Contributed Paper

Public views about editing genes in wildlife for conservation

P.A. Kohl (iD),[1,2]* D. Brossard,[2] D.A. Scheufele,[2] and M.A. Xenos[3]

[1]Nicholson School of Communication and Media, University of Central Florida, 12405 Aquarius Agora Dr., Orlando, FL, 32816-1344, U.S.A.
[2]Department of Life Sciences Communication, University of Wisconsin-Madison, 1545 Observatory Drive, Madison, WI, 53706, U.S.A.
[3]Department of Communication Arts, University of Wisconsin-Madison, 821 University Avenue, Madison, WI, 53706, U.S.A.

Abstract: *Developments in CRISPR-based gene-editing technologies have generated a growing number of proposals to edit genes in wildlife to meet conservation goals. As these proposals have attracted greater attention, controversies have emerged among scientists and stakeholder groups over potential consequences and ethical implications of gene editing. Responsible governance cannot occur without consulting broader publics, yet little effort has been made to systematically assess public understandings and beliefs in relation to this new area of applied genetic engineering. We analyzed data from a survey of U.S. adults* (n = 1600), *collected by YouGov, and that examined respondents' concerns about gene editing in animal and plant wildlife and how those concerns are shaped by cultural dispositions toward science and beliefs about the appropriateness of intervening in nature at the genetic level. On average, respondents perceived more risk than benefit in using these tools. Over 70% agreed that gene editing in wildlife could be "easily used for the wrong purposes." When evaluating the moral acceptability of gene editing in wildlife, respondents evaluated applications to improve survival in endangered wildlife as more morally acceptable than applications to decrease abundance in a population or eliminate a population. Belief in the authority of scientific knowledge was positively related to favorable views of the benefits, risks, and moral acceptability of editing genes in wildlife. The belief that editing genes in wildlife inappropriately intervenes in nature predicted relatively more concern about risks and moral acceptability and skepticism about benefits. Given high levels of concern and skepticism about gene editing in wildlife for conservation among the U.S. public, a take-it-slow approach to making decisions about when or whether to use these tools is advisable. Early opinions, including those uncovered in this study, are likely to be provisional. Thus, consulting the public should be an ongoing process.*

Keywords: benefit perceptions, CRISPR, gene drive, invasive species, moral acceptance, public opinion, risk perceptions

Opinión Pública sobre la Edición de Genes en la Conservación de Fauna

Resumen: *El desarrollo de tecnologías de edición de genes basada en CRISPR ha generado un número creciente de propuestas para editar los genes de especies silvestres y así lograr los objetivos de conservación. Conforme estas propuestas han atraído la atención, han surgido controversias entre los grupos de científicos y accionistas sobre las consecuencias potenciales y las implicaciones éticas de la edición de genes. La gobernanza responsable no puede ocurrir sin consultar a una audiencia más amplia, y aun así se han realizado muy pocos esfuerzos por evaluar sistemáticamente las creencias y el entendimiento público relacionados con esta nueva etapa de ingeniería genética aplicada. Analizamos los resultados de una encuesta en línea realizado por YouGov entre adultos de los Estados Unidos* (n = 1,600), *la cual examinaba las preocupaciones de los respondientes sobre la edición genética en animales y plantas y cómo estas preocupaciones están moldeadas por la disposición cultural hacia la ciencia y las creencias sobre lo correcto que es intervenir en la naturaleza a nivel genético. En promedio, los respondientes percibieron más un riesgo que un beneficio al usar estas*

herramientas. Más del 70% estuvo de acuerdo en que la edición genética de especies silvestres podría "usarse fácilmente para los propósitos equivocados". Cuando evaluamos la aceptación moral de la edición genética de la fauna, los respondientes calificaron a las aplicaciones para incrementar la supervivencia de las especies amenazadas como más aceptables moralmente que las aplicaciones para disminuir la abundancia de una población o eliminarla totalmente. La creencia en la autoridad del conocimiento científico estuvo relacionada positivamente con la opinión favorable sobre los beneficios, riesgos y la aceptación moral de la edición genética de especies silvestres. La creencia de que la edición genética de especies silvestres interviene inapropiadamente con la naturaleza predijo relativamente una mayor preocupación por los riesgos y la aceptación moral y mayor escepticismo sobre los beneficios de la edición genética. Debido a los altos niveles de preocupación y escepticismo sobre la edición genética de especies silvestres para la conservación mostrados por el público estadunidense, se recomienda utilizar una estrategia de hazlo-con-calma para decidir cuándo o si usar estas herramientas. Es probable que las primeras opiniones, incluyendo las descubiertas con este estudio, sean provisionales. Por lo tanto, consultar al público debe ser un proceso continuo.

