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Whose intentions? What consequences? Interrogating "Intended Consequences" for conservation with environmental biotechnology

S. Kathleen Barnhill-Dilling | **Jason A. Delborne**

Department of Forestry and Environmental Resources, Genetic Engineering and Society Center, North Carolina State University, Raleigh, North Carolina

Correspondence
S. Kathleen Barnhill-Dilling, Department of Forestry and Environmental Resources, North Carolina State University, 2800 Faucette Dr., Raleigh, NC 27695, USA.
Email: skbarnhi@ncsu.edu

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Abstract

Novel genetic interventions may offer innovative solutions to environmental conservation challenges, but they also represent new kinds of risks and concerns for diverse publics. Yet, by focusing on potential negative outcomes of emerging technologies like gene editing, their potential utility in species protection could lead to overblown fears of unknown and unanticipated consequences. In response, Revive and Restore organized a workshop in June 2020 entitled, "Intended Consequences," to highlight conservation successes in the discourse and governance of genomic interventions. This article argues that if we seek to emphasize Intended Consequences to embolden innovative conservation efforts, we must simultaneously query whose intentions are included and what consequences are considered to ensure that environmental goals are accompanied by the goals of responsibility, democracy, and justice. These questions reveal that the governance and management of conservation interventions always rest upon value judgements. Inspired and informed by the Responsible Research and Innovation framework, we encourage anticipation of potential outcomes, reflection on assumptions and intentions, inclusion of diverse stakeholders and perspectives, and a commitment to responding thoughtfully to concerns and preferences of communities and broader publics.

KEYWORDS

biotechnology, conservation, responsible research & innovation

1 | INTRODUCTION

As the world faces intractable species loss due to habitat degradation, climate change, invasive species, and other factors, a range of conservation institutions and individuals have called for transformational tools to address these losses (Campbell et al. 2019; Piaggio et al., 2017; IPBES, 2019; Redford, Brooks, Macfarlane, & Adams, 2019). In light of these pressing problems, inaction feels unethical (Brister, Holbrook, & Palmer, 2021). Yet, while novel genetic interventions may offer innovative solutions to environmental challenges, they also represent new kinds of risks and concerns for diverse publics (Burgiel et al. 2021). Moreover, the nature of emerging environmental biotechnologies suggests that policy-makers and conservation practitioners will make impactful decisions in the midst of some uncertainty and

consideration of unintended consequences (Hayes et al., 2018). In the context of such uncertainty, some conservation practitioners are concerned that "decision-making can be hung up on concerns about *unintended consequences* of a particular intervention, undermining the urgent need for action [emphasis ours]" (Phelan, Karieva, Marvier, Robbins, & Weber, 2021, p.1).

In this context, Revive and Restore convened the "Intended Consequences Workshop" in June 2020 (https://reviverestore.org/events/intended-consequences-workshop/), gathering conservation scientists and practitioners, social scientists, ethicists, environmental writers, and agency scientists. The organizers aimed to focus on "the successful achievement of 'intended consequences'" of translocations and genetic interventions for conservation, which some workshop participants described as "underplayed" (Phelan et al., 2021, p. 1). Facing the urgency of global species loss, the workshop highlighted success stories to demonstrate the benefits to nature made possible with innovative interventions.

The workshop theme explicitly countered the "specter of potential unintended consequences" (Phelan et al., 2021, p. 1) of novel conservation interventions. Many workshop participants expressed concern "that over-emphasis on unintended consequences could pose a barrier to innovation" (Phelan et al., 2021, p. 3). They explained that by focusing on potential negative outcomes of emerging technologies like gene editing, their potential utility in species protection could lead to overblown fears of unknown and unanticipated consequences. To counter this paralysis, we might instead consider the moral hazards of inaction (Brister et al., 2021), and how the loss of such tools would be unethical in the context of global species loss.

As social scientists who participated in the workshop, and who work in the governance of environmental biotechnologies for species protection more broadly, we understand the urgency of responding to global species loss. In addition, as Science, Technology, and Society scholars, we see the framework of Intended Consequences' as a "black box" that warrants interrogation (Latour, 1987). Specifically, we pose the questions: *Whose intentions*? And *what consequences*? This paper argues that if we seek to re-center Intended Consequences to embolden innovative conservation efforts, we must simultaneously query *whose intentions* and *what consequences* to ensure that environmental goals are accompanied by the goals of responsibility, democracy, and justice.

Raising the questions—*Whose intentions*? *What consequences*?—reveals complexity, and perhaps even controversy, in the aims of the Intended Consequences workshop and the contents of this special issue. To explore this complexity, we invoke the framework of Responsible Research and Innovation (RRI), which has been proposed and institutionalized to align the processes and products of research and development more closely with public values (Burget, Bardone, & Pedaste, 2017; Stilgoe, Owen, & Macnaghten, 2013; Von Schomberg, 2013). As conservation practitioners and scholars consider a variety of innovative efforts to protect and restore threatened species, RRI brings an infusion of just, democractic principles to this innovation process (Foley, Bernstein, & Wiek, 2016). Intended Consequences invites us to "keep the intended benefits to nature front-of-mind during a responsible planning process and through various stages of intervention and monitoring" (Phelan et al., 2021, p.1). As we describe below, RRI reminds us, for example, that responsible planning should prompt us to ask who has—and has not—participated in defining those intended benefits. More specifically, the framework includes the four dimensions of anticipation, reflexivity, inclusion, and responsiveness, which reveal how asking *whose intentions* and *what consequences* helps position responsibility, democracy, and justice as foundational to ethical responses to species loss.

