Improving environmental interventions by understanding social networks

Emiel de Lange

THE UNIVERSITY *of* EDINBURGH

Thesis submitted for the degree of

Doctor of Philosophy

The University of Edinburgh

School of Geoscience

2021

Abstract

Interventions to conserve biodiversity often aim to change human behaviour. Social relations and interactions, or social networks, have a strong influence on the information people receive and on their behaviour. Thus, the interactions between social networks and behaviour have been the subject of intense research effort in countless domains, and practitioners in fields such as public health have developed a range of strategies which account for relational processes in their interventions. This thesis seeks to integrate these insights into conservation and explore their practical implications. I begin by synthesising the literature and discussing the relevance of social network interventions for conservation. The remainder of the thesis examines the role of social networks in a case study intervention aiming to reduce wildlife poisoning in Northern Cambodia. I first use a mixed-method approach to better understand wildlife poisoning. I find that it is widespread, occurring in eight of the ten villages studied, but generally low prevalence, and often carried out by young men or children. However, most residents hold negative attitudes towards poisoning. With the Wildlife Conservation Society (WCS) Cambodia, I develop and pilot a social marketing intervention to promote the use of a hotline for reporting incidences of poisoning. I then use longitudinal data on behaviour and dynamic social network models to unpick the role of information flow and social influence in this intervention. I find that information from the intervention flowed widely through the village social networks, particularly within households, reaching an audience three-times larger than originally targeted. Having a knowledgeable household member doubled the probability that an individual would become knowledgeable. I also find that intention to report poisoning increases throughout the village in the short-term but returns to baseline levels in the long term. These changes are not driven by knowledge of the intervention. Instead, individuals are influenced by the intentions of network peers. One way to more effectively produce behavioural change that exploits these social influences is to target interventions at influential individuals identified using sociometric data. Using diffusion simulations, I explore the cost-effectiveness of these approaches within the study village. I find that network-informed targeting could result in uptake of the hotline more than double other targeting strategies, but that the relatively high cost of collecting network data makes it cost-ineffective. A more feasible strategy for large-scale interventions might be to conduct network research to identify general rules-of-thumb that can be used to select influential

individuals. However, I find that rules-of-thumb identified in other contexts do not apply in Cambodia. Overall, my findings highlight the critical importance of social relations in shaping the outcomes of conservation interventions and illustrate some possible strategies for exploiting them in intervention.

Lay Summary

Consider some of the major factors causing deforestation or the extinction of wildlife; clearing of forests for agriculture, over-hunting of wildlife, or logging for wood. All these factors result from people's actions. So, to conserve habitats and wildlife, we need to understand why people behave as they do. One of the most important influences on people's behaviour is the behaviour of the people they communicate and interact with on a regular basis – their social networks. Understanding social networks - how and from whom people get information on different topics - can therefore help us to more effectively influence their behaviour, such as by working with influential 'opinion leaders' who are connected to many people. In this thesis, I explore how this might work in a conservation context.

I started by reviewing the published literature from other disciplines, such as public health and sociology, and considered the relevance of the approaches they use to conservation. Then, in the rest of the thesis I looked at the role of social networks in an intervention aiming to reduce wildlife poisoning in Cambodia. First, I used a variety of research methods to better understand wildlife poisoning. I found that some residents are poisoning wildlife for food, particularly young men, and some children. But most residents in the area are strongly against wildlife poisoning. To help local efforts against poisoning, I therefore worked with a local NGO, WCS Cambodia, to develop and test a strategy for promoting the use of a hotline for reporting poisoning in one village.

To look at how the village social network might affect the success of these efforts, I used a survey to gather information from everyone in the village about their social relations, enabling me to map the social network in the village. I then used surveys to measure residents' behaviour and knowledge at three time points, before and after the intervention. I used dynamic network models to determine how these changes relate to the social network. WCS invited a group of 41 people to the promotion event, but I found that information from the event spread through the village, so at least 144 people had received some information after six months. Most of this spread occurred within households. After two weeks, people throughout the village reported being more likely to report poisoning. But this was not a result of them learning about the hotline. Instead, it seems they were influenced by their peers who attended the event. After six months, this peer influence also played a role in people reverting to their previous level of behaviour.

With information about the social network, WCS may be able to better spread information about the hotline, or target people who can persuade others to use it. I use computer simulations to see how information about the hotline, or intention to use the hotline, might spread through the network depending on who WCS targets to receive information. I find that targeting individuals that are highly connected in the network is much more effective than targeting people based on other characteristics, such as wealthy people or those in leadership positions. However, this increase in effectiveness is not large enough to justify the costs of collecting and analysing network data. It would be more cost-effective to target a greater number of randomly chosen people. If WCS are promoting the hotline in many villages, they might be able to analyse the social network of one village to identify some rules-of-thumb about what sorts of people are well connected, which they can then apply elsewhere. For example, perhaps wealthy households tend to be better connected. But I find that rules-of-thumb identified in other studies do not apply here and are probably quite context-specific.

Overall, this thesis highlights how important it is to take social networks into account when designing a behaviour-change strategy. We find that social relationships can help to spread information but can also reinforce existing behaviours and prevent behaviour change. Understanding the structure of a social network can suggest targeting strategies that could overcome this barrier, and interventions should try to use social influences wherever possible. For example, once some residents adopt a new behaviour, they can be a valuable resource for influencing others.

Acknowledgements

Foremost thanks are due to my supervisors, Dr Aidan Keane and Professor EJ Milner-Gulland. They have been fantastic, supportive mentors and I hope we will continue working together in the future. This thesis is impossible to imagine without them. Different parts of this thesis would also have been impossible without the patient guidance and generous knowledge of my collaborators. To Dr Andy Dobson for his assistance developing the simulation models in Chapter 6, and to Dr Cohen Simpson for always being a reassuring voice on the phone when I struggled with RSiena. Thanks to Dr Diogo Verissimo for his guidance in social marketing. I would also like to thank my advisor Janet Fisher, and other staff within the School of Geosciences who have enriched my academic life in numerous ways, including Sam Staddon, Clare Barnes, Isla Myers-Smith, and Casey Ryan. And thanks to ICCS, for being such a positive group of peers.

I am proud that this thesis comes from the real world and was born from a collaboration with the Wildlife Conservation Society Cambodia programme. I am grateful that they gave me room to grow and that they have the open-mindedness to allow a young researcher to interfere in their interventions. Thanks to Simon and Sarah, who took me in to their home in Phnom Penh. To Alistair for guiding me through the halls of power in Preah Vihear. To Sithan, Sitha, Sakuna, Kim Lang, Solita, Khean, Sophan, Vann (may he rest in peace), Sokha, Sokny, Chris Hamley, and all the other staff in Preah Vihear for assisting me in innumerable ways and letting me score in football. My thanks must also go to the Ministry of Environment of the Royal Government of Cambodia, the provincial Department of Environment in Preah Vihear, and the provincial Governors office of Preah Vihear, for providing me permissions. Most of all, this research owes its existence to my fieldworkers who put up with sometimes challenging conditions and always worked with good humour. Vichet and Theavy, we had a baptism by fire (or was it by rain?)! Vimean, Rithy, Sothea, Samreaksa, and Siekleang, thank you all for your company and efforts. Perhaps even more importantly, this research would not have been possible without the generous time and hospitality given by the residents of twelve villages in Preah Vihear province.

សូមអរគុណជាពិសេសចំពោះអោ រឿន និង សៃ សុខន។

On a more personal note: I would not have completed this thesis without the support, distraction, and care of my friends, and family. To the Barradise family: Zac, Emma, Ioanna, Josep, Eoin, and Jack. I could not have dreamt of a more pleasant office environment; I hope we can gather at Kebab Mahal again one day. To my other PhD family: Jiayen, Keiko, Ivonne, Josep, Gergo, and others; we will celebrate our graduations together when this pandemic is over. To Harriet, my Cambodia buddy. To Phun and the gang from Kampong Thom, for letting me be one of them. And last but not least, thank you to my parents, for their unflagging support, and for caring for me as I finished my thesis at home while the pandemic raged. I would not be who I am now without you.

This work was funded by a studentship from NERC UK, and an early career grant from the National Geographic Society.

កំហុសរមែងមានដល់អ្នកធ្វើ អ្នកនៅឥតអំពើរ បានអ្វីនឹងខុស ។

Blame for error always lies with those who act;
those who do nothing, what do they have to be wrong about?

ឃ្វាលក្របីជិះក្របី ឃ្វាលគោជិះគោ ។

Tending the buffalo, ride the buffalo; tending the cow, ride the cow.

ចង់ចេះធ្វើល្ងង់ ។

If you want knowledge, act ignorant.

Declaration of Originality

I, Emiel de Lange, declare that this thesis has been composed by me, that it is my own work, that it has not been submitted for any other degree or professional qualification, and that the publications included in this thesis (listed below) are my own work except where indicated.

Signature: Emiel de Lange

Date: 12/03/2021

Table of Contents

List of Tables & Figures

1. Introduction

1.1 Problem statement

Conservation problems are largely driven by human behaviours. As such, the behavioural sciences can play an important role in designing conservation interventions (St. John, Keane & Milner-Gulland, 2013; Milner-Gulland, 2012; Schultz, 2011; Reddy *et al.*, 2016). Recognising this, conservation scientists have begun drawing on theory and evidence from the behavioural sciences and from behaviour-change disciplines such as public health and social marketing (Bennett *et al.*, 2017). Insight from these fields can provide valuable frameworks through which to analyse conservation issues, and useful tools for designing interventions. For example, the Theory of Planned Behaviour (Ajzen, 1991) is now widely used to assess the determinants of conservation behaviours (Mastrangelo *et al.*, 2014; Steinmetz *et al.*, 2014; Ward, Holmes & Stringer, 2018), and there is a burgeoning discipline of 'conservation marketing' which aims to apply the methods of social marketing to conservation problems (Wright *et al.*, 2015; Ryan *et al.*, 2020).

Social scientists have long understood the importance of social relations in shaping individual behaviours. At the micro-scale, research has highlighted the ways in which individuals influence one another, and shape one another's perceptions of social norms (Cialdini & Goldstein, 2004; Shepherd, 2017). At larger scales, the social relations between individuals aggregate to form social structures (Borgatti *et al.*, 2009) which shape the distribution and patterns of change in behaviour within a population (Centola, 2018; Rogers, 2003). Even in environments with high penetration of mass media and digital communications, social relations have been found to play an important role in people's interpretation of and response to information (Bennett & Manheim, 2006; Hilbert *et al.*, 2017). Understanding how social relations are structured and how they interact with behaviour therefore has the potential to suggest more effective forms of social intervention (Valente, 2012), and such strategies have been widely used in other disciplines, such as public health (Kim *et al.*, 2015; Perkins, Subramanian & Christakis, 2015), counterterrorism (e.g. Everton, 2012), agricultural extension (Beaman *et al.*, 2014), and social work (Sales, Estabrooks & Valente, 2010).

A powerful way by which researchers and practitioners can conceptualise social relations and make them amenable to analysis is as a social network. In a social network, individuals are represented as nodes that are connected to one another through ties, corresponding to different forms of relation or interaction, such as communication, affiliation, or resource exchange. A social network therefore consists of a population of nodes and the ties between them, of multiple types, which can differ in their importance (Borgatti *et al.*, 2009; Knoke & Yang, 2011). Measurement of a social network can be done in a variety of ways, but the most common approach for offline interactions is a survey instrument called the 'name generator', which asks respondents to nominate individuals with whom they interact in specific ways (Shakya, Christakis & Fowler, 2017). This sociometric data can then be analysed using mathematical and statistical methods derived from graph theory (Wasserman & Faust, 1994).

Interventions making use of sociometric data or other information about social relations fall broadly into four categories (Valente, 2012): First, interveners can identify individuals occupying important positions in a network, such as those with high numbers of connections, and target them for an intervention to leverage their positions (Valente & Pumpuang, 2007). Second, interventions can be designed so that they induce further interaction in the network, such as in viral marketing (Kaplan & Haenlein, 2011). Third, individuals in a network can be segmented and targeted separately based on their position in the social structure, such as identifying those at the periphery or core of a social group (Borgatti & Everett, 2000). Finally, practitioners can intervene in the social structure of a group, encouraging the removal or creation of new ties between individuals. For example, they could bring together individuals from disconnected groups to facilitate collective action or learning (Pretty & Ward, 2001). These approaches are discussed more fully in Chapter three.

Behavioural research in conservation science has largely focused on the attitudes, behaviours, and knowledge of individual decision makers (St. John, Keane & Milner-Gulland, 2013; Bennett *et al.*, 2017). This has provided insights into how conservation messages can be framed (Kidd *et al.*, 2019; Kusmanoff *et al.*, 2020), how audiences can be segmented according to relevant characteristics (Jones *et al.*, 2019; St. John *et al.*, 2018), or how individuals are likely to respond to financial incentives (Selinske *et al.*, 2017; Sommerville, Rahajaharison & Jones, 2010). Although frameworks such as the Theory of Planned Behaviour do account for social effects (i.e. the individual's perception of social norms), and the literature on message framing emphasises the importance of normative frames, these perspectives emphasise individual cognition rather than the dynamic social processes through which conservation behaviours spread and norms are produced (Bodin & Prell, 2011; Prentice & Paluck, 2020).

Research on these social processes is still rare in conservation in the context of behaviour-change interventions, but several important studies have been published in recent years, which examine various aspects of social networks in conservation behaviour. For example, Barnes et al., (2016) examined the relation between network structure and shark bycatch in a Hawaiian fishery and demonstrated that social networks do shape conservation outcomes. Turning to the possibilities for intervention, Mbaru & Barnes (2017) used network data to identify influential fishermen on the Kenyan coast. They showed that those in formal leadership positions tend to occupy important positions in the social networks of fishermen. In the related field of agricultural extension, a large randomised controlled trial has demonstrated the effectiveness of using network theory to target farmers for the promotion of new sustainable practices (Beaman *et al.*, 2014). More recently, Rhodes et al. (2020) used simulations to assess the value of social network data for intervening depending on the social structure of human populations and the spatial distribution of wildlife populations.

There is still huge scope for conservation science to better understand how social networks shape conservation outcomes, and to integrate insights from other disciplines to improve the effectiveness of conservation interventions. In this thesis, I hope to contribute to these aims using a case study from Cambodia focussed on wildlife poisoning. Using data from a real intervention, I seek to understand the role of social processes such as information flow and social influence in producing a behaviour change. I then use simulations to explore how data on social relations can be used in designing conservation interventions that more effectively influence behaviour.

1.2 Aims and objectives

The overall aim of this thesis is to contribute to more effective design of conservation interventions, by furthering understanding of the role of social networks in conservation behaviours.

The objectives of the study are as follows:

1. To synthesise knowledge about social networks and explore their relevance for conservation.
2. To investigate wildlife poisoning behaviours in Cambodia's Northern Plains and inform the design of effective interventions
3. To examine the role of social network processes in the success of a conservation intervention intended to reduce wildlife poisoning.
4. To understand how information about a social network could be cost-effectively integrated into intervention design.

1.3 Thesis outline

1.3.1 Chapter 1

In the first chapter, I give an overview of the problems this thesis aims to address and set out the objectives. I then describe some of the key methodological approaches used in the thesis and discuss the positionality and ethics of the research.

1.3.2 Chapter 2

Here I give the background and context of my study site, Cambodia's Northern Plains, and describe the villages where fieldwork was conducted. I give an overview of existing conservation interventions and previous research conducted in the area. Finally, I review knowledge about social relations in the case-study village.

1.3.3 Chapter 3

This chapter synthesises the literature on information flows and social networks in the context of behaviour change interventions – the central concern of my thesis; and presents theory that will underlie the remaining chapters. Information flow in social networks is a well-established field of practice and research in areas such as public health, but it has been little developed in conservation. I therefore relate these insights as much as possible to conservation contexts.

This chapter is published as: de Lange E, Milner-Gulland EJ, & Keane A. Improving Environmental Interventions by Understanding Information Flows. Trends Ecol. Evol., 34 (2019), pp. 1034-1047, 10.1016/j.tree.2019.06.007

I wrote this chapter, with input from all authors.

1.3.4 Chapter 4

Conservation interventions are more likely to succeed if they are grounded in a robust understanding of the problem they are intended to address. In this chapter, I report on a study of wildlife poisoning in Cambodia's Northern Plains, which forms the basis for the intervention studied in later chapters. I used a mixed-methods approach, combing structured surveys with focus group discussions and key informant interviews in 12 villages. I aim to understand the key groups engaging in or enabling wildlife poisoning, their motivations, and the social context in which it occurs.

This chapter is published as: de Lange E, Milner-Gulland EJ, Yim V, Leng C, Phann S, & Keane AM. Using mixed methods to understand sensitive wildlife poisoning behaviours in northern Cambodia. Oryx. doi:10.1017/S0030605319001492

I wrote this chapter. The study was designed by me, AK, and EJMG, with input from all authors. EdL, YV, and LC collected the data. All authors reviewed the manuscript.

1.3.5 Chapter 5

This chapter examines the role of social networks in mediating the success of the intervention aiming to promote a hotline for reporting poisoning. I use complete social network data in the village, together with three waves of data on knowledge and behaviour, to model the relation between networks and behaviour using stochastic actor-oriented models. I focus on the processes of information flow and social influence.

This chapter has been submitted for review at Conservation Biology. I wrote this chapter. The study was designed by me, AK, and EJMG. All authors reviewed the manuscript.

1.3.6 Chapter 6

This chapter asks: How can information about a social network best be used to inform the design of interventions that aim to spread information or change behaviour, in a cost-effective manner? I use complete social network and other forms of data collected in our study village to generate possible intervention targeting strategies. I then use simulations of behaviour change and information diffusion in the network to assess which strategies are most effective, and which are cost-effective.

This chapter has been submitted for review at Biological Conservation. I wrote this chapter. The study was designed with input from all authors. Andy M Dobson and I designed the simulations models. All authors reviewed the manuscript.

1.3.7 Chapter 7

This chapter synthesises the main findings of this thesis and presents recommendations for practitioners and for future study.

1.3.8 Other published research

Throughout my PhD I have had the good fortune to be involved with several other projects and publications, some of which are related to my PhD, but many of which are not. To date, this has resulted in the following publications:

1. Dobson A.D.M., de Lange E., Keane A., Ibbett H., and Milner-Gulland E. J. 2019. Integrating models of human behaviour between the individual and population levels to inform conservation interventions. *Philosophical Transactions of the Royal Society B*, 374: 20180053

2. Brittain, S., Ibbett, H., de Lange, E., Dorward, L., Hoyte, S., Marino, A., Milner-Gulland, E.J., Newth, J., Rakotonarivo, S., Veríssimo, D. and Lewis, J. (2020), Ethical considerations when conservation research involves people. *Conservation Biology*, 34: 925-933.

3. Veríssimo, D., et al. “Ethical Publishing in Biodiversity Conservation Science.” *Conservation & Society*, vol. 18, no. 3, 2020, pp. 220–225.

4. Pienkowski, T., et al. “Personal traits predict conservationists’ optimism about outcomes for nature”. In review at *Conservation Letters*.

5. Pienkowski, T., et al. “Balancing making a difference with making a living in the conservation sector”. In review at *Conservation Biology*.

1.4 Methodological approach

This thesis is a work of applied science. I have not attempted to answer any fundamental questions about social organisation or behaviour. Instead, in this thesis I attempt to generate knowledge that will help a particular set of social actors to achieve their objectives; conservationists (Sandbrook *et al.*, 2013), whose goal is to preserve the diversity of living things that inhabit this planet. Achieving this goal requires tackling complex problems that do not sit neatly within the boundaries of any scholarly discipline (Kareiva & Marvier, 2012). The thesis is therefore an interdisciplinary work, drawing on knowledge from diverse fields. Applied and interdisciplinary conservation research inevitably carries with it significant epistemological, methodological, political, and ethical implications (Nicolescu, 2014; Pooley, Mendelsohn & Milner-Gulland, 2013).

There are distinct epistemologies operating within the natural and social sciences. Conservation science is historically rooted in conservation biology (Soulé, 1985; Kareiva & Marvier, 2012) and *positivism*, which posits that there is an objective natural world which can be understood through the scientific method. But as conservation science becomes increasingly interdisciplinary and focused on social processes, social scientists have critiqued the discipline by showing that 'nature' is understood and constructed through social, cultural, and political processes, a perspective known as *constructivism* (Adams, 2007; Neumann, 2005). A possible synthesis of these perspectives is *critical realism*, which posits that the world (and nature) does exist independently of human knowledge of it, but that scientific knowledge can only produce a representation of this reality (Neumann, 2005). I adopt this perspective, since the representation of reality produced through scientific measurement and observation can be useful for acting upon that reality without making any claims about the true nature of reality.

Applied science aims to generate knowledge which can be used by social actors. This knowledge is most likely to be useful when it is co-produced with local practitioners (Beier *et al.*, 2017; Smith *et al.*, 2009). I therefore undertook efforts to develop this thesis in collaboration with the Wildlife Conservation Society (WCS) and Cambodia's Ministry of Environment. Together, we defined the scope of the research and identified the research problems through a series of meetings and workshops held in March 2017. This collaboration forms part of a longer and broader collaboration between WCS and my supervisors, particularly Professor Milner-Gulland.

Conservation interventions, such as those implemented by WCS and the Ministry of Environment, often follow a project cycle comprising five steps: 1) conceptualising the problem; 2) planning actions to address the problem; 3) implementing these actions; 4) analysing and evaluating data from these actions; and 5) learning from these evaluations (Figure 1.1, Grantham et al., 2010). The thesis follows a similar structure, mirroring the collaborative process undertaken. Following identification of wildlife poisoning as the focal issue, my collaborators and I co-designed research to better understand the problem (presented in Chapter 4). In July 2018, I facilitated a three-day workshop with collaborators and representatives from local communities, to discuss these results and plan an intervention. This intervention was implemented by WCS with support from the various local government departments in February 2019 (see Chapter 2 for more details). I also planned a monitoring and evaluation approach, for which I conducted three seasons of fieldwork in 2019. The results of these evaluations are reported in Chapter five and form the basis of separate communications with collaborators which are intended to facilitate learning. Chapter six also aims to formalise some of the learning from this process.

This thesis, then, focuses largely on a case-study intervention, taking place in one community. Case study research is often mistakenly viewed as of limited interest because of supposed difficulties in generalising from the case (Flyvbjerg, 2006). However, this thesis makes several contributions which are of general interest (Yin, 2014). First, through detailed analysis of fine-scale data I unpick the mechanisms and processes operating within our case. Consequently, I can point to important phenomena which have previously not been considered in the literature. For example, Chapter five details the importance of social influence mechanisms in shaping conservation outcomes. Second, I demonstrate the application and value of novel study designs and analyses which may serve as a model for future research. For example, Chapters five and six respectively demonstrate new ways of modelling and simulating how behaviour change occurs in a social network. These methods could be applied more broadly in conservation research to plan and evaluate interventions. Taken together, these two points suggest that our case study might therefore be seen as a paradigmatic case study for future work (Flyvbjerg, 2006).

