COMMENT

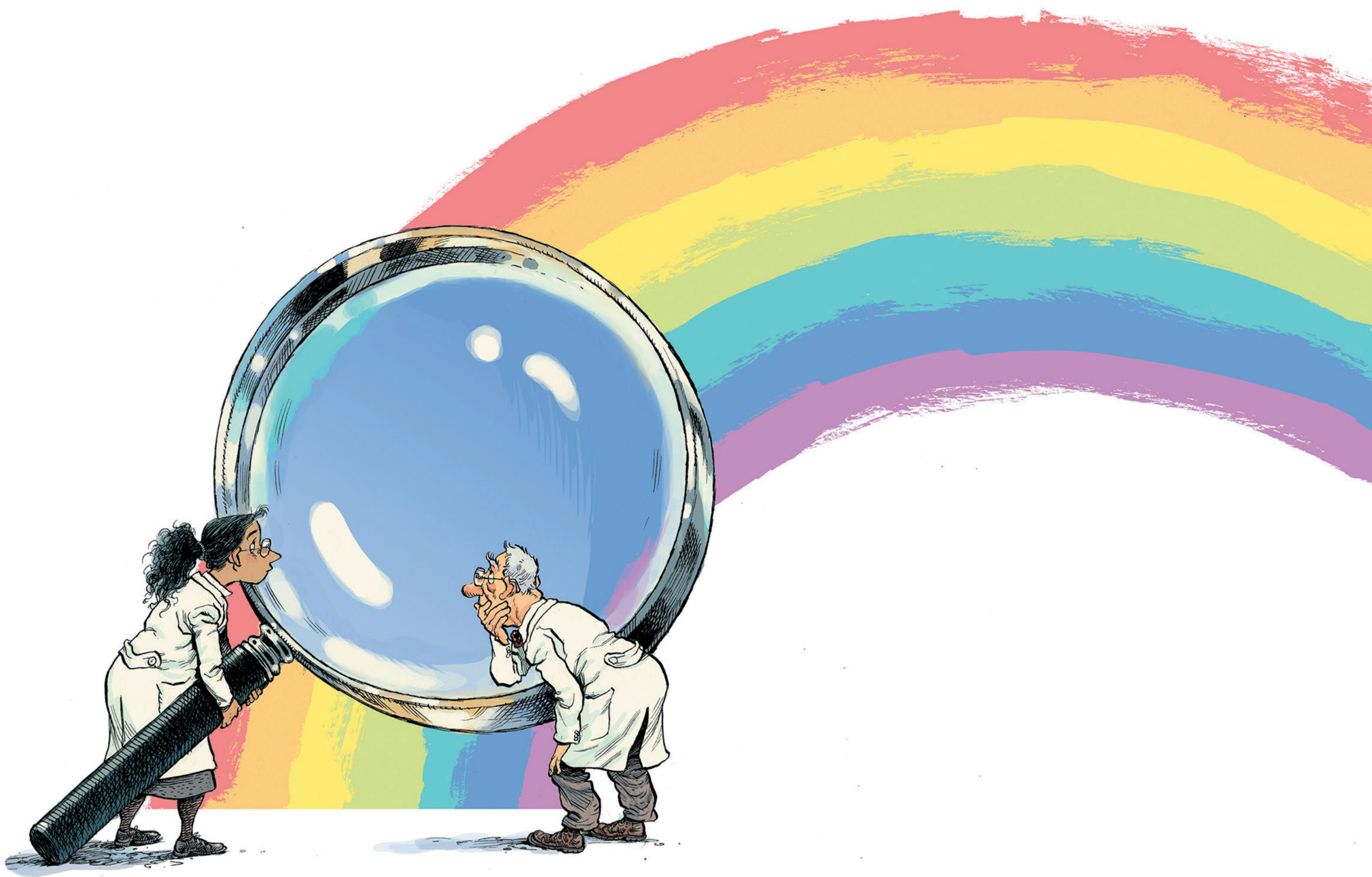

ILLUSTRATION BY DAVID PARKINS

Rethink impact factors: find new ways to judge a journal

A broader, more-transparent suite of metrics will improve science publishing, urge **Paul Wouters** and colleagues, together with 18 co-signatories.