To demonstrate RRI's utility in integrating such complexity into the process of conservation innovation, we first provide an overview of the RRI framework, situated in the context of emerging biotechnologies for conservation. Second, we provide a brief description of the two cases upon which we draw direct experience: (a) the genetically engineered American chestnut tree (NASEM, 2019; Newhouse & Powell, 2020) and (b) gene drive mice for the conservation of island biodiversity (Campbell et al., 2019; Piaggio et al., 2017), advanced through the Genetic Biocontrol of Invasive Rodents (GBIRd) partnership. We then use the dimensions of RRI to explore how asking *whose intentions* and *what consequences* is critical to the re-centering of Intended Consequences in advancing genomic tools for conservation.

2 | RESPONSIBLE RESEARCH AND INNOVATION

RRI has a clearly expressed motivation: to explore how to better integrate responsibility into systems of innovation and governance of emerging technologies (Burget et al., 2017; Correljé, Cuppen, Dignum, Pesch, & Taebi, 2015; Guston et al., 2014). Partly envisioned as a way to shift exclusive focus away from the economic benefits of innovation toward humanity's grand challenges and potential tools for responding to them (Von Schomberg, 2013), RRI also shifts attention upstream to consider the innovation process more systematically (Krzywoszynska et al., 2018). To that end, RRI attends to the socio-cultural elements of technological innovation, including human values, cultural practices, and existing institutions.

RRI emerged largely in response to publicly controversial science and technology, such as genetically modified organisms, synthetic biology, and nanotechnology (Burget et al., 2017; Frewer & Shepherd, 1995; Guston et al., 2014; Owen & Pansera, 2019). As some science policy-makers grew increasingly concerned about public trust in science, scholars demonstrated that increased attention to simply educating public audiences about genetic engineering, for example, had a limited effect on trust and technological acceptance (Owen, Macnaghten, & Stilgoe, 2012). In fact, increased knowledge about a subject like genetic engineering may just correlate with the intensity of one's position rather than with support or opposition (Brunk, 2006; Sturgis & Allum, 2004). Scholars and practitioners developed RRI as an alternative to education initiatives narrowly designed to eliminate "knowledge deficits," instead focusing on deliberative processes as a means of integrating technical expertise and democratic norms.

In the spirit of developing an ethos of responsible conservation (Brister et al., 2021), RRI explicitly generates deliberative space to infuse the development and governance of novel genetic tools with democratic principles oriented toward justice. RRI encourages the inclusion of disparate values, perspectives, and worldviews to consider a broad range of ideas about what is ethically acceptable (Foley et al., 2016; Stilgoe et al., 2013). Moreover, the RRI framework creates opportunities to engage with the complex colonial and arguably undemocratic histories that plague conservation (Martin, McGuire, & Sullivan, 2013; Nelson, 2003). As such, this is a framework for interrogating how conservation practitioners and environmental biotechnology proponents and opponents frame problems and proposed solutions. Many agree that species loss is one of humanity's grand challenges (IPBES, 2019), but not everyone agrees on the same set of morally appropriate responses (Brister et al., 2021).

While RRI has been described by many scholars, we review the framework advanced by Stilgoe et al. (2013), which includes four dimensions of responsible innovation: anticipation, reflexivity, inclusion, and responsiveness.

Anticipation is the deceptively simple act of looking out and ahead to see what possible impacts a particular innovation system may have. Anticipation typically takes place through deliberative processes such as early and upstream community, stakeholder, and public engagement (Stilgoe et al., 2013). In these deliberative spaces, innovators, engagement practitioners, and stakeholders anticipate and interrogate the knowable range of possible outcomes (Stilgoe et al., 2013; Wilsdon & Willis, 2004). In other words, anticipation prompts exploration into an innovation system's potential *intended and unintended* consequences.

Reflexivity is at once foundational to the practice of science and, as RRI defines it, requires questioning the very foundations of scientific practice. Being responsible innovators requires "holding a mirror up to one's own activities, commitment, and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue is not universally held" (Stilgoe et al., 2013, p. 1571). Another important element of reflexivity includes stepping away from the assumed agnosticism of science and acknowledging the moral and values-laden nature of innovation. These are complex ideas that conflict with the scientific norm of objectivity, yet understanding that one's own worldview is not the only way to be in the world is foundational to democratic commitments that underpin RRI. Reflexivity is therefore critical in understanding whose values, worldviews, and intentions come to define Intended Consequences.

In RRI's original framework, *inclusion* referred to broader, more participatory, deliberative decision-making structures that informed science policy and technological innovation (Stilgoe et al., 2013). Scholars then wrestled with how best to implement inclusivity, arguably in an attempt to usher in a new governance paradigm that was more directly democratic (Macnaghten et al., 2014; Valkenburg, 2020). We build on these foundational commitments, situate them more appropriately in the current historical moment, and orient our articulation of inclusion in the context of *diversity and inclusion* scholarship and praxis. Diversity refers to representation—who is at the proverbial or literal table, whereas inclusion refers to how those diverse perspectives are meaningfully attended to, centered, and even elevated (Sherbin & Rashid, 2017). In this light, we use the structure of this paper to explore how diversity and inclusion can shed light on *whose intentions* and *whose consequences* drive the consideration of Intended Consequences from genomic interventions in conservation.

