

## Review

# The future of Global Environmental Assessments: 20 years after the Millennium Ecosystem Assessment

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Global Environmental Assessments (GEAs) are intended to gather expert knowledge on a topic of global importance and present it in a useful format to those who could use the knowledge in decision-making. GEAs have disseminated new knowledge, influenced environmental policy, changed the evolution of science, and furthered many careers. The GEA community has always adapted to changing circumstances, often by increasing the complexity of the assessment process. The current level of complexity of most GEAs, alongside today's increasingly polarized societies, changes in international trade, biophysical changes to the planet, greater interest in cross-sectoral problems and solutions, enhanced technological capacity, and increasingly contested nature of some aspects of environmental science may indicate that we've reached a point where further adaptation cannot be achieved merely by adding more complexity. It may be time for more fundamental changes to the GEA scope, process, and delivery. We use the MA as a touchstone in exploring how GEAs have evolved, considering both challenges and possible paths forward to retain legitimacy, credibility, and salience in a changing world. One strong possibility is for GEAs to reorient to serve as support structures for a broader diversity of levels and types of decision-making and a broader array of decision-making actors. In a rapidly changing world, a diverse ecosystem of assessment approaches is likely to be more robust, have more impact, and evolve more quickly. Continuing to experiment with different models for delivering multi-scale environmental information will help GEAs fit the needs of the 21st century.

## Addresses

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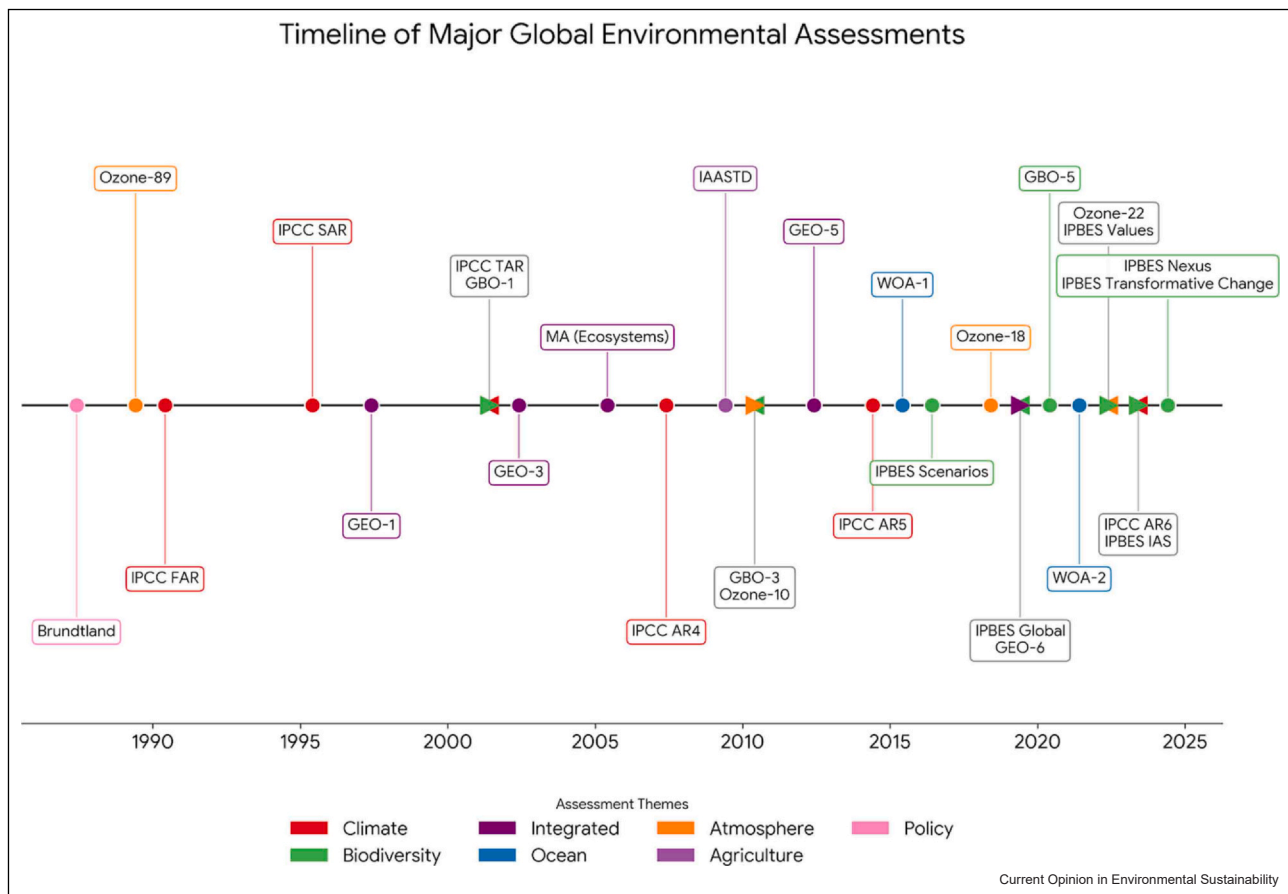
### Introduction

