ABSTRACT

VALDEZ, RENE XAVIER. Environmental Communication and Perceptions Among Different Age Groups and Expertise Levels. (Under the direction of Dr. Markus Peterson)

This dissertation contains three distinct chapters covering wide-ranging topics related to environmental communication and perceptions. In the first chapter, I examine the role of communication for predicting climate change behavior among adolescents. Engaging adolescents is critical to encouraging climate change adaptation and mitigation. Adolescents are typically more receptive to climate change messages than adults, but further research is needed to understand what factors are most influential in changing behaviors. To better understand how communication with teachers, friends, and family, climate change knowledge, and climate change concern predict climate change behavior, a survey was administered to a random sample of middle school students in North Carolina. Among respondents, climate change concern and discussing climate change with family and friends predicted climate change behavior. Further, students from urban, high socioeconomic status schools were more likely to engage in climate change behavior than students in urban low socioeconomic status schools or rural schools. These results suggest that education efforts should leverage communication with family and friends in programing designed to encourage climate change behavior. Efforts to promote climate change behavior among low socioeconomic status urban and rural adolescents will require an understanding of potential barriers to engagement.

In the second chapter, I examine the potential impacts, ethical dilemmas, and governance needs for de-extinction with a survey of synthetic biology experts. Advances in biotechnology may allow for de-extinction of species, but potential impacts remain uncertain. De-extinct species may improve ecosystem function or hinder conservation efforts and damage socio-ecological systems. To better anticipate impacts, synthetic biology experts from multiple

disciplinary backgrounds were surveyed. A mixed-method approach to analysis integrated quantitative responses regarding perceived likelihood of risks and benefits with qualitative responses, to clarify and provide context. Overall, survey participants indicated de-extinction was more likely to induce hazards, not benefits. Reasons for this viewpoint included a "moral hazard" argument, suggesting conservation policies could be undermined if society comes to believe that species can simply be revived in the future. Pessimistic views of de-extinction were linked to concerns about unclear development paths for de-extinction. Participants suggested several entities to potentially govern de-extinction, including biotechnology regulators and environmental management agencies. Experts believed the public would likely be skeptical about de-extinction, due to concerns rooted in science fiction. Our results suggest future de-extinction efforts may benefit from collaborative efforts between stakeholder groups to explore which concerns are most prevalent among the engaged public.

In the third chapter, I examine the news media framing of invasive rodent eradications on islands. Invasive rodents are a major threat to global island biodiversity and have been eradicated from hundreds of islands. Eradication efforts can be contentious due to animal welfare concerns and risk to non-target species. The news media plays a critical role by providing information and context for eradications. To better understand how the news media frames eradications, I conducted a thematic content analysis of 462 newspaper articles published between 1993 and 2014. Articles were analyzed to determine if eradications were framed as conquests or conflicts. Articles often emphasized key elements of a conquest frame, including recast rules and norms, being on frontiers, positioned heroes against nature, creating drama by questioning the success of heroes, orienting towards the future, and positioning the audience as an awestruck witness. Articles rarely framed rodent eradications as conflicts. Results suggest that unique aspects of

rodent eradications may encourage conquest framing and that cultural contexts of place shape framing between countries. In conclusion, rodent eradication framing by the media has largely supported rodent eradication efforts on islands, but that may change when using different eradication methods or when eradications are planned for inhabited islands.

Environmental Communication and Perceptions Among Different Age Groups and Expertise Levels.

by
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BIOGRAPHY

Growing up, Rene lived in various cities in Maryland, New Mexico, and Texas. In 2009, he completed his Bachelor's of Science in Wildlife and Fisheries Sciences, with a minor in English-Rhetoric, at Texas A&M University. He began his doctoral studies at North Carolina State University in 2013. He will probably do other things after this.

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I thank my parents for inspiring me to go farther. I thank my friends for their help, advice, and comradery along the way. And most importantly, I thank Katelin Hodges, who inspires me every single day.

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CHAPTER 1

How communication with teachers, family, and friends contributes to predicting climate change behavior among adolescents

Abstract

Engaging adolescents is critical to encouraging future climate change adaptation and mitigation behaviors. Adolescents are typically more receptive to climate change messages than adults, but educators and communicators need research-based strategies for optimizing engagement, including information about what factors are most influential in changing behaviors. To better understand how communication with teachers, friends, and family, climate change knowledge, and climate change concern predict climate change behavior we administered a survey to a random sample of middle school students in North Carolina, USA (n= 1,371). We measured climate change behavior with a multi-item scale asking respondents about energy conservation, alternative transportation, and engagement with environmental issues. We found that climate change concern and discussing climate change with family and friends predicted climate change behavior. We also found that students from urban, high socioeconomic status schools were more likely to engage in climate change behavior than students in urban low socioeconomic status schools or rural schools. These results suggest that education efforts should leverage communication with family and friends in programing designed to encourage climate change behavior. Further, efforts to promote climate change behavior among low socioeconomic status urban and rural adolescents may be warranted, but would benefit from further investigation into ideological, physical, and knowledge-based drivers of behavior differences documented in this study.

Introduction

Climate change is expected to have unprecedented global impacts, requiring collective action to mitigate effects and adapt to a changing world. Increased flooding and droughts (Michener *et al.* 1997), rising sea levels (Min *et al.* 2011), and reduced food security (Turral *et al* 2011) all seem likely. Climate change behaviors (CC behavior) including using public transport,

conserving energy at home, and recycling, are important mitigation behaviors that individuals may adopt (Stern 2000; Chawla & Cushing 2007; Peterson *et al.* 2013; Chen *et al.* 2016). Promoting behavior changes that address environmental challenges is a foundational component of environmental education (UNESCO 1978; Hungerford & Volk 1990), but understanding what motivates people to engage in behaviors to address and mitigate climate change is incredibly complex. Knowledge, risk perception, social norms, and belief in personal responsibility towards climate change all influence climate change behavior, but do so in complex and sometimes unexpected ways (Gifford 2011).

Scholars have identified several cultural and psychological barriers to pro-active climate change related behaviors. First, simply presenting knowledge of climate change does not effectively increase engagement or overcome skepticism (Whitmarsh *et al.* 2013). Climate change is a complex topic that even the scientifically literate struggle to fully grasp (Sterman 2011), often leading people to rely on heuristics (mental shortcuts) to assess risk. Some of the most dominant heuristics people rely on are political ideology and cultural worldviews (Kahan *et al.* 2011; Brownlee *et al.* 2013). In short, people tend to get information from, and trust those that think like them (Cohen 2003), leading to over-reliance on politicized and scientifically inaccurate news sources (Hamilton 2011) and selective acceptance of new information that reinforces ideologically-supported beliefs (Kahan *et al.* 2012). Other barriers faced by climate change communicators include the belief that climate change is a distant issue, and that adaptation and mitigation strategies challenge lifestyles (Spence *et al.* 2012; Hulme 2009).

These barriers create a dilemma for those striving to increase climate change behavior among the general public. Communicators can attempt to employ strategic frames for communication that may more effectively reach heterogeneous audiences (Nerlich *et al.* 2010;

Whitmarsh *et al.* 2013). This may include using proximate causes as motivators for behavioral change. For example, governments may 'nudge' consumers towards more climate friendly products by highlighting the energy saving aspects of a product or service (Whitmarsh *et al.* 2013). This approach, however, may be ineffective for critical behaviors that require more effort than green consumerism (Chen *et al.* 2016), or require greater lifestyle changes, such as using public transport (Whitmarsh *et al.* 2013). Similarly, Bernauer and McGrath (2016) found that a simple re-framing of climate change was not associated with changes in support for climate-friendly public policies.

Adolescents may represent a vital segment of the population for climate change communication both because they are the future policy and decision-makers who will live with the major impacts from climate change and because they appear to bring less ideological bias to their assessments of climate change. Climate change forecasts project major impacts, including sea level rise, increased extreme weather events, and food shortages, to become disruptive in the mid-21st century (Pachauri *et al.* 2014). This means that it is critical to prepare today's adolescents to adapt to those impacts and mitigate future impacts as they reach adulthood. Research shows that adolescents differ from adults regarding several aspects of climate change knowledge, perceptions, and behaviors. Generally, climate skepticism is less likely among younger age groups (Feldman *et al.* 2010), and this skepticism may be overcome with education (Stevenson *et al.*, 2014), even though similar efforts may be more difficult among adults (Kahan *et al*. 2012). Stevenson et al. (2014) found that for middle-school adolescents, climate change acceptance increased with climate change knowledge, and did so more quickly among students with worldviews typically associated with climate change skepticism among adults. This may be in part because worldviews are developing and forming during adolescence (Vollebergh *et al.*

2001), and may not influence climate change risk perceptions among adolescents as heavily as they do in adults. Climate risk perception appears to be a key driver of CC behavior among adolescents (Taber & Taylor 2009; Ojala 2012). Some climate change messages (e.g., fear-based messaging decoupled from potential solutions), however, may cause adolescents to psychologically distance themselves from the topic (Ojala 2015).

Despite these findings there is less known about how psychological and social variables shape CC behaviors among adolescents than among adults. In previous environmental education research, low socioeconomic status (SES) negatively predicted environmental behavior (Stevenson *et al.* 2013), but it is unclear if this relationship translates to CC behaviors. Socioeconomic status typically refers to household level economic and educational position relative to others (Bradley & Corwyn 2002). Similarly, studies comparing environmental behavior by residency (urban-rural, urban-suburban) return conflicted results as residency predicts specific behaviors (e.g. rural residents have higher support for conservation behaviors and urban residents engage in more anti-pollution behaviors) but not general trends in environmental behavior (Berenguer *et al.* 2005; Ambrosius & Gilderbloom 2015). Because views on climate change clearly associate with political affiliation in the United States (Dunlap & McCright 2008), and that affiliation aligns with rural and urban divisions (Morrill 2016), comparing CC behaviors between urban and rural schools provides a valuable opportunity to evaluate the extent such divisions have already developed among adolescents. To effectively engage with adolescents, more research is needed to understand the relative importance of the predictors of climate change behavior so that communication strategies can engage those factors in ways that promote individual and collective action among adolescents.

Emerging research suggests that communication type and frequency may be important but underexplored variables related to engaging adolescents in CC behavior. This research suggests that adolescents in families that discuss climate change are more likely to seek information about the topic (Mead *et al.* 2012), and that increased frequency of communication with both groups promotes climate change concern (Stevenson *et al.* 2016). Similarly, a study of adolescents in Belgium suggested parents influence their children's environmental concerns, and more frequent communication raised those concerns (Meeusen 2014). Furthermore, adolescents are more likely to engage in community actions if their parents give them encouragement or approval (Fletcher *et al.* 2000) and adolescent behaviors, in the cases of deviant and risky behaviors, are often mediated by parental relationships (Deković *et al.* 2004). A study of UK adolescents highlighted the importance of informal communication channels, especially involving peers, in developing attitudes of efficacy and responsibility towards mitigating climate change (Devine-Wright *et al.* 2004). Despite these findings, little is known about the role of communication from teachers who serve as important climate change literacy educators for adolescents (Chawla & Cushing 2007). We do know that teachers can improve climate change knowledge among students, especially when students engage in hands-on activities (Taber & Taylor 2009). Teachers are commonly mentioned as significant childhood influences for adults who are concerned about the environment, have positive environmental attitudes, and choose environmental careers (Chawla 1998). General motivation and engagement of adolescents in traditional education settings increases when students perceive high teacher support (Ryan & Patrick 2001).

We begin to address the need to situate the role of communication with teachers in adolescent CC behavior using a case study of middle school students (ages 11-15) in North

Carolina, USA. This study provides a first assessment of teachers' role as climate change communicators. We tested the following novel hypotheses: adolescents who more frequently discuss climate change with teachers in classroom settings, adolescents who come from urban backgrounds, and students from schools with higher SES are more likely to engage in CC behaviors. We include several other important variables in our analyses which allow us to situate communication with teachers within the context of previous research on adolescent CC behaviors. We include frequency of communication with friends and family, allowing us to assess whether previously identified positive effects on CC behavior persist while considering communication with teachers. Similarly, we control for several variables which have predicted CC behavior in previous research (e.g. climate change knowledge, climate change concern, gender (Ojala 2012; Stevenson *et al.* 2013; Stevenson *et al.* 2014) to avoid identifying spurious relationships.

Methods

Sampling

For this study, we surveyed 1,371 middle school students in North Carolina. We first compiled a list of all 770 public middle schools in North Carolina from the North Carolina Department of Public Instruction. We then randomly selected 85 of these schools and compiled a list of all science teachers (n = 377) at these schools using each school's website. We randomly selected 205 of these teachers to recruit, based on published response rates from teachers in the same region, in which an initial contact of 150 teachers was associated with a usable sample of 426 students (Stevenson *et al.* 2014). Given the number of variables tested, we wanted to increase power of analysis by increasing student sample size by at least one third, which gave us a sample of 205. Of these teachers, 58 responded and 30 consented to participate. Each teacher

was asked to include at least one of their classes in the study. An average of 60 students per teacher participated in this study, ranging from 5 to 123 students per teacher. In January 2014, we sent all participating teachers survey materials and instructions by mail. We requested teachers return surveys within two weeks of receiving them, and sent weekly reminders for one month after the deadline. Six teachers did not return surveys, citing lack of time.

Instrument Development

We built on previous studies predicting adolescent CC behavior by including a variable addressing teachers' roles as climate communicators. We measured CC behavior with a multi-item scale asking respondents about behaviors linked to lowering carbon emissions- household behavior, information-seeking behavior, and transportation choice, representing three sub-factors. This scale has been successfully used with adolescents and has previously displayed high reliability (Stevenson & Peterson 2016). To measure climate change knowledge (CC knowledge), we used items that originally tested adults' climate change knowledge (Tobler *et al.* 2012) and have been modified for adolescents (Stevenson *et al.* 2014). For climate change concern (CC concern), we used a scale that has been previously implemented in climate change literacy studies with both adolescents and adults (Stevenson *et al.* 2014; Stevenson *et al.* 2015). We used 5-point Likert scale questions to ask participants how often they discussed climate change (CC discussion) with friends, "How often have you discussed climate change with your friends outside of class (*Never, Once, Two or three Times, Four or five times, More than five times*)" and with their family, "How often have you discussed climate change with your family" (Stevenson *et al.* 2016). A similar 5-point scale question was used to measure CC discussion with teachers, "How often have you discussed climate change at school during class". Combining this question with those addressing established predictors (e.g., knowledge, concern,

communication with friends) allowed us to reduce the likelihood of potentially spurious findings, and to place our findings in the context of other research focusing on knowledge and concern.