Responsiveness is the lynchpin of RRI, yet it is challenging for many innovation teams, as it "requires the capacity to change direction in response to stakeholder and public values and changing circumstances" (Stilgoe et al., 2013, p. 1572). Responsiveness involves responding to new knowledge as it emerges and to the complex perspectives, views, and norms made visible through anticipation, reflexivity, and diversity and inclusion. Responding to new perspectives is inherently about power sharing, ensuring that the framing of Intended Consequences is responsible, democractic, and just in both process and outcomes (Stirling, Hayes, & Delborne, 2018).

3 | CASE STUDIES OF ENVIRONMENTAL BIOTECHNOLOGY FOR CONSERVATION

While there are many historical, proposed, and emerging genomic interventions for conservation—including several discussed at the "Intended Consequences Workshop" and in this special issue, we focus on two case studies of environmental biotechnology: the GE chestnut and the gene drive mouse. We have played active roles in engagement activities surrounding these projects, and our experience as researchers and practitioners provides insight into how the questions of *whose intentions* and *what consequences* reveal the complexity of the Intended Consequences framework for conservation.

3.1 | Genetically engineered (GE) American chestnut tree

An invasive pathogen now known as the chestnut blight entered the United States in the early 20th century, subsequently killing upwards of 4 billion trees in the eastern forests. While traditional breeding practices have generated modest success in developing blight-resistant trees, a genetically engineered line of chestnuts is poised to become a significant part of the restoration toolkit (Powell, 2016). Currently under regulatory review, the GE chestnut may well become the first genetically engineered organism to be released freely into unmanaged environments with the end-goal of growing and reproducing freely. While species restoration may seem like a public good, it is not without controversy (Smolker & Petermann 2019; Thompson, 2019). Some are concerned about the high levels of uncertainty in releasing a GE organism that may live for a century or more, while others are concerned about the potential for a GE chestnut to cross sovereign tribal lands (Rosen, 2019).

As engagement researchers, we secured an NSF grant (1632670) to study the governance of the GE chestnut and with that support, organized and facilitated a stakeholder workshop to consider the role of public engagement at different phases of development and potential deployment of a GE American chestnut tree (Delborne et al., 2018). In preparation for that workshop, we cultivated relationships with the scientists who genetically engineered the tree so that our engagement activities included them and their motivations. Simultaneously, we developed a collaboration with members of the Haudenosaunee Environmental Task Force (http://hetf.org/). This collaboration supported an Indigenous scholar in linguistics to explore how a concept like a genetically engineered tree would translate into Haudenosaunee languages (see Delborne et al., 2018, pp.16–17). In addition, we worked to facilitate further engagement between Haudenosaunee Environmental Task Force leadership and the chestnut scientists, as well as federal and state environmental agencies. These activities have precipitated conversations with members of the American Chestnut Foundation and the Indigenous Environmental Network.

3.2 | Gene drive mouse for island biodiversity conservation

Invasive rodents live on 80% of the world's islands and are responsible for significant island biodiversity loss. This is particularly problematic because islands are home to a disproportionate number of endemic species. Ongoing efforts to eradicate invasive rodents rely largely on rodenticides—highly toxic, broad-spectrum compounds that can also endanger the very species conservationists are trying to protect. Moreover, invasive species eradication is only effective on approximately 15% of affected islands. The GBIRd, an international consortium of scientists and partners including the NGO Island Conservation, is trying to develop a gene drive mouse to eradicate invasive rodents on islands. Research is underway to construct a gene drive for mice that would bias offspring to be all male, which would crash an island population over several generations (Barnhill-Dilling & Delborne, 2019; Godwin et al., 2019; Leitschuh et al., 2018).

Delborne has led GBIRd's engagement efforts since their inception in 2016 and Barnhill-Dilling joined the engagement team in 2018, at the time funded by the DARPA Safe Genes program. Together, we organized and facilitated a stakeholder workshop (Farooque, Barnhill-Dilling, Shapiro, & Delborne, 2019) that brought together stakeholders and technical experts to consider the issues and implications associated with GBIRd's project goals. We both remain active leaders in GBIRd's engagement strategy, organizing and moderating panels at GBIRd's annual meetings, as well as representing GBIRd in broader gene drive workshops and conferences.

4 | WHOSE INTENTIONS?

As we contemplate a stronger focus on the Intended Consequences of using new genomic tools for biodiversity conservation, we argue for asking *whose intentions* select the consequences under consideration. The importance of this question emerges across the four dimensions of RRI: anticipation, reflexivity, inclusion, and responsiveness. Below, we first describe how each dimension informs the question

of *whose intentions* matter. We then draw from our own experiences with the GE chestnut and gene drive mouse case studies to illustrate the importance of attending to *whose intentions* in the practice of engagement surrounding environmental biotechnologies.

RRI's dimension of *anticipation* applies to anticipating both unintended and intended consequences of innovation, but a focus on Intended Consequences reveals the impact not just of who is doing the anticipating, but of *whose intentions* are being anticipated as desirable consequences. In the field of conservation, it may appear so obvious what the intentions are for a given project that we forget that conservation initiatives are always shaped by values and interests. We work harder to save some species than others; we cherish some types of habitat in some places more than others; and different stakeholders envision tradeoffs between competing values differently (e.g., how much to restrict human access to a habitat to make it safe for a desired species). Thus, the Intended Consequences of conservation are never completely neutral or objective. *Whose intentions*—the anticipations of those promoting the intervention—matter.

In RRI frameworks, anticipation typically takes place through deliberative processes such as early and upstream community, stakeholder, and public engagement (Stilgoe et al., 2013). These deliberative activities introduce stakeholders, including technical experts, to new perspectives and new ways to interrogate a potential innovation or intervention. Thus, who participates in anticipatory engagement activities serves as a proxy for understanding *whose intentions* have shaped the Intended Consequences of particular projects. As mentioned above, we organized two stakeholder workshops—addressing the GE chestnut and the gene drive mouse—where the diversity of our participants positively impacted the range of anticipations that surfaced.