Global efforts are afoot to create a constructive role for journal metrics in scholarly publishing and to displace the dominance of impact factors in the assessment of research. To this end, a group of bibliometric and evaluation specialists, scientists, publishers, scientific societies and research-analytics providers are working to hammer out a broader suite of journal indicators, and other ways to judge a journal's qualities. It is a challenging task: our interests vary and often conflict, and change requires a concerted effort across publishing, academia, funding agencies, policymakers and providers of bibliometric data.

Here we call for the essential elements of this change: expansion of indicators to cover all functions of scholarly journals, a set of principles to govern their use and the creation of a governing body to maintain these standards and their relevance.

Our proposal stems from a 2017 workshop held in Leiden, the Netherlands. It was co-organized by the Centre for Science and ▶

Technology Studies at Leiden University (where P.W., S.d.R. and L.W. work), Clarivate Analytics (the company that produces the annual Journal Citation Reports) and Europe's life-sciences organization, EMBO[1]. More than two dozen professionals from across the scholarly ecosystem participated (see also go.nature.com/2wfeyjc).

We delineated the key functions of journals, which remain largely unchanged since their inception more than 350 years ago. These are to register claims to original work, to curate the research record (including issuing corrections and retractions), to organize critical review and to disseminate and archive scholarship (see 'What's a journal for?')

The creation of new indicators is particularly important given that journals are evolving rapidly and are becoming platforms for disseminating data, methods and other digital objects. The Journal Impact Factor (JIF) is based on citations, as are most other indicators in common use. These capture only limited aspects of a journal's function.

A more nuanced set of indicators would show how a journal performs across all functions. Indicators around curating, for example, might consider the expertise and diversity of the editorial board as well as the acceptance rate of submitted papers and the transparency of acceptance criteria. Indicators around data (such as data citations or reporting standards) will become more important with the advance of open science and independent analysis. Indicators around evaluating research might consider transparency of the process, as well as the number and diversity of peer reviewers and their timeliness.

CLEAR CRITERIA

Having more indicators does not equate to having better ones. We must also ensure that new indicators are constructed and used responsibly[2,3]. Improved indicators should be: valid (reflecting the concept measured); understandable; transparent (data underlying criteria should be released, with clearly explained limitations and degrees of uncertainty); fair (systematic bias should be avoided); adaptive (updated when bias, abuse or other weaknesses become apparent); and reproducible (those who use the indicator should be able to reproduce it).

We think that these criteria will apply even as research publishing changes. For example, we can imagine a future in which the record of scholarly work includes, and credit is attributed for, units smaller than an individual publication. The principles above could apply to any unit of scholarly work that is being tracked. One existing example is citation of the individual data sets behind a specific figure in a paper (as implemented, for instance, by EMBO's SourceData initiative), which can include a subset of a publication's authors.

KEY FUNCTIONS

What's a journal for?

- **Registering.** Through publishing, journals associate the intellectual claims in a piece of work with a date and authorship, which can be used to establish priority.
- **Curating**. Through editorial and other review, work is selected and placed in a collection; this collection signals associations and delineates the theoretical and methodological scope of a scholarly domain.
- **Evaluating.** Through peer review, works are evaluated according to several criteria (such as quality and novelty), and authors receive feedback from their peers. Through publishing, the journal certifies that the work has been evaluated; the journal continues to perform evaluative functions by issuing corrections and retractions.
- **Disseminating.** By making the work public, a journal formally distributes it to a specialist community; with open access and other communication tools, the journal makes the work available to broader communities.
- **Archiving.** By associating work with adequate metadata and making it available online and to indexes and aggregators, the journal contributes to the permanent scholarly record and facilitates discovery. **P.W. *et al.***

FIT FOR PURPOSE

The Journal Citation Reports, presenting the JIF and other journal indicators, were conceived in 1975 as a summary of journals' citation activity in the Science Citation Index (now owned by Clarivate Analytics in Philadelphia, Pennsylvania). It was specifically intended to support librarians who wanted to evaluate their collections and researchers who wished to choose appropriate publication venues, as well as to provide insights for scholars, policymakers and research evaluators. Its inventors never expected the broad use and rampant misuse that developed[4] (see also go.nature.com/30teuoq).

