POLICY FORUM

TECHNOLOGY GOVERNANCE

Editing nature: Local roots of global governance

Environmental gene editing demands collective oversight

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The end of malaria. Restored island habitats. Resiliency for species threatened by climate change. Many envisioned environmental applications of newly developed gene-editing techniques such as CRISPR might provide profound benefits for ecosystems and society. But depending on the type and scale of the edit, gene-edited organisms intentionally released into the environment could also deliver off-target mutations, evolutionary resistance, ecological disturbance, and extinctions. Hence, there are ongoing conversations about the responsible application of CRISPR, especially relative to the limitations of current global governance structures to safeguard its use [(*1*, *2*); see table S1]. Largely missing from these conversations is attention to local communities in decision-making. Most policy discussions are instead occurring at the national or international level (*3*, *4*), even though local communities will be the first to feel the context-dependent impacts of any release. To be fully representative, therefore, local inputs and perspectives must also be considered. As laboratories around the world develop and perfect gene-editing techniques with unprecedented capacity to alter wild species and, by extension, the ecological and cultural systems of which they are a part, we outline our vision for locally based, globally informed governance.

GENETICALLY ENGINEERING NATURE

CRISPR gene editing and other related genetic technologies are groundbreaking in their ability to precisely and inexpensively alter the genome of any species (*5*). CRISPR-based gene drives hold particular import because they are designed to rapidly spread genetic changes—including detrimental traits such as infertility—through populations of sexually reproducing organisms, to potentially reach every member of a species. Villages in Burkina Faso are weighing the release of gene drive–bearing mosquitoes that could suppress malaria. Nantucket Island residents in the United States are considering the release of genetically engineered white-footed mice to deplete Lyme disease reservoirs. New Zealand communities are discussing the possibility of using genetic methods to eliminate exotic predators.

But what if a gene drive designed to suppress an invasive species escaped its release site and spread to a native population? Or if a coral species gene edited to better adapt to environmental stressors dominated reef ecosystems at the expense of a diversity of naturally evolving coral species and the fish that depend on them (see the photo)? The gravity of these potential outcomes begs the question: Should humans even be meddling with the DNA of wild organisms? The absence of generally agreed on answers can be used to support calls for moratoria on developing and releasing genetically altered organisms, especially those with gene drives (*6*).

However, the promising benefits of environmental gene editing cannot be dismissed (*4*). Gene drives may provide a long-sought-after tool to control vectors of infectious disease and save millions of human lives. Projects to conserve ecosystems or promote species resilience are often intended to repair human-inflicted environmental damage. Put simply, either using this technology irresponsibly or not using it at all could prove damaging to humans, our welfare, and our planet.

National, regional, and international governmental agencies are working to clarify how existing research policy, field-testing frameworks, and risk-assessment guidelines apply to environmental gene editing, enacting some existing rules, and seeking to update and create new policies to address this technology. For example, the U.S. National Academies of Sciences, Engineering, and Medicine's report on gene drives deemed current ecological risk-assessment frameworks as adequate to predict potential ecological impacts of gene-drive release but recommended new guidelines to safeguard gene-drive research and encourage public discourse (*4*). In fact, several national and regional reports echo in their calls for improved fora that can support meaningful public debate (*7*, *8*); however, most frameworks for regulatory decision-making continue to largely preference science-based knowledge and technical risk assessments over ethical and societal considerations. At the international level, the Convention on Biological Diversity (CBD) has enlisted an expert technical panel to, in part, update its Cartagena Protocol (of which the United States is not a party) that oversees transboundary transport of living modified organisms to accommodate gene drive–bearing organisms (*9*). The International Union for the Conservation of Nature (IUCN) is also developing policy to address the release of gene-edited organisms (*3*). Although the CBD and the IUCN offer fora to engage diverse public feedback, a role largely fulfilled by civil society groups, none of these agencies currently use the broad and open deliberative process we advocate.

In the absence of widely agreed-upon governance guidelines or support for more optimal deliberative processes, the developers of a technology seeking consent to release a gene-edited organism may also serve as a community's source of expertise and information (*10*, *11*). Such an advice-and-consent relationship raises the possibility of a real or apparent conflict of interest. Ideally, in these cases, governance plans should incorporate expertise and perspectives that are independent, transparent, inclusive, and based on balanced deliberations.

