derived from two sources: key informant interviews and organizational documents. This research received ethical approval from the University of Alberta Research Ethics Board – Health Panel. The authors and a research assistant interviewed 35 DNA barcoders, iBOL, and CBOL administrators, and key individuals in the international barcoding community who were engaged in policy discussions. We invited key experts and leaders within the DNA barcoding community from diverse regions to ensure broad perspectives on the issues being discussed. The country affiliations of the interviewees were: Australia, Canada, China, Colombia, Ghana, India, Indonesia, Kenya, Mexico, New Zealand, South Africa, United Kingdom, and the US. We conducted most interviews in person at International Barcode of Life conferences in 2011 (Adelaide, Australia), 2013 (Kunming, China) and 2015 (Guelph, Ontario). The remainder occurred over the phone or in person at other locations by the authors or a research assistant. We followed a semi-structured interview guide (Geary and Bubela 2010) that queried research collaborations, sources of genetic resources, views on the national and international frameworks governing ABS for genetic resources, and participation in the DNA barcode commons.

We analyzed organizational documents and statements developed by the two main BOL organizations: iBOL and CBOL. We collected documents and policy statements that described their purpose or governance, or provided instructions to project participants. The formal documents were: the materials transfer agreements (MTAs); iBOL data release policy; microplate and data submission instructions; iBOL Node Memorandum of Understanding (MOU); iBOL Node MOU Appendix; Data Standards for Barcode Records; the Banbury Report on Taxonomy, DNA, and the Barcode of Life; and Guidelines to Authors of Barcode Data Release Papers. We included one document not produced directly by BOL proponents or actors, *The Fort Lauderdale Report on Sharing Data from Large-scale Biological Research Project*, because other BOL documents referenced it as a guiding principle for data sharing. In addition, we accessed informal project descriptions from iBOL.org of global iBOL-supported barcode projects, DNA barcoding, and the iBOL governance structure (iBOL 2015d).

Data analysis

We developed a framework to guide our analysis that integrated qualitative and quantitative approaches for systematic identification and characterization of institutional statements about DNA barcoding activities in the interviews and documents (**Figure 2**). We used NVivo qualitative analysis Software (QSR International Pty Ltd. Version 10, 2012) to facilitate data organization and analysis.

We developed a list of DNA barcoding behaviours based on project descriptions on the iBOL website (**Figure 1**, iBOL 2015d), and the workflow required to produce and share barcodes (**Figure 2a**). The behaviours included: setting the scope of barcoding activities; collaborating with others to conduct a barcode project; collecting, sharing, and storing biological specimens (including whole specimens, tissues, and purified genetic material); generating, sharing, and storing data associated with biological specimens (including barcode sequences and meta-data such as sample locations and reference specimen pictures); and accessing the barcode commons. We read each transcript and document and marked each instance of these behaviours.

Using NVivo, we focused our analysis on the text surrounding the identified behaviours. Individuals do not usually express institutional statements explicitly (Crawford and Ostrom 2005), thus researchers must examine texts to assemble the statements from impartial references contained in larger blocks of interview transcripts. We examined each text source to identify ADICO syntax components in each statement (**Figure 2b**) and then re-organized the statement to produce a simplified version (**Figure 2c**). This simplified version enabled us to classify each statement as a *Strategy*, *Norm*, or *Rule* as per the grammar of institutions (Crawford and Ostrom 1995).

We then used the technique of pattern matching (Reay and Jones 2016) to analyse institutional statements based on their comparison to ideal types of institutional logics (**Figure 2d**). The term “ideal” does not refer to what behaviour would be preferred, but rather is a theoretical construct used to facilitate

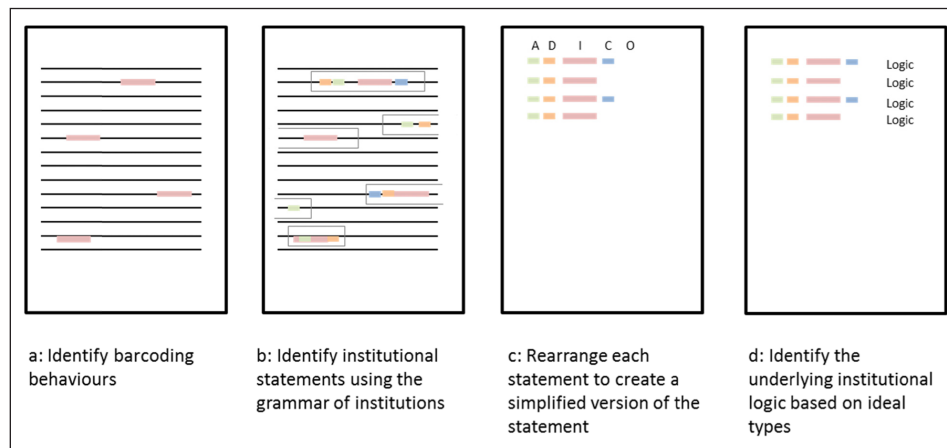


Figure 2: Workflow for analysing institutional statements based on the grammar of institutions (Crawford and Ostrom, 1995) and institutional logics (Thornton et al. 2012). Appendix 2 defines each ideal type of institutional logic for each barcoding behaviour.

classification by defining how that behaviour would be carried out if guided by a single logic (Reay et al. 2015). As per Goodrick and Reay (2011), we first selected four institutional logics that were relevant to our knowledge commons case study: Corporation, Market, Profession, and State. We then created a definition of each of the barcoding behaviours as an ideal type (Appendix 1). Two independent coders then identified the underlying institutional logic(s) for each institutional statement, by comparing the statement to the defined ideal types (Thornton and Ocasio 1999; Thornton 2004; Thornton et al. 2012). Multiple logics could influence a single statement.

