

# Many Methods, Many Microbes: Methodological Diversity and Standardization in the Deep Subseafloor Biosphere

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## Abstract

Standardization is widely assumed to be important to advance science. This assumption is typically embedded in initiatives to devise infrastructure and policies to support scientific work. This paper examines a movement comprising scientists advocating methods standardization in an emerging scientific domain, the deep subseafloor biosphere. This movement is not primarily motivated by the usual rationales for standardization, but instead by the aim of intervening in the politics of an infrastructure upon which the domain depends, scientific ocean drilling cruises. This infrastructure is shared and contested with other domains, and this movement regards standardization as a critical step in reconfiguring the infrastructure to secure a greater share of resources for the deep subseafloor biosphere. This movement encounters two tensions. One tension is between the perceived benefits of standardization vs. methodological diversity. Another tension is between perceived benefits for the domain vs. a lack of incentives for individuals to perform necessary standardization work.

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## 1 Introduction

Scientists in many scientific domains are advocating for standardization. Examples include geology (Dietl & Kosloski, 2013), geography (Barchyn, Hugenholtz, & Ellis, 2011), and the life sciences (Holmes, McDonald, Jones, Ozdemir, & Graham, 2010).

The widespread assumption about the desirability of standardization in science has led to many initiatives, working groups, policies, and recommendations for standardization of various components of the scientific process. Components that have been the focus of standardization efforts include software code (Huang & Gottardo, 2012), methods for data production (Botts, 2004), terminology (Smith et al., 2007), metadata (Lavoie, 2008), and data curation (Wang, Sun, Yang, Song, & Yue, 2013).

However, processes of standardization in science are rarely straightforward. They can expose tensions both between divergent views of whether standardization is in the best interests of a scientific domain, and between the interests of a domain and the interests of individual scientists in that domain. A richer understanding of the dynamics of these tensions is critical if infrastructures and policies are to be designed and implemented that successfully support scientific work.

Here, I present findings from a case study of an emerging scientific domain, the deep subseafloor biosphere, which involves the study of interactions between microbial communities in the seafloor and the physical environment they inhabit. Incorporating scientists from a wide variety of disciplinary backgrounds, this emergent domain is characterized by a high degree of heterogeneity of the methods used by scientists to produce, analyze, and store knowledge products and data. I map the contours of discussions around methods standardization in the domain, addressing the following research questions:

- 1) What rationales do domain scientists advance for and against methods standardization?
- 2) How is the work of devising standards for methods proceeding?

## 2 Standardization: Benefits and Limits

Here, I set the scene for studying debates around determining standards for scientific practices. First, I consider rationales for and against methods standardization. Then, I discuss the work involved in devising standards, and how incentive structures can promote or inhibit such work.

### 2.1 Rationales for Standardization

Many rationales have been advanced for standardization of various components of scientific work, such as laboratory technologies, measurement systems, and experimental procedures. One rationale is that

standardized methods foster common ways of doing science between researchers working in different contexts, thereby promoting collaboration and establishment of new lines of inquiry (Fujimura, 1988).

Another rationale is to increase scientists' trust in the integrity and reliability of knowledge products, such as datasets, that are produced by others. Standards reassure potential users that knowledge products have been made according to established procedures, and are thus trustworthy (Timmermans, 2015). Scientists are more likely to reuse knowledge products made by others if they perceive these products to be trustworthy (Faniel & Jacobsen, 2010). Promoting the reuse of extant knowledge products, such as data, is anticipated to benefit science significantly (Borgman, 2012).

Many scientists support methods standardization to better enable aggregation and integration of datasets produced by different scientists. One expected benefit is in the observational sciences, such as ecology, where different researchers produce datasets about different geographic sites, or about the same site but at different points in time. Standardization could enable comparisons of the same phenomena across sites, or over time (Barchyn et al., 2011). Another anticipated benefit of integration of data into larger datasets is that it will lead to new insights by allowing the use of different methods, such as meta-analyses or data-mining (Huang & Gottardo, 2012; Thessen & Patterson, 2011).