Each decision to release a gene-edited organism has specific considerations that depend on the organism altered, the scope and intent of the alteration, the ecosystem(s) affected, consequences for human health, and the value systems of communities affected by such a decision. Underlying all of this are differing views about what is considered "natural" and to what degree humans should intervene in ecosystems (*12*). Different societal views about the human relationship to nature will therefore shape decision-making. Local community knowledge and perspectives must therefore be engaged to address these context-dependent, value-based considerations.

A special emphasis on local communities is also a matter of justice because the first and most closely affected individuals deserve a strong voice in the decision-making process. This is additionally a matter of urgency. Communities, technologists, and governments

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will require methods to make responsible and informed decisions about environmental applications to keep pace with rapid progress in gene-editing technologies.

Compounding this challenge is that these decisions cannot be made in isolation. Organisms released into local environments may cross regional and even international borders. Hence, respect for and consideration of local knowledge and value systems are necessary, but insufficient, to anticipate the potentially ramifying global implications of environmental release of gene-edited organisms. What is needed is an approach that places great weight on local perspectives within a larger global vision.

INTEGRATED DELIBERATION

We propose a coordinating body that can convene communities, technology developers, and governmental and nongovernmental organizations in ways that ensure inclusive deliberations. Such a body would serve as a neutral third party to help inform decision-making that is free from conflicts of interest and locally based. This organization would (i) establish a deliberation framework that integrates diverse expertise and worldviews, including participants that represent impacted communities; (ii) facilitate deliberation to produce standardized reports and deliver recommendations; (iii) establish information-sharing protocols to connect deliberations around the world; and (iv) report on the outcomes of deliberation to inform global governance of gene editing.

Characterizing what defines an affected "local" community will be an important part of this process and will depend on the nature of the technology and how it is predicted to interact with the environment. For example, if a self-propagating gene drive is under deliberation to counter malaria transmission, then representatives from much of sub-Saharan Africa would deserve a voice. For cases where a technology is more limited in scope or designed to have more limited spread, predictive models could be used to define the communities most likely to be affected and relative riskiness of the alteration. In line with frameworks for responsible innovation, evaluation would ideally begin as early as possible, so that deliberation shapes the development of the application in question (*13*).

The integrated deliberation framework must incorporate expertise from fields such as genetics, philosophy, ecology, economics, law, and risk assessment, as well as representatives of diverse stakeholder groups, and members of affected communities. Historically marginalized voices (indigenous communities, ethnic minorities, women, and children) must be included. Network analysis could identify affected parties, especially those who have previously been overlooked; deliberative procedures should build on frameworks demonstrated to promote inclusive and democratic deliberation (*14*, *15*).

The needs of ecosystems could also be given voice to inform deliberative outcomes through custodial human proxies. Inspired by legislative precedent set by New Zealand, in which the Whanganui River was granted legal "personhood," human representatives, nominated by both an international body like the IUCN and the local community, would be responsible for upholding the health and interests of the ecosystems in question (*16*). Proposed gene-editing strategies would be placed in the larger context of alternative approaches to address the public health or environmental issue in question.

Coral reef ecosystems are estimated to support over 25% of all marine fish worldwide and to contribute over US$1 trillion in economic, social, and cultural value globally. CRISPR-based strategies have been proposed as a means to protect coral from bleaching. Corals genetically engineered to be more resilient to heat stress and ocean acidification could be used to help conserve the Great Barrier Reef (shown above), a UNESCO world heritage site.

To promote equitable representation, neutral and informed facilitators would bring history to the table, reveal existing power structures, and foster relationships between groups that hold disparate ideological stances. Deliberants would be encouraged to observe and reflect on their values—how they value nature, how they perceive risk, their level of trust in technology, and their motives and agendas—with full transparency. Questioning what is "natural" and to what degree ecosystems should be restored will also require exploration to ensure an appropriate ethical basis for decision-making.

In following with recent proposals for more meaningful deliberation over socially complex environmental issues (*17*), facilitators would also strive to cultivate certain virtues in participants. These decisions involve complexity and uncertainty and are motivated by concern for both human and nonhuman well-being; thus, deliberants must be encouraged to think in interdisciplinary ways, act with humility, and be mindful of their membership in an interdependent, planetary community. To incentivize virtue-based participation, the coordinating body must function in a manner that upholds extreme transparency and trustworthiness with deliberative outcomes that carry authority. Accordingly, an outright refusal to either participate in or heed the outcomes of the deliberative process could mark certain agents as untrustworthy, an outcome likely not in line with their strategy for long-term success.