Palabras Clave: aceptación moral, CRISPR, especie invasora, genética dirigida, percepciones de beneficios, percepciones de riesgo, opinión pública

摘要： 基于 *CRISPR* 的基因编辑技术的发展推动了越来越多以保护为目的进行野生生物基因编辑的提议。由于这些提议已经引起了很大关注, 科学家和利益相关者团体之间也对基因编辑的潜在后果和伦理影响产生了争论。在这个问题上, 只有对广大民众进行民意调查, 才有可能实现负责任的管理, 然而目前却几乎没有关于公众对基因工程应用新领域的理解和信念的系统评估工作。本研究分析了 *YouGov* 对美国成年人 (n = 1,600) 进行的一项在线调查, 该调查询问了受访者在野生动植物基因编辑中关心的问题, 以评估文化如何影响他们对于在遗传水平上干预自然的适当性的科学认知和信念。受访者普遍认为使用这些工具的风险大于收益。结果显示, 超过 70% 的人认为野生生物基因编辑 "很容易被用于不当目的"。在评估野生生物基因编辑的道德接受度时, 受访者认为, 与减少种群数量或消灭种群的应用相比, 提高濒危野生生物存活率的应用在道德上更容易接受。此外, 相信科学知识权威性的受访者同时对野生生物基因编辑的好处、风险和道德接受度认同度更高; 而认为野生生物基因编辑不恰当地干预了自然的受访者, 对风险和道德接受度也抱有更多担忧, 并对效果表示怀疑。考虑到美国公众对野生生物基因编辑高度关注和怀疑的态度, 在决定何时或是否使用这些工具时应当循序渐进。早期的意见, 包括本研究中发现的意见, 可能只是暂时的, 因此还需要持续咨询公众的看法。【翻译: **胡怡思**; 审校: **聂永刚**】

关键词: 基因驱动技术, CRISPR, 入侵物种, 公众舆论, 风险感知, 收益感知, 道德接受度

Introduction

The development of advanced gene-editing tools has generated proposals to alter wildlife genomes as a response to the spread of invasive species and other threats to biodiversity, such as disease, low genetic diversity, and climate change (e.g., Corlett 2017; Piaggio et al. 2017; Novak et al. 2018). There is widespread agreement among scientists, nonprofit stakeholders, and scientific advisory institutions that consulting public stakeholders early and often is critical to making responsible decisions about when or whether to use gene-editing tools to address biodiversity challenges (e.g., National Academies of Sciences Engineering and Medicine [NASEM] 2016; Te Pareake Mead et al. 2017; Redford et al. 2019). Yet, to date, there has been little systematic effort to assess how various publics may respond. An assessment of public opinion provides an important first step toward extending deliberations about editing wildlife genomes to account for public understandings, values, and concerns. We analyzed the results of a survey of U.S. public views of editing wildlife genomes for conservation and sought to identify factors related to perceptions of the benefits, risks, and moral acceptability of editing wildlife genomes.

Using Advanced Gene-Editing Technologies for Conservation

Humans have long used genome-altering technologies to manipulate organisms for research and agriculture. However, manipulating genomes of wild populations remained impractical before the discovery of the gene-editing tool clustered regularly interspaced short palindromic repeats Cas9 (CRISPR) (Esvelt et al. 2014; Champer et al. 2016). This tool is faster, more affordable, and easier to use than earlier genome-altering technologies (Doudna & Charpentier 2014). Perhaps most importantly, CRISPR has given a major boost to the development of gene drives, which can be used to spread a genetically altered trait through a wildlife population much faster than it would through normal genetic inheritance (Esvelt et al. 2014; Kyrou et al. 2018).

A growing number of conservation scientists are therefore considering gene editing as an option to address problems that have not been solved by traditional conservation practices (Corlett 2017; Piaggio et al. 2017). Meetings have been convened to foster greater dialogue between conservationists and synthetic biologists developing tools to edit genes in wildlife (Redford et al. 2013;

Redford et al. 2014). But some biologists and others in the conservation community remain wary of proposals to edit wildlife genomes, and a few have come out in opposition (Webber et al. 2015; Civil Society Working Group on Gene Drives 2016).

Benefits, Risks, Moral Acceptability, and Accountability

The unprecedented power and potential of newly discovered gene-editing tools have generated both excitement and alarm. Optimism about the promise of these tools for addressing conservation problems is tempered with caveats about risks (Esvelt et al. 2014; Webber et al. 2015; NASEM 2016). At this early stage of development, outcomes remain largely hypothetical and highly uncertain (NASEM 2016). At the same time, urgent extinction threats create strong motivation to rapidly adopt new and sometimes radical conservation approaches (Redford et al. 2014; Corlett 2017).

