Governing New Biotechnologies for Biodiversity Conservation: Gene Drives, International Law, and Emerging Politics

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Abstract

The outdoor use of organisms modified with gene drives – emerging biotechnologies of biased inheritance – could further human wellbeing and biodiversity conservation, yet also poses environmental risks and diverse social challenges. This article describes and analyzes the international law and politics of gene drives' research, development, and possible use, with an emphasis on their potential biodiversity applications. The Convention on Biological Diversity is central, and its institutions and others have taken actions toward governing gene drive organisms. Gene drives' governance and politics are contrasted with those of agricultural genetically modified organisms, with emphases on states, nonstate actors, the precautionary approach, and decision-making forums. Developing and implementing governance – especially in international forums – for gene drives may prove to be difficult. The observations and analysis here indicate that the politics of gene drive organisms is a manifestation of a larger struggle regarding emerging technologies among those concerned about sustainability.

Keywords

- Biotechnology
- Gene drives
- International law
- Politics
- Governance
- Biodiversity

Introduction

Preventing the loss of biodiversity is a leading global environmental challenge. A recent authoritative report concludes that "Biodiversity… is declining faster than at any time in human history…. with the great majority of indicators of ecosystems and biodiversity showing rapid decline" (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019, 2, 3). A central reason for this is that the drivers of biodiversity loss are plural and complex while countering them is challenging and expensive.

A set of emerging biotechnologies has substantial potential to halt and even reverse biodiversity loss, including in ways that other means cannot. "Gene drives" may be able to eliminate invasive alien species, a leading direct driver of biodiversity loss; protect some endangered species; and help native species adapt to climate change and other threats. Gene drives could also improve human wellbeing, for instance by eradicating diseases. Along with these potentials, however, come environmental risks and social challenges. Like other powerful emerging technologies gene drives' research, objectives, and potential use are highly contested.

As this special issue emphasizes, such contestation is found across technologies, especially powerful ones. This seems all the more acute as we enter the Anthropocene, in which humanity's ability to affect multiple Earth systems – intentionally and unintentionally, beneficially and harmfully – is a central issue. Elsewhere here, Leslie Paule Thiele calls purposeful technological interventions in the natural environment "anthropogenic (caused by humans) [but] not anthropocentric (holding human needs and interests supreme)" (Thiele 2020, XX). This article places gene drives in this context of emerging Anthropocenic technologies by outlining the salient international law and describing the inchoate politics of gene drive technologies, with an emphasis on the conservation of biodiversity.

The next section introduces gene drives and some of their potential uses, while the subsequent one details their environmental risks, social challenges, and relevant governance characteristics. I then summarize how international legal mechanisms and institutions could govern gene drives and their use. The penultimate section considers the emerging politics, especially the debates associated with decision-making at intergovernmental institutions. The paper concludes with analytic observations regarding gene drives' governance and politics, contrasting them with those of agricultural genetically modified organisms (GMOs) and emphasizing, among other things, states, nonstate actors, the precautionary approach, and decision-making forums.

Gene drives

Understanding gene drives requires a quick summary of basic genetics. In sexually reproducing species, an organism typically has equal chances of transmitting to its offspring the versions of a given gene that it got from each of its parents. Importantly, the actual frequency of a given gene variant in a population (that is, the interbreeding members of a species that typically live in a geographic place, in this paper meaning of nonhumans) is greater if the variant confers a net reproductive advantage and less if it confers a disadvantage. This natural selection presents a challenge to genetically modifying *in situ* (that is, in the wild) populations. Most traits that humans desire in nonhuman species are not reproductively advantageous – or are even disadvantageous – causing any modified gene to dissipate as the natural variants outcompete it.

In 2003, Austin Burt proposed that humans could synthesize mechanisms of biased inheritance to "drive" a desired modified gene through an *in situ* population (Burt 2003). His proposal remained theoretical until the development of gene editing using CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) in 2012, enabling CRISPR-based gene drive systems (here called simply "gene drives") (National Academies of Sciences, Engineering, and Medicine 2016).

A gene drive functions by copying itself and an accompanying modified genetic sequence onto the equivalent location on an organism's other set of genes, causing them both to be modified and transmitted to (nearly) all of an individual's offspring. Through this mechanism, gene drives empower humans to genetically modify an entire population by introducing only a small number of gene drive organisms (GDOs). These could spread a gene that is either reproductively neutral or disadvantageous. Most interest in gene drives thus far has been in potentially reducing the size of a population or extinguishing it entirely. This could be achieved through genes that cause most or all offspring to be male or by making members of one sex infertile, or by propagating a recessive infertility gene. Importantly, gene drives are effective only in species that reproduce sexually and have a short life cycle, as several generations are necessary before most of a population becomes altered. These requirements exclude their use in bacteria and large animals. Researchers have successfully modified a few species, including yeast, fruit flies, and mosquitos, to carry and propagate gene drives, while initial steps with mice have been successful. GDOs have been tested in contained environments, and some experts have suggested that outdoor experiments could be undertaken as early as 2023 (Dunning 2018) and outdoor use by around 2025 (Kahn 2020).

