

Into the Unknown: Framing Uncertainty and Risk in News Media Portrayal of Gene Drive Technology

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Abstract: This study examines media representations of gene drive technology between January 1, 2015 and December 31, 2016, focusing on its potential impacts on human health and the environment, ethical and policy considerations, and the overall tone towards the technology. The content analysis of news stories indicates that media coverage was mostly balanced in tone, rather than driven by unwarranted optimism or negative sensationalism – two extremes that often pervade media portrayals of emerging genetic technologies. There was nonetheless a considerable emphasis in the news on scientific uncertainty and heightened risk perceptions, with scientists being the strongest voice in providing authoritative statements about CRISPR-Cas9 gene drives as a high-risk technology. Taking into account the novelty of gene drive research, we suggest that media framing of gene drives as “a plunge into the unknown” may have a lasting effect on public perceptions of risks and may pose additional challenges to the public communication of this emerging technology.

Keywords: media representations, gene drives, CRISPR-Cas9 gene editing, content analysis, framing, science communication

Introduction

Gene drives based on the CRISPR-Cas9 gene editing system are a novel and powerful genetic engineering method that defies the laws of Mendelian inheritance by allowing genetic dominance of specific traits and their spread at an enhanced rate in nearly 100% of the next generation (Oye et al., 2014). Many believe that the technology can offer substantial benefits to humanity and the environment, with a number of promising applications in biomedicine, agriculture, and for ecosystem preservation and protection. For instance, recent small-scale proof-of-concept models of gene drives in insects have demonstrated the ability to quickly suppress or modify disease-bearing mosquito populations, thus raising hopes for global efforts to eliminate and eradicate vector-borne diseases such as malaria, dengue, yellow fever, chikungunya, and Zika (Hammond et al., 2016; Gantz et al., 2015; Beaghton et al., 2017; Eckhoff, Wenger, Godfray, & Burt, 2017). CRISPR-based gene drives can provide solutions for sustainable agriculture such as the reversal of pesticide and herbicide resistance and more efficient pest control to help increase crop productivity (Courtier-Orgogozo, Morizot & Boete, 2017). Additionally, altering entire wild populations through gene drives has promising applications in bio-conservation and for the eradication of invasive species that undermine global biodiversity (Esvelt, Smidler, Catteruccia, & Church 2014, Harvey-Samuel, Ant, & Alphey 2017).

Nonetheless, the rapidly progressing field of gene drive research has generated heated ethical and policy debates, especially after successful experiments with gene drives in yeast, fruit flies, and mosquitoes were reported in late 2015 and early 2016 (DiCarlo et al., 2015; Gantz & Bier, 2015; Hammond et al., 2016). Most concerns revolve around uncertainties regarding the environment impacts of gene drive technology and potential harms to the wellbeing of humans, which are difficult to forecast given the current state of knowledge in this emerging field. While many prospective applications of gene drive research are currently being explored in laboratory

settings, field tests or releases of organisms engineered through this technology into the open environment have not yet taken place. This complicates both risk assessments and decision-making processes, especially the development of appropriate safeguards and efficient mitigation strategies in cases of unconfined release of organisms with CRISPR-based gene drives (Hayes et al., 2018). Another problem that further obfuscates decision-making on the development and use of gene drives is existing gaps in the current regulatory landscape. Gene drives have been consistently viewed and handled as technical, policy and political anomalies in the policy arena, and there is an ongoing debate on what fundamental changes in the regulatory frameworks for biotechnology will be required to address this problem (Evans & Palmer, 2017). Despite scientific uncertainty about risks and the current regulatory vacuum, proponents of gene drive research have pushed for fast deployment of gene drives invoking public health and humanitarian reasons (Koberstein, 2017). Global philanthropic organizations, such as the Bill and Melinda Gates Foundation (BMGF) and the Tata Trusts of Mumbai, have invested heavily in gene drive research to put an end to malaria, a mosquito-borne disease which caused an estimated 445,000 deaths worldwide in 2016 (WHO, 2017). The Gates Foundation has provided \$75 million to Target Malaria, an international not-for-profit multi-disciplinary consortium based at the Imperial College in London, which is planning an open release of gene-drive modified *Anopheles gambiae* mosquitoes, the main malaria vector in Africa, in Burkina Faso (Regalado, 2016). This is the largest investment in gene drive research so far and, if implemented, the project would be the first field test of gene drive technology. In a media interview in 2016, Bill Gates made a rather optimistic prognosis that gene drive technology would be available for wide use in just two years (Regalado, 2016).

In 2016, in response to a request by the U.S. National Institutes of Health (NIH) and the Foundation for the National Institutes of Health (FNIH), the National Academies of Sciences,

Engineering, and Medicine (NASEM) convened a special committee of experts to consider the benefits and risks associated with gene drives and develop recommendations for responsible governance of the technology. The NASEM report, titled *Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values*, was released in July 2016. While acknowledging the enormous potential of gene drive research, the Committee concluded that our present state of knowledge does not warrant the release of gene-drive modified organisms into the environment and emphasized the need for a comprehensive assessment of potential irreversible harms to organisms and ecosystems from gene drives (National Academies of Sciences, Engineering, and Medicine (NASEM), 2016). It further recommended the adoption of a precautionary, step-by-step approach including phased testing, greater engagement of stakeholders and publics, and strict regulatory oversight of field trials (NASEM, 2016).

