ABSTRACT

RIEDER, ERICA KATHARINE. Using Participatory System Dynamics Modeling to Address Complex Conservation Problems: The Case of Tiger Farms. (Under the direction of Lincoln Larson).

Wildlife conservation involves tackling complex problems in dynamic social-ecological systems. However, in these environments it is often difficult to assess the short and long term implications of actions. Furthermore, given the wide range of values, beliefs, and goals of people involved in solving conservation problems, no one person or organization can hold all of the answers. New approaches are needed that capture the dynamics of complex systems and bring together diverse perspectives, improving evidence-based adaptive management to solve conservation's wicked problems. Participatory system dynamics (SD) modeling is a promising collaborative approach that synthesizes existing research with local knowledge while informing interventions and enhancing collaboration among diverse stakeholders. Although systems-oriented approaches are growing in popularity across the conservation world, few studies have explicitly outlined a participatory SD modeling process or attempted to evaluate its efficacy in conservation.

This dissertation applied a virtual participatory SD approach to address a wicked conservation problem: tiger conservation and the threat posed by tiger farms and the illegal wildlife trade. With a population of just 4,500 animals, wild tigers remain severely threatened by habitat constraints, human-wildlife conflict, and persistent consumer demand for their body parts. Meanwhile, there are over 7,000 tigers in captive tiger farms that supply some of this consumer demand – and that number may be growing. In such a complex system, opinions differ on whether these facilities reduce or increase the threat wild tigers face from poaching for trade, resulting in policy conflict among diverse stakeholders. In this dissertation, we describe the development, implementation, and evaluation of a virtual participatory SD modeling process that brought together 49 international experts from over 15 different organizations over a two year period. Participants were invited into three different groups based on levels of engagement through a combination of surveys, presentations, and workshops. At the end of the study, pre-post surveys revealed shifts in beliefs about the relationship between tiger farms and wild tigers and illustrated how the process provided insights into causal-relationships and feedback within the system. Participants appreciated the opportunity to collaborate constructively with others and build a foundation for increased trust. Model-building workshops provided a rare opportunity for participants to talk with and learn from other experts with different perspectives in a way that built consensus and minimized conflict surrounding this contentious issue. Though the process was long and intensive, participants reported finding an increased value in systems thinking and an appreciation for the utility of participatory SD modeling approaches in conservation.

This dissertation is organized in the following five chapters. Chapter 1 provides an Introduction,

giving an overview of each of the three papers and their findings. Chapter 2 (*Using Participatory System Dynamics Modeling to Address Complex Conservation Problems: Tiger Farming as a Case Study*) provides a detailed overview of the methods used in this virtual participatory modeling process. Chapter 3 (*Effects of Tiger Farms on Wild Tiger Conservation: Advancing Understanding with a Causal-Loop Diagram*) describes the development of a conceptual model and initial analysis of the relationship between tiger farms and the poaching of wild tigers. In Chapter 4 (*The Social Benefits of Participatory System Dynamics Modeling in a Wildlife Conservation Context*), we evaluate effects of the participatory SD modeling process on knowledge and understanding, collaboration and trust, and consensus and commitment for action among people who participated in the modeling process at different levels (a Modeling Group who was highly engaged vs. a Consulting Group who was less engaged). Chapter 5 concludes the dissertation by briefly summarizing findings and implications for future research and implementation of participatory SD modeling in conservation contexts.

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Using Participatory System Dynamics Modeling to Address Complex Conservation Problems: The Case of Tiger Farms

by
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BIOGRAPHY

Erica grew up in Connecticut, where she found a love for the outdoors, nature and all animals. After high school she attended Mount Holyoke College in Massachusetts, where she received a B.A in Biology and prepared to go to veterinary school. After moving to Colorado after college, Erica changed direction to pursue a career in wildlife conservation. This brought her to Duke University in North Carolina for her Master's of Environmental Management and then to the World Wildlife Fund (WWF). She was lucky to get the opportunity to work for WWF-Zambia for three years supporting community-based natural resource management around Sioma-Ngweze National Park. After which, Erica returned to the US to support community-based projects in Mozambique and Tanzania through WWF's Coastal East Africa program. Hoping to help communities and the environment closer to home, she joined WWF's Northern Great Plains program to help support tribal wildlife management. In South Dakota a chance meeting introduced her to the field of system dynamics and she (almost) never looked back. Though still passionate about natural resource governance and community-led initiatives, Erica found her way to North Carolina State University to pursue a PhD combining participatory approaches with system dynamics.

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CHAPTER 1

Introduction

Conservation practitioners routinely work within complex social-ecological systems to address threats facing biodiversity and to promote positive human-wildlife interactions. Yet inadequate understanding of the short- and long-term consequences of decision making within these dynamic systems can lead to misdiagnosed problems, con icts, and unintended consequences. New tools and approaches are needed to advance understanding of dynamic systems and build capacity for action (Mahajan et al., 2019). Participatory system dynamics (SD) modeling is a collaborative approach that synthesizes existing research with local knowledge while developing new insights. Preliminary evidence suggests that it can build trust and consensus and improve transdisciplinary collaboration to solve complex problems (Rouwette et al., 2011; Scott et al., 2016).

One example of a complex problem that requires system-level solution is tiger conservation. With a population of just 4,500 animals, wild tigers remain severely threatened by habitat constraints, human-wildlife con ict, and persistent consumer demand for their body parts (Goodrich, J. et al., 2022a, 2022b). Meanwhile, there are over 7,000 tigers in captive tiger farms that supply some of this consumer demand (EIA, 2017; Stoner, Sarah et al., 2016) – and that number may be growing. In such a complex system, opinions differ on whether these facilities reduce or increase the threat wild tigers face from poaching for trade, resulting in policy con ict among diverse stakeholder groups. Considering the growth in tiger farms and potential demand for tiger parts globally, many scientists and conservation managers are seeking to better understand this complex problem. Participatory SD modeling offers a unique opportunity to understand the impact of tiger farming on wild tiger populations (Beall and Ford, 2010; Rieder et al., 2021).

In this dissertation, we describe the development, implementation, and evaluation of a partici-

patory SD modeling process that brought together 49 international experts from over 15 different organizations in a virtual space over a 2 year period. The overall objective of this research was to collaboratively develop a conceptual model of the social, ecological and economic dynamics surrounding tiger farms to answer the question “Do tiger farms help or hinder wild tigers?” However, there is a tendency when applying SD modeling to focus on what is perceived to be the final product: the model itself. Although the model can be an important decision-making tool, it is often not the most valuable outcome. For this reason, we used a mixed-methods approach to evaluate the broader benefits that might result from the participatory modeling process. Specifically, our secondary objective was to evaluate the ability of participatory system dynamics to help a diverse group of conservation practitioners (a) increase knowledge and understanding about the problem; (b) improve collaboration and trust; and, (c) grow consensus and commitment for action. The dissertation is presented in three chapters that correspond with different academic manuscripts, each highlighting a different phase of the process. Chapter 2, titled Using Participatory System Dynamics Modeling to Address Complex Conservation Problems: Tiger Farming as a Case Study, explains how we developed a plan to work with international conservation partners in a virtual environment to utilize a participatory SD modeling approach with the goal of better understanding and promoting coexistence of humans and wild tigers. We highlight a step-by-step process that others might use to apply participatory SD modeling to address similar conservation challenges, building trust and consensus among diverse partners to reduce conflict and improve the efficacy of conservation interventions.

Chapter 3, titled Effects of Tiger Farms on Wild Tiger Conservation: Advancing Understanding with a Causal-Loop Diagram, describes development of the conceptual model to better understand the relationship between tiger farms and wild tigers. Wild tiger populations have declined, in large part, due to poaching driven by international consumer demand for tiger parts and products. In response to this demand, the captive breeding (or farming) of tigers started in the 1980s and today there are currently more tigers in farms than in the wild. Whether tiger farms are hurting wild tiger populations (by increasing demand) or helping wild tigers (by supplying products to meet consumer demand) is contested by the scientific and conservation community. Through a virtual participatory SD modeling process involving 49 experts from around the world, we applied systems thinking to build a conceptual model, or causal-loop diagram (CLD), of the causal relationships between tiger farms and wild tiger populations. We found the likelihood of both positive and negative impacts of tiger farms on wild tiger populations, and we revealed the potential for increased poaching pressure on wild tiger populations if farms are closed without a corresponding decrease in demand for tiger products. Our study highlights the value of systems thinking and participatory modeling as tools for combining research with practitioner knowledge into a conceptual model that enhances understanding and can spark further conversation into solving this wicked problem.

Chapter 4, titled "The Social Bene ts of Participatory System Dynamics Modeling in a Wildlife Conservation Context," evaluated the broader bene ts generated by the participatory SD modeling process. Participatory SD modeling is one approach that may improve participant understanding, enhance strategy development, and provide social bene ts to groups working together to solve wicked conservation problems. We found that participatory SD changed perspectives on the threats farms pose to wild tiger populations. Although participants did not perceive changes in their own perspectives, they reported that the process provided evidence-based insights into causal-relationships and feedback within the system. We did not nd a signi cant increase in trust between participants, but participants appreciated the opportunity to collaborate constructively with others. Model-building workshops provided a rare chance for participants to talk with and learn from other experts with different perspectives in a way that built consensus and minimized con ict surrounding this contentious issue. Though the process was long and intensive, participants reported nding an increased value in systems thinking and an appreciation for the utility of participatory SD modeling approaches in conservation

Overall, this dissertation provides a rigorous framework for developing, implementing, and evaluating participatory SD modeling (and possibly other participatory modeling approaches) and provides support for the use of these approaches for improving understanding, collaboration and trust, and consensus-building in conservation.

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CHAPTER 2

Using Participatory System Dynamics Modeling to Address Complex Conservation Problems: Tiger Farming as a Case Study

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2.1 Abstract

Conservation practitioners routinely work within complex social-ecological systems to address threats facing biodiversity and to promote positive human-wildlife interactions. Inadequate understanding of the direct and indirect, short- and long-term consequences of decision making within these dynamic systems can lead to misdiagnosed problems and interventions with perverse outcomes, exacerbating con ict. Participatory system dynamics (SD) modeling is a process that encourages stakeholder engagement, synthesizes research and knowledge, increases trust and consensus and improves transdisciplinary collaboration to solve these complex types of problems. Tiger conservation exempli es a set of interventions in a complex social-ecological system. Wild tigers remain severely threatened by various factors, including habitat constraints, human-wildlife con ict, and persistent consumer demand for their body parts. Opinions differ on whether commercial captive tiger facilities reduce or increase the threat from poaching for trade, resulting in policy con ict among diverse stakeholder groups. This paper explains how we are working with international conservation partners in a virtual environment to utilize a participatory SD modeling approach with

the goal of better understanding and promoting coexistence of humans and wild tigers. We highlight a step-by-step process that others might use to apply participatory SD modeling to address similar conservation challenges, building trust and consensus among diverse partners to reduce con ict and improve the ef cacy of conservation interventions.

2.2 Introduction

To navigate complex social-ecological systems and promote coexistence with wildlife, researchers and practitioners must focus on knowledge generation while increasing access to and use of information that already exists. Inadequate understanding of systems can lead to misdiagnosed problems and unintended outcomes (Larrosa et al., 2016). These misdiagnoses often create or exacerbate human-wildlife con ict (Hübschle, 2017). Con ict mitigation interventions typically focus on tangible disputes (e.g., livestock depredation and retaliatory killings, illegal poaching) without addressing root causes of problems such as inequitable social relationships and processes (Baynham-Herd et al., 2018; Madden and McQuinn, 2014). While a wealth of information about these social relationships and processes exists, this knowledge often remains on the periphery of decision-making that impacts wildlife management (N. J. Bennett et al., 2017). Interventions that neglect to consider social and political context, such as a singular “war on poachers” are therefore unlikely to succeed. In fact, such interventions may inadvertently fuel social-cultural tensions and subsequent conservation-related con ict (Brashares et al., 2014; Challender and MacMillan, 2014). Efforts to reduce human-wildlife con ict, especially for controversial carnivore species like tigers, rarely address these issues (Krafte Holland et al., 2018).

Madden and McQuinn (2014) argue that “conservation efforts would bene t from improved capacity and resources for understanding and transforming the complex drivers of deep-rooted social con icts impacting wildlife conservation and management actions” (p. 104). Numerous scholars have made a strong case that biodiversity conservation is ultimately a social and political process (Brechin et al., 2002; Lele et al., 2010; Montgomery et al., 2020). Yet, despite a growing body of research focused on the social component of social-ecological systems (Ban et al., 2013), including systems with carnivore species such as tigers (Struebig et al., 2018; Torri, 2011), efforts to apply this research by re-conceptualizing and adapting conventional conservation approaches have been slow (N. J. Bennett et al., 2017). As recognition of these challenges grows, the key ingredients for change are already present. Leveraging them might simply require a shift toward systems-level thinking and adaptation.

2.3 Toward a Systems Approach

Conservation practitioners often acknowledge the complexity of the systems in which they operate, which span a wide array of habitats, stakeholder groups, communities, sectors, and political boundaries. Most adapt and respond to these systems, altering interventions based on data and experience to better achieve their goals. Yet dynamic social-ecological systems make it very dif cult to grasp the long-term implications of management actions due to delays between cause and effect (Kim, 1994). Implementation itself may also change the nature of the problem, in uencing the success of the solution (Game et al., 2014; Larrosa et al., 2016). New tools and approaches are needed to advance understanding of systems and build capacity for action (Mahajan et al., 2019).

To advance understanding of systems, researchers have employed modeling approaches such as bayesian belief networks (E. L. Bennett et al., 2021), agent-based modeling, social network analysis, and system dynamics (Frerichs et al., 2016). There are also approaches that focus more on planning to help managers improve decision making and outcomes, such as structured decision making (Gregory et al., 2012) and the Conservation Standards (CMP, 2020). For example, use of the Conservation Standards provides a number of bene ts, including identifying potential interventions, clarifying theories of change and increasing collaboration; however, it does not explicitly incorporate system behavior such as feedbacks, non-linear behavior or the consequences of time delays. With such a diversity of tools that could be used for understanding complex systems (Voinov et al., 2018), it can be dif cult for managers to know where to start.

The eld of System Dynamics (SD) began in the early 1960s to better understand complex human and industrial dynamics (Forrester, 1971). Today, SD is used to inform decision making and policy in elds such as business (Ford, 1997; J. D. Sterman, 2000), health (Currie et al., 2018; Frerichs et al., 2016), social work (Appel et al., 2019; Fowler et al., 2019; Trani et al., 2016), and agriculture and natural resource management (Ford, 1999; Kopainsky et al., 2017; Stave, 2010; B. Turner et al., 2016). It has even been applied to species such as sage grouse (Beall and Zeoli, 2008), African penguins (Weller et al., 2014) and grizzly and spectacled bears (Faust et al., 2004).

While not suitable in all cases, SD offers a number of strengths in helping to understand the dynamic behavior of complex systems and test assumptions of different actions and policies with a focus on solving problems (Forrester, 1994; J. D. Sterman, 2000). SD traditionally uses two main modeling types: qualitative causal loop diagrams (CLDs) and quantitative simulation models. CLD's identify relationships and feedback mechanisms between elements. Simulation models incorporate the elements of a CLD into a stock- ow structure, where stocks represent what is accumulating in a system (e.g., number of tigers) and ows represent rates of change (e.g., birth or death rate). Structural (e.g. connections between elements) as well as numerical data are incorporated into simulation models to generate endogenous behavior over time under changing conditions and policy

interventions. While not meant for predicting or forecasting, simulation models make it easier to explore the potential implications of changing conditions and selected policy interventions on system behavior (J. D. Sterman, 2000). SD simulation models run quickly and do not require high computing power; the approach is also particularly useful in environments where quantitative data is scarce and integration of qualitative data (e.g. expert opinion) could be used to address knowledge gaps (Gallagher et al., 2020; Luna-Reyes and Andersen, 2003).

SD is ideally used in participatory planning processes where it can support the negotiation of a shared understanding of a dynamic problem (Vennix, 1999). It facilitates exchange of ideas among participants (Sedlacko et al., 2014) and effectively integrates existing scienti c research with local knowledge (Beall and Zeoli, 2008; Rouwette et al., 2016; Stave, 2010). Co-creating SD models necessitates turning implicit into explicit knowledge, so that participants are learning from each other and the model itself (Kopainsky et al., 2017). This also encourages participant ownership of the model and greater support of outputs to address the problem. Model creation can provide a laboratory for a group to examine policies and to visualize potential impacts of actions over time (Forrester, 1994; J. D. Sterman, 2000). This is an especially important bene t when working with endangered species or sensitive environments, where physical experiments are not always possible (J. D. Sterman et al., 2013; B. L. Turner, 2020). In addition to insights from the model, the model building process can increase the social capital of a group (Davies et al., 2015), strengthen relationships and improve communication (Beall and Zeoli, 2008; Stave, 2010). Although there are several terms used for conducting SD modeling with stakeholders, we use the term participatory SD modeling in this paper.

Despite calls to increase the overall use of models in decision making, resistance may persist for several reasons. Primary concerns include lack of transparency regarding model-building and outputs and weak communication between modelers and practitioners (Addison et al., 2013). Participatory SD modeling offers several advantages since models are designed to be built with stakeholders, using the language of people working on the chosen problem. The visual nature of the modeling software is more accessible to a lay audience, and easy-to-use interfaces help minimize technical barriers between modelers and the modeling groups (J. Sterman, 1994). Although the value of participatory SD is well documented (Andersen et al., 2017; Rouwette, 2011; Scott et al., 2016b), adoption of this approach to address complex conservation problems has been slow. The time required of participants in the short term (Stave et al., 2019) and the need for a competent modeler and facilitator to coordinate the process (Andersen et al., 1997) are major barriers to adoption. More research and guidance are needed to help conservation practitioners explore the potential value of the participatory SD modeling approach. This paper explores how a participatory SD modeling process can be used to address a particularly complex problem: conservation of wild tigers.

2.4 Conservation Context: Impacts of Tiger Farming on Wild Tiger Populations

Approximately 3,900 tigers remain in the wild worldwide (World Wildlife Fund, 2021), and they are found in less than 7% of their original global range (Dinerstein et al., 2007). Wild tiger populations are found in up to 13 countries: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Russia, and Thailand (Goodrich et al., 2015), although this list includes several countries where wild tiger may be functionally extinct (EIA, 2017; Rasphone et al., 2019). The continued survival of tigers depends on a complex set of ecological, economic, and social factors across local and global scales. Because tigers need suf cient lands to roam where they can nd adequate prey and live largely undisturbed by people, some experts believe that conservation efforts should focus on law enforcement and protection of habitat and corridors in and around key protected areas (Walston et al., 2010). In areas where tiger conservation succeeds and numbers grow, tigers increasingly come into con ict with growing rural human populations, threatening people and their livestock and potentially increasing revenge killings (Carter et al., 2014; Struebig et al., 2018).

In addition to the interrelated processes of human encroachment, habitat and prey loss, and human-tiger con ict, a persistent consumer market for tiger parts and products economically incentivizes poaching and makes the conservation of wild tigers even more challenging (Wong, 2016). In fact, there is growing consensus that the most urgent threat to wild tigers is poaching (Chapron et al., 2008; Dinerstein et al., 2007). International consumer demand for tiger parts (bones, hides, teeth, etc.) constitutes a major potential threat to wild tigers (Goodrich et al., 2015). Tiger parts are valued across Asia for their perceived health bene ts and may confer status and wealth (EIA, 2017; Goodrich et al., 2015). As the species becomes rarer, illegal harvesting and trade in body parts are likely to increase alongside rising market values.