A different rationale is that standardization of methods can also address scientists' anxieties about the credibility and status of their domain in the eyes of outsiders. Scientists are often concerned that methodological heterogeneity gives the impression that their domain works in an ad hoc way, and cannot agree on reliable methods (Holmes et al., 2010).

## 2.2 Limits to Standardization

Many researchers have noted tensions between standardization, and scientific needs (Cragin & Shankar, 2006). Standards imposed prematurely, or too rigidly, may not adapt to new methods and technologies (Jackson & Barrow, 2015; Yarmey & Baker, 2013). Standards can fail to take account of local cultures (Millerand & Bowker, 2009), or the tacit knowledge and "touch" of scientists (Jackson & Barrow, 2015).

Concerns about premature standardization can apply in particular to new domains. Such domains frequently exhibit high degrees of methodological diversity, because they often incorporate scientists from multiple extant domains who bring a variety of methods with them, as exemplified during the emergence of molecular biology (Rheinberger, 2009). Standardization could thus be of particular concern to emergent domains as they seek to establish legitimacy. However, as Calvert & Fujimura (2011) have found, scientists sometimes oppose standardization, believing methodological diversity to be a strength of their domain. This opposition exposes a deep epistemic division in the domain between proponents of standardized methods, and those supporting methodological pluralism.

## 2.3 The Work of Devising Standards

Even where stakeholders across a domain broadly agree on the desirability of methods standardization, the work of devising standards nevertheless encounters frequent tensions and resistance. For this work to proceed, individuals need to be incentivized to participate. In some cases, individuals or groups regard standardization as threatening to their own interests. The resolution of debates around what standards should be involves privileging certain groups, individuals, and sets of values over others (Bowker, 1999; Lampland & Star, 2009). On an individual level, Bowker & Star (1999) discuss how nurses concerned that standardized methods of documenting their work could expose their profession to "deskilling". For these reasons, individuals or groups may be reluctant to participate in the work of devising standards.

Other incentives relate to the credit an individual may gain from participating in the work of devising standards. Often, this work is invisible, meaning that individuals do not gain recognition for carrying out the work (Bowker & Star, 2000). However, being involved in standardization work can also be attractive to scientists. For example, Sundberg (2011) found scientists were motivated to participate in formulation of standardized methods when such involvement was regarded as prestigious.

## 3 Case Study

To answer the research questions, I present findings from an eighteen-month, qualitative case study of the domain of the deep seafloor biosphere, focussing on the *Center for Dark Energy Biosphere Investigations (C-DEBI)*<sup>1</sup> and the ocean drilling programs on which it depends.

<sup>1</sup> <http://darkenergybiosphere.org>

### 3.1 Center for Dark Energy Biosphere Investigations (C-DEBI)

C-DEBI is a ten-year *Science and Technology Center (STC)* funded by the US *National Science Foundation (NSF)*, and launched in September 2010. The project has two main aims: to build a community of researchers to study deep seafloor microbial life, and to promote the scientific work of understanding interactions between microbial life and the physical environment. These researchers are geographically distributed, with the Principal Investigator (PI) and four co-PIs based at five universities distributed across the U.S. C-DEBI funding covers projects conducted by over 90 scientists in more than 40 universities and research institutions across the USA, Europe, and Asia.

C-DEBI-affiliated scientists address the project's scientific goals by collecting and analysing rocks from the seafloor, known as *cores*. The project's work involves data about the composition and size of microbial communities in these cores and about the core's physical properties, such as geochemical or hydrological. Cores are procured from scientific ocean drilling cruises. From 2003 to 2013, the *Integrated Ocean Drilling Program (IODP)* operated these cruises. In 2013, IODP was replaced by the *International Ocean Discovery Program (IODP2)*, which uses the same material infrastructure as IODP<sup>2</sup>. IODP/IODP2 serves a wide range of scientific domains, of which the deep seafloor biosphere is one (other domains include scientists studying plate tectonics, and historic climate change).