In April 2018, we organized and facilitated an invitation-only workshop for interested stakeholders entitled, "Biotechnology, the American Chestnut, and Public Engagement" (Delborne et al., 2018). Participants included the scientists who had developed the GE chestnut, representatives from conservation and environmental NGOs, representatives from the Haudenosaunee Environmental Task Force (an Indigenous environmental organization), chestnut growers, federal agency representatives, as well as academics from the social and natural sciences. The proponents of the GE chestnut kept Intended Consequences central to the broader conversation: the importance and urgency of genomic tools for the restoration of a functionally extinct species. They also described how they anticipated and accounted for unintended consequences with the demonstrated safety of GE chestnuts in laboratory and field experiments.

Other stakeholders anticipated different consequences of deploying GE chestnut trees into the environment. Chestnut growers raised questions about whether GE chestnuts might "contaminate" the hybrid chestnuts grown commercially, and if so, whether consumers would buy them, introducing a novel unintended consequence to the dialogue. A forest service representative raised concerns about tensions between the chestnut project and their agency mission: there were questions about forest service (and other federal land management agencies) policies with respect to governing genetically engineering organisms. Could the Intended Consequences of chestnut restoration using a GE tree conflict with agency policies? At the time, questions remained about whether or not GE organisms would be allowed on federal lands. Indigenous leaders questioned whether the release of a self-propagating GE forest tree would undermine tribes' sovereignty to decide whether or not to permit GE chestnuts on their land. And some environmental groups argued that GE forest trees threaten the health and "naturalness" of forests. The combination of stakeholders not only expanded what we might anticipate about the chestnut project, but it also interrogated important assumptions about *whose intentions* have and should inform decisions regarding the release, governance, and management of the GE chestnut.

Reflexivity acknowledges that our perspectives—and even the scientific project writ large—are rooted in particular worldviews that are not universal (Salmon, Priestley, & Goven, 2017). Further, reflexivity teaches us that deliberations about the potential use of genomic interventions in conservation are rooted in deep, abiding questions such as what constitutes "wild," and what is humanity's relationship to non-human nature (Brister et al., 2021; Sandler, 2019). The answers to these questions vary among diverse stakeholders, and acknowledging these differences should directly inform how we think about *whose consequences* are centered and therefore intended. The remaining challenge is how to develop conservation plans that could attend meaningfully to diverse intentions in collective efforts to make decisions about conservation practice.

With respect to *whose intentions* have shaped their conservation plans, GBIRd scientists have opened themselves up to reflexivity through a variety of mechanisms, including establishing an ethics board and hosting annual meetings that include scientists and social scientists from multiple disciplines. Even on monthly project calls, stakeholder engagement issues are perennial agenda items alongside the genetics and ecology updates. In addition to the stakeholder workshop referenced above (Farooque et al., 2019), we have organized and moderated panels that attend specifically to values and

worldviews, designed to facilitate reflexivity about *whose intentions* will shape decisions about research and development in the pursuit of a gene drive mouse.

RRI scholarship calls for increased *diversity and inclusion* in the decision-making spaces around innovation. Diversity and inclusion interrogations throw into sharp relief *whose intentions* are—and whose are not yet—shaping Intended Consequences of genomic interventions in conservation.

Increasing diversity and inclusion can help conservation face its troubled colonial past (Phelan et al., 2021) and attend to power dynamics inherited from these histories. Historically, therefore, conservation goals and priorities—and intentions—have been set by the dominant white culture (e.g., Martin et al., 2013; Nelson, 2003). As conservation becomes more explicit in its commitment to broaden representation, the potential tension between pursuing well-established Intended Consequences within the conservation community and just, democratic process becomes increasingly important.

More specifically, there are calls for increased Indigenous participation in conservation, with practitioners noting that "cultural knowledge of Indigenous peoples in particular often proves crucial to the success of conservation initiatives" (Phelan et al., 2021, p.3; also see Taitingfong, 2019). However, if we are attending to those colonial pasts, Indigenous participation must go beyond a data sharing exercise. Instead, rooted in the understanding that the current framing of conservation is dominated by one set of cultural values and worldviews, we need to interrogate and reimagine Intended Consequences. This reimagining would broaden the scope of *whose intentions* shape Intended Consequences and require credible power sharing.

The GE chestnut project demonstrates how these challenging concepts can work in practice. The GE chestnut case is one of the few environmental biotechnology for conservation cases where there is published scholarship and media about Indigenous perspectives regarding the potential use of genetic interventions (Barnhill-Dilling & Delborne, 2019; Rosen, 2019). While we are always improving our praxis, we actively sought to include Haudenosaunee environmental leaders in our engagement activities. Through this effort, we learned about their distinct worldview with respect to species restoration, how their native linguistic structures were both a mirror and a shaper of that worldview, and how challenging it is to bring multiple worldviews together in environmental governance in light of historical power imbalances (Barnhill-Dilling, Rivers, & Delborne, 2020).

RRI's responsiveness elicits a powerful form of power sharing. Some innovators may worry that being "responsive" requires shutting down a project in the face of any degree of opposition, but this reflects a narrow interpretation of responsiveness—one where one group's set of intentions substitute for another's. Instead, innovators could explore dimensions of their project that could shift in response to critical perspectives. RRI's responsiveness guides project proponents to respond to opposition in more thoughtful, perhaps less polarizing ways.