Reduction of the threat of poaching is dif cult because tiger poaching crosses multiple countries with different cultures, laws, and policies, and it is in uenced by complicated market behaviors (e.g., consumer demand for tiger parts) amidst a growing human population (Sharma et al., 2014). A feedback loop of inter-related increasing scarcity and rising prices can lead to a phenomenon termed the anthropogenic allee effect (Courchamp et al., 2006), which can drive a species to extinction or keep a population low. Under these conditions, drawing attention to the rarity of the species through a demand-reduction program can have the perverse effect of stimulating poaching (Courchamp et al., 2006; Hall et al., 2008). Poaching also appears to have a non-linear relationship with tiger survival, indicating that there are thresholds where even steady rates of poaching could suddenly cause an extinction risk to a tiger population (Kenney et al., 1995). Adding complexity, the tiger trade also potentially threatens other big cats around the world, as body parts from other species such as lions are being traded in the tiger parts market (Coals et al., 2020; Villalva and Moracho, 2019; Williams

et al., 2017; Williams, 2015). To mitigate poaching, some have suggested that market demand for tiger products should be supplied from captive sources (Jiang et al., 2007), but this proposal is contested (Gratwicke, Mills, et al., 2008).

As of 2017, at least 7,000 tigers were estimated to be held in captive facilities (hereafter “tiger farms”) across Asia, catering to growing demands for various products ranging from tiger body parts and derivatives to live tigers used for tourist attractions (EIA, 2017). The global captive tiger population is larger, with approximately 5,000 captive tigers in the United States alone (Henry, 2020). Many conservation organizations would like to see this practice end, but the potential impacts of closures of farming operations for species are not entirely clear or without risk (Kirkpatrick and Emerton, 2010; 't Sas-Rolfes, 2010). For the purpose of this study, we de ne a tiger farm as “a facility that keeps or breeds tigers in captivity with an intent (or reasonable probability) of supplying or directly engaging in the commercial trade in tigers or tiger products, be they body parts or derivatives. The application of this de nition is not limited by the stated purpose of such facilities.”

As Asian economies grow, so might consumer demand for wildlife products such as skins and bones of tigers (Linkie et al., 2018). In one case, researchers found that nearly half (43%) of survey respondents in China (one of the largest consumer markets) had consumed a product that contained tiger parts (Gratwicke, Bennett, et al., 2008). There is uncertainty over the preference consumers may have for wild versus farmed tiger products (Coals et al., 2020; Hinsley and 't Sas-Rolfes, 2020), with wild tigers possibly being prized more for their power and strength (EIA, 2017). Stronger preferences for wild versus farmed animal parts have been reported for other species, such as bears farmed for bear bile (Dutton et al., 2011), but these preferences are dynamic and can shift based on access and availability (Davis et al., 2022; Rizzolo, 2021). This uncertainty raises questions about the relationship between tiger farms and demand for tiger parts and products (Song and Yao, 2022).

The challenge of enforcing global wildlife trade under the Convention on International Trade in Endangered Species (CITES) (Challender et al., 2015), combined with limited capacity to combat poachers, has led to some researchers to support limited tiger farming (Abbott and van Kooten, 2011). The argument for legalized tiger farming proposes that increasing the supply of parts will suppress the market price of illegally harvested tiger products (Abbott and van Kooten, 2011). While the demand for tiger parts would persist, diminishing nancial incentives for illegally harvesting wild tigers could deter poaching. Based on this hypothesis, some scientists have advocated for humane, renewable harvest and legal trade of other endangered wildlife species facing similar predicaments - such as African rhinos (Biggs et al., 2013).

Conversely, many argue that farming tigers and facilitating the use of their parts for a consumer market fuels market demand and complicates enforcement efforts to reduce wild tiger poaching (EIA, 2017; Gratwicke, Mills, et al., 2008). According to this argument, the presumed bene ts of

legal supply might be undermined by imperfections in the tiger parts market, including dominance of a small number of producers controlling prices, the luxury status of tiger parts, and the relatively high expense of farming tigers (Kirkpatrick and Emerton, 2010). Legal markets for farmed tiger products might also lead to greater social acceptability of the product, thereby suppressing a stigma effect considered necessary to prevent unsustainable demand levels (Fischer, 2004; Rizzolo, 2021).

Considering the growth in tiger farms and potential demand for tiger parts globally, many scientists and conservation managers are seeking to better understand the impacts of tiger farming on wild tiger populations. The complex dynamics surrounding tiger farms highlight the need for holistic, systems-based approaches to understand their full impact on wild tiger conservation (Rizzolo, 2021). Understanding complex systems such as those impacting tiger conservation efforts is exceptionally dif cult (de Vos et al., 2019), but remains a global priority in conservation science. Participatory SD modeling offers a unique opportunity to understand the problems related to tiger farms and to evaluate the ef cacy of proposed interventions. Below, we describe the development and implementation of a participatory SD modeling process designed to explore the impact of tiger farming on wild tiger populations.

2.5 Applying the Participatory System Dynamics Modeling Process

There is a tendency when applying SD modeling to focus on what is perceived to be the nal product: the model itself. Although the model can be an important decision-making tool, it is often not the most valuable outcome. The process itself is what creates an opportunity for con ict transformation (Madden and McQuinn, 2014). In the following sections, we discuss the primary steps in a participatory SD process and describe how we are currently applying them to improve understanding of the impact of tiger farming. Because our model building efforts are ongoing, the outcomes are not yet known and some aspects of our participatory approach continue to evolve. However, we have already learned multiple lessons that could help to inform participatory SD modeling in other contexts. Using tiger farming as a case study, the framework outlined in this paper illustrates how similar participatory SD approaches might be designed and implemented to build knowledge, trust and consensus among conservation partners with the goal of improving future conservation interventions.

Like any complex system, this process is not linear. At each step new information is learned and the identi ed problem may change, along with system components. Figure 2.1 depicts our participatory SD process in action (adapted from Beall and Ford, 2010). Key steps in Figure 2.1 are described in more detail below. Our process draws from many earlier examples of participatory modeling (Beall and Ford, 2010; Beall and Zeoli, 2008; Homer, 2019; Hovmand et al., 2012; Stave, 2010; J. D. Sterman, 2000; Vennix et al., 1990; Wilkerson et al., 2020), synthesizing and adapting

these based on participant feedback and study context.

Figure 2.1: Diagram of the participatory system dynamics modeling process, highlighting key steps in the cyclical process and the activities and virtual tools that might be utilized at each stage. Adapted from Beall and Ford (2010) Solid lines depict direct paths as the stages processes; dotted lines depict feedback loops and evolving conceptualizations that are a key component of the modeling process.

2.5.1 Setup and Design

The rst step in a participatory SD project involves ensuring the right people are involved and that the process is tailored to match the scope of the problem. To develop a robust understanding of a complex problem, participants should bring diverse perspectives, knowledge, and expertise. This includes people who may not agree about a problem, its causes, or potential solutions. It is

also important consider who is making policy and management decisions and involve these key actors in the process, if possible. This helps generate a model that is comprehensive, valuable to the individuals participating, and supported by leaders. Who participates also depends on the scope of the project (i.e. relevant geographic area, number of organizations or communities involved) and whether the model building will be done in person or virtually. There are bene ts to convening in-person, however virtual platforms (e.g., Zoom) can engage more voices across a wider geographic area at a lower cost (Wilkerson et al., 2020). For either setting, group (or sub-group) size should be structured to make sure everyone can participate fully. Other factors to consider when designing the process include the experience level of facilitators and modelers, funding, and time available for both participants and facilitators/modelers.

Our tiger project was initiated by one organization (an international conservation NGO) starting in 2019, but the desire for diverse perspectives led to the creation of a four-person advisory group, each from varying backgrounds, perspectives, and organizations. This advisory group co-created the process with the research team, then selected and invited the rest of the participants. Throughout 2020, we devoted signi cant time to building understanding of the project within the advisory group and building trust among group members. Extensive conversations helped us reach consensus about which participants to invite, ensuring diverse perspectives regarding the costs and bene ts of tiger farms while maintaining manageable group size for coordination purposes. To date, our participants include over 50 people spread across conservation NGOs (32 people from 20 different organizations), governmental or intergovernmental institutions (4 people), research organizations or institutions (20 people), consultants (5 people), and law enforcement (4 people) (with participants able to identify multiple sectors). Participants live across Europe, Asia, North America and Africa. Expertise varies among participants, with self-reported knowledge being highest in wildlife trade (76% participants), law-enforcement and anti-poaching (40%), tiger farming in Asia (38%), and farming of non-tiger species (30%). Less than 20% of participants reported high con dence in systems thinking or participatory modeling, demonstrating that this process was relatively novel for most of these conservation practitioners.

Given the global network of experts involved, the costs and logistics made in-person meetings prohibitive (with challenges accentuated by the COVID-19 pandemic); thus, we made an early choice to adopt a completely virtual process. To operate in a virtual environment, the research team needed to learn new tools to be utilized at different stages (Figure 2.1). Recognizing not everyone could (or would) be interested in participating directly in the participatory modeling itself, we created two main groups: a modeling group (including the advisory group) and a consultation group (Table 2.1). To incorporate information from such a large group into the model and to support consensus building among the entire group in a virtual format, we decided to integrate a modi ed Delphi process into participatory SD modeling. The Delphi technique has been widely used for

consensus building about topics ranging from program planning to policy development (Hsu and Sandford, 2007). It utilizes rounds of anonymous questionnaires to explore assumptions, illuminate diverse views, develop a range of possible alternatives, and to educate respondents about complex aspects of a topic. After each round, respondents review summarized responses and highlight areas of disagreement (Hsu and Sandford, 2007), as well as additional questions informed by the modeling (Vennix et al., 1990).

Table 2.1: Roles and responsibilities for different stakeholder groups engaged in the participatory system dynamics (SD) modeling process designed to improve wild tiger conservation.

Group	Roles	Important Considerations
Research team (2-5 people)	Small group of senior and junior system dynamists who lead model building and facilitation effort; assistance in managing workshops provided by additional researchers.	Modelers and facilitators must act (as much as possible) as honest brokers in facilitating the group process. Modelers are adept at their practice, but they are not subject matter experts (and may be perceived as objective, third-party mediators). Ideally, the modeler and facilitator are separate people.
Advisory Group (3–5 people)	Small, diverse group of experts who co-lead the process with the research team and join the Modeling Group for all modeling workshops.	Members of this group should bring different perspectives to the table. In addition to advising the research team, this group plays the critical role of identifying and inviting appropriate participants for other groups.
Modeling Group (up to 20 people)	Group of experts who, along with the Advisory Group, build the model with the Research team.	Participants should be chosen from different organizations, geographies, and sectors (law enforcement, ecology, wildlife trade, etc.). Ideal candidates have interest, suf cient time, and willingness to collaborate constructively through differences. Group size should be limited to keep workshops manageable, and may be split to facilitate scheduling across multiple international time zones.

2.5.2 Introduction and Problem Familiarization

Since many participants may not be familiar with systems thinking or the participatory SD process, it is critical to provide a road map to illustrate where the modeling process is going. This overview should include a basic review of systems concepts, such as the de nition of a system and the concepts of reinforcing and balancing feedback loops and stocks (what is accumulating or declining) and ows (the rate of change). The introduction should also lay out the modeling process timeline, and show examples of what a model looks like to give participants an idea of where the process

will end up. Example models should be relevant to participants, but unrelated to the conservation problem being tackled (Beall and Zeoli, 2008). Finally, it is important to get the group talking about the problem they want to address and to begin working toward de ning that problem. The amount of time or focus this takes depends on the particular group, the nature of the problem, and how much clarity and agreement already exists.

The rst step in our modeling process was an introductory meeting with all participants following of cial invitations. The meeting covered the history of the project, introductions, and an overview of the overall process. Basic systems concepts were introduced through real-world hypothetical examples. We used the iceberg model (Senge, 1990) to show that observable events, the tip of the iceberg, are part of larger patterns of change caused by unobservable relationships between elements in a system (also called “system structure”). These are further created and shaped by mental models at the bottom of the iceberg. Changing system structure and mental models produce long term change (Senge, 1990). A demonstration of a simple working dynamic simulation model provided participants with a vision of the end result of their efforts. The meeting ended with a group brainstorm around the broader issue of tiger conservation and the greatest concerns related to tiger farming (Figure 2.1, Problem Familiarization). The most important problems participants identi ed fell into the following major categories:

- Demand for tiger parts and products (or understanding drivers of demand)
- Lack of understanding the connections between wild tigers and tiger farms
- Market dynamics (price, supply of parts, diversity of products and consumers, etc.)
- Consumer behavior change
- Trade and criminality
- Governance and regulation
- Law enforcement

Setting expectations for participants about the importance of integrating diverse perspectives, including those of potential adversaries, was a key element of the rst few meetings. We focused on creating an atmosphere of trying to understand the problem and not to debate speci c positions.

2.5.3 Problem De nition and System Conceptualization

Modeling a system without a boundary or a clear focus would produce a model that was unnecessarily, and maybe impossibly, complex and impractical (J. D. Sterman, 2000). For this reason, the next step in the modeling process is de ning the dynamic problem the group wants to address. A dynamic problem is composed of multiple variables that are changing over time (Homer, 2019), such as a declining wild tiger population, increasing demand for tiger products, and increasing tiger farms. Getting clarity on the problem can be one of the most challenging parts of the process, and may be revisited multiple times as knowledge increases (Mashayekhi and Ghili, 2012). Once

the problem has been de ned, then the system surrounding that problem can be conceptualized. A qualitative model known as a causal-loop diagram (CLD) is iteratively built based on expert judgment and opinion, followed by re ection about the problem and the system elements. The CLD is later used as the foundation of the simulation model. Approaches to eliciting this initial model vary, but efforts such as Scriptapedia (Hovmand et al., 2012) and the Online System Dynamics Collaborative (https://onlinesd.w.uib.no/) provide tested facilitation scripts to get started.

We are using a combination of questionnaires (that include an adapted Delphi process) and small group workshops to develop consensus around the problem and system components. We began with a pre-modeling survey that contained two open-ended questions focused on understanding the potential impacts of tiger farms on the illegal tiger trade and tiger conservation: (1) what is the most important problem to address within this system? and (2) what factors are contributing to this problem? Answers to these initial questions were summarized and used to inform discussions in the introductory meeting with the modeling group (See introduction and problem familiarization above).

After collecting and synthesizing this information, we hosted a longer workshop to begin the collaborative system conceptualization process. We did this with variable elicitation and behavior over time exercises adapted to the Miro online platform (https://miro.com) in Workshop #1. Participant-de ned variables, along with relevant behavior over time graphs describing how variables have shifted in the past and predicting how they might shift in the future, were then worked into a CLD. The CLD was modi ed to include key stocks and ows important in the quantitative model (Figure 2.2) (Homer, 2019). The model was further developed in Workshop #2. Examples of key components of this model include: farmed tiger populations and farm capacity, connections between farmed tiger mortality and sales of products, consumer demand for products and factors that in uence demand, and wild tiger population dynamics. Between workshops, the modeling team worked to re ne the model and incorporate additional input through one-on-one conversations. When this paper was written, our modeling effort remained in this stage. The following sections outline next steps that could be taken in this, or any other, participatory SD modeling process.

Figure 2.2: Example of causal-loop diagram (with stock- ow structure added) of wild tiger population developed in Miro during Workshops 1 & 2 of the participatory SD modeling process. Arrows depict causal relationships, with solid arrows representing a positive relationship and dotted representing negative relationships.

2.5.4 Model Development, Testing and Analysis

Once the initial qualitative CLD is developed around the problem, it is transferred to SD modeling software for creation of a dynamic simulation model. Popular software programs used for this purpose include Stella (https://www.iseesystems.com/store/products/) or Vensim (https://vensim.com). With this transition, additional questions as well as gaps in logic and knowledge become apparent, and changes to the problem de nition or system components are common. Developing, testing and analyzing the quantitative simulation model happens through frequent dialogue between the research team and participants in the modeling group. As the modeler creates the model, they seek input and approval from the modeling group to re ne overall system structure and to ensure necessary data are included. Data may include peer reviewed literature, public or private datasets, and local or expert knowledge. Not every relationship and variable within the system of interest will be captured by the simulation model. The focus of SD model building is to build as simple an explanation for the underlying historic behavior as possible. It is impossible to capture all relationships, but this is often unnecessary for understanding the major endogenous in uences of problem behavior. As

the model is being built, and before it is nalized, it should go through rigorous testing including structure and parameter con rmation, extreme condition testing, and sensitivity analysis (Forrester, 1980; J. D. Sterman, 2000).

For this study, we are using Stella Architect software for the simulation model and complementing this with Miro as a collaborative space for model development. Once the qualitative CLD is suf ciently complete in the previous step, the draft simulation model will be created in Stella (see simpli ed example in Figure 2.3). This model will be built sector by sector, starting with tigers in farms, then demand (and purchasing) of wild and farmed products, and - nally linking to poaching of wild tigers. The model draft goes through a model review exercise (https://en.wikibooks.org/wiki/Scriptapedia/Model_Review), after which it is further re ned by the modeler. After initial system structure has been determined, the second-round questionnaire using the Delphi process will ask stakeholders to review summarized feedback from round one and the logical integrity of the model, provide input into model parameters, and share additional relevant data sources. Information collected will then be summarized, shared with participants (in Workshop #3 and through another round of Delphi questionnaires in in analysis of policy interventions) and used to revise the initial model presented in Workshop #3. In addition to these activities, one-on-one meetings will take place between the modeler and participants to answer questions as they arise.

Figure 2.3: Hypothetical example of a stock- ow model of wild tiger population dynamics, developed using Stella Architect software.

2.5.5 Analysis of Policy Interventions

One of the primary bene ts of an SD model is that it can be used as an experimental platform to explore and evaluate the potential implications of policy interventions (Stave, 2010; J. D. Sterman, 2000; B. L. Turner, 2020). Once the model has been validated and can approximate historical behavior, policy interventions can be added and a more user-friendly interface can be built to help stakeholders interact with the model and discern the impacts of various policy options. An example demonstrating the potential of an SD simulation interface is the C-ROADS climate simulation model from Climate Interactive (J. D. Sterman et al., 2013; https://www.climateinteractive.org/tools/c-roads/). Stakeholders involved in the participatory SD process choose the policy interventions to be tested, in collaboration with the modeler.

For our case study, the ability to test potential implications of policies related to tiger farms is a main focus. Once the nal draft of the model is ready for scrutiny, a nal round in the Delphi process will create an opportunity for the full participant group to review summarized results earlier surveys, to provide input into key components and results of the model, and to suggest priority policy interventions. Input from the Delphi questionnaire will be summarized, reported back to the modeling group, and used to add policy interventions into the model. We anticipate this model could provide an opportunity to explore the potential implications of closing or phasing out tiger farms, or tightening restrictions to the trade or sale of tiger parts and products. Once policies and an interactive interface are added, Workshop #4 will give the modeling group an opportunity to test the model and explore the impacts of different scenarios. To mark the end of this stage and the whole process, a full-project presentation will share SD model results with all participants and provide a forum for re ecting on the process and discussing next steps for policy and practice.

2.5.6 Evaluating the Process, Outputs and Outcomes

A key bene t of participatory SD modeling is its potential impacts on shared knowledge building and social outcomes such as trust, communication, and consensus (Rouwette et al., 2002). Evaluation is necessary to verify outcomes and gather feedback to improve further participatory modeling efforts. Participatory approaches to SD have been evaluated in many cases, generally yielding positive outcomes (Hovmand et al., 2012; Rouwette et al., 2011; Rouwette et al., 2002; Scott et al., 2016b; Stave et al., 2019). Yet, to determine if the process is achieving desired goals, both output and outcome evaluation are an essential part of any modeling effort.

