

LEARNING TO SEE THE PRIDE FOR THE LIONS:
AN INTERDISCIPLINARY ASSESSMENT OF COMPLEX SYSTEMS

By

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ABSTRACT

LEARNING TO SEE THE PRIDE FOR THE LIONS: AN INTERDISCIPLINARY ASSESSMENT OF COMPLEX SYSTEMS

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In this dissertation I conducted, evaluated, and advanced research on complex socio-ecological and socio-cognitive systems. In Chapter 1, I explored the degree to which pastoralist cattle (*Bos taurus*) in northern Tanzania exhibited anti-predator behaviors in response to the risk of depredation by African lions (*Panthera leo*). Using focal animal sampling, I compared two typical anti-predator behaviors, vigilance and grouping, among cattle in village rangelands with high and low background depredation rates. I found that pastoralist cattle exhibit anti-predator strategies that varied both spatially and temporally, and that such strategies might help livestock optimally trade-off the costs and benefits of anti-predator behavior across timescales. In Chapter 2, I investigated the many drivers of human-lion conflict in East Africa to create a novel conceptual model illustrating the intricate interactions within and between the main dimensions of conflict. I highlighted the importance of broadening research efforts to include these multiple dimensions at all stages of the research process and made recommendations on how to approach human-lion conflict from a more interdisciplinary perspective. In Chapter 3, I explored how aspects of perceived team composition were related to the publication performance of integrative environmental science research teams using two common bibliometrics. I found that perceived team size was positively associated with the mean number of peer-reviewed publications per year, and perceived disciplinary diversity was negatively associated with the mean journal impact factor of those publications. My findings may be used to improve the performance of diverse integrative research teams. In Chapter 4, I created a systems-based framework for

conservation research and established a discipline-specific definition of reflexivity to enable the integration of reflexive methods into conservation science and practice. I outlined four major tenets of reflexivity for conservation and presented practical techniques that conservationists can use to adhere to these tenets and foster research-informed conservation efforts that are more ethical, adaptive, and diverse. I close my dissertation with a summary of my key findings and a look towards the future of interdisciplinary research.

For me.
Yesterday I was clever so I wanted to change the world.
Today I am wise so I am changing myself.

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PREFACE

The chapters in my dissertation were conceptualized as separate papers and written collaboratively with co-authors. Two chapters have been published in academic peer-reviewed journals, the third chapter is in peer review as of January 2021, and the fourth chapter is anticipated for submission. The citation for each chapter is as follows:

- Beck, J. M., Moll, R. J., Kissui, B. M., Montgomery, R. A. Do Pastoralist Cattle Fear African Lions? *Oikos*. 2020.
- Beck, J. M., Lopez, M. C., Mudumba, T., Montgomery, R. A. Improving Human-Lion Conflict Research Through Interdisciplinarity. *Frontiers in Evolution and Ecology*. 2019.
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In addition to my dissertation, I collaborated on several additional papers during my time at Michigan State University. The published papers I co-authored include:

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- Montgomery, R. A., Elliott, K. C., Hayward, M. W., Gray, S. M., Millspaigh, J. J., Riley, S. J., Kissui, B. M., Kramer, D. B., Moll, R. J., Mudumba, T., Tans, E. D., Muneza, A. B., Abade, L., Beck, J. M., Hoffmann, C. F., Booher, C. R., Macdonald, D. W. Examining Evident Interdisciplinarity Among Prides of Lion Researchers. *Frontiers in Evolution and Ecology*. 2018.
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- Hayward, M. W., Porter L., Lanszki, J., Kamler, J. F., Beck, J. M., Kerley, G. I. H., Macdonald, D. W., Montgomery, R. A., Parker, D. M., Scott, D. M., O'Brien, J., Yarnell, R. W. Factors Affecting the Prey Preferences of Jackals (*Canidae*). *Mammalian Biology*. 2017.

TABLE OF CONTENTS

LIST OF TABLES	x
LIST OF FIGURES	xi
INTRODUCTION	1
CHAPTER 1: DO PASTORALIST CATTLE FEAR AFRICAN LIONS?	5
CHAPTER 2: IMPROVING HUMAN-LION CONFLICT RESEARCH THROUGH INTERDISCIPLINARITY	6
CHAPTER 3: ASSESSING THE PUBLICATION PERFORMANCE OF INTEGRATIVE RESEARCH TEAMS USING A SOCIO-COGNITIVE SYSTEMS APPROACH	7
3.1 Abstract	7
3.2 Introduction	8
3.3 Methods	13
3.3.1 Data Collection	13
3.3.2 Explanatory Variables	14
3.3.3 Model Fitting and Selection	15
3.4 Results	16
3.5 Discussion	17
3.5.1 Publication Productivity	17
3.5.2 Publication Impact	20
3.5.3 Broader Implications and Conclusions	23
3.6 Acknowledgements	24
CHAPTER 4: THE APPLICATION OF REFLEXIVITY FOR CONSERVATION SCIENCE	26
4.1 Abstract	26
4.2 Introduction	26
4.3 A Framework for Complexity	29
4.4 The Tenets of Reflexivity for Conservation Science	31
4.4.1 Looking Inward: Conservation is Informed by Personal Values.....	31
4.4.2 Looking Outward: Conservation Requires True Partnerships.....	34
4.4.3 Looking Back: Conservation Must Contend with its Own History.....	36
4.4.4 Looking Forward: Conservation Demands Progress.....	39
4.5 Integrating Reflexivity into Conservation Practice.....	42
4.6 Acknowledgements	47
CONCLUSION	48

APPENDICES.....	52
APPENDIX A: Translated Research Summary.....	53
APPENDIX B: Tables and Figures.....	56
APPENDIX C: Positionality Statement.....	68
REFERENCES	70

LIST OF TABLES

Table 3.1. The ranking of models that predict metrics of publication performance for integrative research teams. Top model results ($\Delta AIC_c = < 2.0$) for the average number of peer-reviewed journal articles published by the team per year and average impact factor of the journals in which the teams published and are presented. Bold covariates are indicative of significant effects (P-value ≤ 0.05) 64

Table 3.2. The averages of models developed to predict metrics of publication performance for integrative research teams 65

LIST OF FIGURES

<i>Figure 3.1.</i> A modified input-process-output model for the functioning of integrative research teams which includes perceived team composition as a key additional factor.....	66
<i>Figure 3.2.</i> Mixed linear regression trends from the most supported model predicting publication productivity for integrative research teams. The 95% confidence intervals of the estimate are depicted in gray shading.....	67
<i>Figure 3.3.</i> Mixed linear regression trends from the most supported model predicting publication impact for integrative research teams. The 95% confidence intervals of the estimate are depicted in gray shading.....	68
<i>Fig. 4.1.</i> Conservation science as a complex adaptive system. An example of one potential system, with processes in green, the conservationist (i.e. self) in gray, and other actors in blue. The scientific process is considered nonlinear and actors may stand alone or function as networks. Arrows represent lines of influence between actors and processes, dashed lines represent feedback loops which may cause fundamental changes in the conservationist or their future interactions. Systems will vary across contexts and may change over time. For example, if the scientific process includes a participatory research method, local stakeholders would have additional lines of influence across the system.....	69
<i>Fig. 4.2.</i> Representation of the overlapping nature of the four tenets of reflexivity for conservation science, with example prompts to encourage reflexivity.....	70
<i>Fig. 4.3.</i> Worksheet for Tenet 1. Activities to practice reflexivity for conservation science.....	71
<i>Fig. 4.4.</i> Worksheet for Tenet 2. Activities to practice reflexivity for conservation science.....	72
<i>Fig. 4.5.</i> Worksheet for Tenet 3. Activities to practice reflexivity for conservation science.....	73
<i>Fig. 4.6.</i> Worksheet for Tenet 4. Activities to practice reflexivity for conservation science.....	74

INTRODUCTION

In recent decades, human-wildlife conflict has appeared to increase drastically around the globe (Anand and Radhakrishna 2017). Species extirpations and population declines can result in devastating and often compounding ecological impacts (Sinclair 2003) as well as substantial cultural and financial losses for human communities (Fayissa et al. 2008, Griffiths 2017). These ecological and social intricacies position human-wildlife conflict as a ‘wicked’ problem. Wicked problems are those that are extremely difficult to manage, have no clear resolution, and typically involve often-competing viewpoints among multiple stakeholders (Rittel and Webber 1973). Wicked problems cannot be solved using conventional approaches but require collaborative partnerships across biological, physical, and social sciences, as well as humanities, engineering, and other disciplines (Berkes 2004, Rylance 2013). Interdisciplinary science integrates the vast skills, knowledge, and perspectives needed to fully understand and address wicked problems (Eigenbrode et al. 2007) and is therefore essential to developing and implementing sustainable solutions to human-wildlife conflict. However, building and maintaining interdisciplinary science teams has itself been identified as a wicked problem (Norris et al. 2016).

The foundation of an interdisciplinary team is the composition of the individual team members themselves. This refers to each individual team member’s core scientific disciplines, and the unique combinations of their technical skillsets, social and cultural knowledge, and personal perspectives (Frodeman 2010, Corley et al. 2019). The collaborative research process is fundamentally shaped by interactions among individuals (Bennett et al. 2010, Bennett and Gadlin 2012). Thus, collaborative interdisciplinary science is driven not only by each team member’s scientific expertise, but also by intragroup relations and team-level processes that feed

back into their research efforts (Hinsz et al. 1997, Curşeu et al. 2007). Disagreements between diverse team members can arise if there is a lack of familiarity with the terminology, methods, or underlying assumptions of the various disciplines represented on a team or if individuals have difficulty communicating or building trust (Heemskerk et al. 2003, Jakobsen et al. 2004). Negative power dynamics can also plague teams, stemming from a wide array of differences such as demographics, career status, and institutional affiliations (Pooley et al. 2014, Brittain et al. 2020). Furthermore, scientists studying conservation problems may also collaborate with wildlife managers and other natural resource practitioners, community stakeholders, or civil scientists to conduct transdisciplinary research, adding even more complexity to the team and their work (Olsson et al. 2004, Coreau 2016). Thus, just as human-wildlife conflict is a wicked problem situated in a complex system made up of social and ecological elements, collaborative research is an intricate process within a broader complex system of institutional and inter-relational components. Improving either requires systems-level thinking (Kreuter et al. 2004, Wade et al. 2020).

Complex systems, like the examples described above, are comprised of many interconnected actors and elements that learn and adapt over time, nonlinear processes, and multidirectional feedback loops (Holland 1992, 2006). A system has multiple potential boundaries related to its physical, social, spatial, and temporal attributes, the delineation of which is inherently subjective and may vary across studies (Reynolds 2011, Knight et al. 2019). Thus, any specific system under study represents only a subset of all possible attributes and their inter-relationships. Conservation and natural resource professionals have historically taken a narrow view of the systems in which they work and conduct research, often delineating boundaries in ways that exclude the people, institutions, and politics that shape them (Dowie

2011, Montgomery et al. 2020), and generating knowledge by systematically reducing a complex whole into ever-smaller components. While in practice it is impossible to gather data on all aspects of a constantly adapting system, employing systems thinking can contribute to a broader understanding of the various distinct components as well as the system as a whole (Sterling et al. 2010, Blair et al. 2017). Increasingly, researchers are engaging in systems thinking to investigate and analyze complicated situations. Methods like adaptive management are being utilized, where the goals of multiple stakeholders are considered at once and decisions are reassessed over time to emphasize the importance of continuous learning (Berkes and Turner 2006). However, such methods do not have the power to fundamentally and positively transform the systems themselves (Knight et al. 2019).

Today, as crises like climate change and COVID-19 expose injustices inherent in our social realities, researchers have a responsibility to not only learn about and work to resolve wicked problems, but to alter the patterns of inequity and instability that can perpetuate them. For example, economic inequalities embedded in post-apartheid sociopolitical practices can influence human-carnivore conflict (Rust et al. 2016), and novel scientific contributions made by demographically underrepresented researchers are devalued and less likely to result in academic job placements than their majority peers (Hofstra et al. 2020). Addressing such deeply rooted issues requires a combination of inquiry, introspection, and action. The integration of these processes is known as praxis (Denzin and Lincoln 2005). By linking professional practice, theory building, and self-reflection, praxis involves a commitment to social justice and challenging the status quo (Fahy 1996, Zuber-Skerritt 2001). Through praxis, research is intended to create societal, organizational, educational, or political change; and while researchers may accumulate

data and extend scientific principles, the primary goal remains social transformation (Freire 1970, Tierney and Sallee 2008).

In this dissertation, I engaged in two major interdisciplinary cycles of praxis within contrasting complex systems. My first two chapters address socio-ecological systems, specifically those relating to human-lion-livestock interactions in East Africa. In Chapter 1, I explored the degree to which pastoralist cattle (*Bos taurus*) exhibited anti-predator behaviors in response to the risk of depredation by African lions (*Panthera leo*) by combining theories and ideas from predator-prey ecology, animal science, and rangeland management. In Chapter 2, I reflected on socio-ecological systems broadly by investigating the main dimensions of human-lion conflict and creating a novel conceptual model illustrating the intricate interactions within and between these dimensions. My final two dissertation chapters address socio-cognitive systems, specifically complex and interacting groups of conservation researchers and practitioners. In Chapter 3, I assessed the publication performance of integrative research teams by blending concepts from psychology, team science, and scientometrics. In Chapter 4, I reflected on the complex research process to establishing a systems-based framework for conservation science and a discipline-specific definition of reflexivity. These two cycles of inquiry and reflection are intended to support positive change in both socio-ecological and socio-cognitive systems. Therefore, I conclude my dissertation with a summary of my key findings and recommendations for more ethical conservation action, inclusive team functioning, and future interdisciplinary research.

CHAPTER 1:

DO PASTORALIST CATTLE FEAR AFRICAN LIONS?