Searches for news reports on gene drive research prior to 2015, which we conducted on different databases, did not yield results, thus indicating that early scientific developments in the field did not attract media and public attention. Media coverage, however, has dramatically increased since the reported success of proof-of-concept studies with gene-drive modified organisms and the release of the NASEM report in July 2016. The current media hype surrounding CRISPR-Cas9 based gene drives and their prospective applications has not been previously studied. This study is the first attempt to explore, in a systematic way, the media discourse on the issue, particularly how scientific uncertainty, ethical and policy concerns, and potential benefits and risks associated with gene drive applications have been represented. It is important to engage in such an analysis since media representations may potentially influence both public perceptions and the ongoing policy dialogue on this emerging technology. We explored representations of gene drive technology in 145 news reports published in English-

language media sources around the world from January 1, 2015 to December 31, 2016 - a period when the issue became salient in the popular press. Content analysis was deployed to determine frequencies and major themes in media coverage, focusing on ethical concerns, perceptions of benefits and risks associated with different applications, and policy and practical considerations for implementation.

It is important to note that both media coverage and public debates on CRISPR-Cas9 technology, which makes possible the engineering of gene drive systems, have largely revolved around its use for genome editing of human embryos and potential therapeutic applications (e.g., gene therapy). While the topic of genome editing in humans is worthy of consideration and relevant to our study, it technically does not fall under the category of gene drive research, which currently focuses exclusively on non-human organisms. Although there were a few mentions in news reports of a hypothetical future use of CRISPR-Cas9 gene drive systems in humans, this line of research is not currently pursued due to our limited knowledge on how such systems would work in more complex species and the extended time needed to spread genetic modification in human populations.

Gene drive technology has incited intense interest from governments, philanthropists, and global health organizations, and efforts are under way to deploy gene drive-modified mosquitoes in open field trials to eradicate malaria in Africa (Dunning, 2017). There is nonetheless a fierce opposition to efforts for genetic modification of species in the environment. Environmental advocacy groups and some governments have pushed for a global moratorium on both gene drive research and its applications, warning against deliberate extinctions of wild populations and potential severe impacts on ecosystems (Gallaway, 2016). This proposal was rejected by world governments at the 13th Meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD) in Cancun, Mexico in December 2016, however, the use of

genetically engineered gene drives remains a highly contested technological innovation. We still have limited knowledge of how the release of gene-drive modified mosquitoes or invasive pests may affect non-targeted animal populations and ecosystems, and decision-making is largely informed by theoretical constructs and hypothetical models. A recent study by Noble et al. (2017) has suggested that it may be difficult to contain the spread of gene drives to the targeted population of a certain species. This new theoretical model directly contradicts previous claims that CRISPR-based gene drives are unlikely to invade wild populations (e.g. subspecies of the same species) due to drive-resistant alleles. It further questions conclusions on the safety of field testing in the NASEM Report. Some experts, however, disagree with the assertion of that field trials with gene-drive modified mosquitoes pose unacceptable risks for ecosystems and argue that risks assessments should be made on a case-by-case basis (Koberstein, 2017). Given the existing conditions of scientific uncertainty and conflicting opinions on the benefits and drawbacks of gene drive research, it is important to scrutinize how news media have framed the underlying issues for public and policy debate.

Media framing of controversial science

Past research in science communication has shown that news media play an active role in shaping the public understanding of scientific controversies by giving legitimacy to certain opinions and perspectives and selectively presenting information to their audiences (Mazur, 1981). People routinely use media sources and rely on media professionals for information and interpretation on critical issues concerning innovation in science and technology, especially when they attempt to understand new and controversial science in ways that relate to their own lives and needs (Friedman, Dunwoody, & Rogers, 1999). Moreover, news media have been instrumental in framing risk and uncertainty associated with science and technology innovation

and have frequently influenced the public understanding of scientific debates by providing legitimacy to knowledge claims, social values, ethical concerns, and political interests (Pellechia 1997; Weingart 1998).

Although the notion about media messages having direct impact on beliefs and behavior (the so-called “media effects model”) has been discredited in the past (Gauntlett, 1999, 2005), two interrelated processes in news media production - “framing” and “agenda-setting” provide an analytical framework to assess how media content can potentially influence audiences and public discourse of specific issues. The concept of framing describes the process of selective presentation in news coverage of specific topics, facts, controversies, actors, and assertions in news stories (Entman, 1993; Scheufele, 1999). To frame an issue, according to Entman (1993), “is to select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation” (p. 52). Media outlets routinely deploy frames in news reporting to call attention to some aspects of reality while obscuring other elements. Framing can have a lasting influence, and once news reports have framed an issue in a particular light, public perceptions remain stable over time (Entman, 1993; Nisbet, Brossard, & Kroepsch, 2003). Additionally, dramatic narratives and emotive language are frequently used in news production to attract interest and help media organizations increase their audience share. Similarly, scientific news reports utilize intriguing narratives, striking images, metaphors, and emotive language to make the information exciting, relevant and comprehensible for lay audiences and to provide specific contexts for understanding that often limit the range of interpretations on complex topics (Friedman et al., 1999; Nisbet et al., 2003).