Because we modified established scales and generated new items, we conducted quantitative and qualitative pretesting among adolescents to reduce chances of measurement error. The first draft instrument was administered to 27 7th grade students and 33 8th grade students. Students were asked to identify questions that were difficult to understand and make notes for possible improvement. We also completed cognitive interviews (Desimone & Le Floch 2004) with five students to gather additional feedback and suggestions for item wording and clarity, and to assess construct validity. We tested the behavior, knowledge, and concern scales for reliability and validity. We used Cronbach's alpha to measure the degree to which items within a scale were measuring the same construct. An alpha score above 0.9 is considered excellent, a score above 0.7 is considered acceptable (Gliem & Gliem 2003). The alpha scores for the behavioral scale and the knowledge scale were acceptable ($\alpha = 0.78$; $\alpha = 0.72$, respectfully). The concern scale was above the acceptable level of 0.60 in exploratory analysis (Hair *et al.* 2010) and similar to other measures of general risk perception (Weber *et al.* 2002).

Data Analysis

To determine which factors positively predicted CC behavior we constructed a predictive model using multiple linear regression in STATA version 14.1. We examined the overall goodness of fit for our model with an R-squared value. We observed the p-value of each variable to test our hypotheses, and used standardized beta coefficients to compare the relative importance of CC knowledge, CC concern, CC discussion with teachers, CC discussion with family, and CC discussion with friends in predicting CC behavior. We also included school-level variables, urban-rural status and Title I status as controls, which were determined using data

available through the National Center for Education Statistics (NCES 2013). The National Center for Education Statistics categorizes schools into 12 categories (Large city, midsize city, small city, large suburb, midsize suburb, small suburb, fringe town, distant town, remote town, fringe rural, distant rural, and remote rural areas); we collapsed these variables into urban (including all size cities and suburbs) or rural (including all size towns and rural areas). Because IRB restrictions limited collection of personal socioeconomic status data, we used Title I status as a proxy. Title I status is commonly used as an indicator of low SES as these schools receive additional federal funding based on high percentage of low-income students (107th Congress 2002). Urban residency and high socioeconomic status have been considered predictors of environmental concern (Van Liere & Dunlap 1980), but interactions between them are not typically accounted for in studies of environmental literacy among adolescents (Bogner & Wilhelm 1996; Yilmaz *et al.* 2004; Stevenson *et al.* 2013). To test for differential effects of socioeconomic status among urban and rural respondents, an interaction effect between urban schools and Title I status was included in our model. Because political ideologies likely differ between urban and rural populations in our study area (Morrill 2016), and those differences are linked to differential levels of concern among adults (Dunlap & McCright 2008), we included Urban-CC knowledge and Urban-CC concern interactions in our model. Age has been an inverse predictor of environmental concern and behavior among adolescents (Bogner & Wilhelm 1996), and was included using the students' grade. Gender (male, female), and ethnicity (white, non-white) have been associated with differing levels of climate literacy (McCright 2010; Stevenson *et al.* 2014) and were also included as controls.

Results

Our sample included 217 sixth graders, 346 seventh graders, and 812 eighth graders, ages 11–15. The gender ratio was approximately even (51.6% female) and mostly white (63.3%). Most students (65.6%) attended a Title I school, and most (57.8%) attended a rural school. On average, students were moderately informed about climate change, with CC knowledge scored at 14.3 out of 21 (SD = 3.2). Students were also moderately concerned about climate change; the mean CC concern score was 9.6 out of 17 (SD = 3.1). On average, students scored 26.8 out of 50 on the CC behavior scale (SD = 6.6). This average score would reflect a student who *sometimes* recycles at home ($\bar{x}$ = 3.20 on a 1-5 scale; SD = 1.5), *rarely* walks for transportation ($\bar{x}$ = 2.44 on a 1-5 scale; SD = 1.1), and *often* turn off lights at home when not in use ($\bar{x}$ = 4.04 on a 1-5 scale; SD = 1.0). Factor analysis of CC behavior scale confirmed the expected three sub-factors: household behavior, information-seeking behavior, and transportation choice (Stevenson & Peterson 2015). Results for individual survey items for CC knowledge, concern, and behavior, including factor loadings, are available in Supplemental Materials (Tables S1-S3).

Communication about climate change with friends, family and teachers was relatively infrequent. Over half of the students (57.5%) reported that they had never discussed climate change with their friends. Almost forty percent of students (39.9%) reported that they had never discussed climate change with their family and another fifth of the students (20.6%) reported that they had only discussed climate change with their family once. Climate change discussions occurred more frequently with teachers than with friends or family (Figure 1). Only 14.5% of students reported that they had never discussed climate change in class.

Communication with family and friends, CC knowledge, and CC concern positively predicted climate change behavior. Among these variables, CC concern was the strongest

predictor of climate change behavior (Table 1). Discussion with family was a stronger predictor of CC behavior than discussion with friends or teachers (Table 1). The interaction effect for discussion with family and discussion with friends was not significant, and thus not presented in our model. CC knowledge was also a predictor of CC behavior (Table 1). All hypotheses, except for a positive relationship between increased classroom discussion with teachers and CC behavior, which approached significance ($p = .071$), were supported by our model. Post-hoc tests for collinearity suggested no collinearity issues among independent variables (Mean variance inflation factor = 2.2, all variance inflation factor values <5.4) (O'brien 2007).

Among the demographic predictors, an interaction between rural-urban and Title I status and grade level were both negatively related to CC behavior (Table 1). Climate change behavior was low in rural schools regardless of Title I status but much higher among students in non-Title I status (wealthier) urban schools than among students at Title I status urban schools (Figure 2). Interactions between Urban-CC knowledge and Urban-CC concern were sequentially added to the model to avoid collinearity but neither were significant, and we excluded them from our final model. The student's grade inversely predicted CC behavior, students in higher grades were less likely to engage in CC behavior (Table 1). Neither gender nor ethnicity predicted CC behavior after accounting for variance explained by other key predictors (Table 1).

Discussion

Our results provide preliminary evidence that conversations with peers and family may independently predict CC behavior, suggesting pedagogical approaches encouraging discussion about climate change outside the classroom may be particularly important. Although students were far more likely to discuss climate change with teachers, that discussion did not relate to behaviors, whereas relatively rare discussions with family and friends did predict CC behavior.

Thus, teachers may need to leverage frequent engagement with climate change in the classroom (this study) by using pedagogical approaches that encourage peer discussions in the classroom and family discussions outside the classroom. These types of educational interventions may use norms and peer influence from friends and family to impact CC behavior (Ojala 2015; Stevenson *et al.* 2016). Frequent discussion can increase salience of descriptive norms already established by family and friends (Mead *et al.* 2012). Teaching strategies that incorporate group discussions, projects, and informal learning opportunities typically encourage discussion with peers (Maxwell, 2002), and may help solidify behavioral norms if integrated into climate change education efforts. Similarly, assignments which encourage students to talk with or interview parents may increase information-seeking (Mead *et al.* 2012) in addition to promoting family conversations about climate change. Future research identifying the context of climate change conversations with teachers (e.g., which courses) may help unravel the mechanisms driving relationships, or lack thereof, between conversations and climate change behavior.

Given the need for discussion outside classrooms highlighted in our findings, informal learning opportunities may provide another valuable approach for engaging adolescents in CC behaviors. Informal learning refers to free-choice learning, in which the learner decides whether, how much, and how to interact with a particular learning opportunity (Falk 2005). Informal learning can be facilitated at nature centers, zoos or aquaria (Rennie & McClafferty 1995), but also occurs in every-day living around dinner tables, on social media (Robelia *et al.* 2011), or while watching television (Heimlich & Falk 2009). Free-choice learning often occurs in family groups (e.g., parents taking adolescents to a nature center) or with peers (e.g., interaction over social media) (Falk 2005), which provides adolescents opportunities for discussions with the people that our results suggest may be most important in promoting behavior change. Research

has linked informal education to increased self-efficacy (Devine-Wright *et al.* 2004) and climate change knowledge (Sellmann & Bogner 2013), and one study found that adolescents were more likely to seek information and commit to changing their behavior after engaging with climate change content on Facebook (Robelia *et al.* 2011). Initiatives such as the National Network for Ocean and Climate Change Interpretation (NNOCCI 2016), which trains zoo and aquaria interpreters to facilitate conversations around climate change are particularly encouraging, as they may spur discussion among adolescents and their peers and parents. Our results suggest that similar efforts to infuse climate change topics into informal learning opportunities in ways that promote discussion with friends and families may be effective at promoting climate change behaviors among adolescents. Research documenting the ideological basis of such family discussions may be an important variable in future research given the polarized nature of climate change conversations in many locations (Morrill 2016).

The interaction between urban residence and school poverty levels identified in this study may highlight potential barriers for CC behavior faced by rural adolescents and low SES urban adolescents. Ideology, physical constraints on behavior, and action-related knowledge may drive the interaction effect in our study. Rural ideology may explain lower CC behavior among rural students because rural communities nationwide, including in our study site, tend to be more politically conservative than urban areas (Morrill 2016), and Republican political affiliation aligns strongly with doubt about climate change and anthropogenic climate change (Dunlap & McCright 2008). Similarly, rural residents often engage less in pro-environmental behaviors (Jones *et al.* 2003). The divide among urban adolescents identified in this study, however, seems less likely to be driven by ideology given students exhibited similar levels of concern about climate change. Constraints on the ability to act among poor urban adolescents may help explain

the behavior disparity. First, crime and safety concerns may limit walking and bicycling (Cutts *et al.* 2009) and access to open spaces in low SES urban areas (Slater *et al.* 2013). Further, behaviors such as recycling may be limited as low SES urbanites are less likely to have access to recycling facilities (Berger 1997). Urban adolescents may also have less knowledge about which actions may help mitigate climate change, limiting their ability to engage in new or alternative behaviors (Semenza *et al.* 2008). Future research is needed to explain the degree to which physical constraints and knowledge about CC behaviors drive the interaction in this study, but immediate efforts to remove constraints on climate friendly behavior for low SES urbanites and improve their climate literacy may provide key avenues for engaging low SES urban adolescents in addressing climate change. Engaging rural adolescents may be more difficult if politically conservative ideology underlies their lower climate change behavior scores. Evans et al. (2014) suggest that discussing local climate change adaptation increases willingness to engage in future mitigation efforts, even among skeptics, by presenting them with the local consequences of climate change (Evans *et al.* 2014). Because climate change poses a direct threat to the persistence of many rural communities dependent on agriculture (Prokopy *et al.* 2015), both the local challenges posed by climate change (e.g. drought) and urgency associated with addressing them provide fertile material for efforts to highlight local consequences in climate literacy efforts. Future research may further explore specific ways in which environmental education (EE) programming can address some of the potential barriers we highlight (i.e., structural and ideological barriers). Krasny & Tidball (2012) offer that the most successful EE programs may focus on community resilience and action in ways that empower citizens and encourage engagement with local policy systems to overcome structural barriers that are in some cases endemic to urban environments. Further, EE research may be a promising outlet for overcoming

ideological barriers to CC behavior, as some research suggests EE with children may help shape environmental attitudes and behaviors of adults from topics ranging from recycling to more contentious topics like biodiversity conservation (Duvall & Zint 2007). Though this approach is understudied in climate change contexts, it may provide a pathway to addressing ideological barriers among both current and future generations.

The important role of climate change concern may be leveraged to shape how educational efforts promote climate change behaviors among adolescents. Concern about climate change shared the strongest impact on CC behavior, along with the interaction effect, aligning with previous research on climate related behavior. Concern is an especially important emotion for motivating climate change behavior (Smith & Leiserowitz 2014) that can promote information-seeking to decrease risk (Beckjord *et al.* 2008). As opposed to fear based appeals, which can cause people to disengage or dismiss an issue (Smith & Leiserowitz 2014), concern is a less intense emotion that can activate cognitive and analytical processing of risk information, enabling deliberative and iterative decision-making (Smith & Leiserowitz 2014). Future research might further explore the impact of educational efforts that integrate promoting discussion with family with material intended to foster climate change concern and climate change hope (Ojala 2012; Stevenson & Peterson 2015).

Our results build on the emerging research among adolescents by documenting that communication with teachers is the most prevalent way adolescents discuss climate change, but communication with friends and family may be needed to elicit CC behaviors. Thus, climate change education including activities engaging friends and family, particularly via informal learning pathways, may be particularly efficacious way to promote CC behavior among adolescents. The interaction we observed between urban and low SES schools highlights the

importance of place when conceptualizing and reacting to climate change. Our research does have several limitations. First, our observational study could not elucidate causality. Future experimental research could determine if and how different types of climate change communication influence CC behavior. Second, adolescents and educational systems in North Carolina are not necessarily representative of their counterparts elsewhere in the United States or other regions of the world. Fortunately, our findings largely coincide with those from studies with adolescents from diverse places including Sweden (Ojala 2015), the United Kingdom (Senbel *et al.* 2014), and among a nationally representative sample of the United States (Mead *et al*. 2012). Given this widespread consistency in findings from regional research, it seems unlikely that unique attributes of North Carolina would render our novel findings about climate change communication regional in nature. Future research could help unify these regional case studies if scholars within this subject area begin direct collaborations, and design intercultural instruments and treatments that facilitate direct comparison. Our results associated with the urban versus rural divide in CC behavior, however, may reflect novel attributes of our study area. Like much of the United States, North Carolina has become politically polarized, largely along an urban and rural division (Morrill 2016). Perspectives on climate change follow political divides among adults (Hamilton *et al*. 2015) with rural residents less likely to be accepting of anthropogenic climate change. Further, the conservative 2012 North Carolina state legislature restricted local municipalities and other agencies to using sea level rise projections designated and approved by the North Carolina Coastal Resource Commission (Opt 2015), serving as one example of several in which the political climate of our study area may impact individual perceptions of climate change as well as public policy. A geographic divide in CC behavior and beliefs may differ or not exist in other regions of the world, but does highlight how future

research exploring the geography of CC behavior, may provide valuable insights. Although our findings are preliminary, they clearly suggest that adolescents in the most resource starved schools (rural and low SES urban) need additional help to fully engage climate change within their curricula.

Supplementary Material

Supplementary materials for this chapter are in Appendix A.

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Conflict of Interest

None.

Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and the protocol was approved by the North Carolina State University Institutional Review Board (IRB #4099).

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Table 1. Climate change knowledge, concern, communication, and demographic variables predicting climate change behavior among middle school adolescents in North Carolina, USA (n = 1,371). Adjusted R^2 = 0.248.

Independent Variables	Beta	Std. Beta	*p*
Knowledge[a]	0.15	0.07	0.005
Concern[a]	0.53	0.25	<.001
Discussion- teachers[b]	0.24	0.05	0.071
Discussion- friends[b]	0.50	0.08	0.004
Discussion- family[b]	0.95	0.19	<.001
Grade	-0.45	-0.05	0.049
Ethnicity[c]	-0.15	-0.01	0.652
Gender[d]	-0.03	< -0.01	0.919
Title I x Urban	-4.75	-0.25	<.001
Title I[e]	0.71	0.05	0.317
Urban[f]	3.79	0.28	<.001
Constant	15.39		

[a]Knowledge and concern variables were calculated using multi-item scales.