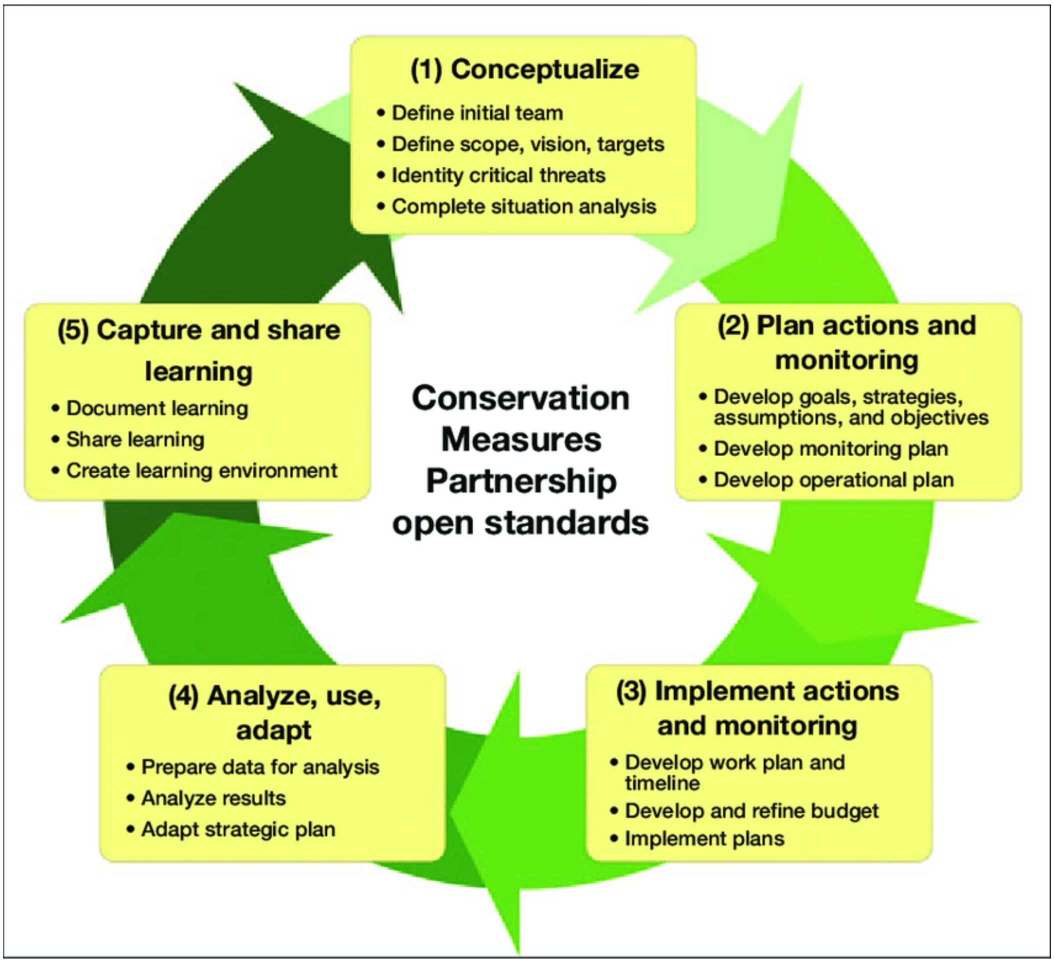


Figure 1.1: The Open Standards Project Management Cycle, produced by the Conservation Measures Partnership. This represents the five key steps of project management: 1) conceptualising the problem; 2) planning actions; 3) implementing actions; 4) analysing and adapting; and 5) capturing learning. For more details, see: http://www.conservationmeasures.org/CMP/

Third, I replicate and deploy methodologies used or proposed by other scholars. Our findings complicate or contradict the findings of this previous research, allowing us to nuance disciplinary understanding and pose further questions. For example, Chapter six finds that methods of identifying key players used in other conservation contexts are difficult to apply in Cambodia. In this sense, our case acts as a critical case (Flyvbjerg, 2006). Fourth, through careful analysis of the context of our case and comparison with other cases, I suggest some general implications from our findings. For example, Chapter six analyses the cost-effectiveness of network-informed targeting strategies using our case study intervention, but I provide some general recommendations by considering how other intervention types might vary from this case study. Finally, effective scientific disciplines require the production of empirical exemplary cases (Kuhn, 1987). As financial pressures and career incentives are reducing the proportion of conservation science publications that are based on fieldwork and data collection from new cases (Ríos-Saldaña, Delibes-Mateos & Ferreira, 2018), rigorous empirical exploration of case studies is more important than ever.

Throughout this thesis I use the Theory of Planned Behaviour (Ajzen, 1991) to conceptualise and measure conservation behaviours and socio-psychological predictors of behaviour. In Chapter 4, I aim to measure the predictors of wildlife poisoning, while in Chapters 5 and 6, I am measuring respondent's intention to report wildlife poisoning. Using the Theory of Planned Behaviour has several advantages. First, it is the most widely studied cognitive theory and there is strong empirical support for its predictive utility across a wide range of behaviours (Hagger, Chatzisarantis & Biddle, 2002; Armitage & Conner, 2001), including dishonest behaviours (Beck & Ajzen, 1991). It has also been used to successfully understand and predict conservation behaviours, such as participation in protected area governance in Madagascar (Ward, Holmes & Stringer, 2018) and forest conservation by landholders in the Gran Chaco (Mastrangelo *et al.*, 2014). Second, there are clear processes and guidelines for operationalising the theory, resulting in quantitative measures that can be used to compare individuals and populations (Fishbein & Ajzen, 2010). Third, the theory provides a clear framework for informing the design of behaviour-change interventions, a consideration at the core of this thesis (Michie *et al.*, 2008; Hardeman *et al.*, 2002). Finally, the focus on individual decision-making is compatible with my research questions, which aim to unpack the role of social relations between individuals that make up a community (Gurney *et al.*, 2016; Agrawal & Gibson, 1999).

As implied by its name, the Theory of Planned Behaviour, is most relevant to behaviours that are intentional and planned (Ajzen, 1991). This distinguishes it from other frameworks, such as social practice theory, which focuses on regular or habitual practices and places the focus of attention on the practice rather than individual (Kurz *et al.*, 2015). Based on preparatory qualitative work, I learned that both the act of wildlife poisoning and the act of reporting poisoning events are likely to be planned actions, and compatible with the Theory of Planned Behaviour. However, the theory may fail to account for affective (van der Pligt *et al.*, 1997) or other forms of context-specific motivations. Indeed, one potential difficulty with the Theory of Planned Behaviour is that it measures intentions within very specific contexts which must be carefully defined in terms of timing, targets, actors, and actions (Presseau *et al.*, 2019), which is challenging for the behaviours I study.

A final methodological consideration worth discussing is the relation between qualitative and quantitative data. Both forms of data are important for understanding complex social problems, and both are employed throughout the thesis in various combinations, enhancing the quality and explanatory power of my results (Hollstein, 2016). In Chapters four, five, and six, a sequential exploratory design is used, whereby qualitative data is collected to inform the subsequent design and deployment of quantitative measures. This ensures the measures are internally valid and well designed. In Chapter four, qualitative and quantitative methods are used in parallel, and the results are jointly interpreted, enabling both breadth and depth in understanding. Chapters five and six also involve some conversion of qualitative data into quantitative data. For example, I ask people about the intervention, and convert their open-ended responses into a quantitative knowledge score.

1.5 Positionality & Ethics

1.5.1 My intellectual position

When I began this research, I hoped it would give me the opportunity to become a fully-fledged social scientist. I had graduated with a bachelor's degree in biology with a focus on ecology, through which I had learned to look at the world from the positivist perspective of a natural scientist. I had also been exposed to little bits of social science, in courses such as resource management, which piqued my interest in the social complexities underlying conservation although they framed these as technical problems that could largely be solved through technical solutions or through market mechanisms.

At the end of my degree, I completed a thesis with Professor E.J. Milner-Gulland (then at Imperial College London). For the first time, I was exposed to literature on social justice, equity, and human wellbeing. I had to come to grips with the distinction between quantitative and qualitative data, the different methods of collecting social data, and many possible study designs for social research. Not yet fully turned away from ecology, I subsequently enrolled in a master's course in 'tropical forest ecology', but I soon realised my interests were firmly with the 'human dimensions'. Thankfully, I had a great deal of flexibility in selecting a 9-month research project, and Professor Milner-Gulland put me in touch with WCS Cambodia. In designing my thesis project, I was simply glad to have the chance of conducting research in collaboration with real conservationists and went along with whatever WCS said would be useful for them.

I spent five months in Cambodia, at the Seima protection forest, and some time conducting fieldwork in a Bunong community. This period felt like a baptism of fire. With very little training or guidance (my supervisors were an ecologist and a practitioner, no social scientist among them), I was conducting interviews in a context completely different from any I had previously been in, culturally and politically. Although from an academic standpoint the project was not a great success, I learned a great deal: about the challenges of social research; about working cross-culturally; about the complex reality and politics of conservation; and about the workings of conservation organisations. My ethical and moral convictions were also being unsettled.

When the opportunity arose to do further research with WCS in Cambodia and with two excellent supervisors I jumped at it. I began with a strong awareness of my patchy education as a social scientist, and therefore a determination to learn from a wide variety of social science perspectives. I also wanted to explore the space between the practitioner and the scholar more fully. I have learned a great deal throughout the PhD, and my perspectives have changed substantially. Experience in the field and exposure to anthropological and geographical thought has disabused me of the notion that society can be explained and acted on with the mathematical surety of a physical system and impressed on me the importance of cultural meaning and power. I have thus felt a tension between conflicting perspectives: between the practitioner's demands for actionable knowledge, and the scholarly desire to step back and reflect dispassionately; between the scientists need for systematic data collection, and human curiosity and empathy in the lives of others; and between the position of critique and the position of co-production. At times, these tensions have been challenging and uncomfortable, but I hope they have also been productive.

1.5.2 Conservation research in Cambodia

Conducting applied conservation research in Cambodia necessarily enmeshes the researcher in a complicated web of relations, which must be acknowledged and negotiated (Brittain *et al.*, 2020).

The collaboration and guidance of the Wildlife Conservation Society Cambodia programme was essential in producing this thesis. WCS have been active in the landscape for over 20 years and have deep, if complicated, links with local government and local communities (see Chapter 2, Riggs, Langston & Phann, 2020). For example, several staff were until recently on secondment from WCS to the local Department of Environment or split their time between both organisations. WCS support was essential for receiving research permissions, and they often acted as a broker for me by arranging meetings with government officials.

Throughout the process, I felt that WCS respected my independence as a scholar and gave me considerable freedoms to pursue the research as I saw fit. Nevertheless, co-producing this research with WCS meant the questions I tried to answer were strongly shaped by WCS priorities through negotiation and discussion. It also meant that throughout the research, I felt some responsibilities towards WCS, such as to provide useful feedback, or to advise on various questions. As a result of the long periods I spent in the villages, some staff at higher levels of the organisation began to see me as an informant. I recognised the limitations of my perspective, but also felt an obligation, and perhaps a pride, in being useful. I felt that WCS listened with an open mind, even when I brought critique and it is to their credit that they dedicated staff and resources to the workshops and interventions I facilitated, which were new and challenging. Nevertheless, there were clear institutional boundaries to what WCS could participate in. To a large extent, these are shaped by their relation to the State.

Another important relation for producing this research was my relationship with my research assistants. Over the course of the PhD, I worked with seven individuals. Yim Vichet, Leang Chantheavy, Bun Sothea, Chor Siekleang, Seang Samreaksa, and Roeurn Rithy, were all undergraduate students (or recent graduates), recruited from the Royal University of Agriculture or the Royal University of Phnom Penh. Vichet and Chantheavy were part of the team at the start of the project, and they contributed significantly to research design and survey piloting. Their contributions are recognised with co-authorship of Chapter four. The other researchers joined the project for several months at a time, such as during their summer break, and were responsible for implementing survey protocols that had already been established previously. Nevertheless, I tried to get their input wherever possible, and to give them ownership of their own working methods and patterns as much as possible. At a later stage I also recruited Hout Vimean, a more experienced freelance researcher, who lives in Preah Vihear province. This allowed me to leave the research team to work independently while I travelled to meetings elsewhere.

The research assistants were the main point of interaction for most respondents (Figure 1.2). Aside from the practical considerations of their involvement (translating conversations, making up for deficiencies in my language skills, and dividing the workload to conduct surveys more quickly), their presence also served to legitimise our status as 'students' and facilitated relations with the host families. Although the research assistants tended to be from more affluent parts of the country and were often surprised at the basic conditions in the villages, they inevitably were a more familiar presence for villagers and may have reduced suspicions. I observed that they often got along well with our host families, they helped to cook and played with the children, and there was genuine mutual exchange of stories and experiences.

Figure 1.2. Vichet and I interviewing a respondent

Conducting academic research in Cambodia's frontier regions, one is continuously aware and made fearful of state power (Schoenberger & Beban, 2018). In order to be able to carry out academic work, researchers are forced to adopt various strategies (Schoenberger & Beban, 2017). Without concealing my relationship with WCS, I attempted to construct an identity as a 'neutral' academic (or even as the less threatening 'student'), carrying letters from the university and many copies of official permission letters. In conversation, I emphasised the aspects of the research that are 'apolitical' and emphasised my status as naïve outsider.

Nevertheless, in Cambodia the presence of outsiders in remote forest areas brings the potential for witnessing violence or corruption. Surveillance is therefore constant, and at some moments is brought vividly to the fore. For example, after reaching one remote village and spending a night at the chief's house, we were awoken by a group of men loudly discussing our presence. The village chief spent some time on the phone, speaking to his superiors, before apologetically demanding that we leave his village. Our research permissions only applied to villages within the protected area, while this village straddled the protected area border and half of the households were outside. The only way for the chief to resolve this ambiguity was to play it safe and refuse us. In another case, I had walked to a village shop to buy a snack and hang out when several trucks carrying illegally logged wood passed by. A policeman was keeping watch and I could see that he was holding up his phone and filming me, ensuring I did not interfere with the operation. Inevitably he approached me. After a brief chat where I explained who I was, he promised to visit us later. In the evening, he did visit us and carefully documented all our research permits and identity documents.

The result of this surveillance, and of wider restrictions on the activities of civil society (extending to the murder of forest activists and the closing of NGOs who are too critical of the government) are self-censorship and a narrowing of the space available for discussion (Morgenbesser, 2019; Beban *et al.*, 2019). As conservation researchers working with an NGO, it means we are limited in the research topics we can address and the conservation actions we can recommend. The processes leading to large-scale deforestation, such as industrial logging and land-grabs (Billon, 2000; Beauchamp, Clements & Milner-Gulland, 2019; Milne, 2015), are largely off-limits, although there is behind-the-scenes lobbying from civil society to prevent land-grabbing, and widespread resistance from communities (Verkoren & Ngin, 2017; Baird, 2017; Sokphea, 2016; Young, 2019, 2019). Much of the action undertaken by formalised NGOs such as WCS instead focuses pragmatically on working with local communities, aiming to improve livelihoods and conserve forests in ways that do not overtly challenge state power, but which do further local control over forests while formalising and influencing access to forest land.

Another factor contributing to this fraught atmosphere is the recent memory of civil war and of the Khmer Rouge genocide. The spectre of violence and chaos is frequently used by the state to legitimise its own rule, and to control local populations (Schoenberger & Beban, 2018; Gidley, 2017). Villagers' own memories of the Khmer Rouge period also produce trauma and a tendency to avoid potentially sensitive issues or conflicts. In many villages, there are deep social fissures originating from past conflicts, and there is a general lack of trust between villagers who are not directly related (Marston, 2011). These factors pose sensitive challenges to researchers for which there are no straightforward answers.

On top of this, the politics of conservation are complex at the village level. Within each village, there are social classes which intersect in different ways with village conservation institutions, and this influences the positionality of the researcher in relation to each household (Biddulph, 2015). The sensitive and controversial nature of our research topic (wildlife poisoning) added a further dimension to this. Some villagers evaded us and our questions, while others were glad to speak with us. Our best efforts to appear neutral and unaffiliated could never correct for the unusual presence of a European researcher in the village (particularly when previous foreign researchers had come to speak about conservation issues), nor could it paper over the potentially alarming questions we were posing. Chapter four discusses this issue in more detail for the surveys I conducted in all ten villages and describes the methodological choices I made to overcome it.

The bulk of our work (Chapters 5 & 6) was focussed in one village, offering the opportunity to develop relationships with villagers and gain a richer understanding of our evolving positionalities. Over time, through exposure, and perhaps because my Khmer language skills improved, my relationships with certain people in the village changed. I developed a positive and familiar relationship with the village chief and his family, at whose home we stayed for many months over the course of the project. By the end of my fieldwork, they asked me to stay a while longer so I could join them at a village party happening a few days later, we made plans for them to visit me in Phnom Penh, and I occasionally speak to them on the phone from Europe. The chief seemed invested in my research project and regularly expressed his belief that we were catalysing positive developments in the community. He was exceedingly helpful in organising village events, such as the feedback presentation I held during my last visit, where his wife and her sister prepared meals for the attendees.

Over time, as research participants came to understand my presence and my research more clearly, their attitudes towards me changed. Initially, there was a uniform sense of dutiful and curious participation. But as the nature and purpose of the research became clearer, participants could decide whether they believed it was beneficial to participate, whether the research might threaten their livelihoods, or simply whether refusing to participate would bring consequences from higher authorities. As a result, some became friendlier and more supportive, taking time to chat, ask questions, or comment positively on the research. Others became more evasive, rude, or simply refused to participate. Their responses were probably linked to their attitudes towards the research topic, their participation in conservation or illegal activities, or their relationships with supportive figures like the village chief. However, I do not believe the village chief's power is such that anyone felt coerced to participate because of my relationship with him.

At the end of my project, I returned to the village and organised an event at the village hall. With the chief's help I sent word around the village that we would share some of the findings of the project and share a meal of noodles. More than 75 people attended, in a village of 155 households. I felt that this was a high rate of participation, potentially reflecting a high level of interest. The village chief and commune chief opened with rousing words of support and I presented my results in Khmer (a proud moment for me). We left a poster hanging and distributed plain-language summary leaflets. Throughout the presentation, the audience indicated that they had understood what we were saying. I was particularly impressed by the silence that fell when we began to talk about the data from the village, as talk about poisoning in general was accompanied by loud chatter. When time for questions came, one man stumbled forward and asked a question about whether it was truly bad to eat poisoned meat. The others shouted, "he's drunk" and apologetically pushed him away. There were no further questions.

1.5.3 Research Ethics

This research was approved by the University of Edinburgh School of Geosciences ethics committee (No. 132, 2017, & No. 191, 2018). Research permissions were received from the Ministry of Environment of the Royal Government of Cambodia, and the governor's office of Preah Vihear province. Before commencing research in any village, we gained the free, prior, and informed consent of the village chief. All respondents and participants in the research also gave their free prior and informed consent verbally before participation. This followed us explaining our identities, the purpose of the research, and providing guarantees of confidentiality. Verbal consent was considered appropriate due to high levels of illiteracy. Following collection, the data was anonymised and is kept on an encrypted, password-protected device.

Collection of network data may raise special ethical concerns (Kadushin, 2005; Klovdahl, 2005). Firstly, data collection is not anonymous. This makes a thorough explanation of the research process, data handling, and confidentiality arrangements prior to receiving consent particularly important. In the context of rural Cambodia, this was challenging, given limited understanding of research processes and terms like 'data'. We explained that we would record their responses but not share them with anyone or any other organisation. I anonymised the data following production of the networks.

Second, respondents can nominate others who have not given consent to participate in the research. As a result, non-consenting individuals may still be included in the dataset and in subsequent analyses. However, this is not unusual in social research, as many other domains of research or methods of data-collection will collect information from respondents about their relations with or ideas about other people. Nevertheless, because very few respondents refused to participate in data-collection, we were able to remove the names of non-consenting individuals from our data (i.e. individuals who refused consent, or who we were not able to ask for consent) (Borgatti & Molina, 2005).

Third, there is a risk that individuals with knowledge of the study population will be able to infer the identities of respondents from presented network data. For example, they may see a network diagram and be able to infer the identity of highly connected individuals. In our case, I believe the network is sufficiently large to eliminate this risk (Borgatti & Molina, 2005). Furthermore, in all publications (and in this thesis), the location and name of the village is withheld.

A final ethical question concerns the distribution of benefits from this research (Kadushin, 2005). The prime beneficiary is me: from this data I will attain a degree, build a reputation from publications and presentations, and raise funds or secure future employment. WCS and the provincial Department of Environment are also clear beneficiaries. The results of this thesis provide them with valuable information which they can use to advance their activities and interests. My research assistants attained short term, but well-paid contracts of employment. They received training in a variety of research methods and developed a network of conservation and development practitioners in Preah Vihear. Almost all have received references from me and found permanent employment. Chantheavy and Siekleang now work with WCS in Preah Vihear, while Sothea works for WWF, another conservation NGO.

Despite my best intentions, benefits to the research participants are variable and indirect. Working collaboratively with WCS, my intention was to design and inform actions that would be supported by and beneficial to local communities. The interventions we piloted aimed to reduce pesticide misuse, and thereby reduce conflict over poisoning, risks to human and livestock health, and improve environmental quality. However, these benefits will be felt unevenly within the village, and some, perhaps those engaging in wildlife poisoning, may perceive negative consequences from this research if they lose access to a source of food or income. Although, I did not find that poisoning was directly related to food insecurity, this may still pose a burden to poorer households. To avoid undue burdens, our interventions were not coercive, and instead aimed to be persuasive. We invited community representatives to participate in intervention planning, although in future I would work to make the process more accessible to a wider range of community members and engage them at an earlier stage in the research process.

Finally, I hope this research benefits the wildlife of Cambodia and helps species such as the Giant Ibis, White-shouldered Ibis, White-rumped Vulture, Slender-billed Vulture, Red-headed Vulture, Banteng, Sarus Crane, Lesser & Greater Adjutant, White-winged Duck, and many others, to avoid extinction.

2. Background

2.1 Cambodia

Cambodia is a relatively small country in peninsular South-East Asia, with a population of approximately 16 million people. Over 95% of the population is Khmer speaking, but there are significant populations of Cham, Vietnamese, Chinese, and several highland groups such as the Bunong. Historically, the Khmer population has been concentrated in the low-lying valleys of central Cambodia, around the Mekong river and in the floodplains of the vast Tonle Sap lake. Away from these areas, the country is densely forested and rises into hills and mountains, which are sparsely populated. From around the 9th Century AD, rice production in the valley areas supported the Angkor civilisation, which built huge cities and monuments, and developed a rich culture until it's decline in the 14th and 15th Centuries (Chandler, 2018).

The events and structures of the ensuing period are less well documented, but it is generally understood to be a period of frequent conflict where neighbouring states (Siam and Viet Nam) exercised control over different parts of the Cambodian territory and population. Khmer elites sought protection from these powerful neighbours and were often set against one another. A low-point was reached in the 19th Century, and in 1863 Cambodia became a protectorate of France, which administered Cambodia as a colony until 1949, and Cambodia achieved full independence in 1953 (Chandler, 2018).

Following independence, Cambodia entered a further period of intense turmoil. King Sihanouk's repressive government bred discontent among leftist intellectuals and among part of the rural population. Some revolutionary groups took arms against the state and already controlled large parts of Cambodia's territory by 1952. A small group of intellectuals, including Pol Pot, returned from studies in Paris and established insurgent bases in the remote province of Ratanakiri – becoming the Red Khmer, or the Khmer Rouge. During the American war in Viet Nam (1955-1973), Sihanouk allowed the Viet Cong to transport materials and manpower through Cambodian territory. In response, America heavily bombed Cambodia, causing mass dislocation and suffering for rural populations, many of whom sought refuge in cities or joined the Khmer Rouge insurgency. In 1970, riots broke out in anger at Sihanouk's tacit support of North Viet Nam, and Prime Minister Lon Nol seized power in a coup backed by the US military.

On 17 April 1975, the Khmer Rouge defeated Lon Nol's forces and took control of Phnom Penh, beginning a nightmare that lasted for three years and eight months. The new regime, called Democratic Kampuchea, immediately evacuated urban populations to the countryside and established a system of communes for production of rice, food, and other raw materials. Families were separated, and others were forced to marry. Communes were forced to work to meet impossible production quotas, and the result was mass famine. The regime distrusted and murdered intellectuals, and other so-called 'new people' with backgrounds not suitable for an agrarian society, such as those who spoke foreign languages or wore glasses. Surveillance and violence became organising principles of the country. In three years and eight months' time about 2.5 million people died; around a quarter of the population.