While media framing theory emphasizes how “frames” as rhetorical and organizing structures influence people to process information and construct meanings in shared contexts, the

related agenda-setting tradition provides additional insight into how media can make people focus their attention on some topics, while overlooking others. The major tenet of this perspective is that even though media cannot make people think or behave in a certain way, they can still have a profound impact on what people think about by highlighting certain issues and excluding others from coverage (McCombs & Shaw, 1972). Mass media, therefore, can play a considerable role in the processes of public opinion formation and policy making through their ability to increase the salience of certain issues on the public agenda. Previous studies of media representations of genetic engineering, particularly its medical applications, have shown that news coverage had been largely unbalanced, focusing either on negative consequences of genetic advances (e.g., insurance or employment discrimination and the possibility of human genetic modification), or exaggerating the potential of genetic technologies for medicine and the health benefits of genetic testing - a phenomenon described as “genohype” (Geller, Bernhardt, & Holtzman, 2002; Caulfield, 2004; Bubela & Caulfield, 2004; Kamenova, Reshef, & Caulfield, 2013). Longitudinal studies have also established that media have tended to portray medical biotechnologies in a positive light by emphasizing their benefits, while exhibiting a negative bias towards agricultural applications, which have been framed in terms of risk and uncertainty (Marks et al., 2007).

In light of the existing media hype in reporting new developments in genetic engineering and genomics, our analysis has a two-fold objective. First, we aim to establish major themes and issues concerning the deployment of gene drives that were highlighted in the news stories and whether the technology was generally represented in a positive, negative, neutral or balanced light. Second, it is important to shed light on how news media have framed scientific uncertainty and risks inherent in emerging applications of gene drives, as this portrayal may have an impact

on people's perceptions and their willingness to support the release of gene drive-modified organisms in the environment.

Methods

We used the database Factiva, which provides an extensive archive of news and business information, including access to 1000 newspapers published internationally. We collected news articles about gene drive technology published from January 1, 2015 to December 31, 2016. The term "gene drive" was used as a main keyword, and at least one of the following additional keywords were applied: "genetically modified mosquitoes," "malaria," "Zika," "dengue," and "chikungunya." The search generated 497 entries: 55 web news (including 14 duplicates) and 442 print articles (including 169 duplicates). A broad range of news sources were searched such as print and online editions of major newspapers, online newsletters, popular magazines, online news, and radio and TV broadcast transcripts. We excluded duplicates and sorted out the remaining news stories for relevance.

Articles were considered relevant if their central theme was CRISPR-Cas9 based gene drives or, alternatively, if there were substantive discussions about the technology and its impacts such as scientific aspects, ethical and policy issues, environmental impacts, public perceptions and engagement, regulatory oversight, public health considerations, related scientific developments, economic considerations, or social factors that can influence adoption. We excluded the following types of articles: 1) news stories that contained only passing mentions of gene drives and no further discussions on the topic; 2) business or industry-related news that did not address ethics, policy or broader societal implications; and 3) abstracts of scientific studies. The final dataset comprised 145 articles published in diverse media sources (Figure 1). The geographic spread of media coverage on the topic included 18 countries (Table 1).

[Insert Figure 1 here]

[Insert Table 1 here]

Coding categories for content analysis were developed through an inductive-deductive process. This involved, as a first step, a close reading of the entire dataset to inductively derive recurrent themes and determine if there were emerging issue-specific frames, particularly around the ethics of gene drives. The next step was to organize them in structured codes and develop a coding book. The coding categories included: 1) frequencies of coverage by country; 2) the central theme of each news story; 3) attributes of CRISPR-based gene drive systems, particularly scope of application, safety, and readiness to be deployed in field trials (e.g., contained or open release of vector mosquitoes with a gene drive system); 4) ethical concerns about the technology; 5) public health benefits and risks; 6) environmental benefits and risks; 7) policy and practical considerations; 8) the overall tone of the article; and 9) the use of sensational language. After coding the media content, statistical analysis using SPSS statistical software was performed to establish frequencies for each category.

We further integrated a deductive approach to frame analysis to place the results in the context of past research on media portrayal of science and technology. We applied a *generalizable typology of frames* in science communication and science policy debates, which was initially developed by Gamson and Modigliani (1989) in their analysis of media discourse and public opinion on nuclear power and subsequently refined in studies of debates over climate change, food and medical biotechnologies (Durant, Bauer, & Gaskell, 1998; Nisbet & Lewenstein, 2002; Nisbet, 2010). This analytical framework has established eight generic frames or cultural schemata that had served as organizing rhetorical devices in media coverage and policy debates on controversial developments in science and technology: 1) social progress; 2)

economic development/competitiveness; 3) morality/ethics; 4) scientific/technical uncertainty; 5) Pandora's box/Frankenstein's monster/runaway science; 6) public accountability/governance; 7) midway/alternative path; and 8) conflict/strategy. The typology of frames in science communication provides an analytical tool to identify the leading general frame(s) in media portrayal of gene drive technology, in addition to emerging issue-specific frames that we inductively derived from the news stories. We present our assessment of how media coverage of gene drive technology can be situated within this general typology of frames in the concluding section.

In order to establish the level of agreement on qualitative codes used in this study, we conducted an inter-coder reliability assessment using Cohen's kappa (κ). We asked an independent researcher to code 10 percent of the news reports in our data set ($n = 15$) and calculated κ scores using SPSS. The majority of κ scores indicated *substantial* or *almost perfect* inter-rater agreement, based on Landis and Koch's (1977) benchmark standards for interpreting kappa. Since the level of agreement on a few of the coding categories was *moderate* or *fair*, the two coders (the first and the second authors) revisited the dataset and resolved disagreements by consensus.