[b]Discussion variables were calculated using the results of 5-point scale questions for frequency of discussion

[c]Student ethnicity (0 = White, 1 = Non-white)

[d]Student Gender (0 = Male, 1 = Female)

[e]School has a Title-I program (0 = Non-Title I, 1 = Title-I)

[f]School categorized as urban (0 = Rural, 1 = Urban)

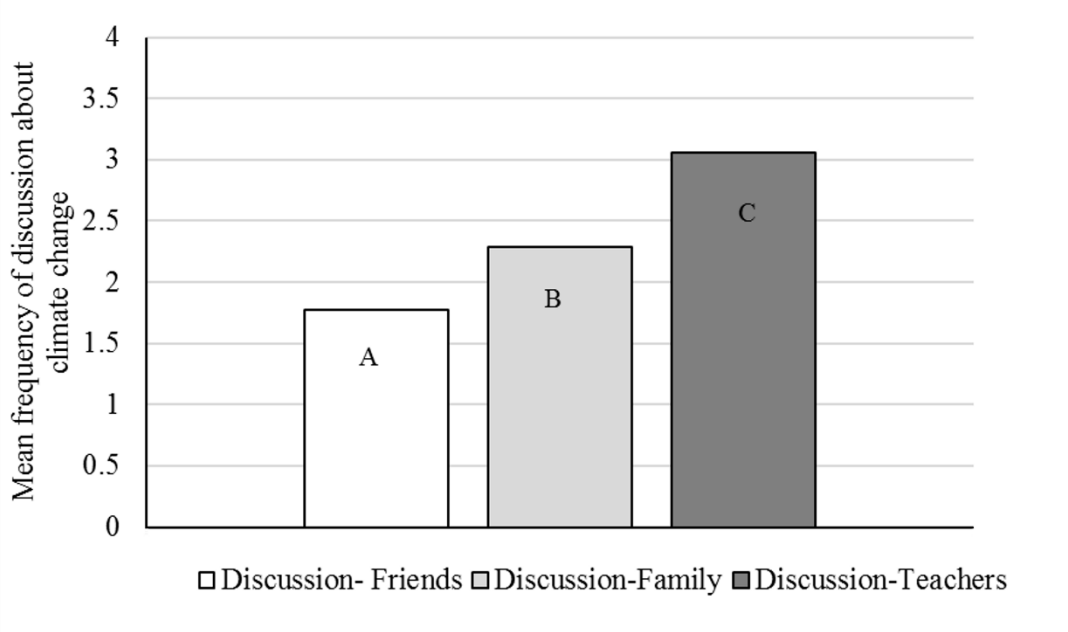

Figure 1. Mean frequency of discussions about climate change with friends, family, and teachers. Means were calculated using 5-point Likert questions for frequency of discussions about climate change (0 = Never, 1 = Once, 2 = Two or three times, 3 = Four or five times, 4 = More than five times). Different letters reflect significant differences based on a one-way ANOVA with Sidak's corrections (F (2, 375.21) p = <.001).

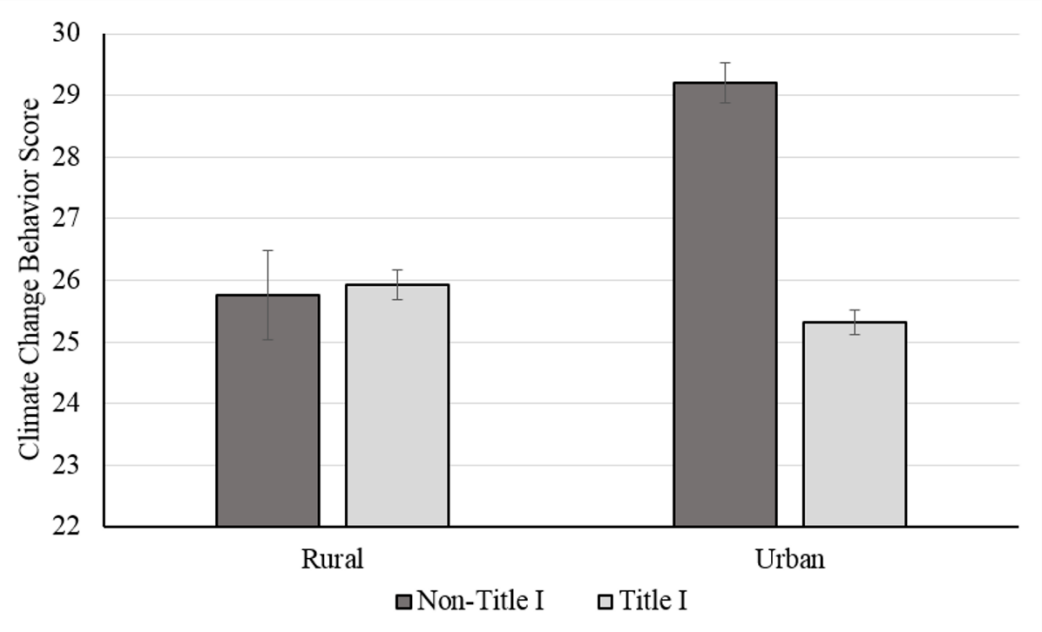

Figure 2. Mean and SE of climate change behavior scores by students attending urban-rural and Title I schools (*n* = 1,371).

CHAPTER 2

Anticipating risks, governance needs, and public perceptions of de-extinction

Abstract

Advances in biotechnology may allow for de-extinction. Potential impacts of de-extinct species remain uncertain; they may improve ecosystem function and re-invigorate the conservation movement, or hinder conservation efforts and damage socio-ecological systems. To better anticipate the environmental impacts, ethical dilemmas, and governance needs for de-extinction, we elicited opinions from experts in the natural sciences, social sciences, and the humanities. We applied a mixed-method approach to analysis of survey results, integrating quantitative responses regarding perceived likelihood of risks and benefits with qualitative responses used to clarify and provide context. Overall, study participants indicated de-extinction was more likely to induce hazards, not benefits. Reasons for this viewpoint included a "moral hazard" argument, suggesting conservation policies could be undermined if society comes to believe that species need less protection because they can be revived in the future. Pessimistic views of de-extinction were linked to concerns about unclear development paths for reviving individuals and populations. Experts believed the public would likely be skeptical about de-extinction, due to concerns rooted in science fiction. Our results suggest future de-extinction efforts may benefit from collaborative efforts between stakeholder groups to clarify the hazards of de-extinction and explore which concerns are most prevalent among the engaged public.

Introduction

Advances in biotechnology may allow for the de-extinction of species. De-extinction is the re-creation of extinct species using methods from synthetic biology, cloning, genetic engineering, reproduction technologies, and stem cell research. Numerous species are currently being considered as candidates for de-extinction, notably the passenger pigeon and woolly mammoth. De-extinction research on passenger pigeons includes genome sequencing (Hung et al. 2014), with plans to integrate DNA from preserved passenger pigeons into the genome of band-tailed pigeons (Novak 2013). Similarly, research on the woolly mammoth includes genome sequencing (Palkopoulou et al. 2015) with plans to gradually add mammoth genes into Asian elephant embryos, creating hybrids with progressively more mammoth traits (Devlin 2017).

Arguments in-favor of de-extinction suggest that de-extinct species will improve ecosystem function, satisfy a moral obligation to revive extinct species, and re-invigorate efforts for conserve biodiversity. The ecological benefits of reintroducing de-extinct species may be the most significant potential outcome of de-extinction (Shapiro 2015; Iacona et al. 2017; McCauley et al. 2017). Potential ecological benefits of de-extinction are purportedly similar to restoring locally extirpated species (Jørgensen 2013; Seddon, Moehrenschlager, and Ewen 2014). For example, reintroduction of musk oxen, hares, and marmots to Pleistocene Park in Siberia altered plant distributions, facilitating grassland restoration, and ultimately increasing biodiversity (Zimov 2005). Some researchers believe returning the woolly mammoth to the Siberian tundra might yield similar results (Shapiro 2015). As an act of restorative justice, reviving species driven to extinction by humans, such as the passenger pigeon, yields a moral good (Cohen 2014). This restorative act aligns with the goals of conservation biology, namely restoring ecological

components and processes previously removed or damaged by human activities (Thorpe and Stanley 2011). Additionally, restoring animals like woolly mammoths may inspire great awe (Sherkow and Greely 2013) and lead to additional support for conservation.

In contrast, arguments against de-extinction suggest that the process may be detrimental to conservation efforts and ecological systems, and rife with ethical dilemmas. Re-creation of extinct species may weaken conservation policies by providing a riskier alternative solution to preventing extinction (Pimm 2013). This moral hazard, or alternative solution, enables riskier behavior (Lin 2013), which is compounded by ecological change. Returning a re-created animal to its former ecosystem could be detrimental to the current, often different, ecosystem or to the de-extinct animal. For example, forests have been fragmented and degraded, and farms and urban systems have expanded in the historic passenger pigeon range (Greenberg 2014). If re-introduced, the bird may exhibit tendencies similar to invasive species (Sherkow and Greely 2013). Alternatively, a passenger pigeon may be unable to adapt to contemporary ecosystems. Would the creators of a de-extinct animal then be obligated to care for the de-extinct population in perpetuity?

Ethical questions such as these extend beyond those considered during wildlife re-introductions (McCoy and Berry 2008) and include ownership responsibilities for de-extinct animals (Carlin, Wurman, and Zakim 2013). In most contexts, wildlife are considered common property until captured in some way (Blumm and Ritchie 2005), but de-extinction challenges these norms. Carlin et al. (2013) suggest that products of de-extinction may be eligible for patents based on their novelty or the technical processes used

to create them. Potential commercial value could then be derived from exclusive rights to exhibit, or by creating pet markets. Further, by reconstituting genomes and creating hybrids, scientists may be accused of playing god (Sandler 2014). Animal rights and welfare concerns further complicate de-extinction. Animals such as the woolly mammoth are presumably social animals (Shapiro 2015), and rearing them in isolation may be cruel.

Other potential de-extinction efforts (e.g. gastric-breeding frog or the Xerces butterfly) may require fewer physical accommodations (Seddon, Moehrenschlager, and Ewen 2014), but would still require navigating issues of public support and outdated biotechnology policies (Kuzma and Tanji 2010; Kuzma 2016). In the United States, federal regulation of biotechnology has not adapted to advancing biotechnological methods and novel products; for example, a de-extinct animal may be regulated following protocol originally intended for animal drugs (FDA 2009). Guiding principles have been suggested for selecting de-extinction candidates, by considering efficiency and feasibility (IUCN SSC 2016) and incorporating the 2013 IUCN Guidelines for Reintroduction and Other Conservation Translocations (Seddon, Moehrenschlager, and Ewen 2014). While these guidelines address many of the ecological risks involved in wildlife reintroduction efforts, such as ecological and socioeconomic impacts, disease risk, and feasibility, they assume opposition based on ethical principles will not matter, and that conservation policy will not inhibit de-extinction efforts. Further, these guidelines do not fully address issues associated with unique biotechnologies, higher uncertainty related to environmental risks, and more conflict between stakeholder groups compared to decision-making groups in traditional wildlife reintroduction efforts.

A more systematic assessment of de-extinction seems necessary to anticipate risk and improve governance. In situations of high complexity and uncertainty, like de-extinction, it is especially important to anticipate risks so that appropriate governance systems are in place before technological deployment (Karinen and Guston 2009). Anticipatory governance suggests building capacities in foresight, engagement, and integration between experts (natural scientists, social scientists, and humanities scholars) and organizations (government agencies, technology developers, publics) may lead to better decisions and increased public good (Barben et al. 2007). In the absence of data on risks and benefits, expert elicitation provides a method for engaging the mental models of experts (Morgan, Henrion, and Small 1992) in order to begin the process of identifying potential risks and responding to them upstream in innovation and governance systems (Stilgoe, Owen, and Macnaghten 2013; Barben et al. 2007).

As a first step in anticipatory governance, this paper presents the first analysis of the potential environmental impacts of de-extinction, ethical dilemmas, and governance needs by eliciting experts' opinions from multiple disciplines. We surveyed experts in the natural sciences, social sciences, and the humanities, who have been involved in technologies and policies associated with genetic engineering and synthetic biology. Experts on biotechnology issues are well suited to assess potential de-extinction impacts, dilemmas, and governance needs because of their experiences with biotechnology development and governance. The science of biotechnology continues to develop, but at least in the United States, biotechnology policy has not explicitly addressed new genetic engineering technologies like gene editing, gene drives, or de-extinction (Kuzma 2016), International frameworks may cover genetically engineered

animals, such as the Convention on Biological Diversity and the Cartagena Protocol on Biosafety, but these have not been ratified by all nations with active de-extinction research programs (Vàzquez-Salat et al. 2012; Kuzma 2016). Public opposition to genetically engineered foods is highly political, varies internationally, and is potentially becoming more controversial over time (Frewer et al. 2013). Controversies also brew within the biotechnology field as some products and companies fail to live up to their own hype (Borup et al. 2006). Biotechnology experts working within these contexts have unique experiences and can provide valuable assessments for the nascent field of de-extinction. To better anticipate the environmental impacts, ethical dilemmas, and governance needs for de-extinction, we applied a mixed-method approach to analyze quantitative responses regarding perceived risks and benefits with qualitative responses used to clarify and provide context. We compare participants' perceptions of potential risks and benefits, highlight salient environmental and societal concerns, identify research and risk assessment needs for managing potential risks, and provide recommendations for de-extinction governance. This is the first study to our knowledge formally eliciting expert opinions about the governance of de-extinction. By conducting this study before viable, self-reproducing de-extinct species are developed, we hope to provide guidance to innovation and governance, promote environmental stewardship, and minimize unintended consequences.

Methods

Expert Elicitation

Expert elicitation is commonly used in emerging fields where information is limited, and uncertainty is high (Fiorese et al. 2013). We conducted purposive sampling to recruit experts from multiple disciplinary fields. We compiled an initial list of potential participants by

reviewing speakers who attended the following three conferences: Biobricks Foundation SB6.0: The Sixth International Meeting on Synthetic Biology, SynBioBeta Conference for Synthetic Biology Startup Companies, Georgia Tech Frontier in Systems and Synthetic Biology. Subsequently, additional potential participants were drawn from the editorial board of the peer-reviewed journal, *Bioengineering and Biotechnology*. Invitations were sent to 234 experts, and forty-eight individuals agreed to participate. These participants are actively involved in, or are studying the unique socio-political contexts of biotechnology (Kuzma 2016; Frewer et al. 2013; Vàzquez-Salat et al. 2012; Borup et al. 2006) and are thus well suited for anticipating the future impacts, dilemmas, and governance needs of de-extinction.