### 3.2 Research Methods

The research methods comprise long-term participant observation, interviews, and document analysis, following standard ethnographic practices (Hammersley & Atkinson, 2007). I was embedded for eight months in a laboratory headed by a leading figure in C-DEBI at a large US research university, and also conducted weeklong observational work in two other laboratories in the USA. In addition, I observed a field research expedition, the C-DEBI Annual Meeting, and domain conferences. I did not observe IODP/IODP2 cruises directly. Instead, I visited one of the IODP/IODP's three repositories where cores from cruises are stored, where I was able to observe curators handle and process cores using similar tools and methods to those on cruises, in response to sample requests from scientists. In addition, I observed online meetings about cruise participation, as well as watching a feature-length documentary featuring footage from a deep seafloor biosphere-focused cruise (Brown, 2013).

The interview sample consists of 49 people. These include C-DEBI-affiliated scientists (n=41), and curators and managerial staff involved in IODP/IODP2 (n=8). These semi-structured interviews range in length from 35 minutes to two hours and 30 minutes, with the majority being between one and two hours long. Interview questions cover a range of topics, including interviewees' backgrounds and career trajectories. Scientists are asked detailed questions about the scientific work they are undertaking, and the importance and role of data in their work. IODP/IODP2 technical staff and C-DEBI scientists who have participated in IODP cruises are interviewed about their work on board expeditions, how they negotiate with other stakeholders for access to cruise resources, and how they transfer data, methods, techniques, and collaborative networks between cruises and their onshore laboratories.

I also assembled a corpus of documents for analysis, including official C-DEBI documents such as Annual Reports, and documents about IODP/IODP2 operations.

## 4 Findings

The domain of the deep seafloor biosphere is characterized by methodological heterogeneity. A movement comprising a number of leading domain researchers has emerged to promote methods standardization. This movement is motivated in part by the prospect of answering fundamental questions in microbiology, but primarily to reconfigure IODP2 infrastructure to better serve the deep seafloor biosphere. This movement faces two tensions in particular. One tension concerns divergent conceptions of whether methods standardization best serves their domain's progress. The second is between domain level interests and individual interests, with scientists facing personal incentive structures that can deter them from carrying out work necessary for standardization to proceed. To understand these tensions, I first present an overview of scientific work in the deep seafloor biosphere.

### 4.1 Workflows and Methods in the Deep Seafloor Biosphere

First, I discuss the work undertaken by domain scientists. Subsequently, I focus on one stage of the workflow to demonstrate how heterogeneity of methods has arisen.

<sup>2</sup> <http://www.iodp.org>

#### 4.1.1 A typical scientific workflow in the deep subseafloor biosphere

Here, I set out a standard workflow that I observed frequently in the laboratory. The goal of a project incorporating this workflow is to understand how the microbial community at a particular research site in the seafloor and the physical profile of the surrounding seafloor shape each other.

The starting point for this data cycle is the collection of cores for analysis from a particular site during cruises conducted by IODP/IODP2. IODP/IODP2 provides two ships for conducting around five drilling cruises per year. Cruises typically last nine weeks. These cruises involve participants from multiple science domains, in addition to deep subseafloor biosphere researchers.

Cores are allocated either for physical science analyses or for microbiological analyses. Cores for microbiological analyses must be collected, processed, and subsequently stored according to different procedures to cores for physical science analyses to avoid biological contamination and to prevent microbial communities from changing over time during storage. For instance, samples for physical science analyses are stored at  $-4^{\circ}\text{C}$ , while samples for microbiological analyses are stored at  $-80^{\circ}\text{C}$ .

Some cores are analyzed on board cruises to produce data about the physical composition of the cores. These analyses are conducted on all IODP/IODP2 cruises, according to standardized protocols, and resultant data are made available through an online database. However, no comparable microbiological analyses are conducted on IODP/IODP2 expeditions.

Other cores are allocated to cruise participants. Following the end of cruises, these samples are taken to participants' onshore laboratories, where they are subjected to analyses according to the specific research questions of the scientist. Some of these analyses may be more advanced and specialized analyses of the physical traits of the core. Other analyses are biological in nature and seek to characterize the size and composition of microbiological communities found in the cores. Scientists can then correlate these three sources of data (IODP/IODP2 cruise physical science data, laboratory-generated physical science data, and laboratory-generated microbiological data).