Gene drives offer several applications for both human wellbeing and biodiversity conservation (Kolodziejczyk et al. 2019; Redford et al. 2019). First, most gene drive research to date has concerned combatting diseases that afflict humans. Malaria, dengue fever, Zika, chikungunya, Mayaro, and yellow fever are transmitted by only a few mosquito species (of which there are thousands). Populations of them could be reduced or eliminated using GDOs in areas where the diseases are endemic (Raban, Marshall, and Akbari 2020). Alternatively, gene drives could modify the populations so that the mosquitos or other vector species would not carry, transmit, or propagate the disease. Indeed, the half million annual deaths from malaria alone offer a powerful moral case for at least researching gene drives. Second, gene drives could benefit agriculture. Pest populations could be reduced, eliminated, or modified to remove evolved resistance to insecticide. Third, gene drives could extirpate invasive alien species, one of the leading direct drivers of biodiversity loss. This is particularly appealing on islands, which are more vulnerable to invasive aliens and could better contain introduced GDOs. In these cases, rodents would be likely potential targets (Godwin et al. 2019). Fighting invasive alien species and diseases can overlap, in that some of the former transmit the latter. For instance, Hawaiian honeycreepers (a small bird species) are endangered in part due to avian malaria that is transmitted by invasive alien mosquitos. Alternatively, a gene drive could modify an invasive alien species to be less competitive with native ones. Fourth, endangered species could be genetically modified to resist diseases (Rode et al. 2019). There is growing evidence that a fungus is the primary cause of the recent decline in amphibian populations, which could be modified to be unaffected by it. Fifth and finally, humans could genetically modify *in situ* populations to increase resilience in the face of changing conditions, particularly due to anthropogenic climate change. As one illustration, corals may be able to be modified so that reefs persist in warmer, more acidic ocean waters. Importantly, the third, fourth, and fifth applications listed here are for conservation goals. However, a highly leveraged technique such as gene drives might not be justified for these last two applications – in which a reproductively advantageous trait would be conferred – in comparison with the introduction of "traditional" GMOs.

One place where gene drives are being considered to help conserve biodiversity is New Zealand. A set of relatively isolated islands that were among the last to be settled by humans, it is a biodiversity hotspot with many unique terrestrial species. Before humans arrived approximately 700 years ago, the only terrestrial mammals were bats, a situation that caused many native species to lose through evolution their defenses against predation, especially that of flight. Settlement – especially by Europeans – brought numerous invasive alien species, including several dozen terrestrial mammals, some of which are predators. Now, about one-third of native bird species are threatened and another half are at risk (Robertson et al. 2017), with invasive alien predators as the primary driver of loss (Parliamentary

Commissioner for the Environment 2017). In 2016, the government resolved that New Zealand will be free of the most harmful alien predators – rats, stoats, weasels, ferrets, and possums – by 2050. Some scientists believe that "predator-free New Zealand is possible through use of novel 'next-generation' pest control tools," (Dearden et al. 2018, 226) and gene drives have been among those researched to eradicate invasive rats and wasps (Royal Society Te Apārangi Gene Editing Panel 2017).

Risks, challenges, and governance characteristics

Besides the potential benefits described above, gene drives would also pose environmental risks (Hayes et al. 2018). GDOs' outdoor use could affect target organisms' genomes at other locations, *in situ* populations of the species beyond the targeted one, or nontarget species through horizontal gene transfer. Furthermore, the desired change could have unexpected impacts on local ecosystems. Because of these risks, their indoor and experimental use also raises the threat of accidental, premature release. In fact, some prominent gene drive researchers are so concerned about these environmental risks – especially of spreading to other *in situ* populations – that they conclude that GDOs should only be placed outdoors when the intention is to affect all populations of the target species (Esvelt and Gemmell 2017; Noble et al. 2018).