We are integrating evaluation throughout our modeling process. Following recommendations by Scott et al. (2013) we are employing a pre-post survey model. We adapted survey protocols from literature evaluating other collaborative model-building processes (Rouwette et al., 2007; Scott et al., 2016a, 2017), and we are distributing questionnaires to all groups of participants using

Qualtrics XM software (https://www.qualtrics.com/). The pre-intervention questionnaire, which doubled as the rst round of the Delphi process, included questions about participants' areas of expertise, speci c perspectives on tiger conservation and tiger farms, and previous experience with systems thinking (see Supplemental survey instrument). We also included questions designed to measure key process outcomes such as knowledge and understanding (Rouwette et al., 2016; Scott et al., 2016a), trust (Basco-Carrera et al., 2017; Stern and Coleman, 2014), and consensus and commitment among conservation practitioners (Basco-Carrera et al., 2017; Scott et al., 2016b). We aim to integrate a post-intervention questionnaire that allows the research team to measure changes in responses from the beginning to the end of the modeling process. This nal questionnaire will include additional questions to gather feedback about understanding of the dynamics in the tiger conservation system (i.e. connections between wild tigers, demand for tiger parts and products, and tiger farming), the utility of the nal model, and perspectives on how the process itself in uenced perceived outcomes such as knowledge, trust, communication and consensus and commitment (i.e., the same outcomes addressed on the pre-intervention questionnaire). Multiple rounds of Delphi questionnaires integrated throughout the process will help us track the evolution of participants' thinking regarding the problem(s) and the complex system surrounding tiger conservation.

2.6 Implications for Conservation Practice

Conservation practitioners work in complex social-ecological systems to address threats facing biodiversity, reduce con ict, and promote positive human-wildlife interactions. Inadequate understanding of the direct and indirect, as well as short- and long-term, consequences of decision making within these dynamic systems can lead to misdiagnosed problems and interventions with perverse outcomes, exacerbating con ict (Hübschle, 2017; Larrosa et al., 2016). Participatory SD provides an opportunity to minimize these risks through building a more complete shared understanding of a problem and potential implications of interventions. This is achieved while increasing trust and reducing con ict among stakeholders working to tackle these wicked problems. Once created, a simulation model can also be used as an experimental platform that is almost impossible to replicate in situ with threatened ecosystems and endangered species.

The process we have outlined in this paper shows how conservation researchers and practitioners can design and implement participatory SD modeling to address a complex problem such as wild tiger conservation. Throughout our ongoing modeling process, we have confronted con- icting perspectives and worked toward shared understandings of the tiger farming problem and its consequences. Through iterative meetings and conversations combining science with expert knowledge, we are building trust and fostering productive collaboration. As our simulation model progresses, it should yield insights regarding policy interventions that enhance the value of the

process for participants. By strategically dissecting the social and political relationships that fuel many conservation con icts (Madden and McQuinn, 2014), participatory SD processes like ours may be a key step on the path to sustainable coexistence between humans and tigers.

The participatory SD modeling process does not occur without challenges (Addison et al., 2013; Stave et al., 2019). It requires a large time commitment for both the research team and the modeling group. Our study, for example, will have taken multiple years from the initial advisory group meetings to development of the nal policy model. The process at minimum requires a competent modeler and, ideally, a facilitator who has experience with systems modeling. Since participatory SD modeling is not common in the conservation world, there is a learning curve for participants to help them understand where the process is going and how to realize its value. Additionally, with a polarized topic such as tiger conservation, it is challenging to nd diverse stakeholders willing to participate. Finally, while SD models provide insights that can help to guide management and policy, key decision makers must be willing and able to utilize these tools to initiate action. Strategies for addressing these potential barriers undoubtedly vary by context, but investments of time and resources into systems-based approaches could ultimately lead to long-term changes the way conservation efforts are conceptualized and carried out.

Despite challenges, enthusiasm with our effort to model the impacts of tiger farming on wild tiger conservation remains high. Some participants may not be able to engage in the whole process, but excitement has grown as conversations delve deeper into complex issues and the practical implications and potential policy impacts of the effort become more apparent. Our approach is showing how systems thinking and systems-based approaches can help to address the complex social, economic, political, and ecological problems that threaten the survival of wild tigers. Application of systems thinking could improve coexistence with other species where contentious policy choices are being critically evaluated, such as elephants (Mahajan et al., 2019), rhinos ('t Sas-Rolfes, 2016), and wild horses (Bureau of Land Management, 2020); it could also facilitate understanding of conservation issues that span multiple species and contexts, such as the substitutability of tiger and lion products across the farmed/wild nexus (Coals et al., 2020; Rizzolo, 2021). Additionally, SD approaches create unique opportunities to explore the effects of different property rights or management regimes on wildlife (Wilson et al., 2016). Regardless of geography, focal species, or management context, participatory SD modeling could represent a valuable tool in a conservation practitioner's toolbox to address con ict and improve coexistence with wildlife around the world.

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CHAPTER 3

E ects of Tiger Farms on Wild Tiger Conservation: Advancing Understanding with a Causal-Loop Diagram

3.1 Abstract

Wild tiger populations have declined, in large part, due to poaching driven by international consumer demand for tiger parts and products. In response to this demand, the captive breeding (or farming) of tigers started in the 1980s. Today, there are currently more tigers in farms than in the wild. Whether tiger farms are hurting wild tiger populations (by increasing demand) or helping wild tigers (by supplying products to meet consumer demand) is contested by the scienti c and conservation community. Many conservation organizations would like to see farms closed for both ethical and ecological reasons, but the potential consequences of closing farm operations are unknown. The complex dynamics surrounding tiger farms highlight the need for systems-based approaches to understand connections between tiger farms and wild tiger conservation. Through a virtual participatory system dynamics (SD) modeling process involving 49 experts from around the world, we applied systems thinking to build a conceptual model, or causal-loop diagram (CLD), of the causal relationships between tiger farms and wild tiger populations. In this paper, we have compared this conceptual model with perceived or actual trends in key variables, discussing the rami cations of different trends, identifying gaps in understanding, and exploring potential implications of closing tiger farms. We discovered a structure similar to the “success to the successful” systems archetype, where the growth of farms has allowed greater availability of farmed products, shifting some of the market from wild tiger products to farmed. We see the potential for increased poaching pressure

on wild tiger populations if farms are closed without a corresponding decrease in demand for tiger products (currently subsidized by farmed products). Our study highlights the value of systems thinking and participatory modeling as tools for combining research with practitioner knowledge into a conceptual model that enhances understanding and can spark further conversation into solving this wicked problem.

3.2 Introduction

The tiger, widely recognized as the most charismatic species in the world (Albert et al., 2018), is also one of the most endangered. Wild tiger populations plummeted through the 20th century to an estimated low between 2,608-3,904 mature animals in 2015 (Goodrich, J. et al., 2022b). With a large united conservation effort through the Global Tiger Recovery Program (GTRP, 2011), the global wild tiger population is believed to have stabilized or possibly risen slightly over the last 10 years to approximately 4,500 individuals worldwide (Goodrich, J. et al., 2022a). This recent global trend is in uenced by stable or increasing populations across South Asia and undermined by declines across much of South-East Asia (Goodrich, J. et al., 2022a). Yet these big cats are still found in less than 7% of their original global range (Dinerstein et al., 2007) and in less than 45% of available habitat (Goodrich, J. et al., 2022b). In the wild, tigers are found in many sub-populations, with breeding populations found in the following 10 of 13 range countries: Bangladesh, Bhutan, China, India, Indonesia, Malaysia, Myanmar, Nepal, Russia, and Thailand (Goodrich, J. et al., 2022b). India has the largest population of wild tigers (over 2,000 animals), followed by Russia, Malaysia and Nepal.

Wild tigers face many challenges. In addition to human encroachment, habitat and prey loss, and human-tiger con ict, poaching remains one of the largest threats (Chapron et al., 2008; Dinerstein et al., 2007; Kenney et al., 1995). Poaching is driven by a persistent, and possibly growing, illegal consumer market for tiger parts and products in Asia (Linkie et al., 2018) making the conservation of tigers even more challenging. Despite relatively recent population growth, wild tigers remain highly endangered due to a variety of ecological, social, and economic threats (Goodrich, J. et al., 2022b), and tiger conservation is one of the most complex contemporary conservation challenges – one that requires innovative and multifaceted solutions.

3.2.1 Demand for Tiger Products

Tigers have been coveted for various purposes for centuries (Moyle, 2009; Verheij et al., 2010; Wong, Ramacandra and Krishnasamy, Kanitha, 2019), and consumption of tiger products has fueled the steep decline of wild tiger populations (Goodrich, J. et al., 2022b). Though consumption estimates are dif cult to obtain, in the early 1990s around 4 tons of tiger bone (equivalent to 330-400 animals) was being consumed annually in China (Moyle, 2009). Estimated consumption rates vary drastically.

One study estimated that 1.9% of respondents in China consumed tiger products within a 12 month period (Anon, 2010), while another claimed that 43% of the population in China had consumed tiger products between 1993 and 2007 (Gratwicke, Mills, et al., 2008). A more recent study found 1% of people in Thailand owned or used tiger products (USAID Wildlife Asia, 2018). The wide range of these gures exempli es the challenges of collecting market data in this illicit economy (Hinsley and 't Sas-Rolfes, 2020; Moyle, 2009).

Consumption of tiger parts and products could be categorized into either health or wealth purposes, with nearly every part of a tiger being used including meat, skin, claws, teeth, and bones (EIA, 2017; Goodrich, J. et al., 2022b). One of the most demanded products, tiger bone, is used in both traditional Chinese medicine (TCM) and in the creation of tiger bone wine sold as a health tonic and as gifts (Stoner, Sarah et al., 2016). Tigers are also frequently used in live-animal tourism including cub petting as well as viewing and feeding of adult animals (EIA, 2017).

The illegal trade in tigers and their parts and products is transnational. Markets across Asia are supplied by wild tigers poached in countries such as India and Russia, and by tigers farmed in countries such as China, Thailand, and Lao PDR (EIA, 2017; Musing, 2020). The trade also extends to Europe (Stoner, Sarah et al., 2016), the Middle East, Africa, Australia and the United States. China is home to the largest market for tiger parts and products, with high demand for tiger in TCM and other high-end goods (Coals et al., 2020; Stoner, Sarah et al., 2016); though there may be recent declines in support for using tiger products by TCM practitioners (Liu et al., 2016). The international trade in tiger products has been of cially banned by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1987; however, the trade operates largely invisibly and is dif cult to monitor (Moyle, 2009) with high levels of corruption and weak law enforcement (Skidmore, 2021; Wong, 2016). Despite the of cial closure of the international trade in wild tigers, efforts have been made to meet persistent demand through both legal and illegal means.

3.2.2 The Debate Over Tiger Farms

In the 1980s, amidst the decline in wild tiger numbers, captive breeding of tigers emerged to address growing demand for tiger parts and derivatives. The Chinese government began the captive breeding of tigers in 1986 to supply their national market, with hopes that trade from captive animals would be legalized in China (EIA, 2013; Moyle, 2009). The number of tigers in farms continued to grow through at least the mid 2000s (Nowell and Xu, 2007; Stoner, Sarah et al., 2016). As of 2017, at least 7,000 tigers were estimated to be held in captive facilities (hereafter “tiger farms”) across Asia, catering to demands for various products ranging from tiger body parts and products to live tigers used for tourist attractions (EIA, 2017). Beyond these facilities, there are many more captive tigers held in zoos, sanctuaries and private households around the world (EIA, 2017; Musing, 2020),

including farms in Africa (Stoner, Sarah et al., 2016).

The domestic trade of tiger bones within China, the largest consumer market for tiger parts and products, was of cially closed in 1993 (Government of China, 1993). Yet, a domestic trade in captive-bred tiger bones and skins may persist (EIA, 2013; Kirkpatrick and Emerton, 2010; Moyle, 2009), despite a reduction in availability of tiger products for medicinal use (Nowell and Xu, 2007). In fact, at some of the larger farms, tiger products are sold publicly (perhaps with different labels) (Nowell and Xu, 2007). Though there may be a preference for farmed over wild tiger products (Coals et al., 2020; Gratwicke, Bennett, et al., 2008; Hinsley and 't Sas-Rolfes, 2020; Liu et al., 2016), availability and price play a large role in demand (Linkie et al., 2018) and it is unlikely that consumers can distinguish between captive or wild products (Gratwicke, Mills, et al., 2008). Additionally, a proliferation of fake products (Moyle, 2009; Nowell, 2000; Vipin et al., 2016) and pressure on other big cat species (Coals et al., 2020; Williams et al., 2017) suggests that demand for tiger bone and other products outweighs supply (Gratwicke, Mills, et al., 2008).

At least two competing arguments have emerged about the relationship between tiger farms and the poaching of wild tigers (Kirkpatrick and Emerton, 2010). The rst argument is that the desire for tiger parts is historical and cultural (and therefore inevitable), and that raising tigers in farms helps meet the existing demand and should therefore reduce the desire for wild tigers and associated poaching pressure (Abbott and van Kooten, 2011; Conrad, 2012; Jiang et al., 2007). The second argument is that the presence of farms normalizes the availability of tiger products for purchase, thereby increasing accessibility and leading to increased desire for tiger products (Gratwicke, Mills, et al., 2008). Both arguments are contested (Bulte and Damania, 2005; Gratwicke, Mills, et al., 2008), yet the question of whether tiger farms are a help or a hindrance to wild tiger populations has not been adequately addressed.

3.2.3 Using Systems Thinking to Understand Tiger Farms

While a growing body of research supports the idea that the illegal wildlife trade (IWT) is a complex system (Moyle, 2009; Oyanedel et al., 2021; 't Sas-Rolfes et al., 2019), much of the existing literature and public rhetoric frames tiger farms as a relatively simple “right” or “wrong”. However, because tiger farms are part of a larger system with multiple competing relationships and feedback loops, both of these narratives may be true. While most conservation organizations would like to see tiger farms closed for both ethical and ecological reasons (Rizzolo, 2020), the potential consequences of the closure of farming operations for wild tigers are not entirely clear (Kirkpatrick and Emerton, 2010; 't Sas-Rolfes, 2010).

In a simple system, it is often easy to predict the results of a single action. However, tiger conservation (like many conservation goals and challenges) is embedded in a complex dynamic system, where it is hard to know the long-term implications of actions, and knowledge is distributed

across many people and organizations. For example, while there has been some success in reversing the trend of wild tiger populations, increased law enforcement in some areas has forced remaining trade networks to adapt and become more ef cient at evading law enforcement (Skidmore, 2021). A more holistic view of the market, one that captures multiple social and ecological causal relationships simultaneously, is needed to critically evaluate policies across multiple dimensions. Systems thinking, applied through participatory modeling approaches, provide an opportunity to look at the problem in a more holistic manner.

Systems thinking is a way of thinking that recognizes inherent complexity and works to understand the structure of the system underlying problematic behavior, and not just individual parts (Meadows and Wright, 2008). There are many ways to practically apply systems thinking, one of which is the creation and use of causal-loop diagrams (CLDs). Co-creating a conceptual model such as a CLD brings diverse perspectives together in a productive environment (Stave et al., 2019), and building the diagram helps turn implicit into explicit knowledge so that participants are learning from each other and the model itself (Kopainsky et al., 2017). The world of tiger conservation is full of many diverse stakeholders, interests, and perspectives (Meacham, 1997). A CLD can serve as a boundary object that helps a group build trust and agreement through its creation (and the iterative revision process), while simultaneously advancing knowledge and understanding of important relationships between variables (Ballard et al., 2021; Black and Andersen, 2012; Black, 2013).

To address and adaptively manage the negative impacts of the IWT for tigers and other species, the conservation community needs to consider how larger systems impact the ef cacy of various policy approaches. While studies focused on the IWT and tiger conservation are relatively common (Goodrich, J. et al., 2022b; 't Sas-Rolfes et al., 2019), there is a gap in the literature (and our collective understanding) of these larger social-ecological systems and the multiple feedback mechanisms present. The overall objective of this research is to leverage systems thinking through the creation of a conceptual model, or CLD, that combines practitioner knowledge with existing science to clarify the causal relationships and feedback loops that connect tiger farms and wild tigers through the illegal wildlife trade. Using such an approach, we hope to better understand the potential rami cations of policies such as closing tiger farms.

3.3 Methods

3.3.1 Study Context: Focus on Tigers and Tiger Parts and Products

This study focuses on wild tiger populations across their current range in Bangladesh, Bhutan, China, India, Indonesia, Malaysia, Myanmar, Nepal, Russia, and Thailand (Goodrich, J. et al., 2022b). Though there are many subpopulations of tigers across the entire range, this study treats

all wild tigers as one contiguous population. While there are sources of captive tigers and other substitutable species in other regions such as in Africa (Stoner, Sarah et al., 2016), and consumer markets are also found in Europe and North America (Henry, 2020), we narrowed our focus to Asia where demand for tiger products and derivatives is the highest. For the purpose of this research, we are de ning a tiger farm as “a facility that keeps or breeds tigers in captivity with an intent (or reasonable probability) of supplying or directly engaging in the commercial trade in tigers or tiger products, be they live animals, body parts or derivatives. The application of this de nition is not limited by the stated purpose of such facilities.”

Although most parts of a tiger can be made into products, including skins, teeth, claws and meat, tiger bone is recognized as one of the most desired products currently in the market (Coals et al., 2020; Stoner, Sarah et al., 2016). Due to the complexity of the tiger market and the economic importance of bones and bone products, we decided to focus on the sale of bones in this research. This includes the use of bones in tiger bone wine and for other products such as tiger bone glue and plaster (Gratwicke, Mills, et al., 2008). Live-tiger tourism was also recognized as an important source of income (EIA, 2017) and potential driver of the breeding of tigers in larger farms, so we also included this source of farm income in our analysis.

3.3.2 Participatory System Dynamics Modeling Process

To understand the larger tiger conservation system, we used a participatory system dynamics (SD) modeling approach adapted to a completely virtual environment. We followed the approach in Rieder et al (2021), though our process was adapted to account for additional time needed for both conceptual model and simulation model development. This study took place over roughly two years, starting in January 2021 and ending in April 2023. Participants were invited to the study based largely on expertise in the illegal wildlife trade, tiger farms or trade, or tiger conservation. Four people formed an Advisory Group to guide the modeling process alongside the core research team, 12 people were invited to participate in a larger Modeling Group, and 59 additional people were invited to contribute as expert advisors in a Consulting Group. The modeling process involved a series of virtual workshops and meetings (Figure 3.1) to build both the conceptual CLD and, later, a simulation model to illustrate behavior within the system. The details of the simulation model, which quanti ed the CLD and allowed participants to test assumptions and some interventions, are beyond the scope of this paper and will be detailed in a later publication.

We implemented surveys with different groups at various stages during the process to maximize diverse input and allow for a greater number of voices into the modeling process. A pre- and post-process survey design was also used to evaluate the participatory SD process and social outcomes for the group (See Chapter 4). Two surveys were used in the construction of the CLD: one before the process began to better understand the problem(s) and challenges with tiger farms, and one

Figure 3.1: Project and research activities of the participatory SD modeling process conducted from 2020 to 2023.

mid-way through the process to gather feedback on preliminary structure and model components.