#### 4.1.2 Heterogeneity of methods

The production of each source of data involves multiple steps. The laboratory that I was embedded in for eight months produced largely microbiological (as opposed to physical science) data. For each step, I observed heterogeneity in terms of the techniques, tools, and protocols used. Even scientists working on adjacent benches frequently employed different methods to accomplish the same steps. One example is the extraction of genetic material from core samples. Extraction is the first stage in microbiological analysis. Although extraction is common to work in all domains of microbiology, the deep subseafloor biosphere faces a particular challenge. Biomass in the seafloor is very low, so traditional techniques of extraction common to other domains of microbiology are unsuitable as they lead to a yield of genetic material that is too low to allow further analysis.

Different scientists improvise using disparate techniques to increase this yield. I observed at least four methods in this single laboratory, and interviews with scientists outside of the laboratory suggested not only the existence of many more in the broader domain, but that new methods are also being introduced over time. This situation is illustrated by the following quote from one of my interviews:

"The DNA extraction, or RNA extraction, procedure is all over the place. We all use different types of DNA extraction procedures... And there's constant developments being made." (Scientist 1)

Researchers have demonstrated that heterogeneity of methods for extraction of genetic material has implications for studies of microbial communities (Mills, Reese, & Peter, 2012). Some methods are more efficient at extracting genetic material. Some methods produce biased results, as they are more efficient at extracting certain types of microbes than other types. Results of studies also vary according to whether the chosen method extracts genetic material from living microbes only, or from dead microbes as well.

Each scientist's particular education and experience prepare them to use a specific technique. Some scientists have drawn on prior experience of studying microbiology in other low-biomass domains. Other scientists had particular scientific backgrounds that enabled them to devise novel techniques. My observational work also revealed other factors driving heterogeneity, for example highlighting the importance of physical access to tools, and how patterns of circulation of knowledge about methods mapped closely to observed social networks and hierarchies.

Another factor that can drive heterogeneity of methods is the lack of closure of debates around scientific issues in the domain. One example is whether bacterial spores (formed by bacterial cells to survive extreme conditions) should be considered as living, dead, or an intermediate category. These debates have implications for the development and choice of techniques to quantify and characterize living biomass in core samples.

The heterogeneity of methods for genetic material extraction, and the implications for the results of the workflow described above, is echoed in other steps of the workflow. For more details about how and why methodological heterogeneity arises in the domain, see Darch et al. (2015).

#### 4.2 Promoting Methods Standardization in the Deep Subseafloor Biosphere

Since 2008, a group of leading deep subseafloor biosphere scientists has attempted to mobilize their scientific domain to standardize methods of microbiological analysis. The scientists most closely involved with promoting standardization are distributed across institutions in the USA, Europe, and East Asia. These scientists are united by their involvement in IODP/IODP2 cruises. Overall, most of the researchers that I have spoken with and observed have *not* participated in these cruises, instead securing physical samples for analysis from other sources, such as other researchers. By contrast, the scientists most active in promoting standardization have typically been involved in negotiations about organization, operation, and resource allocation of these cruises. Many of these scientists have sailed on cruises, some as co-chief scientist of a particular expedition, where they have contested allocation of scarce resources (ship space, cores) with scientists from other domains. Some others have been involved as onshore participants of a particular expedition, not sailing but nevertheless actively involved in negotiations pre- and post-cruise with scientists from other domains regarding allocation of cores.

Although aspiring ultimately to standardize many steps of the microbiological workflow, scientists advocating standardization are first focusing on two workflow components in particular: standardizing protocols for the on-ship handling and storage of cores (such as testing for contamination, known as *contamination checks*) to ensure they remain suitable for microbiological analysis, and standardizing techniques for counting the number of microbes in core samples (known as *cell counting*).

These scientists advocate standardization because they believe it to be in the best interests of the emergent scientific domain of the deep subseafloor biosphere, for two reasons in particular.

##### 4.2.1 Rationale for standardization: Better Integration of Extant Data to Raise the Domain's Status

One motivation for standardization is to improve domain researchers' ability to answer questions about the global distribution and quantity of microbes. This motivation was cited in articles and reports published by domain scientists such as Orcutt et al. (2013), but less so by interviewees. For example, estimating the total global biomass of microbes is important for understanding global environmental processes. Data about microbial biomass in the deep subseafloor biosphere form critical components of these estimates. Another example is a hypothesis about the global distribution of microbes that has been foundational to microbiology for many decades, but remains unproven. Deep subseafloor biosphere scientists anticipate they will make important contributions to resolving debates around this hypothesis.