Indicators, once adopted for any type of evaluation, have a tendency to warp practice[5]. Destructive 'thinking with indicators' (that is, choosing research questions that are likely to generate favourable metrics, rather than selecting topics for interest and importance) is becoming a driving force of research activities themselves. It discourages work that will not count towards that indicator. Incentives to optimize a single indicator can distort how research is planned, executed and communicated[6].

The prominence of the JIF in research evaluation and the subsequent flourishing of abuses (such as stuffing reference lists with journal self-citations) and even fraud (such as the emergence of a cottage industry of questionable journals touting fake impact factors) are particularly distressing examples[4,7]. The San Francisco Declaration on Research Assessment (DORA), which critiques the use of the JIF as a surrogate measure of quality for individual research articles or researchers, has now been signed by 1,356 institutions and more than 14,000 individuals. The Leiden Manifesto, which formulated more general principles for evaluation[8], has been translated into 23 languages (see go.nature.com/2hv7eq3). Despite those initiatives, the influence of the JIF is still dominant.

To prevent such abuse, we propose that any use of indicators meet four criteria:

Justified. Journal indicators should have only a minor and explicitly defined role in assessing the research done by individuals or institutions[9].

Contextualized. In addition to numerical statistics, indicators should report statistical distributions (for example, of article citation counts), as has been done in the Journal Citation Reports since 2018 (ref. 10). Differences across disciplines should be considered.

Informed. Professional societies and relevant specialists should help to foster literacy and knowledge about indicators. For example, a PhD training course could include a role-playing game to demonstrate the use and abuse of journal indicators in career assessment.

Responsible. All stakeholders need to be alert to how the use of indicators affects the behaviour of researchers and other stakeholders. Irresponsible uses should be called out.

GOOD GOVERNANCE

All stakeholders in the system share responsibility for the appropriate construction and use of indicators, but in different ways. We therefore suggest the creation of an inclusive governing organization that would focus on journal indicators.

The governing body could propose new indicators to address the various functions of scholarly journals, make recommendations on their responsible use and develop standards. It could also create educational material (such as training in the ethics of indicator development and use) and serve as a place for people to publicize questionable uses of and good practices concerning indicators. For example, it could help to protect researchers against 'predatory journals' — typically low-quality publications that do not conduct peer review or curate information as promised, and that exist only for financial gain. The body could also give guidance on open-access publishing and data sharing.

The organization of the governing body could mirror successful examples in scholarly publishing, such as the non-profit organizations Crossref and ORCID, which provide unique identifiers for articles and authors, respectively. It would be international in composition and would liaise among various stakeholder groups, including coordinating with various relevant initiatives, such as DORA, the UK Forum for Responsible Research Metrics and the Committee on Publication Ethics. Members could include individuals from across the scholarly communication system, drawn from scholarly societies, commercial and non-profit publishers, higher-education institutes, research funders, government and elsewhere.

We invite all interested stakeholders to contact us to join this initiative. On the basis of these responses, we aim to launch the governing body at a second workshop in 2020.

Critics will counter that any incentive system will be vulnerable to gaming. However, we hope that the principles articulated here serve to work against pathologies and hijacking of our goals. Also, gaming multiple indicators would be much more difficult than gaming today's homogeneous metrics. Scientific publishing is taking on new functions and becoming more open to the public. A new generation of journal indicators must support the diverse roles of publishers and incentivize good performance. ■