Although these risks should be taken seriously, some may be less severe than they initially seem. Regarding potential impacts on nontarget species, horizontal gene transfer from animals is quite rare. The first-order ecological impacts of eradicating a population or species – including invasive alien ones – are independent of whether this is done through gene drives or non-biotechnological methods. Moreover, scientists believe that removing a single mosquito species would typically not be ecologically harmful (Roberts et al. 2017). Gene drives may be able to be technologically contained. For example, a "daisy chain" drive could only be transmitted through a limited number of generations, allowing for localized applications. Likewise, isolated populations, such as those on islands, are often genetically distinct; a gene drive could, at least in principle, utilize locally fixed alleles in order to affect only the population's members. A threshold gene drive system would be effective only if it were released above some frequency within the population. In addition, the spread of a gene drive to undesired populations may be able to be halted by the ex ante use of an immunizing drive or remediated by the ex post introduction of a reversal one. Finally, these risks must be considered in the context of the countervailing ones, among which are the loss of biodiversity through invasive alien species; the use of toxins, chemical repellents, and barriers; and deadly infectious diseases among humans.

Gene drives present social challenges as well. At the very least, their research, use, and governance are deeply value-laden (Thiele 2020). Gene drives also have many hallmarks of a controversial, even polarizing technology that is likely to be perceived as dreadful and unknown (Slovic 2000). This is complicated by the fact that some species in their unmodified condition may have nonuse value, even to distant people. Clearly, intentionally modifying or especially eradicating populations poses challenging ethical questions (Sandler 2017; Callies 2019). Robust, informed, and deliberative engagement with – and perhaps consent from – stakeholders will be essential, but how to proceed is not entirely clear under these circumstances (George, Kuiken, and Delborne 2019; Kuzma et al. 2018). Regardless, it is unclear who has the authority to decide to use gene drives *in situ.* In addition, proposals to use gene drives to help conserve biodiversity might weaken efforts to do so by other means, for example by preserving critical habitat. Finally, gene drives could also be used for malicious purposes, at least in principle.

Because of gene drives' potentials to irreversibly affect species and ecosystems, to improve human wellbeing and help protect biodiversity, and to pose environmental risks and social challenges, governance is essential (Delborne et al. 2018; Rudenko, Palmer, and Oye 2018). Some physical risks can be effectively managed by national and subnational law, both extant and new. Indeed, some countries, among which are the Netherlands, Brazil, and Australia, have already developed regulations specific to gene drives. In others, this work might be governed through existing regulations including those for GMOs, biosafety, toxins, and veterinary medicines. However, this regulation typically addresses only local environmental health and safety risks on case-by-case bases, whereas gene drives pose risks that are of large scale, to ecosystems, and systemic as well as diverse social challenges. Kevin Esvelt – among the most prominent gene drive scientists – writes, “existing biosafety committees and authorities are simply not qualified to evaluate gene drive risks…. The current regulatory brakes are ineffective and inappropriate in the face of this new challenge” (Esvelt 2017, 26).

International law

There is a consensus that the governance of gene drives should, to some degree, be international and legal. Although domestic law and nonstate processes could suffice in some ways, they do not – and likely cannot – satisfy all of gene drives’ governance needs. The endeavor is necessarily transboundary, with researchers, materials, knowledge, and impacts crossing jurisdictional borders. The research and development is, and will likely continue to be, largely conducted in industrialized countries. Yet GDOs’ use appears more probable in developing countries, which have more at-risk biodiversity and higher rates of infectious diseases. Furthermore, some targeted populations straddle or travel across national borders, and even in cases in which they don’t, humans would intentionally or accidentally transport GDOs long distances. A US National Academies report on gene drives concludes, “Responsible governance will need to be international and inclusive, with clearly defined global regulatory frameworks, policies, and best practice standards for implementation…. the anticipated transboundary effects of gene-drive modified organisms give rise to the need for international policies or regulation that build agreements between countries” (National Academies of Sciences, Engineering, and Medicine 2016, 9, 149).

International law provides a framework of rules, processes, and institutions in which the governance of gene drives is developing. The foundation of international environmental law can be considered a double-sided coin (Stockholm Declaration on the Human Environment, 1972, Principle 21; Rio Declaration on Environment and Development, 1992, Principle 2). On one side, states have the sovereign right to exploit their own natural resources as they see fit, pursuant to their environmental and developmental policies (UN General Assembly Resolutions 626(VII), 1803(XVII)). On the other, they are obligated to take steps to reduce and prevent harm arising from activities within their jurisdiction or under their control that pose a significant transboundary risk (*Trail Smelter Arbitration (United States v. Canada)*, 1938 and 1941; *Nuclear Weapons Advisory Opinion*, 1996). Specifically, states are to practice due diligence by, among other things, requiring the activity's authorization, assessing environmental impacts, notifying and cooperating in good faith with potentially affected states, informing the public, and developing emergency contingency plans (International Law Commission 2001, Articles 4, 6-8, 13, 16).