Such contributions will address anxiety frequently expressed by deep subseafloor biosphere researchers about the status of their domain. By attending conferences and symposia, I observed the extent to which the deep subseafloor biosphere, as an emerging domain, is less mature than studies of microbial communities in other environments (such as lakes and soil): for instance, whilst posters and presentations about microbial life in the seafloor often focused on exploratory analyses of microbial communities found at different seafloor locations, scientists studying microbial communities in other environments typically presented findings of research involving generation and testing of hypotheses.

Answering questions about the global distribution and quantity of microbes requires the integration of datasets about multiple sites in the seafloor, produced by different teams of scientists. The heterogeneity of methods used makes it difficult to integrate these datasets as the bias, efficiency, and other dimensions of variance of each method needs to be taken into account. Methods standardization is thus intended to help elevate the status of the deep subseafloor biosphere domain by placing it at the center of – and indispensable to – some of the most fundamental debates in microbiology.

##### 4.2.2 Rationale for standardization: Reconfiguring IODP2 infrastructure

The second rationale advanced by these scientists is that they regard reconfiguration of the IODP2 infrastructure to serve the interests of the scientific domain as a key priority. Standardization forms a critical component of their strategy for achieving this reconfiguration. This motivation was cited not only in reports and articles published by domain scientists, but also frequently by interviewees, suggesting that this motivation is the most important for the standardization movement.

Prior to 2003, the forerunner<sup>3</sup> organizations to IODP focused exclusively on physical sciences. The deep subseafloor biosphere emerged as a domain of serious scientific study in the late 1990s, leading to the expansion of the IODP's scientific agenda in 2003 to include this domain.

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<sup>3</sup> <http://www.iodp.org/history>

Given the relative novelty of the domain of the deep seafloor biosphere, and competition for IODP/IODP2 resources with other domains, leading deep seafloor biosphere scientists are concerned with a 'dearth of data' holding back their domain's progress, as discussed in C-DEBI proposal to the NSF (Edwards, 2009, p. 1). Advocates of methods standardization told us that standardization should address this data dearth by reconfiguring IODP2 to provide more resources to the domain in the future. In particular, standardization will enable the production of basic microbiological data on board all IODP2 cruises comparable to that of the physical science data currently produced on every expedition.

Advocates of standardization anticipate multiple gains from embedding microbiological workflows in IODP2 cruises. One such benefit is that cruise-produced microbiological data should provide a foundation for scientists to conduct more advanced analyses than they are currently able in their onshore laboratories. Another expected benefit is that adding contamination checks onboard IODP2 cruises will better ensure the quality of cores allocated for microbiology, thereby increasing the supply available for microbiological analyses and scientists' confidence in these cores' integrity. Implications of not having contamination checks currently performed as standard on cruises is discussed by one interviewee:

"I have a very difficult time to determine whether or not [samples] are contaminated. And because I do not know if they are contaminated or not, my post-expedition funding to process the samples that I got, that IODP invested in... They did not see fit to give me post-cruise funding on this, because there's no guarantee the samples are clean." (Scientist 2)

Another perceived benefit of standardization is increased incentives for domain scientists to participate in cruises, which then provides a number of benefits for the domain. Currently, deep seafloor biosphere scientists cannot proceed with performing their own microbiological analyses on cores during cruises due to a lack of contamination checks. Domain scientists are often reluctant to go on cruises, because they are unwilling to spend nine weeks at sea without opportunities to perform scientific work. Consequently, IODP/IODP2 cruises have often sailed without a microbiologist on board. Decision-making processes about how to allocate core samples involve negotiation between cruise participants. The absence of a microbiologist in these negotiations can mean nobody is present to advocate for the interests of the deep seafloor biosphere, resulting in poorer-quality and fewer cores allocated to microbiological purposes:

"So for us to get samples, and for us to get dedicated core material, it becomes a political battle on every expedition. The expeditions where a microbiologists sails, we have a better chance... But on certain legs and certain aspects, it just doesn't happen." (Scientist 2)

Standardization of methods for the handling and storage of cores is anticipated to address this situation.