We compared the coding by each independent coder. The coders had complete agreement on the logics coded for 67% of the statements after their initial coding. Agreement occurred when each coder selected the same logic (or logics) for a statement. If one coder selected a logic, and another coder selected that same logic along with an additional logic, it was counted as a disagreement. The coders discussed each disagreement and came to a consensus about which logics influenced each statement. The coders were blind as to participant attributes and the institutional statements were randomly organized for the coders. This reduced the likelihood of systematic errors based on coders' expectations based on the country of participants and the order in which statements were coded.

Appendix 2 provides examples of statements about each barcoding behaviour from interview transcripts for each logic. For example, the statement "customers paying for DNA barcoding services may choose to not store their specimens" was coded as "market", because the choice of how to store specimens was accorded to individuals, not prescribed by professional organizations or the state. The statement "researchers find work-arounds when they cannot fulfill specimen-collection permit requirements" was coded as "profession", because it indicates that some researchers, as professionals, will find ways to circumvent state requirements when they impede research activities.

We categorized interviewees into two groups based on the location of their main work affiliation at the time of the interview: Like-Minded Mega Diverse countries (LMMC) and non-LMMC. LMMC is a group of countries established in 2002 to promote their similar interests in protecting biodiversity (LMMC 2002). The LMMC group included China, Colombia, Ghana, India, Indonesia, Kenya, Mexico, and South Africa, and the non-LMMC group included Australia, Canada, New Zealand, United Kingdom (UK), and the US. Despite not being a member of the official LMMC group, we included Ghana in the LMMC group because, as a lower income country in Africa, its biodiversity, laws, and interests align more closely with countries such as Kenya and South Africa than Australia and the US.

Using a thematic analysis, we additionally analysed statements for specific contextual characteristics that may have served as filters for the four selected logics. We attached a descriptive code to each statement and grouped these codes into themes. We then separated the text by interviewee category (non-LMMC and LMMC) to identify the dominant themes within each category.

We used SPSS v. 19 to calculate odds ratios (ORs) and 95% confidence intervals (CIs) as measures of association between the institutional statements made by non-LMMC and LMMC interviewees. We described the number of logics from BOL organization documents using proportion estimates and closely examined the institutional statements where we identified a relationship between the institutional logic and the interviewee category (non-LMMC or LMMC). We also compared the institutional statements made by

interviewees with the statements articulated in organizational documents. Finally, we identified instances of discordance in the pattern of logics. Based on the assumption that such discordance indicates a lack of shared expectations for appropriate behaviour, we suggest forms of institutional statements that could enhance shared expectations among members of the DNA barcoding community.

Results

In the results section, we detail our analysis of institutional statements from two data sources: twelve BOL documents and 35 interview transcripts. We first present our analysis of institutional statements from the BOL documents using both grammar of institutions and four institutional logics (corporation, market, profession, and state). We then present our analysis of institutional statements in interview transcripts using both grammar of institutions and the four institutional logics, augmented by illustrative quotes from interviewees. We present our institutional logics analysis for each of nine barcoding behaviours (setting project scope, starting collaborations, collecting specimens, sharing specimens, storing specimens, generating data, sharing data, storing data, and accessing and using data). Finally, we present illustrative quotes to explain our global inequities filter that provides context for different meanings attached to the expression of logics by LMMC and non-LMMC interviewees.

Analysis of institutional statements in BOL organization documents

We identified 64 institutional statements in the twelve BOL documents. Applying the grammar of institutions, we identified only one *Rule* statement:

Submission of the specimen data and images to BOLD is a critical prerequisite before tissue samples can be analyzed in the lab. To facilitate effective processing of samples, their accompanying data must be submitted in BOLD compliant format. – Microplate and data submission packing sampling instructions

Most statements were *Norms* (44) or *Strategies* (19) and related to the creation of the commons (**Figure 3**), including storing data (n = 21), sharing data (n = 15), and sharing specimens (n = 12).

Applying our coding for institutional logics, the most common logics we assigned to the 64 institutional statements were profession (n = 40; 63% of total) and corporation (n = 37; 59%) (**Figure 3**). The profession logic was assigned most frequently to statements about sharing specimens and generating and storing data (**Figure 3**; Appendix 3). The corporation logic was most frequently assigned to statements about setting the scope of barcode projects and data generating and sharing (**Figure 3**). The state logic was assigned in greatest proportion to statements on specimen collection and sharing data (**Figure 3**).

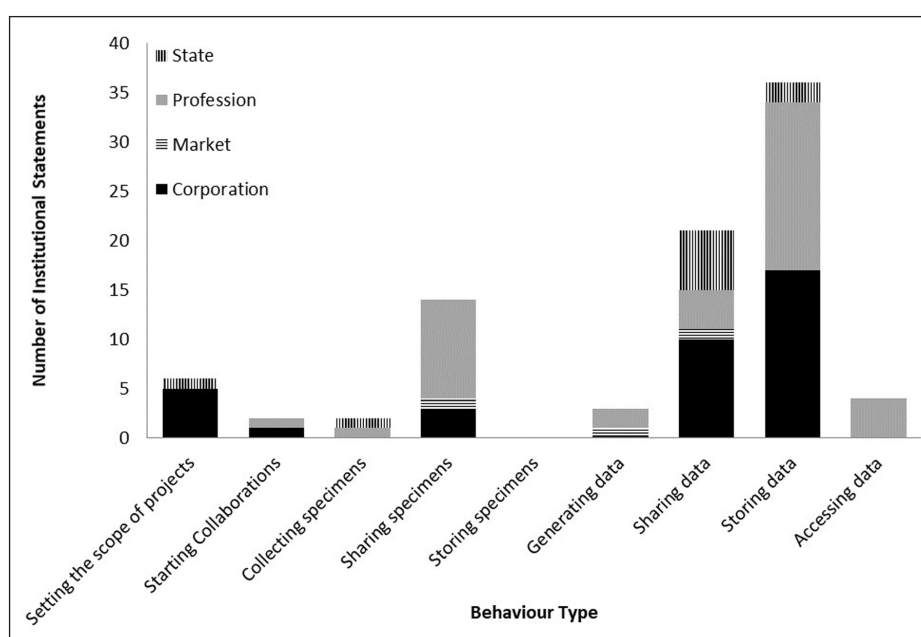


Figure 3: Number of institutional statements about nine barcoding behaviours in twelve BOL documents coded for four institutional logics. Each statement could be coded with more than one logic.