In 1978, neighbouring Viet Nam invaded Democratic Kampuchea and established a pro-soviet one-party state, the People's Republic of Kampuchea. However, fighting continued, and a coalition of factions led by the Khmer Rouge held on to the country's seat at the United Nations. The state government under Prime Minister Hun Sen (himself a defector from the Khmer Rouge) from 1985 attempted to rebuild the state while fighting the Khmer Rouge who held out in the north of the country. A 1991 peace accord negotiated in Paris provided for a cease-fire and elections to be held in 1993, and a United Nations Transitional Authority (UNTAC) was established to supervise and administer these arrangements. At the 1993 elections, Hun Sen's Cambodian People's Party (CPP) narrowly lost to the royalist FUNCINPEC party, but a coalition government was formed. However, in 1997 violent clashes occurred between the two parties, and Hun Sen once again took power in a coup. He remains prime minister to this day.

Today, political scientists characterise Cambodia as a hegemonic authoritarian state as Hun Sen has used a combination of violence, patronage, propaganda, and legal manoeuvres to diminish the opposition and win election after election (Morgenbesser, 2019). The CPP has established a 'shadow state', raising funds greater than those in official state budgets from connected businessmen and exploitation of natural resources, and dispensing these funds to the population to buy support (Strangio, 2014; Craig & Kimchoeun, 2011) while state budgets are largely dependent on foreign aid (Ear, 2007). Today, Cambodia's economy is growing rapidly, but unequally, and the majority of the population is still employed in agriculture (Hughes & Un, 2011).

2.2 Cambodia's Northern Plains

In recent decades, Cambodia's forests have been the site of intense and often violent social and ecological change. In just twenty years from 2000 to 2020, over a quarter of Cambodia's forest cover has been lost (World Resources Institute, 2014), indicating large-scale degradation and loss of habitat for numerous endangered species, and the transformation of rural livelihoods (Chann, 2020; Diepart & Dupuis, 2014). In post-conflict Cambodia, both land and forests emerged as vital resources for smallholders as well as for the consolidation of state power (Loughlin & Milne, 2020; Billon, 2000; Cock, 2016). Powerful actors have used the state apparatus to claim and exploit large areas of forested land, excluding and marginalising local smallholders (Billon, 2000; Loughlin & Milne, 2020; Davis *et al.*, 2015; Le Billon, 2002). At the same time, despite rapid economic growth (Hughes & Un, 2011), the forest frontier remains increasingly important for rural families dependent on natural resources (Beauchamp, Clements & Milner-Gulland, 2019; Beauchamp *et al.*, 2018; Ken *et al.*, 2020). Smallholder farmers are also increasingly being driven to the forest frontiers through dispossession of land in the central provinces, increasing debt burdens (Green, 2020), or the closure of urban labour markets (Kong *et al.*, 2019; Chann, 2021).

Some of the largest forests remain in Cambodia's north, where years of armed conflict in the last holdout of the Khmer Rouge prevented economic activity and kept infrastructure development at bay (Chandler, 2018). The forests in this landscape, referred to as the Northern Plains landscape (largely located in Preah Vihear province), comprise the largest remaining fragments of lowland forest in mainland Southeast Asia, and were once home to dense populations of big mammals, such as wild cattle (Gaur, *Bos gaurus,* and Banteng, *Bos javanicus*). The mosaic of evergreen forest, dry deciduous forest, and grasslands (Figure 2.1), is the result of a long history of migrating grazers and people using fire and irrigation to shape the landscape for rice cultivation (Wharton, 1966). Today, at least 28 Critically endangered or Endangered species persist here, including Cambodia's national bird, the critically endangered Giant Ibis (*Thaumatibis gigantea,* Clements *et al.*, 2010). Other important species are the White-shouldered Ibis (*Pseudibis davisoni*), Sarus crane (*Grus* *antigone*), Greater adjutant (*Leptopilus dubius*), Masked finfoot (*Heliopais personatus),* Red-headed vulture (*Sarcogyps calvus*), White-rumped vulture (*Gyps bengalensis*), Slender-billed vulture (*Gyps tenuirostris*), White-winged duck (*Asarcornis scutulata*), and Pileated gibbon (*Hylobates pileatus)*. There may also be small populations of the Asian elephant (*Elephas maximus)* and the Dhole (*Cuon alpinus*). The Northern Plains is thus a site of considerable conservation interest, centred on three protected areas: Chheb, Kulen Promtep, and Prey Preah Rokha wildlife sanctuaries (Fig 2.2). All three are managed by the Ministry of Environment of the Royal Government of Cambodia, with technical support from WCS Cambodia.

Figure 2.2. The dry forest in Cambodia's Northern Plains

Villages are scattered throughout the protected areas, many of which originated from small groups of Khmer Rouge soldiers or other groups evading state control in the remote forests (Scott, 2009). Some also include households belonging to indigenous groups such as the Kuy (Swift, 2013). Subsistence rice farming and collection of forest products such as wild meat, vegetables, and resin-tapping, remain important livelihood activities. Historically rice growing occurred in a swidden pattern, but today it is usually fixed (Swift & Cock, 2015).

Land tenure can be held jointly by a husband and wife, comprising a single household, and one hectare of land is typically considered the minimum required to support a small family. But, with increased integration into the market economy and loss of access to natural resources, livelihoods are changing rapidly. Besides production of rice, farmers increasingly clear land to produce cash crops for export, such as cassava or cashew (Beauchamp, Clements & Milner-Gulland, 2019; Beauchamp *et al.*, 2018), or speculate on land prices.

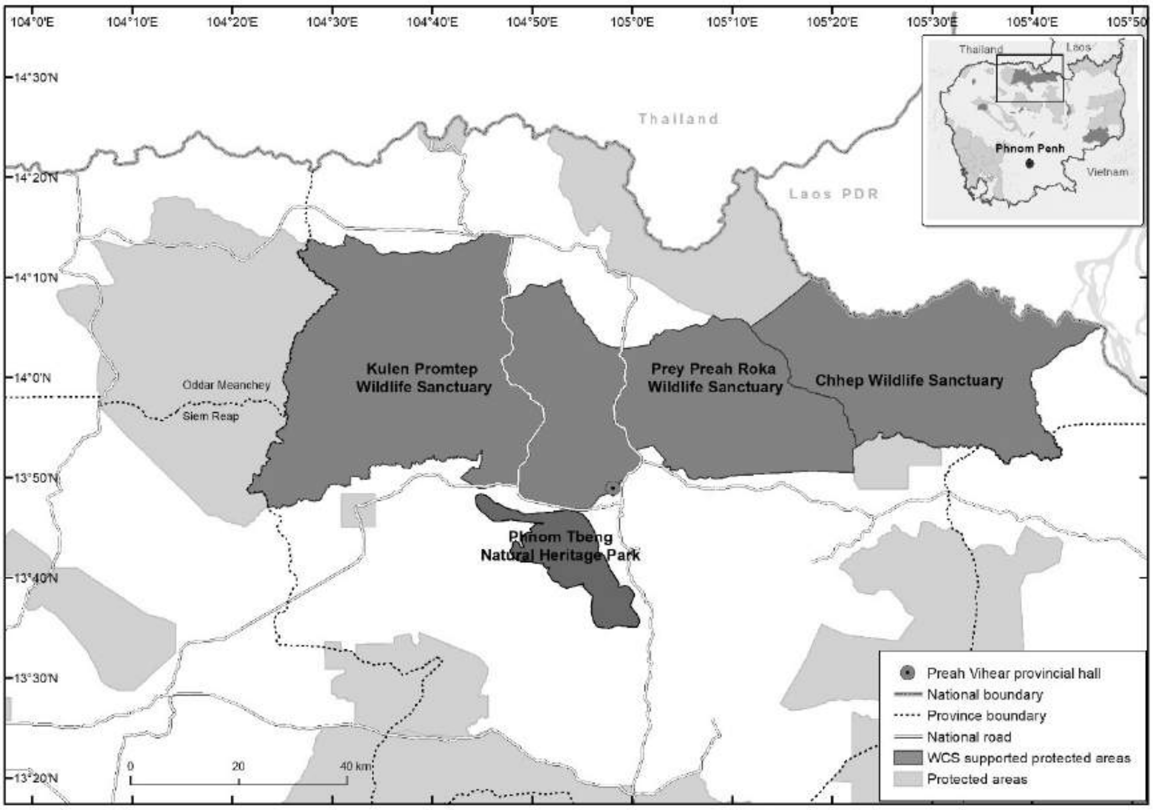


Figure 2.2: A map of Cambodia's Northern Plains landscape, Preah Vihear province, showing the three protected areas: Kulen Promtep; Prey Preah Roka; and Chhep Wildlife Sanctuaries.

Balancing conservation goals with local communities' aspirations for development is a central challenge for governance in this landscape (Riggs *et al.*, 2020). With the support of WCS, the government has implemented a complex set of management interventions to achieve these aims. Underpinning these interventions is the zonation of protected areas into core protection, sustainable use, and community zones, each with distinct rules regarding land use and other activities. The Ministry of Environment conducts patrols to enforce these rules (Paley, 2015). Participatory Land Use Plans were developed by WCS with some local communities to strengthen village institutions for managing community land and forests. To monitor and enforce compliance with these rules, many communities elect a community protected area committee (Beauchamp, Clements & Milner-Gulland, 2018a). Other communities may have a community forest, with a similarly elected management committee (Poffenberger, 2013). However, the community forest model is a remnant of past times when protected areas fell under the jurisdiction of the Forestry Administration. The Ministry of Environment replaced community forests with the community protected area model before the period of research.

To incentivise conservation and compliance with community rules, three payment schemes were instituted by WCS in villages in and around the Northern Plains' Protected Areas (Clements *et al.*, 2010). The first comprises direct payments to individuals for locating nests belonging to priority bird species, and for protecting the nests from disturbance (Clements *et al.*, 2013). Second, in three communities with suitable locations, community-based ecotourism projects have been developed. These communities have received finance and support to establish wildlife-based tourism sites and receive income from tourists. Part of this is paid directly as wages to community members, but the largest part is paid into a village development fund which is managed and disbursed by an elected committee. Third, the Ibis Rice project buys rice from conservation-compliant farmers at 40% above market prices. Participating farmers agree to follow conservation rules, use organic agriculture, and have their land mapped. They may not clear forest for new land unless approved by the local government (Clements *et al.*, 2020).

Long term impact evaluation of these programmes started in 2008 and has continued until the present day (Beauchamp, Clements & Milner-Gulland, 2018a; Clements *et al.*, 2013; Clements & Milner-Gulland, 2015; Clements *et al.*, 2014, 2020). These evaluations show that households within the protected areas are increasing their incomes and their socio-economic status, but at a lower rate than households outside the protected areas. Conversely, within the protected areas, households have more secure tenure over natural resources such as resin trees. Participants in the Ibis Rice project improved their status more rapidly than others and had improved rice yields and food security. In addition, a randomised controlled trial conducted since 2018 shows that participating households were four times less likely to engage in deforestation. However, there are still significant barriers to participation in Ibis Rice for poorer households or those without adequate land (Clements *et al.*, 2020).

2.3 Study villages

This thesis includes data from ten villages spread across two protected areas (Chhep and Kulen Promtep) in the Northern Plains. A further two villages outside the protected areas were used to pilot the methods employed in Chapter four. These villages were all included in previous research, meaning that there is substantial knowledge and data available about livelihoods and wellbeing in each village (Beauchamp, Clements & Milner-Gulland, 2018a; Beauchamp *et al.*, 2018). The villages are varied. Some are predominately Khmer, while others are largely Kuy. Some have over 300 households while others have less than 100. Some are located very remotely, inaccessible by road during the rains, while others are located near covered roads and market towns. Furthermore, some have high rates of participation in multiple conservation programmes, while others do not.

Chapters five and six focus on just one village. This village consists of around 155 households located in Chhep wildlife sanctuary, close to important wildlife habitat. The village has been a focus of conservation attention for over a decade. It was among the first to participate in the Ibis Rice programme and has an unusually high rate of participation in this programme. For example, in 2016-2017, 111 households signed sale agreements to participate in Ibis Rice (this does not mean all were compliant). The village has a community forest instead of a community protected area. The village was chosen as the site of the pilot intervention and as the focus for this research because of its size, ease of access, and because the village chief had previously acted against wildlife poisoning.

According to the village chief, the village was first settled shortly after King Sihanouk began his reign in 1941, at a location a few hundred meters from the current place. It was moved to its present location due to flooding, and to be nearer to a small cart track which passed through the forest. This had become possible because the Royal government at the time had cracked down on bandits, who were previously raiding settlements and travellers along the track. Older villagers recall a close-knit community of around 25, mostly related, households that was largely self-reliant and interdependent. Wildlife was abundant and was the primary source of meat besides fish, and villagers would harvest and process forest products to trade at the Laos border on the Mekong river, approximately 30km away.

The chief told me that at the time of the Khmer Rouge regime (1975-1979), the villagers were forced to re-organise their production on collective lines but were permitted to remain in the village. Since conflict ceased and the Royal Government of Cambodia regained control of the province in the 1990s, rapid transformations have occurred. In 2004, a primary school was built, and in 2014 the first high quality (dirt) road was constructed nearby, reliably linking the village to a market town, the border markets, and to a nearby village with a high school where many village children travel every day. These changes have also attracted migrants in search of land or commercial opportunities. For example, at least two households have arrived in the past five years to open small shops.

Since construction of the road, many households have physically relocated, as the road provides better access to transport and to the rice fields. The village therefore now consists of two sections. First, the 'old' village core of about forty households laid in a dense grid and another 34 households arranged on a slightly newer road grid. In this section, one also finds the primary school, the village hall, and two shop-houses. The second section, separated from the first by several hundred metres of fields, comprises households laid out along the new road. The farthest households on either end of this section are about 8km apart, and the junction into the old village is located roughly halfway between them. Close to the junction there is also a small police post which is manned two days a week, a small garage (motorcycle repair shop) and two well-supplied general stores. Many households maintain small wooden huts at their fields for the intensive work seasons.

2.4 Social life in the village

As much of this thesis is about the role of social networks in producing conservation behaviour change, it is worth discussing what this means within the context of the village being studied. A social network is a way of conceptualising the relations and interactions between individuals. For the purposes of my analysis, I measure very specific forms of interaction between individuals, which are described in further detail in the relevant Chapters (5 & 6). The most important of these ties are the ties between members of a household, and those who visit one another at home. To understand the importance of these ties, and how they fit into a wider village life, it is helpful to discuss the nature of social life in rural Cambodia.

While it may be a slight exaggeration to say that "every household is an island" (Ovesen, Trankell & Ojendal, 1996, Figure 2.3), it is true that social relations in rural Cambodia rarely extend beyond the kinship group. Each household organises its own agricultural or commercial production and therefore acts relatively autonomously (Ovesen, Trankell & Ojendal, 1996), and a household can consist of multiple generations. Often, there is a preference for adult daughters to remain near the parental home and have their husbands join them, and it is not uncommon for a separate house to be built within the parental compound. On the other hand, sons may travel some distance when they marry to be near the wife's family. Although these arrangements are flexible, and may depend on the availability of land or other factors, social life in the village tends to be geographically arranged around the parental home and held together by female relations in this way (Ledgerwood, 1995; Crochet, 2011). The construction of the road passing the village disrupted this spatial organisation for those families who decided to move, but the traditional patterns of household co-location have resumed since, forming a "rosary bead" of compounds spaced along the road – a pattern familiar across Cambodia, and motorbikes now enable families divided geographically to visit one another with relative ease.

Crochet (2011) describes how in another village, people "did not even know the names of the […] people, even though they were 200 metres away". To some extent, this holds true for our village as well, particularly for households along the new road, but within the old core most people are acquainted and may even be distant relatives. This may be a feature of the relative stability experienced by households here during the civil war. Nevertheless, even if they do not know one another's names, there are still social interactions occurring between unrelated households (Ebihara, 1968). Primary among these is the reciprocal exchange of labour on the rice fields during labour-intensive periods such as harvest, but other important interactions include money lending, the sharing of food or tools, and tending of animals. These interactions are reciprocal because they are often limited to a moment of exchange which both parties feel is beneficial, but being able to partake in such exchanges is seen as an important moral and social marker (Sedara, 2011). Of course, weaker interactions occur daily, such as chitchat when passing on the road or at the shop.

Figure 2.3. Two contrasting village houses. Left, a small house in a recently cut area of forest. Right, a larger house with a painted roof in the core of a village. In front are palm mats which will serve as roofing for a new structure.

There is a strong temporal dimension to social interaction. This is tied to the annual rice-growing cycle as most residents are subsistence rice farmers. For large parts of the year, households relocate to small huts at the fields, to work the crops more efficiently or watch over them. Social interaction is thus confined to small household groups, or to other households, usually kin, who may be farming nearby (personal observation). When harvesting or transplanting is complete, the village regains its population (Ebihara, 1968). These times are marked by the important religious and social festivals, such as *pchum ben* (a 15-day ancestor festival) and the Khmer new year, at which social relations are re-affirmed and enacted through acts of patronage (Ledgerwood, 2012b).

It is a matter of debate whether rural Cambodian communities have always lacked durable village-level institutions beyond kinship, or whether this is the result of decades of violent conflict and, more recently, neoliberal reforms (Marston, 2011; Ebihara, 1968; Springer, 2009). Nevertheless, our village is not unique in this lack of social institutions. Furthermore, a Buddhist wat (temple), which is known to play an important role in building social solidarity in other villages (Ledgerwood, 2012a), is not present here - the nearest wat is in the next village. There is, however, a village chief appointed by the state who is responsible for various bureaucratic tasks, and who enjoys some respect (Ledgerwood & Vijghen, 2002). Unusually, the village sub-chief is a woman. Furthermore, as described previously, conservationists and local government have made some efforts to develop village institutions for governing land use, including a community forestry committee and a 'village market network' to manage participation in Ibis Rice, but the role of these institutions in social life appears to remain limited.

2.5 Wildlife poisoning and interventions

In 2015 the first reported cases of wildlife poisoning were documented in Preah Vihear province, and poisoning was identified as a little-understood conservation threat (Loveridge *et al.*, 2019). Chapter four reports an in-depth study of wildlife poisoning. However, I give a brief overview of this phenomenon and the interventions piloted to reduce wildlife poisoning here, as this informs the approach taken in Chapters five and six.

We determined that poisoning was primarily carried out by young men aged 20-30, and young children aged 10-15, as a method for harvesting wild meat. There was no clear relation with food insecurity; instead, it appears that (mis-)perceptions about the health risks of poisoning play a stronger role in decisions to use poison. Furthermore, most villagers had strongly negative attitudes towards poisoning and perceived negative social norms around poisoning, largely due to potential negative impacts including loss of domestic animals, fisheries, access to clean water, and risks to human health. In several villages, local authorities have acted against poisoning, such as by disciplining poison hunters, or discussing the problem at village meetings (Chapter 4).

In 2018, I facilitated a three-day workshop with WCS staff, provincial department of environment staff, and members of local communities. We developed a conceptual model (Figure 2.4, Margoluis *et al.*, 2009) of wildlife poisoning and used a social marketing framework (Smith, Verissimo & Macmillan, 2010) to generate possible intervention strategies. For the purposes of this research, we used a number of these strategies to design a pilot intervention, which was carried out in one village in February 2019.

The intervention was intended to: a) promote the use of a reporting hotline to improve detection and response to poisoning events, and b) reduce community support for poisoning by increasing the perception of risk to human health and from law enforcement. In addition, we believed that these two goals would reinforce one another, as concern about poisoning would increase usage of the hotline, while increased reporting would further increase the salience of poisoning and the risks of detection for poisoners (Saypanya *et al.*, 2013). The idea of a reporting hotline came from literature on similar interventions in Laos and was enthusiastically endorsed by workshop participants (Saypanya *et al*., 2013).

Four barriers to reporting poisoning were identified:

- Unclear procedures & lack of knowledge
- Low concern about personal risks of poisoning
- Fear of provoking conflict with poisoners
- Perceptions that others would disapprove.

The intervention was therefore designed to alter these perceptions (Figure 2.4). The intervention consisted of an event with four components. First, trusted messengers, including officials from the health, environment, and agriculture departments as well as a veterinary expert, gave presentations describing the risks of poisoning to human health, livestock, the environment, and legal risks. Past victims of poisoning from a nearby village also provided testimony with graphic images. Second, practical information about the reporting hotline was provided by WCS staff, explaining the expected response from authorities and anonymity guarantees. The hotline was endorsed by the village and commune chiefs.

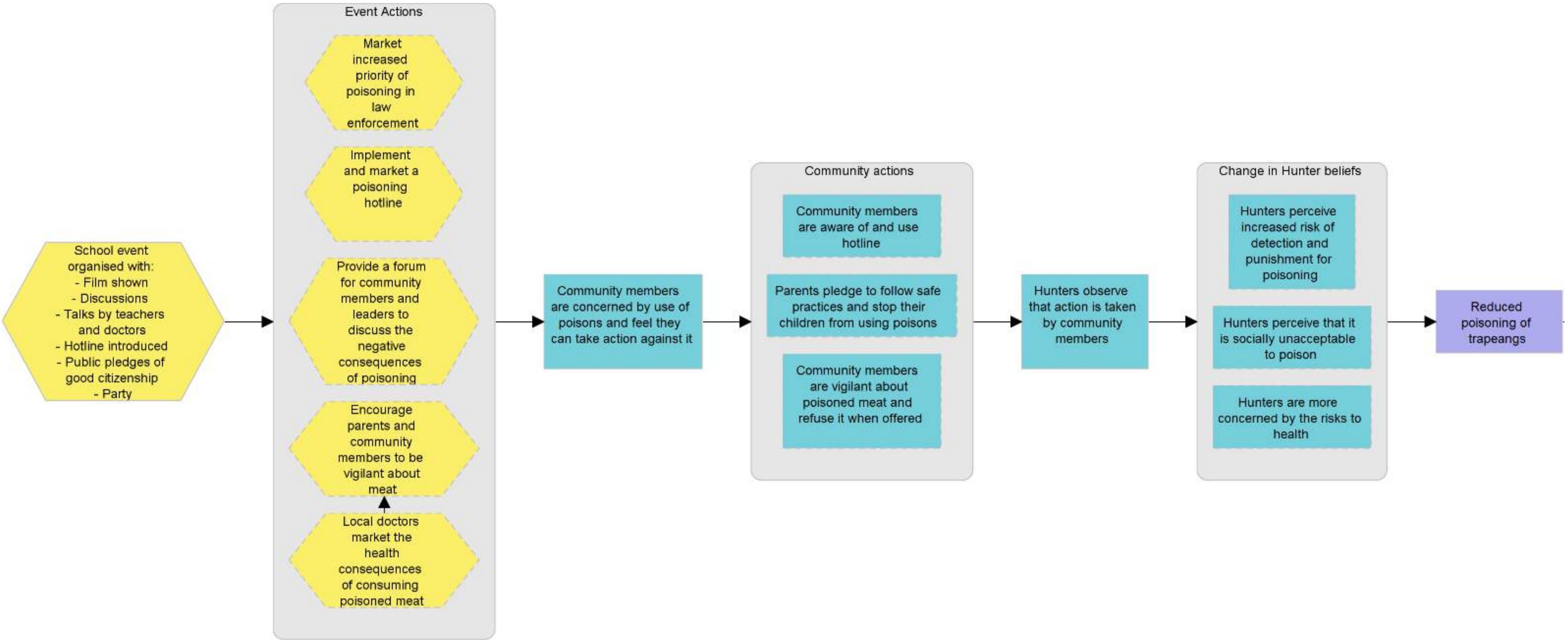


Figure 2.4: a simplified representation of the theory of change for our pilot intervention developed during a three-day workshop

Third, a short film was shown, which dramatised the moral dilemmas and conflicts that might be faced in deciding whether to report poisoning (Bicchieri, 2017b). The main character resolves these dilemmas with advice from his parents and the village chief, and eventually is reconciled with the poisoner after he reports the poisoning. The film also depicts two children who become sick and miss school after bathing in poisoned water. Finally, members of the audience were invited to make a public pledge (Niemiec *et al.*, 2019) of vigilance against poisoning and safe pesticide use. This was framed as a 'good citizenship' pledge, and pledgees received a certificate from the commune chief.