Within the Tarangire-Manyara Ecosystem of Tanzania, I explored the degree to which pastoralist cattle (*Bos taurus*) exhibited anti-predator behaviors in response to the risk of depredation by African lions (*Panthera leo*). Using focal animal sampling, I compared two typical anti-predator behaviors, vigilance and grouping, among cattle in village rangelands with high and low background depredation rates. I found that cattle in high risk village rangelands formed larger groups while cattle in low risk village rangelands spent more time vigilant, and these patterns were influenced significantly by the time of day. My results suggest that pastoralist cattle exhibit anti-predator strategies that vary both spatially and temporally, and that such strategies might help livestock optimally trade-off the costs and benefits of anti-predator behavior across timescales. For a full text of this work, go to:

Beck, J. M. Moll, R. J., Kissui, B. M., Montgomery, R. A. Do Pastoralist Cattle Fear African Lions? *Oikos*. 2020. <https://doi.org/10.1111/oik.07965>.

Since publishing this study, I have also summarized and translated the findings into Swahili for dissemination to Tanzanian stakeholders. This information is available here in Appendix A.

CHAPTER 2:

IMPROVING HUMAN-LION CONFLICT RESEARCH THROUGH INTERDISCIPLINARITY

In this study, I investigated the many drivers of human-lion conflict in East Africa and presented a novel conceptual model illustrating the intricate interactions within and between the five main dimensions of conflict. I highlighted the importance of broadening research efforts to include these multiple dimensions at all stages of the research process and to incorporate higher levels of diversity into research teams. I offered examples and recommendations on how to approach human-lion conflict from a more interdisciplinary perspective and encouraged researchers and institutions to support a team science approach to solving wicked problems like human-lion conflict. For a full text of this work, go to:

Beck, J. M., Lopez, M. C., Mudumba, T., Montgomery, R. A. Improving Human-Lion Conflict Research Through Interdisciplinarity. *Frontiers in Evolution and Ecology*. 2019.

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CHAPTER 3:
ASSESSING THE PUBLICATION PERFORMANCE OF INTEGRATIVE RESEARCH
TEAMS USING A SOCIO-COGNITIVE SYSTEMS APPROACH

3.1 Abstract

The performance of science teams is often measured by research outputs, namely peer-reviewed publications and their bibliometrics, deriving from collaborative research processes. Integrative research, characterized by the key process of knowledge integration, combines the distinctive skills, resources, and know-how of diverse team members to create research outputs that are often novel and interdisciplinary. The outputs of integrative research teams are not only byproducts of team members' unique human capital (i.e., inputs) and the interactions between individuals (processes), but also the composition of the group as a whole and the ways that team members perceive the group and each other. While perceptions can substantially drive interactions between team members, little attention has been given to the ways in which researcher perceptions of team composition are associated with the resultant publication bibliometrics. In this study, I examined if and how aspects of perceived team composition were related to team publications using two common bibliometrics, publication rate and impact factor. I devised a modified input-process-output model positioning team-level perceptions as a critical link between researcher inputs and the knowledge integration processes that result in publications. I applied this model to the publication bibliometrics of 50 NSF-funded integrative research teams. I found that publication productivity (i.e., mean number of peer-reviewed publications per year) was positively associated with perceived team size, and publication impact (i.e., mean journal impact factor of those publications) was negatively associated with perceived

disciplinary diversity. I discuss how these findings differ from past research on science teams and make recommendations for the improved performance of diverse integrative research teams.

3.2 Introduction

In the 21st century, the majority of scientific knowledge is produced by science teams, a dramatic shift from historic scientific practices that were led primarily by solo researchers (Wuchty et al. 2007, Ahn et al. 2014, Larivière et al. 2015a). A science team is a group of researchers who take a collaborative approach to scientific inquiry (Bennett et al. 2010). Individuals bring to these teams unique combinations of scientific, technical, social, and cultural knowledge (i.e., human capital; Corley et al. 2019) and the collaborative research process is fundamentally shaped by interactions among individuals (Bennett and Gadlin 2012). In this way, the production of novel science is driven not only by each team's available human capital, but also by intragroup relations and the team-level information processing that may transpire (Cooke et al. 2015). Thus, science teams are complex and ever-evolving socio-cognitive systems (Hinsz et al. 1997, Curşeu et al. 2007). As more researchers are joining science teams than ever before (Adams et al. 2005, Jones et al. 2008), describing how these human systems function is of major scientific interest (Whitfield 2008).

There is a rich history of science investigation into the social and cognitive functioning of teams (Brown and Pehrson 2019). Studies in organizational management, research and development, health care, education, and a variety of social sciences have resulted in strong foundational theories of team functioning (Hülshager et al. 2009, Kozlowski 2018, Ramos-Villagrasa et al. 2018). For example, fundamental in psychology, and now used widely across fields and disciplines, is the 'input-process-output' model that gives a systematic, stepwise pattern to the many factors and interactions that ultimately result in group outcomes (Hackman

and Morris 1975, Barrick et al. 1998, Omar and Ahmad 2014). A relatively new field of study, referred to as the *science of team science* (SciTS), aims to explain the functioning of science teams, in particular, and how researcher inputs and intragroup processes influence scientific outputs such as the number and type of publications (Stokols et al. 2008a). Much of this research also evaluates the performance of science teams based on those publications, using bibliometrics such as citation counts or impact factors (Carpenter et al. 2014). Bibliometrics are a major consideration in hiring, funding, and promotion decisions for academic researchers and as such, these measures of science team performance are substantial contributors to the success of research programs and individual researchers (Hopkins et al. 2013, Warner et al. 2016).

Currently, science teams are experiencing compositional changes that could subsequently influence group functioning and performance. Researchers are collaborating more often with colleagues from disciplines outside their own, via the formation of multi-, inter-, and transdisciplinary teams (Stokols et al. 2008a, Frodeman 2010). Increases in financial and institutional support for minoritized and marginalized groups have increased demographic diversity among science teams, particularly in STEM fields (National Science Foundation 2019). Concurrently, science teams are becoming larger, as the value of scientific collaboration gains attention and technological advancements make long-distance collaborations more accessible (Adams et al. 2005, Barjak and Robinson 2008, Ahn et al. 2014). Studies have shown that changes in team composition like these can be significantly associated with a team's research outputs (Horwitz and Horwitz 2007, Cook et al. 2015, Hall et al. 2018). However, across the SciTS literature, there is little consensus about how to define and measure various aspects of team composition (Hülshager et al. 2009, Wagner et al. 2010, Bell et al. 2011).

In many studies, team composition is inferred from the team's publications. For example, disciplinary diversity is commonly quantified by the disciplines represented in the literature cited section of an article (Yegros-Yegros et al. 2015). Measuring disciplinary diversity by citations, however, is not necessarily indicative of disciplinary expertise (i.e., available human capital; researcher inputs) within a team and may undervalue disciplines that team members represent (Wagner et al. 2010). Team demographic diversity has also been measured through analysis of coauthor names (AlShebli et al. 2018, Lerback et al. 2020). This practice is tedious and error-prone (Andrew Harris 2015) and may introduce bias, given that scientists from underrepresented groups are less likely to receive authorship invitations and more likely to experience unfair authorship practices within their teams (Settles et al. 2019, Thomas et al. 2019). Additionally, team membership does not guarantee coauthorship and individuals with less professional power, particularly graduate students or those of comparatively lower academic rank, could have a considerable impact on team functioning without being included as authors (Seeman and House 2015). In these ways, studies tend to assess team composition based on team outputs, rather than team outputs based on team composition. This paradox is problematic for explaining how science teams function as groups of individual researchers because such approaches are unable to reflect the socio-cognitive processes that occur during research (Wang et al. 2015). These approaches are also inconsistent with the classic input-process-output model of group functioning and may lead to contradictory explanations of team performance. For instance, some studies have found that the publications of mixed-gender science teams receive higher citations than those of single-gender science teams (Campbell et al. 2013), while others have detected an opposing pattern (Lerback et al., 2020). A more nuanced understanding of the drivers of science team performance is needed (Harrison et al. 2002).

Integrative research teams, sometimes referred to as integrated research teams, interdisciplinary teams, or cross-disciplinary teams (Newell et al. 2005, Porter et al. 2006, Stokols et al. 2008b), are a unique type of contemporary science team for which an increased understanding of functioning and performance could prove especially useful. Integrative research teams often combine information, data, and ideas from multiple divergent sources to design novel, creative solutions to the complex environmental and socio-ecological problems humanity faces today (e.g. climate change, food security, wildlife conflicts; Focht and Abramson 2009, National Science Foundation 2011, Bennett and Gadlin 2012). They rely heavily on the diverse knowledge bases of their team members, who must engage in highly cooperative processes such as group problem solving and interpersonal communication (Newell et al. 2005, Salazar et al. 2012, Henson et al. 2020). Knowledge integration is the key process characterizing integrative research (Porter et al. 2006, Liu et al. 2012) and is likely a determining factor of overall performance for integrative research teams (Cooke et al. 2015). The social interactions that drive team processes such as knowledge integration are largely shaped by individuals' perceptions of fellow team members (Tajfel 1981, Mannix and Neale 2005). For example, when team members perceive differences between themselves and others, they can be motivated to scrutinize information more carefully, lower their resistance to dissenting or contrary information, and be more willing to express novel viewpoints (Sommers 2006, Phillips et al. 2009). Therefore, perceived diversity in team composition can help researchers avoid failures of knowledge integration (Steel et al. 2019). Thus, researcher perceptions could be a critical link between the inputs and outputs of integrative research teams.

Here, I devise a novel socio-cognitive model for integrative research team performance that positions perceived team composition as an underlying mechanism of research outputs (Fig.

3.1). This model is a modified input-process-output model connecting publications back to the inputs of individual researchers while taking into account the perceived social environment in which knowledge integration occurs. Using this framework, I evaluate whether team outputs are associated with certain aspects of perceived team composition, specifically team size and disciplinary, gender, and racial diversity. Because bibliometrics have been shown to robustly demonstrate knowledge integration (Zhang et al. 2018) they provide an appropriate proxy for integrative research team performance. Therefore, I quantified two common bibliometrics using publication outputs from a sample of National Science Foundation (NSF)-funded integrative research teams: *i*) publication productivity, measured as the average number of peer-reviewed articles published by a team each year of NSF funding, and *ii*) publication impact, measured as the average impact factor of the scientific journals in which a team published. Given the central importance of peer-reviewed publications for the advancement of academic careers and scientific knowledge (McKiernan et al. 2019), identifying associations between publication outputs and perceived team composition may offer important insights that support scientific performance at the individual, team, and broader academic scales. I join other researchers in the supposition that diversity undoubtedly enhances team science (Stahl et al. 2010, Smith-Doerr et al. 2017, Swartz et al. 2019), and as such, the aim of this study is to understand correlative rather than mechanistic patterns related to diverse team composition. I discuss the implications of my results for the functioning of large, collaborative, disciplinarily and demographically diverse, integrative research teams today and into the future.

3.3 Methods

3.3.1 Data Collection

To assess team composition, I used an existing dataset of survey responses collected from science teams in 2017 (see Settles et al. 2019). Teams and participants were identified using the NSF database of awards (National Science Foundation 2020). Teams received awards from one of three environmental science programs supporting integrative, transformative research on complex natural and socio-ecological systems, processes, and interactions from local to global scales. Specific program names are not disclosed here to reduce the possibility of participants' identification, however, all program descriptions emphasized the importance of integration across disciplines to advance scientific understanding in novel ways. During 2017, a total of 1,727 individuals from 229 interdisciplinary research teams were invited via email to participate in an online survey using the Qualtrics survey platform (Settles et al. 2019). All data are available in a public archive (<https://doi.org/10.3886/E105622V1>), excluding any demographic data that could be used to identify participants. Because investigating multiple perspectives allows for the identification of differences between individuals but also common patterns across a team (Werder and Maedche 2018), I included only teams in which two or more individuals participated in the survey in this analysis.

To determine team bibliometrics, I collected publication information from the NSF online database, including all peer-reviewed scientific journal articles published by the teams and reported on NSF annual reports through 2019. For publication productivity, I used the number of years that each team received grant funding from NSF to calculate an average rate of publication per funding year (i.e., mean number of publications per funding year). For publication impact, I used the InCites Journal Citation Reports database to obtain journal impact factors for each

article in the year of publication (Clarivate 2020) and calculated an average impact factor for each team (i.e., mean journal impact factor).

3.3.2 Explanatory Variables

In the online survey, participants shared their perceptions of their team and team members, including what they believed to be the scientific disciplines represented and the total team size. Participants were asked to select their team members' genders (man, woman, or don't know) and racial groups (White/Caucasian, Asian/Asian American/Pacific Islander, Black/African American, Hispanic/Latina(o), Middle Eastern, Native American/First Nations/American Indian, or don't know). As the survey participants subjectively determined the characteristics of their teams and team membership, I interpreted participant responses as aggregates of team member perceptions of team composition. For each team, I calculated the mean number of disciplines perceived by all participants to determine a team-level metric. I also averaged all participants' perceived team size responses, and then used this mean team size to calculate perceived proportions of women team members and researchers of color.

Here, I use the term *researchers of color* to represent all racial groups other than White/Caucasian selected on the survey. The term is not meant to discount the distinct experiences of different racial groups but refers to a collective category of people who have been historically marginalized in academia (Kaplan et al. 2018, Sotto-Santiago et al. 2019). This is important for understanding team functioning because racial discrimination can have cognitive effects on those experiencing, as well as those observing, these negative processes within a group (Ozier et al. 2019). The term *researchers of color* is also not meant to refer to minority (i.e., numerically underrepresented) groups necessarily, but rather groups that are known to experience social inequities, such as explicit bias and stereotyping, that can also substantially

impact team functioning (Mannix and Neale 2005, Clauset et al. 2015). For example, Asian/Asian Americans are overrepresented in some STEM fields, but experience forms of discrimination that influence group cohesion and performance (Lee 2006). Thus, while all approaches of categorizing people are reductionist, such techniques can reveal important philosophical insights that could be expanded upon in future studies (Silberstein 2002, Eigenbrode et al. 2007).