Among multilateral agreements with widespread participation, the Convention on Biological Diversity (CBD) is central in several ways e. First, its parties – that is, all countries besides the United States – have numerous obligations regarding *in situ* biodiversity conservation to which gene drives could, if effective, contribute. Among these obligations are promoting the maintenance of viable populations of species, promoting the recovery of threatened species, and controlling and eradicating alien species that threaten ecosystems, habitats, or species (CBD Article 8). These obligations indicate that gene drives' use for conservation purposes are not only prima facie consistent with international biodiversity law (Hochkirch et al. 2018; see also Convention on Biological Diversity 2002), but could be promoted by it. Second, the outdoor use of gene drives would pose risks, and CBD parties are to require environmental impact assessment of proposed projects that are likely to have significant adverse effects on biodiversity and to duly take into account these possible consequences (CBD Article 14). Third, the parties commit in the CBD to promoting research that contributes to biodiversity conservation, particularly in developing countries, and to promote and cooperate in the use of scientific advances in biodiversity research (CBD Article 12). They also must provide and/or facilitate access and transfer to other parties such technologies, explicitly including biotechnologies (CBD Article 16). Gene drives could constitute this research, scientific advances, and technologies, respectively. Finally, all or most GDOs are "living modified organisms" under the CBD regime. If these are likely to have adverse environmental impacts that could affect biodiversity conservation, then CBD parties are to regulate, manage, or control the risks associated with the organisms' use and release, taking also into account the risks to human health (CBD Article 8(g)). They are also to provide information about the use and regulations for the GDOs' handling and potential adverse impacts (CBD Article 19).

The CBD's single provision governing living modified organisms is furthered by its Cartagena Protocol on Biosafety, which has been ratified by 172 countries – not including Australia, Canada, and the United States. It aims for the safe transboundary transfer, handling and use of living modified organisms that could have adverse effects on biodiversity (CP Article 1). The Protocol centers on the requirement that parties that intend to export living modified organisms obtain the advanced informed agreement of importing parties (CP Articles 7-12). The underlying risk assessment is to be carried out in a scientifically sound manner (CP Article 15). The Cartagena Protocol also establishes a Biosafety Clearing-House to facilitate the exchange of scientific, technical, environmental, and legal information regarding living modified organisms (CP Article 20). When a party is aware of an occurrence under its jurisdiction resulting in a release that may lead to an unintentional transboundary movement of a living modified organism that is likely to have significant adverse effects on biodiversity – which GDOs could cause – it is obligated to report this to potentially affected states and the Biosafety Clearing-House (CP Article 17). The Cartagena Protocol parties are also to cooperate in building developing countries' capacity in biosafety (CP Article 22).

The Protocol is advanced by the Nagoya–Kuala Lumpur Supplementary Protocol on Liability and Redress, which requires that the operators – those in control of the living modified organisms – undertake appropriate response measures in the event of damage from living modified organisms (NKLSP Article 5). Its currently forty-five parties are also to provide for civil liability in such cases (NKLSP Article 12). The CBD agreements are supported by a robust set of active institutions, particularly biennial Conferences of Parties (COPs) and the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA). In recent years, these bodies have taken actions toward governing gene drives, discussed in the following section.

Of particular importance in the CBD regime is the precautionary approach. The CBD itself only notes precaution in its preamble: "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat" (recital 9). In some contrast, the Cartagena Protocol places precaution in its objective, which provides that it is "In accordance with the precautionary approach" (CP Article 1). The precautionary approach's precise legal status and implications – in general, in the CBD regime, and with respect to biotechnology – are unclear and have been the subject of scholarly, legal, and political debates (e.g. Pellizzoni and Ylönen 2008; Vogel 2012). These characteristics are especially challenging in high-stakes risk-risk tradeoffs with scientific uncertainty and contested values. Perhaps unsurprisingly, precaution's unclarity and contestation has manifested in discussions of gene drives (Kaebnick et al. 2016), discussed further below in the context of the CBD COPs. Although many observers assume that the precautionary approach implies policies that restrict gene drives' development and use, the countervailing risks must also be taken into account, given the phrasing of the precautionary approach in the CBD.

Intergovernmental institutions, some of which are not affiliated with multilateral treaties, also contribute to global governance. The Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services (IPBES) assesses scientific evidence, supports policy, and builds capacity regarding biodiversity and ecosystem services ("Resolution on the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services" 2012). It is developing an assessment of invasive alien species and their control that will, among other things, review the effectiveness of diverse response options, such as GDOs (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2018).

The World Health Organization (WHO) works toward, among other things, the eradication of diseases ("Constitution of the World Health Organization," n.d., Article 2(g)). In 2014, it published a guidance framework for testing genetically modified mosquitoes (World Health Organization 2014). It relies on a stepwise testing pathway that requires evidence of efficacy, acceptability, and deliverability. More recently, the WHO's Vector Control Advisory Group "encourages further development of tools utilizing gene-drive based technologies" (World Health Organization 2017, 1) and is discussing how gene drive mosquitoes might contribute to the elimination of malaria in sub-Saharan Africa.

