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On the nature of naturalness? Theorizing 'nature' for the study of public perceptions of novel genomic technologies in agriculture and conservation

Sara Nawaz [a,b,*], Terre Satterfield [b]

[a] Institute for Science, Innovation and Society, University of Oxford, 64 Banbury Road, Oxford OX2 6PN, United Kingdom
[b] Institute for Resources, Environment and Sustainability, University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada V6T 1Z4

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A B S T R A C T

Notions of naturalness are widely assumed to drive how people perceive genetic engineering (GE). As newer forms of genetic engineering—namely, gene editing, gene drives, and synthetic biology—are reshaping life forms in both agriculture and conservation, they are increasingly raising questions of what a 'natural' food, organism or ecosystem is, and whether objections toward 'unnaturalness' or preferences for 'naturalness' might reveal a deeper ethical or value-based logic. A number of fields have sought, both directly and indirectly, to define the concept, but insights have not yet been applied to new forms of genetic engineering. This paper proposes that systematically reviewing scholarly interpretations of 'naturalness' might offer weight to a concept that is often dismissed as irrational. Here, we review and synthesize insights from a range of fields, outlining possible logics public groups might employ to reason about what is '(un)natural'. We also offer a novel thought experiment in which we apply these logics to a sample of novel GE applications. One of our core findings is that '(un)naturalness' may be understood not necessarily as a quality of an object, but rather as a characteristic of ecological, social, cultural, and spiritual relationships. Such an understanding implies the need for ongoing engagement with the values embedded in ideas of naturalness and empirical explorations of how such values inform debates on novel engineered foods, organisms and ecosystems.

1. Introduction

Novel genetic engineering (GE) technologies are ushering in a new era of designing life forms. These organisms include (amongst others) both domesticated crops and livestock and wild organisms for release in conservation contexts (International Union for Conservation of Nature, 2019). While gene-editing techniques have been in use for years, the invention of CRISPR-Cas9 in 2012 has made it far cheaper and easier to edit genomes. Unlike with genetically modified organisms (GMOs), scientists are now able to directly edit precise locations in the genome of an organism, and also to produce organisms that not could have emerged via traditional breeding (National Academies of Sciences Engineering and Medicine, 2017). New technologies and processes also include 'gene drives,' which make use of gene editing to push specific traits through populations, and synthetic biology, which applies engineering principles to design biological components (cells or organs), pathways, or even organisms.

A mushrooming of scientific research and synthesis reports have begun to explore and document the potential scope of what, proponents claim, are a range of useful applications of such approaches for agriculture and conservation (e.g., International Union for the Conservation of Nature, 2019; Shukla-Jones et al., 2018). Proponents such as technology developers assert that novel GE offers powerful and urgent techniques for dealing with the challenges of a changing climate and ever-increasing pressures on landscapes and resources (Bain et al., 2019; Kofler et al., 2018). Earlier agricultural approaches to GE centered on improving productivity in a few staple (largely industrial) crops and engineering for pest resistance. However, proponents claim, novel agricultural applications of GE offer a wider range of modifications and intended purposes. These involve new traits such as climate adaptation, they argue, and target a variety of agriculturally relevant organisms beyond staple crops, such as those useful to smallholder farmers. Applications have been proposed to improve animal welfare and reduce greenhouse gas emissions, to name a few possibilities (Goold et al., 2018; Jin et al., 2019). Genetic modification (GM) was not widely supported in conservation contexts, but applications of gene editing and drives are increasingly being considered as serious options (Corlett, 2017). Applications include controlling invasive species with gene

* Corresponding author at: Institute for Science, Innovation and Society, University of Oxford, 64 Banbury Road, Oxford OX2 6PN, United Kingdom.
E-mail address: sara.nawaz@insis.ox.ac.uk (S. Nawaz).

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drives, creating substitutes for overexploited tree or fibrous materials, reviving extinct species and engineering coral reefs to withstand ocean acidification, amongst others (Piaggio et al., 2017). In both agriculture and conservation, potential applications and their scope continue to increase.

However, all such applications are emerging in the shadow of GMOs, which have seen fierce debate and, in some cases, outright rejection. While debates over GMOs originally focused on economic and environmental factors, they grew to encompass social, political, and ethical considerations. Initial thinking on public perceptions of GMOs assumed technical risks as separate from ethical questions (Irwin and Wynne, 1996; Levidow and Carr, 1997). Yet scholars have demonstrated that ethical considerations are inseparable from questions of technical risk, and moreover, that ethical considerations might involve legitimate social, cultural, or political objections, rather than resulting from knowledge gaps. Many such debates also revolved around 'naturalness' as a key proxy for unacceptability of GMOs. Research has found that the 'naturalness' of GE has mattered to publics in both agriculture (Dragojlovic and Einsiedel, 2013; Lusk et al., 2018; Mielby et al., 2013; Román et al., 2017; Rozin, 2005; Rozin et al., 2012; Tenbült et al., 2005) and conservation (Kohl et al., 2019). Scientists and policymakers have tended to dismiss public concerns about naturalness, seeing these as the result of irrational, emotional, politically motivated, or gullible thinking (Marris, 2015). On the other hand, others have wondered if concerns around 'unnaturalness' might be more than an easy or default objection, instead linked to underlying cultural, social and political reasons for opposition. As Wynne (2001) argues, 'naturalness' might be a concern that bears investigation not just as a "touchy-feely", emotional dimension for objection (p. 476) to be taken "face value" (p. 469)—but rather, one that represents an ethical objection to the activities involved in GE.

Some confusion about what 'naturalness' means might also derive from the ambiguity of the term more generally. In fact, naturalness as a concept has a checkered history as one often employed to justify political oppression. Williams (1980) has written that slavery, markets, democracy, and other constructions of societal relations have been justified with arguments about what is 'natural' to human behavior or social systems. To call something 'natural' is to assert claims about how something 'ought to be'. Assumptions about 'nature' have been implicit in the Hobbesian ideas of nature as 'nasty, brutish and short' or Rousseauian associations of nature with the 'noble savage' (Ginn and Demeritt, 2009). Assumptions of a singular definition of 'natural' have, Marxists have argued, been built into hegemonic ideas of progress, or employed to legitimize oppressive understandings of gender and sexuality, according to feminist and queer theorists.

Ambiguity about what it means for something to be 'natural' emerges in this context as well. With applications ranging from synthetic meat to de-extinct mammoths, many novel GE applications are introducing uncertainty about the line between nature and non-nature, that is, the line between the physical world and its resident non-human species, and humans and the things that we have created. We propose further investigating this ambiguity here. Our investigation is grounded in the proposition that concerns about 'unnaturalness' may be one way that people's ethical considerations regarding GE arise—and in turn, get dismissed. We consider in detail the proposition that concerns about (un)naturalness might benefit from being treated as insights into the ethical and value positions linked to novel techniques and applications of GE. In exploring this proposition, we seek to ask: What might 'naturalness' mean in the context of new and emerging life forms in agriculture and conservation? More specifically, we aim to explore how people might reason about 'naturalness', drawing upon a range of philosophical through empirical work. We also seek to explore the relevance of these reasonings to public evaluations of specific novel GE applications. In doing so, our paper explores the proposition that such reasonings might shed light on the values underpinning evaluations of novel GE in agriculture and conservation. The exploration of naturalness provided here might, we hope, make explicit and legitimate some of the rationales for opposing GE—as well as highlight the conditions under which support for, or rejection of, specific applications of GE might arise.