3.3.3 Model Fitting and Selection

I modeled each of the response variables (mean number of publications per funding year and mean journal impact factor) as a function of the explanatory variables (mean number of disciplines, mean proportion of women, mean proportion of researchers of color, and mean number of team members). Prior to model fitting, I examined collinearity, based on Spearman rank and computed variance inflation factors (VIF), and found a lack of multicollinearity among all variables (all values <3.0; Zuur, Ieno and Elphick, 2010). I fit generalized linear mixed models developed from all possible combinations of the four explanatory variables. I ranked models using Akaike Information Criterion corrected for small sample sizes (AIC_c) and weights of evidence ($AIC_c w_i$; Burnham and Anderson 2002). For final model interpretation, I averaged across all models within two ΔAIC_c of the top model using the conditional averaging approach, as these models were similarly supported (Burnham and Anderson 2002, p.151-152). I based inference on coefficients that were statistically significant ($\alpha < 0.05$ level) in the final averaged model. I conducted all analyses in RStudio using R version 3.5.2 (Team R Core 2018) and the packages lme4 (Bates et al. 2015) and MuMIn (Barton 2018).

3.4 Results

After excluding 55 teams due to insufficient survey participants (< 2) or publications ($n = 0$), a total of 187 participants from 50 NSF-funded integrative research teams were included in my analysis. Up to 12 individuals per team participated in the survey, with an average of 4 ($SD \pm 2$) survey participants per team. The disciplines that participants identified on their teams were the natural sciences (represented on 100% of teams), social sciences (66%; $n = 33$), mathematics and statistics (56%; $n = 28$), computer sciences (48%; $n = 24$), engineering (34%; $n = 17$), humanities (22%; $n = 11$), and other disciplines (6%; $n = 3$). Survey participants reported an average team size of 14 ($SD \pm 9$) people, which included an average of 38.2% women ($SD \pm 13.1\%$) and 25.6% researchers of color ($SD \pm 16.2\%$). Between 2005 and 2019, the teams produced a total of 1,074 peer-reviewed journal articles that were published in 394 unique scientific journals. Teams produced between 1 and 99 articles each, with an average of 21.5 ($SD \pm 20.9$) articles across the 5-year period. Journal impact factors ranged from 0.2 to 43.7, with an average of 4.7 ($SD \pm 7.0$).

There were four models that had a $\Delta AICc \leq 2.0$ for each of the two dependent variables (Table 3.1). As these models were similarly-supported, I model averaged. There was one significant predictor of mean number of publications per funding year, and one significant predictor of mean journal impact factor among these models (Table 3.2). Specifically, the mean number of publications per funding year was significantly and positively related to perceived team size (Fig. 3.2, B). There was no significant relationship between mean number of publications per funding year and perceived demographic or disciplinary diversity (Fig. 3.2, A, C, and D). Mean journal impact factor was significantly and negatively related to perceived disciplinary diversity (Fig. 3.3, A). There was no significant relationship between journal impact factor and perceived demographic diversity or team size (Fig. 3.3, B, C, and D).

3.5 Discussion

Today, academic, industry, and political leaders all look to integrative research teams to help solve complex natural and socio-ecological problems around the world (Brunson 2012, Game et al. 2014, Wade et al. 2020). Studying how these research teams function as unique human systems may provide insights that increase the teams' ability to advance scientific understanding and solve complex challenges in novel ways. In this study, I took a socio-cognitive approach to assessing the performance of integrative research teams by incorporating the perceived social environment in which research processes occur into a classic model of team functioning (Fig. 3.1). Applying this model, I evaluated whether team publication bibliometrics were associated with perceived team size and disciplinary, gender, and racial diversity. I determined that perceived team size was positively associated with publication productivity, which aligns with the findings of previous research (Cummings et al. 2013, Verbree et al. 2015). I also found that perceived disciplinary diversity was negatively associated with publication impact, and that perceived gender and racial diversity were not significantly associated with either bibliometric. These results differ from some previous studies that did not consider team member perceptions as a component of team functioning (Hicks et al. 2010, Freeman and Huang 2015, Larivière et al. 2015b, Holman and Morandin 2019). Here, I compare these overall similarities and differences within the literature, discuss the implications of my results for the socio-cognitive functioning of integrative research teams, and offer recommendations to potentially enhance team performance.

3.5.1 Publication Productivity

I found that publication productivity was positively related to perceived team size (Table 3.1, Fig. 3.2, B). Similar trends have been found in studies using different conceptualizations of team size (Adams et al. 2005, Cummings et al. 2013). Some of the most common ways to quantify the

number of team members are through surveys of team leaders (Cook et al. 2015, Verbree et al. 2015) or institutional reports (e.g. university or funding agency accounts; Ebadi and Schiffauerova 2016, De Saá-Pérez et al. 2017). However, team members with varying levels of power can have differing beliefs about what constitutes team membership (Doekhie et al. 2017). Therefore, these approaches are likely to closely represent the team size as perceived by high power individuals (e.g., PIs, administrative officials), but may not represent the actual number of researchers that contributed to knowledge integration processes. In contrast, my results may indicate that when researchers jointly perceive their teams to be large, this awareness contributes to their group productivity. For example, if individuals believe they have many team members, they may feel more supported personally and better equipped professionally to effectively engage in the social and cognitive processes inherent to integrative research (Salazar et al. 2012).

It is theorized that disciplinary diversity can increase a science team's productivity through a greater range of information, cognitive resources, and original ideas (Pennington 2008). However, I did not find that publication productivity was significantly associated with perceived disciplinary diversity. There was even a noticeable, although non-significant, negative pattern (Fig. 3.2, A), suggesting that more articles were published when perceived disciplinary diversity was low. The potential for scientific innovation may be reduced if researchers believe their teams are lacking in disciplinary diversity (Bennett et al. 2010, Hofhuis et al. 2018). An interesting avenue for future research would be to compare self-reported disciplinary expertise to team perceptions of disciplinary diversity. This could explain how membership to different scholarly disciplines, and potential social biases associated with those disciplines (see Urbanska et al. 2019), influence interactions between team members and knowledge integration processes. Alternatively, the patterns of publication productivity I observed may have been influenced by

biases at the journal level, rather than the team level. That is, the socio-cognitive background of peer reviewers and journal editors themselves introduce biases into the review process that result in non-neutral assessments of submitted articles (Langfeldt 2006, Laudel 2006). For example, a reviewer who is an expert in one discipline may demand higher application of that discipline's theories or methods than are necessary for an integrative research project that spans multiple disciplines. This type of bias can lead to the unfortunate rejection of truly innovative articles, stifling scientific progress (Perper 1989). Journals should seek peer reviewers who are versed in general interdisciplinary work, or non-academic researchers from government agencies, industry, or NGOs, who are familiar with the challenges of interdisciplinarity (Nightingale and Scott 2007). More important perhaps than any specific scientific expertise are the personal characteristics of open-mindedness and curiosity to advance the publication of integrative research (Perper 1989, Pautasso and Pautasso 2010).

Finally, although publication productivity did not have a statistically significant association with either of the demographic variables I assessed here, I detected a slight positive pattern with the perceived proportion of researchers of color (Fig. 3.2, D). This result may be an artifact of the relatively recent increase in the number of researchers of color in PhD programs (National Science Foundation 2019). Science teams with high proportions of PhD students and postdoctoral researchers tend to be more productive (Stvilia et al. 2011, Conti and Liu 2015) and researchers of color are receiving PhDs at higher rates than professorships (National Center for Education Statistics 2019a, 2019b). Thus, there may currently be more researchers of color in these particularly productive early career stages, but further analysis is required to determine whether the pattern I detected is related to perceptions of racial diversity, career status, or other factors. Regardless, researchers of color often have multicultural experience, gaining cognitive

flexibility by navigating both minority and majority cultures (Eagly and Chin 2010). These experiences can foster creativity, the ability to shift thinking between contexts, and more detailed information processing (Molinsky 2007, Leung and Galinsky 2008, Crisp and Turner 2011). Teams perceived to have relatively high proportions of researchers of color may therefore benefit from multicultural experience during knowledge integration processes, resulting in increased ideas leading to high numbers of publications.

3.5.2 Publication Impact

As novelty and cross-disciplinarity were conditions of the NSF programs that funded the teams in my sample, and grant-sponsored teams, particularly NSF-sponsored teams, tend to publish in high impact journals (Zhao 2010, Garner et al. 2012, Wang and Shapira 2015), a positive relationship between perceived number of disciplines and journal impact factor might have been expected. However, I found that publication impact was associated with lower perceived disciplinary diversity (Table 3.1, Fig. 3.3, A). This result could mean that teams perceived to be disciplinarily diverse struggle to communicate the quality or applicability of their work to journal editors and peer reviewers. Cross-disciplinary research can be difficult to describe, leading to innovative methods and approaches that are mistaken as invalid or even “unintelligible scholarship” (Khagram et al. 2010, pg 388) to outside evaluators. Alternatively, reviewers from scholarly communities that adhere to well-established disciplinary norms may judge integrative approaches as less rigorous, relevant, or valuable, dissuading research teams from contributing to ‘elite’ journals (Belcher et al. 2016, Lugosi 2020). Also, impact factors and citation trends vary across disciplines, and the same score may seem high in one discipline but low in another. These differences can have direct effects on overall team publication success, as in some disciplines productive teams tend to be cited less, but in other disciplines they are cited more (Larivière and

Gingras 2010, Kolesnikov et al. 2018). Journals of comparatively high impact factor may not even exist for the specific combinations of disciplines that integrative researcher teams represent. Funders of integrative research teams could consider providing teams with skilled research advisors, who may be contacted in real-time to offer publication guidance specific to a team's unique needs and circumstances. Such levels of support would help to ensure that integrative research teams are prepared to create and disseminate more impactful research outputs regardless of disciplinary combinations.

When assessing the relationship between publication impact and team size, many past studies have used the number of coauthors to represent team size (Larivière et al. 2015a, Sud and Thelwall 2016) and have found positive correlations (Cook et al. 2015, Jeong and Choi 2015). However, I found a non-significant negative pattern between publication impact and perceived team size (Fig. 3.3, B). As perceived team size did have a positive and significant relationship with publication productivity, these two results together may suggest that while larger teams produce more publications overall, they might be falling into a 'quantity over quality' academic trap (Fernández-Ríos and Rodríguez-Díaz 2014). Researchers who perceive their teams to be large might feel pressure to produce many publications quickly at the expense of their overall impact (Kolesnikov et al. 2018). More information is needed to fully understand the publishing intentions of integrative research teams and the specific team processes that support higher publication impact. It is also important to note that while teams received funding for proposed integrative research projects, it is impossible to ascertain if team members indeed utilized integrative approaches during the research process. There is a risk that standard disciplinary research adopt "cosmetic changes" to appeal to policy-makers and funders (Nightingale and Scott 2007, pg. 548) and if this is the case, large teams with high resource needs may try to take

advantage of opportunities afforded to integrative research teams while not following through with integrative research outputs.

Like publication productivity, I did not find that publication impact was significantly related to perceived demographic diversity (Fig. 3.3, C and D). Differences in gender and race may represent proxies of cognitive diversity (Austin 1997). Team members bring a variety of backgrounds, perspectives, and knowledge bases to their research that groups may share based on gendered and racialized experiences in science and academia (Rose and Paisley 2012, Hopkins et al. 2013, Lundine et al. 2019). However, if dispersed cognitive resources are not communicated and integrated between team members and steps are not taken to transform and learn as a group, team performance can suffer (Driver 2003, Steel et al. 2019). Participants in this study provided information in the survey about the past training they received that supported their ability to be a member of a large research team. Only 14% of participants ($n = 27$) had received formal diversity training; 45% ($n = 84$) reported receiving no formal team training whatsoever. Perhaps the lack of such training impeded teams' abilities to effectively integrate knowledge between diverse individuals. Team and diversity trainings are important for building essential team science skills (Cheruvilil et al. 2014, Read et al. 2015) and for learning to benefit from a demographically diverse team (Austin 1997, Kozlowski and Ilgen 2006). My results suggest integrative research teams may need more access to, or incentive to take advantage of, such training opportunities which may improve collaborative processes and enable them to consequently see heightened associations between perceived demographic diversity and publication impact.

3.5.3 Broader Implications and Conclusions

My study revealed some additional findings that may have broad implications relating to overall performance and perceived diversity for integrative research teams. First, the average publication rate in my study was 4 articles per funding year and 62% ($n = 31$) of teams published at lower rates than this; 40% ($n = 20$) of teams published less than 10 papers total over the 5-year time period. While this rate from integrative research teams may seem low, it is comparable to the publication rates of science teams across a range of fields and disciplines (Cook et al. 2015, De Saá-Pérez et al. 2017). This suggests that despite the highly collaborative and interdependent nature of integrative research, these teams can be just as productive as discipline-based science teams. Second, the metrics of performance I considered here, number of publications per year and journal impact factor, are limited in scope and importance and do not consider other major scholarly outputs. Integrative research teams that appear to be low performing in this study could have produced alternative outputs such as educational resources, large data sets, or scientific outreach materials not currently accounted for. New metrics of performance may be needed that are unique to integrative research teams.

Finally, within teams, attributes shared between diverse individuals can help bridge differences and promote successful collaboration (Bell et al. 2011, Salazar et al. 2012). When an individual is perceived to have unique attributes within the team, they may experience social isolation, stereotyping, performance pressures, or other negative effects of tokenism (Mannix and Neale 2005, Bear and Woolley 2011, Settles et al. 2018). It has been theorized that these negative effects only diminish when a marginalized group reaches approximately 35% representation (Kanter 1977, Hoffman 1985). 88% of teams in my study ($n = 44$) did not reach this ‘tipping point’ in proportion of women and or researchers of color, highlighting a general

lack of demographic diversity within teams, a pattern that may perpetuate across STEM fields despite efforts to expand diversity and inclusion (Hill et al. 2010). More work is needed to achieve diversity goals in both disciplinary and interdisciplinary research teams.