Global Environmental Assessments (GEAs) gather the knowledge of experts, interpret and synthesize it, and present it in a format intended to inform those who could use it in decision-making [1]. GEAs usually are conducted by intergovernmental agencies or independent bodies established through multilateral regimes. Some, like Intergovernmental Panel on Climate Change (the IPCC) are recurring, while others, like the Millennium Ecosystem Assessment (MA), are one-time efforts. GEAs are crucial to mobilizing science in support of international negotiations on key global environmental challenges [2]. They can also shift global conversations on environmental issues; advance careers; change science, including the funding landscape; impact international geopolitics; and improve public understanding. Over 140 GEAs have followed from the first assessment (the Long-Range Transboundary Air-Pollution, in 1977), with an especially dramatic increase in the number of assessments in the past 25 years (Figure 1) [1].

The logic that motivates most GEAs is that an authoritative synthesis of knowledge relevant to policy decisions, conducted by respected scientists, and organized and legitimized by nation-states, can promote better national and international environmental decision-making. The Social Learning Group [3] and the GEA Harvard Project [4] have suggested that GEAs' influence depends on three criteria: salience (usefulness to the topic at hand), legitimacy (seen as unbiased, fair, and authorized), and credibility (meets standards of scientific plausibility). Trade-offs among these criteria mean that efforts to increase salience (e.g. by addressing topics of greater political relevance) can reduce credibility (e.g. by 'tainting' science with politics) or legitimacy (e.g. through the influence of decision-makers on assessment results) and vice versa [5]. Nevertheless, GEAs have evolved to be increasingly successful across multiple criteria.

Now, GEAs must continue to adapt to remain influential. Rapid technological advances, increasingly polarized

Figure 1



Timeline of major GEAs according to their primary theme. Brundtland = UN's World Commission on Environment and Development; Ozone-89 = The Scientific Assessment of Stratospheric Ozone: 1989; FAR = First Assessment Report; SAR = Second AR; TAR = Third AR; AR4 = Fourth Assessment Report; GBO = Global Biodiversity Outlook; IAASTD = International Assessment of Agricultural Knowledge, Science and Technology for Development. Data from the Inventory of major GEAs found in the Supplementary Material of [7].

societies, weakening multilateral systems, changes in international trade, biophysical changes to the planet, greater interest in cross-sectoral problems and solutions, and the fact that many areas of environmental science are increasingly subject to public contention are changing the context in which GEAs operate. These contextual changes have re-wired the way social-ecological systems function around the world, requiring a fundamental change in GEAs to remain relevant in this new reality. GEAs have been steadily increasing in complexity. This, alongside the growth in the scope and number of assessments, is taxing the capacity of the scientific community, and may no longer be helping GEAs serve their purpose of delivering useful information to decision-makers [6].

