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'Bigger, Faster, Better? Rhetorics and practices of large-scale research in contemporary bioscience'

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This special issue introduces the emerging contours of a series of large-scale biological research projects, drawing them together in dialogue with each other and in critical debate with the extant rhetorics and practices of 'big science' in biology. The category of 'big biology' is in question from the start. On the one hand, it serves to frame and align the ways in which these projects are being developed and positioned in relation to epistemic ambitions, funding imperatives, research governance, choice and maintenance of infrastructure, geographical scope and social importance, especially within scientific, media and policy narratives. Given the vast amounts of resources (skills, technologies, funding and manpower) directed to contemporary bioscience research, and the growing emphasis in Europe, the USA and elsewhere on funding co-ordinated initiatives and projects, the suggestion that biology is 'big science' increasingly figures in popular characterisations and science policy statements (see for example Weinberg, 1999; Collins *et al*, 2003; Nass and Stillman, 2003; Esparza and Yamada, 2007; see also Vermeulen, 2010). On the other hand, the idea and operation of an emerging 'big biology' is far from singular and unproblematic, especially given the difficulties in defining what counts as a shift in the scale of research. The range of initiatives covered in this volume immediately attests to its diverse characteristics, and points to further difficulties in attempting to define what is meant by 'big biology' today, and how it differs, if at all, from historical manifestations of large-scale science. We thus suggest these claims deserve careful scrutiny within science and technology studies (STS) and in relation to changing histories and geographies of science. The authors of this collection draw on a variety of empirical studies to consider how this reorganisation of research and achievement of scale is linked to changes in the production, flow and valuation of knowledge in the contemporary biosciences. In this introduction, we build from these case studies to explore the definitional, scalar and spatial issues at play in such large-scale research, and reflect on the scientific and social stakes of these forms of 'big biology'.

Our starting point is recognition of the need to integrate arguments from literatures on 'big biology' and infrastructure in STS with scholarship on the geographies of science. Given the

centrality of ideas about size, complexity and international collaboration associated with 'big biology' in STS (e.g. Parker *et al*, 2010), there has been surprisingly little exploration of its scalar, spatial and geographical dimensions to date. This is a notable absence given the rich literature on historical geographies of science, which explore the social and material characteristics of sites privileged for the production of scientific knowledge and the influence of local characteristics on how knowledge is created and received (Schaffer, 1998; Livingstone, 1995, 2003; Powell, 2007); and more recent work emphasising the flows of knowledge and the practices mobilising scientific data and materials across space, which brings social relations of trust, the formation of scientific standards and infrastructures, and the commodification of materials and practices to the fore (Latour, 1987; Naylor, 2005; Secord, 2004; Parry, 2004; Howlett and Morgan, 2010). As illustrated by the case studies in this volume, the proliferating circulations of materials, models and data produced through contemporary 'big biology' lead to conceptual and practical challenges in defining, managing and aligning spatial and temporal scales in life science research. New questions are emerging about how these configurations are to be bounded, how they are co-ordinated, and the extent to which they might mesh with or work against the temporalities and spatialities of the biological processes they are seeking to study.

The endeavours examining 'big biology' in this special issue range from self-identified 'projects', such as the Human Genome Project (Hilgartner) and the Knock-Out Mouse Project or KOMP (Davies), to the digital infrastructures designed to manage the challenges of big-data in model organism or cancer research (Leonelli), and the large-scale ambitions of new disciplinary areas like synthetic biology (Frow), and systems biology (Calvert). What holds them together is the suggestion that, in both in rhetoric and practice, certain biological research practices are being co-ordinated to understand and manage biological complexity for specific goals, whether defined by research communities or in relation to wider social imperatives. In each of these cases, these developments are underpinned by the expectation that expanding the scale and speed of biological enquiry will improve the value of biological research[1]. In their different configurations, these projects all demonstrate the emergence of initiatives involving large numbers of people, resources and materials directed towards prescribed goals, with the anticipation that speed, whether measured through outputs or research milestones, is an effective assurance of research quality and efficiency. There are normative assumptions that bigger will be faster, and that faster