This study used a socio-cognitive approach to determine if aspects of perceived team composition were associated with publication productivity and impact of peer-reviewed articles produced by integrative research teams. I found that including team member perceptions as a key link between a team's human capital and knowledge integration processes (Fig. 3.1) facilitated a more nuanced understanding of scientific performance. Specifically, I identified two patterns that differed from previous bibliometric studies that did not consider team member perceptions. First, although perceived demographic diversity can present challenges to teams (Harrison et al. 2002, Bell et al. 2011), my results indicate that the challenges integrative research teams may have experienced relating to perceived demographic differences were not strongly related to their publication productivity or impact. Second, I found that perceived disciplinary diversity was negatively associated with publication productivity and publication impact, indicating that integrative research teams might find the challenges related to working interdisciplinarily more difficult to surmount. Diverse collaborations are the current scientific norm and teams are expected to continue growing and diversifying both disciplinarily and demographically (Adams 2013). Therefore, improved structures of support and training are needed to ensure that integrative research teams will be able to take advantage of their unique combinations of human capital and produce research outputs with increased productivity and impact.

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CHAPTER 4:

THE APPLICATION OF REFLEXIVITY FOR CONSERVATION SCIENCE

4.1 Abstract

In recent years, conservationists have been taking an increasingly holistic, interdisciplinary approach to conservation science, utilizing many methodologies and techniques from the social sciences. Reflexivity is one social science technique that holds great potential to aid in the continued advancement of conservation science but is not yet commonly recognized or applied by conservationists. Here we establish a systems-based framework for conservation science and couple it with a discipline-specific definition of reflexivity to enable the integration of reflexivity into future conservation projects. We outline the four major tenets of reflexivity for conservation science, declaring that conservation science *i*) is informed by personal values, *ii*) requires true partnership, *iii*) must contend with its own history, and *iv*) demands progress. We present practical reflexive techniques that conservationists can use to adhere to these tenets and to foster research-informed conservation efforts that are more collaborative, resilient, and diverse.

4.2 Introduction

Conservation science is in the midst of a paradigm shift. The field is in motion away from purely biodiversity-centered approaches towards a more culturally-conscious, socially-just, ‘human heritage-centered’ discipline (Montgomery et al. 2020). Although the conservation science community has traditionally leaned heavily on the natural and biological sciences, recent efforts have been made to become more interdisciplinary particularly via an increased use of, and engagement with, the social sciences (Mascia et al. 2003, Newing 2010). Many established frameworks exist for integrating social science techniques and methodologies into conservation

science (Evely et al. 2008, White et al. 2009, Moon and Blackman 2014, Rust et al. 2017). One concept from the social sciences that has great potential to aid in the continued progression of conservation science, but is yet to be widely utilized, is reflexivity (Moon et al. 2016, Brittain et al. 2020).

Rooted in the disciplines of philosophy, anthropology, and sociology (Mauthner and Doucet 2003), reflexivity began as a theoretical concept offering scientists various pathways for analytical introspection (Schwandt 2011, Berger 2015). More recently, reflexivity has been adapted and integrated into the fields of human health and medicine, economics, education, and law, and has made similar inroads across numerous multidisciplinary and interdisciplinary research efforts (Freshwater and Rolfe 2001, Alvesson et al. 2008, Sandri 2009). Due to this rapid growth, the definitions of reflexivity and the associated descriptions of reflexive techniques can be ambiguous (Lynch 2000, Finlay 2002, Stronach et al. 2007). In tourism research, for example, reflexivity has been described as “an acknowledgement of the agency of researchers, the researched, academic audiences, students, and others. Being reflexive means... [to] recognize the macro and micro forces which underpin the production of tourism knowledge, and acknowledge our interaction with and responsibilities to the 'researched'” (Ateljevic et al. 2005, p. 10). Conservationists, a term which we use here to be inclusive of the wide range of scientists, practitioners, academics, consultants, technicians, agents of government, and others working under the broad umbrella of natural resource conservation, may find that this definition fails to consider at what points reflexivity ought to be used or to what ends reflexive techniques should even be undertaken. The SAGE Dictionary of Qualitative Inquiry explains that reflexivity can “refer to the process of critical self-reflection on one's biases, theoretical predispositions, preferences, and so forth... [and] can point to the fact that the inquirer is part of the setting,

context, and social phenomenon he or she seeks to understand. Hence, reflexivity can be a means for critically inspecting the entire research process” (Schwandt 2011, p. 261). While this definition provides more detail about when and how to use reflexivity, it does not explain in what ways reflexivity could apply to quantitative research projects or how these techniques might improve the production and application of knowledge, again leaving much to be desired from a conservationist’s perspective.

In addition to the potentially confusing definitions of reflexivity, its implementation has also been hindered by its general repudiation across the natural sciences. In these fields, the influence of the researcher has historically been under-recognized or even purposefully avoided in pursuit of scientific objectivity. This omission has recently been labeled a ‘reflexive gap’ in conservation science (Pooley et al. 2014, Pasgaard et al. 2017), one which could have extensive adverse consequences for the efficacy of conservation practice. For example, research-informed conservation efforts that lack reflexive techniques can inhibit conservationists’ capacity to cope with complexities in the field, facilitate institutional change, drive innovation, work effectively in teams, learn from past events, or benefit from the experiences of other scientists (Lawrence and Molteno 2012, Cooke et al. 2015, Pasgaard et al. 2017). To avoid these pitfalls and further advance new socially-conscious conservation paradigms (see Montgomery et al. 2020), conservationists need a foundational, discipline-specific approach to reflexivity.

Here, we assert that a conservation-specific definition of reflexivity ought to: *i*) be applicable to all research-informed conservation modalities (i.e., quantitative, qualitative, and mixed methods), *ii*) establish reflexivity as a practice that can be constantly applied and continue to evolve over time, and *iii*) explicitly improve the practice of conservation science and its impacts. Within this context, we define reflexivity for conservation science as a continuous and

intentional assessment of a conservationist's influence on the scientific process and the broader socio-ecological system as a means to foster transparency and collaboration, in support of conservation efforts that are ethical, adaptable, and diverse. We expand on this definition by presenting a conceptual framework that positions conservationists as central actors in these complex systems. We describe four essential tenets of reflexivity for conservation science, and explain how conservationists can pragmatically follow each with specific reflexive techniques. Finally, we summarize the important benefits that the implementation of reflexive techniques may bring to conservation science and the conservationists themselves. Although reflexivity is most traditionally applied to projects involving human subjects, the intent of our framework is to illustrate the applicability of reflexivity for all portions of conservation science, regardless of the topic of focus, research methodology, or data collection techniques.

4.3 A Framework for Complexity

Conservation scientists have increasingly adopted the concept of complex adaptive systems (CAS), from micro scales (e.g., insect colonies, immune systems) to macro scales (e.g., ecosystems, coupled human and natural systems), with clear benefits for both applied and theoretical research (Levin 1998, Berkes 2004, Messier et al. 2015). Complex adaptive systems are comprised of many interconnected actors who learn and adapt over time, nonlinear processes, and multidirectional feedback loops (Holland 1992, 2006). For example, in coupled human and natural systems, the ecological and socio-cultural elements inherent to this system are intricately linked with one another, and a change in one element of the system can have unexpected impacts on the other (Liu et al. 2007). In a similar way, the scientific and methodological elements of conservation projects cannot be separated from the personal and interpersonal elements of the individuals living and working within the broader system. Thus, each conservation project can be

seen as a CAS which includes many distinct actors (e.g., academic, government, and non-governmental organizations, funding sources, local stakeholders) and processes (e.g., ethical procedures, methodological decisions, knowledge generation), all of which interact with one another and with the scientific process itself. Thus, every conservation project can be characterized by its own distinct, ever-evolving CAS. One basic CAS, for instance, may include a nonlinear scientific process, networks of key actors, and interactions within networks and between actors and the scientific process (Fig. 4.1). Viewing conservation science as a CAS can help conservationists recognize the critical nature of broader societal contexts and agendas in developing conservation efforts (Cairney 2019). Adopting a CAS framework can also aid in some of the current shifts already taking place in conservation science, such as the move away from reductionism to a *systems* view of the world (Berkes 2004). Through a systems approach, it also becomes clear that the conservationist is a fundamental component of the CAS. Therefore, full comprehension of the system requires critical and strategic examination of the role of the conservationist within it. Via reflexive techniques, conservationists can develop their ability to recognize and manage that role (Finlay 2002, Berger 2015).

The definition and tenets we describe here present reflexivity not as an abstract concept of self-awareness but as a practical and powerful tool for conservation scientists. Our four discipline-specific tenets form a framework that can guide conservationists to look *inward* (to their own values, purposes, and influences), *outward* (to their relationships with and understandings of others), *backward* (to lessons from the past), and *forward* (to future impacts). As we discuss below, these tenets are neither mutually exclusive nor exhaustive, but together they provide a broad conceptualization of reflexivity for the field of conservation. Individual conservationists could address a variety of topics through reflexivity, which will vary based on

their unique CAS and the actors involved. Therefore, we offer a heuristic tool for each tenet (Fig. 4.3 – Fig. 4.6) to help conservationists gauge and expand their capacity for reflexivity, and to determine topics of significance and areas of their work where reflexivity could be most advantageous.

4.4 The Tenets of Reflexivity for Conservation Science

4.4.1 Looking Inward: Conservation is Informed by Personal Values

Rooted in the functional and normative postulates of conservation science, conservation research has always been an action-driven, ‘mission-oriented’ enterprise (Soulé 1985). Although the guiding principles have shifted over the years (Kareiva and Marvier 2012), conservation is still fundamentally motivated by certain human values surrounding the desired state of nature and often uniquely personal ‘missions’ to achieve those desired states (Takacs 2020). In this way, conservation research is, in theory, a type of action research, which aims to study a system and also to effect change in that system (Greenwood and Levin 2007). Decades of conservation scientists have now set out not only to study nature and our relationships with it, but *to do* something with the resulting knowledge (e.g., study human behaviors *to* mitigate wildlife conflict, study nutrient cycling *to* improve stream quality). A similar call for actionability has recently been sounded in the social science community (Watts 2017). Given that these intended actions are grounded in the particular values of the individual scientists, personal objectives and assumptions are a driving force in conservation science (Moon et al. 2018). Therefore, all conservation science mandates some degree of reflexivity to begin to account for the impact of the individual and to ensure that does not overcome effective and ethical science. Reflexive techniques assist conservationists in turning their awareness inward to the many ways they as individuals conceive and shape all aspects of the scientific process.

Philosophers of science have recently focused a great deal of attention on the ways that scientists' values can influence their work (e.g., Longino 2002, Keeney 2004, Douglas 2009, Elliott 2017, Brown 2020). They have shown that these values affect a wide array of judgments, including not only topics chosen and questions asked, but also problem-framing, project design, methodological and interpretive choices, evidential requirements, and terminology. In this way, the conservationist's preferences, perspectives, and ways of knowing unavoidably influence the orientation of each project (*sensu* the observer effect). While value influences are not necessarily a sign of bad science, these effects certainly have the potential to result in biases. Strictly speaking, a value is defined as a quality that is desirable or worthy of pursuit (McMullin 2000) whereas a bias is a systematic deviation from a standard (Danks and London 2017). Values can influence science without clearly or explicitly causing research to deviate from an established standard (Guillemin and Gillam 2004, Elliott and Resnik 2014). However, personal, cultural, and institutional values can scale up, resulting in biases at macro levels that may skew research to the point at which it no longer accurately represents the system under investigation. For example, preferences to study birds and mammals, particularly those that are charismatic or anthropomorphic, has resulted in research-informed conservation efforts that are inconsistent with the species' prevalence in nature and risk of extinction (Donaldson et al. 2016, Davies et al. 2018). This phenomenon has become widely known as 'taxonomic bias,' and has led to an extremely small proportion of animal species being drastically over-represented in scientific literature and popular writing (Wilson et al. 2007, Rosenthal et al. 2017). Such large-scale biases in research can threaten the conservation of lesser-studied species and impede research progress on some of the world's greatest conservation problems, such as climate change and biodiversity loss (Stroud et al. 2014, Feeley et al. 2017). By employing reflexive techniques, conservationists

are encouraged to identify unconscious values that could contribute to such biases and devise more novel and dynamic research goals which have the potential to address serious knowledge gaps.

Adherence to the principles of reflexivity requires conservationists to identify their own limitations, what they as individuals bring to the table that could negatively impact their work, and how aspects of their own identities uniquely shape the scientific process (Moon and Blackman 2014). This is a vital component of reflexivity because a conservationist's identity creates the foundation of their scientific perspective and consequently affects every interaction within the CAS. One practical technique that conservationists can use to stimulate critical awareness of their values, preferences, motivations, and limitations, is via the practice of writing initial position statements. Kept as personal logs before starting new projects, initial position statements outline critical aspects of the conservationist's experience and the 'fore understandings' with which they approach their work (Andrews et al. 1996, Cutcliffe 2003). Initial position statements provide an opportunity for conservationists to think about their current influences and any presuppositions they may have regarding a particular project. By doing this, conservationists can become explicitly aware of their motives for pursuing that project and assess their expectations and concerns. Additionally, these statements can act as benchmarks to measure change over time. Looking back over their logs, conservationists can see if their work had the impacts they initially hoped (i.e., if they achieved their conservation missions) or if they experienced any personal changes during the scientific process that may influence future conservation projects. As the conservation field has largely failed to realize its original missions (Trombulak et al. 2004), this may be a particularly useful technique for conservationists.