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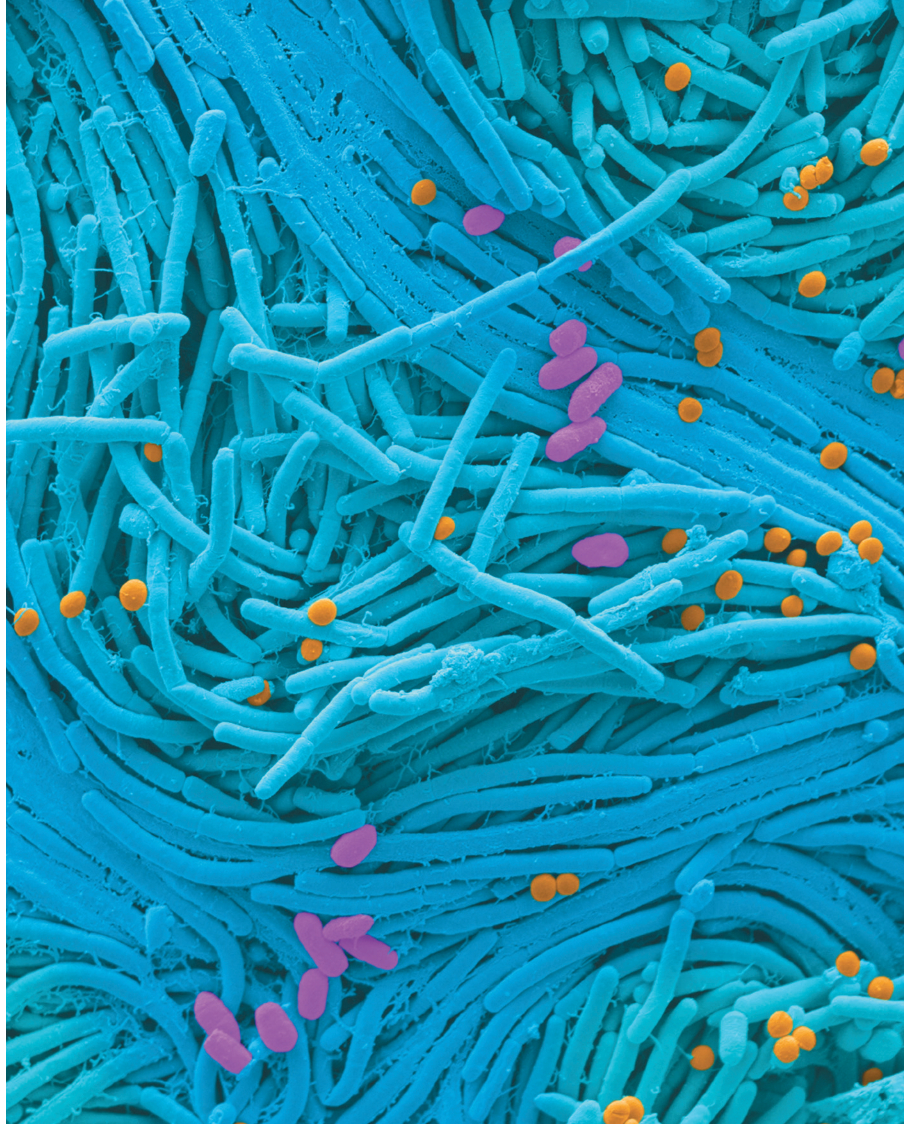
1. Sugimoto, C. *et al. F1000Research* https://doi.org/10.7490/f1000research.1116751.1 (2019).
2. Wilsdon, J. *et al. The Metric Tide: Report of the Independent Review of the Role of Metrics in Research Assessment and Management* (2015).
3. Gingras, Y. *Bibliometrics and Research Evaluation: Uses and Abuses* (MIT Press, 2016).
4. Larivière, V. & Sugimoto, C. R. in *Springer Handbook of Science and Technology Indicators* (eds Glänzel, W., Moed, H. F., Schmoch, U. & Thelwall, M.) (Springer, in the press).
5. Campbell, D. T. *Eval. Program Plan.* **2**, 67–90 (1979).
6. Müller, R. & de Rijcke, S. *Res. Eval.* **26**, 157–168 (2017).
7. Fong, E. A. & Wilhite, A. W. *PLoS ONE* **12**, e0187394 (2017).
8. Hicks, D., Wouters, P. Waltman, L., de Rijcke, S. & Rafols, I. *Nature* **520**, 429–431 (2015).
9. McKiernan, E. C. *et al. PeerJ Preprints* **7**, e27638v2 (2019).
10. Larivière, V. *et al.* Preprint at bioRxiv https://doi.org/10.1101/062109 (2016).

A list of co-signatories accompanies this Comment online (see go.nature.com/2wfeyjc).