To advance their agenda, advocates of standardization have taken a number of actions that include: arguing for standardization in reports and peer-reviewed journal articles (Orcutt et al., 2013); and organizing a workshop bringing together prominent domain scientists that was held in August 2014. At this workshop, scientists resolved to pursue standardization through a variety of mechanisms. One is to develop a handbook setting out procedures for processing and storing core samples for microbiological analyses, and training IODP2 curators to follow these procedures. A second is to recommend that when deep seafloor biosphere scientists are asked to act as reviewers for proposed IODP2 expeditions, they do not support expeditions that plan little inclusion of microbiology onboard, and give full support only to expeditions planning contamination checks and cell counting onboard.

#### 4.3 Concerns About Premature Standardization and Closure of Debates

However, some scientists are concerned about potential negative implications of premature standardization. In particular, a number of researchers expressed concern that standardizing methods now is premature, foreclosing better methods from being implemented in the future. Unlike the scientists who promote standardization, scientists skeptical of standardization have not organized workshops, nor are they arguing in journal articles for preserving methodological heterogeneity. However, in common with the scientists who favor standardization, those who prefer to conserve heterogeneity are also motivated by perceptions of how to promote the interests of the deep seafloor biosphere domain.

C-DEBI has devised its funding strategy to maximize the number of scientists that it draws in to the domain, distributing short-term funding for projects biannually with a policy that previous recipients cannot apply for more grants. Consequently, the domain is very dynamic, with new scientists regularly entering from a wide range of disciplinary and institutional backgrounds. Indeed, consulting the homepages of the more than 90 scientists awarded C-DEBI funding to date, I have counted more than 50 different labels used to describe scientists' disciplinary identities, from the traditional (such as geology, and mineralogy), to the more specialized (such as paleogeomicrobiology, and microbial biogeochemistry).

This disciplinary dynamism is regarded by some interviewees as “good because people have different ideas and see things differently” (Scientist 3). A consequence of this dynamism is that new methods for microbiological analyses continue to be brought into the deep subseafloor biosphere from other domains. Some domain scientists are concerned that standardizing methods now may prevent development of methods in the future that will enable more effective use of scarce resources such as cores. The care with which I observed researchers handling these cores in the laboratory emphasized the importance of maximizing the scientific return from each core. Yet-to-be-developed methods may prove to be higher-throughput than existing methods and increase the rate at which microbial genetic material (DNA or RNA) is extracted from cores, they may be less biased, or they may be more reliable.

As well as foreclosing the possibility of more effective methods in the future, standardization of methods may also contribute to the premature closure of other ongoing and important scientific debates in the field. One notable example was discussed above, namely whether bacterial spores – which are known to constitute a significant portion of biological material in the subsurface – should be regarded as living, dead, or something else. Whether a method for counting living cells includes these spores implies a commitment to a particular position on this debate. Hence, if only one method is chosen as the standard, it is likely to enforce one position of this debate at the expense of the others.

#### 4.4 Resistance to Standardization

So far, I have considered debates around standardization from the standpoint of what best advances the interests of the scientific domain as a whole. Another source of tension arises from the interests of some individual scientists not being aligned with processes of standardization.

##### 4.4.1 Hard work with uncertain reward

The work necessary to standardize methods can require much effort by individuals. Currently, infrastructure to support this work is patchy, placing a substantial burden on individuals conducting the work. Furthermore, meaningful rewards for individuals carrying out such work can be uncertain. Time and effort spent on standardization work is time that researchers cannot spend on their own research, and can thus be detrimental to the careers of these researchers. Hence, although many domain scientists are supportive of standardization at the domain level, incentive structures at the individual level act against the willingness of these scientists to conduct work that contributes towards method standardization.

To illustrate this point, here I consider the difficulties a leading subseafloor biosphere researcher encountered whilst they were undertaking a meta-analysis, using statistical methods to compare competing methods for counting the number of microbes in a core sample. Meta-analyses that incorporate datasets produced by different methods form a critical part of the work of methods standardization, because they allow for the comparison of these methods to assess their effectiveness.