4.4.2 Looking Outward: Conservation Requires True Partnerships

Conservation science has a variety of ecological and social dimensions requiring collaboration across many disciplines (Mascia et al. 2003, Ban et al. 2013, Robinson et al. 2019). It can be a multidisciplinary, interdisciplinary, or even transdisciplinary endeavor, drawing on theories and methods and collaborating with experts from the fields of ecology, psychology, forestry, sociology, geography, history, political science, and, most recently, fine arts, media, communications, and humanities (Soulé 1985, Dieleman 2008, Pooley et al. 2016, Bennett et al. 2017, Brennan 2018). Nevertheless, discipline-specific science remains the norm (Fox et al. 2006, Brook and McLachlan 2008, Pooley et al. 2014, Montgomery et al. 2018a), and conservation science must continue to become more holistic and inclusive not only disciplinarily, but demographically, institutionally, philosophically, and epistemologically. In recent years, calls have been made to diversify the conservation science community (Tallis and Lubchenco 2014, Green et al. 2015) and to embrace varied, if even conflicting, viewpoints (Matulis and Moyer 2017). To make this ambition a reality, conservationists must put in the hard work to establish, strengthen, and maintain partnerships with those unlike themselves both professionally and personally. Consequently, the second tenet of reflexivity for conservation science encourages conservationists to look outwards, towards their interactions and relationships with all actors in the CAS, and to work to appreciate the many unique perspectives and worldviews.

Collaborative partnerships are imperative to effective conservation outcomes. Many conservation problems today are known to be ‘wicked,’ in that they are extremely uncertain and complex, difficult to manage, have no single solution, and frequently involve a variety of stakeholders with often conflicting views of the situation (Game et al. 2014). One of the most reliable and effective methods to confront wicked problems is through the coproduction of

knowledge, whereby scientists work together with non-scientist stakeholders and decision-makers before, during, and after the scientific process to create knowledge and solutions applicable to their unique situations (Cash et al. 2003, Beier et al. 2017). Coproducing knowledge requires that conservationists hone their ability to understand and engage with diverse stakeholders, including academic and non-academic partners, members of the communities adjacent to or within conservation field sites, natural resource managers, government agencies, and nongovernmental organizations, as well as the general public. Knowledge coproduction also requires the establishment of partnerships that are immersive and rooted in mutual trust and respect (Young et al. 2016, Domínguez and Luoma 2020). Through authentic, reflexive collaborations, conservationists increase the likelihood of achieving their project goals and producing information relevant to solving wicked conservation problems (Balmford and Cowling 2006, Gray et al. 2019). Taking the time to understand other actors' distinct missions, values, philosophies, expectations, and assumptions through reflexivity prepares conservationists to build more effective and fruitful partnerships. Reflexive techniques can guide conservationists in their thinking about collaborations and may help in building and enhancing equitable partnerships. For example, a unique 'reflexive strategic action' framework (a combination of techniques including stakeholder interviews, document analysis, and collaborative workshops), has been shown to ease tensions and operational difficulties between ecology researchers and environmental NGOs working together on conservation policymaking (Coreau 2016). Through the use of reflexive techniques, diverse actors were able to establish a shared vocabulary, engage in open discussions about research methods and future opportunities, and identify potential risks in the partnership. This led to mutual understandings between organizations, the lack of which

had previously hindered their ability to successfully achieve their joint conservation objectives (Coreau 2016).

Partnerships can be strengthened using techniques for collaborative reflexivity. Conservationists should take responsibility for generating open discussions within their teams and with other actors across the CAS. Many tools and frameworks exist for helping to facilitate these sometimes difficult discussions (see O'Rourke and Crowley 2013, Cheruvelil et al. 2014). Conservationists can also use the tools provided here (Fig. 4.3 – Fig. 4.6) within a group setting to spark collaborative brainstorming sessions. Collaborative reflexive techniques can solidify team comprehension not only of personal values, ethical standings, and research philosophies, but also important concepts in the scientific process such as interpersonal expectations, communication norms, and academic vocabulary, which allow the team to avoid conflicts and establish a common vision of success (Eigenbrode et al. 2007). Using techniques like these to foster a positive team climate has been shown to promote greater satisfaction among the members of environmental science teams (Settles et al. 2019). Another technique that conservationists can use to stimulate reflexivity is to create a visual representation of their own scientific CAS (see Fig. 4.1). Determining the major stages of their unique scientific process and identifying specific actors involved can help conservationists think strategically about their relationship with and impact on each. Taking the time to depict the CAS may also offer clarity about where and when they should plan to use other reflexive techniques in their conservation efforts.

4.4.3 Looking Back: Conservation Must Contend with its Own History

History and context play critical roles in the functioning of every CAS (Holland 1992).

Conservation science has a long and complex history which varies across countries and regions,

but which often stems from colonial occupation and the theft and capitalization of land and natural resources (MacKenzie 1988, Singh and Van Houtum 2002, Barrett et al. 2013, Ross 2017, Domínguez and Luoma 2020). Because of this, conservation policies and public attitudes toward protected areas and biodiversity are often implicitly rooted in histories of violence, extraction, and the exclusion of local communities from their native lands (West et al. 2006, Randeria 2007, Mkumbukwa 2008, Dowie 2011). Relationships between conservationists and other actors in the CAS also exist within these historical and political contexts. Past events and the treatment, governance, and cultural perspectives of local community members cannot be separated from the influences conservationists hope to have with their work. Reflexivity can assist conservationists in recognizing and attempting to rectify historical inequities and power imbalances (Pasgaard et al. 2017) and to ultimately devise more humane and socially-just conservation practices and research protocols. Reflexive techniques help conservationists to look backwards in time, towards the histories of the field and the hard truths of the past, in order to learn lessons needed to conduct high-quality, impactful science with honesty and humility.

Conservation science is often conducted by foreign research institutions (Wilson et al. 2016, Montgomery et al. 2018a, Gray et al. 2019). Therefore, conservationists may frequently be considered ‘outsiders’ in the communities where they work, not only in terms of race and nationality, but also religion, culture, and language. By being reflexive about important differences between themselves and other critical actors in the CAS, conservationists not only acknowledge that differences *exist* but also that those differences can have direct effects on their work. For example, a ‘Western’ scientific perspective may differ greatly from a diverse range of Indigenous perspectives in regards to values of nature and how human-environment relationships should be maintained (Peterson et al. 2010, Lynch et al. 2016, Milstein et al. 2019).

Relationships between conservationists and community members can be challenging to navigate but inattention to the importance of these dialogues creates barriers to success and research implementation. Negative interactions may result in community members feeling abused by the conservationist (Tapela et al. 2007, Cochran et al. 2008), and continuous negative treatment or exclusion can cause research fatigue, an unwillingness of community members to support or engage in research, or physical, emotional, or economic harm to members of local communities (Clark 2008). The results of these interactions may devalue the potential impact of conservation science and adversely affect conservation efforts far into the future (Lynch 2017). This is particularly important when conservation projects involve human subjects (Brittain et al. 2020). Adherence to the tenets of reflexivity demands that conservationists recognize the impacts of institutional imbalances, become aware of the power dynamics between themselves and others, and to rectify these power differences whenever possible (Drury et al. 2011, Muhammad et al. 2015).

Conservationists who practice reflexivity will take steps to learn about and incorporate aspects of history and culture into their work. For many, this requires engagement with reflexive, decolonial practices that holistically center the needs and desires of local communities in conservation efforts (see Rodríguez and Inturias 2018, Gould et al. 2019, Larocco et al. 2019). Coloniality refers to enduring patterns of inequity “that emerged as a result of colonialism, but that define culture, labor, intersubjective relations, and knowledge production well beyond the strict limits of colonial administrations... [which] is maintained alive in books, [and] in the criteria for academic performance” (Maldonado-Torres 2007, p. 243). Decolonial practice follows as an ‘unsettling process’ in which individuals work to consciously disrupt the patterns of coloniality found in modern, supposedly apolitical and ahistorical, research paradigms

(Garland 2008, Adams et al. 2018, Singh et al. 2018). Conservationists can begin this process by using reflexive techniques that help them identify their own research philosophies and the research paradigms to which they subscribe. One such technique is the creation of positionality statements that clearly explain how personal aspects of the individual's education, background, and identity may have impacted the scientific process and the resulting data (Milner 2007, Syracuse 2016, Larocco et al. 2019). Positionality statements should be included in academic publications and conservation journals should encourage these statements or offer space for them as supplemental documents (for the authors' own example, see Appendix C). Additionally, conservationists should read the works of scholars from different backgrounds and with varying worldviews than themselves, and they should encourage their students to do the same. These include the works of Indigenous, feminist, neo-colonial, participatory action, and critical research scholars both within and outside of the field of conservation. Reading diverse work can aid conservationists in seeing different histories through multiple cultural lenses and more effectively collaborate with scholars and professionals with varying histories. These types of collaborations can even enhance individual success, as scientists who train under mentors with disparate expertise achieve more successful academic careers than those whose work closely aligns with that of their mentors (Liénard et al. 2018).

4.4.4 Looking Forward: Conservation Demands Progress

Conservation science has been criticized for failing to directly contribute to applied outcomes where they are needed and for using valuable resources for study rather than direct action (Knight et al. 2008, Laurance et al. 2012). This issue is prevalent and is often referred to as the 'knowing-doing gap,' or the 'research-implementation gap' (Knight et al. 2008, Gossa et al. 2015, Toomey et al. 2017, Gray et al. 2019). Conservation researchers, for example, may be

wary of becoming advocates for a particular cause out of fear of biasing the research effort (Horton et al. 2016, Gray et al. 2019). In an evaluation of conservation biology however, Noss (1999) explains, “whenever one recommends, however cautiously or conservatively, one advocates” (Noss 1999, p. 117). Thus, conservationists are inherently advocates within the context of policymaking and management, even if they do not seek out or fully accept their role as brokers of information (Pielke Jr. 2007). This can lead to disconnects between conservationists and practitioners and a lack of research-informed conservation action on the ground (Arlettaz et al. 2010). Reflexive techniques help conservationists to consider the implications and feasibility of the messages they send and the recommendations they make, and are thus useful in attempts to reduce the research-implementation gap. Reflexivity is not simply a retrospective assessment of past choices and circumstances, but also an opportunity to think critically about how current choices and circumstances bring about future ones. Practicing reflexivity encourages conservationists to look forward towards the positive impacts they wish to have and take the appropriate actions to explicitly link those impacts with the scientific process.

Improving the impact of conservation science requires a fundamental shift in the way conservationists view data analysis, the knowledge they generate from those analytics, and the way they share the resultant information. First, conservationists should keep in mind that the outcomes of their conservation efforts are directly influenced by ontological and epistemological assumptions rooted in the particular methods of analysis they choose to use (Mauthner and Doucet 2003, Moon et al. 2018). Additionally, because conservation is a policy-relevant field, conservationists cannot avoid making choices that affect whether their results are more favorable to some social or political priorities as opposed to others. For example, methods of modeling animal observational data at an aggregate level might encourage different conservation or

management decisions than if the data were assessed at an individual animal level (Montgomery et al. 2018b). Rather than ignoring the ramifications of these decisions, it is more important to make them thoughtfully, to be transparent about them, and to gather input about them from other scientists and potentially affected communities (Elliott 2017). Finally, conservationists have a responsibility to appropriately guide their findings, including critically assessing the ways in which they present their results and to whom they make findings available (Guillemin and Gillam 2004). As illustrated in Fig. 4.1, conservationists disseminate their results to various actors, which may include academic peers, professionals from other fields, practitioners within conservation NGOs, or even a broader global audience and it is important for conservationists to consider the identities of these various actors. For example, many individuals may find academic jargon difficult to interpret and put into action (Pullin et al. 2004), potentially engendering distrust in or disengagement with academic institutions. Conservationists can use reflexivity to gain a deeper awareness of personal aspects of their audiences, such as native language, formal education, ontology, and professional standing. By taking these factors into consideration when writing up and presenting their results, conservationists show empathy and effort, which can increase the likelihood that their recommendations are implemented by policy makers (Reed et al. 2014).

One specific technique that conservationists can use to help increase the impact of their work is reflexive journaling. This technique consists of daily or weekly notes about project management, methodological decisions and rationale, and personal contemplation. It provides a place for conservationists to engage actively and personally in self-monitoring, to articulate in their own words how they interact with the data and the scientific process. This practice can improve decision making and may help conservationists to understand and interpret results by

adding context to the findings, in both quantitative and qualitative projects (Finlay 1998, Haas and Hoebbel 2018). A reflexive journal can even become data of its own (Schwandt 2011), providing conservationists with valuable new insights that have unique academic and practical value from which others may benefit. Additionally, making the data collection and analysis processes more transparent and accessible may open up opportunities to strategically scrutinize and improve these processes and may reveal new uncertainties and knowledge gaps. This could illuminate productive paths for future research-informed conservation work and potentially increase the actionability of that work (Ban et al. 2013, Pasgaard et al. 2017). Conservationists can also become more reflexive about the potential outcomes of their research-informed conservation efforts through experiences working with those who apply research findings. For example, the American Association for the Advancement of Science (AAAS) offers Science and Technology Policy Fellowships which provide opportunities to collaborate with lawmakers, federal agencies, and environmental NGOs to see how, when, and why policy makers draw on scientific information (Jenkins et al. 2012). For those unable to pursue such intensive experiences, training programs and workshops may also be helpful. For example, the European Union offers a virtual workshop series aimed at creating links between scientists and policy makers at international scales (Commission 2020).

4.5 Integrating Reflexivity into Conservation Practice

Solving conservation problems requires integrated and innovative approaches because of the complex interconnectedness of the socio-ecological systems in which these problems persist. Consequently, conservationists need better tools to more holistically understand and evaluate complex systems (Berkes and Turner 2006). The CAS framework paired with reflexivity for conservation science, as defined and outlined above, fill this need by offering a structured

approach for addressing critical issues relating to: *i*) conservationists' value judgements and positionality, *ii*) partnerships and trust building, *iii*) history and culture, and *iv*) decisions that lead to conservation impacts. The four tenets of reflexivity and their accompanying techniques are neither exhaustive nor discrete, and considering where their major themes intersect in practical settings can be a valuable reflexive technique of its own (see Fig. 4.2). Importantly, by linking and integrating the CAS framework and the four tenets of reflexivity for conservation science into their work, conservationists can practice in more ethical, adaptable, and diverse ways. We now describe how conservationists can productively blend and apply the four tenets in support of these aims and why this type of work is necessary for the betterment of conservation practice.