[1] As the commentary by Lezaun points out, there is a double act of value creation and destruction in these collaborative practices. Devaluation is an equally significant process if researchers are to be encouraged to share resources previously held by individual laboratories or institutions.

is better. We thus suggest these large-scale initiatives are an inventive re-organisation of the spatiotemporal dynamics governing biological research, which has epistemic, spatial and social implications for the knowledge being produced and for the researchers and experimental subjects (whether human or non-human) included in their scope. Bringing these case studies together allows exploration of why and how this reorganisation of biological research is emerging: through new forms of governance (Hilgartner), spatial imaginaries (Davies), research infrastructures (Leonelli) and articulations of value (Calvert), and by creating new kinds of moral economies in biology (Frow). Such moral economies define both the inside and the outside of research, facilitating the identification of those and that which is excluded. Looking comparatively across these case studies facilitates analysis of the tensions within and gaps between aspirations, the geographical and biological boundaries that are being set, and the related shifts in how biological phenomena are being apprehended.

Geographical scholarship has pointed to the importance of critically examining the multiple registers of scale at play in key concepts such as maps, models, complex systems and the social constitution of space, which are being reshaped in the practices of 'big biology'.[2] Scalar considerations are central to the organisation of research in 'big biology', the very objects of interest (organisms), and the content of the knowledge produced about them. Three aspects in particular come to the fore. First, there is the centrality of scale to the *mapping and modelling* aspirations of these different projects in 'big biology'; each case study offers a slightly different resolution to the answer 'what is a biological object?' which do not necessarily articulate easily. Second, different scales of accountability are critical to the *management practices* associated with these projects, and particularly to the institutionalisation of new forms of standardisation, evaluation and economisation that are implemented to try and realise the potential from economies of scale for scientific communities, national investments and biological knowledge production. And third, the scalar *discourses* of 'big biology', which stress the global and large-scale, require critical reflection, for such discourses risk obscuring the multiplicity of scientific and material practices, the divergent places and communities, and the contested spatial imaginaries now involved in making up 'big science'. Some of these processes suggest, and in some cases reinforce, hierarchical scales – as in the definition of global standards from local sites;

[2] For a critical discussion and review of the concept of scale in geography see Marston *et al* (2005), Leitner and Miller (2006), and Moore (2008). The relations between scale, size and different orders of complexity have also been a focus of work in STS; see for example Law (2004) and Kwa (2002). A recent interdisciplinary workshop on Scalography in 2009 bought together scholars in STS, geography and other disciplines to explore the potential of turning the problem of scale into an object of productive enquiry. See http://www.sbs.ox.ac.uk/research/sts/research/Pages/scalography.aspx <last accessed 24/09/13>.

others are more horizontally networked – as in the more distributed processes of collecting and curating data. We do not suggest that these biological, managerial or geographical scales pre-exist current developments in the organisation and practice of biological research; the forms of large-scale science that emerge from these intersections are precarious achievements and could easily be disrupted by future shifts in the scientific, geopolitical and economic contexts of research. However, we do suggest that there is a politics of scale requiring empirical analysis, for to change scale, even if only discursively, is to intervene in the distribution of levels of decision-making, power and control (Bulkeley, 2005).