In the meta-analysis considered here, the scientist analyzed datasets supporting more than 60 journal articles produced since the early 2000s. Although this meta-analysis was successfully completed, and eventually published, the scientist had to overcome many obstacles along the way.

The first challenge for this scientist was in obtaining and analyzing the various datasets. She first had to consult every piece of relevant published literature, and estimate the numerical rates of microbial extraction. These figures were then input on a spreadsheet. In many cases, necessary data were not openly accessible and the scientist had to approach the producers of these data for access. Finally, once data had been obtained, this scientist approached a colleague at the same university with expertise in writing statistical computer code to analyze the large dataset she had aggregated.

All of this work was accomplished manually. This scientist told me “it took a lot of time” (Scientist 4). The meta-analysis also involved critical elements of serendipity: the scientist was able to find a colleague with the requisite coding expertise; and producers of datasets still had copies of their data.

Despite the burden of the work, the potential reward to the scientist was uncertain for two reasons. First, the scientist struggled to find a journal to publish the paper presenting the meta-analysis, explaining that a pervasive culture in microbiology in which “new data is exalted above a really good analysis” (Scientist 4) of old data contributed to several major journals rejecting this paper (although, eventually, this paper has since been published in another journal). In addition, a significant finding of the paper was that the technique used by a senior member of the domain was biased, to the extent that this technique failed to detect one of the three major classes of microbes.

The scientist who was the lead author on the study is a pre-tenure faculty member in the USA. Two critical components of the awarding of tenure are publication record and the support of senior members of the domain. Struggling to have papers accepted by peer-reviewed journals, and exposing flaws in the methods of senior researchers can thus be understood as risky and daunting for this scientist.

#### 4.4.2 Anxieties about marginalization

Some scientists are concerned about the implications of standardization for their own careers. Given the range of methods that are currently employed by scientists conducting microbiological analyses, standardization will necessarily mean that the methods used by a large number of scientists are marginalized. For instance, as discussed above, meta-analyses can cast doubt on the reliability of methods used by a particular scientist. Even in cases where the reliability of a scientist's methods are not called into question, the widespread standardization and adoption of a different method poses the risk that this scientist's work will be considered obsolete.

In addition, researchers may be concerned about standardization for other career reasons. For instance, I observed cases of doctoral students adapting and developing methods, which can be a valid topic for doctoral dissertations as novel contributions to the field, as explained by one interviewee:

“What I'm in the process of developing now. A solid proof of concept experiment that will allow me to see the strengths and the limitations of the technique...this is for my thesis.” (Scientist 5)

Students developing original methods as part of their doctoral dissertations are sometimes concerned that standardization may impede their ability to complete these dissertations successfully.

## 5 Discussion

This paper has presented findings about how processes of methods standardization are unfolding in an emerging scientific domain, the deep subseafloor biosphere. Here, I discuss how the scientists advocating methods standardization are not primarily motivated by the rationales usually advanced for methods standardization, but instead regard standardization as a strategy for reconfiguring infrastructure shared, and contested, with other domains. I also consider two tensions faced by those advocating standardization: one relates to competing conceptions of how best to serve the domain's interests, and the other to conflicts between scientists' conceptions of their domain's interests and of their own interests. These findings have implications for initiatives set up to promote better circulation and of scientific knowledge products, and I briefly consider those implications here.

### 5.1 Rationales in Support of Standardization

Deep subseafloor biosphere scientists promoting methods standardization advance two rationales in particular. One rationale is the major driver of the standardization movement, whilst the other plays a minor role. The minor rationale, that standardized methods will enable multiple datasets to be integrated and compared, echoes some of the usual rationales advanced elsewhere (Barchyn et al., 2011; Huang & Gottardo, 2012; Thessen & Patterson, 2011). Standardization will allow for meta-analyses to answer important questions in microbiology. Hence, standardization is anticipated to raise the status of the deep subseafloor biosphere, albeit in a different way to that considered by Holmes et al. (2010).