2. Methods

To develop the logics that might be used to ethically reason about naturalness, we followed five key methodological steps, which also structure this paper. We first compiled scholarly research that might illustrate what naturalness means and/or how it might be operationalized in agricultural and conservation contexts. To do this, we drew across a broad range of disciplinary and interdisciplinary fields that implicitly or explicitly touch on concepts of naturalness and involved the contexts of agriculture/farming and conservation. We included all relevant papers derived from a Google Scholar search, based on "natur*" AND "agricultur*" OR "farm*" OR "conservation") as well as more unstructured searches (e.g., pursuing references cited in key publications).

This set of papers was then grouped to facilitate four additional analytic steps:

1. Creating reference definitions of naturalness based on the fields of environmental and agricultural ethics, because this was the only field that has directly taken on the challenge of attempting to 'define' naturalness through systematic treatment of the term;
2. Using these definitions as a useful starting point for framing further study of the concept. In particular, we sought any evidence for or empirical applications of the idea of naturalness, be they implicit or explicit. For example, Mielby et al. (2013) offers a qualitative study of different participant understandings of naturalness, while Tenbült et al. (2005) conducted a quantitative assessment of perceived naturalness;
3. Assessing the extent to which empirical work or applications of naturalness reflect the philosophical definitions derived in step 1; and
4. Using the above insights to hypothesize how people might think about naturalness if applied to a broad array of potential and actual gene editing applications. The intention with this final analytic step was to provide a 'road test' for how people might evaluate GE applications as more or less natural.

3. Introducing a framework for naturalness

Philosophical writing offers a broad base of thinking and a viable starting place for engagement with the concept of naturalness; it includes work dating back to Aristotle, alongside important contributions from other prominent scholars such as John Stuart Mill (Kaebnick, 2011). More recently, the field of environmental and agricultural ethics has taken on the project of assessing whether naturalness has normative value in guiding ethical reasoning. To do so, scholars have first attempted to define what naturalness is using the terms 'naturalness', 'nature' and often, 'wilderness', interchangeably.

Below, we compile definitions of naturalness proposed by these foundational thinkers on the topic. Our purpose is to outline the range of possible ways that people might grapple with 'naturalness' as a philosophical concept; this compilation serves as a starting point for our empirical exploration and thought experiment that follow. From this starting point we draw heavily on two scholars in particular. The first is

Siipi's (2008) paper, which has been widely discussed and cited by work engaging the concept of naturalness. Our compilation also draws heavily upon Dussault (2016), who[1] subsequently elaborated and restructured Siipi's framework. Siipi's original framework distinguishes three 'types' or argument for naturalness ('process-based,' 'product-based,' and 'relation-based' naturalness). These proved challenging to parse and the lines between them often blurred (e.g., questions of 'process' vs. 'product' can be hard to disentangle). Instead, we prefer the structure Dussault proposes, which also categorizes arguments for naturalness into three types: what we call Nature 1, naturalness as opposed to "artificial" and Nature 2, naturalness as opposed to "abnormal", along with Nature 3, or naturalness defined relationally. Defining 'natural' *in opposition to 'artificial',* Nature 1 refers to that which is created or affected by humans. Nature 1 has three components that are similar to Siipi's thinking: The first, Nature 1a, posits that something is natural if it is (somewhat) independent from humans. The second, Nature 1b, says that something is natural if it lacks (some degree of) intentional effort by humans. Nature 1c posits that something is natural if it has some degree of autonomy or ability to generate itself.

Nature 2 defines nature *in opposition to what is deemed "abnormal,"* or what is 'status quo' in some capacity. It has six components: Nature 2a regards something as natural if it is in accordance with the natural order. Nature 2b posits that something is natural if it is aligned with its own purpose, essence, or telos. Nature 2c deems something natural if it has a historical or evolutionary antecedent. Nature 2d argues that something is natural if it fulfills its biological function (e.g., helps an organism function, thrive or 'live', as opposed to interfering with that thriving). Lastly, Nature 2e indexes something as natural if it is ecologically harmonious, or, able to regulate itself.

The final logic for defining naturalness expresses naturalness not in opposition to something else, but rather *in relation to entities or people*. Nature 3a distinguishes something as natural if it satisfies a person or entity's needs;for example, something would be natural for a person if it satisfied their nutritional requirements.By Nature 3b, however, something is natural if it is familiar to a person. Preston and Wickson (2016) offer a final definition also known as a relational care ethic, which explicitly emphasizes relationships of personal, social, and cultural significance. By this logic, naturalness can be thought of as having symbolic meaning, accounting for dimensions of reasoning unexplained by other logics, such as the naturalness of taboos that restrict contact with a clan-referencing or totem animal. Table 1 summarizes all three sets of logics.

4. Examining scholarship on naturalness in the empirical sciences and humanities

While philosophers have sought to ontologically examine what naturalness is or is not, empirically informed work from the natural and social sciences as well as the humanities examines how people might or actually reason about naturalness. Insights reviewed here suggest that naturalness is a concept that depends on the ontological and epistemological approach employed, and so tends to mean many different things, though a few common threads can be found. Below, we review several key fields as concerns their methods, central questions, conceptual approach, and key findings as indicative of what naturalness might (or is assumed to) be.[2] This summary is not intended to be comprehensive, but rather to cover the primary themes and approaches from each field. Table 2, below, summarizes this information, and offers key citations for each.

Table 1
Definitions of naturalness, drawn from environmental and agricultural ethics.

How is natural defined?	Something is natural if…	As cited in
Nature 1: In opposition to "artificial"		
1a: Independence from humans	…it is entirely, or partially, free from human influence	Ridder, 2007; Siipi, 2008
1b: Absence of intentionality	…it is free, to some extent, of deliberate human changes	Ridder, 2007; Siipi, 2008
1c: Autonomy	…it has some degree of ability to self-propagate	Karafyllis, 2003; Rabinow, 2008
Nature 2: In opposition to "abnormal"		
2a: The natural order	…if humans occupy their 'correct' place	Ridder, 2007; Siipi, 2008
2b: An organism's essence	…it is in line with its own telos or purpose	Sagoff, 2005; Siipi, 2008
2c: Historical baseline	…it is similar to entities from before a particular point in time	Ridder, 2007; Siipi, 2008
2d: Biological functionality	…it is able to grow and flourish	Siipi, 2008
2e: Ecological harmony	…it supports the surrounding ecosystem	Dussault, 2016
Nature 3: Relationally		
3a: Satisfaction of moderate needs	…if it satisfies an entity's needs, e.g. nutritional; if it is 'necessary', however defined	Siipi, 2008, 2013
3b: Familiarity	…if it is familiar to a person	Siipi, 2008
3c: Supportive of cultural, social and spiritual relationships	…if it supports people's multiple personal, social, and cultural relationships	Preston and Wickson, 2016

4.1. Studies of perceptions

The first set of studies that touch on the concept of naturalness is informed by psychologists—most using risk perception studies to identify thinking about agricultural biotechnologies, and attitudes towards GE as applied to conservation. This scholarship assumes that naturalness is a coarse filter or heuristic of comparable meaning across study participants. The emphasis is on whether judgements of naturalness are a correlate or predictor of attitudes, rather than on how naturalness itself is defined. In this sense, naturalness is often operationalized, but not defined, as things that have 'natural ingredients' or lack 'artificial ingredients' or 'additives' (following Steptoe et al., 1995; see also a meta-analysis by Román et al., 2017). Some studies also operationalize unnaturalness as humans 'messing with' or 'tampering with' nature, or as humans attempting to 'play God' (Kohl et al., 2019; Shaw, 2002).