In addition to raising questions about relative benefits and risks, genetic engineering often generates considerable ethical debate (Frewer et al. 1997; Verhoog 2003; Cooley & Goreham 2004). Proposals to edit wildlife genomes add a unique dimension to questions about whether genetic engineering crosses moral boundaries. As a conservation tool, gene editing could be used to "do bad things to unwanted species" or "do good things to wanted species" (Corlett 2017). For example, gene editing could be used to decrease or eliminate an invasive animal or plant population by introducing a trait to reduce survival fitness or disrupt reproduction. More ambitious applications could include improving survival fitness in threatened and endangered species by increasing genetic diversity or accelerating evolutionary adaptation to invasive pathogens or climate change (Thomas et al. 2013; Piaggio et al. 2017).

Views about the moral acceptability of gene editing in wildlife for conservation may therefore hinge, in part, on whether an application is designed to decrease or eliminate a wildlife population or to improve survival in endangered wildlife. These 2 types of applications may also raise unique concerns about accountability. Is there greater potential for one of these types of applications to be used for the wrong purpose? We examined 3 broad research questions about the views of U.S. residents toward gene editing in wildlife: Will respondents perceive the benefits as outweighing the risks (question 1), perceive applications to decrease or eliminate environmentally problematic wildlife populations as less morally acceptable than applications to improve survival in endangered wildlife (question 2), and have more concern about applications to decrease or eliminate environmentally problematic wildlife populations being used for the wrong purposes than applications to improve survival in endangered wildlife (question 3)?

We also examined how individual-level factors predicted views about editing wildlife genomes. In particular, we tested whether perceptions of the benefits, risks, and moral acceptability of editing wildlife genomes are predicted by individuals' belief in the authority of scientific knowledge and in whether gene editing in wildlife constitutes tinkering with nature (hereafter messing with nature) and their attention to science news.

Belief in Authority of Scientific Knowledge

A growing body of research highlights the important role cultural dispositions toward science play in shaping the way citizens think about complex scientific issues (Brossard & Nisbet 2007; Kim et al. 2014; Akin et al. 2017). In particular, systems of belief that privilege science as having epistemic and social authority tend to correlate with positive attitudes toward scientific issues. For example, individuals who are more deferential toward scientific authority tend to have fewer reservations about the impacts of science and to support emerging technologies even when they involve hard-to-quantify risks over which experts may disagree (Lee & Scheufele 2006; Brossard & Nisbet 2007; Akin et al. 2017). They also tend to perceive them as more beneficial and less risky (Kim et al. 2014).

Deference to scientific authority (Brossard & Nisbet 2007) and related concepts, such as cultural authority of science (Shapin 2007; Gauchat 2011), are conceptualized as stable, long-term predispositions cultivated and reinforced by the educational system and exposure to popularized science (e.g., nature television programs, science museums, and science magazines). Deep-seated belief in the authoritative position of science is similar to, but conceptually distinct from, social and institutional trust, which are less stable than core belief systems. Trust tends to be more variable and issue specific and can vary depending on individual views about specific fields and applications of science and different types of scientists (Critchley 2008).

We focused on one particular dimension of authoritative beliefs about science: the tendency to privilege science as a superior source of knowledge, which we refer to as belief in the authority of scientific knowledge. Given the above considerations, we predicted that individuals who strongly believe in the authority of scientific knowledge would perceive gene editing in wildlife as beneficial, of relatively low risk, and morally acceptable compared with individuals with low belief in the authority of scientific knowledge. To test this prediction, we posed the hypothesis: Belief in the authority of scientific knowledge is related to favorable perceptions of the benefits, risks, and moral acceptability of gene editing in wildlife.

Individuals who embrace the authority of scientific knowledge may also privilege scientific reasoning as a

moral paradigm—a moral orientation anchored in the idea that a "universal morality" can be "established on the basis of 'sound scientific argument'" about consequences (Wagner et al. 2001). When scientific reasoning becomes a paradigm for moral reasoning in debates about genetic engineering, for example, arguments tend to focus on the consequential outcomes of the technique and to deflect intrinsic concerns directed at the technique itself (Verhoog 2003; Cooley & Goreham 2004; Nature 2007). We asked whether the relationship between belief in the authority of scientific knowledge and judgments about the moral acceptability of gene editing in wildlife depends on perceptions about outcomes (i.e., relative benefits and risks). Our question was is the relationship between belief in the authority of scientific knowledge and moral acceptability moderated by relative benefit-risk perceptions (question 4)?