Analysis of institutional statements in interview transcripts

We identified 274 institutional statements about DNA barcoding behaviours in 35 interview transcripts. Applying the grammar of institutions, only five statements were *Rules*; most were *Norms* (n = 127) or *Strategies* (n = 142).

LMMC and non-LMMC interviewees made a similar number of institutional statements (n = 141 and 133, respectively), distributed similarly across barcoding behaviours (**Figure 4**; Appendix 3). However, there was variation in the logics that we attributed to institutional statements by interviewee type (**Table 1**; **Figure 5**). Compared to statements made by LMMC interviewees, non-LMMC statements had 2.3 and 3.0 times the odds of being coded as corporation and market logics, respectively, and 0.53 times the odds of being coded as state logic (**Table 1**).

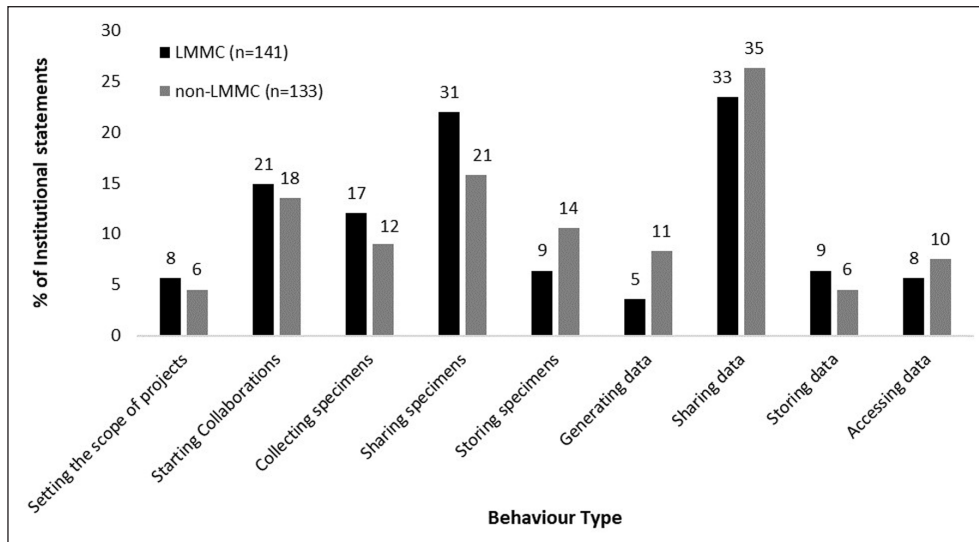


Figure 4: Percentage of institutional statements made by LMMC or non-LMMC interviewees about a DNA barcoding behaviour. The number of institutional statements is indicated above each bar.

Table 1: Relative odds and confidence intervals (CI) of interviewee statements categorized by barcoding behaviour or institutional logic.

	Odds Ratio*	95% CI
Behaviour		
Setting the scope of projects	0.79	0.27–2.3
Starting Collaborations	0.89	0.45–1.8
Collecting specimens	0.72	0.33–1.6
Sharing specimens	0.67	0.36–1.2
Storing specimens	1.7	0.72–4.1
Generating data	2.5	0.83–7.3
Sharing data	1.2	0.68–2.0
Storing data	0.69	0.24–2.0
Accessing data	1.4	0.52–3.5
Institutional Logic		
Corporation	2.3	1.3–4.4
Market	3.0	1.4–6.6
Profession	0.97	0.60–1.6
State	0.53	0.32–0.88

* Odds ratios (OR) compare the frequency statements by interviewees from non-likeminded megadiverse countries (non-LMMC) to the reference group of interviewees from likeminded megadiverse countries (LMMC).

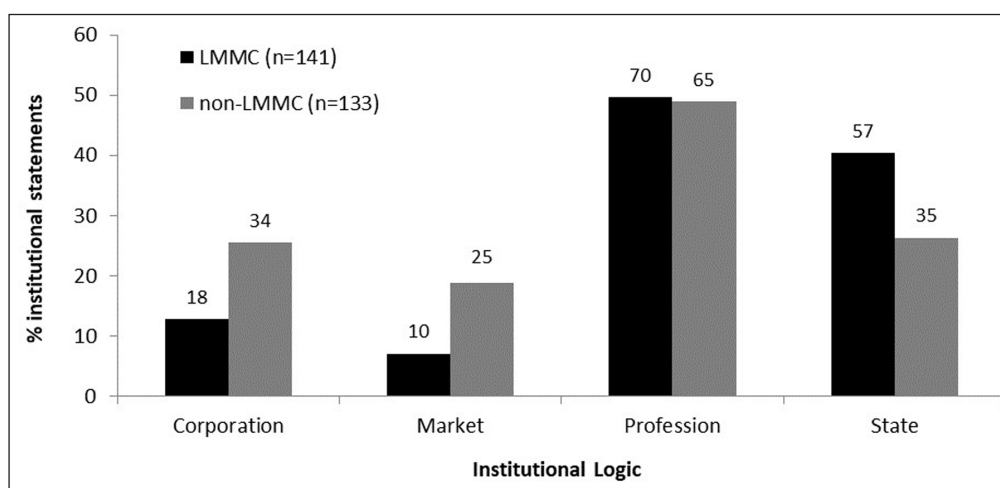


Figure 5: Percentage of institutional statements made by LMMC or non-LMMC interviewees coded by institutional logic. The number of institutional statements is indicated above each bar.