[Insert Table 2 here]

Results

How CRISPR-Cas9 based gene drives were represented in the news

Potential applications

News reports identified the following promising applications of gene drive technology: 1) to combat vector-borne diseases such as malaria, dengue, yellow fever, chikungunya, and Zika

(97%); 2) to eliminate invasive species (30%); 3) to increase agricultural productivity (29%); 4) to support bioconservation projects (17%); and 5) for human genetic modification and enhancement (7%). A small number of articles (17%) highlighted other potential uses, including deployment for bioterrorism; the engineering of algae as a source of biofuel; as a potential solution to mitigate the consequences of climate change; applications in industrial farming and food industry; for the development of genetically engineered bacteria that can eat oil spills; for “reverse engineering” of extinct species (e.g., to bring back extinct species such as the woolly mammoth and passenger pigeon); as a method that can allow to target human cells that carry mutated genes, such as cancer cells and HIV; as well as general statements about potential to fight human diseases without mentioning specific conditions.

Safety and readiness of the technology

The majority of news stories (75%) presented gene drives as a high-risk technology, noting likelihood of unforeseen or unintended consequences for human health and the environment.

[Insert Figure 2 here]

More than half of the reports (51%) cited different experts on the high level of risks, including scientists (28%), representatives of environmental and genetic watchdog organizations (7%), policy and ethics experts (6%), government representatives (3%), journalists (3%), industry representatives (1%), philanthropists (1%), and others (1%). Overall, gene drives using CRISPR-Cas9 gene editing were portrayed as a technology that is still in an experimental phase and far from ready for deployment in field trials (97%).

Central themes

The use of gene drive technology to combat vector-borne diseases was the leading theme of 32%

of the news stories. The second most frequently occurring central theme was the reporting of important scientific meetings or policy forums on gene drives (12%). Most articles in this category focused on the NASEM Report or the UN Convention on Biological Diversity COP-13 Meeting in Cancun, Mexico in December 2016. Other major themes included: general discussions of gene drive technology and its potential applications (10%); gene editing using CRISPR-Cas9 (10%); the biosafety of gene drives, including potential for bioterrorism (8%); the use of gene drives for bioconservation (5%); broad discussions about the latest developments in science and technology (5%); the ethics of gene drives (2%); the Zika crisis (2%); and the UK company Oxitec and its work on GM mosquitoes (2%). There were also single news stories on miscellaneous topics that included substantive discussions of gene drive technology (12%).

Ethical concerns

Ethical issues were addressed in 46% of the articles, with the most prominent critique being that environmental release of gene-drive modified organisms could lead to unanticipated public health and environmental harms (28%). The argument that the deployment of gene drive technology is unethical because nature has intrinsic value and it is immoral to undermine the balance of the natural world was presented in 18% of the articles. Additionally, 17% objected to the use of gene drives, citing “sanctity of life” or “playing God” arguments. These critiques expressed concerns about the hubris of scientists tampering with nature and creating new life forms, which often echoed themes from Merry Shelley’s classic novel *Frankenstein* (1818). Finally, there were principled objections in another 3% based on a “slippery slope” reasoning (e.g., that deployment of gene drives could lead to the normalization of other questionable applications of CRISPRCas9 gene editing).

Policy and practical considerations

The majority of news reports (80%) mentioned policy and practical issues concerning the deployment of gene drives. The most pressing concerns identified by the media fall into the following categories: 1) development of regulatory frameworks (43%); 2) how to ensure biosafety (40%); 3) the need for public engagement and building public trust (40%); 4) to mandate ethics review (15%); and 5) to address potential health risks for human populations (6%). Additional, more specific considerations coded as “other” were discussed in 31% of the articles. These included: the need for international safeguards to ensure biosafety in labs; greater transparency and more funding for research on potential risks; concerns about commercial pressures to deregulate gene-editing techniques; that effects on the specific species and their ecosystems need to be carefully examined and monitored; that instructions for making gene drives should be classified; that a broader moral consensus on genetic modification is needed before implementing gene drive technology; that news media have failed to educate the public about the risks of genetic technologies; and the need to build long-term relationships with scientists in low and middle-income countries.

Benefits and risks

The potential public health benefits of CRISPR-Cas9 gene drives were widely discussed (90% of the articles), with a focus on the potential to prevent the spread of malaria (81%), dengue (28%), Zika (29%), Lyme disease (11%), and eradicate parasitic flatworms that cause Schistosomiasis (3%). By contrast, health risks to humans were discussed in only 31% of the articles. These included: 1) potential harms from deliberate misuse of gene drive research for bioterrorism (19%); 2) harms from unintended effects of gene drive interventions on the environment (6%); 3) potential to increase the population of another insect disease vector, if an entire mosquito species

was removed from the ecosystem (4%); 4) health risks related to accidental release of gene drive-modified organisms from labs (2%).

Benefits to the environment were mentioned in 40% of the news. The following benefits were mentioned: 1) use of gene drives to control invasive species (21%); 2) engineering beneficial traits in threatened species (10%); 3) preventing mosquitoes from transmitting avian malaria (9%); 4) control of nonindigenous rodents (9%); and 5) various other benefits (15%), including the potential to eliminate the use of insecticides, reverse negative impacts from past human activities on ecosystems, produce genetically-engineered bacteria to eat oil spills, develop new ways to interact with nature, using biology rather than bulldozers and toxins, and remove genetic defenses that allow some weeds to resist herbicides.

Potential harms to the environment were discussed in 60% of the articles, with the major issue being unintended and unwanted changes in ecosystems that may result from the release of gene drive modified organisms (48%). There were also concerns about adverse effects on highly valued species that depend on mosquito populations (11%) and the possibility of destabilizing the entire ecological system (10%). Other concerns (13%) were as follows: fears about cross-breeding of GM mosquitos; that GM larvae will damage and contaminate the crop, making it unfit for human consumption; that a pathogen would adapt and becomes endemic in a different species; that suppression of undesirable organisms may lead to the emergence of others that are worse; that another harmful species might take the place of mosquitoes; that altered genes might escape into another species; and that gene drives may cause extinctions.