The International Union for Conservation of Nature (IUCN) is a hybrid intergovernmental and nongovernmental organization that cooperates with other intergovernmental institutions, including those affiliated with the CBD, for which it provides advice and expertise. At its 2016 World Conservation Congress, the IUCN debated and approved a resolution that, in order to later develop guidance, calls for an assessment of the potential impacts of gene drives and synthetic biology, a somewhat poorly defined set of new biotechnologies, on the conservation and sustainable use of biodiversity (WCC-2016-Res-086). The IUCN established a task force for this purpose. In 2019, the task force released a substantial report that adopts a generally ambivalent tone, concluding

> While most synthetic biology and gene drive products are not designed as conservation applications, some of these will nonetheless have substantial impacts on conservation practices and outcomes…

> Some synthetic biology and engineered gene drive applications, if appropriately designed and targeted, could enhance biodiversity conservation…
>
> Engineered gene drive systems can be a transformative tool for direct conservation applications… (Redford et al. 2019)

As with the CBD COPs' decisions, the IUCN process is discussed in the next section.

The emerging politics of international decision-making

Although international law can provide a framework for the governance of gene drives, its necessary vagueness and states' desire and ability to retain sovereignty mean that a substantial portion of governance results from political processes. In these, state and nonstate actors negotiate how international law and other norms should apply to contested issues. Although the politics of gene drives' governance remains inchoate, some contours can be gleaned from the debates surrounding decision-making at intergovernmental institutions, especially those associated with the IUCN and the CBD.

In the case of the IUCN, the 2016 resolution began as a motion to develop a policy on synthetic biology, sponsored by a handful of environmental and scientific organizations, largely from industrialized countries. When the organization's members voted on it, they could also choose from two versions of an optional amendment. Both of these would have supported the additional assessment and the development of a position on gene drives, with one version also containing a further phrase that the IUCN would "refrain[] from supporting or endorsing research, including field trials, into the use of gene drives for conservation or other purposes until this assessment has been undertaken" (WCC-2016-Res-086-EN). The amendment with this somewhat restrictive phrase was approved, with substantially stronger support from nongovernmental organizations (which can also be IUCN members) than from states and intergovernmental institutions. During the IUCN's subsequent Congress, the "Civil Society

Working Group on Gene Drives" – an ad hoc coalition of thirty environmental and other activists – published a statement calling "for a halt to all proposals for the use of gene drive technologies, but especially in conservation [due to] unintended consequences [and] ethical and social impacts" (Civil Society Working Group on Gene Drives 2016b).

As at the IUCN, the CBD COP's actions concerning gene drives also grew out of considerations of synthetic biology and the conservation of biodiversity. As early as 2010, the COP asked parties to submit information on this topic to the SBSTTA (Convention on Biological Diversity 2010). The parties' decision at the following Conference notes "based on the precautionary approach, the need to consider the potential positive and negative impacts of components, organisms and products resulting from synthetic biology techniques on the conservation and sustainable use of biodiversity" and asks countries "to take a precautionary approach… when addressing threats of significant reduction or loss of biological diversity posed by organisms, components and products resulting from synthetic biology" (Convention on Biological Diversity 2012). This process led to a pair of reports – one on synthetic biology's possible impacts on biodiversity and the other on governance by the CBD and other international instruments – just prior to the 2014 COP (Convention on Biological Diversity, Secretariat 2015). In 2014, the COP urged states to generally follow a precautionary approach regarding organisms resulting from synthetic biology and to take five specific actions: have risk assessment and management procedures and/or systems in place to regulate outdoor releases; approve field trials only after risk assessments; carry out scientific assessments regarding potential effects on the conservation and sustainable use of biodiversity, taking into account risks to human health; encourage research into risk assessment methodologies and into the positive and negative impacts on biodiversity; and cooperate in capacity building in developing countries (Convention on Biological Diversity 2014).

Two years later, gene drives were explicitly on the CBD's agenda as a part of its response to synthetic biology. And as with the IUCN resolution earlier in 2016, the Civil Society Working Group on