Appendix 3 presents our analysis of institutional logics, which we assigned to statements about each barcoding behaviour, made by interviewees from non-LMMC compared to the reference group of statements made by interviewees from LMMC.

Setting the scope of DNA barcoding projects

Only 14 statements were about setting the scope of barcoding projects, with 8 made by LMMC and 6 by non-LMMC interviewees (Appendix 3). Statements by non-LMMC interviewees were more likely to be coded as corporation ($n = 4$) and state ($n = 2$) logics and related to either meeting iBOL project targets for barcoding or undertaking projects that create public good. For example, one interviewee stated the following about how the iBOL project influenced setting the scope of barcoding projects:

Because for most of them, their only mandate was I've got a few plates of [species] and I want them done free in Guelph. That was their sort of mandate as a node, very transactional. [IBOL management] said they are going to have to form some sort of steering committee, giving you a mandate, a member that's engaged with other scientists and institutions and with funding agencies in the country and actually form something that we could say, "Yeah, okay—it's not just the two colleagues in [country], it's the [country] barcode of life network." – IBOL administrator

In contrast, seven statements by LMMC interviewees were coded as profession and related to academic interests and project feasibility. A researcher in Africa explained his approach to selecting specimens to barcode:

There are a number of publications about medicinal plants in [country]. I look at the list, and then I try to see which ones have had ethno-botany work done. I try to look at plants that I use for the treatment of malaria, and I go and try to collect them and barcode.

Starting DNA barcoding collaborations

Statements by both LMMC and non-LMMC interviewees about starting collaborations were most frequently coded as the profession logic (21 and 18 statements, respectively). Interviewees referred to the professional benefits of collaborations. However, non-LMMC interviewees had 3.4 times the odds of referencing personal considerations, coded as market, such as pre-existing relationships, personal compatibility, and trust (**Table 2; Figure 6**). A researcher from New Zealand explained "collaboration is a synergistic thing, like if you could get something out of it so. I think that applies to all my collaborations. For me, it's that positive synergy that you get out of working with someone else, so your 1 plus 1 equals 4, or something like that".

Collecting, sharing, and storing specimens

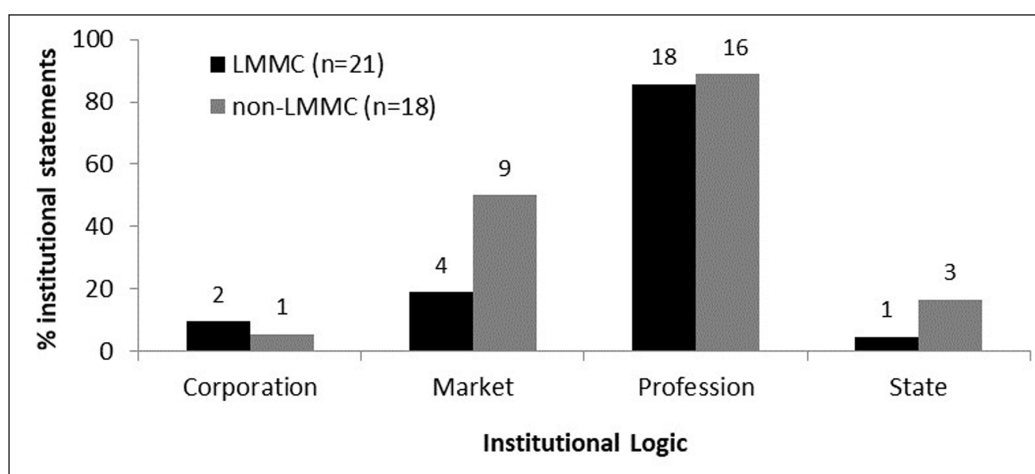
The logics of statements made about collecting ($n = 29$), sharing ($n = 52$), and storing specimens ($n = 23$) differed between LMMC and non-LMMC interviewees (**Table 2**).

Table 2: Relative odds and confidence intervals (CI) of interviewee statements categorized by barcoding behaviour and institutional logic.

Behaviour	Corporation		Market		Profession		State	
	OR*	95% CI	OR*	95% CI	OR*	95% CI	OR*	95% CI
Setting project scope	14.00	0.94–208	–	–	0.13	0.02–0.78	1.50	0.15–15
Starting Collaborations	0.56	0.05–6.7	3.40	0.81–14	0.58	0.11–3	4.00	0.38–42
Collecting specimens	0.68	0.05–8.5	–	–	2.30	0.47–12	0.13	0.02–0.86
Sharing specimens	3.10	0.94–10	1.50	0.01–25	1.10	0.36–3.5	0.29	0.09–1
Storing specimens	0.95	0.13–7.2	–	–	7.30	1.1–48	0.55	0.08–3.6
Generating data	2.30	0.19–28	0.89	0.06–13	1.80	0.21–15	0.40	0.02–8.1
Sharing data	5.40	1.1–27	1.50	0.23–9.3	0.70	0.27–1.8	0.69	0.24–2
Storing data	4.00	0.27–59	–	–	1.40	0.10–20	–	–
Accessing and using data	–	–	7.00	0.61–80	–	–	0.50	0.07–3.8

– Number of statements too small to calculate ORs.

* Odds ratios (OR) compare the frequency statements by interviewees from non-likeminded mega diverse countries (non-LMMC) to the reference group of interviewees from likeminded megadiverse countries (LMMC).

**Figure 6:** Percentage of institutional statements about starting collaborations made by LMMC or non-LMMC interviewees coded by institutional logic. The number of institutional statements is indicated above each bar.

Collecting specimens

Non-LMMC interviewees were less likely to make statements about collecting specimens coded as state logic (**Table 2; Figure 7**; OR = 0.13). While both categories of interviewee referred to permitting and state policies, LMMC interviewees emphasized the need to adhere to state policies. “[Researchers at my institution] have been sampling also in Belize and Guatemala but we respect the rules of each country so we get permission from each country to collect material and to transport the material to Mexico” (Researcher, Mexico).