An online questionnaire was designed to elicit the opinions of experts regarding de-extinction risk and governance, and 35 experts completed the questionnaire. Most (29) identified their disciplines, with 16 social science, humanities, and law experts (hereafter identified as social scientists) and 13 natural science experts. Because de-extinction is novel and developing, participants were provided a short description (available in Supplemental Materials) prior to the beginning of the study. This online questionnaire was self-administered using Qualtrics. This study was ruled exempt by the North Carolina State University Internal Review Board (IRB # 3574).

Questionnaire Development

We developed a questionnaire that allowed respondents to prioritize and then expand on their perceptions of issues related to de-extinction- risks, benefits, future areas of research, and governance needs. A Societal and Risk Evaluation Scheme (SRES), consisting of multiple 10-point Likert scale questions, measured perceived certainty of potential hazards, benefits, and

societal outcomes related to de-extinction (Cummings and Kuzma 2017). This scheme was developed to assess biosecurity risks by evaluating potential risks, epidemic potential, ability to contain hazards, and overall consequences (Latxague et al. 2007; Suffert, Latxague, and Sache 2009). Given the novelty and uncertainty regarding de-extinction, we adapted the SRES to survey environmental and human health risk and added assessments of potential public concern and potential benefit. We used 10-point scale questions to assess potential benefits and hazards for human health and the environment. A similar question was used to ask participants how much public concern de-extinction might generate (Cummings and Kuzma 2017). Using a previous review of biotechnology oversight (Kuzma and Tanji 2010), we listed 16 areas of potential risk reduction research, and participants ranked them from highest to lowest priority. Participants were then asked to expand on their perceptions of de-extinction risks, potential areas for research, and public perceptions with open-ended questions. We also asked the participants which agency, group, or specific organization should have the most central authority for governing de-extinction (Questionnaire available in supplemental materials).

Data Analysis

We applied a mixed-method approach to data analysis, integrating quantitative responses regarding perceived likelihood of risks and benefits with qualitative responses to provide context. Risk reduction priority mean scores were grouped using a Tukey-HSD test. We compared quantitative responses between social science and natural science experts, with a Student's *t* test, to identify potential differences in benefit and risk perceptions between these groups. Given the sample size (n = 35) and exploratory nature of this study we report differences significant at an alpha level of .10. We reported effect sizes, measured with Cohen's *d*, as weak

(<0.5) moderate (> 0.5) and or strong (> 0.8) (Cohen 1988). To identify salient issues related to risk, research, and governance, we performed a qualitative thematic content analysis of responses to open-ended questions (Shellabarger, Peterson, and Sills 2012). Participants were asked about potential impacts to human health, the environment, and society, research needs for assessing potential hazards, what existing research areas may inform assessment, and what novel research areas may generate information to assess hazards. Major themes were identified and synthesized to clarify and provide meaning to quantitative results. Categorization criteria for qualitative results were developed to maintain consistency throughout analysis (Questions and criteria in supplemental materials). We report frequency of major themes and direct quotes from participants. When quoted, participants are identified with a unique code.

Results

Risks versus Benefits

Participants perceived de-extinction as more likely to harm, not benefit, human health and the environment. They strongly perceived de-extinction as more hazardous than beneficial to the environment ($t = 4.70$, $p < 0.001$, Cohen's $d = 1.41$) (Figure 1). The experts suggested numerous potentially negative environmental impacts: de-extinct animals may exhibit characteristics similar to invasive species (e.g., ecological disruptions, outcompeting native wildlife species), broadly impact ecosystems, and increase wildlife disease risks (Table 1). One participant raised these issues when describing the potential for reviving a passenger pigeon, "*How* [passenger pigeons] *would impact modern agricultural settings which have replaced much of the prairie which formed the 'natural' habitat of these is a huge unknown. Where are the predators to keep the flocks under control? What disease might they carry to other occupants of their habitats?"* (R5). Participants also strongly perceived de-extinction to be more hazardous

rather than beneficial, to human health (t = 3.378, p = 0.002, Cohen's d = 0.80) (Figure 1). Almost half of the participants indicated that disease emerging from de-extinct animals may impact human health (Table 1), with concern typically stemming from two causes, "*Rebooting of encoded viruses that are harmful to humans"* (R30) or "*Potential problems of a reintroduced species acting as a vector for a human disease*" (R25). Participant responses indicating low potential benefits may be partially explained by those who were uncertain about what the actual benefits might be. As one participant indicated, "*A key issue here concerns the benefits of these technologies. Other than being interesting, it seems that much of what is driving the effort to de-extinct is commercial interest. The 'whys' and 'what for' have not been clearly addressed*" (R4). At the time of this survey, de-extinction was being advocated by Revive & Restore, a non-governmental organization (NGO) coordinating de-extinction information and research, and a small group of researchers. These advocates lacked support from governments or other NGOs, likely adding to concerns about motives for de-extinction research.

Although all expert views trended toward skepticism of benefits, social scientists held less favorable views than natural scientists. Compared to natural scientists, social scientists perceived de-extinction to potentially be more environmentally hazardous (t = 1.397, p = .087, Cohen's d = 0.538) and less beneficial to the environment (t = 1.384, p = .088, Cohen's d = 0.538). Social scientists also perceived de-extinction to be less beneficial to human health (t = 1.60, p = .06, Cohen's d = 0.628). Perception of potential hazards to human health were similar between these groups.

Some participants were concerned that de-extinct animals might have poor health or be unable to survive in contemporary ecosystems (Table 1). One respondent asked, "*How will the*

species compete with other species for food, water, etc. Why did the species become extinct in the first place?" (R15). Almost a third of the participants indicated that de-extinction may alter ecosystem interactions but did not explicitly describe these impacts as positive or negative (Table 1). For example, one participant contextualized the potential impacts of de-extinction as system dependent, "*Community dynamics will certainly be altered if these forms of hybrids are successfully established in any environment. Whether that is good or bad depends on the system*" (R26).

Research Needs

Participants indicated that both ecosystem and social science research might help assess hazards but were uncertain if any novel research fields could aid risk assessment. Participant ranking of natural science research topics, 'ecological system effects', 'competitiveness with other organisms', 'biopersistence', and 'genetic stability' were the highest priority research topics for managing potential de-extinction risk (Figure 2). Research topics related to tradeoffs with other technologies and regulation were viewed as less important for managing de-extinction risk (Figure 2). Compared to natural scientists, social scientists ranked two research topics as higher priorities, 'horizontal gene transfer' (t = 2.081, p = .047, Cohen's d = 0.823) and 'competitiveness with other organisms' (t = 1.783, p = .086, Cohen's d = 0.707). Horizontal gene transfer was not raised in subsequent open-ended responses. Variance for ranking 'competitiveness with other organisms' may be explained by a few natural scientists who ranked this as a low priority research topic.

Subsequent open-ended responses re-affirmed these risk prioritizations, as participants were most likely to suggest general ecology research as a discipline for assessing hazards and

reducing risks (Table 2). General ecological research was alluded to in this response, "*Broad studies of animal population dynamics and broader ecosystem function are needed for any study of revived species, prior to and after individuals have been revived"* (R28). Occasionally, participants identified more specific questions and types of ecological research, restoration ecology or invasive species biology, to assess hazards and reduce risk (Table 2). One respondent suggested studies may, "*Compare to reintroduction of extant species into formerly-occupied regions. Similarly, how do invasive species affect disease dynamics?"* (R9).

To help assess hazards, some participants also suggested social science research comparing different approaches to conservation, such as cost-benefit analysis or decision analysis, (Table 2). As an example, one participant indicated a need for, "*Research to understand tradeoffs in de-extinction vs conservation and restoration of existing ecosystems and their ecosystem services*" (R14). Many suggestions for social science research did not provide a specific research area and instead provided questions that might drive research agendas. Participants posed questions such as, "*What about the ownership and possible monopolization of the technology?"* (R20), and "*Which species should be reconstructed (and who should decide on this)?*" (R6). Another question raises the potential for a moral hazard, "*Whether the attempt to revive species will overshadow ongoing conservation efforts?*" (R8).

Most participants were uncertain about what novel research programs could reduce de-extinction risk (Table 2). Many did not know what research was needed or indicated that no novel research area could reduce risk (Table 2), exemplified by the following responses, "*Not sure*" (R8), "*None*" (R12), "*Unknown*" (R15). Among participants that did offer a response, molecular studies, such as synthetic biology and genomics, were most commonly mentioned as

areas that may inform hazard assessment and risk reduction, followed by ecology and disease research (Table 2). One respondent suggested a basic science research goal for achieving de-extinction, "*Understanding of the function of the genome as the orchestration of all genes and its modifications, which we don't understand yet*" (R24). Another respondent suggested how further research might improve perceptions of de-extinction, "*Perhaps there are ways to predict susceptibility of a species to human pathogens/diseases from their genomic information… If the risk of an organism acting as a vector for known disease could be predicted, it might allay concerns"* (R25). Most responses suggested already developed or emerging research areas, but *novel* approaches were also mentioned, including suggestions to incorporate big data methodologies with ecological modelling, "*Perhaps this is an interesting case for exploring computational simulation methods in ecosystem analysis"* (R4). Further research on molecular mechanisms as a sub-discipline of systems biology was mentioned as a way to reduce risk, "*Genome editing CRISPR/Cas systems coupled with advanced prediction of function from cryptic elements to screen out hazards and or build in controls*" (R30).

Technological Optimism: A Threat to Conservation?

Participants also believed that de-extinction may threaten traditional conservation efforts by increasing techno-optimism and reducing fear of extinction. Half of participants indicated de-extinction's most important societal impact could be threatening and undermining traditional conservation efforts (Table 1). One participant suggested that de-extinction may result in, "*Less focus on habitat conservation. You may be able to synthesize DNA, but not the rainforest*" (R18), another participant similarly suggested de-extinction may lead to, "*Less public support to protect at-risk species due to the belief that they can easily be 'de-extincted'"* (R27). Along those lines,

some participants worried that de-extinction would result in scientific hubris or techno-optimism (Table 1). Some respondents succinctly responded, "*Hubris*", "*Techno-optimism*" (R11), "*Moral issues, playing god, hubris*" (R6), and one respondent further explained, "*This is a HUGE distraction from saving the habitats of animals that are very endangered today. It tempts humans to think that our technology is the solution*" (R13).

Social Impacts

Participants also suggested de-extinction may negatively impact natural resources and raise ethical concerns. Socio-ecological impacts focused on economic damage to agricultural or water resources (Table 1). Participants also raised ethical concerns, including, "*Whether people will agree with the concept of bringing back extinct species, playing god*" (R8), animal rights, "*Harm to animals caused by the cloning process*" (R13), and public engagement, "*Who will decide which species to restore and where to put them?*" (R12) (Table 1). Other issues were raised, such as this "slippery slope" argument, "*The need to develop cloning techniques to bring to term any extinct mammal raises questions about whether clones of humans would be next.*" (R13).

Although experts perceived de-extinction's greatest societal impact to be the challenge it poses to traditional conservation, they believed the public would be more concerned about the uncontrollable nature of the technology as portrayed in science fiction interpretations of biotechnology in the popular media. The participants indicated public concern regarding the risks of de-extinction might be high ($\bar{x}$ = 6.8 based on a 1-10 scale, SE = 0.3) and were most likely to reference the science fiction series *Jurassic Park*, when describing what might elicit concern from the public (Table 3). The *Jurassic Park* science fiction series includes speculative

biotechnology and moral lessons for re-creating extinct dinosaurs. Science fiction can offer stances to forecast ethical dilemmas (Berne, 2008), but many of the *Jurassic Park* responses were vague, "*Jurassic Park*" (R9), "*Jurassic Park scenario"* (R11), "*Jurassic Park syndrome*" (R18), making it difficult to determine what lessons or ideas might be most salient when comparing *Jurassic Park* to potential real-life de-extinction. Concerns about de-extinction stemming from *Jurassic Park* may include ethics of reviving, hubris, animal rights, ownership questions, regulation, or fear of uncontrollable animals run amok. One participant suggested better understanding of science and technology might alleviate public concerns about de-extinction, explaining, "*Education, as in when the obvious parallels are drawn to an infamous movie, wherein the scientists didn't do so well*" (R29).

Many participants also indicated that the public may question the value of de-extinction. They noted that the public may see de-extinction as, "*Wasteful*" (R9), and ask "*Is a sentimentally fun project of scientific or societal merit?*" (R34). They also suggested that the public may be concerned about ecosystem impacts, "*Impacts on local natural resources management and public property*" (R26). Only one participant expressed the concern that the public might link de-extinction to competition with traditional conservation efforts stating the public may wonder, "*Why reintroduce new species when we are not doing enough to protect existing ones*" (R16) (Table 3). It may be that participants believe that the public will be able to identify potential direct impacts of de-extinction, ecosystem impacts and management and containment concerns, but may not be able identify the potential indirect impacts to conservation efforts. Few participants suggested that de-extinction might positively encourage scientific or conservation

initiatives, for example, "*The benefits might be in capturing the public's imagination and providing a beneficial view concerning applications of the synthetic biology*" (R26).

Regulation and Governance

Participants raised questions about adequacy of current oversight systems and split over who should govern de-extinction. One participant raised several governance questions, "*Do new regulations, or do regulations in existence, need to be developed/modified for de-extincted organisms. Role of Cartagena and or Nagoya protocols?*" (R29) (Table 1). Almost a quarter of the participants indicated that an environmental risk assessment agency such as the EPA should be a central governing authority (Table 4). An equal number of respondents indicated that a government agency should be a central authority but did not name a specific agency (Table 4). A fifth of the respondents suggested the US Department of the Interior (DOI) or the FWS (Table 4) as the governing body. Less common responses included federal agencies and departments governing agricultural products and pharmaceuticals (e.g. USDA, FDA), and other organizations with more voluntary authorities for governance including non-governmental organizations, researchers, and universities (Table 4).

Discussion

New biotechnology ventures often generate optimism, yet de-extinction presents a unique case in which the technology faces pronounced pessimism. The sociology of expectations suggests biotechnology innovators often advance the benefits of speculative technologies to pre-establish value and build socio-political networks (Borup et al. 2006; Fortun 2001). For example, Fortun (2001) suggests optimistic media statements made by a gene bank company in the midst of a litigation scandal were created to ease and encourage corporate alliances. Historically,

researchers have promised grandiose benefits of biotechnology (Turney 1998) and technological optimism remains high among many biotechnology experts (Hamdouch and Depret 2010; Kerschner and Ehlers 2016). De-extinction advocates have similarly promoted the speculative benefits of de-extinction (Brand 2013), but that optimism was not apparent among the experts in this study. We might have expected experts in the natural sciences, including some biotechnology developers, to be more optimistic about de-extinction, compared to scholars from the social sciences and humanities, who often criticized the hype surrounding biotechnology development (Fortun 2001; Nightingale and Martin 2004). We found that both groups doubted the potential benefits, and perceived hazards to be more likely than benefits, although some differences in magnitude were seen between the groups. Future research with larger sample sizes are needed to establish these relationships among the broader community of natural and social scientists engaged in conservation biology.