For example, chestnut innovators decided not to patent the GE chestnut, as a direct result of public and stakeholder outreach, responding to concerns expressed about the GE chestnut following in the footsteps of commercial agricultural biotechnologies (Powell, personal communication). Powell made it clear that his intentions were for a vision of non-commercial chestnut restoration (Popkin, 2020). Similarly, in the wake of controversy over Oxitec's field trials in countries with minimal regulation (Brown, 2016), GBIRd has committed to only exploring field trials in national contexts with well-developed regulatory structures (geneticbiocontrol.org).

5 | WHAT CONSEQUENCES?

Focusing on the Intended Consequences of using new genomic tools for biodiversity conservation also prompts consideration of *what consequences* are considered. Again, we use the dimensions of RRI and our experiences as stakeholder engagement researchers and practitioners to explore that question.

The act of *anticipation* prompts us to look ahead to possible outcomes of using genomic interventions in conservation, and such outcomes will include a mixture of intended and unintended consequences. Phelan et al. (2021, p. 2) write, "Intended Consequences are achieved by addressing the potential for unintended consequences while keeping an eye on the desired conservation benefits." This suggests a need to anticipate both intended and unintended consequences, and we suggest that the boundary between them may not be so sharp. For example, the deployment of herbicides to eradicate an invasive weed will also kill some desired plants. These non-target effects are easily anticipated and possibly acceptable, but are they intended? On one hand, they are intended, given the certainty that deployment of the tool will cause some off-target plant death. On the other hand, they are unintended in the sense of not being desirable, or the prime intention of the intervention. To avoid this quandary, we suggest the importance of anticipating multiple orders of Intended Consequences, beginning with the direct, foreseeable, positive consequences and moving toward indirect, more uncertain, possibly negative consequences. This spectrum implies a gradient from the goals of a conservation

intervention (first-order Intended Consequences) to unintended consequences (that might be positive or negative).

An example of the ambiguity around intended versus unintended consequences emerged during the GBIRd workshop that we organized and convened in March 2019. For that workshop we structured the agenda and deliberation around project phases ranging from laboratory research to contained safety studies to potential field trials in an island environment; in this way we were able to anticipate beyond the current scope of the project—laboratory research—to collectively consider a range of potential outcomes. By design, our diverse participant pool expanded our understanding of the Intended Consequences for GBIRd and highlighted the tension between intended and unintended consequences. For example, animal welfare advocates questioned whether using gene drive to eradicate a population of island mice would be more humane than using traditional rodenticides; they pointed out the potential for increased competition among males as the percentage of females dropped precipitously, which could escalate to violence (Farooque et al., 2019, p. 21). This potential, second-order consequence, which could be seen as either intended or unintended, had not been anticipated by GBIRd scientists until raised in the context of this diverse stakeholder workshop.

Broad reflexivity—an interrogation of assumptions that underpin project intentions—is warranted for thinking about *what consequences* are considered as Intended Consequences. Reflexivity prompts greater attention to deep, ethical questions, such as the definition of "wilderness" and the proper role for humans to intervene in non-human nature (Brister et al., 2021). Current decision-making institutions often lack such reflexivity (Kuzma, 2019).

RRI scholars note that codes of conduct and other guiding principles might be important indicators of reflexivity (Stilgoe et al., 2013), demonstrating how contemplation shapes *what consequences* are most important. For example, GBIRd lists guiding principles on its website:

1. *Early and sustained consistent engagement with stakeholders and communities*
2. *Proceed cautiously with deliberate stepwise methods and measurable outcomes*
3. *Engage early and often with the research community, regulators, communities and other stakeholders*
4. *Maintain an uncompromising commitment to biosafety, existing regulations, and protocols as minimum standards (*e.g., NASEM, 2016; *AAS 2017)*
5. *Use and participate in best practices*
6. *Only operate in countries with appropriate regulatory capacity and*
7. *Be transparent with research, assessments, findings, and conclusion* (www.geneticbiocontrol.org).

These principles both encourage reflexivity in terms of considering a range of intended consequences (e.g., transparency, biosafety, demonstrated caution) and encourage processes of reflexivity (e.g., engagement with stakeholders, regulators, and communities) that might expand *what consequences* are taken seriously.

The lenses of *diversity and inclusion* invite interrogation about how just or democratic the processes have been—and could potentially be—for deciding on *what consequences* matter for innovative conservation practices. Diversity and inclusion remind us that some groups may experience Intended Consequences or even second order consequences differently than do other groups. We should be mindful of these differences overall, but particularly with respect to historically marginalized communities and peoples.

For example, the same consequence, a GE chestnut that is able to introgress freely into wild populations, can impact groups differently. If de-regulated by the Coordinated Framework for the Regulation of Biotechnology, the GE chestnut could, over time, cross into forests within sovereign Tribal lands. Some Haudenosaunee communities have staunch anti- genetic engineering policies and positions and might see their spread as an act of colonialism (Francis, 2015; Indigenous Environmental Network, n.d.). Other Tribal representatives—from the Eastern Band of Cherokee Indians, for example—might welcome the Intended Consequences of chestnut restoration through genetic engineering (Losiah, 2020).

Responsiveness is the process by which innovators adjust to new knowledge, experiences, and perspectives. This dimension of RRI shifts our attention from processes (anticipation, reflexivity, inclusion) to action and substance. What consequences are imagined, considered, and given priority will largely determine the range of potential responses by innovation teams. While these responses may be more or less visible to stakeholders—depending on the stage of research and development and the degree of transparency in project decision making—these are moments where conservation innovations can align with diverse values and priorities.