Overall tone of news coverage

Our analysis showed that the overall tone towards gene drive technology was mostly favourable,

with 38% of the articles presenting a balanced perspective, 26% were neutral/descriptive in nature, 24% were positive and only 12% presented a negative perspective. The articles were assessed as “balanced” if both benefits and risks arising from potential uses of gene drive technology were accurately presented and discussions were substantive (e.g., supported with investigative evidence, references to scholarly perspectives, and expert opinion). By contrast, the category of “neutral/descriptive” was used to categorize news stories that reported on gene drives in a descriptive manner, without presenting more substantive arguments, and did not include evaluative claims about the nature and impact of the technology.

[Insert Figure 3 here]

Sensationalism in reporting

Additionally, 25% of the news stories in our dataset used sensational language to describe gene drive technology. Most sensational headlines and emotive language used to describe gene drives had strong negative connotations as shown in Table 3. Gene drive research in these articles was frequently characterized as a “genetic Pandora’s box,” “hubris,” “scientists playing God,” “moral blackmail,” “mass insecticide,” “next weapon of mass destruction,” “terrorist bio-weapon,” “gene bomb,” “turbocharged version of genetic engineering,” “weaponizing insects,” “radical approach,” “genetic tinkering,” “silver bullet,” etc. The press used similar negative descriptors for gene drive-modified mosquitoes that show potential to eliminate vector-borne diseases, e.g. “mutant mosquitoes,” “biotech bugs,” “newest weapons,” “monster mosquitoes,” “scary,” “Frankenmosquitoes,” “Frankenbugs,” “something out of a horror film,” etc. There were fewer cases of unwarranted optimism and positive hype around the benefits of gene drive technology, as exemplified by phrases such as “promise to revolutionize medicine” and “immense potential.”

[Insert Table 3 here]

Discussion

Media framing of gene drive technology

Our content analysis has shown that media portrayal of gene drives was favorable, with only 12% of the news reports using an entirely negative tone. It further suggests that media representations have tended to be balanced and nuanced, rather than driven by unwarranted optimism about the promise of this emerging technology or entirely by negative sensationalism that can instill fear about it. The enormous potential of gene drives for prevention, elimination and eradication of vector-borne diseases, with an emphasis on malaria, clearly dominated media coverage, yet there were fewer claims exaggerating the technology's readiness for deployment in field trials. The balanced reporting on gene drives stands in stark contrast to the media's general tendency of hyping the potential of emerging technologies in biomedicine as shown in previous studies of media representations of stem cell therapies (Kamenova & Caulfield, 2015; Benjaminy, Lo, & Illes, 2016), genetic testing (Caulfield, 2004; Bubela & Caulfield, 2004) and, most recently, cell-free fetal DNA and non-invasive prenatal diagnosis (Kamenova et al., 2016).

Nonetheless, gene drives were portrayed as a high-risk technology, with a potential for unintended and unforeseen effects on human populations and the environment. There was a considerable emphasis in the news stories on scientific uncertainty, difficulty in forecasting risks, and warnings about premature deployment. More than half of the news reports used expert opinion from different fields in support of heightened risk perceptions. Scientists were the strongest voice, providing authoritative statements about gene drives as a high-risk technology in 55% of all articles that included expert opinion. Interestingly, even critiques of the ethics of gene drive research featured in the news stories have revolved more around scientific uncertainty and

concerns about potential catastrophic consequences for the environment, rather than the morality of genetic modification and tampering with nature in principle.

Furthermore, our analysis has shown a discrepancy in how media presented benefits and risks regarding potential impacts of gene drives on public health and the environment. While public health benefits were mentioned in 90% of the articles, only 31% discussed potential health risks, with the major concern being harms from deliberate misuse of gene drive research (e.g., bioterrorism), rather than resultant human harms from unintended consequences (only 6%). By contrast, discussions about impacts on the environment have tended to emphasize risks over benefits (60%), with most articles in this category warning about unintended consequences to ecosystems, including the potential to destabilize the entire ecosystem (58%). Unlike the focus on anticipated public health benefits, only 40% of the news stories mentioned potential environmental benefits from gene drive systems for bioconservation, control of invasive species, and de-extinction. The greater emphasis on potential benefits over risks in discussions of gene drive applications addressing public health challenges such as vector-borne diseases is consistent with the overall positive media bias towards medical applications of genomics and other biotechnologies vis-à-vis agricultural and environmental applications, established by previous longitudinal studies (Marks et al, 2007).

After applying Gamson and Modigliani's generalizable typology of frames in science communication, we established that the "scientific/technical uncertainty" frame was the central rhetorical and organizing device in media discourse on gene drive technology. The news reports additionally deployed, albeit to a lesser extent, two other generic frames of "morality/ethics" and "Pandora's box/Frankenstein's monster/runaway science," which have traditionally dominated in media reporting on controversial genetic technologies. The overall media framing of gene drive technology in terms of scientific/technical uncertainty brings to the fore the importance of issues

such as establishing what is known versus unknown and whether there is an expert consensus on risks and benefits.

Media framing effects can have a lasting impact on public perceptions, as it is difficult to change the public's understanding of an issue once it has been framed in a certain way in the public domain. Taking into account the novelty of the technology, which has only recently come to the forefront of public attention, it may be suggested that the media framing of gene drives as “a plunge into the unknown” will likely influence public perceptions of risks. While there are complex factors at play in the formation of public opinion and the adoption of gene drive technology, its framing around scientific uncertainty in the media and public debates may further contribute to the already difficult environment for policy decisions on this issue.