Experts were concerned that de-extinction may perversely lead to environmental degradation, by creating a moral hazard, thus detracting from current efforts to conserve species. Experts aligned de-extinction with pessimism about environmental restoration, which associates technological advancement with environmental destruction (Marx 1994; Tutton 2011).

Critics of biotechnology hype have called for increased attention to the social context of innovation (Nightingale and Martin 2004). In this case, de-extinction may critically disrupt conservation efforts. We might have expected natural science experts to promote potential benefits by drawing on technological optimism or ecological modernism. Ecological modernism is a theory suggesting technology promotes both economic growth and ecological stability

(Cohen 1997). Current de-extinction plans may lack the clarity needed to promote ‘buy-in’ among experts.

Uncertainties associated with technology development and the processes for creating a viable population of de-extinct animals may inhibit experts’ ability to envision potential ecological benefits. Instead, experts expanded on a number of risks. A number of factors may impact the success of biotechnology products, including risks revealed during development processes, forming collaborative relationships, market acceptance, regulation, and the regulatory approval processes (Tutton 2011). Experts’ concerns about the well-being of individual de-extinct animals seem well founded. The world’s first de-extinct animal was a bucardo (Spanish Ibex), resurrected from cloned cells (Folch et al. 2009). The bucardo died 11 minutes later because of a birth defect. The literature on cloning cites high rates of miscarriages, stillbirths, genetic abnormalities, and chronic diseases (Fiester 2005). Without further development in cloning techniques the early death of the de-extinct bucardo is likely to represent the norm, not the exception. Additionally, different techniques will likely be required for reviving species of different taxa (Shapiro 2017) and the efficacy of various approaches is likely to differ.

The process of sustaining a population in a natural environment may be even more challenging because estimating a population size that is viable and large enough to create desired ecosystem impacts, but small enough not to cause undesired effects is nearly impossible without significant trial and error (McCauley et al. 2016). Following experts’ suggestions for increased ecological research and modelling may help identify places with adequate habitat for some de-extinction efforts. Advancements in ecosystem modelling and restoration ecology (Thorpe and Stanley 2011) may provide useful insights prior to de-extinction re-introductions, although

ecologists' limited ability to predict invasive species impacts (Ricciardi and Cohen 2007; Hayes and Barry 2008) suggests that this may be a challenging endeavor.

Experts affirmed the importance of social and political contexts to the development and success of biotechnology (Nightingale and Martin 2004). At the broader societal level, concern regarding ownership, moral hazards and opportunity costs contributed to expert's pessimism. Some experts cited issues of power and control over technology; similar issues influenced public reactions to genetically engineered food crops (Finucane and Holup 2005). An opportunity cost is the loss of potential benefits when one alternative is chosen over others (Naidoo et al. 2006). When experts worried that attention or funds for traditional conservation efforts might be re-directed towards de-extinction projects, they were describing the opportunity costs that de-extinction might impose. As suggested by experts, this issue may be partially resolved if de-extinction projects undergo cost-benefit or decision analysis during early planning stages. A challenge for these types of analyses will be incorporating cultural and ethical concerns (Satterfield et al. 2013). Moral hazards are more commonly associated with financial and insurance risks- reckless behavior may become more likely if consequences fall to others; the concept has been tied to geoengineering technologies and climate change mitigation (Lin 2013), and may also apply to de-extinction (Delord 2014). The moral hazard for de-extinction is that risky behaviors for increasing the likelihood of a species extinction may seem more viable today because the responsibility for reviving them through de-extinction can now be given to people in the future. Our respondents believed this undesirable outcome could be catastrophic when combined with de-extinction, which fails to address causes of extinction and applies to few species. De-extinction fails to address the major cause of wildlife extinctions, habitat degradation

and destruction (Pimm and Raven 2000). To minimize potential moral hazards, de-extinction advocates may consider lobbying for stronger conservation policies, such as enhancing the Endangered Species Act in the United States.

The perception that non-experts will rely more on fictional representations of science when considering de-extinction may relate in part to growing stereotypes of the public as less rational and more likely to evaluate science based on personal ideology and heuristics. While experts express dismay over public doubt about science associated with climate change and vaccinations, mismatched perceptions between experts and publics may be partially blamed on failures to acknowledge public concerns (Kahan 2010). This failure appears to extend to biotechnology. Scientists have described non-expert concerns regarding biotechnology and genetic engineering as more emotional compared to their own 'rational' concerns (Cook, Pieri, and Robbins 2004). Furthermore, public concerns regarding biotechnology have been dismissed by comparing their concerns to science fiction, not science (Turney 1998). Experts may have been following similar patterns when describing public concerns as likely to be related to *Jurassic Park.* The *Jurassic Park* series exhibits common science fiction tropes of science experiments gone awry (Turney 1998), and raises ethical dilemmas and ownership concerns. Interestingly, experts raised some of these issues themselves, but the references to science fiction emerged only when describing public concerns. Public concerns and experts' concerns may be more similar than suggested by participant responses. References to *Jurassic Park* in biodiversity conservation have previously emerged. *Jurassic Park* was mentioned in five out of eight stakeholder focus group meetings regarding the potential application of gene drive systems for controlling invasive fish species in the Great Lakes, USA (Sharpe 2014). Clearly this movie

series resonates among various populations. De-extinction advocates may prefer to avoid unwanted comparisons to science fiction in order to protect their professional image. But avoiding the comparison may not be possible. The fictional representations that precede de-extinction are likely to impact public perceptions (Turney 1998). Future deliberations might acknowledge how de-extinction is like *Jurassic Park*, and more importantly, how de-extinction differs in ways that limits problems presented in the science fiction series.

Government agencies and policies have been slow to adapt to development of biotechnology in recent years, likely contributing to the respondents' confusion over who should govern de-extinction. In the United States, genetic engineering (GE) is federally regulated by the Environmental Protection Agency, Department of Agriculture, and the Federal Drug Administration, under the Coordinated Framework for Regulation of Biotechnology (OSTP 1986). This framework has not been updated to adequately cover contemporary biotechnology products (Kuzma 2016). Further, state and local governments also regulate specific GE products (Bratspies 2004). Consequently, genetically engineered pet GloFish® are largely unregulated but restricted from California (Knight 2003), and genetically engineered salmon have waited years for regulatory approval to enter the United States market (Vàzquez-Salat et al. 2012). Regulatory changes appear pressing amid growing concerns about genetic engineering, synthetic biology, and gene drive systems (Oye et al. 2014). Unlike previous genetic technologies, gene drive systems, which could be incorporated into de-extinct populations, may be able to transform entire populations or species, not just individuals, presenting larger regulatory challenges (Esvelt et al. 2014). The lack of agreement about who should govern de-extinction identified in this study may relate to the division of responsibility currently in place, and the lack of updates in the

face of advancing biotechnology. Experts infrequently mentioned international governance institutions, which may reflect the fact that the United States is not party to the Convention on Biological Diversity or the Cartagena Protocol on Biosafety (Kuzma 2016). This represents a critical future governance need, as conservation experts have already cited the lack of an international framework for genetic engineering as a potential limiting factor in future conservation applications (Sutherland et al. 2017).

De-extinction also has characteristics that make it different from previous GE applications, including development of hybrid species, releases into wild or natural places, and ethics of revival. As suggested by experts, DOI/FWS may provide expertise with ecological restoration, invasive species control, and species re-introductions needed for governing de-extinction implementation (Jeschke, Keesing, and Ostfeld 2013). Some standards from the International Union of Conservation of Nature's guidelines for de-extinct proxies (IUCN SSC 2016) may be useful, but at present, inadequately address ethical or governance concerns. As noted by Camacho (Camacho 2015), governance of de-extinct species, at least in the United States, will depend on whether these species are designated as native, hybrids, or invasive species.

De-extinction reflects a vision of integrating science, technology, environmental management, and conservation policy, re-defining what can be done and forcing us to reconsider what should be done. Collaboration with stakeholders may help reconcile experts emphasizing environmental risks and the disruption of current conservation methods, with concerns about the public viewing de-extinction through lenses of science fiction stories of 'science run amok'. Decreasing ambiguity in definitions of de-extinction risk does not guarantee that perceptions of

de-extinction risk will subside (Kahan et al. 2009). Collaborative, anticipatory, decision-making between governmental agencies, experts from multiple disciplines, and stakeholders from the public represent one avenue for de-extinction governance (Davies, Bryce, and Redpath 2013; Barben et al. 2007). Other governance strategies include the use of citizens' juries (Dunkerley and Glasner 1998), allowing for the broad inclusion of stakeholders' considerations regarding the implementation of de-extinction in specific contexts. There is still time for these processes to begin, before viable, self-reproducing de-extinction species are developed. Such processes may help determine contexts where de-extinction might be appropriate, if at all.

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Table 1. Participant response frequency and percentage regarding potential de-extinction impacts to the environment, human health, and society.

Potential impacts to the environment	**n**	**%**
Exhibit invasive characteristics	12	39%
Ecosystem interactions (neutral)	9	29%
Ecosystem impacts (negative)	6	19%
Disease	6	19%
Revived species ecosystem compatibility	6	19%
Revived species health and rearing	3	10%
Socio-ecological impacts	2	6%
Feasibility questions	2	6%
Little to no impact	2	6%
Change conservation	1	3%
Harm surrogates	1	3%
Dangerous Animals	1	3%
Potential impacts to human health	**n**	**%**
Disease	15	52%
None or Limited	8	28%
Socio-ecological impacts	6	21%
Case specific	4	14%
Lead to human genome engineering	2	7%
Physical harm	1	3%
Don't know	1	3%
Potential impacts to society	**n**	**%**
Threatens conservation efforts	13	43%
Hubris and Techno-optimism	6	20%
Ethics of reviving	6	20%
Socio-ecological impacts	5	17%
Animal rights	4	13%
Public engagement	4	13%
Regulation	3	10%
Questionable benefits	2	7%
Ethics of human cloning, gene editing	2	7%
Encourage conservation	2	7%
Public concern	2	7%
Encourage science	2	7%
Ethical obligation	2	7%
Conserving de-extinct animal	2	7%
Irreversible	1	3%
Biodiversity issues	1	3%
No moral obligation	1	3%

Table 2. Frequencies and percentages of responses regarding potential research needs for assessing de-extinction hazards, research areas for reducing de-extinction hazard, and potential novel research areas for reducing risk.

Assessing hazard	**n**	**%**	**Reduce risk**	**n**	**%**	**Novel research**	**n**	**%**
General ecology	9	31%	General ecology	8	30%	Don't know	4	18%
General social science	5	17%	Invasive species biology	6	22%	Molecular and synthetic biology	4	18%
Restoration ecology	4	14%	Restoration ecology	4	15%	Genomics	3	14%
Molecular and synthetic biology	4	14%	Disease and Immunology	4	15%	Disease ecology/Ancient DNA	3	14%
Cost-benefit or decision analysis	4	14%	Conservation biology	3	11%	No novel research	3	14%
Population genetics	3	10%	Paleontology	2	7%	General ecology	3	14%
Invasive species biology	3	10%	Molecular and synthetic biology	2	7%	Ecology/Big data	1	5%
Policy & Regulation	3	10%	Bioethics	2	7%	Cost-benefit analysis	1	5%
Ethics	2	7%	Historical ecology	2	7%	Evolutionary genetics	1	5%
Biosafety	1	3%	Systems biology	2	7%	Reproductive studies	1	5%
Public engagement	1	3%	Physiology	1	4%	Restoration ecology	1	5%
Difficult to assess	1	3%	Evolution	1	4%	Bioethics	1	5%
			Economic	1	4%	Science fiction	1	5%
			Don't know	1	4%	Safety	1	5%

Table 3. Participant response frequency and percentage of responses regarding characteristics that may most concern the public.

Potential public concerns	**n**	%
Jurassic Park (scenario)	9	29%
Ecosystem *impacts*	7	23%
Ethics of reviving	5	16%
Ethics (General)	3	10%
Hubris and techno-optimism	3	10%
Animal welfare	2	6%
Uncertainty	2	6%
Other science fiction references	2	6%
Awe	1	3%
Governance concerns	1	3%
Economic damages	1	3%
Lead to human genome engineering	1	3%
Ignore conservation	1	3%
Depends on the organism	1	3%
Don't know	1	3%

Table 4. Frequency and percentage of responses regarding who should have the most central authority for the governance of de-extinction.

Governance authority	**n**	**%**
Environmental Protection Agency (EPA)	7	23%
Government (General)	7	23%
Natural resources agency (Fish and Wildlife Service, Department of the Interior)	6	20%
US Department of Agriculture (USDA)	4	13%
Human health agency (Federal Drug Administration (FDA), National Institute of Health (NIH), Health & Human Services (HHS))	4	13%
International Organizations (International Union for the Conservation of Nature (IUCN), United Nations Environment Programme (UNEP), Conservation of Biological Diversity (CBD)	2	7%
Non-Governmental Organizations & Non-profits	2	7%
Universities	2	7%
Industry	2	7%
Other (each of the following had a single response: National Science Foundation, research experts, public, none)	1	3%

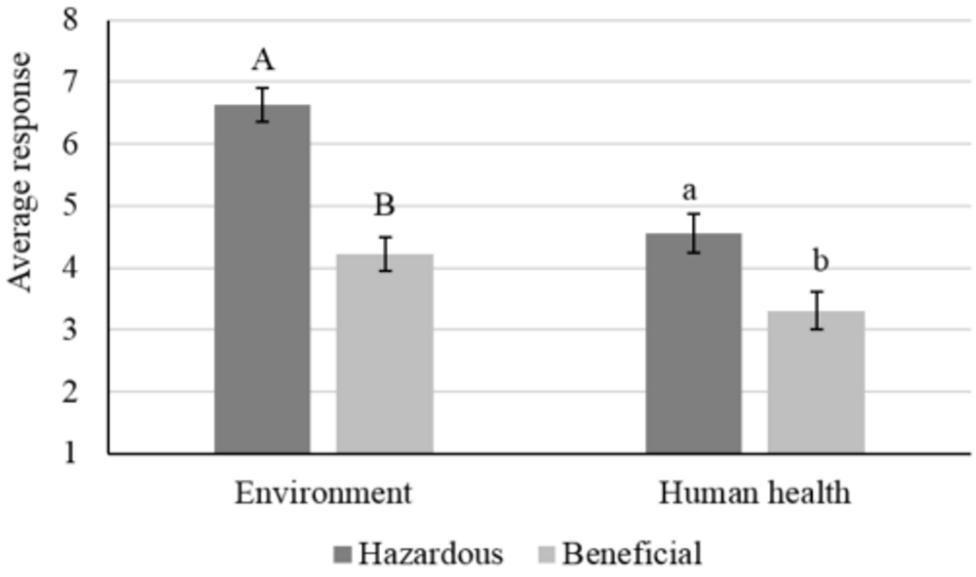

Figure 1. Average responses (Likert scale responses 1-10) and standard error bars of participant responses to potential environmental and human health hazards and benefits from de-extinction. Significant differences indicated by different letters.