Several noteworthy findings from this literature include the suggestion that naturalness is a rapid affective-style evaluation that helps people quickly evaluate something as good/positive or bad/negative. In a study by Siegrist and Sütterlin (2016), participants were asked to rate on scale of 1–100 the affect (e.g., negative or positive ratings) evoked by conventional and GM corn, and the perceived naturalness of conventional and GM corn: ratings of naturalness mirrored ratings of affect very closely for both conventional and GM corn. This finding suggests that 'naturalness' might be interpreted as a measure of participants' general affective response. Second, a study by Swiney (2020) found that some people may view entirely synthetic genes as in fact more natural than combinations of existing genes, taken from taxonomically distant species.

[1] We leave out Dussault's category of nature *as opposed to the supernatural*, as this failed to be relevant to the agricultural or conservation applications examined here. For simplicity, we differentiate this from ideas of 'hubris' or [humans] 'playing God', which we is part of naturalness defined 'in accordance with the natural order'. We view the former category as referring to what is separate from God, and the latter category as referring to humans' proper role in the world, which may involve God or not.

[2] It should be noted that these are not discrete or exclusive categories, but rather many of the approaches in these categories overlap with each other.

Table 2
Empirical approaches to naturalness.

Field	Primary methods	Questions posed	Conceptual approach to naturalness
Studies of perceptions	Surveys on risk perceptions of biotechnologies	Do concerns around naturalness drive or predict attitudes towards new technologies?	Does not engage with what naturalness 'means' and assumes that naturalness means the same thing to people.
Qualitative studies of perceptions	Focus groups, interviews, Delphi studies	What do nature or naturalness mean to people, in the context of new technologies?	Delves into the multiple subjective meanings that naturalness takes for different people.
Environmental planning	Visualization-based surveys on landscape perceptions	What landscape features do people tend to view as natural?	Aims to uncover which aspects of landscapes tend to be associated with greater or lesser degrees of naturalness.
Social construction of nature	Ethnography, discourse analysis, archival research	What might be a way of defining nature that acknowledges the multiplicity of definitions of nature, and/or addresses the inextricability of humans with nature?	Deconstructs assumptions about naturalness prominent in both academic discourse and broader conversations.
Scholarship on Indigenous ways of knowing	Ethnography and other qualitative methods	How have Indigenous traditions conceived of (relationships with) nature?	Does not usually attempt to define nature directly, but rather often reveal Indigenous conceptualizations indirectly.
Conservation science	Variety of qualitative and quantitative analyses	What should the target of conservation practice be, if not necessarily a restoration of past ecosystems?	Aims to challenge assumptions regarding 'natural' ecosystems predominant in the field of conservation. In light of anthropogenic changes, advocates a shifting understanding of nature to accommodate such changes.

4.2. Qualitative studies of perceptions

Qualitative scholars have also studied risk perceptions using focus groups, interviews, and Delphi studies, rather than quantitative survey-based approaches. These studies are particularly useful, as their goal is to explore the multiple subjective meanings naturalness takes for different people. As such, these studies do not assume a singular definition as does most survey work.

Key studies include those by Grove-White et al. (1997) and Marris et al. (2001). Both highlighted that concerns about naturalness were often rooted in a sense that GMOs involve a shift towards a discomforting way of life. They also found that GMOs were perceived as involving a means and pace of change that seemed out of 'balance' with an existing equilibrium.

More recently, a study by Mielby et al. (2013) found five 'lines of arguments' used by participants to reason about the naturalness of the case studies presented: 'history-based', 'substance-based', 'feature-based', 'harmony-based', and 'acquaintance-based'. The authors emphasize that while much of the conversation around naturalness in the psychological literature has focused on feature-based components as biologically (dis)similar or not natural, other important lines of argument may be at play. Ditlevsen et al. (2020) have built upon this work, evaluating Mielby et al. (2013)'s lines of argument. A study by Deary and Warren (2017) offers a similar approach, revealing four ways of thinking about rewilding initiatives: Some participants emphasized ecological diversity and integrity; some valued self-regulation of an autonomous nature with minimal human intervention needed; another valued creation of an experiential sense of wildness for people's recreation; and a last group prioritized preserving historical and cultural values of the landscape.

4.3. Environmental planning

The next cluster of studies are the product of environmental planning and most use visualization-based (quantitative) surveys to understand perceptions of landscapes—particularly to explore what aspects of landscapes tend to be associated with greater or lesser degrees of perceived naturalness. These approaches generally do not assume a *prima facie* definition of naturalness. Qualities or features that people have been found to associate with natural (or wild) landscapes are: density of vegetation and more structurally intact forms of vegetation (Purcell and Lamb, 1998); woodlands with greater levels of succession and numbers of patches (Ode et al., 2009); higher perceived biodiversity (Dallimer et al., 2012); landscapes that appear less 'tended' (Martens et al., 2011); and perceived ruggedness and remoteness from mechanized access (Chang Chien et al., 2020). Some findings from this field also may indicate that the elicitation of the experience of 'awe' could serve as an indicator distinguishing some landscapes as more natural than others: Cottet et al. (2018) found that people tend to gaze longer at landscapes that they perceive as more fully natural.

4.4. Social construction of nature

Anthropologists, geographers, sociologists and historians have all taken qualitative approaches to examining questions of naturalness, making use of methods such as ethnography, document analysis, and archival research. Instead of attempting to define naturalness, or to define how participants think about the concept, many of these studies deconstruct assumptions about naturalness prominent in both academic discourse and broader public conversation. While difficult to encompass all of the work in this category, much of it acknowledges that humans shape both how we think about nature and how we materially create it (Demeritt, 2002).

These approaches apply and produce understandings of nature as culturally, historically and geographically situated and contingent. A key contribution of this approach is the demonstration that 'nature' and 'human' cannot be disentangled (Haraway, 2007; Latour, 2011). For instance, scholars have debunked the assumption that Europeans settled untouched wilderness when they arrived in the Americas (Anderson, 2005; Cronon, 1996; Sutter, 2013). Scholars here have also emphasized that 'natural' is temporally dependent, highlighting how ideas of naturalness have changed over time. This group of scholars has explored what might be involved in an environmentalism that moves beyond dualist notions of nature (e.g., Lorimer, 2012). Related is the insight that 'naturalness' is not a singular category but rather a subjective construct that can take on different meanings depending on the context. Indeed, these 'meanings' are wide-ranging; Macnaghten and Urry (1999, 1995) have emphasized that efforts to deconstruct nature open up debates about human nature, and relationships and responsibilities between humans, other generations, God, the earth, and other species.