The diversity of scalar claims and temporal-spatial configurations in the idea of 'big biology' is detailed in Calvert's paper, but some significant contours across the papers are worth mapping out here. There is the attempt to use large-scale infrastructure projects to reshape biological research practices, which can themselves be either centralised (e.g. KOMP) or more networked (e.g. parts-based synthetic biology). There is the growing international scope of scientific collaborations, with 'big biology' implicated in emerging patterns in the globalisation of science, where the mobilities of data, people and practices both build on and potentially decentre earlier geographies of knowledge.[3] Further, the social imaginaries underlying 'big biology' are becoming more expansive, taking biological goals closer towards societal needs, or grand challenges, whether in systems biology (Calvert), translational research (O'Malley and Stotz, 2011; Davies, 2012) or one-health medicine (Cassidy and Woods, 2012). On the temporal level, there are new imperatives for working faster and more efficiently with the 'deluge of data' from sequencing technologies (Leonelli, 2010a), and demands for short-term returns on translational medicine and research impact (Sunder Rajan and Leonelli, 2013). Last, but by no means least, there is 'big money' at stake, for the idea of a 'big biology' promises to realise the value of large investments through economies of scale, reallocating funds across different research practices, remaking forms of bio-value, and redistributing roles and rewards within the sciences. Thus despite, or perhaps because of, its discursive imprecision, the continuing use of the term 'big biology' demands critical attention and empirical exploration as an inventive way of defining and organising biological research.

[3] There are now a large number of global and regional studies of science and innovation outside of Europe and the USA, most notably in China, India and Brazil (see for example, Sunder Rajan, 2006; Salter *et al*, 2009). These explore the situated nature of knowledge production in modern value-knowledge-networks that are increasingly globalized, even whilst distribution of therapeutic and other benefits of the biosciences remains uneven.

The historical lineages of these claims are also important, for the growing emphasis on 'big biology' is often identified in relation to the legacies of biology's own history, notably the Human Genome Project (HGP), but also in relation to other scientific trajectories, such as the post-war emphasis on 'big physics' (see Kevles, 1997). As Hilgartner's paper explores, the constitution of the HGP as a project, with identified milestones over time and across space, set up a template and a series of expectations for both the organisation and the evaluation of large-scale bioscience. This was not the first time the history of the life sciences witnessed an attempt to assemble vast amounts of resources, funding, individual skills, expertises and data productively; think only of Linnaeus' 18th century botanical networks (Mueller-Wille, 2004) or the International Biological Programme, running from 1964-1974 (Aronova *et al*, 2010). The vision underlying the HGP is also rooted in 20th-century precedents for the organisation of research around non-human model organisms such as *Drosophila* (Leonelli and Ankeny, 2012). We focus on the HGP here because it has come to epitomise a specific template for what counts as a big biological project today, involving (1) the ideation of an epistemic project in biology of value to state funders, and (2) its institutionalisation through the top-down but distributed governance of several competing centres across geographical locations.

With this framework, project management became a central organisational tool for directing the spatio-temporal dynamics and scales of the HGP. The co-ordination of efforts, the evaluation of success, and the demonstration of accountability were achieved by focusing on measurable milestones, or landmarks, through the production of sequence-tagged sites at each genome centre. Focusing on sequence data as the main result of experimental efforts meant each participating institution could contribute to the overarching effort with the same 'currency', with little regard for qualitative differences in the ways in which each centre produced their data. This in turn meant research was turned into a matter of incremental production, aimed at the aggregation of commensurable and quantifiable masses of data across space, where speed was the main factor in evaluating the success of contributions by each centre. Thereby, speed in data production and dissemination was placed at the centre of the HGP; centres were expected to compete to improve their rates of sequence production. Failure became a matter of managerial logics, defined by assessing the relative performance of centres involved in this 'data race'. If centres did not keep up, they did not get further funding. At the heart of the HGP was thus the mobilisation of a particular conceptualisation of informationalised biology, linked to the transportability, accumulation and acceleration of data-collection procedures. The apparent success of this targeted, centralised and quantifiable way of doing biology has brought increased funding, from

the NIH and elsewhere, to subsequent large-scale infrastructure projects, introducing what has been identified as a post-Fordist shift in the biosciences (Gaudilliere and Lowy, 1998; Bonneuil and Thomas, 2009). But as Hilgartner reports, what kind of endeavour should follow on from this way of conceiving a 'biological project' was not conceptually obvious. In part this is due to the recognition of growing complexity and relationality in post-genomic approaches, which are arguably harder to capture through the incremental accumulation of data, experiments and models, and in part because of the logistical difficulties in sustaining and advancing research through such a top-down approach.