The MA, released in 2005, was an important step in the evolution of GEAs. More than earlier assessments, the MA was attentive to multiple scales, multiple disciplines, and the need to address a broad audience. We use the MA as a touchstone to explore how GEAs have evolved, considering the challenges raised above and possible paths forward. We focus on social-ecological assessments, but the findings may be relevant for a broader set of GEAs. We provide a framework for thinking about the tensions involved in GEAs and examine options for the future role and structure of GEAs. We hope to encourage deliberation among diverse communities toward a common vision.

### **The importance and impact of early Global Environmental Assessments**

Early GEAs (from the 1970s to the 1990s) influenced environmental policy by establishing the scientific basis for international agreements, fostering awareness among policy networks and the public, enabling policy learning, and creating shared knowledge to address global environmental challenges like climate change and biodiversity loss. They were powerful tools for bringing about cooperation through shared knowledge [7], while also sometimes serving as flashpoints for political conflict. While primarily intended to inform governments, international convention secretariats, and negotiation processes, they also reached corporate and non-governmental organization (NGO) leaders and the public. GEA results were communicated primarily via reports. While some early GEAs supported international agreements by providing a science-based frame for intergovernmental negotiations, such as the IPCC for the UN Framework Convention on Climate Change, others were meant to provide an evidence base to support multiple conventions, such as the GEO, intended to support all three Rio Conventions. GEAs also helped disseminate new knowledge to national audiences, increasing interest, awareness, and perceived urgency of problems [8]. For example, the IPCC assessments were

crucial in framing climate as an issue worthy of major scientific attention, encouraging research and research funding as well as international coordination on climate policy [11]. Assessments also identified knowledge gaps that could be addressed by research [9], such as the European Union's Biodiversa funding, designed to address knowledge gaps identified in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment [10].

GEAs are an important learning space, not only for policy makers, but also for scholars and others involved at both individual and institutional levels [14]. Assessments are social processes that improve researchers' capacity to produce and communicate relevant research insights [4]. Participation in a GEA can build professional networks and nurture scientific capacity, which may be especially important for younger researchers and those in the global south. GEAs thus have had diverse impacts, influencing not only the policy discussions they target but also broader understanding and the evolution of science and scientific careers.

Over time, GEAs have increasingly focused on science in support of solutions. That evolution has encouraged consideration of a wider audience, more interdisciplinary approaches, analysis across scales, and engagement with diverse forms of knowledge [1]. The earliest GEAs, such as the Convention on Long-Range Transboundary Air Pollution and the 1985 Atmospheric Ozone Assessment, dealt with narrowly defined environmental issues and focused on identifying and characterizing the status and trends in specific environmental conditions, engaging a limited set of disciplines. By 2000, the scope of GEAs had expanded to include social sciences and consideration of response options. For example, starting with its Second Assessment Report in 1995, the IPCC included volumes not only on "The Science of Climate Change" but also "Impacts, Adaptation and Mitigation," and "Economic and Social Dimensions of Climate Change" [12]. The IPCC now includes targeted special reports that directly address questions emerging from policy discussions [13], although many disciplines and knowledges remain under- or even un-represented.

### **Evolution of Global Environmental Assessments since the Millennium Ecosystem Assessment**

The MA, initiated at the start of the 21st century, was designed to build support for a GEA mechanism that could meet the science assessment needs of ecosystem-focused United Nations conventions [16]. It was a major shift in the scope and design of GEAs, driven by both the nature of the topic being assessed and by consideration of diverse potential users [16]. The MA was designed as a response-oriented assessment that could

be targeted to multiple audiences, engage an expanded set of disciplines, include Indigenous and other extra-scientific knowledge, and explore not only global scales but sub-global scales as well [17]. In particular, the MA played a leading role in developing each of the following features of contemporary GEAs.

#### **Focus on identifying response options**

One of the four MA working groups was devoted to a detailed assessment of options for responding to ecosystem change. The MA examined an inventory of responses and identified promising solutions, exceeding previous assessments in both the breadth of its coverage and the depth of its analysis of social-ecological systems [18]. The solutions focus encouraged other advances in GEAs, including interdisciplinarity, consideration of multiple scales, and engagement with non-academic knowledges. By 2005, other GEAs were also considering potential solutions.