Applying these ideas to conservation and restoration has led to the exploration of distinctions between hybrid, wild and non-wild animals. Fredriksen (2016) demonstrates, for example, that attempts to protect and conserve the Scottish wildcat have led to the exclusion of care for some individual (hybrid) animals that resulted from wildcat that interbreeding with domestic cats. According to this thinking, conservation practices may defend (arbitrary) boundaries rather than nature itself. Examples of related studies include Harrison et al. (2019), Rutherford (2018) and others. Among this group of scholars, distinctions between in situ and ex situ conservation, also highlights the construction of nature as 'in' or 'out of' place (Braverman, 2014).

4.5. Indigenous ways of knowing

A noteworthy and rapidly expanding category of research involves Indigenous ways of knowing. This encompasses a range of approaches that directly and indirectly explore how Indigenous peoples have conceptualized nature and their relationship to it. This broad range of work includes an emphasis on understanding nature through relationships, including anti-dualist theories of nature and thus criticism of assumptions rooted in the idea that nature is or can be controlled by humans. Indigenous approaches tend to emphasize instead human connections, relationships, and dependencies on nature (Duncan, 2020; Turner et al., 2000). Applications of these ideas to new technologies include Barnhill-Dilling and Delborne's (2019) exploration of Indigenous responses to restoration efforts for the American chestnut and the use of genetic modification. While the modified chestnut might offer spiritual, cultural, or other benefits, some Indigenous (Haudenosaunee) community members disapprove of the control-based approach such possibilities entail; relationships with the trees and with nature, the authors found found, involved people as 'managers' or 'manipulators'. Mäori concepts of genealogy or interconnectedness of human and nonhuman descent (*whakapapa*), intrinsic spiritual integrity or the potential power of things (*tapu*) and the elemental energy or life force (*mauri*) are relevant to how communities perceive the acceptability and naturalness of genetic engineering (Roberts et al., 2004). Similarly, Bowman (2017) has found that while some scientists have claimed to have bred improved wild rice that is genetically identical to the original wild rice, some Anishinaabe communities disagree with this understanding, citing important phenotypic differences (such as the ability of seeds to shatter and thus be reseeded, as traditionally practiced). Lastly, 'land healing' offers an Indigenous reconceptualization of colonial 'Eden-based' restoration goals that assume the goal is to return to an ecosystem's prior, 'untouched' state (Grenz, 2020).

4.6. Conservation science

The last group of studies emerge from scholars and practitioners of conservation science. This small body of literature encompasses natural science approaches that tend to situate themselves in relation to rapid anthropogenic ecological changes. (We have discussed other social science work on conservation above, in the 'Social construction of nature' section.) A key line of study in conservation science explores metrics that might be applied to measuring the naturalness of an ecosystem. Criteria for such metrics tends to emphasize natural ecosystems as those that have not been influenced or disturbed by humans (Anderson, 1991; Hunter, 1996; Machado, 2004). For example, Anderson (1991) proposes that a natural ecosystem is one that (1) would not change if humans were removed, (2) does not require additional energy to maintain its current functioning, and (3) contains similar species compared with those prior to human settlement.

A more recent stream of scholarship challenges the assumption that 'natural' ecosystems are those that harken back to a certain past ecosystems. In different ways, each of these scholars asks whether any definition of 'natural' needs to shift to accommodate the challenges of anthropogenic climate change. A key proposition from this group is the suggestion of using measures of ecosystem functionality as an alternative metric to historical fidelity, in order to aid in the evaluation of ecosystem quality and the setting of management goals (Baker et al., 2013; Hallett et al., 2013).

5. Putting it all together: evaluating our framework in light of empirical studies on naturalness

Now we return to our original set of definitions of naturalness and evaluate them in light of the range of diverse empirical findings we reviewed in the last section. Our overarching purpose is to highlight particular logics that might be articulations of key objections or rejections of agricultural and conservation applications of novel GE. We ask: which definitions are supported by empirical evidence, either from the studies explicitly focusing on naturalness discussed above, or other empirical works? What can each definition explain or not explain? Are some definitions particularly challenging to apply to specific contexts or technological applications?

5.1. Evaluating Nature 1a ("Something is natural if it is independent from humans")

Mielby et al. (2013) and Ditlevsen et al. (2020) find similar evidence of people thinking about naturalness using the 'history-based argument' they identify; that is, something is unnatural because it is "a product of human interference" (p. 477). The landscape perceptions literature also echoes this approach, indicating that people view natural landscapes as ones that have less evidence of human-induced change (Chang Chien et al., 2020; Foo, 2016; Hoyle et al., 2019; Ode et al., 2009; Purcell and Lamb, 1998).

This definition of naturalness explains a number of rapid intuitions about what is natural or not (e.g., that many see wild landscapes as more natural, and cities as less natural; or that some might see a fish caught from the sea as more natural than farmed fish). On the other hand, this definition is 'continuum insensitive' and so it is difficult to determine a threshold past which something becomes 'too' influenced by people to be seen as part of nature. For example, this definition does not clarify why synthetic fertilizers may be seen as less natural than organic fertilizers, as they arguably result in similar amounts of human involvement in agriculture. The definition also does not explain why any forms of agriculture might be seen as natural, given that agriculture is not independent from human intervention.

5.2. Evaluating Nature 1b ("Something is natural if it is lacking in intentional human effort")

As with Nature 1a, the history-based argument originally discussed in Mielby et al. (2013) and also in Ditlevsen et al. (2020) supports this logic. Scholars of landscape perceptions also seem to give credence to this logic. It might explain why some GE proponents view gene editing as an expedited version of similar evolutionary processes, whereas members of the organics sector disagree. Because this logic does not distinguish between degrees of intentional effort by humans, it too tends to be categorical. Therefore, any involvement of humans would, by this logic, render something unnatural as might indirect impacts by humans. For example, objects or ecosystems said to be 'less natural' might include wild reindeer suffering Chernobyl-derived genetic mutations; despite being 'wild', many likely would perceive them to be less natural than farmed reindeer (Deckers, 2020).

5.3. Evaluating Nature 1c ("Something is natural if it is autonomous")

While there is no evidence of public perceptions of naturalness as informed by understandings of 'autonomy', Ditlevsen et al. (2020) found that experts expressed concern around more 'autonomous' or living applications of synthetic livestock vaccines. These they saw as more natural yet less controllable, and thus riskier, than conventional vaccines involving more controllable materials. A focus on autonomy might help explain why a perennial garden may seem more natural to many than a commercially farmed field, as the former at least appears to persist on its own, while the latter appears to require more external inputs to continue to exist. A focus on naturalness defined as 'autonomy' might also be used to evaluate an organism's ability to adequately 'fight back' against undue intervention from human tinkering. In practice, however, it is not fully clear how this logic might differ from Nature 2b (essence) and 2d (biological functionality), both of which are discussed further below.

5.4. Evaluating Nature 2a (*"Something is natural if it is in accordance with the 'natural order'"*)

This definition of naturalness might offer two different interpretations. First, the 'natural order' of things could be a religious question, defined as 'the natural order as determined by God'. Such a definition is hard to explore without delving into an array of religious beliefs, but a number of studies have indeed demonstrated that people evaluate technologies on the basis of whether they involve humans 'playing God' (e.g., Amin et al., 2010; Rose et al., 2018); several studies have demonstrated an explicit connection between concerns about naturalness and concerns about 'playing God' (Ditlevsen et al., 2020; Dragojlovic and Einsiedel, 2013). Participants' discomfort with the new 'way of life' introduced by GMOs, as found in qualitative studies by Grove-White et al. (1997) and Marris et al. (2001), also substantiates these logics.