The trope of scientific uncertainty has been routinely used in past and current debates on climate change by politicians and other groups to undermine expert consensus, create confusion and forestall action (Nisbet, 2010; Lewandowsky, Oreskes, Risbey, Newell, & Smithson, 2015). As organizing devices for arguments and interpretations, frames are valence neutral and it remains to be seen how references to scientific uncertainty and calls on the authority of “sound science” will play out in policy debates on gene drive technology. This is particularly relevant in the current context of strong public sentiments against GMOs, as illustrated by the wide opinion gap between experts and the public on the issue of the safety of GM foods demonstrated in the 2015 Pew Research Center's Report on Public and Scientists' Views on Science and Society (Funk & Raine, 2016). As our analysis has shown, concerns about biosafety and environmental risks appear prominent in media discourse on gene drives and can additionally reinforce such negative public attitudes towards genetic modification of species. While it may be tempting to draw a further comparison with the argumentative dynamics of climate change scepticism and intelligent design, concerns over the safety of gene drive research are real and hardly constitute a

“manufactured” scientific controversy - a notion proposed by Ceccarelli (2011) to designate cases in which deceptive arguments about science are used to undermine scientific consensus and manipulate policy outcomes.

Authors' contribution: K.K. designed the study, collected the materials, developed the coding frame, coded the articles, completed the statistical and qualitative analyses, wrote and edited the paper, and completed all revisions on the final manuscript. J.A. contributed to the development of the coding frame, coded the articles, and proofread the paper. C.E. commented on earlier drafts and proofread the paper.

Acknowledgements: The authors would like to thank Katelyn Cullen for research assistance. The authors were supported by Bill & Melinda Gates Foundation (BMGF). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

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Table 1: Country of origin of news articles in the analyzed data set

Country	Number (<i>n</i>)	Percentage
United States	76	52.4
United Kingdom	30	20.7
Canada	2	1.4
Australia	12	8.3
New Zealand	7	4.8
Ireland	1	.7
India	5	3.4
Sri Lanka	1	.7
Jordan	1	.7
South Korea	1	.7
Uganda	1	.7
Oman	1	.7
Qatar	1	.7
Pakistan	1	.7
Thailand	2	1.4
Singapore	1	.7
South Africa	1	.7
Japan	1	.7
Total	145	100.0

Table 2: Inter-coder agreement on coding categories*

Coding frame question	Cohen's κ	Number (n)
Were gene drives characterized as a high-risk technology, with potentially unforeseen consequences?	.842	15
What was the central focus/theme of the news story?	.834	15
Did the article claim gene drives were ready for field trials?	1.000	15
Did the article provide ethical arguments against gene drives?	1.000	15
What specific ethical objections were raised?	.828	15
Did the article include discussions of policy and practical issues?	.222	15
What specific policy and practical issues were discussed?	.278	15
Did the article mention public health benefits of gene drives?	1.000	15
What specific health benefits were discussed?	.484	15
Did the article mention public health risks from gene drives?	.700	15
What specific health risks were discussed?	.265	15
Did the article mention environmental benefits of gene drives?	.829	15
What specific environmental benefits were discussed?	.796	15

Did the article mention environmental harms from gene drives?	.700	15
What specific environmental harms were discussed?	.472	15
What was the overall tone of the article towards gene drives? (Positive/Negative/Neutral/Balanced)	.906	15
Was sensationalist language used to describe gene drives?	1.000	15

** The level of agreement between coders was interpreted based on the Landis & Koch Benchmark Scale (1977). This scale establishes the following as standards for strength of agreement denoted by κ : <0 = "poor," 0.01 to 0.20 = "slight," 0.21 to 0.40 = "fair," 0.41 to 0.60 = "moderate," 0.61 to 0.80 = "substantial," and 0.81 to 1 = "almost perfect."*

Table 3: Examples of negative media hype

Article	Sensational language
Genetic Engineering: Who Cleans up the Mess? <i>World Net Daily</i> , 26/11/2016	“Unintended consequences that could be catastrophic”; “potentially disastrous effects”
U.S. Military Preps for Gene Drives Run Amok <i>Scientific American</i> , 18/11/2016	“Gene drives gone wild”
The Perils of Planned Extinctions <i>The Jordan Times</i> , 2/11/2016	“A cynical move is underway to promote a new, powerful and troubling technology known as “gene drives”; “the idea that we can--and should--use human driven extinction to address human-caused extinction is appalling”; “game-changing bioweapons”; “technological silver bullets”
To Fight Malaria, Scientists Try Genetic Engineering to Wipe out Mosquitoes <i>National Public Radio</i> , 14/12/2016	“He shows me one of the gene drive mosquito larva magnified on a screen. It looks like something out of a horror film, like a huge radioactive worm.”
The Perils of Planned Extinctions <i>Korea Joongang Daily</i> , 12/09/2016	“A cynical move is underway to promote a new, powerful, and troubling technology known as gene-drive for conservation”; “a biological tool with unprecedented power”; “we recklessly throw in our lot with technological “silver bullets” as the way forward”
PLAYING GOD: Major Fears as Scientists Begin to Alter Genes and Affect Ecosystem <i>Express.co.uk</i> , 06/09/2016	“Scientists are at risk of playing God and could ruin the natural ecosystem.”
GM Insect Research Can Be a Lifesaver, and London Leads the Way	“Frankenbug”

London Evening Standard, 03/08/2016

Three Babies Born in US with Birth Defects Caused by Zika, Government Report Reveals

Daily Mail Online, 16/06/2016

“Genetic Pandora’s box”

A Fruit Fly or Two Is behind Most Scientific Breakthroughs

Waikato Times, 13/06/2016

“Last year, using gene drive, American scientists turned fruit flies into yellow mutants. Had any mutants escaped their lab they could potentially have turned every fruit fly in the world yellow.”