Forty-one people attended the event on invitation (Figure 2.5). These were the parents of children aged between 10 and 15 years, who we selected because we believed parents would be especially concerned about poisoning and would be able to influence their children who may be poisoning. In addition, it was necessary to select a small group for the purposes of our research. We produced and disseminated several types of material (Figure 2.6) to ensure the intervention messages would remain salient, and to facilitate communication of the messages to other residents in the village. Materials with information about the hotline included colourful stickers and small calendar leaflets, which people might display, keep at home, or share with others. We printed colouring books for children with the story from the short film, and distributed DVDs. Finally, as well as receiving certificates, pledgees also received large and attractive posters describing their commitments which they could display on their houses. This intervention forms a core component of Chapter six, and especially Chapter five, which analyses the impacts of the intervention on knowledge and psychological outcomes in the village.

Figure 2.5: a WCS staff member speaking at the pilot event.

Figure 2.6: Material disseminated in the intervention. Clockwise from top: 1) a villager receiving a good citizenship certificate from the commune chief, 2) a poster given to good citizen households, 3) a still from the short film (Chan), 4) the Chan story book distributed to parents, 5) a sticker with the hotline number.

3. Improving environmental interventions by understanding information flows

This chapter is published as: de Lange E, Milner-Gulland EJ, & Keane A. Improving Environmental Interventions by Understanding Information Flows. Trends Ecol. Evol., 34 (2019), pp. 1034-1047, 10.1016/j.tree.2019.06.007

3.1 Abstract

Conservationists are increasingly interested in changing human behaviour. One key aspect of such interventions that has seen little attention is information flow. Different patterns of interpersonal communication and social structures within communities influence the adoption of behavioural changes through processes of social influence and social reinforcement. Understanding the structure of information flow in a group, using tools such as social network analysis, can therefore offer important insights for interventions. For example, communications may be targeted to highly connected opinion leaders to leverage their influence, or facilitation of communication between distinct subgroups may enable collective action. Incorporating these approaches into conservation interventions can promote more effective behaviour change. This review introduces conservation researchers and practitioners to key concepts underpinning information flows for interventions targeting networks of individuals.

3.2 Glossary

Bridge; an individual or individuals that connect two subgroups in a community, or connect neighbourhoods in a network.

Centrality; various measures indicating an individual's influence in a network (i.e., degree centrality is the number of connections an individual has to others in the network).

Channels; the technology or media used for communication, such as television, radio, social media or interpersonal communication.

Complex contagion; contagions, such as behaviours, that require social reinforcement before they can be adopted by individuals.

Contagion; the cultural items, such as behaviours or information, that spread within a group.

Diffusion; the spread of cultural items such as behaviours, ideas, or knowledge.

Homophilous groups; are groups that consist of similar individuals that are highly connected. The same community may be characterised as homophilous or heterophilous depending on the behaviours and interactions in question. For example, a small, rural community of rice farmers is homophilous in the context of agricultural activity, but may be heterophilous in terms of the forest products they gather.

Incubator neighbourhoods; a small group of individuals that are socially connected and that are collectively targeted for adoption of a new behaviour.

Induction; attempts to stimulate information flows and encourage further communication of a message, by incentives or incorporating encouraging features into the message.

Inductive messaging; messaging strategies that are designed to encourage further dissemination or spread of the message, such as by incentivising communication, facilitating signalling, or incorporating encouraging features into the message.

Information flow; the overall pattern of communication within a group or the route taken by a specific message within the group.

Information transfer; the directed communication of a message by the conservation to its intended recipient, whether directly or indirectly

Opinion leaders or hubs; highly connected individuals who can exert influence on their groups, often key to disseminating new information or behaviours.

Social norms; expectations or rules around appropriate behaviour within a social context.

Social reinforcement; positive signals or information received from others about a behaviour.

Target; the individuals who are intended to receive a communication, or the individuals who are intended to change their behaviour.

Threshold; the number of an individual's social relations, or the proportion of their ties, that must adopt a behaviour before an individual also adopts.

Ties; are the links between individuals. In the context of information flows these will usually be the interactions through which individuals communicate, but many other types exist.

3.3 Behaviour change and communication

Conservation interventions frequently seek to change people's behaviour to stem human-driven loss of biodiversity (St. John, Keane & Milner-Gulland, 2013). As people respond to information received about the world (Schlüter *et al.*, 2017), transfer of information is a key component of all interventions (Table 3.1). Many types of information can be used to motivate behaviour change, such as information about the risks and benefits of an activity (Thøgersen, 2005); social norms (Schultz *et al.*, 2016); or evoking emotional responses (Schneider *et al.*, 2017). Some behavioural changes are simple and adoption is a direct result of receiving information, but for complex **behavioural changes** (see Glossary), adoption is mediated through social influences and social reinforcement, which occurs through further interpersonal communication and information flow between peers (Centola & Macy, 2007; Green *et al.*, 2019).

Much research is devoted to improving the effectiveness of conservation interventions (e.g. Nilsson et al., 2016), and researchers increasingly look to the behavioural and social sciences for insight (Reddy *et al.*, 2016), such as in the field of conservation marketing (Wright *et al.*, 2015). However, the role of information flows in promoting conservation behaviour change is poorly understood. Understanding this can help to improve the effectiveness of interventions (Barnes *et al.*, 2016b), and applications have been developed in other behaviour-change settings, most notably public health and social marketing (e.g. McKenzie-Mohr & Schultz, 2014). Drawing on insights from such fields, we clarify key concepts in the study of information flows. We examine how messages reach their targets and how interpersonal communication and social structures determine patterns of behavioural adoption (Rogers, 2003). We discuss the tools used to study these structures, most notably social network analysis (SNA), and the insights these methods have generated. Finally, we draw on other behaviour-change disciplines to suggest strategies for designing more effective interventions.

Table 3.1: Examples of information transfer and targeting strategies in common conservation behaviour change interventions.

Behaviour-change Strategy	**Information Transferred**	**Example Targeting strategy**	**Reference**
Rule enforcement	Risks & costs of punishment	Offenders learn this information when caught and pass it on to their network	(Keane *et al.*, 2008)
Environmental education	The importance and cultural value of nature	Education sessions are held at local schools and children pass information to their parents	(Monroe, 2003)
Payments for ecosystem services	Payment structure & conditions	Communities are invited to a meeting where this is explained directly [62]	(Clements *et al.*, 2010)
Alternative Livelihoods	New livelihood options	Training workshops are held to teach local farmers alternative livelihoods	(Wright *et al.*, 2016)

3.4 The Anatomy of Information Flows & Behaviour Change

3.4.1 Information Transfer, Flow, and Communication

The fundamental process of information transfer is that a message is communicated from conservationists to behaviour-change targets. Communicating information is not a “magic bullet” with predictable effects on the receiver, but a complex social process where messages may reach their intended target by different, indirect, routes and their meanings are continuously revised within the context of social relationships (Littlejohn & Foss, 2011). Understanding these processes is important to enhance the probability of desired targets receiving and acting on a message in the desired way.

Communication occurs through channels which differ in what they can convey, who they can reach, and how they are likely to affect behaviour (Bryants & Heath, 2000). Mass communications through channels such as TV and radio can potentially reach large audiences with a uniform message. Such messages can be agenda-setting but are transient and, alone, may not be effective at changing complex behaviours (Wakefield, Loken & Hornik, 2010). The internet and social media also enable large audiences to be reached, but with personalised messages (Bennett & Manheim, 2006). Where access to technology is low, speaking with people directly may be the only possibility.

Interpersonal communication between peers is likely to comprise a significant volume of information flow in all interventions. Messages disseminated through mass media typically reach much of their audience indirectly, following interpretation and propagation of the message by influential individuals. Most information therefore flows to receivers through multiple steps (Bennett & Manheim, 2006). As a result, messages will usually have reach and influence beyond just those people directly targeted, and these multi-step flows are intentionally embedded into the design of some conservation interventions (see Table 3.2).

When information flows through multiple steps, the identities and relationships of communicators will influence how they understand and respond to a message. This 'social influence' is composed of multiple factors, such as the perceived credibility of the information source (Pornpitakpan, 2004); the relationship between source and receiver (Faraji-Rad, Samuelsen & Warlop, 2015); their positions in larger power structures (Smith & Magee, 2015); and perceptions of relevant social norms (McDonald & Crandall, 2015). Social influence can make the difference between a message that is rejected and ignored, and a message that changes behaviour, so interventions that stimulate more interpersonal communication are more likely to change behaviour (Green *et al.*, 2019).

Table 3.2. Selected information flow concepts and examples of interventions using these concepts from various disciplines

Concept	**Public health or development example**	**Marketing or Management example**	**Conservation example**
Targeting communications at opinion leaders	In a randomised trial across 32 villages, a sample of villagers were educated and given multivitamins, as well as vouchers to pass on to others. In villages where targets were identified using peer-nomination surveys a 12.2% increase in adoption was seen compared with villages where targets were randomly selected (Kim *et al.*, 2015)	Microsoft identified opinion leaders and distributed pre-release copies of *Windows 95* to 450,000 of them. The commercial product was quickly adopted and within four days of release a million copies were sold (Galeotti, 2009).	Rare 'Pride' campaigns seek to identify 'trusted messengers': influential community members that can drive widespread behavioural change, once a number of peers have already adopted the new behaviour and some momentum has been generated (Butler, Green & Galvin, 2013)
Targeting an incubator neighbourhood	In a randomised controlled trial, agricultural extension workers in Malawi trained individuals in 200 villages on pit-planting (an agricultural technique) and trained them to disseminate this in their village. In some villages, these individuals were chosen to span the entire network, but in other villages they were chosen as 'clusters' of	None found	None found

	connected individuals. In clustered villages, there was a 56% greater likelihood that diffusion would occur, and after three years a 3% greater adoption (Beaman *et al.*, 2014)		
Recruiting opinion leaders as change agents	An anti-conflict intervention was experimentally introduced to 54 schools with 24,191 students, after measuring their social networks. Selected students were trained and then took the lead in designing anti-conflict strategies for their school. Schools where highly connected students were recruited had a 30% greater reduction in conflict than where students were randomly selected (Paluck, Shepherd & Aronow, 2016)	Marketers working for Hokey Pokey, a premium ice-cream store in India, researched the local social media market. They identified influential social media users that were observed to have many connections and gained many responses to their activity, in addition to other characteristics. Influencers with relevant interests were invited to create a personal ice-cream creation and incentivised to tweet and Facebook about their creation. Customers could also see these creations on a wall at the store and purchase them. Flavours used in	Ewaso Lions' 'Warrior Watch' programme recruits Samburu Warriors to act as ambassadors for wildlife in their community, raising awareness and mitigating conflicts with predators. These warrior ambassadors are selected in cooperation with community leaders and are provided a small stipend and given education in return. Attitudes toward wildlife were found to have improved for 90% of community members, with most attributing this to information received from the warriors (H. Gurd, MSc thesis,

		these creations increased in popularity, and brand awareness and sales revenue increased dramatically (Kumar & Mirchandani, 2012).	Imperial College London, 2012).
Connecting subgroups	In 1995 the US Public Health Service launched the National Information Infrastructure. One of the key objectives of this project was to improve communication between healthcare providers across the US, as well as other actors essential to delivering public health such as the media, government and citizens. For example, medical practices across a city now began to share information with a central database, which enabled monitoring of wider trends and early warnings for epidemics (Lasker, Humphreys & Braithwaite, 1995).	A global consultancy firm believed one of their highly skilled strategic teams was underperforming. A SNA was performed to understand the information flows, revealing two disconnected sub-groups within the team. Each group had a different expertise and skillset, with little knowledge of the other. A facilitated discussion was held with the entire team, resulting in practice changes designed to encourage closer connection: projects were jointly led by one member of each group, and new communication channels were	Three settlements in Nepal made use of the same forest, but had organised themselves into two separate forest associations, as two of the settlements were more closely connected. This led to conflicts over boundaries and memberships. Meetings were organised between the leaders of the three settlements where residents agreed to merge the two forest associations. The new, single, forest association functions well and has overseen improvements in the condition of

		opened. This led to improvement in outcomes, and a follow-up SNA revealed a much more connected group (Cross, Borgatti & Parker, 2002).	the forest (Varughese & Ostrom, 2001).
Connecting peers for learning and reinforcement	Alcoholics Anonymous is one of the few models to show positive abstinence outcomes. Participants join support groups where they are connected with peers undergoing the same behavioural change and discuss their experiences. Studies have shown that support-group peers often replace non-supportive friends in participants social-networks, and that this method is most effective for individuals with harmful social networks (Groh, Jason & Keys, 2008)	As part of a strategy to increase the effectiveness of institutions in developing countries, the OECD organises peer-learning sessions. For example, individuals working at anti-corruption organisations in Eastern Europe and Central Asia were invited to a workshop to meet with experts and discuss their experiences and knowledge. Though little evaluation has been done, it is thought that this enables greater learning and that the connections generated between peers will sustain long-term knowledge sharing	Following requests from local women, Ewaso Lions' 'Mama Simba' project provides general and environmental education to women in Samburu communities. Participants learn and share their knowledge together, including of environmentally sustainable practices, and disseminate this knowledge to their peers (Ewaso Lions, 2018), see http://ewasolions.org/conservation/mamasimba/

		(Andrews & Manning, 2016)	
Inducing multi-step communication flows to indirectly reach the target audience	Injecting drug users (seeds) were given coupons to distribute to their peers, which contained information about a safety education class. When a peer redeemed a coupon at the education centre, they were given additional coupons to distribute, and the seed was awarded $10, incentivising distribution. An additional $10 was awarded if the peer had been given some education by the seed before arriving. Compared to worker-based outreach, this method recruited 36% more participants over a 2-year period, and a much wider range of individuals. Peer-outreach was also found to be more effective at reducing risk-related behaviours, and many times more cost-effective (Broadhead *et al.*, 1998).	In 2008, Burger King began their 'Whopper Sacrifice' campaign. Using a specially designed application on Facebook, individuals would receive a coupon for a free whopper in return for removing 10 connections from their Facebook account. These connections would receive a message explaining why they had been removed and encouraging them to download the app themselves. The campaign only ran for 10 days but over 20,000 coupons were generated and 233,096 people were reached (Kaplan & Haenlein, 2011).	Environmental education is often targeted to children. One reason for this is the assumption that children will pass information to their adult relatives and influence them. Lessons are often design to induce such further communication, for example by asking students to complete worksheets together with their parents (Duvall & Zint, 2007; Damerell, 2010)

3.4.2 Social structures

Social influence is important because often only a few 'low-threshold' individuals adopt an attitude or behaviour directly after receiving a message, while most targets require social reinforcement and influence from others before they adopt. These 'complex contagions' occur for several reasons, depending on the social context and nature of the behavioural change (Centola, 2018): Firstly, as the outcomes of behavioural change are uncertain, individuals may wait to see how it benefits others (i.e. credibility) before adopting (Rogers, 2003). Secondly, social norms play an important role in human decision-making (McDonald & Crandall, 2015), and people may wait for others to adopt (i.e. legitimacy) before following (Cialdini & Goldstein, 2004). Finally, in other cases new behaviours are only beneficial if they are also adopted by others (i.e., complementarity). For example, many conservation issues relate to the management of common-pool resources where collective behavioural changes are required (Ostrom, 1990). Such decisions may be made collectively or by authorities recognised as legitimate by the group.

For complex behaviours, information about the behaviours and views of an individual's social peers are key to driving diffusion, rather than the messages that were used to initiate behaviour change. As a result, these behaviours diffuse through a group along social ties as information about the behaviour flows through repeated interactions (Rogers, 2003). The structure of a social group will therefore influence the rate and patterns of diffusion. For example, groups of strongly connected individuals tend to behave more similarly (Mcpherson, Smith-lovin & Cook, 2001), and shape each other's perceptions of social norms (Shepherd, 2017). If a group member receives information about a new behaviour from outside the group, they may not adopt unless other members also adopt (Centola, 2018). To predict how behavioural changes spread, we need to understand these social structures and how information about new behaviours flows through them.

3.5 Studying Information Flows

Understanding how information flows through a group and drives adoption of a behaviour can be a demanding exercise, but there are several key pieces of knowledge that can inform meaningful improvements to intervention design (Valente, 2012):

1) Identifying and defining relevant social interactions
2) Measuring or observing these social interactions
3) Identifying key structural features and key individuals

3.5.1 Identifying relevant interactions

How do targets communicate, seek advice, or learn about the behaviour in question? As a rule of thumb, in traditional societies multiple types of information tend to be sought from the same relations, such as kin. Conversely, in modern societies individuals seek different types of information from different specialised networks (Weimann, 1994). Even in contexts where information appears to flow through formalised channels (e.g. in organisations), informal interactions such as friendships are still likely to play a significant role (Soda & Zaheer, 2012; Weenig, 1999). We can determine the types of ties that are relevant in a given instance by using qualitative methods, such as group discussions or interviews with group members. Methods such as ECCO (Episodic Communications Channels in Organisation) analysis may also be used to empirically investigate the ties through which specific messages flow (Box 3.1). Understanding the ways in which targets receive information from external sources is also important, particularly if mass-media is used (Veríssimo *et al.*, 2018).

3.5.2 Social structure

Once ties have been identified and defined, we can investigate how they are structured within the group. Social network analysis (SNA) is a powerful tool widely used in the social sciences to study social structures (Borgatti *et al.*, 2009) and can provide a global description of the system and identify many important features (Figure 3.1, Box 3.1). Qualitative methods such as group discussions or interviews can also provide more detailed information about certain features.

Box 3.1: Methods for studying information flows

ECCO Analysis

Episodic Communication Channels in Organisations analysis is used to understand how messages flow through informal channels. Conservation researchers could use this method to test assumptions about information flow when piloting interventions; to investigate the types of ties through which a message flows, to map a social network, or validate whether a mapped network predicts the route taken by a message. Firstly, a relevant message is identified and disseminated in a controlled manner. A series of follow-up questionnaire surveys is then administered, assessing which individuals have received the message and asking them from whom they received the message (Zwijze-Koning, 2005).

Social Network Analysis

Social Network Analysis (SNA) is a powerful tool that is widely used in the social sciences to study the structures of social groups. A vast multi-disciplinary literature has contributed to the development, application and interpretation of SNA data (Knoke & Yang, 2011). Here, we give an overview of the basic principles of SNA.

SNA generates a 'sociogram' (Figure 3.1), depicting individuals as nodes and their interactions as ties. The interactions represented are usually of a single type, can be directional or non-directional, and usually have some measurement of tie-strength associated. For example, an intervention aiming to promote new agricultural techniques may ask farmers to nominate individuals they go to for advice (Isaac *et al.*, 2007). Advice-seeking is a directional interaction, and tie-strength could be measured in the frequency of interaction, or perceived value of the advice received.

SNA data can be collected using several methods. Most common is the name-generator questionnaire, which is suitable when the relationships can be reported on by the actors involved in them, such as most communicative interactions. Respondents list the names of people with whom they interact and provide other information such as interaction frequency. This method is simple and reliable, but effort intensive as a large proportion of the community must be questioned to obtain an accurate representation of the network. Furthermore, responses may be subject to recall or social desirability bias (Knoke & Yang, 2011).

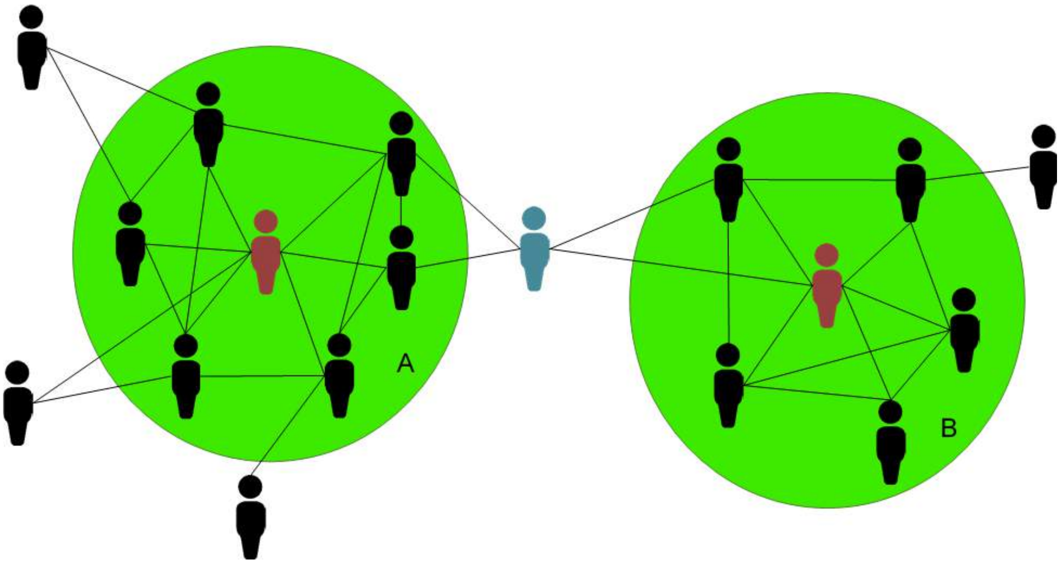


Figure 3.1: The ties between individuals in a group can be visualised as a network, revealing the structure of information flows. Some groups of individuals are more densely connected than others, suggesting the existence of sub-groups (A & B). Each subgroup has a core (green) and a periphery of less connected individuals. The most highly connected individuals (red) tend to be more influential and are also known as Opinion Leaders, while those connecting different sub-groups are known as bridges (blue).

3.5.2.1 Structural features

In homophilous groups, where individuals are similar and densely connected, information flows rapidly but complex behaviours face resistance as individuals resist deviating from existing social norms (Valente, 2012). Conversely, heterophilous groups with more different individuals and sparser ties tend to be more open to innovations (Rogers, 2003). However, density is rarely uniform across a network, and many groups have a homophilous core, or multiple homophilous subgroups (Figure 3.1), and a periphery of more loosely connected individuals (Borgatti & Everett, 2000). Information may flow between these subgroups via mutual acquaintances, but the social norms in each may vary (Mcpherson, Smith-lovin & Cook, 2001; Crona & Bodin, 2011). For example, subgroups in an information-sharing network of Hawaiian fishers were found to differ in their fishing behaviour, with significant implications for shark bycatch (Barnes *et al.*, 2016b). Several quantitative methods have been developed to detect such groupings in social network data (Borgatti & Everett, 2000).

Using qualitative methods to determine groupings requires careful elicitation from respondents with knowledge of the group.

3.5.2.2 Individual positions – hubs or opinion leaders

The positions that individuals occupy in their networks will, to a large extent, predict the role that they play in the flow of information and the social influence that they wield (Pei, Morone & Makse, 2018). Most importantly, individuals vary in the number of ties they have and their position within the global network. The most connected individuals (i.e. 'opinion leaders' or 'hubs') play an important role in successful dissemination of messages and can catalyse widespread adoption of new behaviours due to their social influence (Valente & Davis, 1999; Valente & Pumpuang, 2007). However, they tend to be less susceptible to influence and are rarely among the first to adopt complex behaviours, while less connected peripheral individuals tend to be less constrained (Aral & Walker, 2012).