A second way to interpret the 'natural order' is as a non-religious sense of believing that things should be kept 'in their place'. By this definition, something follows the natural order if humans do not overstep or overreach implicit bounds or demonstrate excess hubris. Evidence of something being unnatural when it is seen as 'messing with' or 'tampering with' nature might fall into this category (Kohl et al., 2019; Shaw, 2002). Applying this definition to explore further contexts or applications of GE is nonetheless difficult as it is not obvious what such a natural order, God-designated or not, would or would not include, thus rendering this definition challenging to apply.

5.5. Evaluating Nature 2b (*"An organism is natural if it is in alignment with its essence"*)

Indigenous attitudes towards and understandings of genetic engineering and genetic research also support this logic. Anishinaabe understandings of phenotypic differences might be interpreted as capturing a sense of identity or 'essence' beyond scientific 'genetic' identity (Bowman, 2017). Similarly, Mäori concepts of the intrinsic spiritual integrity or the potential power of things (*tapu*) or the elemental energy or life force (*mauri*) might also align with essence-based thinking (Roberts et al., 2004).

Swiney (2020)'s findings suggest that some people might be less opposed to synthetic biology—where genes are created from scratch—than transgenics, which involves the combination of genes from different non-sexually compatible species. These findings support the idea that people may view organisms and genes as having an 'essence'. Other evidence for the salience of this definition includes the observation that some members of the organic sector have expressed opposition to biotechnology on the grounds that it interferes with the integrity of the cell (Lammerts Van Bueren et al., 2003). This definition may draw upon ideas of cells or organisms having an essence. Despite this evidence from a range of sources, a key challenge to applying this logic is determining the basis by which people form ideas about the telos or purpose of an organism, population, or landscape. Another challenge is distinguishing between this logic and Nature 1c (autonomy) and Nature 2d (biological functionality, discussed below).

5.6. Evaluating Nature 2c (*"Something is natural if it is in accordance with a historical baseline"*)

Mielby et al. (2013)'s 'feature-based' argument offers evidence for the salience of this definition: the authors found that some individuals might perceive the addition of a native gene or trait as more natural than the addition of a novel trait, suggesting that a return to an organism's 'past state' is seen as natural. Similarly, Zwart (2009) has argued that people may define a natural 'way of life' as linked to the type of agriculture that arose during the Neolithic era known as the 'Common Human Pattern'. By this logic, people may view Neolithic agriculture as more natural, because they have a baseline whereby any techniques developed before that time are deemed natural and any techniques after unnatural. The logic for these baselines is, however, unclear.

5.7. Evaluating Nature 2d (*"Something is natural if it is biologically functional"*)

The approaches to naturalness offered by conservation biologists and ecologists seem to offer credence for both this and the next definition of naturalness–that is, that something is natural if it supports an organism's functioning. This definition can explain why many tend to see actions that support an organism in thriving to be natural—for example, it appears 'natural' that a fish would swim in water—perhaps because the fish evolved to function in that environment. However, this definition cannot explain why enhancing crops to survive, such as by genetically modifying them to be more drought- or pest-resistant, is sometimes rejected by people as unnatural. A note is that the distinction in practice between this logic and Nature 1c and Nature 2b requires further clarification.

5.8. Evaluating Nature 2e (*"Something is natural if it is ecologically harmonious"*)

It is difficult to clearly differentiate biological functionality from ecological harmony, but we suggest defining the latter as emphasizing systems and connection, while the former emphasizes individual organismal thriving. The 'harmony-based' reasonings originally cited in Mielby et al. (2013) and in Ditlevsen et al. (2020), by which unnatural crops were seen as "upset[ting] the delicate balance of nature" (p. 476), offer support for this definition; so does the discomfort with nature 'out of balance' found in Grove-White et al. (1997) and Marris et al. (2001). Studies of landscape perceptions also offer some indication that people tend to view landscapes with higher amounts, densities, levels of succession, number of patches, intactness and related features of vegetation as more natural (e.g., Purcell and Lamb, 1998; Foo, 2016). These factors may correspond, implicitly, to intuitions around a preference for ecological functionality.

An advantage of this logic is that it gives space for 'functionality' to change in the context of climate change. In other words, while a given species may have an important functionality in its current ecosystem, it may be less relevant or important in a future version of that ecosystem: does that mean that it will be less 'natural' in the future? On the other hand, 'harmony' is a vague concept; what does it mean, operationally? This definition also does not address the fact that ecologically based approaches such as organic agriculture may potentially have indirect negative environmental effects—for example, if organics result in lower yields and thereby displace wilderness lands (Seufert and Ramankutty, 2017). In other words, the logic does not fully account for system-wide effects, focusing instead only on the harmoniousness (naturalness) of a specific, isolated ecosystem.

5.9. Evaluating Nature 3a (*"Something is natural if it satisfies moderate needs"*)

While we are not aware of literature that demonstrates this as a way people think about the naturalness of biotechnologies, a paper by Helliwell et al. (2019) discusses 'necessity' as a factor in environmental NGO actors' reasoning about gene editing. In other words, some people may be more apt to view a technology as natural if it appears to have no other substitutes or alternatives; we suggest that one way to make sense of this logic is to think about how 'necessary', for themselves or society, one might perceive a modification or intervention to be. This definition might also contribute to explaining why nutritious foods may be seen as more natural (e.g., fruit), and more indulgent foods (e.g., donuts) might be seen as less natural. Of course, defining "moderate" needs is not straightforward.

5.10. Evaluating Nature 3b ("Something is natural if it is familiar")

'Acquaintance-based' rationales found in Mielby et al. (2013) and Ditlevsen et al. (2020) echo this definition, wherein people found entities unnatural if they were unacquainted with them. This definition can explain why many tend to view things that they are more familiar with as more natural, but it fails to explain why some things, even after they have become quite familiar with them (such as GM crops), never appear 'natural' to some. As well, this is a challenging logic to apply systematically, as it is a moving target—by this definition, whether something is natural or not will constantly shift.

5.11. Evaluating Nature 3c ("Something is natural if it is supportive of cultural, social and spiritual relationships")

While at first glance it might seem misplaced to separate the 'spiritual' from 'the natural order as defined by God(s)' (Nature 3a), evidence suggests that people may conceive of naturalness in terms of more broadly defined spiritual relationships with the natural world. For example, Deary and Warren (2017) found people to understand Scottish wildernesses as containing a spirit or spiritual value. Indeed, 'awe' in response to nature or wilderness, religious or otherwise, has been a key aspect of philosophers' musings on nature (Cronon, 1996; Ridder, 2007). Scholarship on Indigenous understandings of nature has also highlighted such relational understandings. For example, in studying wild rice Bowman (2017) found that Anishinaabeg view this rice as 'belonging', or having meaning, only within relationships. The effect of this is that when wild rice, or knowledge about it, is commodified, the rice no longer has the same meaning or significance. Mäori ideas of *whakapapa*, or successive human and nonhuman generations, highlight that ideas of relationships relevant for understanding what is 'natural' or 'unnatural' GE may be based not in genetics, but in ecosystem-based, spatial, temporal, and morphological associations (Roberts et al., 2004).