Gene Drives organized a letter of opposition during the lead-up. This time it took a firmer stance – calling for a moratorium on further "technical development and experimental application [because of] ecological, cultural and societal threats" – and gathered endorsements from more than 160 activist organizations (Civil Society Working Group on Gene Drives 2016a). Although many of these organizations are relatively small, the list contains larger ones such as Friends of the Earth, the International Union of Food Workers, La Via Campesina, and the International Federation of Organic Agricultural Movements. Scientists who research gene drives were also active: eighty of them – many from developing countries – issued their own letter to the CBD parties, urging the COP to support cautious and responsible research and potential use, while invoking arguments regarding human health and conservation (Burt et al. 2016). The relevant CBD working group considered but rejected a moratorium, instead recommending to the full COP various options that emphasized a precautionary approach (Convention on Biological Diversity 2016a; Kuiken 2017). At the COP, discussions were divided, with some states' delegations favoring a strict position; at least Australia, New Zealand, and Canada opposing the call for a precautionary approach; and others rejecting any reference to gene drives, believing that decisions regarding synthetic biology were sufficient (Earth Negotiations Bulletin 2016). On the final day, the COP rejected requiring "consent from other governments whose biodiversity could be affected by any proposed gene drive before approval of its release" (Convention on Biological Diversity 2016a), instead merely noting that the 2014 decision on synthetic biology can also apply to "some" GDOs (Convention on Biological Diversity 2016b).

Prior to the 2018 COP, the CBD's SBSTTA recommended that the parties call on states "to apply a precautionary approach… [with regard to][and refrain from] the release, including experimental release, of organisms containing engineered gene drives" (Convention on Biological Diversity, Subsidiary Body on Scientific, Technical and Technological Advice 2018, paragraph 10). When and if approved by the COP, the two bracketed options would have each been nonbinding "soft law," offering respectively only a cautionary statement and a request to prohibit GDOs' outdoor release. The latter option was introduced by Bolivia. That country, Venezuela, and Japan also successfully defended a passage recognizing that research and analysis are needed before GDOs are considered for environmental release, which Australia and Canada sought to remove (Earth Negotiations Bulletin 2018a).

The lead-up to the 2018 COP in some ways replayed some of the dynamics from 2016. The organizer of the Civil Society Working Group on Gene Drives – the ETC Group, a radical antitechnology organization – organized a letter calling for a moratorium, this time on only GDOs' outdoor release and accompanied by a critical report (ETC Group 2018; ETC Group and Heinrich Böll Foundation 2018). Scientists and other supporters of gene drive research were now better organized, having formed the Outreach Network for Gene Drive Research earlier that year. The Network counts as members not only research institutes, catalyzing projects, and their funders, but also an environmental advocacy organization – Island Conservation – that has long worked "to prevent extinctions by removing invasive species from islands" (Island Conservation n.d.). The Outreach Network for Gene Drive Research countered the ETC Group's letter with one of their own, now with approximately 125 endorsements, some of whom notably represented environmental organizations (Outreach Network for Gene Drive Research 2018). In addition, the UK's Royal Society – one of the world's most prestigious scientific organizations – published a statement supporting gene drive research and opposing a prohibition or moratorium on gene drives (Royal Society 2018). Other actors were also more vocal in the debate prior to the 2018 COP. The African Union's African High-Level Panel on Emerging Technologies issued a report on gene drives that concludes, among other things, "Given the potential of this technology *vis a vis* the threat of malaria to human health and development, it is imperative to comprehensively examine the technology, so as to guide further development and adoption in African countries" (African Union and New Partnership for Africa's Development 2018, 1; see Glover et al. 2018). The African Panel also recommended governance measures including an network of African researchers who register, selfregulate, and peer-review their work; national guidelines, frameworks, and enabling legislation that consider both potentials and risks; and the "development, coordination and harmonization of regulations and guidelines for regulating the development, approval and use of the final product" (African Union and New Partnership for Africa's Development 2018, 31–32).

At the 2018 COP, the African Group (led by Ghana, Nigeria, and South Africa), Argentina, Brazil, Canada, India, Indonesia, Malaysia, New Zealand, Panama, Peru, and Switzerland backed the cautionary statement, whereas Bolivia, Egypt, El Salvador, Thailand, and Venezuela were on the record supporting the call for states to prohibit gene drives' outdoor use (Earth Negotiations Bulletin 2018b). But an anonymous "veteran of the Convention" said that "the moratorium proposal [i.e. the prohibitive statement] was too radical to fly" (Earth Negotiations Bulletin 2018c, 24). The European Union (EU) offered a compromise that would ask states to refrain from outdoor releases unless risk assessment had been performed and relevant measures were in place. Yet this proposed modification of the prohibition was unsuccessful. After a raucous discussion in which "heckling turned into a yelling match of misinformation" (Kofler 2019, 25), the COP rejected the request to prohibit outdoor use and endorsed a decision closer to the cautionary statement:

> before these organisms [containing engineered gene drives] are considered for release into the environment, research and analysis are needed, and specific guidance may be useful, to support case-by-case risk assessment;
>
> … the free, prior and informed consent of indigenous peoples and local communities might be warranted when considering the possible release of organisms containing engineered gene drives that may impact their traditional knowledge, innovation, practices, livelihood and use of land and water;

> [The Conference] Calls upon Parties and other Governments… to apply a precautionary approach… and also… to only consider introducing organisms containing engineered gene drives into the environment, including for experimental releases and research and development purposes, when:
>
> a. Scientifically sound case-by-case risk assessments have been carried out;
>
> b. Risk management measures are in place to avoid or minimize potential adverse effects, as appropriate;
>
> c. Where appropriate, the "prior and informed consent", the "free, prior and informed consent" or "approval and involvement" of potentially affected indigenous peoples and local communities is sought or obtained, where applicable in accordance with national circumstances and legislation (Convention on Biological Diversity 2018a).