Sharing specimens

LMMC and non-LMMC statements about sharing specimens had similar odds of being coded as the profession logic (**Table 2; Figure 8**). However, non-LMMC statements had 3.1 times the odds of being coded as the corporation logic, focusing on barcoding organization rules for specimen sharing, and only 29% of the odds of being coded as the state logic (**Table 2**). When asked about clauses in MTAs for sending materials within the barcode of life project, a researcher from Africa explained “we’ve always been quite clear we are also governed by the laws of our country and there are strict legal requirements around tissue transfers and things like that that are now in operation”.

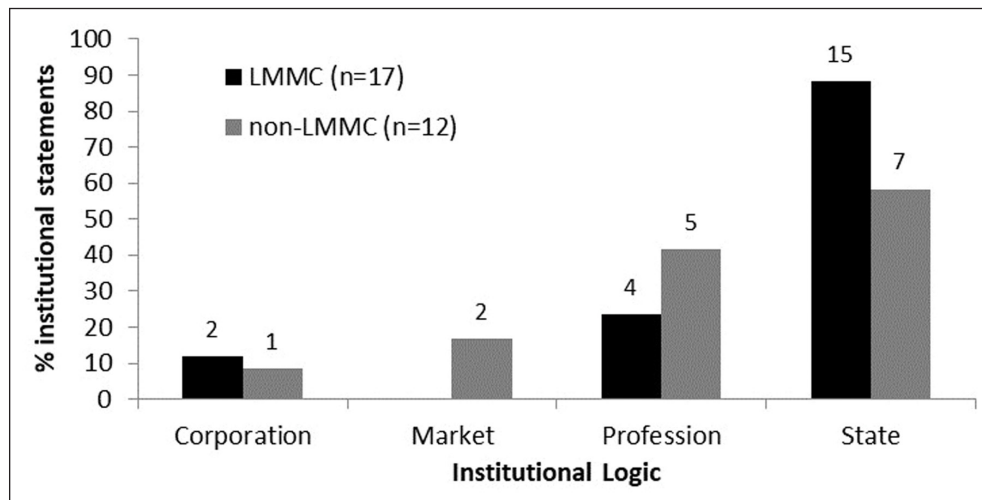


Figure 7: Percentage of institutional statements about collecting specimens made by LMMC or non-LMMC interviewees coded by institutional logic. The number of institutional statements is indicated above each bar.

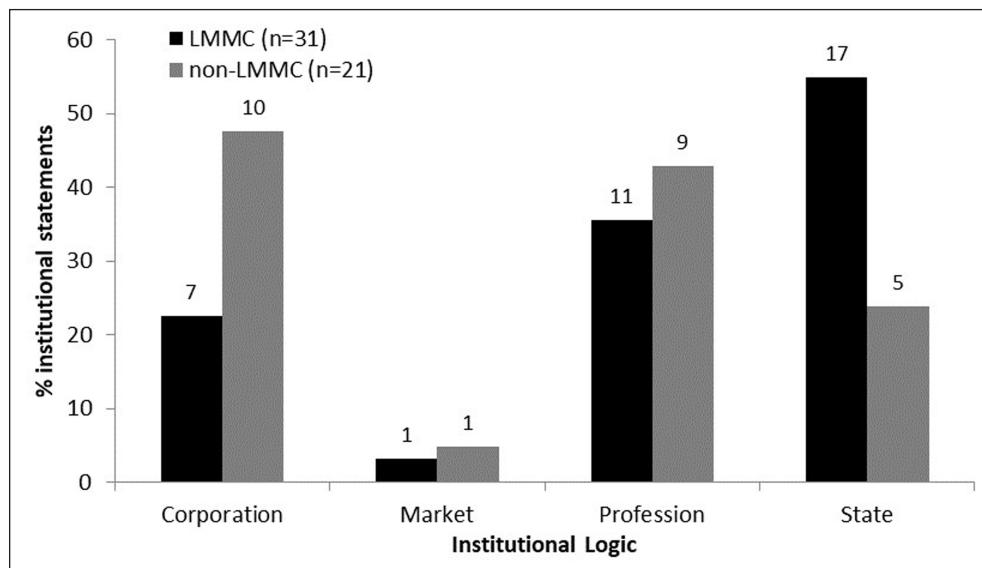


Figure 8: Percentage of institutional statements about sharing specimens made by LMMC or non-LMMC interviewees coded by institutional logic. The number of institutional statements is indicated above each bar.

Storing specimens

Most of the 23 statements about storing specimens were coded as the profession logic ($n = 15$, 65%) for both categories of interviewees. These statements referred to the need to store duplicate specimens in multiple locations for quality control and back-up. Three LMMC statements were coded as state logic; these focused on storing specimens domestically to protect national sovereignty over genetic resources. For example, an African researcher said “The imperative now is that we should be lodging the material that is of value to our society in our own institution such that the work is facilitated, this is what’s beneficial”.

Generating, sharing, and storing data

The logics of statements made about generating ($n = 16$), sharing ($n = 68$), and storing ($n = 15$) data similarly differed between LMMC and non-LMMC interviewees (**Table 2**).

Generating data

Eleven statements about data generation from non-LMMC interviewees, were coded as profession ($n = 6$) and corporation ($n = 4$) logics. These statements focused on maintaining and improving data quality, for example: “There are currently mechanisms in, for example, the barcode of life data systems, for data

validation that precede the submission that prevent apparent garbage from coming in" (Researcher, Canada). We identified no dominant logic for the five statements made by LMMC interviewees.