Each deliberative process would yield a standardized report that summarizes concerns raised, areas where consensus was reached, and recommendations as to whether or how a gene-edited organism should be developed for environmental release. Reports could also accommodate a recommendation of "maybe, but not yet" and stipulate ecological, technical, and ethical considerations that require further study, reflection, and consideration. Ultimate control over the deliberative process would be shared by nominated local leaders, but the coordinating body would provide frameworks for deliberation and provide support throughout the process.

To allow deliberative outcomes to have immediacy, while not being encumbered by what will likely be a long-drawn-out process

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to update national and international regulatory policy, a certification model for integrated deliberation could be one way to lend immediate authority and impact. In this vein, any project that successfully passes through the deliberative framework could be given a seal of completion to alert regulatory bodies and the general public that informed and inclusive deliberation steered the development of that specific technological application. This is not to deny that new regulatory policies need to be in place to cope with this technology, but a certification approach could address concerns about environmental applications in a timely way, while providing incentive for developers to participate.

FROM VISION TO ACTION

Our proposed environmental gene editing coordinating body could be jointly supported by several intergovernmental organizations. Similar to how the Intergovernmental Panel on Climate Change falls under the joint sponsorship of the World Meteorological Organization and the United Nations Environment Programme (UNEP), this new initiative could receive shared support from several concerned organizations, such as the World Health Organization (WHO), UNEP, or the IUCN. Falling under the auspices of existing intergovernmental organizations would serve to hasten the development of the coordinating body, so it can meet the rapid development of gene-editing technologies. Joint support would also lend immediate accountability and authority, while ensuring that environmental and human health concerns are equally upheld in deliberative procedures.

A trust fund built on contributions by concerned governments, nongovernmental organizations, and intergovernmental organizations and managed in a manner consistent with International Public Sector Accounting Standards could provide financial support. Our hope is that governments from around the world and global health and environmental organizations will financially support this organization, because in the absence of global guidelines, improper use of this technology could prove costlier than any up-front investments that ensure its responsible use.

An interdisciplinary leadership committee diverse in gender, age, geography, and worldviews and whose members are not direct beneficiaries of any decision-making process, would need to oversee the following essential next steps. First, a task force must be established to design the integrated deliberative framework. This task force would also be charged with defining the scope and type of edits to be covered, convening deliberative processes, and overseeing iterative improvements to deliberative design. Organizational procedures could be built on models used by existing international organizations. For example, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services has developed protocols to integrate normative inputs into science-based policy (*18*), and effective measures for global coordination of diverse stakeholders and expertise could be garnered from the IUCN.

Second, an online registry for all projects intending to release genetically engineered organisms into the environment must be created. Currently, no central database exists for environmental gene-editing applications or for decision-making outcomes associated with their deployment, and this potentially puts the global community at risk. Third, a communications task force needs to create an online space that allows communities, technology developers, and policy-makers from around the world to share information resources, discuss issues faced, and provide expertise. The communications team would also oversee an annual summit and the publication of annual reports to share lessons learned and promote continued conversation on concerns raised.

"Put simply, either using this technology irresponsibly or not using it at all could prove damaging..."

Finally, leveraging the experience and infrastructure of its support organizations (for example, perhaps the WHO and UNEP), a global coordination task force would be charged with coordinating multiple communities, nations, and regions to ensure successful deliberative outcomes. As a hypothetical example, genetic strategies to eliminate invasive possums from New Zealand must include representatives from Australia, the country likely to be affected should animals be transported outside the intended range. Similarly, the African Union is currently deliberating appropriate governance of gene drive–bearing mosquitoes to combat malaria on a regional scale. The global coordination team would establish mechanisms to provide integrated deliberation services for regional and national decision-making. Coordination would serve to minimize geopolitical threats and ensure that the rights of affected communities are upheld at all levels of decision-making. Moreover, the new avenues forged for open communication by the coordinating body will enable deliberative outcomes to shape gene-editing governance on a global scale.

The success of this approach will depend on inputs and expertise from diverse worldviews and disciplines. Important questions remain to be answered: How can deliberative procedures effectively weigh local benefits with more-widespread global risks? How would transfer of control for the deliberations to local leaders take place? What structures are in place to guarantee historically marginalized voices are heeded in deliberation? What institutional procedures and evaluation mechanisms are needed to ensure accountability? Through the collective creation of this new governance model, the first that proposes a connection between local needs and global frameworks and expertise, our world may realize this technology's most profound benefit—the opportunity to inspire a more healthy and just future for all who share our planet. ■

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SUPPLEMENTARY MATERIALS

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