At the GBIRd stakeholder workshop in 2019, we used a series of fictional scenarios to prompt stakeholders to evaluate trade-offs and make decisions about *what consequences* mattered most in the hypothetical selection of an island for a field trial. The outcomes and subsequent discussion of these island scenarios provided insight regarding a range of potential consequences: for example, the

risk to a closely-related mouse species on the island and the ethical implications of re-introducing invasive mice to an island where they have been previously eradicated in order to test the function of the gene drive system (Farooque et al., 2019, pp. 18–21). The latter example illustrates the importance of choosing *what consequences* matter most. If the primary Intended Consequence of the first field trial of a gene drive mouse is to prove that the system works, then re-introducing invasive mice and eradicating them satisfies this intention and increases confidence that if the experiment went awry, traditional methods of eradication could eliminate the gene drive mice. If, however, the primary Intended Consequence is biodiversity protection, then re-introducing invasive mice (even with a gene drive meant to crash the population) puts island species at risk and provides no benefit to island biodiversity even if the experiment is "successful." Ultimately, GBIRd, in consultation with stakeholders and communities, will need to respond to this tension between competing Intended Consequences.

6 | CONCLUSION

This paper explores the hidden complexity of calls for re-centering the Intended Consequences of genomic interventions for biodiversity conservation. Specifically, we have raised the importance of asking *whose intentions* and *what consequences* are considered and prioritized in the research, development, and potential deployment of environmental biotechnologies. These questions reveal that the governance and management of conservation interventions always rest upon value judgments, which highlights the importance of seeking democratic, just, and responsible decision making. This paper has invoked the framework of RRI to interrogate how Intended Consequences are identified, explored, and agreed upon. The four dimensions of RRI—anticipation, reflexivity, inclusion, and responsiveness—intersect with the questions *whose intentions* and *what consequences*, revealing the complexity of Intended Consequences of novel genomic interventions for conservation.

Neither this paper nor RRI dictates the proper responses to problems as wicked as species loss, but we have argued for the importance of identifying the multiple intentions that surround a proposed conservation project and exploring a broad range of potentially knowable consequences. To that end, RRI provides a roadmap for conservationists to:

1. *Anticipate* second and third-order consequences—as possible outcomes from what are identified as intended consequences—that may result from the development and deployment of novel technologies for conservation;
2. *Reflect* on the fundamental assumptions and values-based preferences that support the pursuit of some "intended consequences" and not others;
3. *Include* people with disparate perspectives, diverse disciplinary training, and varied worldviews in processes of problem formulation and longer-term governance of conservation interventions; and
4. *Respond* to new information and alternative perspectives that clarify the impact of intended consequences.

Using these dimensions as guideposts, RRI pushes for deeper understanding of an innovation's context by prompting questions such as those found in Table 1.

TABLE 1 Responsible research and innovation: The governance of intended consequences for conservation using environmental biotechnologies

Anticipation	• How can a systems approach improve our ability to anticipate first, second, and third-order intended consequences of using environmental biotechnologies for conservation? • How can project teams use community, stakeholder, and public engagement to broaden anticipation of possible outcomes, thereby expanding the range of intended consequences considered?
Reflexivity	• How do values and socio-cultural assumptions shape the intended consequences of environmental biotechnology projects? • How can innovation systems align with the values and perspectives of innovators and stakeholders?
Inclusion	• What greater diversity of disciplines, perspectives, worldviews, and lived experiences provide a better understanding of the intended consequences of genetic interventions for species protection? • How can diversity and inclusion be meaningfully integrated throughout the innovation and deployment of environmental biotechnology projects for conservation?
Responsiveness	• How can project teams integrate new knowledge and perspectives to shape intended consequences for conservation using environmental biotechnologies? • How might responsiveness represent power sharing in the context of whose intentions and what consequences shape intended consequences?

If the primary intended consequence for conservation projects is species protection, then time is precious; indeed the urgency of the problem prompts important ethical questions about inaction in the face of the fear of unintended consequences (Brister et al., 2021). Yet, we urge caution in forging ahead and drawing a bright line between intended and unintended consequences. Instead, inspired and informed by the RRI framework, we encourage anticipation of potential outcomes, reflection on assumptions and intentions, inclusion of diverse stakeholders and perspectives, and a commitment to responding thoughtfully to concerns and preferences of communities and broader publics. Such practices may help navigate the controversies and complexities that arise when novel genomic tools are proposed to solve ongoing environmental challenges. Re-centering Intended Consequences is consistent with this vision, but only if we carefully consider *whose intentions* and *what consequences* are prioritized.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare. The authors are both part of the Genetic Biocontrol of Invasive Rodents (GBIRd) described in this article.

AUTHOR CONTRIBUTIONS

Katie Barnhill-Dilling and Jason Delborne equally conceptualized this study. Katie Barnhill-Dilling developed and refined the framework and conducted the literature review. Jason Delborne contributed to the literature review and significantly edited each draft of the manuscript.

DATA AVAILABILITY STATEMENT

N/A.

ETHICS STATEMENT

The authors complied with Institutional Review Board review and Human Subjects research approval where relevant.

ORCID

S. Kathleen Barnhill-Dilling https://orcid.org/0000-0003-3442-738X

REFERENCES

Australian Academy of Science. (2017). Synthetic gene drives in Australia: implications of emerging technologies. Australian Academy of Science. https://www.science.org.au/support/analysis/reports/synthetic-gene-drives-australia-implications-emerging-technologies.