Sharing data

Statements made by non-LMMC interviewees about sharing data had 5.4 times and 1.5 times the odds of being coded as corporation and market logics, respectively (**Table 2; Figure 9**). The corporation logic referred to statements about the requirement to release data when using iBOL sequencing facilities to produce DNA barcodes. LMMC statements were most frequently coded as profession logic, because interviewees emphasized the need for researchers to exercise judgment in deciding what data to share based on needs and opportunities for professional contributions (e.g., publications).

There needs to be some value-added capacity [to databases]; if I can see my data in the context of other species that becomes helpful for me and informative. Some of the tools that had been added to BOLD for visualizing data and doing analysis become important because it is those tools that provide some incentive for people to upload the data so they can see what the data look like with respect to the other data that are available on the database. – Researcher, US

Both categories of interviewees made statements coded as state logic. These referred to state interests in protecting sensitive data (like locations of endangered species, or identification of newly invasive species) or the obligation to share data to increase the value of state investment in research.

Storing data

Fifteen statements about storing data were coded as the profession logic; these statements emphasized the professional requirement to keep backups and ensure data quality. One African researcher explained succinctly "We still submit to BOLD because firstly for us in Africa, it's sort of a back-up system".

Accessing and using data from the commons

Eight LMMC statements and ten non-LMMC statements about accessing and using data were coded as state logic. LMMC statements emphasized that specific types of data should be accessible for the public good, such as increasing public understanding of biodiversity. However, statements by non-LMMC interviewees had 7.0 times the odds of being coded as market logic, emphasizing how the open nature of the database resulted in use the data by anybody for any purpose. One Canadian research explained, "Because it is a public database I don't think there can be any control who uses and for what purpose. I don't think there can be any control on that. As soon as it goes into a public domain I don't think anybody can control how that information is being used".

Global inequities as a filter for institutional logics

Our thematic analysis additionally identified a global inequity filter for the four selected logics. We identified 38 institutional statements that had apparent influences beyond the four logics we defined for

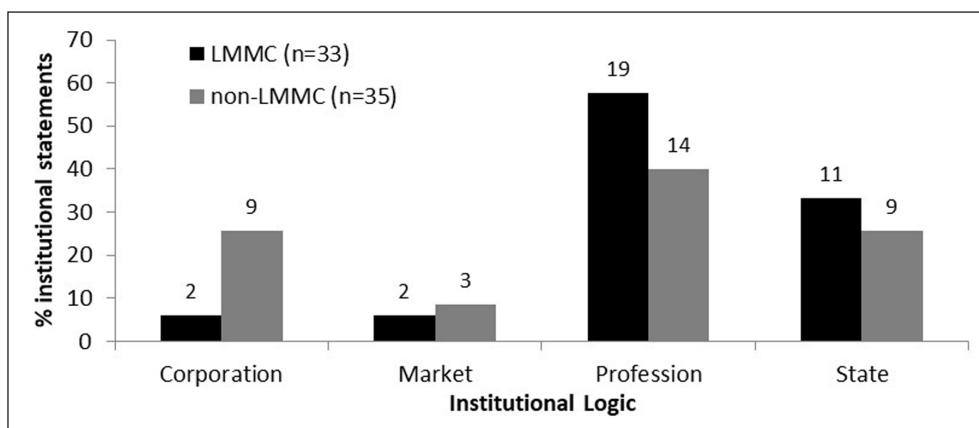


Figure 9: Percentage of institutional statements about sharing data made by LMMC or non-LMMC interviewees coded by institutional logic. The number of institutional statements is indicated above each bar.

our study (27 from LMMC interviewees and 11 from non-LMMC interviewees). These statements referred to the negative history of genetic resource misappropriation between developed and developing countries and the resultant inequities that persist.

LMMC statements often referred to resource and power imbalances between rich and poor countries and their institutions. These imbalances continue to limit the participation of developing countries in global research endeavors as equal partners. Specifically, interviewees mentioned: problems with accessing materials housed in foreign institutions; the need to store project resources domestically (both data and specimens); an imbalance in human and infrastructure capacity to participate in barcode projects; the need to protect sensitive data from misappropriation (especially traditional knowledge associated with genetic resources); and the need for all DNA barcoders to be aware of rules for access and benefits sharing of genetic resources. One interviewee stated:

I think [they will not store Mexican specimens in a foreign repository] because the people firstly will think to develop locally. You see, they are angry because the server with the BOLD system is in Canada – that is why we are going to create a mirror in Mexico because they don't want even the information to be in a server that is outside the country. – Researcher, Mexico

Other non-LMMC statements acknowledged the need for capacity building in lower income countries and suggested options to reduce the likelihood of misappropriation. These options included shipping amplified gene products of barcoding regions rather than specimens that contain full genomes and storing specimens in the country of origin to allay concerns about shipping materials. Interviewees favoured negotiated agreements to ensure developing country participants benefitted from specimen sharing. As one interviewee stated:

Institutions in the [global] north are going to have to get used to being more open and more careful about documenting where they got specimens from, who they lend specimens to, all that has to be rethought and made much more transparent and accountable. – Researcher, US.

We also noted that the global inequities filter provided context for different meanings that attached to the expression of logics by LMMC or non-LMMC interviewees, especially the state logic. For example, when LMMC interviewees discussed sharing specimens, they emphasized sovereignty over genetic resources, whereas non-LMMC interviewees focused on exporting and permitting. Similarly, non-LMMC interviewees emphasized the importance of open-access data to produce public benefits, whereas LMMC interviewees emphasized the need for state control of sensitive information.

Discussion

Actors in the DNA barcode commons comprise a global and heterogeneous network of individuals and research institutions that works collectively to build and maintain infrastructure and resources for rapid species identification to support biodiversity research and other applications. To date, BOL organizations based in Canada and the US have led the international coordination of the DNA barcode commons and have added to the *Rules, Norms and Strategies* that govern how actors participate in the commons. *Rules, Norms and Strategies* range from undocumented and unenforceable scientific community norms to organizational and institutional policies to national and international laws and regulations.