First, two major types of ethics in conservation science are procedural ethics and 'ethics in practice.' The former involves acquiring approval from relevant ethics committees and clearly stating how the research-informed conservation efforts intend to be conducted ethically. Conservation science has, at times, been criticized for failing to establish or adhere to appropriate procedural ethics (Law et al. 2017). For example, nearly half of all conservation studies that involve human subjects do not include necessary ethics information regarding the treatment of those subjects (Ibbett and Brittain 2019). The second main type of ethics, refers to 'everyday ethical issues' that arise while in the field (Guillemin and Gillam 2004) which involve certain responsibilities on the part of the scientist, to act humanely, and to not exploit other actors in the CAS. While these types of ethics are challenging to quantify, there is evidence that conservation science is among the many fields guilty of harmful, invasive, and exploitive projects in the past (Schroeder et al. 2018). Patterns of poor conduct have led to the establishment of new procedures to prevent unethical research (see for example, the South African San Institute's Code of Ethics

for researchers (Schroeder et al. 2019) and the Climate and Traditional Knowledges Workgroup's guidelines for scientists and policy makers (Climate and Traditional Knowledges Workgroup 2014)). However, such procedures for ethics in practice are still rare and conservationists should encourage community stakeholders to develop their own ethics codes or work to devise these codes collaboratively. Ultimately, the success of conservation efforts results from inclusion, equity, and the long-term development of trust with various stakeholders (Peterson et al. 2010, Young et al. 2016). Engaging with tenet 3 can help conservationists more fully understand and address issues relating to the treatment of community stakeholders and integrating tenets 2 and 4 can offer guidance for conservationists to build the type of fair and trusting relationships that enhance the credibility of their work. As the trustworthiness of science is increasingly being questioned, conservationists must raise their standards of ethical conduct to sustain the integrity of the conservation field into the future (Horton et al. 2016, Hopf et al. 2019).

Second, change is ever-present in the socio-ecological systems where conservation science is applied, as well as in each unique scientific CAS. To contend with uncertainty and change in the field, conservationists are increasingly utilizing collaborative learning-based methods, such as coproduction (described in tenet 2), co-management, adaptive management, and participatory action research (Olsson et al. 2004, Bacon et al. 2005, Knight et al. 2019). These approaches are seen as long-term, iterative, and circuitous processes rather than linear progressions of cause and effect (Redpath et al. 2013). And while they may hold a lot of promise, adaptive methods can be extremely difficult to implement in practice (Game et al. 2014). Additionally, to successfully participate in adaptive research and decision making, a thorough and accurate understanding of stakeholder values is required, an ability that conservationists may

not traditionally be trained to develop (Robinson et al. 2019). Conceptualizing the scientific process as a CAS and adhering to the tenets of reflexivity for conservation science can foster the critical thinking, experiential learning, and social awareness needed to participate successfully in adaptive conservation efforts. It can also assist conservationists in managing change within their own systems, supporting the continued functioning and reorganization of the CAS during uncertain times (e.g., loss of funding, data collection failures, communication issues, new stakeholders). Specifically, tenet 4 can assist conservationists in explicitly addressing both success and failures and learning how to change course when necessary to achieve their goals. Blending tenets 1 and 2 in practice can support conservationists in recognizing their own values and those of others, and to hone important social skills that are often overlooked in natural science trainings. As conservationists increase their ability to anticipate changes and become more resilient to stressors, they also increase the potential for multifaceted, adaptive conservation strategies to be successful.

Finally, across various fields of science, teams are becoming larger and more diverse (Wuchty et al. 2007, National Science Foundation 2019). Some forms of diversity on teams can promote positive team climates and enable team members to solve complex problems more successfully (Whitfield 2008, Woolley et al. 2010). Engaging with diverse team members can also help conservationists recognize their own values and become more thoughtful about their choices (Longino 2002, Schuurbiers and Fisher 2009). However, a lack of understanding between diverse team members is a major challenge for interdisciplinary teams (Lélé and Norgaard 2005, Miller et al. 2008) and individuals who contribute disciplinary and demographic diversity to teams may have more negative experiences than their peers (Settles et al. 2019). Additionally, while interdisciplinarity in natural and social sciences has been encouraged for

decades (MacMynowski 2007), methods and concepts from the social sciences are still not being as productively integrated into conservation science as they might be (Bennett et al. 2016).

Reflexive techniques can be combined with all other research methods and may offer conservationists accessible approaches to assess the functioning of their teams and to alleviate some of the challenges of working in disciplinarily- and demographically-diverse groups. For example, adhering to tenet 2 can help conservationists to establish deeper epistemological awareness and bolster communication between scientists from dissimilar backgrounds while the integration of tenets 1 and 3 may provide much-needed structure to understand themselves through the eyes of others. Ultimately, fostering an inclusive and diverse community will help conservationists to increase their collaborative impact and devise conservation efforts that are themselves more diverse, with the novelty and innovation needed to solve today's wicked environmental problems (Game et al. 2014, Green et al. 2015).

To achieve future conservation outcomes that are ethical, adaptable, and diverse, instruction in reflexive techniques should be added to course curricula at the graduate and undergraduate level of higher education institutions providing instruction in conservation science. The tenets and guidelines presented here can be adapted for use as training materials in conservation methods or environmental ethics workshops for both students and professionals. By learning to be reflexive throughout the scientific process, conservationists at all career levels can begin a continuous cycle of self-reflection, assessment, and improvement. It is the responsibility of the conservationist to decide when to utilize reflexive techniques and how much of the resulting information to share with others. However, increased transparency and collaborative reflexivity will increase the conservation community's ability to solve the complex problems that blight the field, while also promoting personal and professional development in the broader

conservation community. Recognizing the tenets of reflexivity will encourage conservation science that is socially and ethically responsible, inclusive of diverse ways of knowing, and attentive to the inherent complexities of social-ecological systems.

4.6 Acknowledgements

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CONCLUSION

Conservationists have been criticized for focusing research efforts so intensely on ecological details, that they fail to see the ‘big picture,’ the broader social, relational, cultural, political, historic contexts in which conservation exists (Knight et al. 2008, Laurance et al. 2012). For this reason, conservationists have been largely unsuccessful in their chief goal of stopping global biodiversity loss (Trombulak et al. 2004), and the field of conservation science is consequently experiencing a paradigm shift as conservationists seek more holistic and human-centered approaches to their work (Montgomery et al. 2020). In this dissertation, I took such a holistic approach. Through my research, I established a broad understanding of conservation science and practice, not despite their major social complexities, but because of them. The results of my research have implications for topics as broad as livestock husbandry, human–carnivore coexistence, conservation research techniques, and science team functioning.

One of the greatest conservation priorities today is promoting coexistence among humans, domestic livestock, and large carnivores (Ripple et al. 2014). Because pastoral livestock herding occurs on about 25% of the Earth’s land area and supports more than 200 million households (Dong et al. 2016), there is a serious need to address knowledge gaps regarding interactions between pastoralist livestock and large carnivores. In the first half of my dissertation, I addressed some of these gaps empirically and theoretically. In chapter 1, I found that pastoralist cattle in northern Tanzania exhibited anti-predator behaviors while grazing on village rangelands shared with lions and that anti-predator strategies varied both spatially and temporally. While current conflict mitigation strategies have mainly focused on direct livestock loss (van Eeden et al. 2018), my results indicate that anti-predator behaviors may represent an

overlooked cost of depredation risk for pastoralist livestock, the effects of which likely play an important role in perceived conflict. Therefore, future research and on-the-ground practices should consider grazing strategies that optimize cattle health and human livelihood, which may thereby facilitate increased tolerance for lions and other large carnivores. My results also emphasized the importance of assessing human-lion conflict in interdisciplinary ways that consider more than one of its five main dimensions (i.e., human, carnivore, livestock, wild prey, and environmental dimensions). In chapter 2, I gave examples of what this kind of research may look like, addressed several main barriers to interdisciplinarity in conflict research, and encouraged researchers and institutions to support a team science approach to solving wicked problems. While disciplinary studies on aspects of one dimension of conflict only (e.g., local people's perceptions of depredation risk, or carnivore movement patterns) provide important scientific evidence, successful conflict mitigation efforts require consideration of multiple perspectives and collaboration over time. This is likely a contributing factor as to why East African lion numbers continue to fall (Bauer et al. 2016). My findings may be used as a stepping stone toward more interdisciplinary human-carnivore conflict research and mitigation in Tanzania and beyond.

Academic, industry, and political leaders all look to interdisciplinary researchers to help solve complex natural and socio-ecological problems around the world (Brunson 2012, Game et al. 2014, Wade et al. 2020). However, conducting interdisciplinary research aimed at resolving wicked problems is no simple task. In the second half of my dissertation I explored interdisciplinary research processes both quantitatively and qualitatively. In chapter 3, I devised a modified input-process-output model positioning team-level perceptions as a critical link between researcher inputs (i.e., human capital) and the knowledge integration processes that

result in peer-reviewed publications. I applied this model to the publication bibliometrics of integrative environmental science research teams. Although perceived demographic diversity can present social challenges to teams (Harrison et al. 2002, Bell et al. 2011), I found a lack of any significant associations between perceived demographic diversity and bibliometrics, indicating that any challenges integrative research teams may have experienced in regards to demographic differences were not related to their publication productivity or impact. Conversely, I determined that perceived disciplinary diversity was significantly and negatively associated with publication impact, suggesting that challenges related to interdisciplinarity may be difficult to overcome during the research process. My results show the importance of considering perceptions of team composition in bibliometric studies and future research should aim to expand on my foundational findings. In chapter 4, I explored the complex research process using systems thinking and devised a novel framework that provides structure and guidance for addressing social and relational issues in collaborative conservation science, including building trust with stakeholders, establishing personal positionality, and navigating cultural contexts. I identified and outlined reflexive techniques aimed at facilitating conservation efforts that are ethically responsible, inclusive of diverse ways of knowing, and attentive to the inherent complexities of systems. Engaging with the tenets of reflexivity for conservation that I created in this final chapter can help conservationists establish sustainable relationships that enhance the credibility of their work and foster an equitable and diverse scientific community. Ultimately, this may lead to conservation practices that are themselves more diverse, with the novelty and innovation needed to solve wicked environmental problems at a global scale.

Conservationists today are presented with a multitude of complex and daunting challenges. However, these challenges may alternatively be seen as opportunities to change and

improve the way we approach our conservation work. The time is ripe to reimagine conservation praxis and to determine a more holistic, inclusive, and ultimately successful path forward. I have used my dissertation research to investigate complex human and natural systems, to reflect deeply on the established norms of our field, and to find unseen connections and patterns by employing methods from a variety of disciplines. I aimed to learn from the complexities rather than avoid them, to metaphorically see the pride for the lions. My goal for this collection of work is that it will inspire and enable others to do the same and that the cycles of inquiry, reflection, and transformation I've established herein may continue. In this vein, I state no formal conclusion to my dissertation, but rather I ask, what questions will we pursue now, how can we re-conceptualize old problems, with whom will we seek to collaborate, what changes will we ultimately make, and how might we *ourselves* be changed?

APPENDICES

APPENDIX A

Translated Research Summary

Layman's summary of Beck, J. M., Moll, R. J., Kissui, B. M., and Montgomery R. A. 2020. Do pastoralist cattle fear African lions? *Oikos*. Translated into Swahili for dissemination to Tanzanian stakeholders.

Utangulizi

Duniani kote, maeneo ya malisho Afrika Mashariki wana uzoefu wa kiwango cha juu zaidi cha uvamizi wa mifugo. Tafiti za kutosha zimeangalia uvamizi wa moja kwa moja wa wanyama wanaokula nyama, kwa mfano simba. Hata hivyo, haifahamiki vya kutosha kuhusu athari ambazo siyo za moja kwa moja, kama vile ni kwa kivihi *uoga wa kuvamiwa* wa wanayama wanaokula nyama inavyo weza kuathiri Maisha ya mifugo. Wakati wa uoga, mnyama anayewindwa anaweza kubadilisha tabia zao na kujaribu kupunguza athari zao za kuvamia. Kwa mfano mnyama anayewindwa hubadilisha mifumo ya miondoko, kutoka kwenye makundi makubwa, au wanaongeza muda wanaotumia kutafuta wanayama wanaokula nyama (tabia hii inaitwa uangalifu au umakini wakati wa hatari). Tabia hizi zinaweza kuleta changamoto kwa mnyama anayewindwa. Kwa mfano, mnyama anayewindwa huwa mwenye uangalifu au umakini wakati wa hatari wanatumia muda mchache kula, ambao inaweza kupunguza uzito wa mifugo na kuongeza uwezekano wa magonjwa. Matukio ya uvamizi au uharibifu yanaweza kuwa na matokeo ya kitabia au kimuonekano ya muda mrefu kwa mifugo. Kama mifugo ikiwa na uzoefu mwingi wa uvamizi (ikimaanisha, ikiwa hatari za uharibifu au uvamizi zipo juu), athari hizi zinaweza kuwa imara zaidi. Katika utafiti huu, tulitathmini tabia za wafugaji za mifugo wa ekojolia wa Tarangira-Manyara, kaskazini mwa Tanzania ili kuelewa zaidi ni kivihi ng'ombe wameathirwa kwa kuhofia simba.

Mbinu za Utafiti

Kwanza, tulitambua hatari za uharibifu kwenye kila Kijiji kwanze eneo let la utafiti. Kwa muda wa kipindi cha miaka mitano (2009-2003), tulitembelea wamiliki wa mifugo na kukusanya taarifa kuhusu matukio ya uharibifu. Tulichangua vijiji vinne(4) kwa ajili ya utafiti wetu. Vijiji vya Losirwa and Naitolia walipata uzoefu wa kiwango cha chini cha uharibifu (wanyama wala nyama walivamia mara 3 au chini kwa kipindi cha miaka 5). Vijiji vya Esilalei na Makuyuni walipata uzoefu wa kiwango cha juu cha uharibifu (wanyama wala nyama walivamia mara 137 au zaidi kwa kipindi sawa). Wakati wa kiangazi wa mwaka 2017, tulifatilia na kuchunguza ng'ombe moja mmoja kumi (10) kwa kila Kijiji ili kupima tabia zao. Tulikusanya taarifa za tabia mbili (2): uangalifu au umakini wakati wa hatari na kujikusanya katika makundi. Tulitegemea ng'ombe waliopo kwenye vijiji hatarishi wangeonyesha tabia za uoga zaidi kuliko ng'ombe waliopo kwenye vijiji vilivyo na hatari kidogo.