3.3.3 Conceptual Model Development

We began the participatory modeling process by working with the Advisory and Modeling Groups to identify a central problem statement ("Do tiger farms help or hinder wild tigers?"), which helped de ne the boundary of the system. An iterative participatory process followed to create the CLD (Rieder et al., 2021). Key elements were elicited through discussions at workshops and meetings, with opportunities to clarify de nitions and causal relationships. Variables were not restricted to those which are easily or already measured, and they were named without directionality ("price of bone" vs. "high price of bone"). In following best practices for SD modeling, we focused on de ning system components, causal relationships, and feedback loops rather than on identifying potential policy actions (Lindqvist et al., 2021).

Initial components of the model and problem de nition were drawn from open-ended survey responses in the pre-process survey ("From your perspective, what is the most important problem to address within this system?", "What factors are contributing to this problem?", "What is a possible solution to this problem? How do we x this?" and "What are the challenges in implementing this solution?") during workshops. This survey was distributed to 75 participants in Spring 2021 via

Qualtrics, with 50 responses for a 67% response rate.

A second online questionnaire was distributed in Spring 2022 to 58 participants via Qualtrics, with 26 responses (45% response rate). These survey questions were focused on verifying an initial, simpli ed conceptual model, reviewing components of the simulation model, and identifying historical trends over time in the following key variables: purchases of wild and farmed tiger parts and products, farmed tiger population, and poaching. Participants were given options for trends that followed common behaviors of complex systems (Sterman, 2000): s-shaped growth, exponential growth, exponential decay, oscillation, and overshoot and collapse. We recognize that survey responses are perceptions of historical behavior and may not re ect actual trends, yet when no other reliable data are available then expert opinion can be a helpful place to begin (Kuhnert et al., 2010; Luna-Reyes and Andersen, 2003).

3.3.4 Conceptual Model Analysis

Through the iterative process of creating and analyzing the CLD, we identi ed and labeled feedback loops and compared the structure to known archetypes of standard system behavior to gain insights for policy (Meadows, 1982). Additional analysis was done by qualitatively comparing the model to historical trends (or perceived trends) in key variables that emerged from initial modeling workshops to better understand structure and loop dominance. A trend that shifts from growth or decline to equilibrium (s-shaped growth) indicates a balancing loop(s) overtaking a reinforcing loop. Oscillations, which represent alternating periods of growth and decline in the system, are caused by balancing feedback loops with time delays in some relationships. A comparison of trends between variables in the CLD enabled us to highlight gaps in understanding and to identify unexpected elements and relationships that are not yet understood. The purpose of this paper is to illustrate how the participatory SD modeling process generated a comprehensive CLD that improved holistic understanding of the connection between tiger farms and wild tigers, providing a conceptual framework for future research and conservation action.

3.3.5 Assumptions

Given the complexity of this social-ecological system, we made a number of assumptions to keep the CLD as simple as possible. We assumed that all wild and farmed tigers each exist in one population. Given that smaller populations are more vulnerable to collapse (eAsh et al., 2022), we could underestimate any declines in wild tiger populations. Likewise, we tried to average across tiger farm operations, instead of breaking these down into size or country or other de ning characteristic. Although some farms may receive nancial support from external sources, we did not include that in uence in our model. We also chose to focus on tiger bone and live-tiger tourism at farms (without

integrating other forms of consumption), in order to simplify the economic dynamics of the model and facilitate conversations. Future iterations of this CLD could account for other tiger products and uses. Additionally, fake products (those without any tiger in them or from a domestic animal) and products from other species of big cat (such as lion or leopard) are left out of the model. We also omitted any cultural differences in preferences or behaviors among people in different countries or regions. We assumed that consumers can tell the difference between wild and farmed tiger products, even though this is unlikely (Gratwicke, Bennett, et al., 2008). We also assumed that price changes non-linearly with changes in supply and demand, though we recognize that this real-world market is complex (Bulte and Damania, 2005). Finally, we assumed that price is the main driver of poaching (Linkie et al., 2018), and we did not account for socio-economic factors related to local household income and human-wildlife con ict.

To complete our conceptual model, we also needed to reconcile differences in language as terms shifted slightly during the process. We considered the *Amount of Farmed Bone Sold* in the CLD (Figure 3.2) to correspond to the *Total Purchases and Purchases of Farmed Tiger Products* (Table 3.1). We considered the *Amount of Wild Bone Sold* in the CLD (Figure 3.2) to correspond to the *Total Purchases and Purchases of Wild Tiger Products* (Table 3.1). Likewise, we equate *Purchases of Farmed Tiger Products* (Table 3.1) to *Amount of Farmed Bone Sold* (Figure 3.2).

3.4 Results and Discussion

The full CLD developed by participants for the tiger conservation system includes loops devoted to wild tiger populations, farmed tiger populations, and interactions between the two (Figure 3.2). Detailed descriptions of selected variables and causal linkages are found in Table 3.2, with full descriptions of all causal linkages in Appendix B, Table B.1. The model incorporates 24 different feedback loops (Figure 3.2, Table 3.3) derived from behavior over time graphs that emerged from survey responses (Table 3.1). Each of these loops is explained in detail in Appendix B, Table B.2. The following sections describe perceived trends or reference modes, key variables (denoted in Italics) and feedback loops, and a discussion of the implications of trends in key factors and system structure.

3.4.1 Wild Tigers and Poaching

Following decades of decline, the wild tiger population (*Wild Tiger Population*) has begun to make a recovery in the last decade (Goodrich, J. et al., 2022a) (Table 3.1). A major cause of this decline and continued threat comes from poaching (Chapron et al., 2008; Goodrich, J. et al., 2022b), yet there is not range-wide poaching data or clear consensus about poaching trends in existing literature. Most participants in this study (>95%) did not think poaching is currently increasing, though the trend is

uncertain (Table 3.1). Forty-one percent of respondents think poaching has oscillated since 2000, meaning that overall poaching has not systematically increased or decreased, despite uctuations. Other respondents perceived that poaching initially grew and then either declined (32%) or leveled off (18%) since 2000. Available data from India supports a decline in poaching since 1995, with possibly a slight increase in the number of tigers killed in recent years (WPSI, 2023).

Underlying these trends, the Wild Tiger Population is affected by Wild Tiger Habitat and Prey Availability (B11), reproduction (R10), and poaching (B7). Habitat and prey improve the health and growth of the tiger population (Thapa et al., 2017), while poaching can lead to smaller tiger populations. Though we know there is high variability in the effectiveness of law enforcement and anti-poaching efforts, in the model increases in anti-poaching efforts result in lower poaching (Linkie et al., 2015). A lower (and therefore more endangered) tiger population will drive more attention and money to anti-poaching and other law enforcement activities designed to reduce poaching (B6) (GTRP, 2011). Changes in sales of wild tiger products (Amount of Wild Bone Sold) in uences the net bene ts to poaching, leading to changes in poaching driven by commercial markets (depending on law enforcement risks) (R2).

The steep decline in the wild tiger population suggests the dominance of reinforcing loops driving poaching (R2) and the pro tability of supplying wild tiger products to market (R8). Though not included as an exogenous variable in this model, degradation of tiger habitat and prey over this period also probably reduced tiger carrying capacity (B11) and reproduction (R10) (Goodrich, J. et al., 2022b). Although tigers' population decline was likely driven (at least partly) by poaching, we should expect poaching (the number of animals poached per year) to also be in decline. This is because of growing dif culty of nding and harvesting increasingly rare animals, on top of increasing conservation and anti-poaching efforts (B6). This trend is supported by existing data from the Wildlife Protection Society of India (WPSI, 2023) and is also similar to the oscillation perceived by survey respondents since 2000 (Table 3.1). A limited increase in wild tigers poached might be expected if there is an increase in poaching effort, however this would likely be short term given low overall population numbers.

Overall, the shifting trajectory of the wild tiger population, from decline to growth (Goodrich, J. et al., 2022a), indicates a shift where births outnumber deaths. This could be due to conservation efforts that have improved or stabilized habitat and prey availability (B11), as well as enhanced law enforcement and other efforts to reduce poaching (B6) (Goodrich, J. et al., 2022a). Market in uences, such as a reduction in the amount of wild bone desired, could have also weakened the reinforcing loops responsible for the tiger's decline (e.g. R2, R8). Or it might represent a shift of pressure from wild to captive sources described in more detail below.

Figure 3.2: Causal-loop diagram (CLD) of the connections between farmed and wild tigers. Green represents wild tigers, orange represents farmed tigers and Blue represents summary variables from both sources. Feedback loops are labeled with a brief description and whether they are balancing (B) or reinforcing (R).

Table 3.1: Hypothesized dynamic behavior over time (or reference modes) for key variables identi ed and validated during the modeling process. Validation included through participant survey [A], literature [B] (reference included), and available datasets [C]. Given poor data and high uncertainty in this system, multiple options are given for some variables. Adapted from Lindqvist et al. (2021).

Variable	Hypothesized Behavior Over Time	Description
Wild Tiger Population		This trend was not elicited through our survey, however was pulled from the best available data (Goodrich, J. et al., 2022a). Since 2000, tiger numbers most likely declined until roughly 2010, when they began to stabilize and possibly increase slightly. Validation: B (Goodrich, J. et al., 2022a)
Poaching		Opinions varied, however an oscillation trend received the most support (41%), with others perceiving that while poaching initially grew, it stabilized (18%) or fell (32%) after 2000. Validation: A, C (WPSI, 2023)
Farmed Tiger Population	(a) (b)	The majority of respondents were divided on the trend in the farmed tiger population, with 30% believing that the farm population has (a) grown since 2000 and 30% believing the population has (b) leveled off in s-shaped growth. Validation: A, C (personal communication, Environmental Investigative Agency)
Total Purchases		Respondents were asked whether they believed the purchase trends for farmed and wild products where the same, and 43% of respondents thought the trends over time were the same or weren't sure they were different (n=10). And 50% of those respondents thought purchases of tiger products oscillated since 2000, while 20% thought purchases grew and then declined (overshoot and collapse). Validation: A
Purchases of Wild Tiger Products	(a) (b)	There was a wide variety of responses for perceptions of historical purchases of wild tiger products, for those who believed farmed and wild products followed different trends (n=13). There was less support for either growth, s-shaped growth, or oscillation of purchases (15% each). Most respondents thought purchases are currently declining (46%), either following a trend of (a) overshoot and collapse (23%) or (b) continual decline (23%). Validation: A
Purchases of Farmed Tiger Products		There was more consensus around the trends for farmed product purchases, for those who believed farmed and wild products followed different trends (n=13). There was relative consensus (62%) on the growth in the purchases of farmed tiger products, with fewer respondents (23%) feeling that purchases have leveled off (s-shaped growth). Validation: A

Table 3.2: Key variables with de nitions and causal relationships with polarity for tiger farms and wild tigers. Adapted from Lindqvist et al. 2021. Arrows denote direction of causal relationships, with solid arrows representing a positive polarity relationship and dotted arrows denoting a negative polarity relationship. See Table B.1 for a complete list of variables.

Variable (in italitcs, with de nition)	Polarity	Causal Relationship
	Wild Tigers	
Wild Tiger Population: This is the total population of wild tigers, including all sub-populations across all range states.		Wild Tiger Habitat and Prey Availability Wild Tiger Births Anti-Poaching and Other Law Enforcement Capacity Wild Tigers Poached with Parts Harvested
Wild Tiger Births: The number of wild tigers born each year.		Wild Tiger Population
Wild Tiger Habitat and Prey Availability: This is the total available habitat and prey for wild tigers.		Wild Tiger Population
Anti-Poaching and Other Law Enforcement Effort: The effort put into anti-poaching and other law enforcement activities to protecting wild tigers from poaching.		Wild Tigers Poached with Parts Harvested
Net Bene ts to Poaching: This is the bene ts minus the costs of poaching wild tigers for trade.		Wild Tigers Poached with Parts Harvested
Wild Tigers Poached with Parts Harvested: These are the total wild tigers poached, whose bones end up in trade.		Wild Tiger Population Wild Tiger Bone Supply
	Tiger Farms	
Total Tigers Farmed: The number of tigers being kept in tiger farms, from cubs to mature animals.		Tiger Harvest Farm Tiger Births Space and Food for Farming Tigers Farm Tourism

Continued on next page

Table 3.2: Selected feedback loops identified through the modeling process and the dynamic behavior they generate. (continued)

Variable (in italics, with definition)	Polarity	Causal Relationship
Farm Tiger Births: Total number of tiger births in tiger farms.		Total Tigers Farmed
Costs of Tiger Farms: The money that farms must spend to manage their tigers.		Farm Profit
Space & Food for Farming Tigers: Amount of space and food available to manage tigers in farms.		Total Tigers Farmed
Tiger Harvest: Total numbers of tigers being harvested from farms, with parts available for trade (includes natural mortality).		Farmed Tiger Bone Supply Total Tigers Farmed
Farm Profit: Income made by farms from bone sales and tourism, minus costs of management.		Farm Tiger Births Need to Harvest Tigers to Save Money
Farm Tourism: Amount of tourism for people to interact with live adult tigers or cubs.		Farm Profit
Tourism Availability: Interest in tiger tourism and capacity of farm to host tourism activities.		Farm Tourism
Need to Harvest Tigers to Save Money: The need farmers have to reduce costs to save money when profit is low.		Tiger Harvest

3.4.2 Tiger Farms

The number of tigers living in farms grew rapidly following the introduction of farms in China in the late 1980s (Nowell and Xu, 2007; Stoner, Sarah et al., 2016), yet since the mid-2000's the population growth of farmed tigers (*Total Tigers Farmed*) may have slowed according to data collected by the Environmental Investigative Agency (personal communication). However, information about smaller farms, which could still be growing, is missing. We asked participants about the farmed tiger population since 2000 and the majority of respondents were divided between believing that farm populations have continued to grow (30%) and believing that populations followed s-shaped growth (30%) (Table 3.1).

The number of tigers kept in farms is determined by breeding (*Farm Tiger Births*), Space &

Food for Farming Tigers, and the amount of Tiger Harvest. Given persistent demand for tiger parts and products, the number of tigers harvested is determined by how many tigers are in a farm and whether the farm needs to cut costs. The more pro table a farm is, the more tigers will be bred and harvested for further pro t (R1) and consumption (R7). Farm Tourism (R6) provides additional revenue to some farms through tiger-based tourism.

Overall, growth in farmed tiger populations re ects the dominance of reinforcing loops of increasing pro tability of farming for bones (R1) and consumption of farmed bone (R7). If farmed populations of tigers continue to grow, we can also expect purchases to increase as these reinforcing loops remain strong. Fitting with this expectation, the continued growth of purchases was supported by 62% of respondents (Table 3.1). Both the growth in tiger farm populations and in purchases of tiger farm products is supported by literature (Nowell and Xu, 2007; Stoner, Sarah et al., 2016), however data on both farm populations and purchases are limited.

Alternatively, if growth of farm populations has slowed down or reached an equilibrium (Farmed Tiger Population, Table 3.1), this indicates a shift in loop dominance to balancing loops stabilizing harvest (B8) and/or slowing down breeding to reduce costs (B7). The farmed tiger bone market could be reaching an equilibrium between what people are willing to pay and how much it costs to raise tigers (involving B10, B2, B4-F and B5-F). It is also possible that the supply of tiger bone is starting to meet the amount of bone desired (B14), leading to a cooling of the market and weakening of the reinforcing loops driving increased consumption (R1, R7). A decrease in the Social Desire for Bone for Medicinal and Cultural Reasons or an increase in the Perception of Legality and Risk of Punishment for Farmed Bone may be in uencing this change, or even increased access to alternative products. This shift could also indicate market constraints such as limited Space and Food for Farming Tigers (B11). However, if the farmed tiger population has stabilized while purchases have continued to grow, several things might be happening. First, products sold above the current harvest might come from an external source such as lion or leopard (Williams et al., 2017) or fake products (Moyle, 2009). Second, the initial growth of farmed tigers was faster than sales and farm bone accumulated in stockpiles (Nowell and Xu, 2007), which are now being used to meet a continued growth in purchases.

3.4.3 The Tiger Bone Market: Connecting Wild and Farmed Tigers

Various studies have reported growth of demand in the international tiger trade (EIA, 2017; Linkie et al., 2018), but very little data or literature exists to support this. It is often impossible to collect sales data in this illegal market as a measure of demand (Moyle, 2009; Veríssimo and Wan, 2019), so we gathered expert perceptions of the historical trends in purchases of both wild and farmed tiger products (Table 3.1). Forty-three percent of respondents either weren't sure whether the trends in wild and farmed tiger products were different or believed they were the same. Of that group, 50%

perceive that purchases of both farmed and wild have oscillated since 2000. Among respondents who thought there was a different trend between farmed and wild purchases (57%), there was relative agreement on the growth of farmed tiger products (62%). We found less consensus about the behavior of wild bone purchases, with 43% of respondents believing purchases are currently declining, with another 13% believing that purchases had grown and then stabilized (s-shaped growth). Though uncertain, these perceptions are a starting point for us to learn more about the system.

We established a similar market structure for both farmed and wild tiger products (Figure 3.2), with effective and latent demand (Thomas-Walters et al., 2021; Veríssimo and Wan, 2019) expressed through *Amount of Farmed/Wild Bone Sold* and *Desired Amount of Farmed/Wild Tiger Bone*, respectively (Figure 3.2, Table 3.2). Sales of farmed bone drive the pro tability of tiger farms while sales of wild tiger bone increase the net bene ts to poaching, therefore increasing supply and availability of bone from the respective sources (R1, R2, R7, R8). The choice in purchasing farmed or wild tiger bone is determined by four factors: (1) relative availability between products (*Relative Availability of Wild Over Farmed Bone*) (Anon, 2010), (2) social preference between bone types (*Social Preference for Wild Over Farmed Bone*) (Helinsley and 't Sas-Rolfes, 2020), (3) perception of legality and risk of punishment (*Perception of Legality & Risk of Punishment for Farmed/Wild Bone*) (Anon, 2010; Wong, 2016), and (4) the price of bone (*Price of Farmed/Wild Bone*) (Anon, 2010; Linkie et al., 2018). Balancing feedback to resist market growth comes through price in the model. If the supply of tiger bone increases relative to the amount of bone desired, then the price of bone (*Price of Farmed/Wild Bone*) will drop and consumption (*Amount of Farmed/Wild Bone Sold*) will increase (B1, B2, B4-F/W, B5-F/W). If the bone supply drops (such as from a lower *Wild Tiger Population*) the price will rise and incentives to poach (Linkie et al., 2018) or raise more tigers in farms will increase. Overall, the greater availability of either farmed or wild bone leads to more sales and creates more incentive for either tiger farms or poaching as long as the demand for tiger bone (or other products) is greater than supply. In addition, if the *Total Bone Supply* drops below the *Total Bone Desired*, which is currently likely (Gratwicke, Bennett, et al., 2008), then the *Unmet Demand* will increase and put more pressure on nding alternative sources such as products from other species (Williams et al., 2017), tiger farming in cheaper locations (Williams, 2015), or fake products (Vipin et al., 2016).

The CLD provides support for contrasting arguments regarding tiger farms. The argument that tiger farms increase demand for both farmed and wild tiger parts by fueling a greater *Acceptability of Bone Purchase* through word-of-mouth (Anon, 2010; Kirkpatrick and Emerton, 2010), which leads to more *Total Potential Consumers* of tiger bone (assuming satis ed customers), is part of multiple reinforcing feedback loops in the model (R4, R5, R3-F and R3-W). In contrast, the argument that farms reduce pressure on wild tigers by providing an alternative supply of bone (and other

products)(Jiang et al., 2007) is captured in Tiger Harvest, increasing Farmed Tiger Bone Supply, which increases the relative availability of farmed bone for purchase, increasing the Consumers Choosing Farmed Tiger Bone and Amount of Farmed Bone Sold. Multiple feedback loops (R1, R7) grow this in uence and there is support for the hypothesis that product availability is a strong determinant of purchase.