This decision amounts to calls for additional research, a precautionary approach, and conditions limiting GDOs' release into the environment. These conditions include risk assessment, risk management, and possibly some involvement of the public in decision-making.

At the same 2018 meeting, the parties to the Cartagena Protocol called for international cooperation, knowledge sharing, and capacity building in assessing GDOs' potential adverse effects. They also requested research outputs from the CBD Executive Secretary, SBSTTA, and the Ad Hoc Technical Expert Group on Risk Assessment (Convention on Biological Diversity 2018b). Parties will address whether to develop further guidance at their next meeting in 2020.

Analytic observations

Like some prior and currently emerging technologies, gene drives' combination of high-stakes benefits and risks fosters controversy. Because they would involve releasing GMOs outdoors, a comparison with the debates concerning agricultural GMOs during the past 25 years is useful.

Gene drives' emerging governance and politics resembles those of agricultural GMOs in four important characteristics. First, industrialized countries have adopted similar positions with respect to the two sets of technologies. These are evident in a divide between the Anglosphere and Europe (Paarlberg 2009; Pollack and Shaffer 2009). The United States regulates agricultural products based on their characteristics, including scientific assessment of their physical and environmental risks, not on the processes through which they were created. Australia, Canada, and New Zealand have also approved numerous agricultural GMOs, although their use in those countries has been substantially less than in the United States. The United States – not a party to the CBD – is the home of most gene drive research, while Canada – and to a lesser extent Australia and New Zealand – has consistently pushed for liberal positions at the CBD COPs. In contrast, the EU assumes a restrictive stance toward agricultural GMOs, *de facto* prohibiting them. Regarding gene drives, the EU's proposed compromise at the 2018 CBD COP was still fairly prohibitive. European leaders appear to have little to lose politically by expanding its restrictive biotechnology policies to gene drives: most insect borne diseases have been eradicated there, its biotechnology industry is relatively small, and this restrictive position can satisfy "green" environmental domestic constituencies.

Second, most of the activists and advocacy organizations that resist gene drives also opposed GMOs in the 1990s and 2000s. In fact, they have recently shifted their rhetoric to more strongly emphasize GDOs' similarity to agricultural GMOs and their risks to agriculture (e.g. ETC Group 2018; ETC

Group and Heinrich Böll Foundation 2018). This is understandable, as these political actors achieved substantial success with agricultural GMOs.

Third, the gene drive debates are playing out at the same intergovernmental forums as those for agricultural GMOs. Those affiliated with the CBD are central, with the IUCN secondary. The fact that the CBD – instead of, for example, action by the Food and Agricultural Organization – is the dominant instrument for the international governance of agricultural GMOs is somewhat of a historical accident, as biotechnology's outdoor use arose coincidentally with a renewed push for the conservation of biological diversity in the early 1990s. As a consequence of that coincidence, the CBD is the leading existing multilateral agreement that could govern GDOs' use.

Finally, divergent understandings of precaution have played a central role in how state and nonstate actors have responded to both agricultural GMOs and gene drives. The US generally rejects the precautionary approach, whereas the European Union has formally adopted a precautionary principle (Commission of the European Communities 2000; Bodiguel and Cardwell 2009). As noted, the former has a relatively permissive regulatory regime for GMOs and is supporting gene drives' research and development, while the latter restricts agricultural GMOs and has sought to do so for gene drives as well. Furthermore, the activist organizations that oppose gene drives' development repeatedly and strongly invoke precaution in their rhetoric. The result is evident in the emphasis on the precautionary approach in the decisions of the CBD COPs and, to a lesser degree, the IUCN's output (e.g. Redford et al. 2019).

At the same time, the politics of gene drives and of agricultural GMOs differ in five key ways. For one thing, during the agricultural GMO debates, scientists remained largely quiet and politically on the sidelines, especially early on. Perhaps having learned from that experience, in which activists' claims and popular understandings significantly diverged from emerging scientific evidence, gene drive researchers – as well as scientific bodies such as the Royal Society – are now taking proactive roles with gene drives.