SNA data can be used to calculate the centrality of individuals (Figure 3.1), as well as indicating different roles (see Mbaru & Barnes, 2017). Opinion leaders can also be identified through expert elicitation or peer-nomination surveys (Valente & Pumpuang, 2007). Most commonly, opinion leaders are identified using assumed correspondences with personal characteristics such as wealth, or formal leadership positions. However, comparison with SNA data has shown that these correspondences are context specific. For example, in a Kenyan fishery formal leaders, but not the wealthy, were among the most connected (Mbaru & Barnes, 2017).

3.5.2.3 Bridges

Where different subgroups exist, some individuals may be connected to others outside the group, acting as bridges. In some cases, groups may be linked by just a single individual, forming a very 'narrow' bridge (Figure 3.1). Such bridging individuals are unique as they have access to information from multiple groups and control the flow of information between them (Bodin, Crona & Ernstson, 2006). In homogenous societies this gives them a high level of social capital, but where they bridge conflicting or competing groups they may be mistrusted. For example, in a Hawaiian fishery, individuals who bridged ethnic groupings were denied access to information, resulting in lower fishing productivity (Barnes *et al.*, 2016a).

Bridges can be identified from SNA data using several metrics (Valente & Fujimoto, 2010). However, few other methods of identification have been used. Potential alternatives include eliciting knowledge from local informants, or identifying context-specific individual characteristics (e.g. wealth) that indicate bridging roles (Mbaru & Barnes, 2017). For example, in remote rural areas, individuals with commercial livelihoods may be more likely to travel, visit markets and interact with outsiders.

SNA or other data on key individuals or structural features are essentially predictions about how information will flow through the group and result in behavioural changes. In some cases, it may be valuable to validate these predictions, such as when piloting an intervention. For example, have the relevant ties been identified correctly? Do identified opinion leaders exert influence on the target behaviours? ECCO analysis, which empirically observes the flow of a message (Zwijze-Koning, 2005), can be used to answer these questions. Weenig (1999) used ECCO analysis with SNA to investigate the adoption of a new programme in a large company. Results showed that information about the programme was usually received through formal channels, but that intention to adopt was more strongly influenced by informal ties, such as friendship. Stochastic Actor-Oriented Models can also be used to statistically investigate whether a measured network is influencing the observed spread of knowledge or behaviour (Snijders, 2017).

3.6 Network Strategies for Behaviour Change

We can use this knowledge to design more effective interventions. Most simply, we can target communications more effectively, but more complex interventions may attempt to alter group structures. Many of these approaches have been applied successfully in public health and marketing (Table 3.2). The best strategy will depend on the capacity of the intervener, the type of behaviour change required, as well as current social structures, norms and values.

3.6.1 Communication targeting

For widespread dissemination of a message, hubs are essential communication targets (Kaplan & Haenlein, 2011, Figure 3.2). Different SNA metrics can be used to identify individuals for different purposes, such as: ‘closeness’ (distance to all other individuals) for rapid diffusion of information, or 'eigenvector centrality' (connectedness to other well-connected individuals) for long-term widespread diffusion of complex behaviours (see Mbaru & Barnes, 2017). In certain cases, it may be effective to recruit opinion leaders as 'change agents', providing training and incentives to help encourage adoption of new behaviours within their network, but this requires buy-in and commitment from these individuals (Nisbet & Kotcher, 2009). Where multiple subgroups exist, hubs can be selected and matched to specific target groups (Valente, 2012). Empirical evidence suggests targeting opinion leaders (e.g. Kim et al., 2015) or recruiting change agents (e.g. Starkey et al., 2009; Paluck et al., 2016) can be more effective than conventional messaging approaches. In conservation, Rare's Pride campaigns target "trusted messengers" in the community who provide an example for others to follow (Butler et al., 2013, Table 3.2).

For complex behavioural changes, hub individuals may be too constrained by existing group norms to act as initial adopters (Valente & Pumpuang, 2007). In such cases, targeting clusters of connected and similar individuals as "incubator neighbourhoods" can allow a new behaviour to become established within a socially-reinforcing group (Beaman *et al.*, 2014). These adopters can then influence mutual contacts and collectively promote the behaviour more effectively than an individual could (Centola, 2011, Figure 3.2). Complex behaviours are also less likely to spread between sparsely connected subgroups (i.e., via narrow bridges), so clusters within each subgroup could be targeted.

Where equitable development outcomes are required, targeting individuals on the periphery of a community with empowering information may be an end itself, as these are often less likely to have access to social services or to participate in governance (Valente, 2012). Similarly, if the poorest and marginalised are less likely to participate in institutions that are targeted for promoting collective conservation action (Agrawal & Gibson, 1999), and therefore do not change their behaviour, it may be important to communicate with them directly.

3.6.2 Message induction

A full discussion of message design is beyond the scope of this review (see e.g. Cialdini, 2015), but induction approaches to message design are relevant. These approaches attempt to increase information flow by incorporating positive, attractive or encouraging features into the message, such as in viral marketing (Kaplan & Haenlein, 2011, Table 3.2). As evidence suggests widespread behaviour change is more likely when communication between adopters is greater (Green *et al.*, 2019), induction can be an important tool. Induction strategies can also encourage adopters to signal their behaviour to others. For example, by incentivising participants in a livelihoods improvement scheme to recruit new members, or ensuring that adoption of a new behaviour is visible to others through public commitment-making or promotional signalling (e.g. free clothing) (Niemiec *et al.*, 2019). Messages can also be designed to reach otherwise hidden or hard-to-reach parts of the population (Johnston & Sabin, 2010). For example, the relatives of an arrested poacher are likely to know more poachers and could be given communication materials to disseminate.

3.6.3 Channel choice

Communication channels differ in what they can communicate, who they can reach, and how they affect recipients. Complex behavioural changes may require direct experience of the new behaviour which is reinforced by peer learning, while passive use of mass media might be sufficient for preventing future adoption of negative behaviours (Wakefield, Loken & Hornik, 2010). For example, televised health warnings may effectively prevent people from trying new pesticides, whereas in communities where use is already widespread, more work might be needed to encourage alternative practices. Secondly, individuals differ in the types of media they consume, so the appropriate channel will depend on who is targeted. In many cases, mass media can be effective at reaching large audiences, but the media habits of the audience must be understood in detail if this is to occur (Veríssimo *et al.*, 2018). Interventions targeting a small select group, such as recruitment of change agents or incubator neighbourhoods, may require more personalised approaches involving direct contact by the intervention team. Ideally, interventions aiming to effect widespread behaviour change will make use of a mix of channels, combining the strategies described. For example, workshops targeted to incubator neighbourhoods could initiate adoption while simultaneously mass media could increase the likelihood of diffusion to the wider population.

3.6.4 Altering Networks

If current network structures are not conducive for widespread behavioural change, interventions can attempt to alter them. New channels of communication can be developed by facilitating meetings or providing communication technology, e.g., to coordinate community-led anti-poaching patrols, facilitate peer-learning, or promote collective action. One notable success in agricultural extension has been 'farmer field schools' that enable farmers to collectively learn and adopt more sustainable techniques (Pretty & Ward, 2001). Such peer-learning can be more effective than conventional approaches because the group can co-produce the new practice in a socially meaningful way. Connecting adopting individuals alters their normative environment by increasing the proportion of ties engaged in the behaviour and reducing pressure to conform to previous group norms (Kincaid, 2004). For example, smokers who have contact with abstinent ex-smokers are more likely to quit successfully (Myneni et al., 2015, Table 3.2). The existence of disconnected sub-groups could lead to the divergence of norms (Friedkin & Johnsen, 2011), and so encouraging communication between groups could help maintain desirable norms, and improve the spread of complex behaviours. These bridges will need to be wide (i.e. multiple strong connections between members of each group) to enable the spread of complex behaviours, and require significant time and investment to form (Centola, 2010).

In cases where collective action is required, such as for governing common pool resources, it may be necessary to create forums where participants can communicate and ensure compliant behavioral norms are maintained and enforced (Ostrom, 1990; Clements *et al.*, 2010). Interventions aiming to create such bodies often co-opt existing structures, such as traditional councils, but this risks neglecting peripheral groups or those underrepresented in these structures. For example, in one community-based ecotourism project designed to incentivise protection of wildlife, geographically distant groups had little awareness of the project and may therefore have no incentive to change their behaviour (see http://tinyurl.com/y32jydya). In such cases, identifying disconnected subgroups can enable facilitators to connect them. At the same time, to avoid resentment, exclusion, and conflict, it is important to understand and respect current social structures and norms (Brown & Lassoie, 2010; Leach, Mearns & Scoones, 1999). For example, existing hierarchies within each subgroup and cultural concepts of legitimacy could be considered in selecting representatives. Finally, providing individuals with access to information can also alter their position in the network with potentially unexpected consequences. Opinion leaders may lose respect if they champion an unpopular cause. Conversely, beneficial information can improve an individual's prestige (Matous & Wang, 2019).

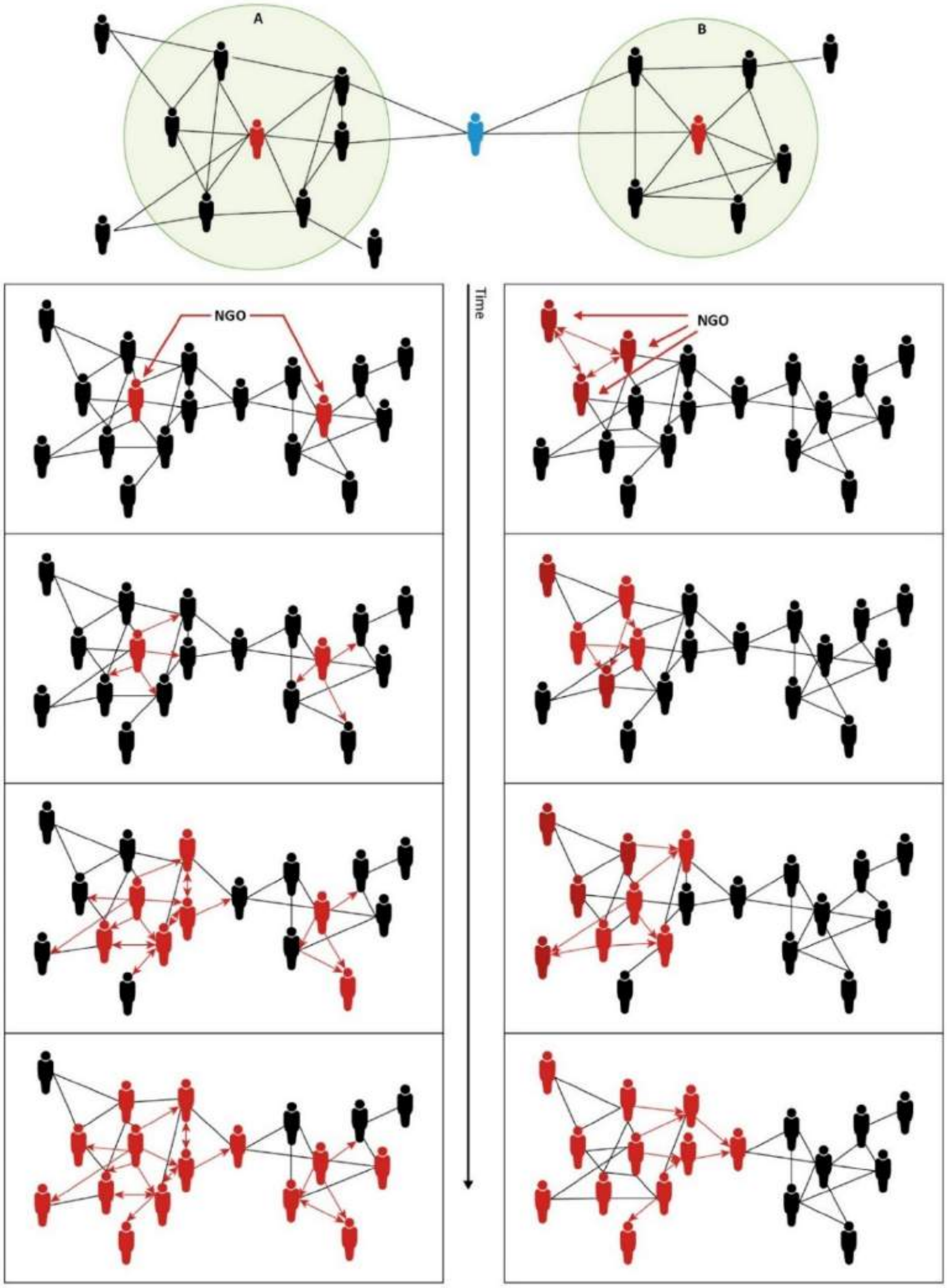


Figure 3.2: Two stylised intervention scenarios showing the flow of a message (red arrows) and the adoption of a new behaviour (red figures) through a social network in time: (left) recruitment of opinion leaders as change agents and (right) targeting an incubator neighbourhood. Recruiting highly connected individuals to spread a behaviour can be highly effective. Due to the influence these individuals wield, others in their network are likely to follow them in adopting new behaviours. However, they may be resistant to adopting risky or complex behaviours. Using incubator neighbourhoods, the new behaviour is socially reinforced, and adopters can work together to spread the behaviour. In this example, two adopters are needed to recruit another. In the subgroup on the central hub has catalysed a widespread shift in behaviour, but the behaviour is not able to spread to the other group via a single bridging individual.

3.7 Concluding Remarks

Disciplines such as public health have intervention strategies which exploit social networks, such as targeting communications to influential individuals, or facilitating social reinforcement between adopters (Valente, 2012). Evidence suggests that such network-based interventions can be more effective than conventional approaches (e.g. Kim et al., 2015; Paluck et al., 2016), and incorporating these practices can make conservation more effective. The optimal strategy will be context-specific, dependent on the nature of the behavioural change and the social context. Many interventions may require multiple strategies to be implemented at different stages. It is therefore essential to gain an in-depth understanding of the context prior to the intervention, including baseline research and active piloting of messages and delivery mechanisms, as well as evaluation of interventions to enable learning (Ferraro & Pattanayak, 2006). Currently it is unknown what strategies are used to target conservation interventions, and what sort of information about group structures is used when designing interventions. More research is required to understand the types of information flow that commonly occur in conservation contexts and whether generalities exist that can be used as rules of thumb to guide intervention planning (see Box 3.2). Furthermore, SNA is a costly method, so more feasible accurate methods for identifying important individuals or structural features must be developed if practitioners are to adopt these approaches. As conservation interventions increasingly focus on changing human behaviour, incorporating insights from the social sciences, such as by understanding information flows, will be critical for achieving conservation goals.

Box 3.2: Outstanding Questions

- How do conservationists currently target their communications in behaviour change interventions?
- What sort of information about group structures is currently used when designing interventions?
- How well do qualitative methods for identifying key positions or structural features correspond to SNA results? What low-cost methods are most reliable?
- How do conservation interventions alter the structure of local social networks, and how does this influence conservation and wellbeing outcomes?
- What sorts of social ties are most important for influencing conservation behaviours, and how are these networks structured in conservation areas?
- What are the costs and benefits of adopting network-informed intervention strategies? Do the increases in effectiveness justify the costs of conducting formative research?

4. Using mixed methods to understand sensitive wildlife poisoning behaviours in northern Cambodia

This chapter is published as: de Lange E, Milner-Gulland EJ, Yim V, Leng C, Phann S, & Keane AM. Using mixed methods to understand sensitive wildlife poisoning behaviours in northern Cambodia. Oryx. 2020; doi:10.1017/S0030605319001492

4.1 Abstract

In northern Cambodia, threatened wildlife, livestock, and people are being poisoned by pesticides deposited in seasonal waterholes. Addressing this critical conservation threat requires understanding the drivers of poisoning behaviours and the social contexts in which they occur. This study across 10 communities in two protected areas aimed to provide a first assessment of this phenomenon. We used the theory of planned behaviour to measure socio-psychological determinants of behaviour and deepened this understanding using informant interviews and focus group discussions. Informants reported that so-called termite poisons, including powerful carbamates, are deliberately deposited at waterholes to catch wildlife for consumption. This method is perceived to be low effort and high efficacy, and perceptions of the health risks vary. Predominant users are young men and children, but it is not clear whether the practice is related to food insecurity. Threatened wildlife species reported as affected include the giant ibis *Pseudibis gigantea* and vulture species. Overall, social norms are strongly negative towards poisoning; 75% of survey respondents perceived negative norms because of impacts on human and livestock health, environmental quality, and risks of legal sanctions. This has led to interventions by local authorities in half of the studied villages. We suggest that future interventions should raise the salience of negative norms by providing a non-conflictual mechanism for community members to participate in monitoring and sanctioning, such as a reporting hotline. Regulatory interventions are also required to control the supply of restricted pesticides.

4.2 Introduction

Toxic agrochemicals used in agriculture are a major threat to wildlife, leading to widespread declines in insect and bird populations (Carson, 1962) and deaths of larger animals(Berny, 2007). Deliberate poisoning of large animals is also widespread (Richards, 2011); e.g. in Africa, some farmers use Carbofuran pesticides to kill predators (Ogada, 2014) driving a crash in vulture populations (Buechley & Şekercioğlu, 2016; Ogada, Botha & Shaw, 2016). However, the use of agrochemicals for harvesting wild meat has rarely been documented (e.g. (Odino, 2011).

In 2015, five seasonal waterholes (*trapeangs*) in Cambodia's Preah Vihear province were found to contain the pesticide Carbofuran. Threatened wildlife species found dead included critically endangered vultures, and people fell ill after drinking contaminated water (Figure 4.1, (LACANET, 2016; Loveridge *et al.*, 2019). Although reports of suspected wildlife poisonings in Cambodia are common, including 51 suspected vulture poisonings during 2004–2015 (Loveridge et al., 2019), these were the first records of poisoned waterholes with toxicological confirmation. Because of the potentially critical threat to human health and populations of threatened wildlife, conservation groups took immediate action based on assumptions about poisoning, including awareness-raising meetings in local communities, and producing educational media (Loveridge et al., 2019). To inform intervention design, this study aims to provide a broad assessment of waterhole poisoning in Preah Vihear province: identifying the actors involved, understanding their motivations and describing the social context in which poisoning occurs.

Cambodia has been described as a dumping ground for unwanted pesticides because of weak regulation of imports (imports increased 17-fold during 2002–2012; (Matsukawa *et al.*, 2016) and sale (Environmental Justice Foundation, 2002). For example, although Cambodia is signatory to international conventions restricting Carbofuran use, it remains widely used (Rotterdam Convention, 2013; Matsukawa *et al.*, 2016). Inadequate education and labelling mean that pesticide misuse is widespread, and poisoning of farmers, both acute and chronic, is common (Environmental Justice Foundation, 2002). Researchers have suggested that misuse, accidental run-off and intentional poisoning are affecting fish and wildlife populations at a national scale (Saroeun, 1999).


Figure 4.1: A waterhole poisoning showing dead wildlife (a plaintive cuckoo, Cacomantis merulinus) close to the water. A purple granular pesticide is visible on the fallen tree. Photo credit: WCS Cambodia

Effectively addressing wildlife poisoning requires understanding the specific practices and actors involved, their motivations and attitudes (St. John, Keane & Milner-Gulland, 2013), and the social context (St. John, Edwards-Jones & Jones, 2010). Local NGO workers have suggested that waterhole poisoning could be an unintended consequence of agriculture, a result of conflicts such as land disputes or intentional wildlife killing. Each practice may have multiple interacting drivers. For example, intentionally poisoning wildlife could be driven by socio-cultural demand for wild meat (Delisle *et al.*, 2018) or by economic incentives to supply wildlife products to market (Milner-Gulland *et al.*, 2003). It may also be employed as an act of resistance against conservation authorities (Norgrove & Hulme, 2006; Peterson, Essen & Hansen, 2017).

Theory from social psychology can guide research on human behaviour. The theory of planned behaviour (Figure 4.2) has been widely used to understand the socio-psychological determinants of conservation behaviours (St. John, Edwards-Jones & Jones, 2010; Ward, Holmes & Stringer, 2018). This theory posits that an individual's intention to carry out a behaviour in a particular context is predicted by that individual's attitudes (i.e., is it a good thing to do?), perceptions of social norms (i.e. do others do it?), and perceived control over the behaviour (i.e. am I able to use this method?). It assumes that these are semi-stable constructs that can be reliably determined by measuring relevant salient beliefs (Ajzen, 1991). The theory of planned behaviour can inform the design of behaviour change interventions (Hardeman *et al.*, 2002; Michie *et al.*, 2008). For example, there may be multiple actors with different psychological determinants, requiring multi-faceted interventions that segment audiences (Mckenzie-Mohr, 2000; Jones *et al.*, 2019; Travers *et al.*, 2019). Where individual behaviours are constrained or enabled by external factors, conservationists may additionally intervene at higher levels, such as by influencing economic drivers (McKenzie-Mohr & Schultz, 2014).

To inform intervention design, our study set out to understand waterhole poisoning across two protected areas in Preah Vihear, using a mixed-methods approach. We aimed to quantify the prevalence of relevant practices and measure variables from the theory of planned behaviour to unpack socio-psychological drivers. We collected qualitative data on poisoning practices to contextualise our quantitative data, and to determine the motivations of poisoners and the social contexts in which poisoning occurs.

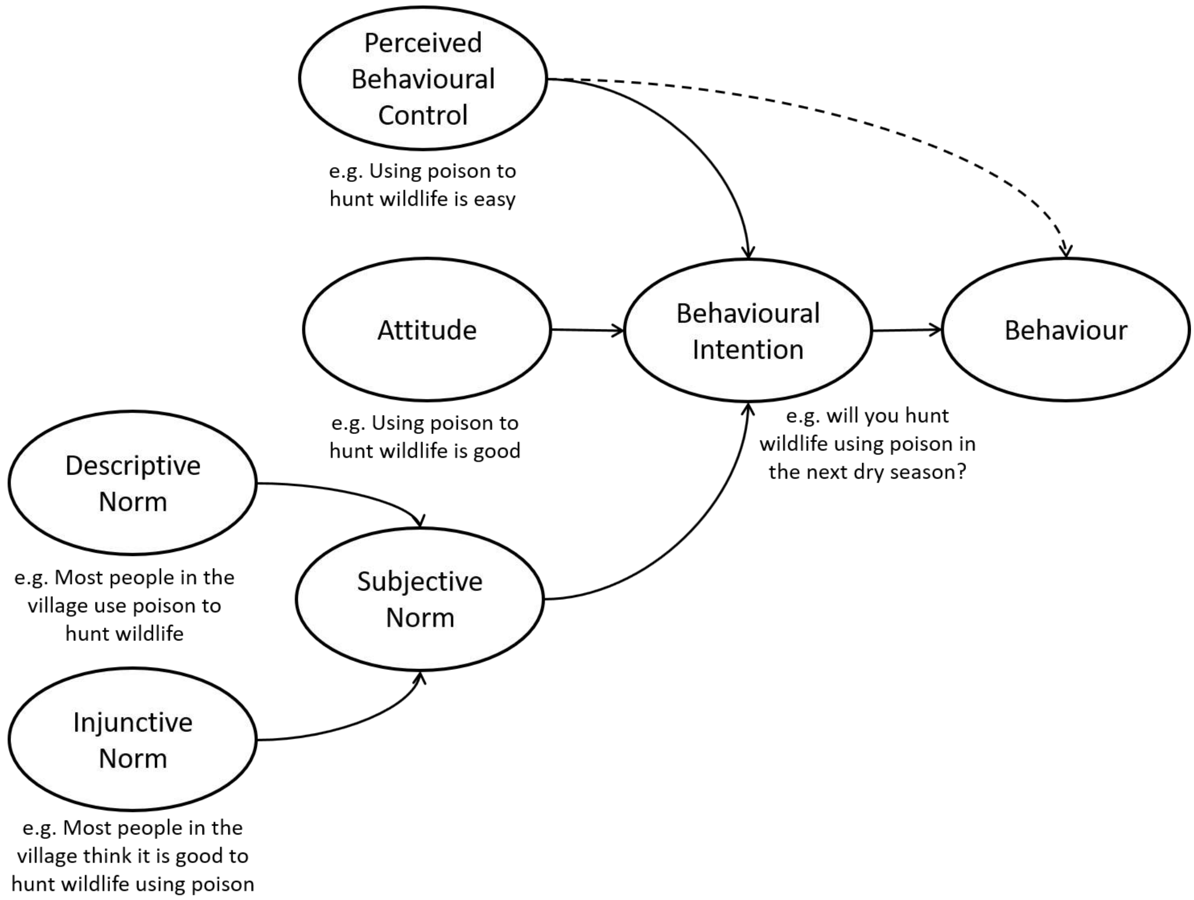


Figure 4.2 A summary of the theory of planned behaviour (Ajzen, 1991) as applied to wildlife poisoning in this study. Within the theory an individual's behaviour is predicted by their intention to behave, which in turn is influence by their attitudes towards the behaviour, their perceived control over the behaviour, and their perception of social norms related to the behaviour. The subjective norm is in turn influenced by descriptive norms (how others behave) and injunctive norms (how others think one ought to behave). We found that attitudes, and perceptions of social norms towards poisoning are on average negative, whereas perceived behavioural control are mixed. Because of the sensitivity of the behaviour, behavioural intention or prevalence could not be measured.