Supply of bone should mirror changes in populations of farmed tigers and related harvest and sales. Similarly, the number of wild tigers poached should follow the population of wild tigers. We would expect the supply of farmed tiger bone to be increasing as long as more tigers are being bred and harvested in farms. Likewise, as long as the wild tiger population is declining, we should expect the supply of wild tiger bone (and other products) to be declining. If stockpiles are accumulating tiger bone from either source, as seen historically (Nowell, 2000), this indicates that more supply is entering the market than is being purchased, either due to changing consumer desires, efforts by traders to control price (Bulte and Damania, 2005), or expectations of increased future demand (Moyle, 2009).

In summary, as the number of tigers in farms has grown, purchases of farmed tiger bone and other products have also likely grown (Table 3.1), as seen by an increasing portion of tiger products seized from captive sources (Stoner, Sarah et al., 2016). The opposite seems likely for wild tigers: a decline in wild tiger populations, coupled with increased law enforcement, has presumably led to a decline in availability and purchase of wild tiger products (Nowell and Xu, 2007). If we frame wild and farm tiger bone as two competing products for the same market, we see that this dynamic follows the “Success to the Successful” systems archetype (Meadows, 1982; Senge, 1990). This means that the development of tiger farms, leading to growing sales of farmed bone, increases the dominance (or success) of the farmed bone product in the market (and vice versa). The growth in the farmed tiger market, in both the number of farmed tigers (now larger than the number of wild tigers) and the reported growth in the purchases of farmed tiger products, supports the notion that there has been a shift from wild to farmed tiger products dominating the market (not including alternative sources). Removing tiger farms from this market under these dynamics, could lead to signi cant and unexpected consequences if the desire for bone and other tiger products remains the same.

Table 3.3: Selected feedback loops identi ed through the modeling process and the dynamic behavior they generate. Relevant loops are shown here for illustrative purposes, see Appendix B (Table B.2) for a complete list of feedback loops. Adapted from Lindqvist (2021).

Loop	Description
	Reinforcing Loops: Loops that result in growth or decline in behavior.
R1: Farming for Tiger Bones	Causal chain: Amount of Farmed Bone Sold Farm Pro t Farm Tiger Births Total Tigers Farmed Tiger Harvest Farmed Tiger Bone Supply Amount of Farmed Bone Sold Behavior: If the amount of farmed bone sold increases, this will increase farm pro t. The increased pro t is used to breed more tigers and the farm tiger births increases over time, increasing the total tigers farmed. More tigers farmed increases the tiger harvest and the farmed tiger bone supply. With more bone available, the amount of farmed bone sold will increase, further increasing the farm pro t.
R2: Poaching for Wild Tiger Bone	Causal chain: Amount of Wild Bone Sold Net Bene ts to Poaching Wild Tigers Poached with Parts Harvested Wild Tiger Bone Supply Amount of Wild Bone Sold Behavior: If the amount of wild bone sold increases, then the net bene ts to poaching increases and poaching is further incentivized leading to increase in the wild tigers poached with parts harvested. More tigers poached increases the wild tiger bone supply and the amount of wild bone sold.
R3 (W and F): Impact on total demand from bone	Causal chain: Consumers Choosing Wild/Farmed Tiger Bone Desired Amount of Wild/Farmed Tiger Bone Amount of Wild/Farmed Bone Sold Acceptability of Bone Purchase Total Potential Consumers Consumers Choosing Wild/Farmed Bone Behavior: This loop is the same for both farmed and wild bone markets. If the consumers choosing tiger bone (wild or farmed, respectively) increases, the total desired amount of tiger bone and the amount of bone sold (assuming availability) increases. Increased sales results in an increase over time in the social acceptability of bone purchase and therefore an increase in the total potential consumers and the consumers choosing tiger bone (wild or farmed, respectively).

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Table 3.3: Selected feedback loops identi ed through the modeling process and the dynamic behavior they generate. (continued)

Loop	Description
R7: Consuming and supplying bone from farming	Causal chain: Relative Availability of Wild Over Farmed Bone Consumers Choosing Farmed Tiger Bone Desired Amount of Farmed Tiger Bone Amount of Farmed Bone Sold Farm Pro t Farm Tiger Births Total Tigers Farmed Tiger Harvest Farmed Tiger Bone Supply Relative Availability of Wild Over Farmed Bone Behavior: If there is more farm bone available and the relative availability of wild over farmed bone decreases, then the number of consumers choosing farm tiger bone increases. This increases the desired amount of farmed tiger bone. If there is bone available in the farm tiger bone supply, then the amount of farm bone sold increases. This increases the farm pro t and the farm tiger births and total tigers farmed increases over time. An increase in tigers farmed increases the tiger harvest and the farmed tiger bone supply, decreasing the relative availability of wild over farmed bone.
Balancing Loops: loops that result in equilibrium or reaching a goal, oscillation is common.	
B1: Impact of wild bone price on poaching	Causal chain: Total Bone Supply Gap Between Bone Desired and Supply of Bone Price of Wild Bone Net Bene ts to Poaching Wild Tigers Poached with Parts Harvested Wild Tiger Bone Supply Total Bone Supply Behavior: If the total bone supply increases, the gap between the bone desired and the supply will be reduced (assuming more bone is desired than in the supply). This reduction over time will cause a drop in price of wild bone to encourage more consumption. The lower price of products will decrease the net bene ts to poaching and reduce the number of wild tigers poached for their bone, therefore reducing the wild tiger bone supply and the total bone supply.
B5 (W & F): Impact of bone price on total bone demand	Causal chain: Price of Wild/Farmed Bone Desired Amount of Wild/Farmed Tiger Bone Total Bone Desired Gap Between Bone Desired and Supply of Bone Price of Wild/Farmed Bone Behavior: This loop is the same for both farmed and wild bone markets. If the price of bone increases (for either wild or farmed bone), then the desired amount of bone will decrease. With a smaller amount of bone desired, the gap between bone desired and supply of bone will decrease, and the price of bone will decrease.

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Table 3.3: Selected feedback loops identi ed through the modeling process and the dynamic behavior they generate. (continued)

Loop	Description
B6: Anti-poaching effort	Causal chain: Wild Tiger Population Anti-Poaching and Other Law Enforcement Effort Net Bene ts to Poaching Wild Tigers Poached with Parts Harvested Wild Tiger Population Behavior: If the wild tiger population falls, then (after a delay) anti-poaching and other law enforcement efforts to protect tigers will increase, which will decrease the bene ts to poaching and the number of tigers poached.
B14: Farmed bone consumption	Causal chain: Farmed Tiger Bone Supply Relative Availability of Wild Over Farmed Bone Consumers Choosing Farmed Tiger Bone Desired Amount of Farmed Tiger Bone Amount of Farmed Bone Sold Farmed Tiger Bone Supply Behavior: If the farmed tiger bone supply increases, then there is more farmed bone relative to wild bone, which increases the number of consumers choosing farmed tiger bone. This increases the desired amount of farmed tiger bone, and if there is bone available, then the amount of farmed bone sold increases. Selling bone results in a short-term decrease in the farmed tiger bone supply.

3.5 Implications

The IWT that connects tiger farms to the poaching of wild tigers has long been recognized as complex and dynamic (Bulte and Damania, 2005; Moyle, 2009; Phelps et al., 2016). Our application of systems thinking tools helped make sense of this complexity. Although nding reliable data related to tiger markets and the tiger trade is challenging (Moyle, 2009), a conceptual CLD allowed us to explicitly combine existing research with practitioner knowledge to better understand this complex market to improve conservation policy and research.

3.5.1 Policy Implications

We set out to understand whether tiger farms were helping or hurting wild tiger populations. While most conservation organizations and professionals would like to see tiger farms closed (EIA, 2017; Rizzolo, 2020; World Wildlife Fund, 2021), perhaps unsurprisingly, tiger farms likely have both positive and negative effects on wild tigers. Systems thinking and the use of tools such as the CLD allow us to better understand these effects and the risks of closing tiger farms. Our diagram generally supports escalating concerns that there could be risk to wild tiger populations in closing tiger farms (Rizzolo, 2020; 't Sas-Rolfes, 2010).

The conceptual model supported our expectation that tiger farms encourage purchasing through increased acceptability or popularity of tiger products. People who purchase tiger products often know other consumers (Anon, 2010) and so purchases may increase desire for whatever product has been bought (either farmed or wild) and acceptability for tiger products overall (Linkie et al., 2018). The strength of the impact of increasing purchases of farmed bone on wild tigers would depend on the strength of social preference and the difference in acceptability (including perceived legality and risk of punishment) between farmed and wild tiger products. However, the greater access and availability of farmed bone may supersede preferences for wild tiger bone (Linkie et al., 2018). With over 7,000 tigers in farms across Asia (EIA, 2017), farms can produce more tigers than could be poached from the smaller wild population. The success of farms has likely led to a growing share of the market to be met by farmed products (Stoner, Sarah et al., 2016) (not counting alternatives), perhaps drawing consumption away from wild tigers.

If farms are closed, our model suggests that removing their important products from the market could have detrimental effects for wild tigers if demand shifts from farmed to wild tigers. Without available farmed tigers, tiger bone consumption could shift to wild sources or spill over into other species, as has already been documented (Williams, 2015). Making this danger even greater in the short term are dynamics such as option demand, when consumers purchase more than their current need to stockpile for future access (Moyle, 2009). This has been seen with increased trade in species in the period before a ban goes into effect, such as with Kleinmann's tortoises and Geoffroyi

cats (Rivalan et al., 2007). We are not encouraging the expansion or legalization of the captive breeding of tigers for consumption, given that this could undermine the trade ban in reducing product availability (Nowell and Xu, 2007) and encourage an increase in potential customers who are currently dissuaded by the stigma of purchasing illegal products (Fischer, 2004) However, our conceptual model clearly supports a focus on consumer behavior change and demand reduction advocated by others (Thomas-Walters et al., 2021; Veríssimo and Wan, 2019).

Given the historical cultural signi cance of tigers and the consumption of wildlife, there will probably always be demand for wild tiger products. Though not included explicitly in this model, the rarity of wild tigers may increase desirability of tigers and tiger products through the anthropogenic allee effect (Courchamp et al., 2006; 't Sas-Rolfes et al., 2019), which likely has a positive in uence on the demand for tiger bone. Yet, the endangered status and conservation focus of wild tigers already may have reduced consumer demand and support from the TCM community (Anon, 2010; Moyle, 2009). To reduce the negative impacts of the IWT on wild tigers, conservation strategies should focus on reducing need and desire for tiger products for both medicinal and wealth purposes (Thomas-Walters et al., 2021). Reducing overall desire for tiger products, whether they are wild or farmed, might also have the bene t of reducing pro tability of farming tigers and lead to a natural shrinking of farm operations.

3.5.2 Future Research

Given the complexity of the socio-ecological system connecting farmed and wild tigers, it is impossible to capture all the nuances that affect real-world tiger conservation efforts. However, conceptual models can help us distill major dynamics from noise and improve our understanding as to what might happen under different policy scenarios. Taking such a holistic view using systems thinking and modeling also provides critical insights for future research.

There are a few important limitations of our CLD that could in uence outcomes suggested in this paper and underscore important directions for future research. To reduce complexity, we simpli ed our model to focus speci cally on one prominent tiger product: tiger bone. The inclusion of other tiger products (e.g. skins, teeth and claws) along with substitutions from other species into this system might alter dynamics and should be explored. Additionally, we did not include a detailed exploration of competing consumer preferences for either wild or farmed tiger products, and it would be valuable to explore consumer motivations (Thomas-Walters et al., 2021) and the extent to which people would be (un)willing to switch between farmed and wild products as seen in other species (Davis et al., 2022). Finally, given the complexities in the tiger trade (Abbott and van Kooten, 2011; Bulte and Damania, 2005), further exploration of the relationships between price, bone supply, and demand (amount of bone desired and amount purchased) could help to inform a more comprehensive understanding of the system.

No conceptual model can fully represent the complexity of the real world, especially in systems such as the IWT where data are limited. Yet, this effort highlights the importance of trend data (Goodrich, J. et al., 2022a), the role that expert opinion could play in lling in gaps, and highlights important variables beyond tiger populations. Given the amount of “noise” in any dynamic system, the numeric quantity of any variable at one point in time tells us very little about how a system works or how to solve complex problems. Long term trends give us insights as to what is happening beneath the surface of complex systems, inclusive of time delays and feedback, yet we are largely lacking in consistent data collection in key variables. While a focus on improving the rigor of our data collection methods is important, it can reduce the ability to reliably compare numbers across years (Goodrich, J. et al., 2022a). Conservation needs to balance these trade-offs to prioritize nding creative and consistent methods of collecting long-term trend data to encourage long-term problem solving that reduces the risk of unintended consequences.

Our CLD provides a starting conceptual framework that can guide future research priorities and foster constructive conversations to improve understanding of how tiger farming affects wild tiger conservation. We hope that future efforts can improve and build on this model, perhaps applying it to other species as well. Conversion of this qualitative conceptual model into a more quantitative simulation model, which can provide further insight into leverage points and the relative strengths of relationships and feedback loops, would aid future decision-making and policy development related to tiger conservation. Overall, our study demonstrates how tools like participatory SD modeling can provide methods appropriate for the complexity that exists in the real world (Mahajan et al., 2019; Rieder et al., 2021), ultimately fostering collaboration and integration of diverse perspectives and insights to address wicked conservation problems.

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CHAPTER 4

The Social Bene ts of Participatory System Dynamics Modeling in a Wildlife Conservation Context

4.1 Abstract

Traditional conservation planning tools rarely capture the complex behavior of social-ecological systems, suggesting the need for different tools and approaches to avoid unintended consequences and solve wicked problems. Conservation organizations around the world are therefore adopting systems thinking and related approaches to improve evidence-based decision making and problem solving. One complex system where systems thinking could be especially valuable is the illegal wildlife trade, and speci cally connections between captive breeding or farming of tigers and wild tiger conservation. Participatory system dynamics (SD) modeling is one approach that could improve participant understanding, enhance strategy development, and provide social bene ts to groups working together. Yet, more rigorous evaluation of this method is needed. In this study, we used mixed-methods evaluation involving pre-post surveys, key informant interviews, and researcher observations to assess the social bene ts of a 2021-2023 virtual participatory SD process with 49 subject matter experts (27 of whom completed pre-and post-process questionnaires) spanning diverse and global perspectives from around the world. We found that participatory SD changed beliefs about the threats farms pose to wild tiger populations; while participants did not perceive tangible shifts in thinking, they said that the process provided evidence-based insights into causal-relationships and feedback in the system. Although participants appreciated the opportunity to talk, learn, and collaborate with other experts, changes in trust among participants were minor. The process was

long and intensive, but participants reported nding an increased value in systems thinking and an appreciation for participatory SD modeling after participating. Compared to a peripherally-engaged Consulting Group (n = 19), participants in the more frequently-engaged Modeling Group (n = 9) generally reported higher collaboration, consensus and overall perceived value of the process. This study provides a rigorous framework for evaluating participatory SD modeling approaches and provides support for the use of such approaches for improving understanding, collaboration and trust, and consensus building in conservation.

4.2 Introduction

Making decisions within complex social-ecological systems is challenging, and often requires operating with a lack of information and high uncertainty (Coals et al., 2019). Often the most obvious solutions are not solutions at all, and they could even make problems worse (Forrester, 1971; Meadows, 1982). With increasing emphasis on evidence-based decision making in conservation contexts (Salafsky et al., 2019), we need participatory processes to enhance frequent and iterative communication between researchers, managers and decision makers, as well as to mobilize knowledge in a way that is action-oriented and appropriate (Cook et al., 2013; Kadykalo et al., 2021; Sutherland et al., 2004). Despite these goals, there is often a gap between information and action (Cook et al., 2013; Kadykalo et al., 2021; Knight et al., 2008; Lauber et al., 2011), which is exacerbated in complex systems where it becomes more dif cult to understand implications of available data (Forrester, 1971). Furthermore, human behavior is not purely rational and never based on information alone (Heberlein, 2012; Kollmuss and Agyeman, 2010; Steg and Vlek, 2009). In conservation, where a multitude of actors and organizations with different values and political priorities are constantly interacting, it can be challenging to develop a shared vision and direction. Traditional conservation planning tools rarely account for all of these potentially in uential factors and typically fail to adequately capture the complex behavior of systems (Game et al., 2014; Mahajan et al., 2019; Polasky, 2006). New tools and approaches are needed that address both dynamic complexity and support the social process of understanding and decision making that lead to more sustainable action (Mahajan et al., 2019).

Participatory modeling can be a particularly valuable tool in complex social-ecological systems, where high levels of uncertainty and con icts abound (Kimmich et al., 2019). One well-established participatory modeling approach to decision making in complex environments is participatory system dynamics (SD) (Rouwette et al., 2002; Scott et al., 2016b; Stave, 2002, 2010; Voinov and Bousquet, 2010). Participatory SD involves the collaborative building of conceptual causal-loop diagrams (CLDs) (Chapter 3) and computer simulation models to better understand a problem and potential policy solutions (Stave, 2010; Sterman et al., 2013; B. L. Turner, 2020). The use of SD is

increasingly common in elds such as business (Rouwette et al., 1998; Sterman, 2000) or health (Appel et al., 2019; Currie et al., 2018), but there are fewer examples of its use in conservation or natural resource management (Beall and Zeoli, 2008; Kopainsky et al., 2017; Stave, 2002; B. Turner et al., 2016). Social bene ts of participatory SD, and other related approaches, have been documented (Király and Miskolczi, 2019; Rouwette et al., 2002; Scott et al., 2016b; Stave et al., 2019). Yet, opportunities for rigorous evaluation of the broader social and decision-making impacts of this approach are rare. Furthermore, while traditional participatory SD modeling has focused on in-person interaction, the use of virtual tools in the facilitation space is limited, but growing especially in the wake of the COVID-19 pandemic (Wilkerson et al., 2020; Zimmermann et al., 2021). Virtual tools may be especially useful for international collaborations where spatial and temporal distances preclude regular face-to-face meetings (Zimmermann et al., 2021). However, the broader social impacts of modeling in a virtual environment remain largely untested, and there is a need to assess the ef cacy and practical utility of this form of participatory SD modeling to address complex conservation problems (Zimmermann et al., 2021).

The collaborative process of building a systems model effectively combines existing scienti c research with less formal knowledge sources (Beall and Zeoli, 2008; Rouwette et al., 2016; Stave, 2010). Co-creation of SD models improves communication between people with diverse perspectives more effectively than some traditional facilitation approaches (Rouwette et al., 2011; Stave et al., 2019). Creation of either a qualitative or quantitative model necessitates turning implicit knowledge and mental models into explicit knowledge through the iterative process of clarifying and de ning variables and causal relationships, so that participants are learning from each other and the model itself (Kopainsky et al., 2017; Sedlacko et al., 2014); this may increase knowledge and insights among participants (Király and Miskolczi, 2019; Kopainsky et al., 2017; Rouwette et al., 2002) and yield greater individual insights (Black and Andersen, 2012; Rouwette et al., 2002; Scott et al., 2017). By improving knowledge and understanding of a problem, a co-created model may also improve decision making (Stave et al., 2019); yet more evaluative research is needed to document the bene ts of these time-intensive approaches.