Messing-With-Nature Beliefs

Beliefs about naturalness can make technologies, technological products, and environmental interventions more or less acceptable to people (Rozin et al. 2004; Gaskell et al. 2010; Corner & Pidgeon 2015). Beliefs about unnaturalness are often linked with unfavorable attitudes toward synthetic biology, genetically modified (GM) foods, and genetic engineering more broadly (Shaw 2002; Gaskell et al. 2010; Pauwels 2013). Focus-group participants and survey respondents who oppose genetic engineering often explain their rejection based on a belief that it "messes" with nature or allows humans to "play God" (Wagner et al. 2001; Shaw 2002; Pew Research Center 2018b). Focus groups refer to messing with nature or playing God to articulate both intrinsic moral concerns reflecting a view of nature as sacred and concerns about humans' limited capacity to predict and control beneficial outcomes and risks when intervening in complex natural systems (Wagner et al. 2001; Corner et al. 2013). Given the above considerations, we predicted messing-with-nature beliefs would be linked with unfavorable views about the benefits, risks, and moral acceptability of gene editing in wildlife. To test our prediction, we posed the following hypothesis: Messing-with-nature beliefs are related to unfavorable perceptions of benefits, risks, and moral acceptability.

Attention to Science News

The amount and content of media coverage can influence public perceptions of advances in science and technology (Nisbet et al. 2002). Media coverage of technologies can provide audiences with a mental shortcut in forming attitudes about emerging technologies (Scheufele & Lewenstein 2005). Researchers have identified several patterns in how media cover emerging technologies. Early coverage tends to be largely positive,

framing emerging technology in terms of progress and emphasizing benefits while downplaying risks (Nisbet & Lewenstein 2002; Nisbet et al. 2003; Nisbet & Huge 2006). At the same time, anecdotal evidence suggests that public discourses on CRISPR may also be permeated by an unusual degree of critical reflexivity; CRISPR scientists themselves draw attention to possible risks and ethical dimensions (Baltimore & Berg 2015; Doudna 2015). Given the above considerations, we asked whether attention to science news is related to favorable perceptions of benefits, risks, and moral acceptability (question 5).

Methods

Data Collection

We obtained data from an online survey of 1600 U.S. adults. The data were collected by YouGov in December 2016 and January 2017. The completion rate was 41.7%. To ensure representativeness across sociodemographic characteristics, YouGov matched respondents drawn from a panel of U.S. residents to a sampling frame on gender, age, race, education, political ideology, party identification, and political interest. The sampling frame was constructed using stratified sampling from the Census Bureau's 2010 American Community Survey. Matched cases were weighted to the sampling frame based on propensity scores. YouGov excluded non-U.S. residents by profiling panelists on full mailing addresses and blocking IP addresses from outside the United States. Incentives for participating in surveys were delivered by postal mail. Respondents were 48.3% male and on average 47 years old (SD 16.92), and 62% had at least some college.

Before the survey was distributed, study approval was obtained from the University of Wisconsin Institutional Review Board. Question items we used in our analysis were part of a survey that also included questions about other gene-editing applications, including human genome editing, that were used for other public-opinion research studies. Sample size was determined by the number of variables examined and design of this and other studies drawing on the survey. Questions from the survey used in the present study are described below. The full text of questions and definitions of *genes* and *gene editing* provided to respondents is given in Supporting Information.

Measures

Risk perception was measured as the averaged response to 2 items: how risky do you think gene editing wildlife will be for nature and for humans (1, not at all risky; 5, very risky). Benefit perception was also measured as the averaged response to 2 items: how beneficial do you think gene editing wildlife will be for nature and for

Table 1. Correlation or Cronbach's alpha for all pairs of predictor variables of perceptions of gene editing in wildlife and reliability measures for multi-item measures (values on the right-most diagonal).[a]

Variable[b]	Mean	SD	1	2	3	4	5	6	7	8
Ideology	4.11	1.55	0.79[c]							
Religiosity	5.80	3.65	0.39**	NA						
Authority of scientific knowledge	4.66	1.47	−0.40**	−0.43**	0.73[c]					
Messing with nature	5.04	1.61	0.19**	0.24**	−0.17**	0.75[c]				
Science news attention	2.69	0.93	−0.08**	−0.01	0.25**	−0.06*	0.84[d]			
Risk	3.57	1.03	0.19**	0.24**	−0.27**	0.55**	−0.12**	0.73[c]		
Benefit	2.63	1.02	−0.28**	−0.23**	0.42**	−0.42**	0.17**	−0.51**	0.72[c]	
Moral acceptability	3.87	1.50	−0.21**	−0.18**	0.36**	−0.34**	0.12**	−0.37**	0.57**	0.57[c]

[a]*Cronbach's alpha is reported for multi-item measures with >2 items, and Pearson's r is used as a measure of reliability for 2-item measures.*
[b]*Perceptions of risks and benefits of gene editing in wildlife and attention to science news were measured on a unipolar 5-point scale. Religiosity was measured on a 10-point scale. All other variables measured on a bipolar 7-point scale.*
[c]*Pearson's r.*
[d]*Cronbach's alpha.*
Probability: *$p < 0.05$; ** $p < 0.01$.

humans (1, not at all beneficial; 5, very beneficial). We also created a relative measure of benefit-risk perception by subtracting the risk variable from the benefit variable (-9, risks outweigh benefits completely; 9, benefits outweigh risks completely).