Understanding nature relationally contrasts market practices of commodification with practices of gift giving, such as those discussed extensively by Kimmerer (2013). The concept of 'gifts' or 'contributions' has also emerged as a response informed by Indigenous peoples and others to the concept of ecosystem services. This response is evidenced via the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which shifted in 2015 from speaking of 'Nature's Benefits to People' to 'Nature's Contributions to People', in efforts to capture broader worldviews and knowledge systems that emphasize, in part, relationships and relational values (Kadykalo et al., 2019). Arguably, part of the power of this logic of naturalness is that it de-emphasizes object-focused definitions and as such forces an acknowledgment that what defines 'natural' might not be specific to a given entity or object.

6. Analyzing applications of GE in agriculture and conservation: Which logics of naturalness apply?

In this section we offer a thought experiment, wherein we introduce 10 sample applications and use them to explore the potential usefulness of the logics discussed above. The purpose of this thought experiment is to offer an applied context in which to further evaluate which logics of naturalness offer specific conditions for evaluating novel GE. We have selected exemplar applications of GE to both make this question more tangible, and to apply these logics to the new (often yet understudied) applications that are emerging. Table 3 briefly summarizes each application and offers a 'comparator' for evaluation purposes. [A full

Table 3
Applications of GE for the thought experiment.

Application		Brief description[a]	Comparator
Non-browning apple		Apples edited to not brown to avoid food waste	Conventional apple that browns
Tomato with re-introduced heirloom traits		Supermarket tomatoes edited to add back lost heirloom traits for sweetness	Conventional supermarket tomato
Disease-resistant cacao		Cacao trees edited to be more resistant to diseases that will worsen with climate change	Unmodified cacao
Micro-organisms with enhanced nitrogen fixation		Micro-organisms edited to fix more nitrogen to avoid use of synthetic	Unmodified soil micro-organisms, and/or use of synthetic fertilizers
Hornless cattle		Dairy cattle edited to be hornless (and pass on hornless genes) to avoid painful polling processes	Conventional dairy cattle that require polling
Lab-grown meat		Development of synthetic or 'lab-grown' meat to avoid animal cruelty and emissions	Meat from animals
Rodent control for island biodiversity conservation		Release of rodents in island biodiversity hotspots with genes edited to produce sterile offspring to gradually reduce rodent population and help conserve biodiversity	Rodents controlled via conventional measures, e.g., rodenticide
Blight-resistant American chestnut		American chestnut edited with disease-resistant gene from wheat to be blight resistant to help save vulnerable tree species	Unmodified (blight-prone) American chestnut
De-extinct wooly mammoth		Release of elephant edited to look and function as the (now extinct) wooly mammoth to help support ecosystem function and carbon storage in Arctic tundra	No re-introduction of the mammoth
Heat-tolerant coral reefs		Corals edited to be more tolerant of warmer oceans	Unmodified coral reefs

[a] See Appendix 1 for full description of applications.

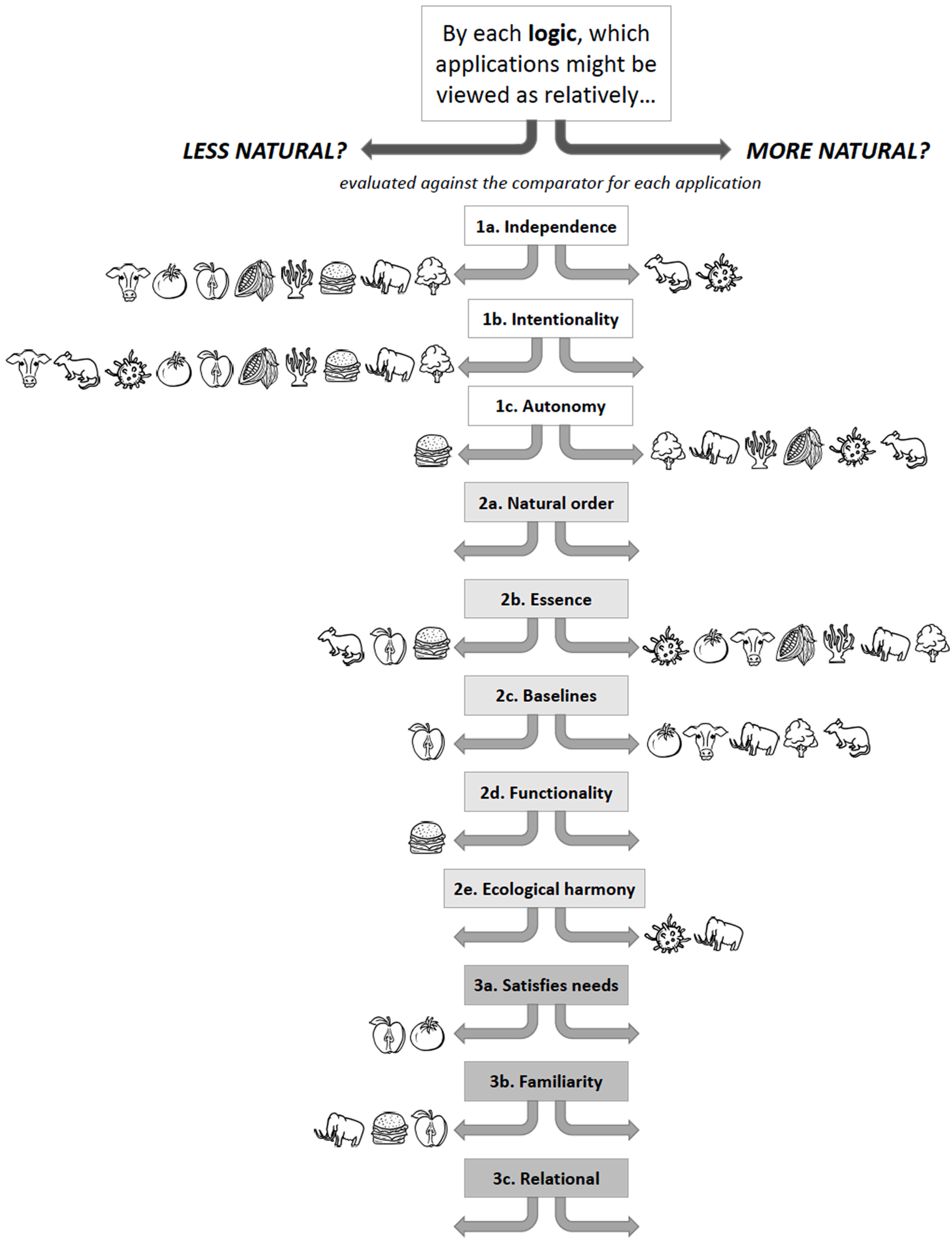

Fig. 1. Which logics might be relevant for sample applications of GE? Some hypotheses.

description for each application can be found in Appendix 1.][3]

Fig. 1 summarizes the results of this thought experiment. We emphasize that these are possibilities, conjectures, or hypotheses, rather than claims. Our goal is to imagine how each of these logics might be applied to these applications, and to ask if they are useful in thinking through the ways people might view the 'naturalness' of each application, or not. These suggestions might also be used to develop questions for focus groups or a survey or assist in other future empirical investigations that explore attitudes towards novel GE.