Could GM Mosquitoes Stop Zika? Scientists Warn Powerful Gene Editing Technique Could Cause More Harm Than Good”

Daily Mail Online, 10/06/2016

“Genetic Pandora’s box”

Bill Gates: Some People Think Eradicating Mosquitoes with Genetics Is Scary, But I Don't Think It Will Be

Forbes.com, 10/06/2015

“Next weapon of mass destruction”

The National Academies’ Gene Drive Study Has Ignored Important and Obvious Issues

The Guardian, 10/06/2016

“Gene bomb”

New Genetic Engineering Method Called Promising - and Perilous

National Public Radio, 08/06/2016

“Turbocharged version of genetic engineering, weaponizing insects”

A World without Mosquitoes

Smithsonian, 01/06/2016

“Mutant mosquito”

Tweaking Genes to Save Species

The New York Times, 17/04/2016

“Genetic tinkering”; “brought back from the brink”; “hubris to think”; “ecosystems are messy, murky and highly complex”; “silver-bullet”; “species circling the drain”

GM Insects and Moral Blackmail

The Guardian, 11/04/2016

“Moral blackmail”; “radical approach”, “hyped”,
“cheerleading”

Move over Ebola, here comes Zika!

Alive, 06/04/2016

“Biotech bugs”; “newest weapons”

Mass Insecticide Set to Halt Zika

Taranaki Daily News, 03/03/2016

“Nothing can make mosquitoes cuddly, whereas
healthy babies definitely are cuddly”

**Genetic Sex Change for Mosquitoes
Could Stop the Spread of Zika**

The Guardian, 17/02/2016

“Turn deadly, blood-drinking females into
harmless, nectar-sipping males”

**Should We Wipe Mosquitoes off the
Face of the Earth?**

The Guardian, 10/02/2016

“Blood suckers”, “no one ever had a cuddly
mosquito”, “game changer”

**Technology Bends Rules of Genetic
Inheritance**

Sunday Tribune, 07/02/2016

“Endowing genes with special equipment to foil
the rules of genetics may sound magical”

**Mosquitoes, This Time It's War; Zika
Is the Last Straw: Eradicate the
World's Deadliest Creature**

USA Today, 04/02/2016

“Scary”; “monster mosquitoes”;
“Frankenmosquitoes”

**Using Mutant Mosquitoes to Kill
Malaria Can Be Dangerous for
Humans**

Daily O, 16/12/2015

“Mutant mosquitoes”

**Modified Mosquitoes Can Halt
Malaria Spread**

Deccan Chronicle, 08/12/2015

“A team of researchers playing God”

Gene Drive Turns Mosquitoes into Malaria Fighters
Science, 27/11/2015

“Firestorm has erupted over the risks of experimenting with gene drives”

Improving on Mother Nature?
The Daily Herald, 25/11/2015

“California researchers hatched some malaria-resistant mosquitoes and then gave evolution a shove - using ground-breaking technology”;
“mutant mosquitoes kept in a secured lab”

A Mutant Mosquito That Could Wipeout Malaria
Guelph Mercury, 25/11/2015

“Mutant mosquito”

Malaria-Resistant Mosquitoes Have Scientists Abuzz
Toronto Star, 24/11/2015

“U.S. researchers hatched some malaria-resistant mosquitoes and then gave evolution a shove”; “the mutant mosquitoes kept in a secured lab”

Supercharged” Genes Could Wreak Havoc
The Canberra Times, 08/08/2015

“Supercharged” genetically modified organisms;
“could be used a terrorist bio-weapon”;
“technology is like a nuclear chain reaction”;
“promises to revolutionize medicine”

New Isis Weapon: Mozzies
The Daily Star, 05/08/2015

“TERRORISTS are planning to create killer mosquitoes to attack their enemies”; “the genetically modified creatures could be used by terror nuts to spread lethal diseases”; “If warped Islamic State militants get hold of the idea, it is feared they could use it as a terror tactic.”

Threat of Lethal Attacks
The Advertiser, 05/08/2015

“‘Supercharged’ genes in insects could be used by terrorists to cause an environmental disaster.”

GM Mosquitoes “Could Be Used by Terrorists”
Scottish Daily Mail 04/08/2015

“Supercharged” genes in insects could be used by terrorists to cause an environmental disaster, an unstoppable “nuclear chain reaction,” “gene drives carrying cargo for delivering lethal bacterial toxins to humans”

**Worry That “Super GM” Organisms
May Accidentally Escape**
Cape Times, 04/08/2015

“Supercharged” genetically modified organisms

**Could “supercharged genes” be used
by terrorists? Technique to genetically
modify insects could spread lethal
diseases**

Daily Mail Online, 03/08/2015

“the GM creatures could be used to spread lethal diseases”; “supercharged genes”

**Scientists Sound Alarm on
“Supercharged” GM**
The Independent, 03/08/2015

“Supercharged” genetically modified (GM) organisms, “could be used a terrorist bio-weapon”, “technology is like a nuclear chain reaction”

**A Power for Good or Evil: The
Technology of ‘Gene Drives’ Holds
Immense Potential for Improving Our
Life on This Planet – And Also Great
Dangers**