Evidence suggests the participatory model building process can also increase the social capital of a group in multiple ways (Fisher et al., 2019; Király and Miskolczi, 2019), helping to generate bene ts that extend beyond knowledge gains. By improving communication and strengthening relationships among key stakeholders (Beall and Zeoli, 2008; Stave, 2010), model building can enhance trust and foster collaboration. By serving as boundary objects, SD models can help build trust and consensus through their collaborative creation and repeated revisions (Ballard et al., 2021; Black, 2013). There are multiple dimensions of trust relevant for collaborative natural resource management (Stern and Coleman, 2014). Procedural trust (trust in rules or procedures) and af nitive trust (feelings of connection between actors) may be particularly key considerations in collaborative

modeling processes. Participatory SD modeling can become even more valuable when a conceptual model is converted into a simulation model, where dynamic and live action enhances participants' ability to visualize, test and re ne policies (Stave, 2002; B. L. Turner, 2020). This can provide a platform for building shared mental models (Scott et al., 2016a) that lead to shared visions and consensus (Rouwette et al., 2002; Stave, 2002). Through this iterative and holistic process, participants can develop a greater commitment to a strategy (Basco-Carrera et al., 2017; Rouwette et al., 2002; Scott et al., 2016b) and feel more empowered to act or support a particular intervention (Basco-Carrera et al., 2017). While all of these social bene ts are possible in participatory modeling, few studies have systematically operationalized and evaluated them in a conservation context. Our study sought to ll that gap in one especially complex and controversial system: tiger conservation.

Tiger conservation represents a dynamic conservation problem where participatory SD could be valuable. Tigers are one of the most charismatic (Albert et al., 2018) and endangered animals in the world, with only approximately 4,500 wild tigers remaining in the wild (Goodrich, J. et al., 2022a) in less than 7% of their historic range across Asia (Dinerstein et al., 2007). Tigers are threatened primarily by habitat loss and poaching, in addition to threats from human-tiger con ict and reductions in prey base (Goodrich, J. et al., 2022b). Poaching is driven by demand from an illegal consumer market for tiger parts and products used for medical and cultural purposes (Stoner, Sarah et al., 2016) as part of the illegal wildlife trade (IWT). This trade may be exacerbated by the captive breeding and farming of tigers for their parts and products in countries such as China and Thailand (EIA, 2017). Disagreement and uncertainty surrounds the overall impact of tiger farms on wild tigers (Abbott and van Kooten, 2011; Bulte and Damania, 2005), but - despite this uncertainty - most conservation organizations and experts want to close or phase out tiger farms (EIA, 2017; Rizzolo, 2020). Evidence-based decision-making regarding the future of tiger farms is dif cult, however, because tiger conservation is a contentious arena where data collection is challenging or even impossible (Meacham, 1997; Moyle, 2009). To enhance decision making capacity in this environment, an SD approach that improves knowledge and policy insights as well as relationships between conservation practitioners could be especially important (Beall and Ford, 2010; Rieder et al., 2021). But can participatory SD modeling effectively accomplish all of these concurrent goals?

Over a two-year period, we worked with conservation practitioners around the world to collaboratively build an SD model to better understand the relationships between tiger farms and wild tigers. In this study, we used a mixed-methods approach to explore to what extent this iterative process of participatory model building improved collective knowledge and understanding, helped build trust and collaboration, and ultimately catalyzed consensus and commitment surrounding the issue of tiger farms (see Figure 4.1). To do this, we evaluated the SD modeling process with four objectives in mind. First, we sought to measure changes in knowledge and understanding to see

if participation in the process transformed the way people thought about the tiger farm problem. Second, we measured trust and collaboration to see if participation in the process strengthened relationships and affected the way people interact to solve the problem. Third, we measured consensus and commitment following participation to see if the project affected people's agreement about the problem and commitment to any future conservation actions. Fourth, we sought to characterize the process as a whole to assess its overall value (for research and practice) in the eyes of participants and get feedback via strengths and weaknesses of participatory SD. Across all objectives, we also investigated if, and how, different levels of participant engagement in our virtual participatory modeling process affected achievement of broader social outcomes.

Figure 4.1: Conceptual model of potential bene ts that might be achieved through a participatory SD modeling process.

4.3 Methods

4.3.1 Participatory SD Modeling Process

The virtual participatory SD modeling process used in this study is explained in more depth in Rieder et al. (2021)(Chapter 3), though adjustments were made to the initial scope to accommodate

delays associated with the COVID-19 pandemic and provide suf cient time for construction of the simulation model. Our project was initiated by a single organization, yet a desire to have a diverse group of participants led to the development of a small advisory group who generated a larger list of participants to invite from around the world (Rieder et al., 2021). Participants were invited to participate in the process via one of three different levels of engagement based on facilitation capacity of the research group, limitations of the virtual space (a group too large might stymie productive conversation), and estimated availability of time and interest of participants. An Advisory Group of four highly-engaged experts to help lead the model-building effort and provide guidance to the research team throughout the study. One member of this group had to drop out but consistent support was provided by the three remaining Advisory Group members. A larger group of people (initially 12, but ultimately eight at the end for the project) formed a Modeling Group that was actively engaged with the Advisory Group and the research team to build both the conceptual and simulation models. Finally, a broader group of experts formed a Consulting Group that had more limited engagement with the lead researcher and the Advisory and Modeling Groups. This group, which initially consisted of 59 people invited to attend three presentations and contribute input via three different surveys, ultimately consisted of about 20 people at the end of the study.

A more detailed description of meetings and engagement points across the entire project period from November 2020 to May 2023 can be found in Chapter 3. Model building and related workshops, meetings and interviews were conducted over Zoom (https://zoom.us/). Models were built using Stella Architect (https://www.iseesystems.com/store/products/stella-architect.aspx), with the simulation model being hosted on iSee Exchange for participants. Tools to facilitate discussions and data collection included Miro (https://miro.com/) and Google Docs (https://docs.google.com). Prior to data collection, the study protocol was approved by NCSU IRB (#21029).

4.3.2 Evaluation Design

Survey Instruments

Following best practices in the eld of Participatory SD (including group model building), we used a mixed methods design that included a pre- and post-intervention survey as well as qualitative interviews and researcher observations (eld notes) to evaluate key objectives (Rouwette et al., 2011; Scott et al., 2013). Both surveys were essentially identical, though the post-intervention question contained a few additional questions about the process. Pre-surveys were administered between November 2020 and May 2021, and post surveys were administered following the release of the nal simulation model (in March 2023). We administered surveys online using the Qualtrics online survey platform (https://www.qualtrics.com) (See Appendix A for questionnaires). The survey protocols and individual questions were adapted from multiple sources evaluating participatory

modeling approaches (Michaud, 2013; W. R. Michaud, 2009; Rouwette, 2011; Rouwette et al., 2007; Scott et al., 2013, 2017). Details on constructs and items included within questionnaires are described below, along with a summary of how major themes align with the research objectives (Table 4.1). For each factor of items, we evaluated the dimensionality of the scale with principal axis factoring and promax rotation, retaining and reporting only factor loadings > 0.400 in the Pattern Matrix (See Appendix C). We assessed internal consistency of multi-item subscales using Cronbach's alpha. Psychometric properties of relevant scales are also presented below. See Hair et al. (2014) for more details about decision criteria used in this multivariate analysis.

Changes in beliefs and perspectives regarding tiger farms were assessed using six questions measured on a Likert scale from 1 (strongly disagree) to 7 (strongly agree) on both the pre- and post-survey. These questions assessed participants' feelings about the threat tiger farms pose to wild tigers, including common assumptions about how tiger farms interact with wild tiger populations. One particularly important question pertained to support for closing or phasing out tiger farms. We reverse-coded questions where disagreement corresponded with a higher negative impact to ensure that negative responses received higher point values. Two themes emerged in factor analysis: Perceived Threat of Tiger Farms (5 items, Cronbach's α = 0.923) and Tiger Farm Closure (1 item; Table C.1). Overall, these questions contributed to the Knowledge and Insight and Consensus and Commitment objectives (Table 4.1).

Changes in perspectives regarding conservation partners and the overall collaborative process were assessed using eight questions on the same 7-point disagree to agree scale on both the pre- and post-surveys. These included questions about goals and perspectives shared with other conservation practitioners, as well as procedural trust and con dence in the modeling process. We also included questions about the extent to which participants' voices were heard and their willingness to collaborate. Four themes emerged in factor analysis: Shared Goals (2 items, Cronbach's α = 0.799), Trust in Process (4 items, Cronbach's α = 0.782), Valued Voice (1 item), and Cooperation (1 item; Table C.2). Overall, these questions contributed to the Trust and Collaboration and Consensus and Commitment objectives (Table 4.1).

Perceived outcomes of the participatory modeling process were assessed using nine questions on the same 7-point disagree to agree scale, but in this case only on the post-process survey (Table 4.1). This included two questions that asked directly about shifts in thinking about the problem and how to x it, four questions on the content and usefulness of the model, and three more questions about participant engagement in the modeling process. Three themes emerged in factor analysis: Shift in Thinking (2 items, Cronbach's α = 0.904), Model Integrity (4 items, Cronbach's α = 0.819), and Collaborative Success (3 items, Cronbach's α = 0.822; Table C.3). Overall, these questions contributed to Trust and Collaboration and Consensus and Commitment objectives (Table 4.1).

Additional perceptions about how the modeling process helped participants to better understand

tiger farms and tiger conservation were assessed with six questions on the same 7-point disagree to agree scale, again only on the post-process survey. Questions focused on how the modeling process created a shared understanding and vision, af nitive trust of partners, and support for ndings of the project. Two themes emerged in the factor analysis: Process Utility (5 items, Cronbach's α = 0.879) and Trust in Partners (1 item; Table C.4). A nal question asked directly about agreement on components of the problem, as measured on a ve point scale from 1= “agreement reached on all key components” to 5 = “No agreement, we ended the process without making much progress”, including an option for “I am not sure if any agreement on key components was reached”. Overall, these questions contributed to Consensus and Commitment and Trust and Collaboration objectives (Table 4.1).

We used ve questions to assess the overall value of the modeling process and systems thinking (Table 4.1). In the post-survey, we assessed whether participants viewed the modeling process as more effective than other approaches with one question on the same 7-point disagree to agree scale. Participants were asked whether they would participate again or recommend the process to others in two questions on a scale from 1 (de nitely not) to 5 (de nitely). Changes in the perceived value of systems thinking for participant's work and broader wildlife conservation was assessed with two questions on a scale from 1 (“not at all valuable”) to 5 (“highly valuable”) that appeared on both the pre- and post-questionnaires. Finally, we provided participants with an opportunity to provide additional, open-ended feedback by asking the following questions: (1) “If you could use 3 words or short phrases to describe your reaction to this model-building process, what would they be?”, (2) “If this model changed the way you think about the problem, how?”, (3) How would you suggest this model be used to inform tiger conservation efforts?” and (4) “Please explain your response above” following questions about the value of systems thinking and interest in participating in the process again.

Interviews and Field Notes

In addition to surveys, we conducted short (30 min) semi-structured online interviews (Flick, 2018) with strategically selected key informants from all groups (Advisory, Modeling and Consulting) to collect feedback on learning outcomes, social outcomes, and recommendations for improving the process. Questions covered positive and negative experiences in the study and with the modeling process, the most important things that participants learned, perspectives on potential changes in knowledge and impacts on relationships with fellow participants. All interviews were conducted between March and May 2023, after the nal version of the simulation model was shared with participants.

Throughout the project period (2021-2023), observations of interactions among participants and unsolicited comments about the experience and process were documented as eld notes (Flick,

2018). These eld notes supplement the contextual information shared during the interviews.

Table 4.1: Summary of key outcomes and how they were operationalized in the evaluation of the participatory SD modeling process.

Themes	Construct	Surveys	Scale and Details
Knowledge and Understanding	Perceived Threat of Tiger Farms (Table C.5)	Pre/Post	5 Items: e.g. Tiger farms are currently a major threat to wild tiger populations; If there were no tiger farms, poaching of wild tigers would increase (assuming demand for tiger parts and products remains the same) Scale:1 = strongly disagree to 7 = strongly agree
	Shift in Thinking (Table C.7)	Post	2 Items: e.g. My opinion of the most important problem to address in this system has changed because of this process Scale:1 = strongly disagree to 7 = strongly agree
	Model Integrity (Table C.7)	Post	4 Items: e.g. The modeling process has helped me understand the feedback processes that play a role in the problem; I trust the technical information used in development of the model Scale:1 = strongly disagree to 7 = strongly agree
Collaboration and Trust	Collaborative Success (Table C.7)	Post	3 Items: e.g. The use of this model has clari ed the communication between participants about the problem Scale:1 = strongly disagree to 7 = strongly agree
	Cooperation (Table C.6)	Pre/Post	1 Item: I worked cooperatively with other participants in this process Scale:1 = strongly disagree to 7 = strongly agree
	Valued Voice (Table C.6)	Pre/Post	1 Item: I believe that my voice was heard in this process Scale:1 = strongly disagree to 7 = strongly agree
	Trust in Partners (Table C.7)	Post	1 Item: Participants trusted each other more as a result of this process Scale:1 = strongly disagree to 7 = strongly agree
	Trust in Process (Table C.6)	Post	4 Items: e.g. I trust the strategies developed by the partners in this project will ultimately bene t wild tigers; I am con dent that the partners involved in this project will reach agreement about priority actions/ interventions following this process Scale:1 = strongly disagree to 7 = strongly agree
Consensus and Commitment	Shared Goals (Table C.6)	Pre/Post	2 Items: e.g. I feel that individuals working in conservation organizations have similar goals as mine Scale:1 = strongly disagree to 7 = strongly agree

Continued on next page

Table 4.1: Summary of key outcomes and how they were operationalized in the evaluation of the participatory SD modeling process. (continued)

Themes	Construct	Surveys	Scale and Details
	Consensus on Components	Post	1 Item: Please indicate, in your opinion, the extent to which agreement was reached on the components of the problem Scale: 1=agreement reached on all key components to 5 = No agreement, we ended the process without making much progress, with 6 = I am not sure if any agreement on key components was reached
	Tiger Farm Closure (Table C.5)	Pre/Post	1 Item: All tiger farms should be closed or phased out. Scale:1 = strongly disagree to 7 = strongly agree
	Process Utility (Table C.7)	Post	5 Items: e.g. I support the conclusions/ ndings that were drawn during the modeling process; I will try to convince others in my organization or network of the importance of these conclusions/ ndings that were drawn during the modeling process Scale:1 = strongly disagree to 7 = strongly agree
Value of Process	Value of Systems Thinking (Table C.8)	Pre/Post	2 Items: How valuable do you think systems thinking is (1) to your work and (2) to wildlife conservation in general Scale:1 = not at all valuable to 5 = highly valuable
	Value Comparison (Table C.9)	Post	1 Item: We could not have progressed as far using any other process of which I am aware Scale:1 = strongly disagree to 7 = strongly agree
	Future Participation (Table C.9)	Post	2 Items: Would you (1) participate in this process again and (2) recommend this process to others Scale:1 = de nitely not to 5 = de nitely

4.3.3 Data Analysis

Given the small sample size, we used non-parametric tests for all analyses given the probability of type I error. For paired pre- and post-process change score comparisons, we used a non-parametric Wilcoxon Signed-Rank Test. For post-only analyses, we primarily reported descriptive statistics. After assessing samples for descriptive statistics and considering pre-to-post score differences, we also analyzed differences in results based on each groups' reported level of engagement. Given the small sample size and similar study activities, we added the Advisory Group's responses to those of the Modeling Group, allowing us to compare two levels of engagement (Modeling vs. Consulting Group) more ef ciently. The responses to each Likert-scale question were treated as continuous

variables (Rhemtulla et al., 2012). Group comparisons were conducted using non-parametric Mann-Whitney U-Tests or Chi-square tests, depending on the structure of responses. All quantitative data were analyzed using SPSS Version 29.0.

Interviews were recorded in Zoom with transcription enabled. Following each interview, transcriptions were reviewed in detail and corrected for accuracy. To summarize and understand feedback from participants about the value of the participatory modeling process and suggestions for improvements, we coded and analyzed transcriptions. Coding was completed by a single researcher who used inductive coding based on the content of the responses, following guidelines for thematic analysis (Nowell et al., 2017). Once coding was complete, codes were organized by the major study themes of Knowledge and Insight, Collaboration and Trust, Consensus and Commitment, and overall process value and feedback. Field notes were then integrated with the textual data according to theme. Quotes and eld notes that illustrated main points were extracted from transcripts to complement the statistical analysis. Open-ended survey responses were also coded using a similar process, and responses to the “list three words or phrases that come to mind” question were depicted in a Word Cloud. Throughout the process, the researcher conducting the modeling and evaluation, kept observational eld notes about online interactions, emails and other informally shared sentiments.

The researcher conducting the modeling and evaluation had no previous experience in tiger conservation or the wildlife trade, and had not worked directly with any participants prior to this process. However, the researcher does have experience in conservation and is a former employee of one non-pro t with staff who participated. The researcher regularly re ected on their own perspective and biases to remain as neutral and open to participant input as possible throughout the process.

4.4 Results

4.4.1 Sample and Group Characteristics

Seventy- ve people were invited to participate in the project and received a link to the pre-process survey invitation; of those 75, 49 (65%) completed the pre-process survey. The 49 people who completed this initial survey represented approximately 15 different organizations based across Europe, Asia, North America, Africa and Austral-asia. The majority of people were from conservation NGOs or research institutions (Rieder et al., 2021). Initial self-reported expertise was highest for Wildlife Trade, Tiger Farming in Asia, and Farming of Non-Tiger Species, and lowest for Ecology, Economics and Participatory Modeling.

Following the project, 62 people received the post-process survey (13 people of cially dropped out of the process, primarily due to time constraints). Of those 62, 29 (47%) completed the survey,

including two people who had not completed the initial survey. In total, 27 people completed both the pre- and post- process survey (8 in the Advisory/Modeling Group, 19 in the Consulting Group); these responses were used in the statistical comparisons. As expected, members of the Modeling Group reported spending substantially more time engaged in study activities than the Consulting Group. For example, 88% of respondents from this group reported spending more than 5 hours on the project (with 4 people reporting spending more than 20 hours). On the other hand, 86% of the Consulting Group spent less than 5 hours on project activities. The majority of respondents in both the Modeling (75%) and the Consulting Groups (57%) saw the nal model and/or report.

Interviews were conducted with eight participants. Three from the Advisory Group, three from the Modeling Group, and two from the Consulting Group. Attempts were made to interview more members of the Consulting Group but time constraints limited the total number of interviews.

4.4.2 Knowledge and Understanding

Comparisons of the Threat of Tiger Farms index scores (i.e., the difference between post- and pre-process survey scores) indicated that project participation reduced the sense of threat tiger farms pose to wild tigers (W=-2.16, p=0.031, Figure 4.2, Table C.5). Overall 78% of respondents still saw tiger farms as a threat to wild tigers at the end of the study, however the mean response changed -0.29 over the study period. This drop came primarily from a signi cant decrease in agreement with the statement “tiger farms are currently a major threat to wild tiger populations” (W=-2.15, p=0.032) and a signi cant increase in agreement with “if there were no tiger farms, poaching of wild tigers would increase (assuming demand for tiger parts and products remains the same)” (W=-2.66, p=0.008)(Table C.5). There were no signi cant differences between group responses, however the mean change for the Consulting Group (-0.35) was slightly higher than the Modeling Group (-0.15; Figure 4.2, Table C.5).