6.1. Applying Nature 1a ("Something is natural if it is independent from humans")

The apple, tomato and cacaoexamples all involve comparators that are domesticated plants/animals. Thus we suggest that it is unlikely that people will view these novel applications as any more dependent on humans than comparator examples. This line gets blurrier when turning to micro-organisms, which are arguably more independent of human agricultural control, and with lab-grown meat, which arguably less. Conservation applications blur things further still, however much 'wild' animals may involve active management. For example, it is difficult to argue that coral becomes 'more dependent' on humans when it is engineered: it is possible that it becomes less susceptible to human-caused ocean warming, and as a result of this intervention, more able to function. Thus, the logic of 'independence from humans'—while seemingly straightforward—is a challenging logic to use as a rubric for hypothesizing people's perceptions of naturalness, as it is arguably not sufficiently discriminatory.

6.2. Applying Nature 1b ("Something is natural if it lacks intentional human effort")

All the applications discussed here involve the intentional modification of genomes by humans. However, such intentional modification is possibly less relevant in the case of gene drives, such as dehorned cattle or release of rodents, or in the cases of releasing de-extinct mammoths or creating heat-tolerant coral reefs or blight-resistant American chestnuts. In these applications, future generations will not themselves be directly modified, but instead will inherit genes that had been modified in generations prior. Thus, people might view the first engineered generations as unnatural, yet it is unclear if future generations would be seen similarly. There is currently minimal empirical research on how people might think about these offspring generations.

6.3. Applying Nature 1c ("Something is natural if it is autonomous")

By this logic, the apple, tomato, and cattle applications are just as autonomous as their comparators, as they are still controlled by humans who farm and manage them. Micro-organisms are also not clearly either more or less autonomous because of this intervention. Similarly, in the cacao application, some might view modified cacao trees as more autonomous from humans because they require farmers to conduct fewer disease management practices; others might not pay attention to this. Such thought processes might also apply to the American chestnut and coral reefs applications, as these are both actively managed via conservation practices.

The logic of autonomy may be most useful in explaining people's perceptions of lab-grown meat as unnatural, as it involves the development of a tissue that does not have an ability to function as an independent, whole organism. But does the tissue's lack of 'aliveness' mean that people are less likely to view this lack of autonomy as unnatural? Difficult existential questions arise around questions of autonomy as they related to question of life itself, or (threats to) the existence of a species. The rodent application raises questions around whether curtailing life will be perceived as unnatural. Might people view a rodent gene drive as unnatural because rodents' ability to live has been limited by humans? Is the wooly mammoth natural because its ability to live has been reinstated (or is it less natural, because it is only due to humans that its existence has been returned)?

6.4. Applying Nature 2a ("Something is natural if it is in accordance with 'the natural order'")

This logic is challenging to apply in that some people may see *any* type of intervention in genes as unnatural, when 'unnatural' is understood as human overreaching, defined in accordance to either God or some other sense of moral correctness. Thus, we do not offer any hypotheses as to which of these applications might engender a sense of unnaturalness along the lines of this logic, but emphasize that this does not mean the logic does not apply—simply that further study is needed to develop hypotheses around how it might affect perceptions of (un) naturalness.

6.5. Applying Nature 2b ("An organism is natural if it is in alignment with its essence")

It is possible that some may perceive the apple application as unnatural because it introduces a trait not originally found in apples; in other words, some may perhaps feel that browning is part of what 'makes an apple an apple'. The opposite may be true for the tomato: some might view this application as 'restoring' the tomato's essence by reinstating lost traits. For the cacao, American chestnut, wooly mammoth, and coral applications, it is possible that some might perceive this application as natural because the interventions support their growing and flourishing and thus their essence—although this logic overlaps with others, namely ecological harmoniousness and biological functioning.

People might not view the cattle intervention as changing the essence of cattle, as hornless beef cattle already exist, and thus the removal of horns might not appear to affect their essence. As with the autonomy logic, we wonder about this logic as it applies to non-living products, or potential population reductions. For lab-grown meat, it is unclear: would it offend people that such tissue be deprived of having an essence, or a link to a living organism? Or would they find this application unproblematic, not feeling preoccupied about questions of 'essence' at all? For the rodent application, does reducing a population offend people's sense that the essence of the organism is being threatened—or do they accept the removal of rodent 'essence' because it is a pest species (or neither)?

6.6. Applying Nature 2c ("Something is natural if it is in accordance with historical baselines")

Some may perceive the apple to be unnatural because the non-browning trait does not have a historical antecedent; whereas they might perceive the tomato as natural because it represents a return of traits that have existed in past tomatoes. They might perceive the cacao as no more or less natural, given that this case does not involve a new kind of cacao tree in terms of function or appearance, but rather in its ability to survive disease. For micro-organisms, it is not clear that people have a salient memory of microorganisms against which to judge this application and so historical baseline logics are likely less relevant here. For the cattle application, it is possible that because beef cattle are hornless, there is indeed a precedent for hornless cattle to appear 'natural'. The chestnut, wooly mammoth, and coral applications involve

[3] While people do not necessarily view non-GMO organisms as 'natural' (Grove-White et al., 1997), we thought that this thought experiment benefited from the clarity of offering an example for comparison. Furthermore, we do know that people tend to view GMOs as relatively less natural than conventionally bred organisms (Frewer et al., 2013).

supporting species that either exist today (though threatened) or existed in the past, and thus are likely seen as relatively natural following this logic. Similarly, the rodent application involves returning islands to their historical baseline, and thus may be perceived as more natural. For lab-grown meat, it is not clear what the historical baselines would be; might people view it as lacking a historical precedent and thus as unnatural, or would they instead disregard this logic as irrelevant?

6.7. Applying Nature 2d ("Something is natural if it is biologically functional")

We do not anticipate that people would view the apple, tomato, or cattle as more or less natural according to this logic, as those applications do not appear to facilitate greater biological functionality. For the cacao, American chestnut and coral, it is possible that people may perceive improvements to biological functionality, given that each of these applications improves the organism's ability to thrive. That is less true for the micro-organisms or the wooly mammoth, where the interventions are more useful for broader ecosystem functioning than their own individual biological functioning. We hypothesize that the rodent application might be seen as unnatural by biological functionality arguments, as the rodent population is being reduced via a diminishing of their ability to thrive. This logic might motivate a sense of the unnaturalness of lab-grown meat if people view its lack of life as evidence of a lack of ability to function.

6.8. Applying Nature 2e ("Something is natural if it is ecologically harmonious")

It is not immediately obvious how this logic would apply to the agricultural applications (apple, tomato, cacao, or hornless cattle), unless they were to be integrated into more agroecological approaches. It does not seem to apply to lab-grown meat, which does not exist in an ecosystem. The micro-organisms might be perceived as more natural because they rely on natural processes and reduce reliance on synthetic fertilizers. Rodent control would be ecologically harmonious, helping support island biodiversity rather than letting it get overrun. Similarly, the American chestnut application might also have positive effects on the broader ecosystem, as might the coral reefs, which are important in supporting their broader ecosystems particularly in the face of climate change. Last, the wooly mammoth may also have climate-relevant effects, via the preservation of Arctic permafrost via mammoth trampling.