The Independent, 02/08/2015

“Immense potential.....but also great danger”, “spreading genetic traits rapidly....like a virus”, “supercharges genetically modified genes so that they defy the normal rules of inheritance”

Figure 1: News coverage by media type

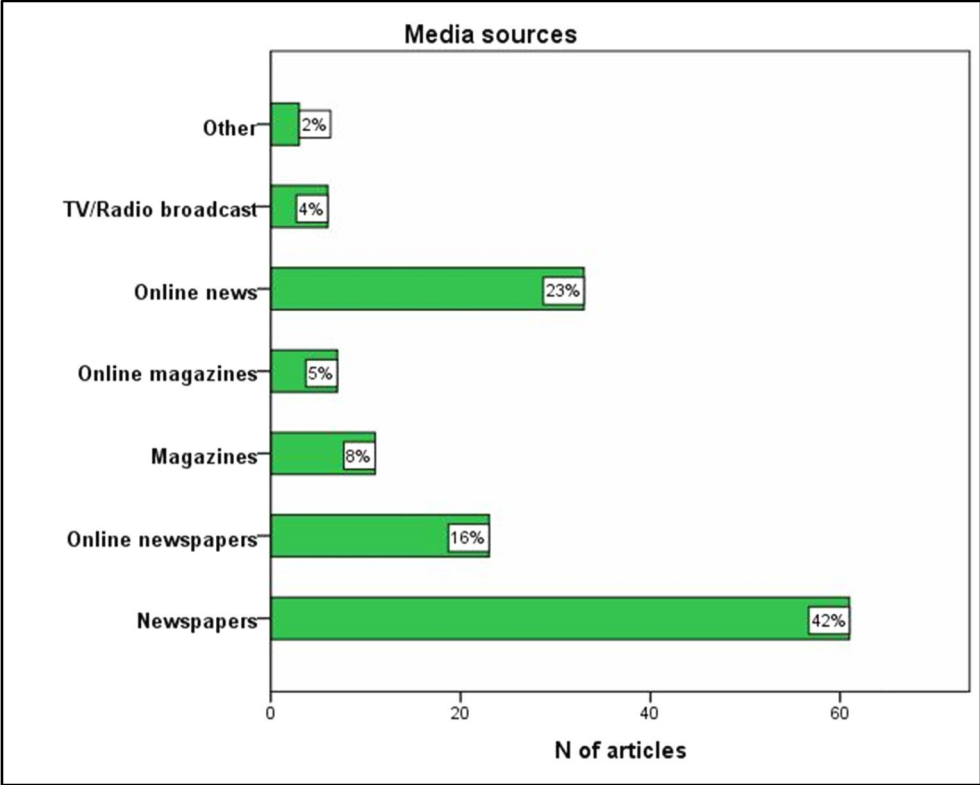


Figure 2: Perceptions of risks associated with gene drive technology

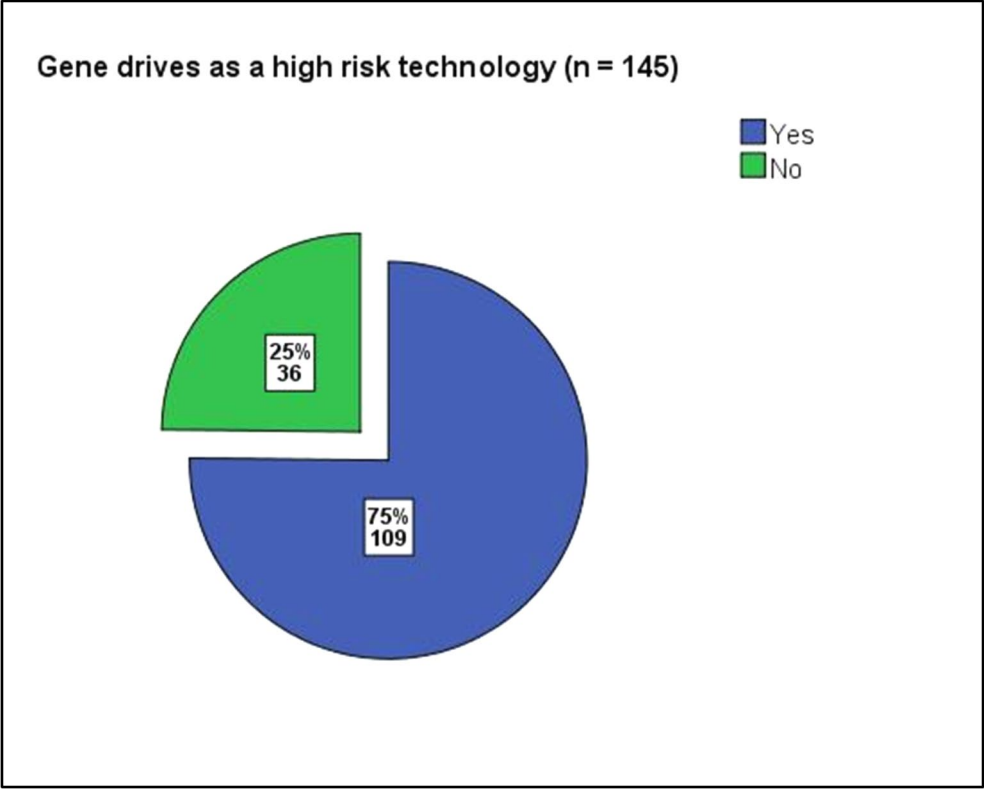


Figure 3: Overall tone towards gene drive technology