Matokeo na Hitimisho

Tulifanya jumla ya uchunguzi 826, ambapo ni matokeo ya masaa 138 ya kukusanya taarifa za tabia za ng'ombe 40 ambapo zilikusanywa kwa ng'ombe mmoja mmoja. Tuligundua utofauti mkubwa wa tabia za ng'ombe kwa vijiji tofauti. Ng'ombe ambao wako katika vijiji hatarishi zaidi walikuwa makini kuangalia/kuzingatia hatari kwa muda mfupi kuliko ng'ombe ambao wanatoka katika vijiji vilivyohatarishi kwa kiwango cha chini. kwenye maendeleo hatarishi zaidi, tabia za uoga zinaweza kuwa dhaifu wakati mfupi wa usalama. Tanzania, wakati wa kiangazi

unaweza kuwa wakati wa usalama kwa vile uvamizi wa simba mara nyingi unatokea wakati wa masika. kwahiyo, ng'ombe walioko katika vijiji hatarishi zaidi wanaweza kuwa wanapunguza umakini wa kuzingatia hatari iliyopo na kuongeza kasi katika kula wakati wa mwanzoni wa kiangazi ili kufidia wakati wa mwaka ambao kutakuwa hatarishi zaidi. Kupatikana kwa nyongeza ya chakula wakati wa kiangazi inaweza kusaidia ng'ombe kupata usawa wa tabia zao. Pia, tuliweza kugundua kwamba kuna tabia za ng'ombe katika kujiweka kwenye makundi makundi katika vijiji vilivyo wa hatari kubwa na hatari ndogo ya uvamizi.

Ng'ombe walio katika vijiji ambavo siyo hatarishi zaidi waliunda makundi makubwa zaidi (kwa wastani wa asilimia 21 (21%) kulinganisha na ng'ombe walio katika vijiji hatarishi zaidi. Hii inaweza kumaanisha kwamba ng'ombe waliopo kwenye vijiji hatarishi zaidi wanaweza kunufaika kuchungwa kwa ukaribu kwenye makundi makundi. jinsi kimo cha mimea kinavyoongezeka, ng'ombe, wote waliopo katika vijiji hatarishi zaidi na ambavyo siyo hatarishi zaidi waliunda makundi madogo madogo. Hii inawezekana kwasababu ng'ombe wanaweza wasionane wenyewe kwa wenyewe kwenye mimea minene au mizito. Hata hivyo, simba wanatumia mimea ili kuvamia na kwahiyo ng'ombe mawaweza kuhitaji ulinzi zaidi kwenye maeneo haya katika vijiji vyote vine(4). Mbinu za kuswaga ng'ombe zinaweza kuboreshwa kwa kuendelea kutathmini kwa kivihi hatari za uvamizi zinatofautiana kati ya vijiji na tabia za ng'ombe zinakuwae wakiwa na uoga.

Kuwatambua

Kwa dhati kabisa, tungependa kuwashukuru viongozi wa vijiji na washiriki wa utafiti wetu kutoka Losirwa (Mollel, Ngisajo, Metui, Lekujuu, Lekilazier, na Kariya Loloyani), Makuyuni (Mwenda, Lemuta, Bashiri, Ndodi, na Pandari), Esilalei (Natuli, Lailori, Ndinina Moko, Kesuma, na Lesi Lenjai) na Naitolia (William Mollel, Peter Shauri, Loti Mollel, Logeliek, Mathe Shauri, na Ndakelwa). Asante sana!

APPENDIX B

Tables and Figures

Table 3.1

The ranking of models that predict metrics of publication performance for integrative research teams. Top model results ($\Delta\text{AICc} = < 2.0$) for the average number of peer-reviewed journal articles published by the team per year and average impact factor of the journals in which the teams published and are presented. Bold covariates are indicative of significant effects (P-value ≤ 0.05).

	df	ΔAICc	AICcW
<i>Publications per year</i>			
team size + number of disciplines	4	0.00	0.26
team size + number of disciplines + proportion of POC	5	0.56	0.20
team size	3	0.86	0.17
team size + number of disciplines + proportion of women	5	1.80	0.10
Global model	6	2.78	0.06
Null model (intercept only)	2	6.98	0.01
<i>Impact factor</i>			
number of disciplines	3	0.00	0.29
number of disciplines + team size	4	0.55	0.22
number of disciplines + proportion of women	4	1.92	0.11
number of disciplines + proportion of POC	4	1.94	0.11
Global model	6	5.20	0.02
Null model (intercept only)	2	6.53	0.01

Table 3.2

The averages of models developed to predict metrics of publication performance for integrative research teams.

	Estimate	SE	p value
<i>Publications per year</i>			
Team size	0.17	0.06	0.00
Total disciplines	-0.71	0.59	0.23
Proportion POC	1.21	2.65	0.65
Proportion women	-0.46	1.90	0.81
<i>Impact factor</i>			
Team size	-0.02	0.03	0.63
Total disciplines	-1.09	0.37	0.00
Proportion POC	-0.24	1.12	0.84
Proportion women	0.30	1.38	0.83

Figure 3.1

A modified input-process-output model for the functioning of integrative research teams which includes perceived team composition as a key additional factor.

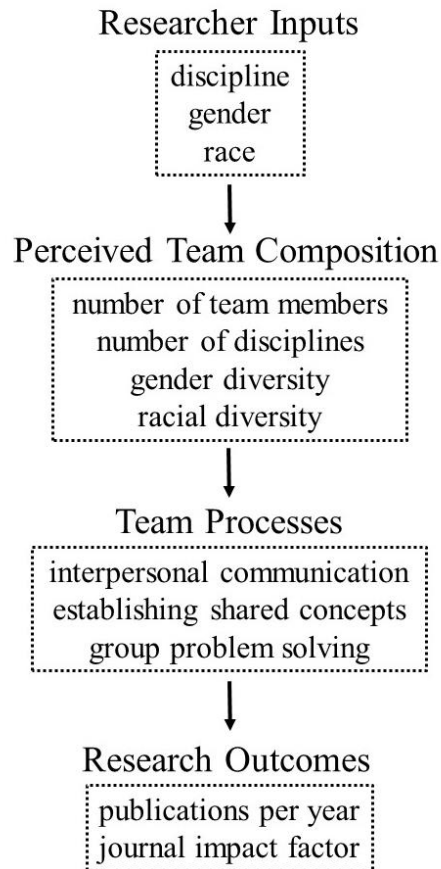


Figure 3.2

Mixed linear regression trends from the most supported model predicting publication productivity for integrative research teams. The 95% confidence intervals of the estimate are depicted in gray shading.

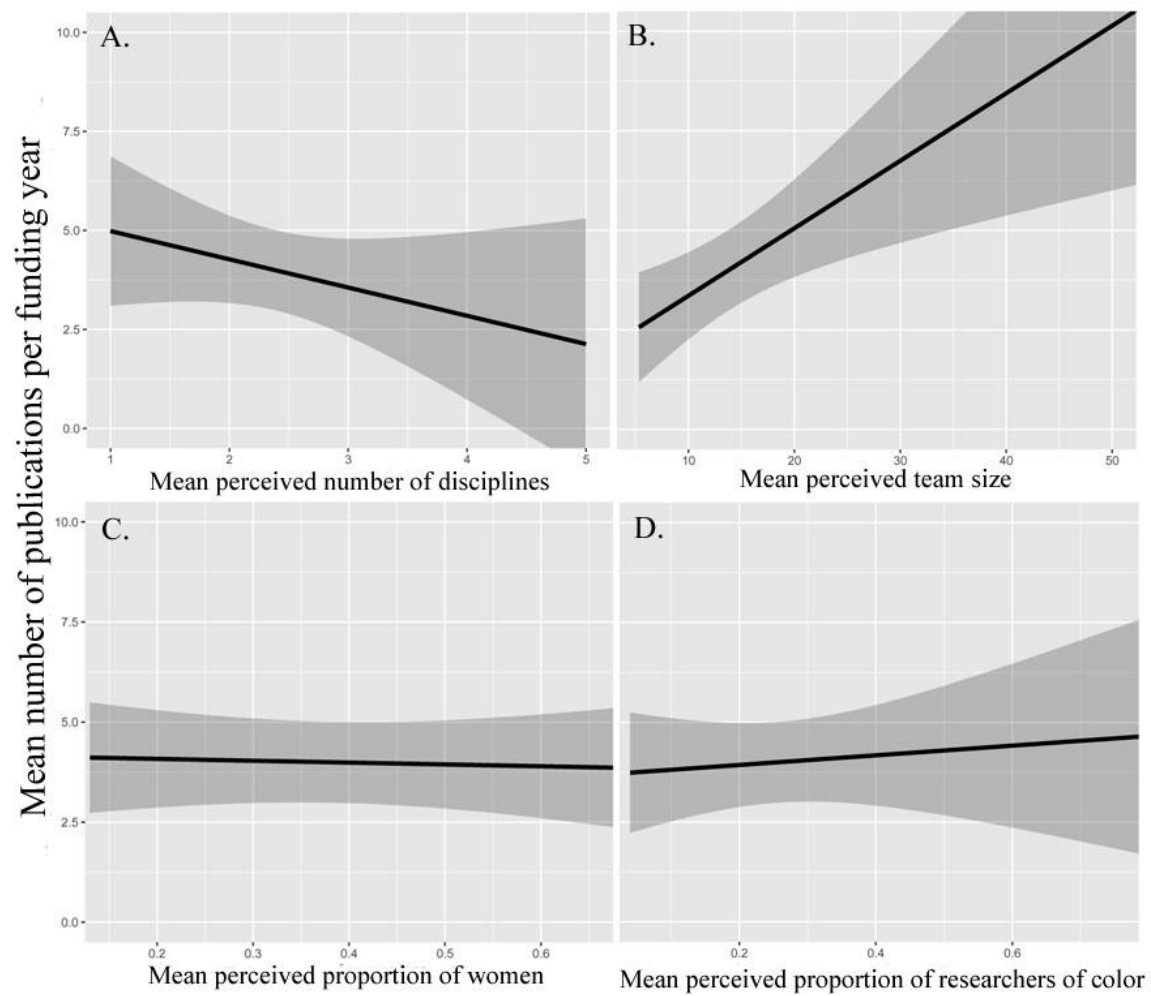


Figure 3.3

Mixed linear regression trends from the most supported model predicting publication impact for integrative research teams. The 95% confidence intervals of the estimate are depicted in gray shading.

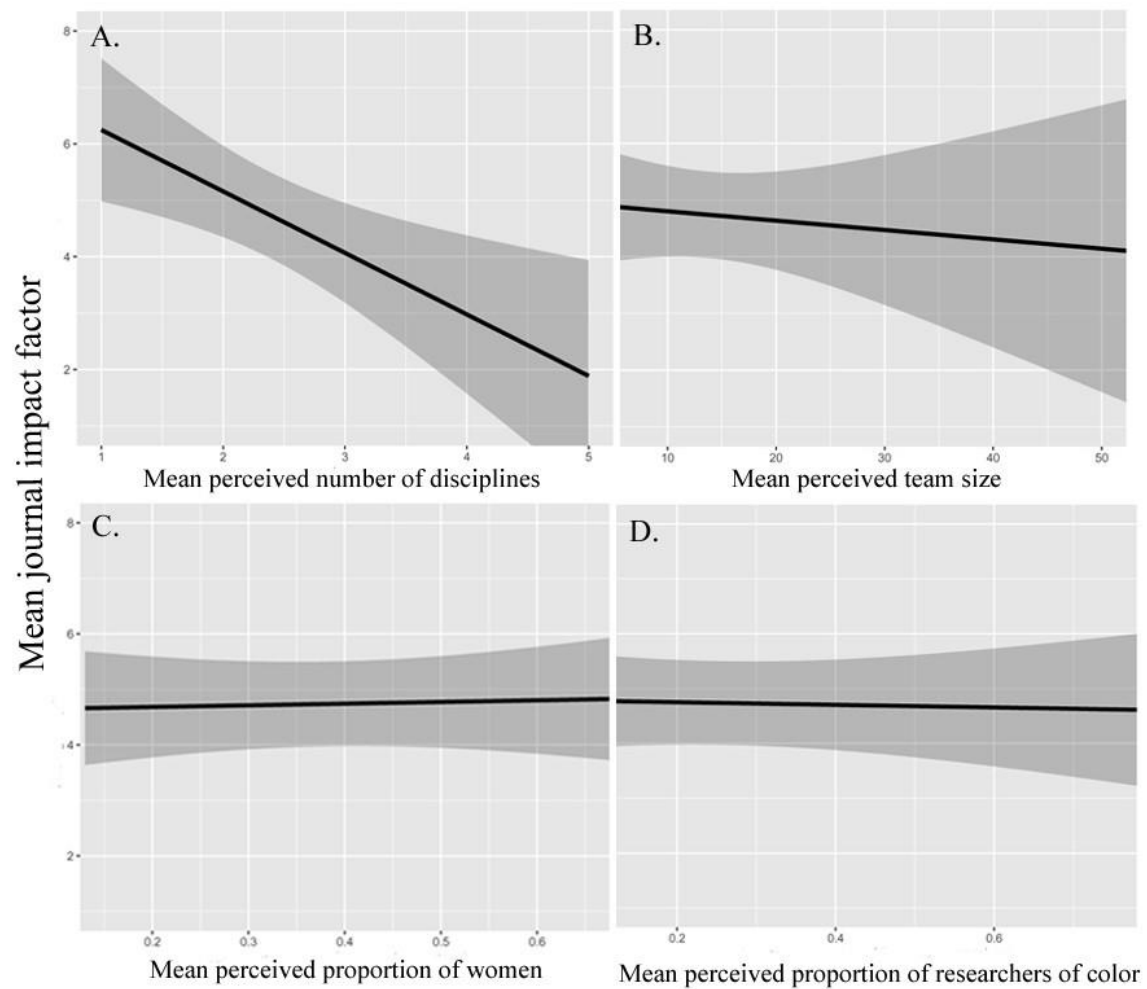


Fig. 4.1

Conservation science as a complex adaptive system. An example of one potential system, with processes in green, the conservationist (i.e. self) in gray, and other actors in blue. The scientific process is considered nonlinear and actors may stand alone or function as networks. Arrows represent lines of influence between actors and processes, dashed lines represent feedback loops which may cause fundamental changes in the conservationist or their future interactions. Systems will vary across contexts and may change over time. For example, if the scientific process includes a participatory research method, local stakeholders would have additional lines of influence across the system.