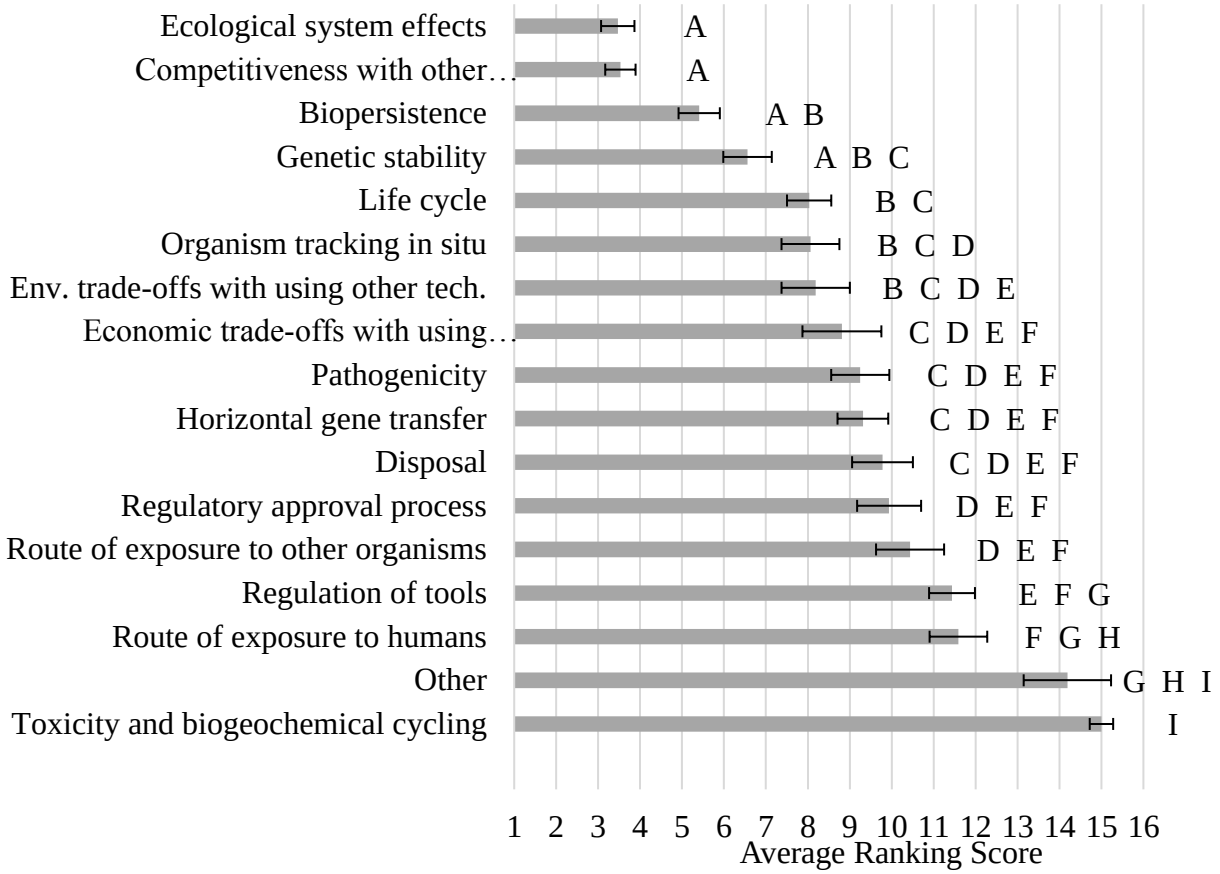

Figure 2. Average ranking scores (1-16) for research topics to manage de-extinction risks. Topics were ranked by perceived priority (low rank = high priority). Significant groupings are indicated by letters and were calculated using a Tukey-HSD test for comparing multiple means.

CHAPTER 3

International news media framing of invasive rodent eradications

Abstract

Invasive rodents threaten global island biodiversity and have been eradicated from hundreds of islands. Eradication efforts can be contentious due to animal welfare concerns and risk to non-target species. The news media plays a critical role by providing context for eradications. To better understand how the news media frame invasive rodent eradications, we conducted a thematic content analysis of 462 newspaper articles published in newspapers from 13 countries between 1993 and 2014. Although the media typically frames environmental stories as conflicts between stakeholders, the media tended to use "conquest frames" for rodent eradications. Articles often emphasized key elements of the conquest frame, including recast rules and norms, being on frontiers, positioning heroes against nature, creating drama by questioning the success of heroes, orienting towards the future, and positioning the audience as an awestruck witness. We detected international differences for some themes. Articles from Canada and Australia often included costs of eradication, articles from New Zealand were less likely to include endemic species, and articles from the United States were most likely to include conflict. Our results suggest that unique aspects of rodent eradications may encourage conquest framing, and cultural contexts of place shape framing between countries. We conclude that conquest framing by the media has largely supported rodent eradication efforts on islands, but that may change when new eradication methods are developed or when eradications are planned for islands with human populations.

Background

Islands provide critical habitat to a high proportion of the world's biodiversity and have disproportionately high rates of endemic species (Kier et al. 2009). Islands contain 20% of terrestrial plants and vertebrate species within 5% of the world's land mass. Unfortunately, extinction rates on islands are also extremely high, largely due to anthropogenically introduced invasive species (Clavero & García-Berthou 2005; Grosholz 2005; Sax & Gaines 2008). Among invasive species, rodents are a leading threat to biodiversity on islands (Towns et al. 2006), occurring on over 80% of the world's major islands (Atkinson 1985). They have caused extinctions and extirpations of flightless invertebrates, ground-dwelling reptiles, land birds, and burrowing seabirds (Towns et al. 2006).

Eradicating invasive species on islands represents the most effective approach for protecting biodiversity on islands, though this approach can be contentious, and its success is not guaranteed. Rodent eradications were pioneered in the late 1950s and early 1960s (Ross 1993; Thomas & Taylor 2002; Lorvelec & Pascal 2005). The first documented rodent eradication was completed on Maria Island, New Zealand (1 ha) (Thomas & Taylor 2002), and more recent eradications occurred on larger islands including the UNESCO World Heritage site, Macquarie Island, Australia (approx. 12,785 ha) (Parks and Wildlife Service 2014). As of 2014, over 470 successful rodent eradications have been completed (Campbell et al. 2014). A typical rodent eradication deploys rodenticide via bait stations, hand broadcast, or aerial broadcast, across an entire island, ensuring that every individual is exposed to a lethal dose of rodenticide (Howald et al. 1999). Rodent eradications are high-stakes, multi-million-dollar campaigns coordinated between multiple government and non-government entities. Eradication attempts are dramatic

interventions because they are one-time events, and there is a stark contrast between success and failure. Success only occurs when every individual has been removed: even a very small surviving population (possibly even a single pregnant rodent) can re-populate an island in a short period, rendering the eradication effort a failure. From an animal welfare perspective, failure means a high level of animal suffering without achieving anything (Cowan & Warburton 2011). Successful eradication of an invasive rodent population, however, can lead to dramatic recoveries among native species populations (Smith et al. 2006).

In addition to the potential to incur significant financial costs, animal welfare issues can make rodent eradications contentious among stakeholders (Simberloff 2011). Concerns of non-target impacts and animal rights are especially pertinent to rodent eradications (Salmon et al. 2010; Howald et al. 2005; Cowan & Warburton 2011). Anti-coagulants such as brodifacoum are the most often used rodenticides for island eradications (Howald et al. 2007). Death of a rodent ingesting brodifacoum may take 5–15 days (Meerburg et al. 2008), a lengthy and painful process. Brodifacoum is a non-discriminate poison that has killed individuals of numerous species following rodent eradications (Eason & Spurr 1995). For example, following the rodent eradication on Rat Island (United States), renamed Hawadax Island following the successful rodent eradication, more dead bald eagles were found than were known to have inhabited the island prior to the eradication (Salmon et al. 2010).

As rodent eradications are attempted on larger islands and contemplated for human-inhabited islands (Howald et al. 2005; Ogden & Gilbert 2011; Wilkinson & Priddel 2011), public interpretation of these events will become a more pressing issue for conservation practitioners. Opposition has impeded proposed rodent eradications in the past. For example, the United States

National Park Service was sued and forced to obtain a Migratory Bird Treaty Act permit after proposing a rat eradication on Anacapa Island, off the coast of California (Howald et al. 2010). Prior to the eradication on Anacapa, an animal rights activist landed on the island and spread bait pellets with Vitamin K in an attempt to prevent the lethal effects of the anticoagulant rodenticide (Stolzenburg 2011). Rodent eradications are typically conducted on uninhabited islands. In Australia, a proposed rodent eradication for Lord Howe Island, a human inhabited island, was withdrawn amidst concerns of risk to humans and endemic species (Wilkinson & Priddel 2011).

Media framing may influence perceptions of eradications. Framing is a process where certain aspects of an issue or event are emphasized and thereby made more salient (Entman 1993). Although all forms of communication contribute to framing, mass media plays a significant role when deciding how to present, interpret, and ultimately influence the understanding of issues and events. A media frame is the central organizing idea or storyline that provides meaning to events (Garrison & Modigliani 1994; Scheufele 1999). News articles may adhere to common media frames such as conflict, attribution of responsibility, human interest, morality, and economic frames, or articles can follow unique, topic-specific frames (Semetko & Valkenburg 2000). News articles covering environmental issues are often framed as conflicts (Cox 2012, Lester & Hutchins 2013).

News frames can be identified by a few attributes within an article. For example, a conflict frame might be identified by disagreement between parties, a reproach from one party to another, and the presentation of two sides of a single issue (Semetko & Valkenburg 2000). Dayan & Katz (1994) suggest that media events are framed as contests, conquests, or coronations. Events framed as contests focus on conflict, are often political, are governed by

rules and invite the audience to rationally judge the contestants. Events framed as conquests are rare, and represent an advancement for society if accomplished, whereas events framed as coronations are highly ceremonial and invoke previous, similar events (Dayan & Katz 1994).

Although no research has addressed media framing linked to island eradications, research on the framing effects associated with other conservation issues suggests it has powerful effects on public perceptions. News framing is the process of communicating the news, and framing effects are the potential impacts on the audience's knowledge, attitudes, and behaviors (De Vreese 2005). For instance, Gore *et al*. (2005) found that public perceptions of bear attack risk actually decreased after a fatal black bear (*Ursus americanus*) attack on an infant in New York and attributed this outcome to news media frequently highlighting the extremely low risk of bear attacks. Conversely, research on news reporting of wildlife commonly ascribes negative valence to predatory animals (e.g., sharks, mountain lions) and describes risk and danger to humans (framing wildlife predators as a threat), thereby damaging conservation efforts (Muter et al. 2013; Jacobson et al. 2012).

In this article, we explore international news media framing of rodent eradications on islands. We use Dayan & Katz's (1994) media event frames -- conquest and contest (hereafter we use the term "conflict" instead of "contest" to align with conservation terminology) -- as theoretical grounding for our analysis. We also highlight differences in reporting frame attributes among the nations coordinating most rodent eradications. We then consider how perceptions of charismatic wildlife and environmental risk, newsworthiness, and local values may influence rodent eradication framing. We conclude by forecasting potential changes in future media framing, as methods for island rodent eradications advance.

Methods

We used LexisNexis® Academic to collect newspaper articles (hereafter articles) reporting on island rodent eradications. We collected articles reporting on eradications of black, Norwegian, and Pacific rat species (*Rattus rattus*, *R. norvegicus*, and *R. exulans*) and house mice (*Mus musculus*), the most common rodents introduced to islands worldwide (Atkinson 1985). The search was limited to the period after 1993, given the paucity of both rodent eradications (Howald et al. 2005) and media coverage of them prior to that point in time. A Boolean keyword search for 'island' AND 'eradication' AND 'rodent' OR 'rat' OR 'mouse' OR 'mice', was conducted in February 2015. This search yielded 462 articles after removing non-relevant articles (e.g., rats in cities) and excluding non-news articles (e.g. letters to the editor).

We used thematic content analysis to systematically identify and group passages across the media articles (Krippendorff 2012, Dayan & Katz 1994) into media event frames. Media event frames provide an appropriate lens for this study because they focus on contexts involving large-scales, and pre-planned events which allow news media time to plan and develop a frame for the event, and these two attributes characterize rodent eradications. As mentioned above, media event framing typically includes a three-part typology of conflict, conquest, and coronation (Dayan & Katz 1994). Conquest frames focus on recast rules (e.g. spreading toxicants on an island to conserve wildlife), occur on thresholds of frontiers, present hero vs nature, invoke drama by emphasizing the challenge, position the audience as an awestruck witness, and orient audiences to the future (e.g. outcome of successful conquest) (Dayan & Katz 1994). Conflict frames focus on agreed rules (e.g. public debate), occur in established arena or forums (e.g. a town hall), position human interests at odds, invoke drama by emphasizing the uncertainty of

who will win, position the audience as a judge over a conflict, and orient audiences to the present (Dayan & Katz 1994). Coronation frames focus on customs and traditions (e.g. the staged process of funerals and weddings), occur in areas with large human audiences (e.g. city streets, churches), invoke drama by questioning whether the ritual will succeed (e.g. funeral lays leader to rest, can society reconcile the loss), and invite viewers to pledge allegiance to societal values (Dayan & Katz 1994). We focused only on conflict and conquest frames. We included a conflict frame because environmental articles are typically framed as conflicts (Cox 2012, Lester & Hutchins 2013) and both non-fictional and fictional accounts of rodent eradications have been explicitly described as conflict (Stolzenburg 2011, Boyle 2012). We included conquest framing because rodent eradications on islands logically include key elements of a conquest frame (e.g., isolated locations, challenging circumstances, and heroes vs nature). We did not include coronations because the framing did not emerge in preliminary review of articles, likely because rodent eradications lack three key elements of this event frame: focus on traditions and customs, occurrence in areas with large human audiences, and inclusion of rituals.

Within the conquest framing, we coded text addressing eradication cost as "recasting the rules." This coding decision stemmed from media accounts describing the immense cost of eradications as warranting new rules for approaching conservation decisions, such as normative support for completely covering a natural area with pesticides. We coded text describing islands as isolated or rugged in the conquest frame attribute, "threshold of frontier" because isolation and ruggedness reflect commonly accepted descriptors for frontiers. We coded text addressing conservation practitioners (e.g., dog handlers, helicopter pilots), conservation departments (e.g., United States Fish and Wildlife Service, New Zealand Department of Conservation), non-

governmental organizations (NGO), and scientists in the conquest frame attribute “hero vs nature” because these were the actors working to eradicate rodents. We coded text describing an eradication as challenging in the conquest frame attribute “will hero succeed?” We coded text describing the scale of eradication and the size of the island as the conquest frame attribute, “awestruck witness,” because these descriptions invite the audience to marvel at the scope of eradication efforts. Finally, we coded text addressing endemic species and extirpated species as the conquest frame attribute for time orientation, “future” because the descriptions of these species were related to future recovery or future re-introductions of native species after the rodent eradication is completed.