4.3 Study area

Preah Vihear province in northern Cambodia lies in a global biodiversity hotspot (Chapter 2; Myers *et al.*, 2000), contains the largest remaining mosaics of forests and grassland in mainland South-east Asia and is home to 28 Critically Endangered or Endangered species (Clements et al., 2010), including the giant ibis *Pseudibis gigantea*, white-shouldered ibis *Pseudibis davisoni*, and three vulture species. Many rely on waterholes for food and water throughout the dry season (Pin *et al.*, 2018). At the time of this study, two protected areas were managed by the Ministry of Environment (a third was gazetted in late 2017, Figure 2.2), with support from the Wildlife Conservation Society: Chheb and Kulen Promtep Wildlife Sanctuaries.

We conducted our study across the two protected areas in 10 villages that reflect a cross-section of levels of wealth, access to markets, and involvement in conservation programmes. All were involved in previous research (Beauchamp, Clements & Milner-Gulland, 2018a; Beauchamp *et al.*, 2018; Beauchamp, Clements & Milner-Gulland, 2019). Many originated from small groups of indigenous communities, Khmer Rouge soldiers, or other fugitives, living in the remote forest. After the Royal Government recaptured this area from the Khmer Rouge in the late 1990s the state consolidated control over the region through mass patronage and infrastructure development. Cambodia's political system is described as hegemonic authoritarianism and the government closely monitors rural life and political activity (Chapter 2; Craig & Kimchoeun, 2011; Beban *et al.*, 2019; Morgenbesser, 2019).

Cambodia has liberalized its economy, with GDP growth averaging 8.7% per year (Hughes & Un, 2011). Although this has led to increased employment opportunities and improved access to markets, for many residents it has led to dispossession of agricultural land and nearby forests by corporate interests with state backing, and migration of landless people from other provinces (Davis *et al.*, 2015; Milne, 2015; Beauchamp, Clements & Milner-Gulland, 2018a). Given these pressures and opportunities, many residents who previously farmed subsistence rice now clear forest and accumulate land, to grow and sell cash-crops such as cassava or cashew or to take advantage of rising land prices (Beauchamp, Clements & Milner-Gulland, 2018a). Clearing land within the protected areas is illegal, but is facilitated or promoted by personal relationships with local officials (Milne, 2015). Cambodian society is marked by neopatrimonialism: power is exercised through personalized patron-client relations, with an emphasis on kinship. A village is a geographical collection of relatively autonomous households and much interaction is governed by norms of reciprocity (Ovesen, Trankell & Ojendal, 1996; Ledgerwood & Vijghen, 2002; Sedara, 2011). Each village has a chief who is either appointed by the state or nominated by village elites. Chiefs vary in influence; they tend to be loyal party members who participate in surveillance and disciplining of the community (including researchers). Their bureaucratic position gives them power to mediate access to the state (i.e. registration of land titles), but some may enjoy respect for facilitating the community's interests (Ledgerwood & Vijghen, 2002; Biddulph, 2015). Other disputes may be settled through informal processes by village elders (Luco, 2002; Travers *et al.*, 2011).

The Ministry of Environment and the Wildlife Conservation Society support village institutions and conservation programmes in most communities within the protected areas (Chapter 2). Participatory land-use plans have been developed with residential, conservation, agricultural and other zones. Community protected area or community forest committees are elected in nine out of the 10 villages, to monitor and enforce compliance with these rules. To incentivize compliance, the Ibis Rice company buys rice at a premium from farmers who follow conservation rules (including no hunting and no use of pesticides; Clements et al., 2010). Village market network committees are elected to monitor farmers' compliance and determine eligibility in five of the villages. There are also community-managed ecotourism projects in three villages that generate village development funds and direct payments to individuals to protect the nests of priority birds (Clements *et al.*, 2010; Clements & Milner-Gulland, 2015). Medium-term evaluations show that these programmes have contributed to improved tenure security and have provided additional livelihood options (Beauchamp, Clements & Milner-Gulland, 2018a). Law enforcement patrols are also conducted by the state.

Fish and wild meat remain important dietary components, and collection of non-timber forest products, such as liquid resin and mushrooms, provides additional income (Travers et al., 2011; Beauchamp et al., 2018a). Most households are engaged in incidental wildlife hunting for home consumption, such as setting traps around agricultural land, taking dogs into the forest when collecting mushrooms or a slingshot while fishing. This affects common species such as water monitors (*Varanus salvator)*, muntjac (*Muntiacus muntjak)*, or wild pigs (*Sus scrofa*), and is tolerated by authorities. The meat is considered preferable to domestic or market meat because it is seen as chemical-free. Only a small proportion of households do targeted hunting in the forest using homemade guns or snares, as this requires skilled labour. They target high-value species for sale at local markets (Coad, Lim & Nuon, 2019; Ibbett *et al.*, 2020).

4.4 Methods

The research team comprised students from the UK and Cambodia and operated independently of the Wildlife Conservation Society. We used unmarked vehicles and discussed our position with chiefs and other participants. Participants (all aged over 18) gave verbal consent following explanation of the research.

Exploratory pilot studies were conducted in two villages, outside the protected areas, which had been matched to our study villages (Clements & Milner-Gulland, 2015). We used key informant interviews and focus group discussions to investigate pesticide usage. We identified salient beliefs to measure for the theory of planned behaviour and to develop the questionnaire, which was piloted with c. 30 respondents in each of the two villages. Question wording was refined after each village. To measure the prevalence of sensitive poisoning practices we initially used the single sample count method (Petroczi *et al.*, 2011) but switched to the unmatched count technique for the second village because of its lower cognitive demand. The surveys were initially translated into Khmer and back into English to ensure accuracy and again whenever modifications were.

In the full study, we administered the final survey to a sample of households, organized focus group discussions, and conducted key informant interviews in each of the 10 villages. We visited each village for approximately 5 days during July–September 2017, staying at the home of the village chief or a nominated subordinate. It was necessary to stay at a home for security reasons, and association with the chief was considered the best option as it is a common practice for visitors without personal contacts in the community. This also legitimized our activities, and reassured villagers that talking to us was condoned, but may have raised concerns that responses would be shared with authorities, despite our assurances.

We administered the questionnaire to 30–60 households in each village. Sampling was opportunistic because of the unpredictable availability of household members, but we attempted to sample proportionally from all geographical sections of a village. We sought to interview male household heads (as in the pilot these were found to be most knowledgeable on the topic), but also surveyed 24 woman-headed households. We visited respondents at their homes and survey data was collected using *Open Data Kit* (Brunette *et al.*, 2013). We collected demographic and livelihood information and used an adaptation of a basic necessities survey previously developed for the same area, to give an index of household wealth (Beauchamp et al., 2018a).

We used the unmatched count technique to estimate prevalence of sensitive wildlife poisoning practices (Hinsley *et al.*, 2019). In each round, respondents selected one of two face-down cards. One card displayed images of four related non-sensitive behaviours. The second card was identical but included the sensitive behaviour. Without identifying which, respondents were asked to state the number of displayed behaviours they had practised in the past year. A non-sensitive practice round was used to confirm that the procedure was understood before continuing (Hinsley et al., 2019). We then asked about pest control issues and uses of pesticides identified during the pilot study. We used images of pesticide packaging collected during a market shelf survey to help respondents identify specific products. We used five-point Likert scales to measure constructs from the theory of planned behaviour related to wildlife poisoning: two items for each of attitudes, perceived behavioural control, and perceptions of descriptive and injunctive norms. Finally, we directly questioned the respondent about their hunting practices, including use of poison for hunting.

Focus group discussions were organised separately for men and women in each village. We invited eight participants, selected in consultation with the village chief, but the number of attendees was 4–10. We began by asking about non-sensitive topics such as pest issues, pest control, and use of pesticides, and finally other forms of poisoning. We adapted key informant interviews depending on the specific knowledge of the informant. In each village we made efforts to interview the village chief, local doctors, shopkeepers, and leaders of conservation committees, and opportunistically interviewed other individuals. When informants indicated direct knowledge or experience of wildlife poisoning, we asked about the practice, the motivations for it, and how they learned this method.

Statistical analysis was performed in *R* 3*.5.2* (R Core Team, 2017). We used the *list* package to analyse unmatched count technique data (Blair & Imai, 2010). We calculated estimated prevalence of each behaviour and counted the number of maximal responses (i.e., respondents stating that they perform all behaviours on the card). Using the method described by Blair & Imai (2012) we also tested for design effects: lower than expected responses from respondents who see the sensitive item, indicating dishonest responses. When theory of planned behaviour construct measures was internally consistent (i.e. Cronbach's alpha >0.5), we summed them into single continuous measures. We fitted linear mixed models with a Gaussian or binomial response to test for associations between individual variables and beliefs, practices, perceptions, and theory of planned behaviour variables. For individual ordinal Likert measurements, we used cumulative link (logit) mixed models. Village was included as a random effect in all models. Qualitative data was translated, and transcribed into *NVivo* (QSR International, 2015). Text was then coded into pre-defined themes related to the research questions. New themes were also allowed to emerge from the data, following which the data were recoded. Our results subheadings reflect these themes.

In total, we interviewed 462 respondents (20–50% of households in each village) and carried out 20 focus group discussions and 53 key informant interviews. We preserve the anonymity of the villages.

4.5 Results

4.5.1 Waterhole poisoning practices

During the dry season termite poison mixed with rice, water, fruit or fish, is placed in the water of a waterhole or in a container nearby, to hunt wildlife (Figure 4.1). One respondent summarized this as follows, and similar descriptions were provided by a total of 28 informants from eight villages, including during two focus group discussions.

In the dry season, when the waterholes are dry, I put the poison in a coconut shell. It is a powder which I dissolve in the water and put in the shell […]. Using this poison, I used to catch a lot of birds, maybe five or six each time, and I would try three times in one season.

Termite poisons are considered the strongest chemicals available. This term referred to multiple products, identified by packaging, including carbosulphan, carbofuran, fipronil, diazinon and cypermethrin. Respondents often described the poisons by their blue, red or purple colour. Small unlabelled bags of termite poison are also available in local shops for KHR 1,000 (c. USD 0.25, Figure 4.3). We also recorded other misuses of pesticides (Appendix 1).

Figure 4.3: Packaging of one of the most commonly available 'termite poisons' as (a) sold in a provincial market, and (b) resold in a village shop. This is a Carbamate which is banned in many countries in the world and is restricted in Cambodia (Royal Government of Cambodia, 2012).

4.5.2 Prevalence

When directly questioned, 174 respondents (38%) stated they hunted wild meat, but only six respondents (1.3%) admitted to poisoning waterholes (Appendix 2). In the unmatched count technique, the practice round showed no design effect ($p=0.67$). The estimated prevalence of waterhole poisoning was –40% of the population ($SE=0.12$, $p<0.01$). This is an impossible result, and the significant design effect ($p<0.01$), suggests it is produced because respondents actively reduced their answer in response to the treatment question. Nonetheless, six respondents (2.4%) gave a maximal response to the treatment card, effectively indicating engagement in waterhole poisoning.

Informants in eight villages reported occurrences of waterhole poisoning. In one village the chief estimated c. 30% of households engaged in the practice, and two other informants gave estimates of 25–30%. In other villages, estimates varied more widely. For example, one chief denied any poisoning, but his deputy gave an estimate of 30%. In another village, some estimates varied from c. 4 to 10%, and another two informants estimated 50%. In the other four villages, just a few households were indicated to engage in the practice (Figure 4.4). Three informants reported practising waterhole poisoning for many years. One man admitted that he stopped poisoning 7 years ago after suffering from symptoms of poisoning and accidentally killing one of his dogs. Another told us he had learnt the method from his father who had been practising it for many years.

4.5.3 Impacts of poisoning

Informants and focus group discussion participants described impacts of poisoning on the environment, wildlife, domestic animals and human health. Concerns raised included reduced availability of clean water, and lost fishing grounds. Poisoning at waterholes was seen as indiscriminate and many informants reported seeing a wide variety of species killed, including species of conservation concern (Table A1.2). Many were unable to identify the species they had observed but reported seeing large numbers of dead animals.

Informants in three villages complained their dogs had been poisoned. Similarly, two village chiefs reported cattle being killed after drinking poisoned water. There were widespread concerns about consuming poisoned meat; many respondents across all types of questioning gave direct or indirect accounts of symptoms, including diarrhoea, stomach aches, chest pain, intestine pain, joint pain, fever, tiredness, hot eyes, thirst and dizziness. One traditional doctor in a village where the pilot study was conducted reported the death of a young boy who consumed poisoned meat whilst suffering malaria, although this could not be corroborated. Some respondents who admitted having used poison had stopped after suffering stomach aches, but others had not suffered any symptoms. Other informants attributed symptoms to other factors such as the being meat unwashed or did not consider the symptoms significant. There was a widespread belief that removing the internal organs and head of the animal renders the meat safe to eat. One male focus group discussion participant, during the pilot study, summarized these beliefs:

A few men have had stomach aches after eating poisoned birds, but they continue to eat. It is of low concern, and they avoid eating the internal organs for this reason […]. Some who have experienced this have switched to using nets, but not all […]. The stomach pain is mild and happens after a lot of meat is eaten, there is no diarrhoea […]. They don't worry enough to go to the doctor, and not even all men experience this.

4.5.4 Motivations and key actors

Most reports were of villagers using poison to catch food for household consumption, including six individuals, the participants of one focus group discussion who had engaged in poisoning themselves, and almost all of the 34 informants who had indirect knowledge of poisoning. Informants in three villages explicitly denied the existence of trade in poisoned meat when asked, but one informant reported that trade with the nearest market was occurring, and another described trade occurring within another village. Sharing surplus poisoned meat with relatives and neighbours was more common. Further reports from two villages indicated that workers from nearby agro-industry concessions used poison to defend crops from cattle encroachment. Similarly, in one focus group discussion participants implicated soldiers stationed nearby. One chief suggested that poisoning may be done as retaliation, or out of jealousy, by conservation rule-breakers who had been excluded from the benefits of conservation programmes.

Most informants stated that poisoning is practised predominantly by young men of up to c. 30 years of age, to provide meat for their families. Some informants suggested that poorer households are more likely to use this method. For example, one male informant explained the motivations of a friend: *'He had no work and is poor and wanted to eat meat.'*

Other informants suggested that wealthier households were also likely to use the method, one explaining that poison was too expensive for him. From four villages we obtained reports that children older than c. 12 years were using poison. We spoke to a mother who admitted that her children used this method and were taught by a shopkeeper. Although she did not condone the practice, the family shared the meat together. Shopkeepers may be a source of knowledge about these methods. Informants reported that adults may also learn the method from sellers at local markets, through personal experimentation, or from other villagers. For example, one informant learnt the method from his father, who in turn was taught by a neighbour.

4.5.5 Village perceptions

During one pilot focus group discussion, poisoning was discussed openly, and multiple male participants admitted to practising it. In this village, informants and discussants claimed that wildlife poisoning was not illegal and spoke in detail about the practice. Participants claimed they discussed this practice with each other and learnt from each other, such as when eating wild meat at a relatives' home and enquiring about its origin or asking acquaintances about their dinner plans. Others knew not to catch fish at poisoned waterholes. Half of participants had practised poisoning, and other informants gave prevalence estimates as high as 70%, but many had decided to switch to nets because of health concerns.

Poisoning was only acknowledged in three of the 20 focus group discussions within the protected areas, as something done by other villagers or by outsiders. In remaining focus group discussions, participants claimed to know nothing about poisoning and discussions were generally characterised by low levels of disagreement, perhaps reflecting pressures to produce socially acceptable responses. This occurred in villages where other informants reported poisoning to be common. In one case such an informant was participating in the focus group discussion but remained silent on this point. We elicited views about waterhole poisoning on a hypothetical basis. For example, in one discussion participants claimed not to know about poisoning but suggested that if it were happening, it would be done in secret to avoid legal repercussions. When asked who else might disapprove of the practice, a male participant stated: *'If people in the village knew this was happening, they would be unhappy as it could kill their cattle'.*

In the same village, multiple informants indicated that poisoning was occurring, and the chief reported having raised the issue at a meeting. The chief estimated that c. 30% of households used poison, but that they *'are not among [his] friends'.* One young man informed us that a lot of people in the village are unhappy about the practice. A woman in this village told us: *'Everyone in the village knows this happens and many people don't even like using pesticides on their crops but will poison animals'.*

In another village, one male informant reported that poisoning was widespread in the past, but that now only c. 50% of the village continued to use this method. He suggested that those who had stopped became concerned about the health effects and were unhappy about the risk posed to livestock. Another man gave a similar estimate for prevalence and believed that although most others might refuse to buy poisoned meat because of health concerns, they don't mind that it occurs and prefer to avoid arguments. Nevertheless, some are unhappy about lost access to waterhole fisheries. The chief downplayed the prevalence of poisoning as just 'four or five households' and stated that it never led to arguments.

4.5.6 Attitudes, perceptions and beliefs

4.5.6.1 Attitudes

The survey data showed that hunting with poisons was regarded as unsafe by 87% and not viewed as a good method by 89% of respondents (Figure 4.5). Nonetheless, 32 respondents from across all villages stated that it is a good method. The two Likert items measuring attitudes were internally consistent (α=0.51) and were combined into a single measure. Wealthier respondents tended to have more negative attitudes, but no other variables had significant effects (Figure 4.6, Table A1.3). Of 168 self-reported hunters asked to explain why they did not use poison, concerns for safety and health were the most frequent response (63%, Figure 4.7), with lack of knowledge about the practice second (20%).

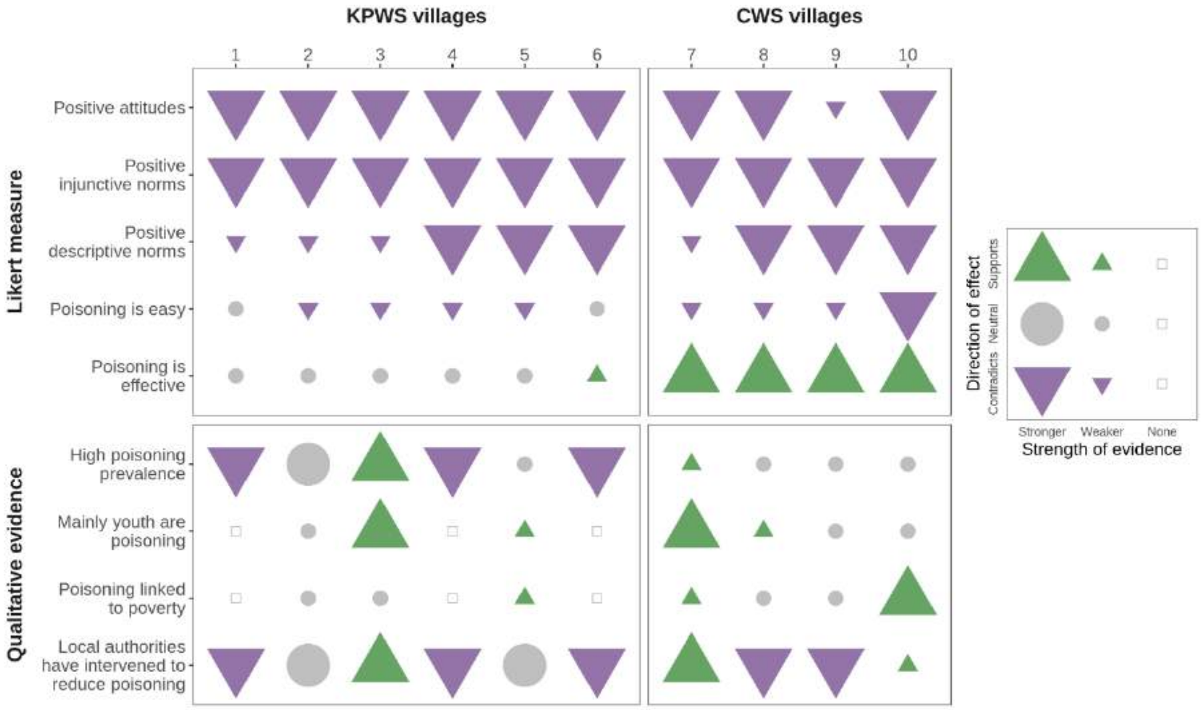


Figure 4.4: The strength of evidence to support each statement or research question across all 10 villages. Villages 1–6 are in Kulen Promtep Wildlife Sanctuary, and villages 7–10 in Chhep Wildlife Sanctuary. Triangles pointing downward indicate that the evidence contradicts, circles indicate that the evidence is neutral, and triangles pointing upward indicate that the evidence is in support of the statement on the left. Larger shapes indicate that the evidence is stronger for this conclusion. Blank squares indicate that the conclusion is not applicable (i.e., because poisoning is not thought to occur in a particular village) or that there is no evidence related to the statement. The top five rows are based on quantitative measurements using Likert scales. Evidence is considered weak if the SD overlaps with the centre of the next category (e.g., mean attitude is negative, but SD overlaps with centre of the neutral category). The remaining rows are based on qualitative evidence, and subjective judgement of the evidence. Evidence is considered strong if more than three independent sources confirmed it.

4.5.6.2 Perceived behavioural control

Likert measures for perceived behavioural control were not consistent (Cronbach's α=0.09), so these were analysed separately: 65% of respondents did not think poisoning was an easy (*sruol*) method, and 13% did not know if it was easy. Wealth, agricultural pesticide use, and membership of the village market network correlated positively with perceived ease of use, whereas age and length of local residence correlated negatively (Figure 4.8, Table A1.4). Agricultural pesticide use (effect=0.82, SE=0.25) had the largest effect. Conversely, 68% of respondents stated that poisoning is an effective method for catching wildlife, especially younger people and those using agricultural pesticides (effect=0.61, SE=0.28). Respondents living in Kulen Promtep Wildlife Sanctuary were more likely to perceive it as effective (effect=1.63, SE=0.50, Figure 4.4, Table A1.5). Informants from four villages (three in Kulen Promtep Wildlife Sanctuary, one in Chheb Wildlife Sanctuary) referred to the efficacy of poisoning as an advantage and a potential reason for others to practise it. This included the ease with which the method can be learnt and applied, the effectiveness and speed with which animals are killed, and the quantity of wildlife that can be harvested. Two informants also made favourable comparisons to guns and slingshots. Small amounts of termite poison are cheaply available locally, and several respondents suggested this made it accessible to even the poorest.