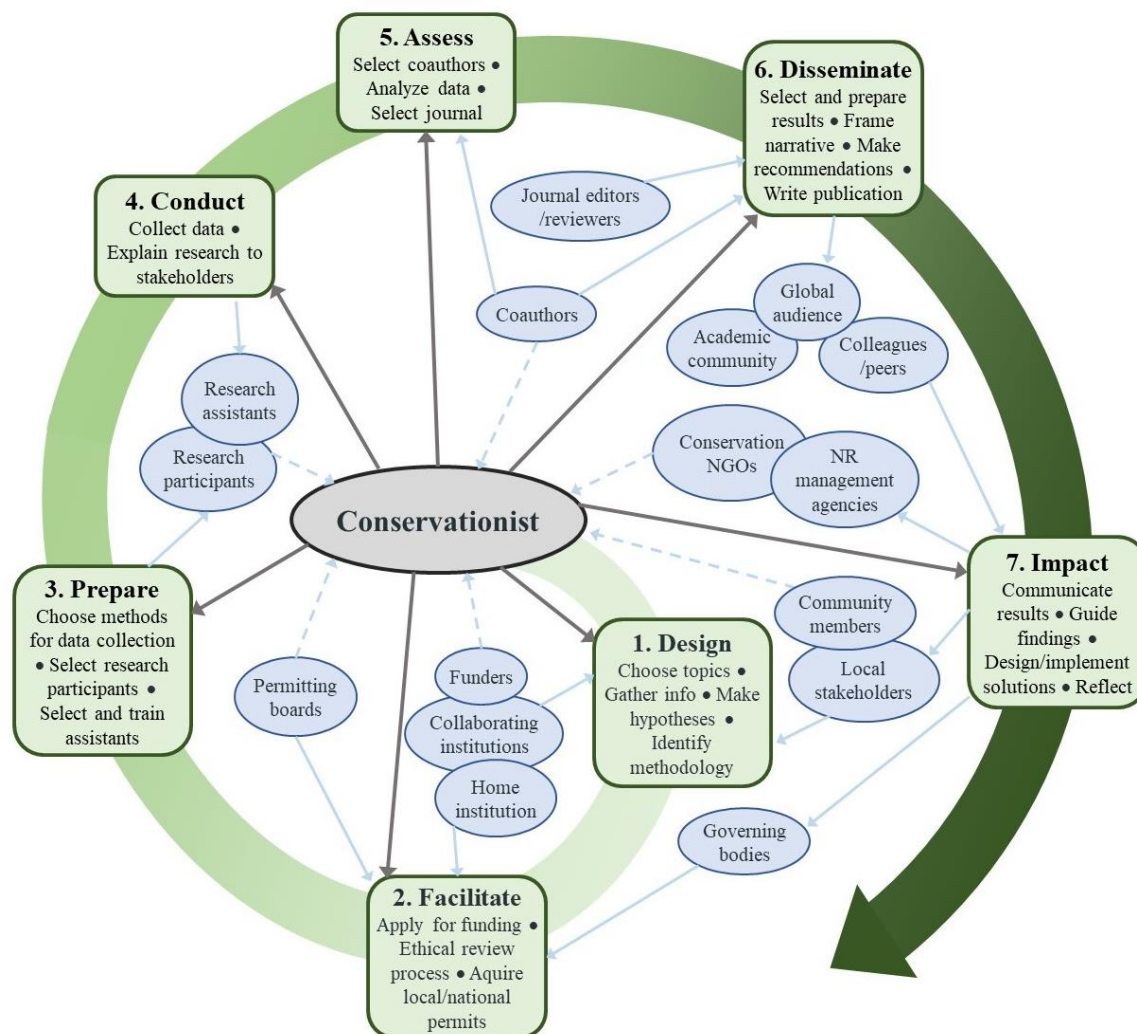


Fig. 4.2

Representation of the overlapping nature of the four tenets of reflexivity for conservation science, with example prompts to encourage reflexivity.

<i>Understand your purpose</i> • What are my motivations for conducting this project and how do I benefit from it? • How might I describe my personal conservation agenda to various other people?	• Have I shared my values with my teammates? • What can I do to build trust with stakeholders?	<i>Establish real connections</i> • Do I share the same philosophical assumptions as my teammates? • In what ways have I considered diversity, equity, and inclusion in my work?
• What actions do I hope to inspire with my work? • What mistakes did I make during this project that others could avoid in the future?	• How does my own unique identity impact every aspect of the scientific process?	• How could my actions perpetuate stereotypes, maintain negative power dynamics, or cause harm to community members or research subjects?
• What specific policies or management initiatives can my work support? • What will change if my recommendations are implemented? <i>Inform and transform</i>	• How might different audiences interpret my results based on past and current cultural contexts?	• What are the histories of local and indigenous people in my study area? • In what ways are social conditions unavoidably impacting my project? <i>Learn from the past</i>

Fig. 4.3

Worksheet for Tenet 1. Activities to practice reflexivity for conservation science.

Reflexivity for Conservation Science	Beck et al. 2021
Tenet 1: Conservation is informed by personal values <i>Look inward, understand your purpose</i>	
Think:	
☐ What problem is my conservation project trying to solve?	
☐ Who determined it was a problem and how?	
☐ Why do I care about this?	
☐ What are my motivations for conducting this project?	
☐ Whose aims does it serve?	
☐ What actions do I hope to inspire with my work?	
☐ How do I benefit from it?	
☐ How will I know if my goals have been met?	
☐ What are the overall changes I want to see?	
☐ What are the potential consequences of these changes over time?	
☐ How might I describe my personal conservation agenda to various other people?	
Reflect:	
<i>Were any of these questions difficult to answer? Why?</i>	
<i>How have my personal values influenced the design, interpretation, and communication of my project? How might it have been done differently by someone with different values? What makes my vision for the project unique?</i>	
Practice:	
Select three actors from your scientific system that you know personally. Ask them to describe some of your strengths and weaknesses. Reflect on any unexpected answers and the role that these characteristics may play in your work.	
Read:	
Elliott, K. C. <i>A Tapestry of Values</i> . New York, NY, Oxford University Press, 2017.	
Brown, M. <i>Science and Moral Imagination</i> . Pittsburgh, University of Pittsburgh Press, 2020	
1	

Fig. 4.4

Worksheet for Tenet 2. Activities to practice reflexivity for conservation science.

Reflexivity for Conservation Science	Beck et al. 2021
Tenet 2: Conservation requires true partnerships <i>Look outward, establish real connections</i>	
Think:	
☐ Have I shared my values with my teammates? ☐ Do we have the same philosophical assumptions regarding our work? ☐ If not, how do we plan to address these differences? ☐ Have I been open to new perspectives? ☐ What can I do to build confidence, respect, and trust with my team and our stakeholders? ☐ What may I need to compromise on in order to create a shared vision of success? ☐ In what ways have I considered diversity, equity, and inclusion in my conservation project? ☐ Have I been engaging in safe and honest dialog?	
Reflect:	
<i>Were any of these questions difficult to answer? Why?</i>	
<i>What lessons have I learned from past partnerships? What specifically made these collaborations difficult or successful?</i>	
Practice:	
Imagine a group of scientists comes into your community to study some of the local natural resources. Draft a code of ethics that the scientists must agree to before conducting their research. Consider how you would expect them to treat you, your family, and friends, what role your community would play in the scientific process, who would own the data the researchers collect, and whether or not there would be expectations for long-term partnership.	
Read:	
Deming, A. H. and Savoy, L. E. <i>Colors of Nature: Culture, Identity, and the Natural World</i> . Minneapolis, MN, Milkweed Editions, 2011.	
Schroeder D., Cook J., Hirsch F., Fenet S., and Muthuswamy V. <i>Ethics Dumping: Case Studies from North-South Research Collaborations</i> . Springer Nature; 2018.	
2	

Fig. 4.5

Worksheet for Tenet 3. Activities to practice reflexivity for conservation science.

Reflexivity for Conservation Science	Beck et al. 2021
Tenet 3: Conservation must contend with its own history <i>Look backward, learn from the past</i>	
Think:	
☐ What is the historic context for conservation and natural resource management where I work?	
☐ What are the historic and current circumstances of local and indigenous people?	
☐ What is my position in relation to them?	
☐ How might my positionality effect my work?	
☐ In what ways are social conditions unavoidably impacting my conservation project?	
☐ Could my actions in this place create stereotypes, maintain negative power dynamics, or cause harm to community members or research subjects?	
☐ How can I create positive relationships here?	
Reflect:	
<i>Were any of these questions difficult to answer? Why?</i>	
<i>How would I describe the power dynamics within my scientific system? What is my relationship with my assistants, participants, and stakeholders? What steps have I taken to ensure that all people have been treated fairly?</i>	
Practice:	
Look back at some of your previous conservation efforts or scientific publications. Write a positionality statement for each. Consider how your positionality has changed under various contexts or over time. Highlight aspects of your identity that are always relevant to your work.	
Read:	
Dowie, M. <i>Conservation Refugees: The Hundred-year Conflict Between Global Conservation and Native Peoples</i> . Cambridge, MS, The MIT Press, 2009.	
Brechtin, S. R., Wilshusen, P. R., Fortwangler, C. L., and West, P. C. <i>Contested Nature: Promoting International Biodiversity with Social Justice in the Twenty-first Century</i> . Albany, NY, State University of New York Press, 2003.	
3	

Fig. 4.6

Worksheet for Tenet 4. Activities to practice reflexivity for conservation science.

Reflexivity for Conservation Science	Beck et al. 2021
Tenet 4: Conservation demands progress <i>Look forward, inform and transform</i>	
Think:	
☐ What mistakes did I make or unexpected costs did I incur during my conservation efforts that others could avoid in the future?	
☐ Who needs this information and how can I get it to them in a form that is usable?	
☐ Are my conservation recommendations feasible? What will change if they are implemented?	
☐ What specific policies or management initiatives can my work support?	
☐ Who will have access to my message and how might different audiences interpret it?	
☐ How can I guide the use of my findings?	
☐ What should be done differently next time?	
Reflect:	
<i>Were any of these questions difficult to answer? Why?</i>	
<i>What were some of the most difficult things I've experienced while trying to reach my conservation aims? Do barriers still exist for the implementation of my research results by relevant decision makers or natural resource managers? How could I overcome these?</i>	
Practice:	
Have a conversation with a local policy maker about conservation efforts in your area. Reflect on their response to your opinions and how the conversation made you feel. List some ways you could collaborate even if you hold dissimilar views on current conservation policies.	
Read:	
Turnhout, E., Tuinstra, W., and Halfman, W. <i>Environmental Expertise: Connecting Science, Policy, and Society</i> . Cambridge, UK, Cambridge University Press. 2019	
Benessia A., Funtowicz S., Giampietro M., Pereira Â. G., Ravetz J. R., Saltelli A., Strand R., and van der Sluijs J. P. <i>The Rightful Place of Science: Science on the Verge</i> . Tempe, AZ and Washington, DC: Consortium for Science, Policy & Outcomes; 2016.	
4	

APPENDIX C

Positionality Statement

Coauthor positionality statement, included as supplementary material in: Beck, J. M., K. C.

Elliott, C. R. Booher, K. A. Renn, and R. A. Montgomery (*in review*). The application of reflexivity for conservation science. *Biological Conservation*.

The multidisciplinary team that has convened to develop this paper includes both conservation scientists and professionals outside of the field of conservation working to improve academic research and the researcher experience. As such, we recognize that the advice and recommendations we provide in this document apply to the authors as well, both directly and indirectly. The first author, JMB, is currently a PhD candidate in the field of Fisheries and Wildlife. Through her experience in applied conservation research, particularly her fieldwork on human-wildlife conflict in rural East Africa, she developed a recognition of the limitations of disciplinary research and aims to expand the connections between social and natural sciences to amplify underrepresented and understudied communities in conservation. KCE is a Professor at Michigan State University with a joint appointment in Lyman Briggs College (a residential college focused on undergraduate natural science education) and the Department of Fisheries and Wildlife, as well as a courtesy appointment in the Department of Philosophy. As a philosopher of science who works in an institutional context that is highly interdisciplinary, his central research focus is to understand how ethical and social values influence scientific research and how those influences can be handled responsibly. CRB is currently an MS student in the fields of Wildlife Biology, Public Administration, and Natural Resource Conflict Resolution at the University of Montana. In his experience in private, public, and academic conservation settings, he found a need for a rethinking of the role of science in conservation management, governance, and policy, and plans to build a career at the intersection of these important disciplines. KAR is Professor of Higher, Adult, and Lifelong Education at Michigan State University, where she also serves as Associate Dean of Undergraduate Education for Student Success Research. Primarily a qualitative researcher, she studies college student learning, development, and success with a focus on diversity, equity, and inclusion. RAM is an Associate Professor of Conservation Science at Michigan State University. Via 20 years of research in East Africa, and in other parts of the Global South, RAM is acutely aware of the problematic power imbalances that exist between conservationists and local community members regarding the application of conservation practice.

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