STEVE GSCHMEISSNER/SPL

Coloured scanning micrograph of a community of bacteria from the nose.

What's next for the human microbiome?

Medical insights will flow from dissecting host–microbe interactions using ecological and evolutionary approaches, argues **Lita Proctor**.

Over the past decade, more than US$1.7 billion has been spent on human microbiome research. Major projects are under way in the United States, the European Union, China, Canada, Ireland, South Korea and Japan.

This investment has confirmed the importance of the microbiome to human health and development. It is now known, for instance, that newborns receive essential microorganisms from their mothers[1]. Moreover, the sugars in breast milk that infants cannot digest nourish babies' developing microbiomes[2], which in turn shape their immune systems[3].

Now is a good moment for reflection. The biggest investment made (around $1 billion) comes from the United States. Some 20% of this has gone to two phases of the Human Microbiome Project (HMP), which is creating the research resources needed for studying the human microbiome (see 'Big spend'). A review[4] of what that decade of investment in human microbiome research has achieved was published in February (see 'Big wins'). And findings from the second phase of the HMP are published in this week's *Nature* (see pages 641, 655 and 662)[5–8].

In my view, most of the research so far has placed too much emphasis on cataloguing species names. We've been characterizing the human microbiome as if it were a relatively fixed property to be mapped and manipulated — one that is separate ▶

from the rest of the body. In fact, I think that interventions that could help to treat conditions such as diabetes, cancer and autoimmune diseases will be discovered only if we move beyond species catalogues and begin to understand the complex and mutable ecological and evolutionary relationships that microbes have with each other and with their hosts.

BEYOND INVENTORIES

The HMP, funded by the US National Institutes of Health (NIH), has clearly catalysed human microbiome research in the United States and globally. The same is true of other projects with similar aims, such as the European Union's Metagenomics of the Human Intestinal Tract (MetaHIT) consortium (in partnership with China) and other European projects[9]; the Irish Metagenomics of the Elderly programme (ElderMet); the Canadian Microbiome Initiative; and the Japanese Human Metagenome consortium[10], to name a few.

One of the main goals of the HMP, launched in 2007, was to create a toolbox of reference data sets, computational techniques, analytical methods and clinical protocols. This seems to have been a success: around 75% of the 2012–16 NIH grant recipients for microbiome research outside the HMP — working on more than 100 diseases — cited reliance on HMP data and tools in their funding applications[4].

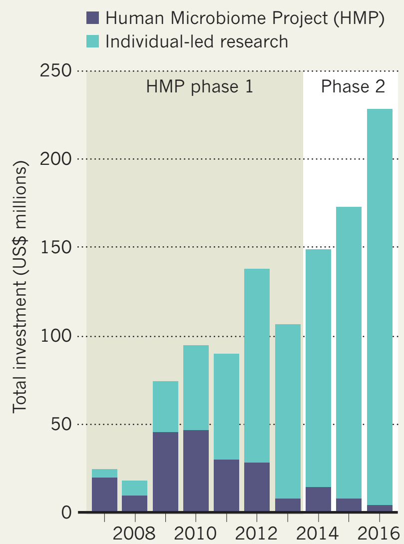
This progress in microbiome research has excited industry. The current value of human-microbiome-based products and interventions for diagnostic and therapeutic use is estimated to be between $275 million and $400 million worldwide. This is expected to increase to between $750 million and $1.9 billion by 2024.

Yet even with this considerable public and private investment, many fundamental questions about the human microbiome remain.

Researchers don't yet agree on what constitutes a healthy microbiome or how to define an impaired one. There is still uncertainty about which microbiome properties will be the most informative biomarkers in clinical and epidemiological studies. And little is known about how the microbiomes of different body regions, such as the mouth, gut or skin, interact.

BIG SPEND

The US National Institutes of Health (NIH) invested more than US$1 billion in human microbiome research between 2007 and 2016.