We coded text describing stakeholder conflict over rodent eradications in the conflict frame attribute “conflict between groups”. This excluded disagreements about funding, because in these contexts all groups were in-favor of rodent eradication. We coded text regarding the effects of rodenticide, and positive descriptions of rodents as the conflict frame attribute, “who will win” because these are points that were made if there was an argument against an eradication. Themes that might indicate conflict frame attributes -- agreed rules, the locus of an arena, and the audience’s role as a judge -- were not identified within our sample of articles. All coding was performed using QSRI Nvivo Version 10.

We generated definitions for each theme to train coders and assess intercoder reliability (Krippendorff 2012). We chose a small sample (n=8) to practice coding until intercoder reliability for themes was greater than 95%. We then randomly selected 49 articles to measure intercoder reliability. Using the standard error proportion to estimate minimal sample size, we calculated 49 articles as the necessary number of articles to ensure a 95% confidence interval for

reliability measurements between two coders (Lacy & Riffe 1996). We used Cohen's Kappa to measure agreement between two coders (Banerjee et al. 1999). Cohen's Kappa was calculated to be above .70 for all themes and above .90 for 55% of all themes, indicating a high level of intercoder reliability (Lombard et al. 2002).

We conducted further analysis on country origin of the articles by comparing themes between countries using chi-square tests. We compared articles from New Zealand (NZ) (n=152), Australia (AU) (n=124), United Kingdom (UK) (n=110), the United States (US) (n=20), and Canada (CA) (n=13). Articles that were originally printed in one country and re-printed in a different country were excluded from analysis. We only included conquest and conflict themes appearing in enough articles to yield valid statistical inferences from chi-square tests. Themes with expected values of less than 5 in more than 20% of contingency cells were excluded from analysis. All statistical analysis was performed using STATA Data Analysis and Statistical Software Version 14.1.

Results

Articles and utterances within them more often framed rodent eradications as conquests compared to conflicts (440 articles include conquest frame attributes; 46 articles include conflict frame attributes). Some articles contained conquest and conflict frame attributes, but conquest attributes were included in articles more frequently than conflict attributes (Table 1). Specifically, articles focused on recast rules, occurring on frontiers, pitting heroes against nature, invoking drama by questioning the success of heroes, future orientation, and positioning the audience as an awestruck witness. The conquest theme of high financial costs, which recast the financial rules of conservation efforts, was included in 44.8% of articles. Similarly, the conquest

theme of overcoming challenges associated with the large scale of an eradication occurred in 20.4% of articles (Table 1). For instance, an article from New Zealand describes why a rodent eradication is different from typical conservation work, “The project would be New Zealand’s largest pest-eradication campaign ‘by a wide margin’, would cost millions and would be a major logistical challenge due to the [Auckland] islands’ size and isolation.” Articles described islands as isolated and rugged to ground these stories on the thresholds of frontiers (Table 1). For example, an article from Australia describes the island for a proposed eradication, “Macquarie Island: a sliver of land conjured abruptly from the vast watery wilderness of the Southern Ocean…Dangers posed by climate and terrain are accentuated by its extreme isolation.” Conservation practitioners were sometimes explicitly described as heroes (Table 1), exemplified in this article’s introduction, “A team of experts is bound for a remote island, with $24.6 million of government funding, helicopters, guns and dogs, and eradication on their minds. And they’re the good guys.” Opinions voiced from conservation departments, NGOs, and scientists were often implicitly given authority and positive valence, because less than 10% of articles included stakeholders opposed to eradication (Table 1). The drama of the conquest is whether the eradication will succeed, so articles described eradications as challenging (Table 1), as written in this Australian article, “It meant flying five helicopters for more than five hours over the roughest ocean in the world in the middle of winter, but the world’s largest rat eradication programme on Campbell Island has gone to plan.” Focusing on the size of islands, the enormous scale of an eradication, and inherent challenge to the hero all worked to invoke awe (Table 1). This opening line about the Macquarie Island eradication is one example, “It will take seven years, cost $25 million and is the world’s largest program to eradicate feral animals from an

island." Most articles (72.5%) included endemic species that would benefit from rodent eradication. The conquest frame orients readers to the future by describing how wildlife populations will thrive in the future (Table 1). For example, "It is hoped bird species such as kakapo, saddleback, mohua, kokako and teal may eventually be reintroduced to Stewart Island [NZ]."

Few articles included any aspect of a conflict frame. Conflict between stakeholders was mentioned in only 9.7% of articles (Table 1). The few articles with opposition stakeholders included multi-faceted arguments against eradications. An article covering the Lundy Island (UK) eradication quoted an animal rights group, "Not only is the toxic poison used causing great suffering to the targeted animal, it is bound to affect other wildlife and the ecosystem/food chain on…Humans do not have the right to massacre other species". Themes that represented objections to rodent eradications were similarly rare. Only 2.8% of articles mentioned stakeholders with an interest in protecting the invasive rodents (Table 1). Only two stakeholder groups argued for rodent protection, animal rights groups, and the native Mauri of New Zealand, as described here, "The plan is opposed by local iwi Ngati Wai, who argue that kiore [Pacific rat] are taonga (treasure) and the department should opt for control rather than eradication." Although, non-target impacts were included in 23.6% of all articles, the narratives did not clearly fit conflict or conquest frame attributes. We expected that the harmful effects of rodenticide would be included in arguments against rodent eradications. But only 18.8% of articles describing rodenticide effects also included conflict among stakeholders; we did not detect a significant statistical relationship between the themes ($\chi = 1.5587$, $p = 0.212$). Many conflict

frame attributes, agreed rules, arena as stage, and audience's role as judge, were not part of any rodent eradication articles (Table 1).

Beyond the general analysis of our dataset, our assessment of how media framing differed among nations, notably for Canada and New Zealand. Chi-square analysis of conquest and conflict themes and articles from different countries suggest that articles from Canada more frequently included conquest themes relative to other nations, and articles from the United States were more likely to include conflict between groups (Table 2). Articles from Canada and Australia most often included collective efforts aimed at overcoming challenges associated with costs of rodent eradication (Table 2). All articles from Canada included emphasis on how endemic species would benefit from rodent eradication in the future, whereas only half of the New Zealand articles included endemic species (Table 2). However, New Zealand articles more often included future orientations in contexts of describing potential reintroduction of extirpated species following a rodent eradication (Table 2). Articles from the United States included extirpated species at a rate similar to articles from New Zealand (Table 2). Stakeholder conflict over rodent eradications never appeared in articles from Canada (Table 2) and appeared in a quarter of all articles from the United States.

Discussion

Conquest framing organizes perceptions of rodent eradications on islands by reducing moral ambiguity. Island eradications, unlike most conservation efforts, are high-stakes, can have permanent effects, and often occur far from people. The conquest frame highlights the drama, scope of action, and concentration of human labor and resources that are associated with eradications. Within this frame, completing the conquest becomes an inherent good. Positioning

the conquest as inherently good allows the outcomes of an eradication to go unquestioned, suggesting that there is little need for public deliberation about removing invasive species to protect native biodiversity. For rodent eradications framed as conquests, the outcomes are the removal of an invasive species and higher native biodiversity, which aligns with widespread preferences for conserving native species (Meuser et al. 2009).

News articles framing rodent eradications as conflict may be uncommon because invasive rodents are perceived as pests and the environmental risks incurred by rodent eradication methods are likely abstract to most audiences. Unlike articles about rodent eradications, media coverage often frames wildlife and environmental issues as conflicts (Cox 2012), by presenting opposing, yet compelling interests. For example, climate change articles portray economic concerns versus environmental concerns (Brossard et al. 2004), and carnivore management articles often discuss wildlife conservation in contrast to human safety (Jacobson et al. 2012). Rodents, however, are widely considered to be pests—a category that inspires distancing rather than connection. House mice and brown rats have been ranked as the least charismatic mammal species among international audiences (Macdonald et al. 2015), but birds, the most frequent beneficiaries of eradications, are considered charismatic (Gray 1995). The methods used to manage invasive species may be a source of conflict because of the harm that they can cause to both target and non-target species (Gobster 2011). Rodenticide use was occasionally questioned in articles, but our results indicate that rodenticide effects were not often associated in arguments against rodent eradication. The most common theme that could generate conflict regarding invasive species management in other contexts, non-target impacts, usually goes unseen on isolated islands. Non-target impacts occur during rodent eradications (Eason &

Spurr 1995) but are managed so native populations are not endangered. Therefore, rodent eradications can be described as unobtrusive events, which typically go unseen and impact few people's day to day lives, especially when occurring on uninhabited islands (Cox 2012).

Although conquest framing utilizes newsworthy attributes of rodent eradications, it de-emphasizes risks to human health and native wildlife. The risks that eradications pose to human health and native wildlife are taken seriously by conservation professionals and researchers (Salmon et al. 2010; Cowan & Warburton 2011), but they may not be considered newsworthy by journalists (Yopp & McAdams 2002). Criteria for newsworthiness include prominence, timeliness, proximity, impact, magnitude, conflict, oddity, and emotional impact (Yopp & McAdams 2002). Because rodent eradications are unobtrusive events, framing them as conflicts highlights only one criteria of newsworthiness, but does not elevate the others. On the other hand, a conquest frame can be used to highlight the impact, magnitude, and oddity of a rodent eradication. Conquest framing may be interpreted as an attempt to maximize newsworthiness, and this framing is likely to influence broader perceptions of rodent eradications.

By choosing conquest frames over conflict frames, news media provide support for native wildlife conservation on islands. The conquest frame privileges viewpoints that aim to make rodent eradications more acceptable by suggesting that there are no alternatives, and that normal rules do not apply. Thus, where other contexts may raise concerns about spreading poison that causes slow painful deaths among mammals, island eradications are depicted as exceptional events, where heroes operating on the edge of frontiers make their own rules to win against overwhelming odds. To some degree, conquest framing impacts and reinforces the positive perceptions of island conservation that it creates, deflects public concern about island

eradications, and creates latitude for practitioners to operate in. Some invasive species researchers have been skeptical of news media, suggesting that journalists seek to oversimplify and sensationalize their work (Rotherham & Lambert 2012). Although articles on rodent eradications tended to simplify the events by excluding details and rodent eradication histories, the portrayals of rodent eradications largely followed narratives offered by conservation agencies and scientists.

Differences in the themes that were emphasized between countries suggest that, to some extent, the cultural context of nations shapes media framing of rodent eradications. Canada has a shorter rodent eradication history and has attempted fewer rodent eradications compared to the other countries analyzed (DIISE 2015). The relative novelty of a rodent eradication may have contributed to frequent mentions of cost and endemic species, which invoke awe and demonstrate the importance of the events. Differences in the frequency of reporting financial costs may reflect differences in conservation policy. Articles from the United States infrequently reported costs, and funding for rodent eradications in the United States often comes from an oil spill liability trust fund (OPA 1990). Articles from Australia may have reported costs more often because the Macquarie Island eradication involved political debates over funding. The Australian federal government and the Tasmanian state government clashed over who would fund the eradication. Interestingly, although funding is often a limiting resource for conservation efforts, funding of rodent eradications was typically obscured in conquest frames. Articles from New Zealand often did not mention the endemic species to benefit from rodent eradication. This was surprising, considering the country's leading role in developing and implementing rodent eradications. It may be that the purpose of a rodent eradication is well-known among local

audiences, and the news media did not feel obligated to explicitly include endemic species. Opposition to a proposed rodent eradication on the Farallon Islands, off the coast of San Francisco, largely explains the higher percent of United States articles that include conflict. Newspapers from urban areas are more likely to include conflict in news articles on wildlife (Corbett 1995). The tendency for wildlife agency headquarters to be located in urban areas (the Farallon Islands are part of the San Francisco Bay National Wildlife Refuge Complex, headquartered in the San Francisco area), coupled with high levels of pluralism in urban areas, make discussions of conflict more likely (Tichenor et al. 1980).

Moving forward, conservation stakeholders should be aware that the news media can provide positive coverage of conservation work, particularly through conquest framing. Rodent eradications have been favorably framed from a conservation perspective, by de-emphasizing environmental risks, but this trend may change. As more human-inhabited islands are considered for rodent eradications, concern about the risk of pesticide and voices of opposition are more likely to emerge (Varnham et al. 2011). Similarly, potential novel systems for rodent eradication, such as self-limiting genetically-engineered rodents (Campbell et al. 2014; Leitschuh et al. 2018) have the potential to both reduce non-target impacts, by eliminating the need to use pesticides, and create new sources of conflict rooted in moral norms about interfering in nature or playing god (Macnaghten 2004). Although conquest frames currently dominate the coverage of rodent eradications on islands, they may also apply to zoonotic disease management, and some forms of invasive species control in continental locations. Attention and funding for zoonotic disease management is limited for many diseases (Mableson et al. 2014) and re-framing the issue as a conquest may help draw increased interest without threatening public support. Similarly, some

continental invasive species, such as Asian longhorned beetles in the United States (Antipin & Dilley 2004), may fit conquest frames, and control efforts may benefit from the increased attention generated by media coverage. Conservation efforts that engage in public relations may be well served by messages focusing on recast rules, frontiers, and whether heroes will succeed and ensure a better future as alternatives to more traditional "fearful" policy narratives (Mableson et al. 2014). These messages may work to build and strengthen cooperative efforts between stakeholders who are interested in positive conservation outcomes.

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Table 1. Conquest and conflict frame attributes and corresponding rodent eradication themes with article frequency and percent of all articles.

Dimension	Event frame	Frame attributes	Rodent eradication themes	Article frequency (n)	%
Rules	Conquest	Recasting the rules	High cost	207	44.8
	Conflict	Agreed rules	N/A	0	0
Locus (stage)	Conquest	Threshold of frontier	Isolated	64	13.9
			Rugged	30	6.5
	Conflict	Arena	N/A	0	0
Opponents	Conquest	Hero vs nature	Conservation practitioner vs invasive rodents	110	23.8
			Conservation department vs invasive rodents	144	31.2
			NGO vs invasive rodents	139	30.0
			Scientist vs invasive rodents	93	20.1
	Conflict	Conflict between groups	Stakeholder conflict	45	9.7
Drama	Conquest	Will hero succeed?	Challenging	59	12.8
	Conflict	Who will win?	Will Maori or animal rights groups lose rodents	13	2.8
Role of audience	Conquest	Awestruck witness	Scale of eradication	94	20.4
			Size of island	63	13.6
	Conflict	Judge	N/A	0	0
Time orientation	Conquest	Future	Endemic species recovery	335	72.5
			Extirpated species re-introduction	41	8.9
	Conflict	Present	N/A	0	0

Table 2. Frequency of themes and results of chi-square analysis of conquest and conflict themes for five countries' coverage of rodent eradications.