Moral acceptability was measured as the averaged response to 2 items: level of agreement with the moral acceptability of editing genes in wildlife to improve endangered plants' and animals' chances for survival and with editing genes in wildlife to decrease or eliminate local populations of animals or plants causing environmental problems (e.g., invasive, non-native species) (1, strongly agree; 7, strongly disagree).

Perceptions that editing genes in wildlife could be used for the wrong purposes were measured with 2 separate items. Respondents were asked how much they agreed that editing genes in wildlife could easily be used for the wrong purposes when used to improve endangered plants' and animals' chances of survival and to decrease or eliminate local populations of animals or plants causing environmental problems (e.g., invasive, non-native species) (1, strongly agree; 7, strongly disagree).

Belief in the authority of scientific knowledge was measured as the averaged response to 2 items. Respondents were asked to indicate how much they agreed that science is the best way that society has to produce reliable knowledge and that science is the best way to understand the world (1, strongly disagree; 7, strongly agree).

Belief that gene editing is messing with nature was measured as the averaged response to 2 items. Respondents were asked to indicate how much they agreed editing genes in wildlife messes with nature and allows humans to play God (1, strongly disagree; 7, strongly agree). A Pearson's correlation coefficient for these 2 items showed good reliability ($r = 0.75$) (Table 1). However, to further evaluate whether it would be appropriate to treat these 2 items as a single mea-

sure, we also examined whether they exhibited similar patterns of correlation with our outcome variables. We found very similar correlations for "playing God" and "messing-with-nature" in relation to benefits ($r = -;0.38$; $r = −0.40$), risks ($r = 0.51$; $r = 0.53$), and moral acceptability ($r = −0.33$; $r = −0.31$).

Attention to science news was measured by averaging responses to 3 items asking people how much attention they give to news stories about science and technology; new scientific tools or developments, such as CRISPR-Cas9; and political or ethical implications of emerging technologies, such as gene editing (1, none; 5, a lot).

Ideology was measured by averaging responses to 2 items asking respondents whether they considered themselves liberal or conservative with respect to economic issues and social issues (1, very liberal; 7, very conservative). Religiosity was measured by asking respondents how much guidance religion provides in their everyday lives (0, no guidance at all; 10, a great deal of guidance)?

Finally, we included demographic factors to control for the effect of age, gender, and education. Age was measured as a continuous variable. Gender and education were measured as dichotomous variables (0, no college; 1, at least some college).

Data Analyses

All analyses were conducted with R (version 3.0.3). We analyzed the data with 3 paired-sample *t* tests to explore questions 1–3 and 4, hierarchical ordinary least squares regression models to test our 2 hypotheses and questions 4 and 5. All 4 of the regression models included the same set of predictor variables except for the fourth model, which included 2 additional terms: benefit-risk perceptions and an interaction term (benefit-risk perceptions × authority of scientific knowledge). For each regression model, we calculated
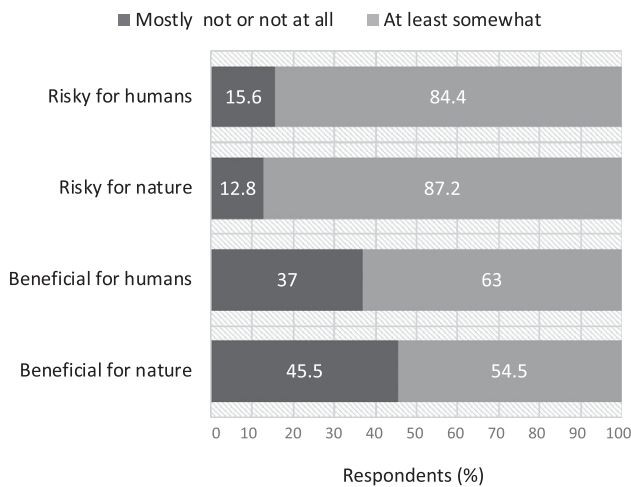
Figure 1. *Percentage of respondents who thought using gene editing in wildlife would be somewhat risky or beneficial or who thought it would be mostly not or not at all risky or beneficial.*
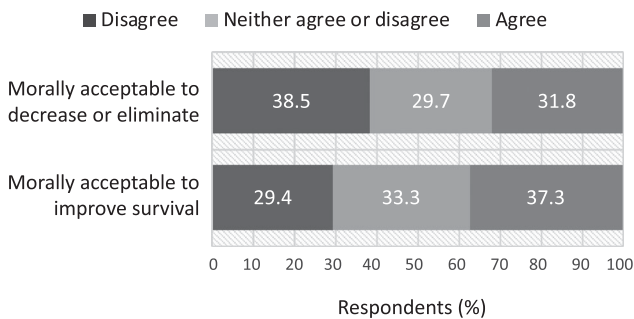