Biogeochemical habitats that are unique to each body region have been discovered through the analysis of metagenomic data. These DNA sequences, derived directly from environmental samples, can be used to characterize the microbial communities present and their metabolic capabilities[11]. For example, the main metabolic process used by microbes in the mouth is anaerobic respiration, because oxygen is limited. By contrast, in the oxygen-free gut, the dominant process is microbial fermentation (the extraction of energy from carbohydrates in the absence of oxygen). Yet researchers have not investigated the factors that drive these shifts in microbial processes — such as oxygen concentrations, pH levels and nutrient sources.

Furthermore, it is becoming clear that microbes are needed to support human development and maturation, and to activate and maintain stability in the immune system and metabolism. But we do not understand how these fundamental biological phenomena involving human cells and microbes co-evolved. What's more, some ecological concepts are not yet commonly considered in studies of the human microbiome. These include how communities of microbes operate as a whole; how 'keystone species' can pave the way for others by altering local conditions; and the predator–prey relations between different microbes.

HOLISTIC VIEW

Some researchers have studied the microbiome as if it were an organ[12]. But even this approach is not entirely satisfactory, because the cardinal property of the microbiome is its mutability — during development, over a lifetime and in response to stressors or disease. This means that it does not demonstrate typical organ-system biology.

For all these reasons, I think that the most effective route to discovering microbiome-based remedies will be to establish which microorganisms — and which assemblages of them — play a major part in dictating local conditions, or in affecting important cellular processes.

Much could be learnt about human–microbe associations if researchers investigated the mechanisms underlying the development of these associations in the well-characterized animal models commonly used in biomedical research, such as mice and rats. Indeed, factoring the microbiome into animal preclinical studies might drastically alter the conclusions[13].

Evolutionary biologists have argued for decades that human microbiome research would benefit from the evolutionary understanding provided by symbiosis research[14]. Certainly, human–microbiome systems share some of the features of highly regulated symbiotic associations. As just one example, a class of molecules produced only by bacteria (short-chain fatty acids) has a central role in host–microbe interactions. These molecules provide an energy source for the cells lining the human gut (most other cells depend on glucose). And they mediate interactions between different gut microbes, and between microbes and human cells.

TWO FRONTS

Developing a new conceptual framework and applying it to the human microbiome will require much more collaboration between investigators working across disparate fields, including evolution, ecology, microbiology, biomedicine and

BIG WINS

A wealth of discoveries in human microbiome research

The finding that thousands of bacterial species (as well as viruses and fungi) live in people, and are an integral part of human biology, has challenged medicine's view of microorganisms solely as agents of infectious disease.

- The discovery that dietary fibre stimulates the particular groups of bacteria that produce key host-signalling molecules (such as short-chain fatty acids) is leading to the development of nutrition-based approaches to treating and restoring people's microbiomes.
- The transplantation of gut microbiota from one person to another has been found to be more than 90% effective in the treatment of recurring *Clostridium difficile* infections. The current care standard is repeated doses of antibiotics.
- Some cancer treatments activate the immune system. A new approach to these has emerged with the discovery that efficacy is related to specific members of the patient's gut microbiome[17]. **L.P.**

computational biology. It will also demand significant changes in how data and other resources are distributed between scientists, and in how currently disparate areas of microbiome research inter-relate.

Here I address what's needed in the United States. These changes must happen elsewhere as well.

Data standards. Microbiome researchers have not yet broadly embraced quality-control practices for their data in a way that would make results more reproducible, and that would facilitate the analysis and interpretation of data across multiple studies.

Studies based on characterizing genetic material, proteins or metabolites using high-throughput analyses will remain the norm for the foreseeable future. To produce useful results, however, researchers must adopt better data-sharing practices.

The Genome Standards Consortium, established in 2005, has developed standards and templates for reporting metagenomics data, as well as for environmental measurements and various clinical metadata. These have been adopted by the Data Coordination Center of the HMP, the public repository for everything produced by the project. But this is insufficient on its own. Funding agencies and journals must also promote the use of these standards in reporting microbiome data in databases and publications — much as was done for RNA microarray studies in the early 2000s[15].

Coordination and collaboration. Currently, 21 of 27 NIH institutes provide extramural funds for human microbiome research. Any coordination that does occur is mediated by the trans-NIH Microbiome Working Group — a committee of programme directors established in 2012. More than 40 staff members gather each month to discuss key developments in the field. However, the committee has no budget and no authority to make funding decisions.