The heterogeneity of the actors who participate in DNA barcoding results in a lack of shared expectations. Many of these expectations do not align with the goals of this knowledge commons and its supporting *Rules, Norms and Strategies*. Indeed, scholars suggest that attributes of a knowledge commons, including resources, community, goals, and objectives, are influenced by the history of the commons (Frischmann et al. 2014). Our analyses support this suggestion; heterogeneous actors in the DNA barcode commons referenced the negative influence of the history of genetic resource misappropriation by the biodiversity research community.

As efforts continue to advance the governance of the DNA barcode commons with the establishment of ISBOL, it is timely to consider the expectations that are shared by participants and those which are not. Such understanding can inform commons governance, including the development of *Rules, Norms and Strategies*. *Rules, Norms and Strategies* in a knowledge commons should encourage contributions of resources to the commons, use of those resources and re-contribution of value-added knowledge and resources (Bubela et al. 2012; Bubela et al. 2017). However, in a global knowledge commons, governance should ensure contributions and use of the commons in a manner that equitably distributes risks and

benefits among the diverse set of participants. If appropriately designed, *Rules, Norms* and *Strategies* can enhance collective action among the heterogeneous participants of this knowledge commons and account for historical inequities.

Contributions to knowledge commons theory and analysis

Commons research on heterogeneity has, to date, typically selected one source of heterogeneity and quantified its impact on a measured outcome, such as the quality of the resource or the level of collective action (Ruttan 2008). While these studies suggest heterogeneity has a measurable impact on outcomes, they fail to illustrate *how* heterogeneity produces the outcome or to suggest *how* to mitigate undesired outcomes. Our analytical approach combined the grammar of institutions and institutional logics to identify conflicts between heterogeneous participant expectations and conflicts between expectations and *Rules, Norms* and *Strategies*. Our approach identified the behaviours that need to be incentivized to build and maintain a knowledge commons and the logic behind the heterogeneity that may negatively impact its governance.

While our analytical approach did not quantify or model the impacts of heterogeneity, it can inform institutional arrangements that advance collective action in a heterogeneous knowledge commons. Differences in the use of institutional logics by two categories of heterogeneous actors (those from LMMCs and those from non-LMMCs), as understood via a global inequities filter, can inform specific recommendations on the governance of the global barcoding commons. These recommendations lead to the crafting of institutional statements based on the grammar of institutions *ADICO* syntax (**Table 3**).

Our analysis of institutional logics accords with the suggestion that heterogeneity impacts collective action because of a lack of shared expectations and common ground (Ruttan 2006). The use of institutional logics to characterize institutional statements helps to identify participants' expectations for behaviours that are and are not shared. Indeed, an analysis of institutional logics may enhance analyses that employ the grammar of institutions, because the latter enables researchers to demonstrate institutional statements that are too vague or weak to be enforceable and therefore effective (Crawford and Ostrom 2005). Identification of discrepancies in the logics used by heterogeneous actors enables the development of *Rules, Norms* and *Strategies* that mitigate the potential negative effects of heterogeneity. Indeed, our approach identified the behaviours that likely will require more precise institutional statements based on a lack of shared expectations (**Table 3**). Institutional statements can aid in the establishment of shared expectations that might otherwise naturally exist amongst a more homogeneous set of actors.

Implications of heterogeneity for the DNA Barcoding Community

Our analysis confirmed that heterogeneous actors have different expectations about what constitutes appropriate behaviour within the DNA barcode commons. These differences in expectations are likely to lead to governance and collective action challenges (Ruttan 2006; Varughese and Ostrom 2001; Hayo and Vollan 2012). While appropriate institutional arrangements can mitigate a lack of shared expectations among participants (Varughese and Ostrom 2001), our analysis suggested that current institutional arrangements, articulated in institutional documents, may be insufficient to mitigate the challenges that arise from the lack of shared expectations between LMMC and non-LMMC actors.

Because of its global nature, the heterogeneity of the DNA barcode commons derives from cultural, historical, geographical, technical, and financial differences. These forms of heterogeneity raise challenges in natural resource commons (Lindahl 2012; Ruttan 2006; Vedeld 2000; Poteete and Ostrom 2004). For example, wealth heterogeneity may be favourable in sustaining natural resource commons, because wealthy actors, with a stake in the resource, could use their wealth to ensure continued resource availability (Ruttan 2006). However, researchers categorize this sustainability as a positive outcome, regardless of how equitably actors use or contribute to the resource (Ruttan 2006). Our analysis suggests that sustainability as an outcome should be informed by equity in access and use.

In comparison to natural resource commons, knowledge commons are more dependent on collective action to establish and sustain their infrastructure and resources (Ostrom 2005; Frischmann et al. 2014). A robust DNA barcode commons, therefore, relies on collective action to generate, sustain, and enable use and re-use of the commons in a manner that results in an equitable distribution of risks and benefits. This reliance on collective action makes a knowledge commons more susceptible to challenges created by a lack of shared expectations. While participants from non-LMMC may provide the financial resources to support a knowledge commons, they cannot compel participation by individuals and institutions in LMMC. The latter participation is essential to the success of the DNA barcode commons because LMMC are the locus of

Table 3: Recommendations for the formulation of DNA barcoding institutional statements based on the grammar of institutions *ADICO* syntax and analysis of institutional logics.