Comparison with earlier academic analyses of 'big science' in the form of physics programmes is also instructive, for it highlights further ambiguities around the notions of scale at work in contemporary 'big biology'. Social scientific accounts of these earlier instantiations of large-scale science often focus on the expensive equipment and centralised facilities of 20th century physics (e.g. Weinberg, 1967; Hughes, 2002; Galison, 1997; Traweek, 1988), where the large numbers of people working on projects based around large apparatus function as a visible marker of 'big science'. Particle physics in particular has a long history of orchestrated efforts to generate large quantities of data through centralized experimental set-ups, such as the hadron collider. This phenomenon has been well-documented in the case of CERN (Kriege, 1996; Knorr-Cetina, 1999). The practices of 'big physics' were dependent on an international migratory workforce, shaped by global governance, and explicitly geopolitical in ambition. Scale emerges from these experimental sites by way of their articulation with national funding priorities and international scientific collaborations. They also depended on the enrolment and integration of very specific sets of experts. Such experts are not easy to integrate, as Galison (1997) and Knorr-Cetina (1999) demonstrate in their discussion of the interactions between theoreticians and experimentalists. But their respective responsibilities are relatively well-defined and they were generally visible to each other. In comparison, contemporary large-scale biology does not function through a single experimental site, but operates through the bureaucratic surveillance of widely distributed and less visible research practices, to include a variety of differently situated forms of expertise. The labours of 'big biology' involve an increasing raft of fieldworkers, the scale of whose contributions are not always discernible to others. The relevant skills and knowledge to tackle problems may also come from any field of the sciences or even the humanities, as demonstrated

by the unexpected collaboration between biologists, medics, computer scientists and logicians involved in setting up classification systems for bio-medical databases (Leonelli 2010b).[4]

One reason for the fluid mix of skills and scale in large-scale biology projects is the living and lively nature of biological objects. A major task for the life sciences is finding ways to manage the irreducible contingency and emergent properties of organisms, through strategies to reduce and parcel complexity into manageable units, for instance through the use of model organisms and other disciplinary lenses. Yet, and as often pointed out by biologists themselves, this requires constant awareness of the limitations of any one perspective and the willingness to accept that new strategies, ideas and skills might be needed to tackle emerging questions. Scale has long been a key criterion for reduction and for the division of research labour, for instance enabling biologists to distinguish between molecular and cellular levels, or between microbial and macrobial scales of analysis (Dupré, 2011). In contemporary large-scale biology, the managerial obsession with the 'project' as the basic unit for research organisation acts as a further device to direct and limit the attention of researchers, preventing individual laboratories from 'drifting off' when they encounter something interesting or unexpected. However, any such attempt to compartmentalise and standardise biological processes is necessarily bound to specific short-term research goals. The tensions that emerge between attempts to govern and regulate interactions and divisions of labour between the components of large projects, and the importance of letting individual laboratories explore biological systems in creative and unpredictable ways, are another important characteristic of contemporary 'big science', one that is discussed and problematised in most of the papers in this special issue.

Rhetorics and practices of data sharing, standardisation and milestone-setting mobilise and aggregate biological properties and capacities at different scales, through different means and with different effects. Some of these projects may be bigger and faster than what came before, but the question of whether they are necessarily better is more openly contested. Such questioning is coming from at least three different directions, which we explore in turn. The first is in the encounter between engineering or managerial logics and experimental biological emergence. The second is in the relation between global and local practices in specific experimental settings and

[4] We are not in a position to address potential parallels between contemporary developments in biology and physics, owing to the relatively scarce literature available on large-scale physics today. Forthcoming publications by Sharon Traweek and collaborators will undoubtedly facilitate comparison.

individual locales. The third is from the opening out of the ambitions of 'big biology' to a wider set of societal needs, and their transformation into grand challenges.