Figure 2. *Percentage of respondent agreement with statements about the moral acceptability of using gene editing in wildlife to decrease or eliminate wildlife populations versus applications to improve survival of endangered wildlife.*

partial eta-squared (η_p^2) to quantify predictor-variable effect sizes. Effect sizes with η_p^2 are considered small at 0.01, medium at 0.09, and large at 0.25 (Tabachnick & Fidell 2007; Watson 2017). All categorical predictors were centered with contrast coding. Visual inspection of residual plots did not reveal any obvious deviations from assumptions of linearity or homoscedasticity. Tests for multicollinearity indicated that the variance inflation factors for all predictor variables in regression models fell well below the common threshold value (O'Brien 2007).

Results

From 84.4% to 87.2% of respondents thought editing wildlife genomes would be at least somewhat risky for nature and humans, but they were relatively split about
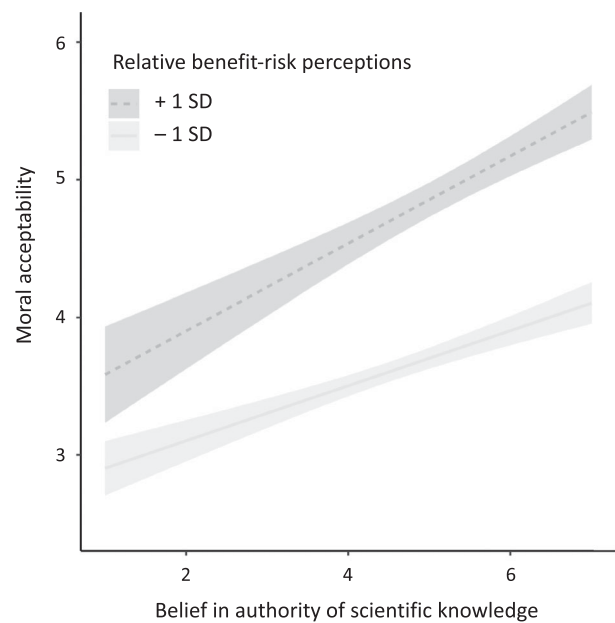

Figure 3. *Relationship between respondents' agreement that gene editing in wildlife is morally acceptable and belief in the authority of scientific knowledge as moderated by relative benefit-risk perceptions (moral acceptability: 1, strongly disagree; 7, strongly agree; belief in the scientific authority of knowledge: 1, weak belief; 7, strong belief).*

whether it would be beneficial (Fig. 1) or morally acceptable (Fig. 2). A majority of respondents agreed that gene editing wildlife messes with nature (71.3%) and allows humans to play God (59.7%) (also reported in Brossard et. al [2019]). Large percentages of respondents agreed gene editing was likely to be used for the wrong purpose (72–75%).

Respondents perceived the risks of editing wildlife genomes as outweighing the benefits (mean difference = 0.96, $t = 21.28$, df = 1525, $p < 0.001$). Respondents viewed applications of gene editing to improve survival in endangered wildlife as more morally acceptable than applications to reduce or eliminate wildlife populations (mean difference = 0.24, $t = 6.13$, df = 1555, $p < 0.001$). Finally, respondents agreed more strongly that applications to decrease or eliminate environmentally problematic wildlife populations could be used for the wrong purpose (mean difference = 0.13, $t = 4.57$, df = 1557, $p < 0.001$) than agreed that applications to improve survival in endangered species could be used for the wrong purpose.

As we hypothesized, authority of scientific knowledge was positively related to benefits and moral acceptability and negatively related to risks (Table 2). Belief in the authority of scientific knowledge was most strongly related to belief in benefits ($\eta_p^2 = 0.11$) and moral acceptability ($\eta_p^2 = 0.09$) of editing wildlife genomes. Also as

Table 2. Results of regression of predictor variables on perceptions of benefits, risks, and moral acceptability of the use of gene editing in wildlife conservation.[a]