In my view, the big investment in human microbiome research should be formally managed. The research community has pushed for this kind of formalized coordination before[16]. Indeed, the EU, Canada, Ireland and Japan have arguably done better than the United States when it comes to coordinating human microbiome research; for instance, by mandating partnerships between researchers in academia and government agencies or industry.

Recognizing that many disciplines are needed to study the microbiome, 33 universities, research institutions and medical schools in the United States have now formed microbiome centres. In principle, these could champion data-sharing practices. Researchers at the centres could agree to adopt such practices and advocate for

AMELIE BENOIST/BSIP/GETTY

Newborn babies receive essential microorganisms from their mothers.

them at meetings. In partnership with journals and funding agencies, this network of centres could identify and promote shared resources, such as biobanks, analytical and computational standards, protocols and public databases.

ENCOURAGING SIGNS

Another government agency, the US National Institute of Standards and Technology, is leading efforts to develop analytical standards for microbiome sequencing. In the next few months, discussions will take place on how to build on the lessons learnt by the US microbiome centres. A research coordination network could emerge.

> *"Researchers don't yet agree on what constitutes a healthy microbiome or how to define an impaired one."*

Outside the United States, the Canadian Microbiome Initiative is developing national core resources for microbiome research, such as public data repositories and analytical centres. The International Human Microbiome Consortium (IHMC) has been raising awareness of the importance of data sharing and standards internationally by holding conferences around the world since 2008. But the IHMC, a 13-country organization formed to coordinate microbiome research, has never had a budget and relies on volunteers, so its powers are limited.

Microbiome researchers should take inspiration from the many examples of other disciplines that are advancing thanks to collaboration. Take my former field of oceanography. Studying an ecosystem that spans 70% of the planet's surface requires expensive research vessels, satellite data and high-speed computing. Oceanographers have had to share ships, instruments, hardware and other resources to further their own lines of enquiry. They have also had to collaborate across physical, chemical, biological, geological and meteorological approaches to assess what drives oceanic physical, biogeochemical and marine food-web dynamics. These oceanographic studies now form a foundation for global climate science.

The fruits of a coordinated effort in microbiome research that is grounded in ecological and evolutionary principles could be similarly significant. ■

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1. Ferretti, P. *et al. Cell Host Microbe* **24**, 133–145 (2018).
2. Kirmiz, N., Robinson, R. C., Shah, I. M., Barile, D. & Mills, D. A. *Annu. Rev. Food Sci. Technol.* **9**, 429–450 (2018).
3. Thaiss, C. A., Zmora, N., Levy, M. & Elinav, E. *Nature* **535**, 65–74 (2016).
4. NIH Human Microbiome Portfolio Analysis Team. *Microbiome* **7**, 31 (2019).
5. The Integrative HMP (iHMP) Research Network Consortium. *Nature* **569**, 641–648 (2019).
6. Lloyd-Price, J. *et al. Nature* **569**, 655–662 (2019).
7. Zhou, W. *et al. Nature* **569**, 663–671 (2019).
8. Fettweis, J. M. *et al. Nature Med.* https://doi.org/10.1038/s41591-019-0450-2 (2019).
9. Hadrich, D. *Front Genet.* **9**, 212 (2018).
10. Nishijima, S. W. *et al. DNA Res.* **23**, 125–133 (2016).
11. Lloyd-Price, J. *et al. Nature* **550**, 61–66 (2017).
12. Clarke, G. *et al. Mol. Endocrinol.* **28**, 1221–1238 (2014).
13. Aaronson, A. C. *et al. PLoS ONE* **10**, e0116704 (2015).
14. McFall-Ngai, M. *et al. Proc. Natl Acad. Sci. USA* **110**, 3229–3236 (2013).
15. Brazma, A. *et al. Nature Genet.* **29**, 365–371 (2001).
16. The 2017 NIH-wide Microbiome Workshop Writing Team. *Microbiome* **7**, 32 (2019).
17. Zitvogel, L., Daillere, R., Roberti, M. P., Routy, B. & Kroemer, G. *Nature Rev. Microbiol.* **15**, 465–478 (2017).