4.5.6.3 Perceived social norms

Over 75% of respondents indicated anti- or non-poisoning norms for each of the four Likert items, and average responses did not vary by village (Figure 4.4). Nevertheless, 28 respondents (6%), 17 of whom resided in two villages in Chheb Wildlife Sanctuary, perceived wildlife poisoning to be a common practice in their community. The four Likert items were internally consistent (Cronbach's α=0.61) and were analysed together. Older respondents and those living in Kulen Promtep Wildlife Sanctuary (effect=–1.89, SE=0.24) were more likely to perceive norms as being anti-poisoning (Figure 4.6, Table A1.3). Furthermore, when descriptive and injunctive norms were analysed separately, differences emerged: wealth had a small positive effect (effect=0.15, SE=0.06) on descriptive norms (i.e. wealthier people were more likely to think poisoning is common in the village), but in villages where local authorities had taken action against poisoning (effect=0.48, SE=0.15) wealth had a negative correlation with perceptions of injunctive norms (i.e. more likely to say that other villagers did not approve).

4.5.7 Perceived and actual repercussions

According to informants and focus group discussions, hunters carry out poisoning in secret, which they suggested may be a reason why conflict or sanctioning has rarely occurred. For example, in one focus group discussion participants believed that if a cow was poisoned it would not lead to an argument because they would be unable to identify the poisoner. An informant who had a dog killed gave a similar explanation. The possibility of facing legal consequences was cited by four respondents across four villages, and by participants in two focus group discussions, as reason to conduct poisoning in secrecy. For example, one chief expected that most adults would phone the police if they saw children using poison. Another informant suggested that no one would talk to us about poisoning because of fear we would report them to the government. Nevertheless, among those who admitted hunting, legality was only offered as a reason not to use poison by three individuals (2%, Figure 4.7). Among former poisoners, only one cited law enforcement as a reason for having stopped the practice.

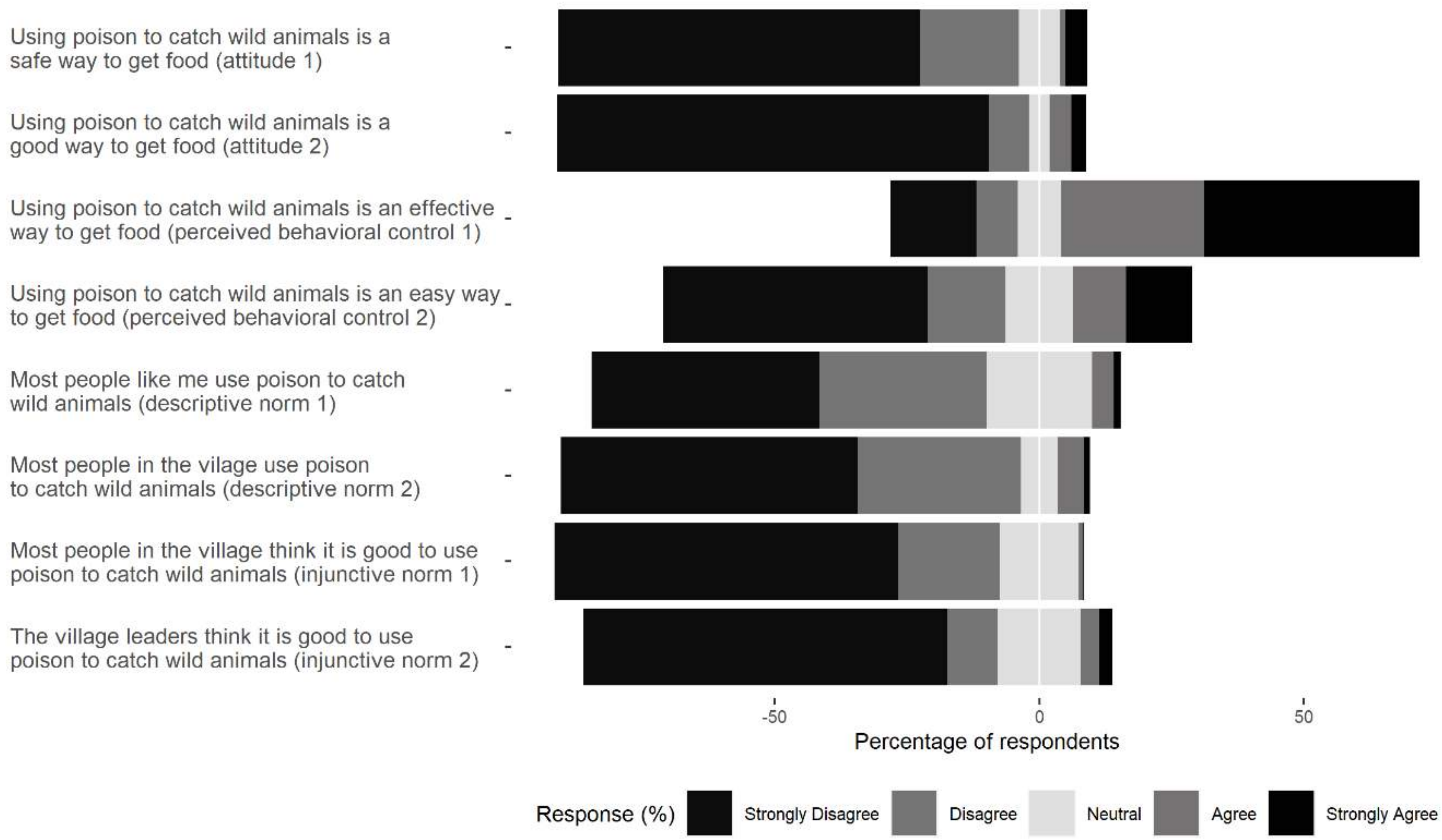


Figure 4.5 Each construct from the theory of planned behaviour (attitudes, perceived behavioural control, injunctive norms, and descriptive norms) was measured using two questions on a five-point Likert scales. The respondent was presented with a statement and asked to what extent they agreed or disagreed. The percentage of respondents (total = 462) providing each answer for each statement is shown.

In five villages, local authorities reported action to deter or punish poisoning, after receiving reports from members of the community or directly observing poisoning. Usually, members of community protected area committees observed these incidents when patrolling. The first response is a verbal warning, but they may also be referred to the village chief. One chief asked offenders to sign a contract, a common practice in Cambodia, promising to refrain from poisoning. Informants perceived that these individually targeted interventions were successful in deterring individual hunters from using poison again. For example, one community protected area chief claimed:

In 2013 we caught someone and brought him to the village chief. He had put a plastic bag in a hole in the waterhole and put a termite poison in […] If cattle had been poisoned, he would have to pay a big fine, but the [village] chief made him sign a contract [not to continue] and he has now stopped…

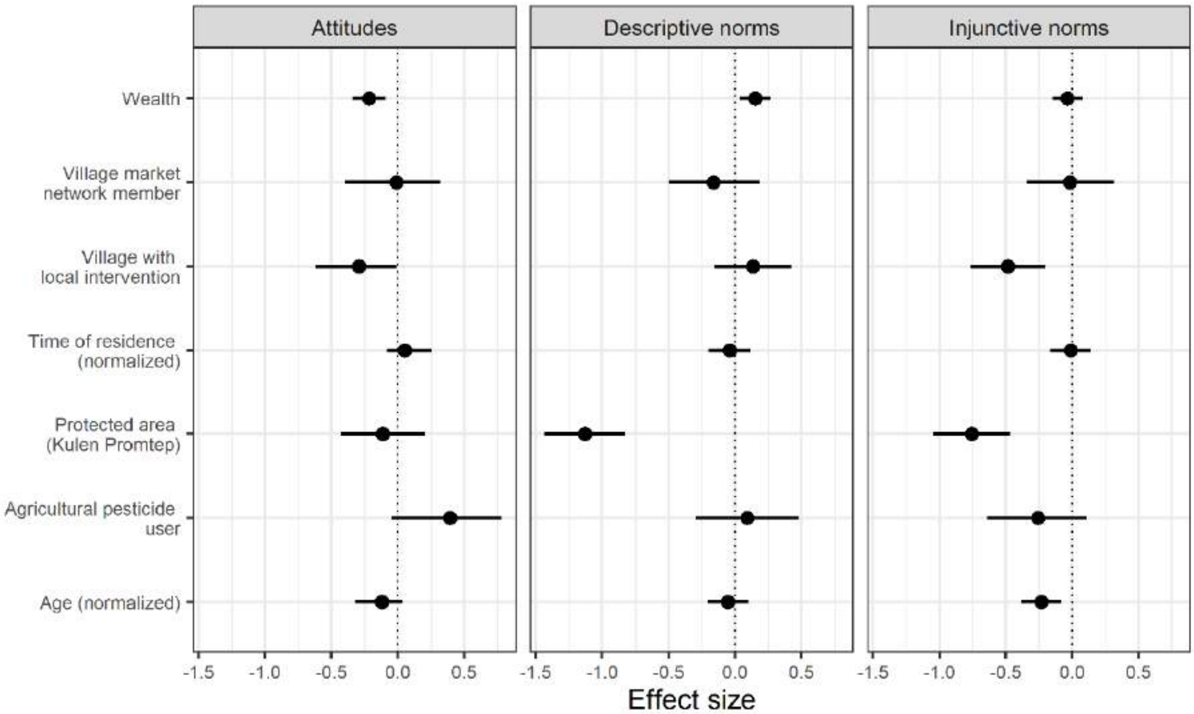


Figure 4.6 We fitted generalised linear models to understand which variables predict constructs from the theory of planned behaviour. This figure shows the effect sizes of several variables on attitudes, descriptive norms and injunctive norms. The bars represent 95% confidence intervals. Intercept values are 4.08 for attitudes, 3.86 for descriptive norms, and 4.61 for injunctive norms. Normalised variables have been divided by their standard deviation.

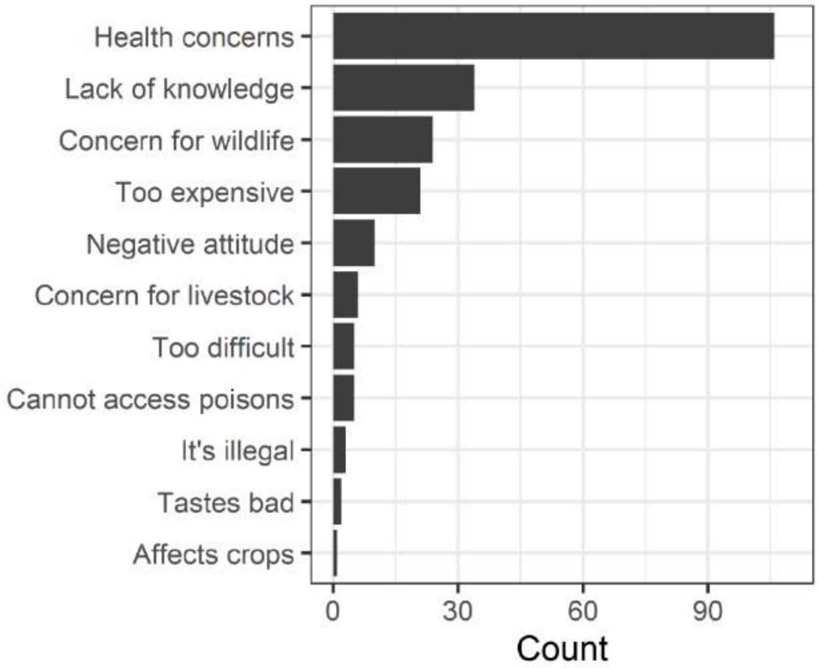


Figure 4.7 Reasons given for not using poison, by 168 survey respondents who stated they hunt wildlife.

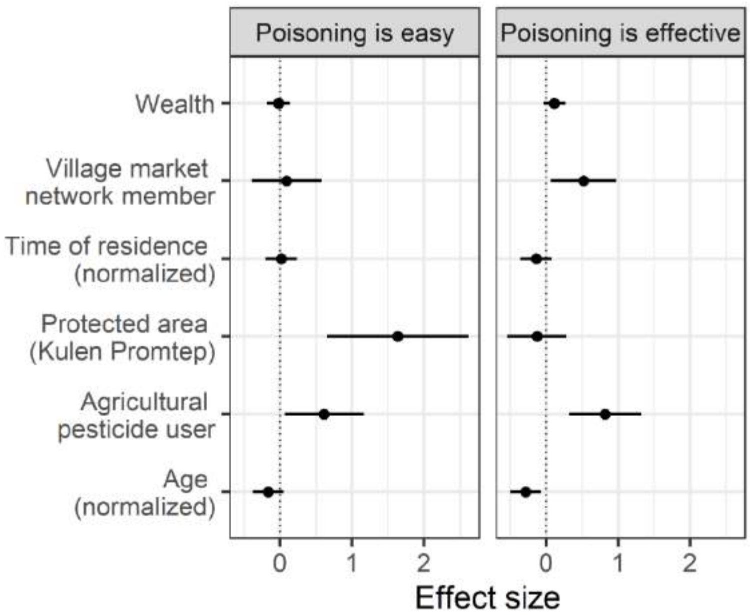


Figure 4.8 We fit cumulative linked mixed models (logistic regressions), to understand which variables predict perceived behavioural control. The two Likert responses (poisoning is easy, and poisoning is effective) used to measure this construct were analysed separately. This figure shows the effect size for each variable, and the bars show the 95% confidence intervals.

In three villages, preventive action had been taken at the community level. Two chiefs used village meetings to ask villagers not to use poison, and in one case also forbade shopkeepers from stocking the poison (although several informants indicated local stocks existed and a shopkeeper reacted angrily when we inquired). Another chief had referred the issue to the commune chief, following which environment authorities came to hold a similar meeting. This chief also expressed the expectation that a fine should be levied if a hunter was known to have poisoned cattle. However, wildlife poisoning continues, and this was acknowledged by the chiefs, for example:

The villagers are all unhappy [about poisoning] […]. Last year I told everyone at a meeting to not do it and forbade the shopkeepers to sell the poison, […] but people continue to do it in secret.

4.6 Discussion

In northern Cambodia, wildlife is being poisoned by pesticides deposited near to seasonal waterholes. We found that several practices and actors may be contributing to wildlife poisoning, but most significant is an intentional form of hunting carried out by local residents, particularly young men and children older than 12 years. Our study presents a first characterization of this practice using a mixed methods approach and quantifies its socio-psychological determinants using the theory of planned behaviour (Ajzen, 1991). Although we were unable to quantify the prevalence of poisoning, reports suggest that it was being practiced in eight of the ten villages surveyed, and that it is affecting the environment, public health, livestock and wildlife. The pesticides used include carbamates, which are extremely toxic to birds (Richards, 2011), and placement at critical dry season water sources means that even low frequencies of poisoning may be having significant impacts on threatened bird species (Pin et al., 2018; Loveridge et al., 2019). For example, individuals of Critically Endangered species of vulture and ibis were reported to be affected. Further anecdotal evidence suggests these practices are occurring beyond our study area (e.g. (Sokpheng, 2015) and they should be taken seriously by local and national authorities.

Some poisoning in Cambodia may be occurring as a symbolic and visible form of resistance to conservation rules (Norgrove & Hulme, 2006; Essen & Allen, 2017). This was suggested by one village chief in a community with a long-standing ecotourism project, where a waterhole had been poisoned close to the guest lodge. However, most poisoning occurs where visibility is low, and the low salience of conservation law enforcement among hunters and interviewees suggests this form of symbolic poisoning is a limited occurrence (Peterson et al., 2017). Most reports indicated that poisoning is predominately a method of harvesting wild meat for household consumption. It is seen as an effective method that requires few skills and little effort, and is practised during the dry season, when other sources of meat are less available (Coad et al., 2019). Our data do not suggest a clear link with poverty or food insecurity as wealthier households were also implicated, and many poorer households expressed disapproval. Similarly, hunters using poison whom we spoke to directly did not raise food insecurity as a consideration in deciding whether or not to continue using poison. Nevertheless, it may play a role for some hunters.

Varying perceptions of the health risks associated with consuming poisoned meat seem to play a larger role. Among other hunters and former poisoners, health concerns were a prominent reason given for not using poison. But others downplayed these risks or believed that removing the internal organs rendered the meat safe. For them, the ability to catch meat with ease in the dry season outweighed the perceived health risks. This form of poisoning is unusual as most documented cases of wildlife poisoning are symbolic acts related to conflicts (Berny, 2007; Richards, 2011), but there are similarities with practices documented in Bunyala, Kenya, where carbofuran pesticides and baits are used to harvest wild birds at seasonal wetlands. Consumers there also believed that poisoned meat can be rendered safe, although in Cambodia, hunters consume the meat themselves, whereas in Kenya they supply markets (Odino, 2011).

Waterhole poisoning affects other members of the community (i.e., harming cattle and dogs) and represents a risk to public health through distribution of contaminated meat and contamination of water sources (used for drinking and washing) and fisheries. Concerns about these impacts have led some local authorities to sanction individual hunters or organize meetings to discourage further poisoning. These have taken place in villages where injunctive norms are more negative, either because the authorities' actions produced these negative norms or because authorities feel enabled to act where negative injunctive norms already exist. Whether these sanctions have had deterrent effects is unknown, but poisoning continues to occur. This suggests there are groups of villagers who consider poisoning acceptable and who are not influenced by the chief, and potentially that other influential villagers condone poisoning (perhaps implicitly) among their clients (Ledgerwood & Vijghen, 2002). In other words, there are variable perceptions of social norms within different parts of the village social network (Shepherd, 2017), or as one chief articulated: 'they are not among my friends'. For example, younger respondents tended to have less negative norm perceptions, suggesting they may feel less constrained by village norms. This may also explain why informants gave diverging estimates of prevalence: either because they had access to different social information (i.e., they believe it was common because their relatives all did it), or because they felt different social pressures to exaggerate or downplay poisoning in their responses to us. Our association with the chiefs may have played a role in this.

We did not record any reports of conflicts caused by poisoning. Some informants suggested that they simply don't know who is poisoning and so can't do anything about it. Perhaps some are not aware that it occurs, particularly in villages where it has not yet had large negative impacts. Others were aware but chose to keep silent, as revealed by the actions of one informant who spoke freely in private, but not in a group setting. Many of the questions related to poisoning posed during group discussions were met with long silences. This culture of silence may have been towards us as outsiders, who potentially cannot be trusted and who might bring law enforcement or other consequences to the village, or to maintain the village's reputation (Nyumba *et al.*, 2018). Law enforcement was cited by some as reason for secrecy, but only rarely cited as reason not to poison.

Alternatively, silence is maintained to preserve harmony within the community, or to avoid retribution. Khmer culture is conflict averse, but resentment can simmer before erupting violently (Luco, 2002). Data from one pilot village outside the protected areas provides a stark comparison, as poisoning was discussed openly, was widespread, and was perceived as legal. Perhaps the absence of conservation activity there meant villagers did not understand the illegality of their actions and were not concerned about legal sanction. But we also recorded no negative impacts on other villagers here, perhaps because there were social norms regulating where and how waterholes could be poisoned, which served to prevent conflict. For example, discussants knew to avoid fishing in poisoned waterholes. Similar dynamics may exist among some groups in the other villages, but perhaps involvement in conservation has precluded the possibility of these norms emerging at village level, as at least some elites will be interested in maintaining conservation programmes. Our study does not indicate how different networks and individuals, with different poisoning norms and behaviours interact within a village, and how conservation may be producing anti-poisoning norms or resistance to these norms at different levels.

Our study highlights some methodological challenges in the study of sensitive behaviour. We applied the unmatched count technique to measure the prevalence of poisoning, but observed a design effect, suggesting respondents actively manipulated their responses to avoid implication of engagement in poisoning. Other unmatched count technique studies in Cambodia or on wildlife poisoning have encountered similar problems (Nuno & St. John, 2015; Fairbrass *et al.*, 2016; Ibbett *et al.*, 2017). If the unmatched count technique is to become a widely applicable tool, more research will be needed into how respondents perceive the method, and how this varies across contexts (Hinsley et al., 2019). Other measured variables such as beliefs and attitudes may be equally susceptible to social desirability biases but lack specialized methods for measurement in sensitive cases. For example, individuals who have positive attitudes towards poisoning might disclose a negative attitude. Researchers should develop methods to measure complex sensitive variables that go beyond prevalence (but see (Kramon & Weghorst, 2019). An alternative is to use more in-depth ethnographic approaches to study the social dynamics in one place, but there is a trade-off between depth and generalizability. We chose in this study to gain a more superficial understanding of broad patterns over a landscape, as a prelude to gaining deeper understanding in fewer locations. Despite these limitations, our study nonetheless generated reliable insights into wildlife poisoning by using multiple complementary methods and triangulating qualitatively across a large number of data sources. The many informants across multiple communities giving similar descriptions of poisoning practices, motivations, actors and community perceptions gives confidence in these results. The neutral presentation of the research team was key to collecting this data (Drury, Homewood &

Randall, 2011). We have carried out a more in-depth study in one village that further supports our findings (Chapter 5).

Our results could be used to guide the design of more effective interventions (Michie *et al.*, 2008). Perceptions of health risks were a salient factor in decisions about poisoning. The approach employed in Bunyala, Kenya, focused on raising awareness about the risks of consuming poisoned-meat, but this was unsuccessful as consumers had extensive personal experiences that supported their belief that risks were low (Wu & Shaffer, 1987; Odino, 2011). We found similar beliefs in our study, but these could potentially be influenced by selecting appropriate messengers, such as local doctors (Pornpitakpan, 2004). Social norms can be a powerful motivator for behaviour change (Cialdini, 2015), so the anti-poisoning norms present in some places may be effective levers (McDonald et al., 2013). Interventions could increase the prominence of these norms and provide new avenues for villagers to apply social pressure on others in ways that avoid direct conflict. Conflict could have unintended negative consequences in this context, such as reinforcing poisoning as a norm within certain subgroups, or provoking poisoning as a form of resistance (Luco, 2002; Peterson et al., 2017). For this reason, commonly used normative interventions such as community discussions may be culturally inappropriate as they require open confrontation. Media dramatization could alternatively be used to provoke changes in normative perceptions (Bicchieri, 2017b), and encouraging and rewarding public pledges (i.e. to use pesticides correctly, or to report poisoning) could facilitate strong normative signals and positive social incentives to engage (McKenzie-Mohr & Schultz, 2014). One approach successfully trialled in Laos was implementing a hotline to facilitate anonymous reporting of hunting, and then providing public feedback on these reports (Saypanya *et al.*, 2013). As a result, influential individuals might perceive that authorities are aware of the problem and that to continue condoning poisoning within their networks could jeopardise their position.

As children appear to be using poisons to hunt, interventions could encourage parents to be more vigilant by focusing on health risks, working with trusted messengers such as local schools. Because there is heterogeneity in use of poison between villages (Figure 4.4), interventions could prioritize those where poisoning is more prevalent, tailored to the situation in each community. Where local chiefs have already acted against poisoning and strong anti-poisoning norms exist, interventions could be co-designed with these authorities. In other places where poisoning is less salient (i.e., villagers are less conscious of it), and norms are weaker, awareness-raising activities could be more impactful. Finally, enforcing existing pesticide regulations, and limiting the availability of restricted chemicals, such as carbofurans, should be a national priority.