The main rationale is for standardization to be an intervention in the inter-domain politics around allocation of scarce IODP2 resources. Standardization of methods is intended to enable these methods to become embedded in IODP2 infrastructure, allowing the deep subseafloor biosphere domain to secure a greater share of scarce IODP2 resources in competition with other domains. Processes of working out what standards should be embedded in infrastructure often involve negotiation between different groups, and the resolution of these processes involve the privileging of one social order or set of values over another (Bowker, 1999; Lampland & Star, 2009). However, in the case studied here, those advocating standardization regard devising and embedding standards in IODP2 as the first step in reconfiguring infrastructure that is contested with other domains to the advantage of the deep subseafloor biosphere. These findings suggest that movements for methods standardization in a domain should be understood not only motivated by a desire to improve interoperability of data and information across a domain or with extant infrastructure, but instead as interventions in material politics of infrastructure.

### 5.2 Tension: Divergent Perceptions of the Domain's Best Interests

One major tension identified here is between two conceptions of what is in the best interests of the deep subseafloor biosphere, with some researchers believing that standardization does not serve these interests. As an emerging domain, the deep subseafloor biosphere comprises scientists from diverse backgrounds who bring a wide range of methods and approaches with them (Rheinberger, 2009). Some of these scientists value the domain's methodological pluralism, and are skeptical about the benefits of standardization, echoing what has been found in other domains (Calvert & Fujimura, 2011). In particular, they are concerned that premature embedding of standards in infrastructure might inhibit better methods from being developed and implemented in the future (Jackson & Barbrow, 2015; Yarmey & Baker, 2013).



The assumption that standardization is necessary for the progress of science is embedded in the many initiatives set up to promote better circulation and of knowledge products (Huang & Gottardo, 2012; Lavoie, 2008; Smith et al., 2007; Wang et al., 2013). My findings suggest two implications for such initiatives, particularly in the case of emergent domains characterized by methodological heterogeneity. The first is that such initiatives are likely to fail to secure the support of domain researchers who believe standardization is not in their domain's best interests. The second implication is that such initiatives should attend to whether a particular domain is ready for methods standardization and should address how infrastructures can be designed to support methodological pluralism. One possible way to support this pluralism is to ensure the interoperability of the domain's infrastructure with infrastructure in other domains. As stated, a major source of methodological diversity is researchers adapting methods from their various scientific backgrounds, so infrastructure that enables tracking the origins and development of adapted methods across domain boundaries should help to support methodological pluralism.

### 5.3 Tension: Researchers' Perceptions of the Domain's Interests and Their Personal Interests

Another major source of tension seen in this case study relates to researchers who support standardization efforts for the domain. These researchers' perception of the domains' best interests conflict with their own individual interests, in the sense that they face individual incentive structures that discourage them from conducting the work necessary for determining what the standards should be. Echoing the findings of Sundberg (2011), processes for determining standards can be burdensome. In the case here, meta-analyses to assess competing methods form a necessary part of these processes, yet there is a critical lack of infrastructure to enable easy access to, and aggregation of, relevant datasets. Furthermore, the rewards for conducting this work seem uncertain, suggesting that this work risks being invisible (Bowker & Star, 2000). In addition, some domain researchers are concerned that standardization will work against their own personal interests (Star & Bowker, 1999). If standardization is to proceed, infrastructure to support the necessary work of standardization needs to be in place, and incentives to carry out this work must align with the interests of researchers.

## 6 Conclusions

In the case of the deep seafloor biosphere, the major driver of standardization is to intervene in the politics of infrastructure to secure a greater share of scarce infrastructural resources for the domain. However, the work of standardization in this domain is encountering tensions. One tension is between standardization and methodological pluralism, with scientists holding divergent conceptions of what is best for this emergent scientific domain. A second tension is between individuals' perceptions of what is best for the domain, and their own interests, due to a lack of infrastructure and reward structures to incentivize standardization work. These tensions challenge assumptions about standardization currently embedded in many initiatives to implement infrastructure, tools, and policies to serve scientific domains.

Discussion around methods standardization continues in the deep seafloor biosphere. Who prevails will have profound long-term implications for individuals' careers, configurations of infrastructure, and the very ways in which scientists come to know the microbial communities that exist in the seafloor.

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