#### **Embrace of interdisciplinary science**

Early were framed with a tight focus on a particular environmental problem *per se* (climate change, ozone depletion). In contrast, the MA was framed to address how an environmental problem (ecosystem change) influenced human well-being and was influenced by human action. Thus, economics and other social sciences were central to the MA, a contrast with previous GEAs that drew primarily on biophysical sciences. The MA promoted integration across disciplines and thus accelerated the evolution of conceptual approaches to social-ecological systems [19,20].

#### **Multi-scale approach**

Some previous assessments included chapters on regional impacts and options, but the regionally differentiated nature of the MA's focus required more comprehensive sub-global assessments. Unlike climate change, where greenhouse gas emission at any location has the same global impact, the consequences of ecosystem change may differ dramatically in different locales and when viewed from different scales. Clearing a forest to expand agriculture can significantly enhance human well-being at a local scale, but could harm well-being at a regional or global scale through changes in rainfall, flood frequency, or climate impacts. To address this complexity, the MA initiated 34 sub-global assessments and included a sub-global assessment working group [16].

#### **Integrating indigenous knowledges**

The MA recognized that an assessment of ecosystem change that excluded Indigenous Knowledge and local knowledge would be incomplete and even perhaps illegitimate, and that the consequences of environmental change for Indigenous communities might differ from the impacts on other communities [21]. As a result, the MA was the first GEA to develop a protocol for the

validation and incorporation of Indigenous knowledge and local knowledge alongside scientific knowledge [22].

#### **Written for multiple audiences**

The authorization for the MA came from the four international conventions that had requested input (the Convention on Biological Diversity, the Convention to Combat Desertification, the Convention on Migratory Species, and the Ramsar Convention on Wetlands). The MA prepared five different summaries: one for each of the four conventions, plus one for the private sector. This was much more diverse than the target audiences for previous GEAs.

Since the publication of the MA 20 years ago, what society expects and wants from GEAs has evolved, and assessments have responded by incrementally adjusting their governance, underlying objectives, and principles [15]. As the issues addressed by GEAs increase in complexity, so too have GEAs, increasingly considering policy and response options [2], adding regional and cross-sectoral analysis [23], and including a broader array of scientific expertise as well as engagement with regionally grounded expertise, including local, Indigenous, and other traditional knowledges [24,25]. Different GEAs have taken different approaches to co-production, too. Where the MA was co-produced with the intergovernmental bodies of four international conventions, IPBES has followed the IPCC model and been formally co-produced with a single dedicated intergovernmental body that oversees the assessment. (In both cases, national governments are involved in scoping, reviewing, and approving the final document.)

One of the most important trends that follows from MA precedents has been the steady increase in steps taken to increase the legitimacy, credibility, and salience of assessments. Perhaps the most significant attempt to enhance the salience of GEAs has been the steady increase in identifying and evaluating action options [1,2]. GEAs have moved from a focus on setting global targets to facilitating national policies to achieve those targets [26]. It is now common for the mandates authorizing assessments to include requests for policy and solution analysis, sometimes even foregrounding the human dimensions of global environmental change. These changes accentuate the role of the humanities and social sciences in assessments, while also giving considerable space for knowledge originating outside academia. There have also been increasing calls to pay more attention to the politics of knowledge, including whose knowledge counts and the processes used to gather knowledge [27,28].

The scope of literature and the breadth of the issues being assessed by GEAs have grown to support these changes. In a review of 20 GEAs, Jabbour and Flachsland [7] found a significant increase over time in the number of individual objectives per assessment and the number of framing questions that the assessments

were intended to address, even as the number of authors and expert contributors has remained nearly unchanged. This expansion has amplified demands on the scientific community that undertakes assessments [7,26].