Barnhill-Dilling, S. K., & Delborne, J. A. (2019). The genetically engineered American chestnut tree as opportunity for reciprocal restoration in Haudenosaunee communities. *Biological Conservation*, *232*, 1–7.

Barnhill-Dilling, S. K., Rivers, L., & Delborne, J. A. (2020). Rooted in recognition: Indigenous environmental justice and the genetically engineered American chestnut tree. *Society & Natural Resources*, *33*, 83–100.

Brister, E., Holbrook, J. B., & Palmer, M. J. (2021). Conservation science and the ethos of restraint. *Conservation Science and Practice*, e381.

Brown, K.V. (2016, September 19). Genetically engineered mosquitoes could wipe out the world's most deadly viruses. If we let them. *Splinter News*. Retrieved from https://splinternews.com/genetically-modified-mosquitoes-could-wipe-out-the-worl-1793862023

Brunk, C. G. (2006). Public knowledge, public trust: Understanding the knowledge deficit. *Community Genetics*, *9*, 178–183.

Burget, M., Bardone, E., & Pedaste, M. (2017). Definitions and conceptual dimensions of responsible research and innovation: A literature review. *Science and Engineering Ethics*, *23*, 1–19.

Burgiel, S. S., Baumgartner, B., Brister, E., Fisher, J., Gordon, D. R., Seddon, P. J., & Weber, M. (2021). Exploring the intersections of governance, constituencies, and risk in genetic interventions. *Conservation Science and Practice*, e380.

Campbell, K. J., Saah, R. J., Brown, P. R., Godwin, J., Howald, G. R., Piaggio, A., Thomas, P., Tompkins, D. M., Threadgill, D., Delborne, J., Kanavy, D., Kuiken, T., Packard, H., Serr, M., & Shiels, A. (2019). A potential new tool for the toolbox: assessing gene drives for eradicating invasive rodent populations. *USDA National Wildlife Research Center – Staff Publications*. https://digitalcommons.unl.edu/icwdm_usdanwrc/2235/.

Correljé, A., Cuppen, E., Dignum, M., Pesch, U., & Taebi, B. (2015). Responsible innovation in energy projects: Values in the design of technologies, institutions and stakeholder interactions. In *Responsible innovation* (Vol. 2, pp. 183–200). Switzerland: Springer International Publishing.

Delborne, J.A., Binder, A.R., Rivers, L., Barnes, J.C., Barnhill-Dilling, S.K., George, D., Kokotovich, A., and J. Sudweeks. 2018. Biotechnology, the American chestnut tree, and public engagement. *Genetic engineering and society center, North Carolina State University*. Raleigh, NC. Retrieved from http://go.ncsu.edu/ges-chestnut-report

Farooque, M., Barnhill-Dilling, S.K., Shapiro, J., & Delborne, J. (2019). "Exploring Stakeholder Perspectives on the Development of a Gene Drive Mouse for Biodiversity Protection on Islands" Workshop Report. Genetic Engineering and Society Center, North Carolina State University. Raleigh, NC. Retrieved from http://go.ncsu.edu/ges-gene-drive-workshop

Foley, R. W., Bernstein, M. J., & Wiek, A. (2016). Towards an alignment of activities, aspirations and stakeholders for responsible innovation. *Journal of Responsible Innovation*, *3*, 209–232.

Francis, A. (2015). Akwesasne moves to ban genetically modified food. *Aboriginal Peoples Television Network*. Retrieved from http://aptn.ca/news/2015/06/29/akwesasne-moves-ban-genetically-modified-food/

Frewer, L. J., & Shepherd, R. (1995). Ethical concerns and risk perceptions associated with different applications of genetic engineering: Interrelationships with the perceived need for regulation of the technology. *Agriculture and Human Values*, *12*, 48–57.

Godwin, J., Serr, M., Barnhill-Dilling, S. K., Blondel, D. V., Brown, P. R., Campbell, K., Delborne, J., Lloyd, A. L., Oh, K. P., Prowse, T. A. A., Saah, R., Thomas, P. (2019). Rodent gene drives for conservation: opportunities and data needs. *Proceedings of the Royal Society B: Biological Sciences*, *286*, 20191606. https://doi.org/10.1098/rspb.2019.1606.

Guston, D. H., Fisher, E., Grunwald, A., Owen, R., Swierstra, T., & van der Burg, S. (2014). Responsible innovation: Motivations for a new journal. *Journal of Responsible Innovation*, *1*, 1–8. http://doi.org/10.1080/23299460.2014.885175

Hayes, K. R., Hosack, G. R., Dana, G. V., Foster, S. D., Ford, J. H., Thresher, R., … Dambacher, J. M. (2018). Identifying and detecting potentially adverse ecological outcomes associated with the release of gene-drive modified organisms. *Journal of Responsible Innovation*, *5*(sup1), S139–S158. https://doi.org/10.1080/23299460.2017.1415585

Indigenous Environmental Network. (n.d.) Indigenous peoples unite to stop genetically engineered trees: GE trees: another form of colonization. Retrieved from http://www.ienearth.org/indigenous-peoples-unite-to-stop-genetically-engineered-trees/

IPBES (2019). In E. S. Brondizio, J. Settele, S. Díaz, & H. T. Ngo (Eds.), *Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services*. Bonn, Germany: IPBES secretariat.

Krzywoszynska, A., Matt, W., Buckley, A., Chiles, P., Gregson, N., Holmes, H., & Mawyin, J. (2018). Opening up the participation laboratory: The cocreation of publics and futures in upstream participation. *Science, Technology, & Human Values*, *43*, 785–809.