Despite changes in beliefs about the threat of tiger farms (Figure 4.2), only 19% of participants agreed that their perspective on the most important problem and how to x it had changed (Figure 4.3, Table C.7, Shift in Thinking). Overall, agreement on Shift in Thinking was similar between groups, though the Modeling Group disagreed slightly more (Figure 4.3, Table C.7). And within this index there was a signi cant difference between groups in changes of opinion for the most important problem to address (U=2.34, p=0.019, Table C.7). Participants reported relatively high levels of support for the Model Integrity index (X=5.08), with no signi cant differences reported by the groups (Figure 4.3, Table C.7, Model Integrity); 84% of respondents thought the model helped them understand feedback processes and 72% found that the model presented a realistic portrayal of different management alternatives (Table C.7).

The modeling process worked off of participants' assumptions, available data, and existing research to identify cause-and-effect relationships, therefore “new” insights may seem logical

to many participants and potential changes in understanding might be difficult to perceive. In interviews, participants reported that the process did not necessarily change their perspective, but it helped them see and understand complexity. One Modeling Group participant reported that "I don't think [my views] radically shifted. But...it's always good to...look at a bigger picture and see how... those different levers change things, and probably in ways that I didn't necessarily anticipate or believe to be true... [it gave] me a more holistic view of the trade, and the different drivers and influences of the trade." The same person thought the process improved the collective understanding [of the system]. Another Modeling Group participant reported the model confirms some of the fears that some of us... have had about the impact of closing tiger farms before we do other things... [and] it emphasizes that this isn't a simple supply chain." One Modeling Group participant highlighted that the process increased "awareness of data [needed] or awareness of the absence of data".

Although those in the Consulting Group reported appreciation for the process, some felt "still on the periphery of really understanding what you came up with." Like one Consulting Group member, others may have felt they "need more time to understand how the model works - given this, I believe others would also need to understand the model". This aligns with other expressions of caution about future use of the model given uncertainty and complexity. One Modeling Group member expressed it in this way, "I think [the model] is valuable, and a tremendous amount of thought [and expertise] went into it...But at the end of the day it's only as good as all of the uncertainties that are built into it. And...that would be my caution to someone who's given it [and thinks] `this is how tiger trade works'. [Because instead it is] `this is how we believe tiger trade to work, based on what we know, and there's a lot that we don't know,' right?"

4.4.3 Collaboration and Trust

Following the modeling process, participants revealed mixed responses regarding collaboration. Participants responded positively on the Collaborative Success index, with no significant differences between groups despite a slightly more positive response from the Modeling Group (Figure 4.3, Table C.7). Comparisons of pre-post differences in Valued Voice scores revealed minimal changes over time ($W=0.98$, $p=0.326$), with 74% agreeing in the post-process survey that their voice had been heard in the process and no significant difference between groups (Figure 4.2, Table C.6). On the other hand, comparisons of Cooperation score changes revealed a significant reduction in perceptions of working cooperatively during the study ($W=-3.78$, $p<0.001$, Figure 4.2, Table C.6), primarily driven by a much larger decline in the Consulting Group ($U=-2.25$, $p=0.030$).

Despite variable quantitative metrics regarding collaboration, when asked what the greatest strength of the process was, all participants interviewed in the Modeling Group cited collaboration with others. One Modeling Group member reported we "don't always provide enough time to

just sit and talk to other people working around the same issues. And I especially like the fact that we had [people with] different views than others. . . So it was good to see that... we could have a dialogue." Another member appreciated learning from others, "Yeah, for me [the strength] was the collaborative nature of it. It was the opportunity to think more deeply and hear other perspectives,. . . to hear other areas of expertise talk about the different dynamics and in uences on the tiger trade, and how adjustments to those in uences alter outcomes." Modeling Group participants expressed pleasant surprise that meetings were free of con ict, despite sometimes strong differences in views. One participant re ected, "You know we never, we never melted down. We never got accusatory or sharp. . . it was all very nice. [And] I didn't feel that it was nice-y, nice-y on a super cial level...I felt there was a genuine [focus on] `How do we keep wild tigers?'" People from the Consulting Group reported that they appreciated being more aware of other's views, but that they did not have enough opportunity to engage with others through the process. Even one Modeling Group member said, "I felt I would have appreciated engaging with others more." This might help to explain the Consulting Group's signi cant drops in perceptions of collaboration on the post-process survey.

Enhanced opportunities for collaboration did not translate to signi cant increases in trust in our evaluation. Although there was a very slight measurable increase in trust reported by participants, the change was not signi cant (Figure 4.2). Only 32% of respondents agreed that Trust in Partners (af nitive trust) increased through the process, with negligible differences between groups (Table C.6). Comparisons of pre-post differences in Trust in Process (procedural trust) index scores did not reveal signi cant increases in trust over the course of the study for either group (W=1.51, p=0.770), though participants in the Modeling Group reported slightly higher increases (Table C.6). The only signi cant differences between engagement groups was associated with the statement “I believe every partner on this project team is committed to doing what is best for tiger conservation”, with the Modeling Group scoring higher (W=2.04, p=0.042, Table C.6).

In interviews, Modeling Group participants reported that the process helped build or strengthen relationships, though no one directly agreed that trust had changed. One said, "It just solidi ed. . . the relationship I already have with the individuals. So that was interesting to me." A few participants reported appreciating getting to know people who had different views, such as this person in the Modeling Group - "I was working [through this process] with people who, at a previous time, we would have considered each other as having very polar opposite views and I think the real bene t of this process was to get to know each other and nd that actually we've got a lot more in common than perhaps people thought." Another Modeling Group member reported their relationship improved "with one of the participants [in particular]. . . I maybe had an assumption about them. . . [But] this process provided us with a lot more contact time than I would have had otherwise. [They were someone I ended up having] more in common with in how we look at these situations

and. . . challenge each other. . . than I would have thought.” Another Modeling Group member even commented that it was good to “actually be in a really small group. And. . . actually listening to what they [those with opposite views] are saying,...[to realize] they're actually human beings who care about tigers.” Though the process seemed to improve relationships and humanize people with different views, some were skeptical that the process was able to overcome some of the longer standing differences in the group.

Figure 4.2: Change between pre- and post- process survey scores for outcomes associated with the participatory SD modeling process, with comparisons based on level of engagement in the process (Modeling Group = higher engagement, Consulting Group = lower engagement). Change in mean scores shown in bars, with mean standard error of differences in error bars. Percentages represent mean % scoring 4.0 or higher on post-process measure. (a) denotes statistical signi cance of Wilcoxon signed-rank test comparing pre-post changes at p 0.10 (b) denotes statistical signi cance of differences in change scores between groups based on the non-parametric Mann-Whitney U-test at p 0.10 (n=27).

Figure 4.3: Mean post-process survey scores for outcomes associated with the participatory SD modeling process, with comparisons based on level of engagement in the process (Modeling Group = higher engagement, Consulting Group = lower engagement), with mean standard error for each Group in error bars. Post-process score means with % scoring 4.0 or higher on post-process measures. (b) denotes statistical signi cance of Mann-Whitney U-test comparing group scores at p 0.10 (n=27).

4.4.4 Consensus and Commitment

Positive, but not signi cant pre-post differences were reported in the Shared Goals index (W=0.74, p=0.46, Figure 4.2, Table C.6). At the end of the study, 76% of respondents agreed that they had similar goals to others in conservation organizations, while only 52% agreed that they agreed on approaches to tiger farms. Interestingly, the mean for the Modeling Group's sense of agreement about farms declined slightly (-0.38), while the Consulting Group's rose (+0.26), though differences were insigni cant (Table C.6). Overall, most participants reported perceived agreement on most (41%) or some (26%) of key components of the system. Members of the Modeling Group were nearly twice as likely to report agreement on most key components (62% vs. 32%), but this difference was not statistically signi cant, X2(3)=4.67, p=0.198. Through the Process Utility index, a majority of participants (82%) agreed the process helped them focus on key issues, fostered a shared vision,

and produced ndings that they supported (Figure 4.3, Table C.7). The Modeling Group reported higher perceived utility of the process than the Consulting Group (U=-2.20, p=0.029). The lowest levels of agreement from either group (<52%) came from the item “Everyone had an equal voice in discussions” (Table C.7), possibly re ecting the differences in engagement among participants.

Given the complexity of the problem and the sensitivity of the issues around tiger farms, participants acknowledged that there was more common ground than expected, yet complete consensus on model components would be dif cult. One Modeling participant found it "really useful to see where and why there was such differences of opinion, and how many of us,...including myself,... we've got quite tunnel vision,...we're looking at...this case, chain or route or set of actors, which leads us to start opinions very different, perhaps, from situations in other other countries. But it was also interesting that there was quite often common ground." Another Modeling Group member remarked "I don't recall that we had radical disagreement on anything, and in some ways that's a little bit of a red ag for me. Why didn't we? I mean. This is a complex and complicated topic." One participant said "No [this model didn't change my thinking]. I still believe that the interactions between wild and farmed tiger products is incredibly complicated, which makes it hard to make realistic predictions. Efforts to demotivate consumers might be the only way to decrease the demand, which this model is very useful for. It shows the direct link between the two, and the impact such efforts might have." This highlights the importance of trying to reach consensus and the challenges in such a complex system.

Results of the modeling exercise suggested that closing tiger farms, without reducing demand for tiger bone and other products, might be detrimental to wild tigers. Given this, we considered any changes in perspective regarding Tiger Farm Closure to be a measure of Consensus and Commitment. Comparison of pre-post scores for the Tiger Farm Closure variable revealed no signi cant effects of the process on support for closing or phasing out of tiger farms (W = 1.10, p = 0.27, Table C.5). Across both groups, 78% of participants agreed that tiger farms should be closed or phased out after the study. The Modeling Group reported a small decline in support for closing tiger farms (-0.43), while the Consulting Group actually showed a slight, but not signi cant, increase in support (+0.50) (U=0.96, p=0.46, Table C.5).

One person from the Consulting Group claimed they were "skeptical of theoretical models, using hypothetical data, being used to inform conservation management." Yet, at least one Modeling participant felt "it [de nitely] informs where [we] move forward [with our conservation program]" and reported already sharing model results with colleagues. However the same person also re ected that "I'm worried how this will be used, because I think there's really important outcomes of this research that are really valid and to me give guidance on what we should do. I think it can [also] be completely easily misinterpreted." This highlights some of the challenges within such a complex and contentious issue, pointing to large barriers that still make consensus

and commitment and future action dif cult. One Modeling Group member re ected on the ethical challenge, "It's a big step to take to say this. These things that are treating tigers that we love so badly, and doing really [bad things], and raising them to kill them, to sell illegally are. . . potentially contributing to less tigers coming from the forest." Another Modeling participant added, "My learning out of that is that this can be a very useful tool. But at the end of the day these issues can still get overshadowed by politics [and culture]. . . I'm not sure that a systems model, even if it's the most accurate model in the world, is going to be able to overcome" that.

4.4.5 Value of Systems Thinking and the Modeling Process

By the end of the study, 88% of participants agreed that systems thinking was valuable for their work and 100% agreed systems thinking is valuable for wildlife conservation (Figure 4.4, Table C.8). Comparisons of pre-post score changes for the Value of Systems Thinking variable revealed small increases (+0.39) in the perception of value for participants' work (W=1.53, p=0.125) and signi cant increases (+0.58) for the perceived value of systems thinking for wildlife conservation in general (W=1.97, p=0.048, Figure 4.4, Table C.8). Changes were larger for the Consulting Group, but these differences were not statistically signi cant (Figure 4.4, Table C.8). Perceptions about how outcomes of this process compared to others varied, with only 48% of respondents agreeing with the question "We could not have progressed as far using any other process of which I am aware" (Figure 4.5, Table C.9). There were signi cant differences between groups for this question, with the Modeling Group agreeing signi cantly more than the Consulting Group (U=-2.46, p=0.022, Figure 4.5, Table C.9). Yet, 77% of participants said they would probably or de nitely participate in the process again and 81% of participants said they would recommend this process to others (Figure 4.5, Table C.9). The Modeling Group had signi cantly more agreement for future participation (U=-1.89, p=0.090) and slightly higher agreement for recommending to others (U=-1.17, p=0.285, Figure 4.5, Table C.9).

Figure 4.4: Change between pre- and post- process survey scores for outcomes associated with the participatory SD modeling process, with comparisons based on level of engagement in the process (Modeling Group = higher engagement, Consulting Group = lower engagement). Change in mean scores shown in bars, with mean standard error of differences in error bars. Percentages represent mean % scoring 4.0 or higher on post-process measure. (a) denotes statistical signi cance of Wilcoxon signed-rank test comparing pre-post changes at p 0.10 (b) denotes statistical signi cance of differences in change scores between groups based on the non-parametric Mann-Whitney U-test at p 0.10 (n=27).

Figure 4.5: Mean post-process survey scores for outcomes associated with the participatory SD modeling process, with comparisons based on level of engagement in the process (Modeling Group = higher engagement, Consulting Group = lower engagement), with mean standard error for each Group in error bars. Percentages represent mean % scoring 4.0 or higher on post-process measure, (b) denotes statistical signi cance of differences in change scores between groups based on the non-parametric Mann-Whitney U-test at p.10 (n=27).

Positive feedback about systems thinking included statements such as, "Most conservation problems are complex, dynamic, and systemic in nature and getting people to understand this is critical for future success." Another Modeling group member acknowledged the value of the process, stating that "Conservation action has long been overly focused on simplistic approaches. Systems thinking is critical to advancing conservation efforts going forward." Though another Modeling participant re ected on inherent challenges, "It's a very different way for people to think [which I liked, but]... I think some did nd... challenging from `oh [no], I got 1,000 things to do. This is just too much to get my head around when I don't see it impacting on my day to day work'." Yet a Consulting Group participant linked systems thinking to more common planning guidelines, saying "Systems thinking and the conservation standards have many similarities. Conservationists need to be better at setting realistic achievable goals and conservation targets. The actions...must be monitored to ensure that conservation outcomes are realized... an adaptive management approach must be adopted to ensure that the models are exible enough to adjust to the ever changing situations that we nd ourselves [in]".

When asked to react to the process in just a few words, participants spoke of both bene ts (e.g. useful, informative, enlightening) and challenges (e.g. complex, complicated, time) (Figure 4.6). Open-ended responses and interviews enabled us to unpack this feedback in more detail. One Modeling Group member cited the importance of "[getting] everyone at the table," while another re ected that "this was an exceptional effort of bringing so many participants with different viewpoints along this process and capturing their input without creating rifts." A Consulting Group participant remarked that they appreciated the collaboration between people of different backgrounds, saying it "is the gap between scientists and practitioners." One Modeling Group member said the approach surprised them by being "something very applied that can immediately inform what we're doing on tigers and trying to protect tigers." Though at least one Consulting Group member "found the process too academic for my interests," which echoed early skepticism in the process and the value of systems thinking. Another Consulting Group participant, echoing the impact of a lack of engagement, said "I was not as deeply involved in the process as some other colleagues, so it would be harder for me to properly motivate other people to use such a process." Meanwhile, most of the Modeling Group participants interviewed found that the process was a helpful space, with one participant saying the "[most] rewarding part [was] being able to kind of really focus on a topic for a bit of time with, and be able to talk to other experts about it."

Multiple participants also mentioned the value of having either the CLD or the simulation model as a visual tool that combined feedback. One Modeling Group member said, "I think one of the strengths was that I could see how discussions that we were having within [the group] developing a sort of visual, you know whether it was the concept model, and then the simulation model, that... we can have a group discussion and then see the different models that you were creating." Yet another

Figure 4.6: Word cloud generated from the question “If you could use 3 words or short phrases to describe your reaction to this model-building process, what would they be?” (n=27).

person said, “everyone [in the Modeling Group] felt that sort of Eureka moment when you actually see the [simulation] model.” Another Modeling Group member attributed the lack of con ict to “the fact that we kept coming back to [a physical product]. . . that we had invested in.” For future use of the model, a Consulting Group member re ected that the model “could be a useful tool to engage stakeholders and decision makers in dialogue over the complexities of this issue, using the model to spark discussion and focus on the key aspects of interest. Hopefully this could lead to tangible action being taken for wild tiger conservation.” Another Consulting Group member was more critical of the model and process, “I think systems thinking in general is a valuable tool. However, if the process of building the model is 1) lengthy, 2) missing key variables, and 3) lack of trust among collaborators, I don't believe it can effectively respond to urgent conservation issues.” However, others spoke of the potential value of reducing con ict and silos between conservation practitioners, one Modeling Group member said, “hopefully, methods like this are able to sort of pull the people away from [the] poles, and. . . gather the center.”

Process Design Feedback and Challenges

Our process was designed to be completely virtual given the wide geographic spread of participants and logistical and nancial constraints, and the COVID-19 pandemic reinforced the need for adapting to a virtual environment. Modeling participants appreciated the virtual workshops and thought the tools, such as Miro, were helpful and well-used. However, nearly all Modeling Group participants thought hybrid would be best, with one participant summarizing the trade-offs: "Well, I think the most ideal would be a hybrid. . . The problem with an in-person meeting is. . . logistically it is dif cult to pull off, and. . . [then] you've only got them for a certain amount of time, and. . . I think there's a lot to be said for [the iterative process of deep dives in virtual meetings with breaks in-between]...I think we got a lot further with that iterative process, then we would have got in a in a one off hit. That said, it's a lot slower to get through stuff in a session when you're not all in the room." At least one Modeling participant thought in-person would have made more progress in breaking down barriers, they said: "Potentially by having people together and forcing them to have some sort of social thing. . . might have even broken down some of those. . . [barriers] we put amongst ourselves, like well, 'they're in that group', and 'we're in this group'." One Modeling participant re ected that virtual conversations are a lot harder, yet another person reinforced the value of the time and virtual nature by saying: "I appreciated that this was spread out over a long period of time, and so in-person really isn't going to give you that opportunity."

Instead of the initially planned time frame of 6-9 months, the study lasted for over two years. This was the result of impacts from the COVID-19 pandemic, the complexity of the topic, limitations of relatively short virtual meetings, and a lack of project funding that reduced time available for the research team. Yet, counter to the expectations of the research team, multiple Modeling Group participants appreciated the length. One person said: "taking that time and thinking through all those different factors and doing it over an extended period of time where we can think about it and come back and have more discussion. . . . I think there's a big value [in that]." Multiple Modeling Group members reported enjoying discussions, such as one person who said: "I like to talk with other people about something that's near and dear to my heart that could take a decade. I'm happy." Similarly, another Modeling Group member called meetings "enjoyable", yet a "luxury thing" and they expressed: "a lot of guilt, and that I could not make enough time for it." Both participants and the research team struggled with loss of momentum and the amount of input required, with one Modeling participant re ecting that: "I felt like I was dipping in and dipping out, so sometimes I felt like I'd forgotten how we'd go from A to B." Multiple participants felt they did not have enough time to engage properly and they wished there was more consistent attendance from a larger number of participants.

While attendance was sometimes a challenge, there was also a sense from some that important perspectives were missing from the conversation. Given the illicit nature of the tiger trade and

sensitivities around farms, some Modeling Group participants debated about how to manage or incorporate perspectives from those more closely involved with the tiger trade or tiger farms. One Modeling participant re ected,I'think in some ways, at the end of the day probably everyone in the group, even though we bring different perspectives and contrary views. We all - we're all rowing essentially in the same direction, right? And so, maybe it might have been interesting to have some of the counter-currents directly involved - probably would have livened up the debate a little bit, more, and - whether it would have fundamentally changed the outcome? Maybe not. But - I think it would have been interesti'g.

4.5 Discussion

Our results illustrate the multiple ways that participatory SD modeling can improve decision making within a complex conservation system, supporting the growing body of research highlighting the bene ts of this approach (Kopainsky et al., 2017; Stave et al., 2019; Wilkerson et al., 2020). Results also indicate some limitations of our virtual modeling process and provide insights for future efforts.