Many of the advances initiated by the MA have been institutionalized and sometimes expanded by IPBES, such as taking steps to improve the incorporation of Indigenous Knowledges to strengthen both the credibility and legitimacy of the assessment [29]. IPBES has made additional advances in applying Findable, Accessible, Interoperable, Reusable (FAIR) and Collective Benefit, Authority to Control, Responsibility, Ethics (CARE) principles to ensure that data are used ethically and shared for reuse. IPBES has built on the MA's multidisciplinary, increasing social science engagement and focus on policy options. One of IPBES' six core objectives is to identify and promote the development and use of policy instruments and policy support tools for biodiversity and ecosystem services. Recent IPBES products that focus on interdisciplinarity include the completed 'Nexus Assessment' on the linkages among biodiversity, water, food, and health, and the 'Transformative Change Assessment' that examined the underlying causes of biodiversity loss and identified opportunities for transformative change to sustainability [30].

### **At a crossroads: growing tensions in Global Environmental Assessment structure and process**

The MA prompted advances in GEA methods, infrastructure, and tools. Since then, GEAs have become even more complex, more interdisciplinary, more solutions-oriented, and more frequent. These changes in GEA structure and process, as well as changes in the world in which GEAs operate, have led to tensions that must be resolved for further progress. In particular, the growing number of interlinked environmental issues and solutions have made GEAs of today far more complex (multi-scale, multi-dimensional, multidisciplinary). While their scope has expanded over time, it has not always improved GEA's effectiveness. Indeed, the ever-growing scope has made it difficult to frame the solution space [31] and raises challenging normative and ethical issues about the current state of the world and what is desirable in the future [1,31]. Additionally, the expansion of scope without growing capacity may dilute assessment depth, slow GEA processes, and make assessments less actionable.

Engagement with international conventions has given GEAs legitimacy, but constrains their flexibility, speed, audience, and impact. GEA processes have usually involved government approval, often via a link between a GEA and an issue-focused convention. While this provides legitimacy, the scope of the convention may limit

which questions and which solutions are considered. Government involvement in the consensus process used to determine the scope of assessments and the final wording of assessment documents may lead to vague, non-threatening conclusions. Some GEAs are now being generated by private groups and others outside international conventions. They can be faster, more flexible, more radical, and more attentive to communication and outreach because they don't have to follow the inclusive and consensus-building procedures that characterize contemporary GEA practice. But this approach also opens the door to assessments undertaken by groups with less scientific expertise, less legitimacy, or those sceptical of, for example, climate change or other scientific consensus. [34].

Most GEAs still focus salience efforts on informing multilateral environmental agreements, with national environmental ministries, businesses, NGOs and publics as additional desirable audiences. However, global enforcement mechanisms on the environment seem unlikely [35,36], and national environmental ministries can be limited in their power to generate policy changes. Targeting results primarily to environmental ministries and convention bodies may preserve legitimacy, but fail to engage other actors who strongly shape environmental action such as finance and trade ministries, NGOs, religious movements, Indigenous communities, and businesses whose decisions drive environmental change [26].

Another major tension lies between GEAs' slow consensus-building process to ensure credibility and the urgent global challenges that demand faster, more adaptive approaches and novel, dynamic, and interactive delivery. While some GEA conclusions will persist over time, others may require rapid updating [37]. Special reports (e.g. IPCC's 1.5 °C report) show how targeted assessments can be more responsive, but the broader structure is still cumbersome and relatively inflexible. The topics covered and the structure of the assessment reports themselves are shaped by the interests of the nation states that commission them. The consensus process used to design and execute GEAs can result in reports and summaries that are slow, dull, and overly-conservative [28]. Additionally, rules regarding country input usually allow each country in the convention to dispute the summary of the findings (often line by line), which can result in lowest-common-denominator texts that are unclear, downplay urgency, and avoid specific actions [38]. Additionally, most GEAs still deliver reports in static formats (e.g. electronically via pdfs), while newer, online methods are available that could be more dynamic or even interactive, which would expand their audience and potentially their use.