Variable	Benefits[b] model 1			Risks[b] model 2			Moral acceptability[c] model 3			model 4		
	SE	β	η_p^2	SE	β	η_p^2	SE	β	η_p^2	SE	β	η_p^2
Gender	0.04	−0.05	–	0.04	−0.01	–	0.07	0.01	–	0.07	0.04	–
Age	0.02	0.09**	0.01	0.02	0.08**	0.01	0.03	−0.05	–	0.03	−0.05	–
Education	0.05	−0.07	–	0.05	0.06	–	0.07	0.06	–	0.07	0.12	–
Ideology	0.03	−0.09**	0.01	0.03	0.05	–	0.04	−0.08	–	0.04	−0.02	–
Religion	0.02	0.03	–	0.02	0.05*	–	0.04	0.04	–	0.04	0.05	–
Authority of scientific knowledge	0.02	0.35**	0.11	0.02	−0.14**	0.02	0.04	0.47**	0.09	0.04	0.33**	0.05
Messing-with-nature beliefs	0.02	−0.34**	0.14	0.02	0.52**	0.27	0.04	−0.43**	0.10	0.04	−0.12*	0.01
Science news attention	0.02	0.07*	0.01	0.02	−0.05*	–	0.04	0.01	–	0.04	−0.06	–
Adjusted R^2 (%)		32.5**			34.5**			21.7**				
benefit-risk perceptions										0.04	0.64**	0.17
Interactions												
authority of scientific knowledge × benefit-risk perceptions										0.03	0.10**	0.01
Adjusted R^2 (%)											33.9**	

[a]*Abbreviations: β, standardized regression weight; η_p^2, partial eta squared (only partial-eta effect sizes of at least 0.01 are displayed).*
[b]*Measured on a unipolar 5-point scale.*
[c]*Measured on a bipolar 7-point scale.*
Probability: *p < 0.05; ** p < 0.01.*

hypothesized, messes-with-nature beliefs were negatively related to beliefs in the benefits and moral acceptability of editing wildlife genomes and positively related to beliefs about the risks of the approach. Messing-with-nature belief was most strongly related to beliefs about the risk of the approach ($\eta_p^2 = 0.27$).

Moral acceptability judgments were more strongly related to benefit-risk perceptions among individuals who more strongly believed in the authority of scientific knowledge (Fig. 3). Attention to science news was negatively related to risks and positively related to benefits. Models 1–4 (Table 2) accounted for 21.7–33.9% of the variance in the dependent variables.

Discussion

We conducted a systematic assessment of public attitudes about gene editing in wildlife as a tool for conservation and how these attitudes relate to cultural dispositions toward science, messing-with-nature beliefs, and attention to science news. Our results suggest that U.S. residents are generally skeptical about the outcomes of gene editing in wildlife. On average, respondents thought risks would outweigh benefits, and large majorities thought gene editing in wildlife would be at least somewhat risky for humans (84%) and nature (87%). These percentages appeared high compared, for example, with public risk-perception measures involving GM food. Fifty-nine percent of U.S. residents think it is at least "fairly likely" that GM foods will lead to health problems for the population as a whole and 56% think it is at least "fairly likely" that GM foods will create problems for the environment (Pew Research Center 2018a).

We found considerable concern about accountability; >70% of respondents agreed that gene editing in wildlife could easily be used for the wrong purposes. Although the difference was small, this concern was significantly greater for gene editing used to decrease or eliminate environmentally problematic wildlife populations than for applications to improve survival in endangered species. There was no clear majority opinion in response to questions about the moral acceptability of gene editing in wildlife. On average, however, moral acceptability evaluations were significantly greater for applications to improve survival in endangered species compared with applications to decrease or eliminate environmentally problematic wildlife populations.

These results suggest that moral frames could influence how the American public responds to proposals to edit genes in wildlife for conservation. Advocates and opponents have begun to leverage moral framing to advance their viewpoints. Some advocates, for example, refer to applications to edit genes in wildlife as "genetic rescue" (Revive & Restore 2016). Meanwhile, others have come out against gene editing as a conservation tool, warning against the release of "genocidal genes" or "genetic extinction technology" (Civil Society Working Group on Gene Drives 2016; Friends of the Earth 2016).

Several limitations should be considered in interpreting our results. First, we did not account for the possibility that respondents' attitudes toward related but more

familiar genetic engineering applications, such as GM organisms and GM food, may spill over into evaluations of the less familiar issue of gene editing in wildlife (Akin et al. 2018). Future research in this area should take into account whether, or to what degree, attitudes about gene editing in wildlife are linked to attitudes toward other more familiar genetic engineering applications.

Furthermore, we asked respondents to evaluate gene editing in wildlife without providing examples of specific applications. A survey presenting respondents with a range of possible conservation applications targeting different organisms might yield somewhat different results. Previous studies have revealed greater acceptance for genetic engineering applications involving plants and microorganisms compared with those involving animals (Frewer et al. 1997; Dragojlovic & Einsiedel 2013). Furthermore, individuals may view invasive species control through gene editing to subvert reproduction as more humane when presented with existing alternatives, such as traps, guns, and poison (e.g., Borel 2017). Attitudes toward editing wildlife genomes may also vary depending on the purpose of the application. Future research should compare attitudes toward applications representing a wider range of anthropocentric and conservation goals. These might include, for example, applications to prevent the spread malaria by mosquitos, protect crops from pests, and create extinct species proxies (i.e., de-extinction) (Esvelt et al. 2014; NASEM 2016; Novak et al. 2018).