6.9. Applying Nature 3a ("Something is natural if it satisfies moderate needs")

We interpret this logic as relevant to whether the intervention is necessary or not. It is possible that inserting genes for the non-browning trait into the apple would be deemed 'unnecessary'. It is also possible people would view the tomato application as less necessary, as its purpose is for largely for flavor. But this question of what is 'necessary' or not becomes increasingly hard to answer, as it involves making claims about how people will respond to ethical tradeoffs. For example, will people view the coral intervention as necessary because oceans are warming, and coral dying off? This logic seems crucial, yet is challenging to use to develop hypotheses, as different people are very likely to interpret these tradeoffs quite differently.

6.10. Applying Nature 3b ("Something is natural if it is familiar")

One of the challenges with this logic is that it is particularly variable. For example, if people get used to an application or intervention, will they view it as more natural? Lab-grown meat may be perceived as unnatural simply because it is unfamiliar—but that also may be already changing in the age of the Impossible Burger. The mammoth application introduces an interesting question: is it enough that they know 'of' the mammoth from history books or television shows in order to perceive it as familiar?

6.11. Applying Nature 3c ("Something is natural if it is supportive of cultural, social, and spiritual relationships")

The cultural, social, and spiritual relations logic, as with other relational-based logics, is somewhat ambiguous and very context-dependent. Below are a few conjectures about what this kind of logic might entail.

It is possible that some may perceive the modified apple as unnatural because it affects an existing relationship between people and apples: this relationship involves a long history and intimate sense of connection between humans and this fruit, indicated by symbolism (e.g., apple on the teacher's desk) and narrative history (e.g., Johnny Appleseed). This could also be the case with the tomato, the cattle, and perhaps the cacao. We imagine that people are less likely to feel a cultural, social, or spiritual relationship with micro-organisms—yet of course, some may or do. It is less clear to us what people will feel regarding lab-grown meat—some may see this as eroding cultural and social relationships between people and cows, yet for others they may see this as improving the relationship between humans and cows, who are no longer abused for food.

In the context of the conservation applications, this logic is not easily understood. Some may see these applications as facilitating an organism or ecosystem's ability to thrive and thus see them as 'natural'—but others may disagree, and instead see these technologies as interfering in broader social, cultural, and spiritual relationships. While generating related hypotheses are challenging, we suggest this is likely an important logic that bears further empirical investigation.

6.12. Reflections on this thought experiment

The exercise above offers a few useful insights into the utility of logics of naturalness as a lens to understanding people's ethical grappling with novel GE. We notice that many definitions might explain people's ideas of what makes something 'natural', but some of these are general and so difficult to evaluate. The relational logics of Nature 3 are arguably the most challenging to evaluate, as applying them would need to consider an individual or group's particular values and worldviews. Yet, as we will discuss in our concluding section, they are some of the most important. These require, perhaps, more context to understand their value than we have been able to provide in this exercise.

There are also some outstanding confusions. For example, Natures 1c, 2b, and 2d all share considerable overlap; it is not fully clear how to distinguish between 'autonomy', 'having an essence', and 'biologically functioning', as all relate (albeit somewhat differently) to notions of having life, being able to (independently) thrive, or being able to fulfill some sort of goal or purpose. Another confusion is between Nature 3a and 3c: if people view GE as unnatural because it signifies a controlling or manipulative relationship towards nature (such as in Barnhill-Dilling and Delborne, 2019), should that be interpreted as a Nature 3a logic, because it violates the perceived natural order of people in relation to nature, or a Nature 3c logic, because it is unsupportive of spiritual relations between humans and nature? Might both logics be at play here?

There may be other significant factors not included in the framework that could explain differences in perceived naturalness across these applications. One possibility is the question of salience. Is it possible that in some of the applications, the technological change is simply more obvious? Studies on GM indicate that people do not need to 'see' a difference to oppose it, but this salience might be a potential explanatory factor to consider.

5. Conclusion

This paper has attempted to consider relevant ethical reasonings embedded in ideas about 'naturalness' and 'natural objects'. While concerns around naturalness are often dismissed as 'irrational', we assert that the process of understanding these logics can shed light on dimensions of naturalness rooted in ethics, values and belief systems about the world. As Midgley (2000) argues, gut senses—often dismissed as "mere feeling"—sometimes turn out to be "articulable and legitimate objections, which with time can be spelled out, weighed, and either endorsed or dismissed" (p.1). Parsing different understandings of naturalness can, we believe, help to shift the conversation from one of 'mere feeling' to 'articulable and legitimate objection'. An open-ended exploration of the concept such as that conducted here may serve a purpose in clarifying which values guide technological innovation and the ensuing changes they engender in organisms, ecosystems, and indeed, people. Of course, theorizing can only take us so far; further empirical explorations of naturalness such as that conducted by Mielby et al. (2013), Deary and Warren (2017) and others will be of particular use moving forward to generate more fulsome evidence of how people make sense of the naturalness (or not) of novel GE.

By focusing on 'naturalness', this paper has inevitably excluded several important ethical questions relevant to novel GE in agriculture and conservation. Other ethical dilemmas not discussed here may also arise with novel GE, such as our ethical duties to life forms that humans create, or the potential moral hazard involved in novel technologies (Deplazes-Zemp, 2012; International Union for the Conservation of Nature, 2019; Sandler, 2020). Other important critiques of GE, such as of corporate control or the political-economic systems that GE is seen to underpin (Davis Stone, 2010; Helliwell et al., 2019), may also be subsumed in the language of 'naturalness'. However, as we have shown in this paper, these system-level critiques might also be understood as unwelcome shifts in the relationships that people value. As Wynne (2001) has argued, many of the debates about GMOs have framed objections to 'unnatural interference with nature' or humans 'playing God' as individual objections to technological objects. Yet such a framing obscures the ways that these objections might in fact represent rejection of specific economic, cultural, or political trends.

To conclude, we offer a nudge for broader reflection on the policy implications that specific assumptions about 'natural' entail. 'Naturalness' is a common justification for triggering GE biosafety regulation globally (Nawaz and Kandlikar, 2021); the European Union, for example, asserts that GMOs and now new GE techniques should be regulated if they alter genetic material 'in a way that does not occur naturally' (Court of Justice of the European Union, 2018). Genetic similarity, lack of targeted intervention at the genetic level, lack of combination of genes from different species—are all approaches to 'natural' that biosafety regulations rely upon, globally. With GE complicating the simple 'transgenic or not' dichotomy, regulators are left to rely on opaque and sometimes conflicting ideas of 'naturalness' to justify important biosafety frameworks. Conservation policy is no less fraught. As we discussed earlier, scholars have demonstrated that binary notions of wild vs. society and nature vs. culture underpin much of conservation policy (e.g., Berseth and Matthews, 2021). Assumptions of 'naturalness', defined genetically, phenotypically, phylogenetically, or otherwise, translate directly to specific ideas of how species should be conserved, orienting institutions to support specific species. These policy-relevant implications also suggest that naturalness is not a term that can be easily discarded. As such, ongoing reflection on the diverse meanings and interpretation of 'naturalness' should, we argue, be an area of inquiry for much time to come.

CRediT authorship contribution statement

Conceptualization: SN, TS. Methodology: SN, TS. Formal analysis: SN. Investigation: SN. Data curation: SN. Writing – original draft: SN. Writing – review & editing: SN, TS. Visualization: SN. Supervision: TS. Project administration: n/a. Funding acquisition: n/a.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2022.06.008.

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