GEAs have thus far been restrained in their inclination, and generally lacking capacity, to engage deeply with

politics [32,33]. They tend to have difficulty including, acknowledging, and engaging with politics-centered research, despite increasing recognition that obstacles to needed transformations to sustainability may be more political or social than technical in nature. Existential questions about the role of GEAs in fomenting change may need to be unearthed and examined [30,32].

Finally, these changes to advance credibility, salience, and legitimacy have placed a greater burden on the scientific community, especially in countries that lack scientific capacity. Including social sciences, context-specific science, multidisciplinary integration, cross-scale analysis, Indigenous knowledge, and solution-oriented research has made GEAs more comprehensive, but also more demanding and slower. Scientists are overburdened, and institutional support for their contributions to GEA has decreased rather than increased with growing demand for assessment products and increased complexity [7]. The increased frequency of requests to participate in assessments, alongside limited capacity (especially in some countries or on some topics), is exceeding the limits of the scientific community and may require additional support to grow the capabilities of the scientific community to do assessment work.

### Reimagining Global Environmental Assessments for the mid-21st century

GEAs were created nearly 50 years ago as the world was beginning to recognize and grapple with the challenges of climate change, stratospheric ozone depletion, and biodiversity loss. As countries developed multilateral environmental agreements to address those challenges, GEAs provided a mechanism to synthesize and interpret existing scientific knowledge to inform decisions contemplated under those agreements. Knowledge and assessment social processes were co-produced, contributing to the emergence of a “new kind of global knowledge... a new class of global knowledge institutions to produce it; and a new form of global politics centred on forging global policy responses to global problems” [39]. GEAs’ impact on science, science funding, participants’ careers, and global understanding of environmental issues has been substantial. The 1985 Ozone Assessment followed by the 1987 Montreal Protocol, was arguably the high-water mark of this arrangement [40].

But since this early success, while GEAs have been influential in advancing understanding and contributing to the setting of objectives and targets under multilateral agreements, those agreements have not led to the level of national implementation needed to address the considerable environmental challenges we face. What changes are needed to effectively deploy science in the face of broader hopes for GEAs? A growing literature explores how existing GEAs could evolve [1,13,41], and alongside that

literature exists a growing diversity of assessment types. The traditional broad GEAs, commissioned and designed by global conventions of nation-states, continue. Many nations or regional consortia also now conduct assessments (e.g. the Arctic Resilience Report [42]). Still others are commissioned by journals, non-profit organizations, or foundations (the EAT Lancet assessments, Corporate Ecosystem Services Reviews, and Strategic Environmental Assessments). And in many nations, an independent body such as the US National Research Council or the Council of Canadian Academies generates scientific assessments. The variation in focus, process, and sponsorship of these many assessments may provide a useful basis for better developing a ‘science of science assessments’.

Thus far, the approach of most GEAs has been to expand GEAs scope to encompass as much complexity as possible. Continuing on this pathway would maintain the basic structure of GEAs, and their strong association with multilateral agreements, even as elements are added to provide a more pluralistic, solution-focused, and multidisciplinary approach. A first step in this direction has been called GEA 2.0 [1]; here, GEAs are not only focused on response strategies, but also strengthen processes of stakeholder engagement and policy advice. Such assessments include more normative content, adopt an approach that is able to engage diverse expertise, and focus more on solutions than earlier GEAs.

Taking this approach further yields ‘GEA 3.0’, which broadens the scope, process, and delivery mechanisms for assessments. GEA 3.0 would expand to deeply engage environmental social science and humanities, as well as knowledge from outside the academy, such as Indigenous Knowledge and business, engineering, and other practical knowledge. It introduces pluralist forms of political reasoning and structured normative debate, and situates policy-relevance in a non-consensus-based understanding of possibilities [1]. The ‘value added’ of GEA 3.0 is that it recognizes the politics of knowledge and leans significantly toward higher-order processes of interpreting and weighing the significance of different forms of evidence from multiple perspectives.