Prior research shows that perceptions of the risks, benefits, and moral acceptability of genetic engineering technologies vary by nationality. For example, in a meta-analysis of research on public perceptions of GM foods, risk perceptions were greater in Europe than North America and Asia. The reverse was true of benefit perceptions, whereas moral concerns were higher in North America and Asia (Frewer et al. 2013). It is unclear how public perceptions of gene editing in wildlife for conservation will vary across international boundaries. There have been few efforts in North America or beyond to systematically assess public perceptions of editing genes in wildlife for conservation purposes. One exception includes preliminary results from a survey conducted in New Zealand in which 32% of the 8000 people surveyed were comfortable with pest-control technologies that include gene drive, 18% thought such technology should never be used, and 50% were undecided or wanted strong controls (Biological-Heritage National Science Challenge 2017).

Although our study involved only U.S. adults, our findings can inform the collection of data in other countries. Consulting and engaging with the public about emerging issues is tricky when public awareness is low. Early opinions, including those uncovered in this study, are likely to be provisional. Thus, consulting the public should be an iterative process in which societies continually revisit issues, allowing people to reframe their views in the light of subsequent experience (Jasanoff et al. 2015). Although issue-specific perceptions are often subject to change, systems of deeply held beliefs are more resistant.

Relevant to this, we found that beliefs about science were important to predicting views about editing wildlife genomes. Individuals who more strongly believed in the authority of scientific knowledge held more favorable views of gene editing in wildlife, particularly views regarding the benefits and moral acceptability of these approaches. Consequently, such individuals may be especially receptive to claims about benefits and moral arguments in favor of editing wildlife genomes. Belief in the authority of scientific knowledge also appeared to play a role in the relationship between relative benefit-risk perceptions and moral acceptability judgments. Perceptions about the relative benefits and risks of gene editing in wildlife more strongly predicted moral acceptability judgments among individuals with greater belief in the authority of scientific knowledge. These results should be interpreted with caution. Because this study relies on correlational data, we could not be sure about the causal direction of the relationship. It is possible that instinctive moral judgments about gene editing in wildlife drive benefit-risk perceptions, rather than the other way around (Haidt 2001).

Previous research shows that early media coverage of emerging technologies tends to emphasize benefits while downplaying risks (Nisbet & Lewenstein 2002; Nisbet et al. 2003; Nisbet & Huge 2006), and anecdotal evidence suggests that public discourses about CRISPR have been permeated by an unusual degree of critical self-reflexivity (Baltimore & Berg 2015; Doudna 2015). Nonetheless, our results revealed a positive relationship between attention to science news and favorable attitudes toward gene editing in wildlife. Individuals who paid more attention to science news perceived gene editing in wildlife as more beneficial and less risky.

Finally, our findings suggest that concerns about messing with nature are likely to become central to debates about gene editing in wildlife. A majority of respondents agreed that gene editing in wildlife messes with nature (71.3%) or, relatedly, allows humans to play God (59.7%). This is consistent with previous research indicating that concerns about interfering with nature or disrupting the natural order often looms large in public opinion about agricultural genetic engineering (Wagner et al. 2001; Shaw 2002; Gaskell et al. 2010). Messing-with-nature beliefs were associated with greater moral concern and skepticism about benefits, but most strongly predicted concern about risks. The relationship between messing-with-nature beliefs and risk perceptions was twice as strong as the relationship between messing-with-nature beliefs and perceived benefits or moral acceptability.

Some limitations should be considered when interpreting these results. We measured messing-with-nature

beliefs by combining responses to 2 items that asked respondents whether they agreed that gene editing messes with nature and allows humans to play God. We found strong reliability between these items and close correspondence in the way the items correlated with outcome variables. However, we could not be certain that they necessarily expressed the same sets of values. We acknowledge this limitation and recommend that future research undertakes more in-depth exploration of the nature of the relationship between these 2 terms.

With this limitation in mind, our results highlight the need for renewed focus on what nature means to various publics and expert stakeholders and what kind of nature the public thinks conservation ought to save and how. The question of how humans understand their relationship with nature is gaining importance as advanced gene-editing tools and other modern technologies extend abilities to deliberately shape evolutionary processes and synthesize nature. Debates about gene editing in wildlife for conservation are beginning to emerge among stakeholder groups and some conservationists and have only just begun to enter mainstream dialogue. There is growing need for open debates that engage diverse expert and lay voices. Our results shed light on how people may respond to proposals to edit wildlife genomes and how those proposals may intersect with different belief systems. We hope our results will help lay the groundwork for conservation scientists to organize constructive deliberations with the public about when or whether gene editing in wildlife should play a role in future conservation practices.

Acknowledgment

Supporting Information

Definitions supplied and questions posed to respondents (Appendix S1) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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