In relation to the first, the technical and biological logics of investing so heavily in high-throughput techniques may be reaching their limits. This critique was articulated in relation to the HGP, where investments in sequencing came into conflict with norms of discovery-driven science (e.g. Balmer, 1996), and it is now re-emerging with new strength. New bottlenecks are evident in the co-ordination of large-scale projects that cannot be solved solely by working faster within existing disciplinary areas. Questions about complex biological phenomena such as metabolism or specific behavioural traits require the integration of results from several branches of biology (Landecker forthcoming).[5] The relationship between standardization and innovation or biological insight is being repeatedly questioned in relation to large-scale biology. Leonelli and Davies both discuss the challenges in prioritising and aggregating standardised data when faced with the enormous complexity of the biological systems under investigation, the parameters of which are potentially infinite. Similarly, Frow shows how attempts to standardize biological components to enable the industrial scaling-up of related biotechnologies (as in the case of Biobricks in synthetic biology) is encountering multiple forms of local resistance, as the contextual and contingent qualities of biological complexity and experimental practice (and practitioners) challenge and re-define the contours of this imagined design space. Calvert discusses the contrast between synthetic biologists, many of whom view the management and containment of context and complexity as a key organizing principle for their activities, and systems biologists, who embrace biological complexity and emergence. The emphasis on an integrative systemic approach as the central rationale of systems biology means it tellingly falls furthest away from easy identification as 'big biology' (see also O'Malley and Dupré, 2005). Ideas about context, control, reductionism and integration are granted different epistemic value across these two branches of 'new biology', and help to constitute in distinct ways their practices, institutional configurations, collaborative strategies, and rhetorical self-presentations in broader social and policy contexts.

The second set of questions emerges at the interface between the global biological and the locally contextual. Such questions were present in the HGP — where a key organizational question was 'What does it mean to run a genome centre here?' (Hilgartner) — and have not gone away. As

[5] There is also growing demand for databases capable of integrating research across diverse research areas, focusing on different organisms, levels of organisation and types of data.

Leonelli illustrates, large-scale infrastructure projects would have no value if local research groups were not using them to tackle specific questions in the context of their own laboratory set-up and species of interest. While the emphasis of large-scale sequencing projects at the turn of the century was on disseminating data as widely as possible, 21st century biology has turned decidedly to the question of how specific laboratories can actually integrate and re-use the data available online for their own research purposes. Similarly, Davies highlights key debates within the mouse genetics community over whether the most valuable biological insights are likely to emerge through centrally engineered programmes or in the context of smaller research projects and 'letting nature tell us […] on an ad hoc, case-by-case basis'. Arguably there is no 'global' biology, as all biological claims are situated within specific research settings and with reference to specific forms of life. What counts as synthesis, unification or integration of biological claims varies, depending on the purpose and means of aggregation at hand.[6]

The increasing demand for data integration and collaboration among scientists also has the potential to bring some knowledge communities into closer dialogue and interaction. This is illustrated in a number of the papers, such as in Leonelli's work on different kinds of databases and Davies' research exploring the integration of previously dispersed scientific communities working with mouse models. Yet, as shown Leonelli, and others, the development of 'big biology' also increases entry costs, and is accompanied by continuing debates about the ownership of and access to data, as well as arguments about the spatial location of databases and other resources, resulting in new forms of exclusion and enclosure. 'Big biology' is not only characterised by accelerating spatial and temporal flows of biological throughput, it is also patterned by the spatial, political and economic redistribution of resources across disciplines, researchers and countries, whether seeking to build capacity within the European 'knowledge-based bio-economy' or to increase efficiencies through out-sourcing mundane work. It thus becomes important to highlight the counterpart to the question asked above with reference to the HGP: 'What does it mean not to run a genome centre there?' and to interrogate who, in the context of these asymmetric collaborations, gets to define where is 'here' and 'there'. As Sunder Rajan's commentary points out, the relations between the global and the local in the production of biological knowledge intersect in critically important ways with questions of the transnational and postcolonial (see also Anderson, 2009; Harding, 2011).

[6] Philosophers of biology have reflected extensively on what it means for biological claims to be aggregated, and how one can think about unification and 'theory' in biology (see e.g. the *Biological Theory* special issue on 'The Meaning of Theory in Biology' edited by Callebaut et al (2013)).