The vision of GEA 3.0 works well in a world of deepening globalization and multilateralism. But the world appears to be moving in another direction, and solution-oriented, norm-heavy assessments risk being dismissed as partisan politics. Additionally, GEA ties to multilateral agreements could fray if those agreements themselves lose influence in a less multilateral world. Ultimately, infinitely expanding the GEA scope obviously cannot work; GEAs require a clear path that isn’t broader and more complex in every direction.

One option is to reorient the GEA process as well as scope in order to help GEAs serve as support structures

for a broader diversity of levels of decision-making and a broader array of decision-making actors, not only in government, but also in civil society and business, possibly while narrowing the topics of individual assessments to best serve these stakeholder-partners. This type of assessment makes most sense in a world where multilateral environmental agreements continue to exist, and in which there is an ongoing role for science assessments to improve problem analysis, but where agreements have only a weak influence on solutions taken up by decision-making agents. In this scenario, different regions, with different contexts and values, follow different sustainability transformation pathways, and the role of GEAs would be to provide information and knowledge to help navigate and to identify interactions across different regional pathways or different decision contexts [43]. Following the model of assessments commissioned not by conventions but by other decision-making bodies, GEAs in this scenario could be diversified to better support a wider diversity of decision-makers in policy, business, and society, featuring deeper co-production with these actors.

The key role for these GEAs would be to leverage the power that assessments have in global knowledge-making to create and support new knowledge capabilities that aid decentralized polycentric action by a variety of actors [39]. Because of the global nature of many environmental issues, the framework of a global assessment is still essential to help guide responses, even if the development of precise responses takes place at sub-global scales. Under this vision, greater effort would be devoted to informing those sub-global decisions in a way that delves deeper into approaches that have local, global, or regional salience. As Miller [39] notes, the assessment process could advocate for new investments in developing the sub-global knowledge capabilities needed to inform decentralized action. This sub-global focus is also better suited to the co-production of knowledge with the communities and decision-makers that would ultimately take action and is thus more in line with the current approach of the research community, while highlighting the importance of national and subnational networks taking up and disseminating findings.

This model of GEAs builds on the trajectory of the sub-global assessments of the MA, the sub-global focus of IPBES, and the various MA reports written to synthesize results for different decision-making audiences [44]. The mechanisms that would be established or expanded to develop sub-global knowledge capabilities would ideally catalyze and strengthen sub-global assessments that might be a formal component of a GEA (e.g. as is the case in IPBES) but could alternatively be a separate national or subnational assessment designed to directly inform national or subnational decisions. They could also provide tools, templates, and a community of practice that could be used to strengthen ad-hoc efforts to

synthesize policy-relevant information at sub-global scales or for a wider variety of decision-makers. For example, the MA sub-global methodology manual [45] helped in the design of a number of national and sub-national ecosystem assessments after the conclusion of the MA.

## Conclusions

Assessments provide an arena for important conversations among policymakers, research funders, scientists, and decision-makers and present reports that serve as snapshots of the outcomes of those conversations for decision-makers. The way these assessments have evolved to maintain their salience, legitimacy, and credibility in a changing world has dramatically increased assessment complexity, leading to tensions that must be addressed to remain influential. Because the best way forward is unclear, a diverse ecosystem of assessment approaches is likely to be more robust, have more impact, and evolve more quickly than a monoculture. Different GEAs could be designed to align with different key purposes and goals and with different theories of change, offering multiple pathways toward impact. GEAs that strongly support analysis of sub-global actions are a key element of this approach. Granting more adequate attention to the socio-political dimensions of global change, including within research communities themselves, is also essential. At the same time, there will be a continuing need for GEA processes that consider global processes and their interactions across scales. There is no single path forward, but rather multiple paths that allow learning and evolution. The GEA community has repeatedly innovated and adapted to changing circumstances, and will undoubtedly continue to do so, especially as a diversity of approaches facilitates learning and change.

## Data Availability

No data were used for the research described in the article.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

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- of special interest
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