Attribute	All		New Zealand		Australia		United Kingdom		United States		Canada		χ^2
	n	%	n	%	n	%	n	%	n	%	n	%	
Conquest themes													
High cost	189	45	45	29.6	78	62.9	52	47.3	6	30.0	8	61.5	34.0815 ***
Extirpated species re-introduction	36	9	23	15.1	6	4.8	4	3.6	3	15.0	0	0.0	16.2085 **
Endemic species recovery	298	71	76	50.0	91	73.4	102	92.7	16	80.0	13	100.0	64.3728 ***
Conflict theme													
Stakeholder conflict	42	10	22	14.5	3	2.4	12	10.9	5	25.0	0	0.0	17.8051 ***

APPENDICES

Appendix A

Supplementary Materials for CHAPTER 1

Supplemental Table A.1. Survey items (Likert 1-5 scale) and factor loadings for climate change behavior scale.

Survey item	Mean	SD	Household behavior	Information-seeking	Transportation
Choose and environmental topic when I can choose a topic for an assignment in school	2.28	0.95		.64	
Talk with my parents about how to do something about environmental problems	1.92	1.01		.79	
Turn off the lights at home when they are not in use	4.04	0.99	.65		
Ask my family to recycle some of the things we use	2.77	1.39	.73		
Ask others about things I can do about environmental problems	1.75	0.92		.78	
Ask other people to turn off the water when it is not in use	3.18	1.41	.61		
Close the refrigerator door while I decide what to get out of it	3.00	1.53	.49		
Recycle at home	3.20	1.50	.70		
Walk for transportation	2.44	1.10			.84
Bike for transportation	2.18	1.13			.84

Supplemental Table A.2. Survey items used to construct climate change knowledge variable. All items were true-false responses.

Survey Item	**% Correct**
Burning oil, among other things, produces CO2.	78.6
Carbon dioxide (CO2) is a greenhouse gas.	73.2
Greenhouse gases warm the Earth by trapping some heat that would otherwise escape into the atmosphere.	75.0
The ozone hole is the main cause of the greenhouse effect.	64.7
Weather and climate are different names for the same thing.	74.3
At the same quantity, carbon dioxide (CO2) is more harmful to the climate than methane.	62.3
The global CO2 concentration in the atmosphere has increased during the past 250 years.	80.2
The increase of greenhouse gasses in mainly caused by human activities.	73.7
With a high probability, the increase of CO2 is main cause of climate change.	54
Climate change is mainly caused by natural variations such as changes in solar radiation intensity and volcanic eruptions.	57.8
The last century's global increase in temperature was the largest in the last 1000 years.	60.6
The Earth's climate has changed naturally in the past, therefore humans are not the cause of global warming.	66.1
The decade from 2000 to 2009 was warmer than any other decade in over 150 years.	59.2
Global warming will stop as soon as we stop producing greenhouse gasses.	74.6
Over the next several decades, we can expect…	
… an increase in extreme events, such as droughts, floods, and storms.	75.2
… a warmer global climate to increase the melting of polar ice, which will lead to an overall rise of the sea level.	76.3
… the climate to change evenly all over the world.	68.3
… a precipitation increase in every region worldwide.	56.9
… changes in animal migration patterns	75.8
… wildlife communities to move toward the poles.	36.1
…. some places to get wetter, while others get drier	80.5

Supplemental Table A.3. Survey items used to construct climate change concern variable.

Survey Item	**Mean**	**SD**
How worried are you about climate change?	2.28	0.85
How much do you think climate change will negatively affect you personally?	2.00	0.85
When do you think climate change will start to negatively affect people in the United States?	3.14	1.33
How much do you think climate change will negatively affect future generations of people?	2.16	1.44

Appendix B

Supplementary Materials for CHAPTER 2

Case study description of de-extinction provided to participants prior to the questionnaire.

De-extinction

While some synthetic biology projects aim to create new life, others are attempting to bring life back to how it was prior to human involvement. One such technology titled "de-extinction" is taking shape through the convergence of disciplines including synthetic biology, cloning, genetic engineering, and stem cell research. Put simply, de-extinction will recreate endangered and extinct species. Stewart Brand, editor of the Whole Earth Catalog describes the exigence of the de-extinction plan noting that "[h]umans have made a huge hole in nature in the last 10,000 years… [and] we have the ability now, and maybe the moral obligation, to repair some of the damage."

The plan of de-extinction technology is two-fold: First, to catalog the genomes of a great host of species around the world, and second to help restore organisms and habitats damaged or destroyed by human activity. Projects like Genome 10K aim to assemble a genomic zoo—a collection of DNA sequences representing the genomes of 10,000 vertebrate species, approximately one for each vertebrate genus. The project is making use of a variety of technologies including DNA extraction, amplification and sequencing, phylogenetic and population genetic analysis, and bioinformatic approaches to whole-genome analysis in order to

record such genetic diversity with the hope that the catalog will serve as an unprecedented resource for the life sciences and for worldwide conservation efforts.

Other projects are going beyond cataloging and recoding genetic information and are trying to actively recreate endangered and extinct species. One recent example is the recreation of a gastric-brooding frog embryo, from which the primary species became extinct in 1983. Scientists were able to complete somatic cell nuclear transfer, by implanting a cell nucleus of a preserved gastric brooding frog sample into a living egg from a distantly related great barred frog. The scientists deactivated the living egg nuclei and replaced them with dead nuclei from the extinct frog's preserved egg, which subsequently began to divide and grow to early embryo stage. Other projects include the recreation of an extinct variety of wild mountain goat in 2010. The goat died minutes after being born. Also, Harvard geneticists are currently working to bring back the passenger pigeon, which has been extinct since 1914.

Many researchers are investigating de-extinction technologies. Beth Shapiro, an evolutionary biologist at UCSC is sequencing of Passenger Pigeon DNA extracted from museum specimens and making comparisons to determine compatibility with its closest relative, the Band-tailed Pigeon. George Church at the Harvard Wyss Institute is also working with the Passenger Pigeon project. Other notable organizations, including the National Geographic Society and Revive and Restore, are supporting de-extinction scientists worldwide to build a roster of potentially revivable species to enrich the fields of conservation and ecology. Internationally, the Tauros Foundation in the Netherlands is facilitating a project with Rewilding Europe and European Wildlife to restore Aurochs, an ox that stands up to six feet tall at the shoulder and became extinct around 1630. Project Lazarus intends to revive particularly exotic,

extinct species, and researchers **Michael Archer** and **David French** are working on refinements of somatic cell nuclear transfer in order to do so.

Many cloned animals have complications and die quickly—an ethical problem likely to continue with reviving extinct animals. Altered habitats to return to is another practical and ethical issue. There is also the fear that revived species could negatively impact other current species or habitats. Some species may have the potential to become invasive or serve as vectors for disease. **Ecologists** suggest that endogenous retroviruses residing in genomes of extinct species may be problematic as well. Lastly, some conservationists are concerned that bringing back extinct species would be resource intensive, and in an environment where resources are already scarce, may detract from efforts to prevent extinctions.

De-extinction References and Sources

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Supplemental Table B.1. SRES Questions. Formatted adopted from Qualtrics

- How potentially hazardous is deextinction to human health?

Completely unhazardous (1) 2 3 4 5 6 7 8 9 Completely Hazardous (10)

- How potentially hazardous is deextinction to the environment?

Completely unhazardous (1) 2 3 4 5 6 7 8 9 Completely Hazardous (10)

- How beneficial is deextinction to human health?

Completely Not Beneficial (1) 2 3 4 5 6 7 8 9 Completely Beneficial (10)

- How beneficial is deextinction to the environment?

Completely Not Beneficial (1) 2 3 4 5 6 7 8 9 Completely Beneficial (10)

- What might be the level of public concern regarding the risks of deextinction?

Completely Unconcerned (1) 2 3 4 5 6 7 8 9 Completely Concerned (10)

Supplemental Materials. Categorization definitions for major themes among open-ended responses.

What issues related to deextinction do you foresee as being important in terms of potential impacts on human health?

Disease- Historic zoonotic disease could be re-introduced or de-extinct population acts as novel vector

None or Limited- No impact or very limited impacts to human health

Socio-ecological impacts- De-extinct animals disrupt agricultural, land, or water resources

Case specific- Impacts to human health depend on species and place

Lead to human genome engineering- De-extinction successes will lead to human cloning or engineering

Physical harm- De-extinct animals may physically harm humans

Don't know- Didn't indicate an impact (but did write-in response)

What issues related to deextinction do you foresee as being important in terms of potential impacts on the environment?

Exhibit invasive characteristics- Potential impacts explicitly compared to invasive species or potential impacts similar to invasive species- outcompetes other species, lacks natural predators

Ecosystem interactions (neutral)- Impacts to ecosystem, but response lacked positive or negative valence

Ecosystem impacts (negative)- Negative impacts to ecosystem

Disease- Historic zoological disease could be re-introduced or de-extinct population acts as novel vector

Revived species environment/comp- De-extinct species will be unable to compete and survive in contemporary environments

Revived species health and rearing- De-extinct species may not be healthy or raised well

Socio-ecological impacts- De-extinct animals may disrupt agricultural, land, or water resources

Feasibility questions- Question whether technology can actually lea to de-extinction

Little to no impact- De-extinction will not have substantial impact, animals cannot be made or will only be in captivity

Change conservation- May alter conservation biology research and practices

Harm surrogates- Harm de-extinct animals surrogates (i.e. Elephants used for growing mammoth population)

Dangerous animals- Fear of de-extinct carnivores

What issues related to deextinction do you foresee as being important in terms of potential impacts on society?

Threatens conservation efforts- Draws efforts and funds from traditional conservation efforts, or removes justification for preventing extinction

Hubris and techno-optimism- De-extinction might increase hubris and techno-optimism, beliefs that scientists and technology are solution to problems

Ethics of reviving- Question whether reviving species is morally permissible

Socio-ecological impacts- De-extinct animals may disrupt agricultural, land, or water resources

Animals rights- Animal welfare or suffering during rearing

Public engagement- Concerns about how to engage with public

Regulation- Question what regulations exist for de-extinction

Questionable benefits- Concern that de-extinction is not beneficial

Ethics of human cloning, gene editing- If de-extinction occurs, technology may be applicable to humans, raising new concerns

Encourage conservation- De-exctinction may lead to increased attention or funds for conservation efforts

Ethical obligation- People are obligated to revive species if people caused their extinction

Conserving de-extinct animal- Concern that de-extinct animals will not be valued

Irreversible- Concern that de-extinct animals may not be controlled once released

Biodiversity issues- Question whether de-extinct animals improve biodiversity

No moral obligation- Refute the belief that people are obligated to revive extinct species

What other observation or suggestions do you have in terms of research needs for assessing potential hazards of deextinction?

General ecology- Broad studies of ecology, ecosystems, or ecological modelling

General social science- Broad questions of how society may accept de-extinction

Restoration ecology- Studies from sub-discipline of restoration ecology

Molecular and synthetic biology- Studies from molecular and synthetic biology needed for achieving de-extinction or minimizing risks

Cost-benefit or decision analysis- Analyses to help decide if de-extinction is worthwhile and who decides

Population genetics- Studies on genetic variation between and within populations

Invasive species biology- Studies from sub-discipline of invasive species biology

Policy & regulation- Question whether de-extinction will be regulated

Ethics- Studies that explore the ethics of de-extinction

Biosafety- Question implementing biosafety measures

Public engagement- Question on how to engage public

Difficult to assess- Assessing all potential hazards may be difficult

What existing research areas do you believe may be particularly useful in helping to inform the question about potential environmental health and safety (EHS) hazards posed by deextinction?

General ecology- Broad studies of ecology, ecosystems, or ecological modelling

Invasive species biology- Studies from sub-discipline of invasive species biology

Restoration ecology- Studies from sub-discipline of restoration ecology

Disease and immunology- Studies on disease ecology and resistance

Conservation biology- Studies from disciplines of conservation biology

Paleontology- Paleontology studies

Molecular and synthetic biology- Studies from molecular and synthetic biology

Bioethics- Studies on bioethics or welfare of cloned animals

Historical ecology- Studies on historic ecosystem processes

Systems biology- Studies on function and processes of biological systems

Physiology- Studies about animal health

Evolution- Studies about evolution

Economics- Studies on costs of de-extinction

Don't know- Didn't indicate research area (but wrote-in response)

What novel research areas do you believe may be particularly useful in generating information to inform the question about potential EHS hazards posed by deextinction?

Don't know

Molecular and synthetic biology- Studies on molecular and synthetic biology, including biological processes among hybrids, stem cell research, and genetic engineering

Genomics- Studies on genomics, whole system genetics

Disease ecology/ Ancient DNA- Studies on the DNA of extinct animals and the possibility of hidden diseases

No novel research- No novel research or there will be no novel research for de-extinction in the future

General ecology- Broad studies of ecology, ecosystems, or ecological modelling

Big data ecology- Integrate advancing computer simulations to model complex ecological processes

Cost-benefit analysis- Utilize better data for better informed cost-benefit analysis in the future

Evolutionary genetics- evolution of novel species and hybrids

Reproductive studies- Studies on transferring embryos

Restoration ecology- Studies from sub-discipline of restoration ecology

Bioethics- Studies on health of clones

Science fiction- Verbatim response

Safety- Safety studies for de-extinct animals

What characteristics of deextinction will be most concerning to the public?

***Jurassic Park* (scenario)**- Public may rely on interpretations related to *Jurassic Park*

Question- Public may question the value of de-extinction, or perceive it as a waste

Ecosystem impacts- Negative impacts to ecosystem

Ethics of reviving- Question whether reviving species is morally permissible

Ethics (General)- Mentions ethics but does not specify an issues or concern

Hubris and techno-optimism- De-extinction might increase hubris and techno-optimism, beliefs that scientists and technology are solution to problems

Animal welfare- Concern about animal health

Uncertainty- Concern about novelty and undefined risks

Other science fiction references- Public may rely on *Frankenstein* or other science fiction references

Awe- Public may be enthralled by de-extinction

Governance concerns- Asks who decides whether to enact de-extinction

Socio-ecological impacts- De-extinct animals may disrupt agricultural, land, or water resources

Lead to human genome engineering- De-extinction successes will lead to human cloning or engineering

Ignore conservation- Question whether de-extinction should be pursued when current species are threatened and being ignored

Depends on the organism- Public interpretations depends on de-extinct species

Don't know- Didn't indicate characteristic (but wrote-in response)