Behaviour	Recommendation based on <i>ADICO</i> grammar of institutions	Justification based on analysis of institutional logics and the global inequities filter
Setting the scope of barcode projects	In setting the scope of BOL projects, establish <i>aim</i> s for professional targets in addition to those of BOL organizations	LMMC interviewees were not influenced by the corporation logic, despite participation in BOL organizations
Starting collaborations	Set out <i>Conditions</i> that promote equity in how participants derive personal benefits from collaborations	Non-LMMC interviewees were more likely to be influenced by market logic, indicating a potential need to mitigate the impact of seeking personal gain within BOL collaborations
Creating the commons (including standards setting)		
Collecting specimens	The <i>aim</i> of specimen collection should be <i>Conditional</i> on adherence with relevant state laws, regulations and policies and collectors should receive training in their obligations and permitted and forbidden actions (<i>Deontic operators</i>)	LMMC and non-LMMC interviewees held divergent views on specimen collection under the state logic. Given the history of misappropriation of genetic resources, BOL organizations should support adherence to and training on laws, regulations and policies on genetic resources and access and benefit sharing
Sharing specimens	As above in the context of sharing specimens. In addition, BOL organizations should develop enforcement mechanisms, including sanctions, to ensure compliance (<i>Or else</i>)	As above and BOL organizations should develop enforcement mechanisms to ensure compliance with state laws, regulations and policies for dimensions of the barcoding commons that are within their control
Storing specimens	BOL organizations should <i>aim</i> to store collections in the country of origin, and include best practice <i>Conditions</i> under which storage in foreign repositories, especially in non-LMMCs, is permitted for quality control and back-up	LMMC and non-LMMC interviewees shared expectations under the profession logic that duplicate specimens should be stored in multiple locations for quality control and back-up, however differed in their state logic that specimens should be stored in the LMMC of origin
Generating data	BOL organizations should <i>aim</i> to create data standards (<i>Conditions</i>) informed by experts	Interviewees were most influenced by the profession logic, which focused on maintaining and improving data quality
Sharing data	BOL organizations should <i>aim</i> to promote equitable data sharing that recognises the contributions of LMMC participants and impose <i>Conditions</i> for some forms of data, such as sensitive data about endangered or invasive species	LMMC interviewees were influenced by the profession logic, indicating that their data contributions acknowledge their professional contributions, for example, through joint publications. LMMC and non-LMMC interviewees used the state logic to recognise data sharing limits for sensitive data
Storing data	BOL organisations should <i>aim</i> to promote (<i>Deontic operators</i>) the professional requirement to maintain data quality and backup	All interviewees shared expectations about storing data to maintain quality and generating backup data
Using the commons		
Accessing and using data	BOL organisations should <i>aim</i> to maximize data access and sharing, while supporting <i>Conditions</i> that recognize access and use limits imposed by genetic resource and access and benefit sharing laws. BOL organizations might consider sanctions for noncompliant access and use (<i>Or else</i>)	LMMC and non-LMMC interviewees diverged in their use of logics to describe their experiences and expectations in accessing and using barcoding data. The latter used the market logic to favour no restrictions, while the former used the state logic to support restrictions on access and use for the public good, accounting for historical misappropriation of genetic resources and resultant access and benefit sharing laws.

the world's biodiversity. Thus collective action requires the development of *Rules, Norms* and *Strategies* that address the concerns and promote the interests of participants from LMMC.

Previous research suggests that “legitimate authority” may have a positive impact on the creation of institutional arrangements for effective governance of knowledge commons (Schweik and English 2012; Fleischman et al. 2014). The creation of ISBOL (Castle et al. 2015) offers an opportunity to establish such legitimate authority, but only if it is representative of heterogeneous community interests and works towards the establishment of shared expectations. LMMC perspectives on the equitable distribution of risks and benefits of participation in the DNA barcode commons must therefore be included in development of ISBOL governance and the operation of its institutional statements.

Recommendations to improve the governance of the DNA barcode commons

The logics we identified in institutional statement varied across interviewees, BOL documents, and behaviour types. Formal institutional statements (rules-in-form) that reflect the expectations of commons participants are more likely to be viewed as legitimate, and therefore, followed (Tyler 1990). We observed that the most differences in the pattern we coded were for controversial behaviours: collecting specimens for research, sharing specimens, and sharing data. Establishing enforceable institutional arrangements for these behaviours should be a priority for ISBOL. Based on observed differences in the pattern of logics we identified in BOL documents and the categories of interviewees, we made recommendations for the institutional statements of BOL organisations (**Table 3**).

Overall, new institutional arrangements for the DNA barcode commons could calibrate expectations across actors. Such calibration will require explicit recognition of the lasting effects of historic inequities and the implications of this history for current international partnerships. No BOL documents contained institutional statements that accounted for global inequities, an omission that needs to be rectified. Institutional arrangements need to reflect global inequities or potential contributors will likely view BOL organisations as illegitimate. Even though many aspects of a DNA barcode commons are non-rivalrous, many inputs, such as research funding, are rivalrous. The ‘leveling of the playing field’ is not about making the outputs freely available, but about equalizing the cost at which contributors get equivalent benefits (Frischmann et al. 2014).

Limitations of our study and future directions

This study has several limitations. We interviewed participants over several years, and, therefore, responses may have been influenced by factors that changed over time. However, the DNA barcoding governance structure did not change during data collection. Individual behaviour might also depend on experience and length of time a participant has engaged in barcoding efforts, and we did not account for these potential differences between interviewees. A single researcher conducted the thematic analysis of the contextual factors. While it is possible that another researcher may have drawn different conclusions, our use of qualitative software to track our analytical decisions enables confirmability of our findings.

Future research might test our finding that institutional logics are a useful proxy for evaluating heterogeneity in community where many factors may be responsible for differences between participants in a commons.

Additional Files

The additional files for this article can be found as follows:

- **Appendix 1.** Descriptions of ideal institutional logics for each DNA barcoding behaviour. DOI: <https://doi.org/10.5334/ijc.861.s1>
- **Appendix 2.** Examples of institutional statements about each barcoding behavior from interview transcripts coded for each logic. DOI: <https://doi.org/10.5334/ijc.861.s2>
- **Appendix 3.** Number and percentage of statements from 35 interviews and 12 BOL organization documents categorised by barcoding behaviour and institutional logic. DOI: <https://doi.org/10.5334/ijc.861.s3>

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Competing Interests

The authors have no competing interests to declare.

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