Finally, we turn to closing questions about whether these spatial complexities and epistemic controversies signal the end of the aspirations of 'big biology', or their transformation into something different, and to the roles social scientists are playing in shaping these changes. In her paper on systems biology, Calvert identifies the reshaping of the practices of large-scale science towards socially defined goals in the form of 'grand challenges'. This brings social questions, and sometimes social science researchers, into the explicit framing and evaluation of large-scale biological research, albeit in different ways. Constructing challenges for science at a global scale can provide a social rationale for research, and promises to encourage the social engagement and strategic positioning of researchers and their funders. At the same time, it risks reinforcing the accelerating logics of 'big biology' through the ethical injunction to act as soon as possible in the face of emerging threats to the environment and global health. Moreover, the identification of grand challenges in this way may import culturally specific notions of the global, ideas of health and ontologies of life into the definition of research priorities, resulting in the exclusion of other useful trajectories (Hulme, 2010). There are thus a series of questions about the roles social scientists can or should play vis-à-vis these new collaborative practices, the extent to which they are able to open up spaces for constructive critique, and the ways in which they may be folded into these existing dynamics and further perform these spatial and temporal dynamics of accountability.

The cases examined in these papers do call into question whether such grand challenges always encourage biologists to engage with the social outcomes of their research. Patterns of wider social engagement are unevenly distributed across the initiatives in this volume, with divergent understandings or imaginations of the public and regulatory dimensions of research, and differing degrees of engagement with social scientists. For instance, while the HGP and synthetic biology have incorporated explicit ELSI dimensions and have encouraged interactions between natural and social scientists, this form of interdisciplinary exchange is almost entirely absent from KOMP, systems biology and the set-up of data sharing tools. Why this should be the case becomes a socially, politically and spatially intriguing set of questions to ask, particularly since many of the authors in this collection have conducted their empirical research by entering collaborative relationships with the scientists and funders of the initiatives they study. The study of the practices of 'big biology' unavoidably includes some form of incorporation and personal investment into those practices, ranging from friendly relations with researchers, which guarantee long-term dialogue and access to laboratories (Davies, Hilgartner), to the involvement in

synthetic biology projects as collaborators or as 'ELSI consultants' (Frow, Calvert), and the appointment to steering committees for the coordination of research efforts (Leonelli). Even when social dimensions of the research are explicitly sought, for example by incorporating social scientists into the scope of research endeavours such as nanotechnology and synthetic biology, social researchers themselves can occupy a peculiar position, also serving as representatives of the public and proxies for scientific accountability to public funding and society at large (Doubleday, 2007; Calvert and Martin, 2009). Lezaun elaborates on these questions and their implications in his closing commentary, brining the papers into dialogue with critical literatures on the growth of the project as an organisational form in contemporary capitalism.

In conclusion, 'big biology' is a quite contested and explicitly divisive term, for to recognise something as large-scale research by definition identifies other science as 'small'. As Hilgartner's opening paper explains, the HGP was constituted alongside the simultaneous redefinition of extant molecular biology as 'ordinary biology'. This served the purpose of positioning the HGP as being about resources, rather than a competitor for research funds. Yet, this special issue shows that as ideas and models of large-scale science proliferate and diversify, more people and more projects are being drawn into their scope and the spatial, social and epistemic divisions of labour that they create. The contestations and concerns about 'big biology' continue, both within the community and from its diminishing outside[7]. However, as it grows and diversifies, large-scale bioscience retains these expansionary logics, through forms of accounting that value acceleration and efficiency, and incorporate the social injunction that 'something must be done'. As more and more biological research is brought within the auspices of 'big biology', whether as explicit projects or more expansive grand challenges, there is less and less scope to be left outside its logics and reach, for scientists and perhaps for social scientists too.

[7] There are growing concerns about who might be left 'outside' of these research projects and thus be in a position to review them from what scientists would deem an objective position (Xin and Yidong, 2006).

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