Kuzma, J. (2019). Procedurally robust risk assessment framework for novel genetically engineered organisms and gene drives. *Regulation & Governance*. https://doi.org/10.1111/rego.12245

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Leitschuh, C. M., Kanavy, D., Backus, G. A., Valdez, R. X., Serr, M., Pitts, E. A., Threadgill, D., Godwin, J. (2018). Developing gene drive technologies to eradicate invasive rodents from islands. *Journal of Responsible Innovation*, *5*(sup1), S121–S138. https://doi.org/10.1080/23299460.2017.1365232.

Losiah, J. (2020, October *12*). Mann seeks EBCI's help in American Chestnut Tree preservation. *The Cherokee One Feather*. Retrieved from https://www.theonefeather.com/2020/10/mann-seeks-ebcis-help-in-american-chestnut-tree-preservation/

Macnaghten, P., Owen, R., Stilgoe, J., Wynne, B., Azevedo, A., de Campos, A., … Garvey, B. (2014). Responsible innovation across borders: Tensions, paradoxes and possibilities. *Journal of Responsible Innovation*, *1*, 191–199.

Martin, A., McGuire, S., & Sullivan, S. (2013). Global environmental justice and biodiversity conservation. *The Geographical Journal*, *179*, 122–131.

National Academies of Sciences, Engineering, and Medicine (NASEM). (2016). *Gene drives on the horizon: Advancing science, Navigating Uncertainty, and Aligning Research with Public Values*. Washington, DC: National Academies Press. https://doi.org/10.17226/25221

National Academies of Sciences, Engineering, and Medicine (NASEM). (2019). *Forest Health and Biotechnology: Possibilities and considerations*. Washington, DC: National Academies Press. https://doi.org/10.17226/25221

Nelson, R. H. (2003). Environmental colonialism:" saving" Africa from Africans. *The Independent Review*, *8*, 65–86.

Newhouse, A. E., & Powell, W. A. (2020). Intentional introgression of a blight tolerance transgene to rescue the remnant population of American chestnut. *Conservation Science and Practice*, e348.

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy*, *39*, 751–760.

Owen, R., & Pansera, M. (2019). Responsible innovation and responsible research and innovation. In *Handbook on science and public policy*. Edward Elgar.

Phelan, R., Karieva, P., Marvier, M., Robbins, P., & Weber, M. 2021 Introduction to this special issue.

Piaggio, A. J., Segelbacher, G., Seddon, P. J., Alphey, L., Bennett, E. L., Carlson, R. H., … Rosales, M. (2017). Is it time for synthetic biodiversity conservation? *Trends in Ecology & Evolution*, *32*, 97–107.

Popkin, G. (2020, April 30). Can genetic engineering bring back the American chestnut? *New York Times*. Retrieved from https://www.nytimes.com/2020/04/30/magazine/american-chestnut.html

Powell, W. (2016). New genetically engineered American chestnut will help restore the decimated, iconic tree. *The Conversation*. Retrieved from http://theconversation.com/new-genetically-engineered-american-chestnut-will-help-restore-the-decimated-iconic-tree-52191

Redford, K. H., Brooks, T. M., Macfarlane, N. B. W., & Adams, J. S. (Eds.). (2019). *Genetic frontiers for conservation: An assessment of synthetic biology and biodiversity conservation*. Switzerland: International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2019.05.en

Rosen, J. (2019, June 25). Should we resurrect the American chestnut tree with genetic engineering? *Los Angeles Times*. Retrieved from https://www.latimes.com/science/sciencenow/la-sci-genetically-modified-trees-american-chestnut-20190625-htmlstory.html

Salmon, R. A., Priestley, R. K., & Goven, J. (2017). The reflexive scientist: An approach to transforming public engagement. *Journal of Environmental Studies and Sciences*, *7*, 53–68.

Sandler, R. (2019). Should we engineer species in order to save them? *Environmental Ethics*, *41*, 221–226.

Sherbin, L., & Rashid, R. (2017). Diversity doesn't stick without inclusion. *Harvard Business Review*, *1*, 1–5.

Smolker, R. & A. Petermann (2019). Biotechnology for forest health? The test case of the genetically engineered American chestnut tree. Retrieved from https://stopgetrees.org/wp-content/uploads/2019/04/biotechnology-for-forest-health-test-case-american-chestnut-report-WEB-1.pdf

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy*, *42*, 1568–1580.

Stirling, A., Hayes, K. R., & Delborne, J. (2018). Towards inclusive social appraisal: Risk, participation and democracy in governance of synthetic biology. *BMC Proceedings*, *12*, 15.

Sturgis, P., & Allum, N. (2004). Science in society: Re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, *13*, 55–74.

Taitingfong. (2019). Islands as laboratories: Indigenous knowledge and gene drives in the Pacific. *Human Biology*, *91*, 179.

Thompson, E. (2019). Chestnut champions quit to protest genetic engineering. Worcester, MA: Worcester Telegram. https://www.telegram.com/news/20190328/chestnut-champions-quit-to-protest-genetic-engineering.

Valkenburg, G. (2020). Consensus or contestation: Reflections on governance of innovation in a context of heterogeneous knowledges. *Science, Technology and Society*, *25*, 341–356.

Von Schomberg, R. (2013). A vision of responsible research and innovation. *Responsible innovation: Managing the responsible emergence of science and innovation in society*, 51–74. Hoboken, NJ: Wiley.

Wilsdon, J., & Willis, R. (2004). *See-through science: Why public engagement needs to move upstream*. New York, NY: Demos.

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