4.5.1 Improved understanding of the system

Our ndings demonstrated that participatory SD modeling can affect changes in knowledge and understanding of participants, supporting results of previous studies (Scott et al., 2016b; Stave, 2010; Stave et al., 2019). Insights gained from the development of the CLD (Chapter 3) and associated simulation model seem to have translated into signi cant, albeit slight, reduction in perceived threat tiger farms pose to wild tiger populations. Surprisingly, most participants did not report that their perspectives had changed when asked directly. However, most agreed that the model effectively helped them understand feedback in the system, realistically portraying different management alternatives and balancing key interests of participants.

Differences in beliefs between the Modeling and Consulting Groups were not signi cant, yet some trends were surprising. Despite enhanced engagement, the Modeling Group reported smaller changes in Perceived Threat of Tiger Farms, and fewer group members agreed that a Shift in Thinking had occurred. There are several possible explanations for these surprising trends. First, in this small sample, shifts in mean or median belief scores might be disproportionately impacted by major changes in the views of a few individuals. The smaller shifts in the Modeling Group could be a result of members entering the project with lower and more nuanced baseline scores regarding tiger farm threats, leaving less capacity for change, a common phenomenon in evaluation research known as the ceiling effect (Chyung et al., 2020). A possible explanation why participants did not think their perspective had changed, is that people are not always aware they have changed their minds (Doyle, 1997) due to effects such as hindsight bias, where an individual assumes they have

always held their current views (Kahneman and Tversky, 1973). We hypothesize that these factors may be especially pronounced for the Modeling Group, with any new conclusions being drawn logically and gradually over multiple discussions.

The lack of signi cant difference between groups in the Model Integrity index was surprising given the additional time the Modeling Group spent developing and using the models. The Modeling Group expressed slightly higher support for all items except for trust of the technical information used in the model. This could be a result of increased awareness of complexities and uncertainties behind the models, coupled with limited time to fully explore the dynamics. This is similar to Stave et al.'s (2019) modeling experience, where participants reported a decreased con dence in decisions and a lower process satisfaction, despite improved quality of decision making.

4.5.2 The importance of collaboration and trust-building

Our ndings underscored the value participants placed on opportunities for constructive collaboration with others. Participants from both groups generally felt their voices were heard, the model integrated diverse viewpoints, and that the process successfully fostered collaboration. In interviews and open-ended questions, participants (especially from the Modeling Group) repeatedly mentioned their appreciation for being able to engage constructively on an important topic with a diverse group of experts. Given the increased opportunities to engage with other participants and the model, the Modeling Group saw more positive responses in all collaboration measures. Yet we observed the largest differences between the Modeling and Consulting Groups for "I worked collaboratively with other participants in this process." Given limited opportunities Consulting Group members were granted to collaborate beyond surveys and the extended project timeline with few checkpoints, this was unsurprising and highlights the importance of realistically managing expectations for engagement.

Trust is critical for successful conservation, but is notoriously dif cult to cultivate (Stern and Coleman, 2014). Our ndings suggest that participatory SD modeling can support trust-building, yet is not a silver bullet to overcome long-standing social and political barriers. Small increases in perceived Trust in Process supported the idea that increased collaboration during the project helped build relationships and foster a sense of procedural trust. Af nitive trust proved more dif cult to foster; when asked directly if the process had improved Trust in Partners, only 32% of participants agreed. While disappointing, this nding is not unexpected given the dif culties that may exist in relationship-building, especially in a virtual context (Ford et al., 2017). Encouragingly, interviews with participants how modeling activities might lay the foundation of trust-building. Several Modeling participants described how the experience enabled them to connect with people they had previously been reluctant to work with, challenging assumptions about their motivations and goals and highlighting commonalities.

4.5.3 Consensus, but not necessarily commitment

There is evidence that participatory SD modeling helps achieve a shared understanding and consensus among participants that could ultimately lead to improved conservation interventions (Rouwette et al., 2011; Scott et al., 2016b; Stave, 2010). Many previous case studies of SD modeling have focused on clearly de ned working groups or existing project teams (Beall and Zeoli, 2008; Stave, 2002). Alternatively, our project involved participants from many different organizations with presumably different positions on the tiger farm issue - thereby adding complexity and signi cantly limiting chances for consensus and commitment around a clear set of actions. Thus, at the start of our study, we were not sure how diverse conservation practitioners viewed tiger farms or what strategies they might be implementing. We were also unsure about what insights might emerge from the modeling process, making it dif cult to anticipate measures for strategy change or commitment to action. This highlights the importance of careful alignment between group objectives and evaluation metrics (Curzon and Kontoleon, 2016).

Despite these challenges, our results suggested that some consensus was reached among many project participants, with 40% of people feeling there was agreement on most key components. We found a positive increase in perception of Shared Goals from the Consulting Group, though surprisingly a decreased sense of Shared Goals among the Modeling Group. We attribute this to insights the Modeling group members may have gained regarding the perspectives of other participants through in-depth discussions. Roughly half of respondents reported the process led to a shared vision and conclusions that they would support and share. Though we saw less consensus than some studies of similar approaches (Rouwette, 2011), we attribute this to the contentious nature of this topic and our multi-group study design. Additionally, high degrees of complexity and uncertainty in IWT dynamics (Chapter 3) ('t Sas-Rolfes et al., 2019) could make it unlikely to reach consensus on all factors.

The CLD (Chapter 3) and associated simulation model developed with participants revealed that closing tiger farms, without a corresponding reduction in consumer demand, could harm wild tigers through a possible increase in poaching pressure (See Chapter 3). While recognizing that further research is needed around the potential implications of closing tiger farms and demand reduction strategies, we considered changes in agreement with Tiger Farm Closure to represent a measure of commitment related to insights from the modeling process. Changes in agreement on this measure were not statistically signi cant, but support for this policy increased in the Consulting Group and declined in the Modeling Group. Support for closing tiger farms is unlikely to change easily given a high degree of consensus among conservation professionals (76% of participants supported farm closure post-process), momentum of years of advocacy from many organizations, and considerable animal welfare issues surrounding farms (EIA, 2013). The tiger farm issue is also likely tied to deeply held beliefs and values, which need to be accounted for in any conservation

decision making (Manfredo et al., 2021). Multiple reasons could underlie increased support in the Consulting Group. Given the polarization around this topic, opening up the discussion or exposure to people with different views may have led some to more strongly hold to their position that farms should be closed, perhaps fueling a type of psychological reactance that is often seen with controversial conservation issues that threaten people's values (Liang et al., 2018).

4.5.4 Value of systems thinking and modeling

Overall, participants expressed broad support for the participatory SD process. The perceived value was re ected in an increased appreciation of systems thinking for both personal work and in wildlife conservation, and the fact that a majority of respondents would be likely to participate again or recommend the process to others. In qualitative responses, people reported that the modeling process provided a rare opportunity to look at the whole picture of a problem, a bene t that has been noted by other researchers (Stave, 2010). Additionally, participants appreciated the visual nature of both the CLD (Chapter 3) and the simulation model and the ability to explore the models outside of workshops and meetings. The tangible aspect of the models also helped avoid con ict by focusing conversations away from positions and onto speci c variables and assumptions of cause and effect (Ballard et al., 2021; Black and Andersen, 2012).

There is signi cant evidence that participatory SD modeling, relative to alternative approaches, helps develop improved decision making strategies and many social bene ts (Rouwette et al., 2011; Scott et al., 2016a; Stave et al., 2019). Given this evidence and the enthusiasm expressed by participants, we were surprised to see only 48% of participants agreed with the item “we could not have progressed as far using any other process of which I am aware” (Table C.9). Perhaps the extended study timeline and inconsistent engagement from the research team might have led people to prefer alternative approaches that were shorter and more familiar. Additionally, it is possible that participants felt less procedural satisfaction with this modeling process than they experienced during other planning processes. Stave et al. (2019) reported a similar response, attributing this feeling to there being enough time for a group to start to dig into the complexity of an issue, but not enough time in limited meeting blocks for participants to feel they fully understand the model and complexities. We faced the same challenge in this study, as many participants voiced feelings of frustration or guilt that they did not have more time to spend with the model or in discussions with others. Despite these challenges, participants expressed enthusiasm for using systems thinking in the future and the potential for SD models to be used to improve conservation strategies. Perhaps most importantly, participants welcomed a carefully-facilitated process where they could engage with a diverse group of fellow conservationists to discuss an issue and species they care deeply about.

4.5.5 Limitations

There are a number of limitations in this study that should be kept in mind when interpreting results. While we attempted to include a wide range of people in this process, our sample size for the final evaluation was small. This made quantitative evaluation difficult, though qualitative data provided a valuable complement. We also relied heavily on self-reported perceptions of change, which can be difficult to accurately assess (Doyle, 1997). Furthermore, tiger conservation, and corresponding perspectives on tiger farming, are incredibly controversial and characterized by high uncertainty. A similar modeling process might be even more effective if it focused on less-controversial topics in more data-rich environments. Adding a diversity of voices to the table created rich discussions and provided opportunities for bridge-building, but it also made it difficult for some people to attend meetings who were not comfortable with other participants. While we found the diversity of perspectives critical, this dynamic warrants careful consideration in designing future initiatives.

4.5.6 Implications for future modeling efforts

Through this process we learned a number of lessons that can inform future participatory modeling efforts. First, there is value in a longer process to give time for reflection and further research between meetings; however, loss of momentum can happen if reflection periods are too long. Virtual meetings and well planned workshops allow participants to meet in international contexts when in-person is not practical, however conversations and relationship building can be more difficult virtually. Hybrid designs may be ideal, as one Modeling Group member suggested: "the team setup would be like 2 or even 3...in-person meetings. One near the beginning, one sort of check in halfway through, and one at the end. And then the in-between stuff could be virtual." Practically, both virtual and in-person approaches have logistical challenges. The research team and participants found it very difficult to juggle time zones across North America, Europe, and Asia, which contributed to low or declining participation throughout the study. These practical considerations should be carefully considered in project planning.

Future participatory modeling processes should also ensure that the research team has sufficient capacity to manage group coordination, facilitation and model building, as well as data collection and project evaluation. More people are often recommended as a best practice (Hovmand, 2014), however we would recommend at least two to three people to manage convening people, note taking, facilitation and modeling. Our efforts to engage more often with participants over a shorter period of time were thwarted by limited capacity among both the research team and participants. One member of the Modeling Group emphasized this limitation, when they said: "I think it's quite important in the process like this to maintain some kind of level of momentum, to keep everybody engaged and interested, because if they go away for too long. it's sort of coming back

cold, and because of the complexity of it, then it's pretty hard to get back into that head"space. Greater capacity and more realistic expectations could help to align levels of engagement with participants' expectations, potentially generating and sustaining further social bene ts. Finally, our study highlights the critical role of evaluation in participatory modeling. Greater capacity and intentional integration of evaluation strategies could help project managers determine if, and to what extent, broader bene ts are being achieved. Future SD modeling evaluation efforts could link more directly to theories of collaboration and consensus such as the co-orientation model, helping to explicitly identify accuracy of interpretations and assumptions, areas of agreement and congruency, and possible sources of con ict (Bail et al., 2018; Simcic Brønn and Brønn, 2003).

Conclusion

Participatory SD modeling can help researchers and practitioners work together to better understand challenging social-ecological problems in wildlife conservation and to design more effective, evidence-based strategies. Our study showed that virtual participatory modeling has the potential for individuals and group bene ts such as increased knowledge and collective understanding, improved collaboration and foundations of trust, and enhanced consensus - though these bene ts can vary based on level of engagement. The application of participatory SD in virtual environments allows for greater use in international wildlife conservation, providing an exciting opportunity for combating global challenges. Being explicit and clear about desired bene ts and limitations, and how they might be evaluated, can inform effective application of participatory modeling and systems thinking approaches. Despite its promise, there are no perfect solutions to addressing wicked problems that are inherently complex and involve diverse stakeholders with multiple values and goals. Yet even if immediate, tangible progress is not achieved through participatory modeling, this approach provides a valuable opportunity for participants to hear other perspectives and learn from each other in a constructive environment. Integrated into an adaptive management process, participatory SD modeling has the potential to generate social bene ts that build stronger coalitions and improve decision making in wildlife conservation.

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CHAPTER 5

Conclusion

To successfully protect imperiled species and natural resources, we need to integrate systems thinking into adaptive management in ways that capture dynamic complexity, integrate diverse perspectives, and improve collaboration for action. This dissertation shows that participatory SD modeling can be a valuable tool in this toolbox. We found that the participatory SD modeling approach could be adapted successfully to an international and virtual context. Co-creation of a conceptual CLD and a simulation model helped participants gain a more complete understanding of the potential connections between tiger farms and wild tigers. In addition to shifting some participants' perspectives regarding the impacts of tiger farms, the process also gave participants the opportunity to talk with others who have different views and it successfully provided a space to collaborate without creating further con icts.

Despite these bene ts, participatory SD modeling processes do not occur without challenges (Addison et al., 2013; Stave et al., 2019). There is often a learning curve given participants' unfamiliarity with systems thinking principles and the approach itself, which we witnessed in our process. Although we took time in the initial stages to introduce topics such as stocks, ows and feedback and discuss how these translate to tiger conservation, we still needed to revisit these topics multiple times. Participants also began the process with different levels of comfort and familiarity with systems thinking, and attention was needed to ensure no one was confused or left behind. As a result, effective participatory modeling requires suf cient technical capacity and a signi cant time commitment for both the research team and participants. Additionally, while SD models provide insights that can help to guide management and policy, key decision makers must be willing and able to utilize these tools to initiate action. Importantly, given the complexity of social-ecological

problems, care needs to be taken to minimize potential misinterpretation of any model outputs. Strategies for addressing these potential barriers undoubtedly vary by context, but investments of time and resources into systems-based approaches could ultimately lead to long-term changes in the way conservation efforts are conceptualized and carried out. Regardless of these challenges, we found that participants appreciated the unique opportunities this modeling process provided to challenge their assumptions and work with a diverse group of peers on an issue they were passionate about.

The causal-loop diagram (CLD), or conceptual model, presented in Chapter 3 provides a starting conceptual framework that can guide future research priorities and foster constructive conversations to improve understanding of how tiger farming affects wild tiger conservation. This CLD shows how the problem of tiger farms de es simple explanations, and how applying systems thinking and modeling approaches can provide a more rigorous and complete view of the social-ecological system connecting farms to wild tigers. Hopefully this CLD can be further re ned and improved, and complemented with a simulation model to help to guide future research to support better conservation strategies. We hope that future efforts can improve and build on this model, perhaps applying it to other species.

For researchers hoping to use participatory SD modeling in their future works, we offer the following recommendations based on our experience:

1. Identify at least two to three people with suf cient time and resources for project management, facilitation and recording, model building and evaluation. Successful implementation of this process involves skilled workshop facilitation and coordination of participants, model building and related data collection, and research. If the topic is contentious, time and attention will also be needed in managing relationships and responding to the needs of participants to minimize con ict.

2. Capitalize on the use of virtual tools, especially for international collaborations, but try to incorporate hybrid or face-to-face elements whenever possible. Tools such as Miro and Zoom can be used as virtual whiteboards and meeting rooms, but they need to be used strategically to be effective collaboration spaces. Surveys can serve as useful tools for model-speci c feedback.

3. Provide opportunities for different levels of engagement to balance the tension between getting input and support from diverse participants and the capacity of the research team and limits of constructive meetings. Set and manage realistic expectations for participant engagement to avoid overpromising, and provide multiple opportunities for variable engagement based on participants' preferences and availability, especially if working across multiple time zones.

4. Develop a clear problem statement or question to direct the modeling effort and to avoid becoming overwhelmed by complexity. This statement, which is a key component of SD modeling processes (Andersen et al., 2017) should be informed by relevant reference modes, or changes over time in key variables such as the decline of wild tiger populations. Refer to this statement often to focus discussions and model boundary, yet be open to the statement evolving as the process develops (Mashayekhi and Ghili, 2012).

5. Spend suf cient time developing the conceptual model (the CLD) and use it as reference throughout the process, but recognize that participant excitement in the process will likely grow when the simulation model is introduced. The CLD focuses discussions while remaining informal enough to edit and change, as needed. Use the simulation model to gain insights from the CLD - testing the impacts of different policy interventions within the system - and update each model iteratively as understanding grows. Strive to keep both models as simple as possible because a complicated model is harder to understand and discuss, and not all participants may be equally comfortable with systems thinking.

6. Allow for the reality that seemingly contradicting viewpoints can be true under different conditions or points in time. Additionally, people often use the same words yet de ne them differently. Foster an environment where people can ask questions and encourage being explicit in the use and de nition of terms. As people work through this process they are also likely to become more aware of complexity and uncertainty, and their picture of the problem may become murkier before it gets clearer. Encouragement may be needed to keep working through these challenges and building comfort with the uncertainty inherent in complex systems.

7. Incorporate multiple opportunities for participant input and feedback throughout the process. This could include surveys, interviews or one-on-one meetings, or collaborative shared documents. Feedback is especially important for ensuring that the modeler and participants agree on key relationships in the simulation model to ensure model integrity and avoid misinterpretation of results.

8. Incorporate systematic evaluation of multiple process outcomes to ensure that diverse goals (e.g., advanced understanding, increased trust, enhanced consensus and commitment to action) are being achieved, and identity opportunities for improvement. Be clear on the realistic objectives of the modeling process and align evaluation metrics carefully with objectives. Remember that social outcomes such as trust may take longer to change than the modeling effort allows, and adjust the process accordingly.

9. Remember that, while it is tempting to focus solely on creating the most accurate model, participatory modeling is as much a social process as a technical one. Especially with contentious issues such as tiger conservation, veri cation of the accuracy of all statements may be less important than making sure that participants are heard and input is valued. Unintended consequences (e.g., emergence of unexpected disagreements once perspectives are dissected) may require additional time to strengthen relationships and smooth disagreements, helping participants arrive at some type of collective understanding and consensus.

10. Maintain optimism throughout the process but recognize, and make sure participants recognize, that there may be no “silver bullet” solutions.There are reasons why wicked conservation problems often remain unsolved, and why addressing them takes substantial time and coordinated action. The process is bound to be a little messy, and potentially frustrating for some. For maximum sustainable impact, nd ways to incorporate participatory SD modeling into larger initiatives or existing adaptive management practices. Whether or not it is possible to reach agreement on clear cut policy solutions, people will appreciate the opportunity to constructively engage on problems they are passionate about solving and a more integrated approach allows for iterative model and strategy revisions as more is learned about the system.

In summary, participatory SD modeling is a valuable tool that can help researchers and practitioners advance understanding of challenging social-ecological problems in wildlife conservation and design more effective, evidence-based strategies for addressing them. Participatory modeling provides wide-ranging bene ts for individuals and groups that includes increased knowledge and collective understanding, improved collaboration and trust, and overall consensus and commitment for action. The use of participatory SD in virtual environments, though not without challenges, allows for increased applications in international wildlife conservation, providing an exciting opportunity for combating global challenges. Being explicit and clear about desired bene ts and limitations, and how they might be evaluated, can help to fuel successful outcomes for conservation. Despite this promise, it is important to realize that there are no silver bullets; in situations where diverse stakeholders hold multiple values and goals, developing strategies and creating change to address wicked problems is inherently challenging and time consuming. But even if immediate, tangible progress is not made through participatory modeling, this approach provides other social bene ts by creating a valuable opportunity for participants to hear other perspectives and learn from each other in a constructive environment. Integrated into an adaptive management process, participatory SD modeling holds great potential for building stronger conservation coalitions and improving decision-making with respect to challenging and contention issues.

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APPENDICES

APPENDIX A

Survey Instruments