Second, although the activist organizations that are resisting gene drives opposed agricultural GMOs in the past, the converse is not true. Indeed, most major environmental advocacy organizations – which may be the wildcard in governance debates – have thus far remained silent on gene drives, and at least one such group, Island Conservation, supports their research and development.

Third, and somewhat related, the two sets of biotechnologies have differing implications for the conservation of biological diversity, or at least the perceptions thereof. Agricultural GMOs were largely understood as only a threat to biodiversity (although they have had modest benefits such as reduced pesticide use). Gene drives, as emphasized here, may be an essential means to protecting threatened species. However, throughout the recent international discussions of GDOs' governance, their uses for biodiversity conservation have largely been overshadowed by their protentional to eradicate vector-borne diseases.

Fourth, the private sector's roles in these biotechnologies are distinct. Agricultural GMOs were mostly developed and promoted by large businesses which sought to profit. In contrast, the private sector has been almost entirely absent from gene drives' research and development. This can be explained by the fact that – unlike in the case of agricultural GMOs – the decisions regarding whether to use GDOs as well as the funding to do so will likely come from the public sector (Mitchell, Brown, and McRoberts 2018). Thus, there are limited opportunities to profit from what would amount to public works programs such as eradicating diseases in relatively poor countries.

Finally, and perhaps most importantly, the positions of developing countries – especially the poorer ones in Africa – are now different. In the 1990s and 2000s, they generally rejected agricultural GMOs or limited their use to cotton, in order to maintain food export markets in Europe and due to the influence of activist organizations based in wealthy countries (Paarlberg 2009). This block of countries was essential in drafting, approving, and ratifying the Cartagena Protocol's relatively restrictive language.

But as described, the African Union has worked at the CBD COPs to ensure that gene drives may be researched and developed. This is in large part due to the scourge of malaria, the fifth-leading cause of death in Africa (World Health Organization n.d.). This seems to create a distinct different set of incentives for African states.

Looking forward, matters of international governance are likely to increasingly dominate conversations concerning the research, development, and possible use of GDOs. Yet crafting and implementing governance – especially in intergovernmental legal institutions – may prove to be difficult. At the very least, because biotechnology has been framed to date as only a threat to biodiversity, any argument to the contrary must overcome the associated discursive inertia. The uncertainties regarding gene drives' capacities and risks are presently great, although they presumably could be reduced through research. Perceptions of gene drives might become polarized, perhaps with significant differences between experts and laypeople. Along these lines Thiele states elsewhere in this issue that "The controversy [between critics and advocates] is fueled by the paradox of engineering nature in order to save it" (Thiele 2020).

Specifically, the CBD regime is arguably a poor fit for governing GDOs (National Academies of Sciences, Engineering, and Medicine 2016, 164–66). For one thing, its objectives include the conservation of biological diversity but not the improvement of human wellbeing (although the CBD's single provision on living modified organisms takes "into account the risks to human health" (CBD Article 8(g)). For another, as noted, its regulation of GMOs appears to be a consequence of coincidental timing. And although the CBD's emphasis on precaution may have been appropriate at that time, when GMOs seemed more uncertain, it now seems out of step with current empirical evidence. Nevertheless, the short-term consideration of GDOs' governance will likely persist in the CBD's institutions. An alternative forum is warranted. This could be state centered, such as a joint endeavor of the WHO and the UN Environment Assembly. Alternatively, given the uncertainty and contestation, a nonstate one – for example, a panel of diverse experts and stakeholders – may be able to better overcome some of the political challenges.

This points toward a challenging tension for governance, in which GDOs could offer both benefits for and risks to biodiversity (Sandler 2017; Boëte 2018). In fact, gene drives and related technologies could constitute a paradigm shift in conservation biology, in which preserving natural species and ecosystems – which may no longer be possible – and minimizing human impacts gives way to intentionally managing them to adapt them for new conditions. For example, the IPBES concludes that "Goals for conserving and sustainably using nature and achieving sustainability… may only be achieved through transformative changes across economic, social, political and technological factors [among which are] ensuring environmentally friendly technological and social innovation" (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019, 5, 8).

This politics of GDOs' governance is a manifestation of a larger struggle regarding emerging technologies among those concerned about sustainability. Many environmentalists resist these technologies when they are centralized, invisible, relatively unfamiliar, and in others' control, such as nuclear power, climate geoengineering (Reynolds 2019), and gene drives. Yet in a persistent echo of the movement's "small is beautiful" principle, environmentalists are often quick to embrace those that are decentralized, visible, relatively familiar, and in consumers' control, such as solar panels, insulation, and electric cars. Whether we proceed with contested technologies is, to a degree, political. Yet whether we can both conserve biodiversity and improve the wellbeing of the world's peoples with decentralized technologies is largely an empirical matter.

Biography

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