Effectively addressing new conservation threats such as wildlife poisoning requires knowledge of behavioural drivers and social contexts (St. John et al., 2013). For such sensitive behaviours, data collecting can be challenging. Nevertheless, as our study shows, using multiple complementary methods and triangulating data allowed us to draw more reliable inferences. These findings can be used to select interventions that are likely to be more effective than those based on intuition or expert opinion (Cook, Hockings & Carter, 2010). Robust testing and evaluation of the ensuing interventions will also be essential (Baylis *et al.*, 2016) but, whether or not evaluation occurs, formative mixed-methods research such as those used in this study can play a valuable role in conservation interventions. As poisoning is potentially widespread and may have catastrophic impacts on wildlife, people, animals and the environment, this issue should be prioritized by local and national authorities.

5. Social networks can both amplify and undermine conservation behaviour change interventions

5.1 Abstract

Social networks are critical to the success of behavioural interventions in conservation as network processes such as information flows and social influence can enable behaviour change to spread beyond a targeted group. We investigated these mechanisms using dynamic network models and longitudinal behavioural data from a conservation intervention in Cambodia. The intervention initially targeted ~11% of a village population, but knowledge of the intervention reached ~40% of the population within six months. The likelihood of having this knowledge doubled with each additional knowledgeable household member. In the short term, there was also a small, but widespread increase in pro-conservation behavioural intention (+5%), but this did not persist into the long term. Estimates from network models suggest that the influences of social peers, rather than knowledge, were important in changes in intention and contributed to the failure in behaviour-change in the long term. Our results point to the importance of accounting for the interaction between networks and behaviour when designing conservation interventions.

5.2 Introduction

Biodiversity conservation practitioners and researchers are increasingly interested in designing interventions that influence human behaviour (St. John, Keane & Milner-Gulland, 2013). Social networks – i.e. the connections between individuals within a population – play a strong role in shaping behaviour as individuals communicate with and learn from one another (Borgatti *et al.*, 2009; Prentice & Paluck, 2020). The structure of social networks therefore have important implications for environmental and conservation outcomes (Bodin, Crona & Ernstson, 2006; Barnes *et al.*, 2016b), and understanding how social networks influence behaviour can enable practitioners to design more effective interventions (Chapter 3, Valente, 2012).

Most network studies aiming to inform conservation practice use observations of social relations taken at a single point in time, usually before the intervention takes place (Groce *et al.*, 2018) to predict the social dynamics that are likely to occur following an intervention. For example, researchers may use network data to identify individuals likely to influence others (Mbaru & Barnes, 2017) or to uncover relevant structural features such as the existence of disconnected sub-groups (Crona & Bodin, 2006). Other studies measure both behaviours and networks to identify the social processes that shape conservation outcomes (Barnes *et al.*, 2016b). However, to untangle the mechanisms shaping behaviour there is a need to move beyond cross-sectional approaches and adopt a longitudinal perspective (Robins, 2015; Shalizi & Thomas, 2011; Steglich, Snijders & Pearson, 2010). Such studies have not been conducted in conservation.

Two network processes are thought to play an important role in any social intervention: information flow and social influence (Banerjee *et al.*, 2013; Contractor & DeChurch, 2014). First, as people make decisions based on information they receive about the world, the transfer of new information is a core part of any intervention and it is likely that many will receive such information indirectly, through their social networks (Hilbert *et al.*, 2017; Cai, De Janvry & Sadoulet, 2015). The social contexts within which information is shared significantly influence how information is interpreted and acted upon. This can involve effects related to the identity of the messenger, the relationships between communicators, and their positions in larger power structures (Pornpitakpan, 2004; Wakefield, Loken & Hornik, 2010; Faraji-Rad, Samuelsen & Warlop, 2015).

Second, individuals tend to behave similarly to others in their social networks, and decisions to change or adopt new behaviour can be strongly determined by social influences (Centola, 2018). For example, individuals may seek to comply and conform with the behaviours of others in their social network (Cialdini & Goldstein, 2004), or adjust their perceptions of social norms based on the behaviours or attitudes of their peers (McDonald & Crandall, 2015; Bicchieri, 2017; Shepherd, 2017). Many interventions aim to leverage such forms of social influence, such as intentionally targeting influential individuals and expecting behavioural spill-over to occur (Nakano *et al.*, 2018; Kim *et al.*, 2015).

To understand how information flow and social influence mediates the success or failure of a conservation intervention, we present a longitudinal study of an intervention in a part of Cambodia where pesticide misuse has been linked to the killing of threatened wildlife species and harm to humans. The intervention aimed to promote the use of a hotline for reporting pesticide contamination in one village (Chapters 2 & 4). We use a combination of linear models and Stochastic Actor-Oriented Models (SAOMs) to understand how knowledge and psychological outcomes changed throughout the village, and to explore the role of village social networks in these changes.

5.3 Methods

5.3.1 Study context

Cambodia's Preah Vihear province lies in a global biodiversity hotspot (Myers *et al.*, 2000), and contains the largest remaining mosaics of forests and grassland in mainland South-east Asia, and 28 Critically Endangered or Endangered species (Clements *et al.*, 2010). Waterhole poisoning was first documented here in 2015 and is an increasing threat to wildlife. It is practiced by some local farmers to harvest wild meat for home consumption, but most residents do not approve of this practice and are concerned by possible risks to health and the environment. In some villages, local authorities have taken action to prevent further poisoning (de Lange et al., 2020). To support these efforts the Wildlife Conservation Society (WCS), in partnership with the provincial Department of Environment, is piloting the introduction of a reporting hotline (Chapter 4). Residents can call this number anonymously to report pesticide contamination. After receiving a report, local officials will respond by removing the poison and beginning an investigation. By communicating the results of these investigations clearly within the community, conservationists hope to reduce the perception that poisoning is tolerated by the community and by authorities (Saypanya *et al.*, 2013).

5.3.2 Study design

In February 2019, the Wildlife Conservation Society (WCS) delivered an information session to a group of 41 adults in the target audience of parents with children aged 10 to 15, an age-group known to participate in poisoning and whose parents may be particularly concerned about the consequences of poisoning for their children's health (Chapter 4). Attendees received information about the threat of poisoning and about the hotline (Figure 2.5). To persuade them to use the hotline, testimony was provided by past victims of poisoning, and a short film was shown dramatizing a poisoning incident affecting children. Finally, attendees were invited to make a public pledge of safe pesticide use and to participate in poisoning prevention, for which they received a certificate. Materials with practical and persuasive information were distributed, which attendees were encouraged to display or share with others, such as posters and stickers (Figure 2.6).

The intervention served as an experiment, allowing us to observe how changes in knowledge and psychological outcomes throughout the village changed with respect to village social networks. The intervention aimed to increase attendees' intention to report pesticide contamination, by providing information that was expected to alter their beliefs and perceptions. Other residents who did not attend the event were also expected to increase their intention to report poisoning through network effects. This could occur through (a) information flow, if they receive information about the intervention causing them to re-evaluate their beliefs and perceptions, or (b) social influence if they observe social networks peers (e.g., event participants) changing their intention or attitudes causing them to re-evaluate their own (Figure 5.1).

In advance of the intervention (in September 2017) we measured the village social network through a survey of nearly adults in the village. We then measured behaviour, knowledge, and perceptions related to the intervention through three survey waves before and after the intervention. The first wave took place two weeks before the intervention, the second wave took place two weeks after the intervention, and the third wave was six months later, in August 2019. The study was approved by the University of Edinburgh School of Geosciences ethical review board, and all participants gave their informed consent. All survey instruments were initially piloted and refined using a small sample of respondents in another village or using a small sample of respondents from the study village which was not included in the analysis.

In communities such as the one being studied; the presence of outside researchers may potentially have a strong influence on the behaviour of respondents. For example, a foreign researcher asking questions about poisoning and reporting, may increase the salience of this topic, causing respondents to re-evaluate their beliefs, communicate with others, or seek further information. Although network analysis requires complete data, we considered it necessary to be able to control for this effect. In wave 1, we therefore excluded a randomly selected half of the village. In all other waves, we aimed to interview all adults in the village and all event attendees.

5.3.2.1 Network data

We measured a general social network which aims to capture habitual social contact (i.e., time spent together) between adult villagers (>18 years). To construct this network, we measured and combined ties of three kinds: 1) co-residence ties between adults in the same household, 2) household visits, and 3) household visitors. For co-residence ties, we assumed that ties existed between adults living in the same household (i.e., that individuals within a household mix and communicate homogenously). We measured the other ties using a name-generator survey: respondents were asked to nominate others whom they visit at home, or who come to visit them at home (Knoke & Yang, 2011). Extensive prior qualitative research suggested that these ties are likely to comprise the bulk of every-day social interaction in the village, therefore making them a key conduit for both information and influence (see Appendix 2). We excluded individuals who did not participate in the survey from the social network.

Networks and behaviour co-evolve (Snijders, 2017). However, the study village is remote and has a low rate of population change. We therefore assumed that change in the social network would be minimal within the period of the research. Furthermore, conducting research in this context poses resource and logistical constraints. For these reasons, we did not re-measure the social network at each survey wave, except in the final wave (wave 3). We also measured other network ties such as friendship, and communication about NGO activities, but did not use these in the analysis because of low response rates.

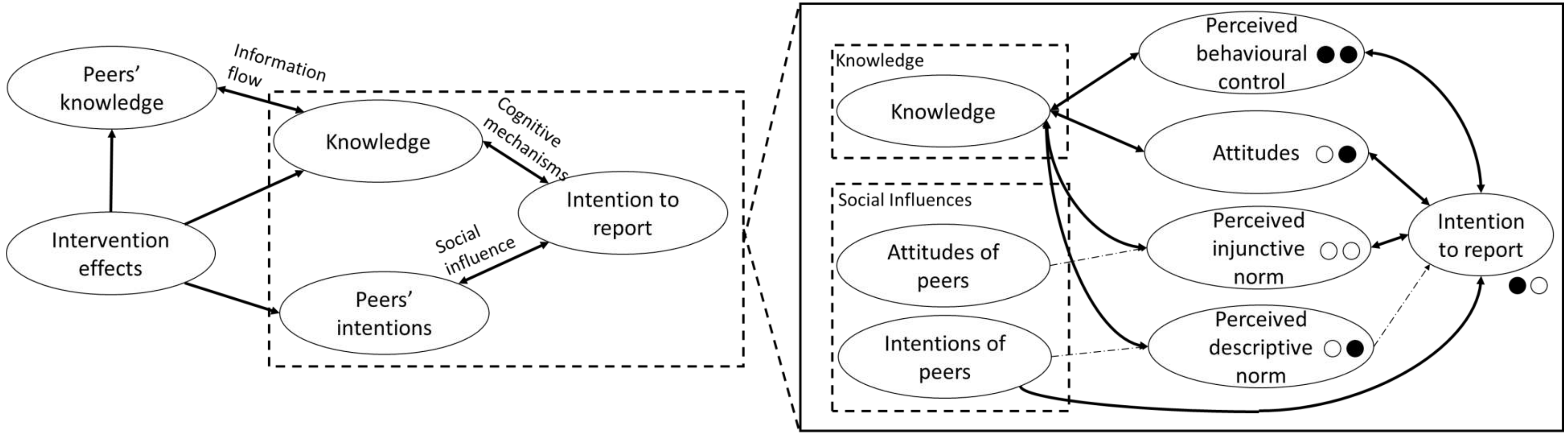


Figure 5.3: The hypothesised and observed relations between knowledge and variables from the theory of planned behaviour (TPB) throughout the village. The data were analysed using a combination of linear mixed effect models and stochastic actor-oriented models (SAOM). (a) Overview of the observed mechanisms of behaviour change in the village. The intervention influenced people's intentions and increased knowledge about reporting of poisoning. This information flowed through the village. Moreover, changes in intention propagated through the social network through social influences. (b) Further detail on the hypothesised and observed cognitive mechanisms of behaviour change. Dotted arrows indicated hypothesised relationships between variables that were not supported by the data, while the thicker solid arrows represent correlations observed in the data. For the TPB variables, small circles indicate whether the variable changed in the short term (left) and long term (right). Black indicates change, and white indicates no change, relative to the baseline. In turn, attitudes, perceived behavioural control, and perceived injunctive norms also correlated with intention. SAOMs showed a strong effect of peer intention but did not support other social influence mechanisms.

5.3.2.2 Psychological data

Poisoning events are rare, therefore measuring reporting events as an indicator of behavioural change would provide highly biased data. Instead, we used the Theory of Planned Behaviour (TPB) to conceptualise and measure changes in psychological constructs produced by the intervention (Ajzen, 1991). This theory predicts that use of the hotline will be strongly determined by an individual's intention to report poisoning. In turn, intention will be influenced by an individual's attitudes towards reporting (e.g., do they think reporting is good?), their perceptions of behavioural control (e.g., do they feel they can report?), and their perceptions of social norms. We further divide the social norm perception into descriptive norms (e.g., do they perceive that others would report?) and injunctive norms (e.g., do they perceive that others support reporting?). We used multiple five-point Likert scales and summed these for each variable to produce continuous measures of each variable from the TPB at each survey wave. We assessed the internal consistency of the measures for each construct using Cronbach's alpha.

Following the intervention, we measured respondents' knowledge of key intervention messages using twelve questions related to three components of the intervention: details of the hotline, details of the short film, and details of the pledge. We asked questions in an open-ended manner and recorded the response verbatim before coding correct and wrong answers. We then summed the correct responses to arrive at a knowledge score. Questions were worded so as not to give away any of the information for future surveys. We also asked respondents to describe the source of their information and coded responses into the following categories: relatives, other people, and intervention materials.

5.3.3 Analytical approach

All analyses were conducted in R 4.02 (R Core Team, 2017). We used linear models to explore variation in TPB variables and knowledge over time and across the population. We used SAOMs to determine whether network or other factors were influencing these changes. To describe the network, we calculated simple statistics using the igraph package (Csardi & Nepusz, 2006): Density is the number of ties measured as a proportion of all possible ties. Transitivity is the proportion of connected triples that form a closed triangle (a measure of clustering). Assortativity measures the extent to which individuals tend to connect with other similar individuals using Pearson's r coefficient of correlation.

5.3.3.1 Missing data imputation

Due to missingness in our psychological data (see Appendix 2), we use a combination of complete-case analysis and multiple imputation (Pepinsky, 2018). We generated 20 imputations using predictive mean matching in the 'mice' package (van Buuren & Groothuis-Oudshoorn, 2011). Twenty imputations was considered to be a good compromise between robustness and computation time (Krause, Huisman & Snijders, 2018). Furthermore, we observed that the model estimates did not vary greatly between 5 and 20 imputations, suggesting that they are robust to the number of imputations. The imputation model included all knowledge and psychological constructs for all waves, and all demographic and other variables used in the analysis models. We compared the imputed and observed datasets graphically to check for implausible imputations, such as those that have distributions very different to the observed data (Nguyen, Carlin & Lee, 2017). To estimate SAOMs we carried out 20 joint multiple imputations of the network and behaviour following the procedure in Krause et al. (2018). This takes the imputations produced using mice as a starting point, and then accounts for the SAOM specification to generate the imputations (Krause, Huisman & Snijders, 2018). For full details of the imputation procedure and model specification, see Appendix 2.

5.3.3.2 Changes in knowledge and behavioural intention

To explore variation in the data, we fitted linear mixed effect models (LMMs). First, we examined how knowledge and TPB variables changed over time within the attendee and non-attendee groups, by modelling these dependent variables with the interaction between attendance at the event and time-period as predictors. We used linear hypothesis testing in the 'car' package to compare the effects of time on different groups, and calculated standard errors using the delta method (Fox & Weisberg, 2019). Second, we examined the relation between knowledge and TPB variables. We modelled TPB variables with the total knowledge score, and separately with knowledge of the three intervention components as separate predictors (hotline, story, pledge). Each model also included the following control variables; gender, age (normalised by dividing by the standard deviation), pesticide use, household wealth, inclusion in the baseline survey and participation in the conservation agriculture programme Ibis Rice. Individual identity was included as the random effect. We modelled the complete-case data, and pooled estimates modelled with the twenty imputed datasets (van Buuren, 2018). Finally, to assess the psychological determinants of intention to report poisoning, we fit a generalised linear model (GLM) for the TPB at each survey wave.

5.3.3.3 Stochastic actor-oriented models

To understand whether changes in knowledge and behaviour are being influenced by network or other processes, we fitted SAOMs implemented in the R package "RSiena" (Ripley *et al.*, 2020). SAOMs are dynamic models of network-behaviour co-evolution which enable us to model how changes in behaviour are influenced by the structure of the social network (Snijders et al., 2010; Greenan, 2015). These changes are driven by the simulated decisions of individual actors in continuous time, where the SAOM simulations are calibrated to empirical observations of the network/behaviour at fixed time points (Snijders, 2017). We fitted the SAOMs with three waves of data and used forward estimation to build the model; including theoretically important effects, and then including effects related to our research questions (Ripley *et al.*, 2020). We continued until the models included as many effects of interest as possible, had an overall convergence ratio under 0.2, and adequately fitted the data as observed using the visual method described by Wang et al. (2020).

Because our research questions are about the effects of the network on behaviour change (not evolution of the social network) and we did not expect significant changes to the structure of the network to occur over the time period in question, we fitted each model with the network kept constant throughout all periods, akin to a stationary SAOM whilst allowing the behaviour to change (Block, Stadtfeld & Snijders, 2016; Snijders & Steglich, 2015). The partial re-measurement of network data in wave 3 was incomplete and not sufficient for dynamic network models. However, assuming both network measurements represent observations of the same underlying social network, we perform a robustness check by repeating our models using the updated network. In this network, individuals not surveyed in wave 3 retain their network ties from wave 1.

5.3.3.4 Modelling information flow

To determine whether network ties predicted information flow we modelled knowledge using the 'Diffusion of Innovations' extension to the SAOM (Greenan, 2015). In this model, knowledge is binary (i.e., does the individual have any knowledge?) and non-decreasing. In the first wave, we assume that only those who participated in the intervention had knowledge. First, we modelled information diffusion in relation to the habitual social contact network. Second, we modelled information diffusion with the three types of social tie (i.e., co-residence, visits, and visitors) included as separate social networks, to compare their effects. In each model, the effect of interest was the total exposure of each individual to the information (i.e., the total number of network connections with knowledge). No further effects were included as this decreased model fit or reduced convergence.

5.3.3.5 Modelling social influence

Next, we used SAOMs to examine network influences on behaviour. We separately modelled three social influence pathways, using the combined network: First, do individuals tend to change their behavioural intention to match their peers? Second: Do perceptions of descriptive norms vary with the intentions of an individual's peers?; and Third: Do perceptions of injunctive norms vary with the attitudes of an individual's peers? For the first model, we modelled social influence using the 'average similarity' effect. This effect is defined as the average of the similarity scores between an individual's behaviour and that of the others to whom they are tied. In this case, a positive effect reflects the tendency for individuals to become more similar to the average of their peers over time.

The second and third models examined the effect of peer intentions or attitudes on an individual's perceived norms. We therefore used the 'alter's covariate average' effect. This is defined as the product of the individual's perceived norm (i.e., descriptive or injunctive norm) and the average covariate values (i.e. intention or attitudes) of those with whom they are connected. A positive effect indicates the tendency that individuals whose peers have higher intentions or attitudes tend to also increase their perceived norms over time.

To compare the effects of knowledge and social influences on behaviour, these models included the effect of knowledge about the intervention. We also included a time dummy variable to account for heterogeneity in effects between time periods (Lospinoso *et al.*, 2011). This dummy variable would indicate whether psychological outcomes tended to increase or decrease in the second period. We interacted this variable with the social influence effects to determine if social influence is stronger in either period. We also interacted knowledge with social influence, to determine if having more knowledge of the intervention reduced the influence of peers or vice versa. The first two models included effects controlling for gender, age, wealth, participation in Ibis Rice, pesticide use, in-degree and out-degree. The latter effects express the tendency for individuals with higher numbers of incoming or outgoing connections, respectively, to increase their behavioural outcome over time. Due to difficulties with SAOM convergence (see Ripley *et al.*, 2020), only in-degree and out-degree were included as control effects in the third model.

5.4 Results

Overall, 400 adult residents from 156 households were represented in our data, of which 365 were included in the measured social network and network models. The three waves had 181, 283, and 192 respondents, respectively. As a percentage of the 365 individuals included in the social network, the missingness for each wave of behavioural data is 50%, 22%, and 47% for waves 1, 2, and 3, respectively.

5.4.1 Changes in psychological outcomes

Before the intervention attitudes and intention to report poisoning were positive on average but varied widely (Figure 5.2). Perceptions of control and perceptions of both descriptive and injunctive norms were lower on average. In all three waves, intention was correlated with attitudes, perceptions of control, and perceptions of injunctive norms, but not with perceptions of descriptive norms (Figure 5.3). Attitudes remained the most important predictor (GLM, β_{att}=0.25, SE=0.05, $p<0.01$, in wave 3), while the correlation with injunctive norms was higher in wave 2 (β_{inj}=0.28, SE=0.03, $p<0.01$), than in wave 3 (β_{inj}=0.12, SE=0.04, $p=0.02$). Analysis of the imputed data showed similar patterns (see Appendix 2, Table A2.11).

5.4.1.1 Changes among participants

Initially, there were no differences between those who would later attend the intervention and others (Tables A2.5:A2.9). LMMs and linear hypothesis testing showed that the intervention successfully changed behavioural intention among intervention participants in the short term (β_{par+w2}=1.19, SE=0.39, $p<0.01$). Perceptions of injunctive norms (β_{par+w2}=1.76, SE=0.55, $p<0.01$) and perceptions of control (β_{par+w2}=1.41, SE=0.44, $p<0.01$) also increased significantly, but attitudes and perceptions of descriptive norms did not. Analysis of the multiply imputed data only showed clear evidence for an increase in perceptions of injunctive norms in the short term (β_{par+w2}=1.76, SE=0.50, p<0.01, Table A2.9). However, after six months, no measured variables were significantly different from baseline.

5.4.1.2 Changes among non-participants

Behavioural changes also occurred amongst residents who did not attend the intervention (Tables A2.5:A2.9). After two weeks, intention to report poisoning (β=0.55, SE=0.18, p<0.01), and perceptions of control (β_{w2}=0.79, SE=0.21, p<0.01) increased by a similar magnitude as for attendees. In the long term, intention to report poisoning declined back to baseline levels, but perceptions of control remained higher than baseline (β_{w3}=0.67, SE=0.22, p<0.01). Attitudes (β_{w3}=0.58, SE=0.25, p=0.02) and perceptions of descriptive norms (β_{w3}=0.41, SE=0.14, p<0.01) also increased in the long-term. Analyses of the imputed datasets suggested similar patterns of change for each variable, except that perceived control was not significantly higher than baseline in the long-term (Table A2.7).

5.4.1.3 Changes in knowledge of the intervention

Intervention participants could recall on average, 58% (SD = 25%) of messages from the intervention after two weeks, and 48% (SD = 27%) after six months, across all imputations. Residents who did not attend also learned about the intervention. After two weeks, at least 55 (15% of the sample) individuals had some knowledge about the intervention. Across all imputations, an average of 79 individuals (SD=5.1) were knowledgeable, recalling on average 18% (SD = 13%) of messages presented. After six months at least 141 adult residents (39%, including attendees) could recall information from the event (Figure 5.4). Across all imputations an average of 148 respondents (SD=8.6) were knowledgeable, recalling on average 32% (SD = 22%) of messages shared. Information about the three key components of the intervention spread differently: on average after six months, 50 (SD=5.6), 52 (SD=7.4), and 72 (SD=9.2) non-participants were knowledgeable about the hotline, pledge, and film, respectively across all imputations.

Of the non-attendees who were knowledgeable, 27% stated that they had learnt about the intervention from relatives. Others reported learning about the intervention through disseminated materials (e.g., stickers with the hotline number printed, ~10%), or through communication with others in the village (~8%). However, 52% could not recall where they had received the information.

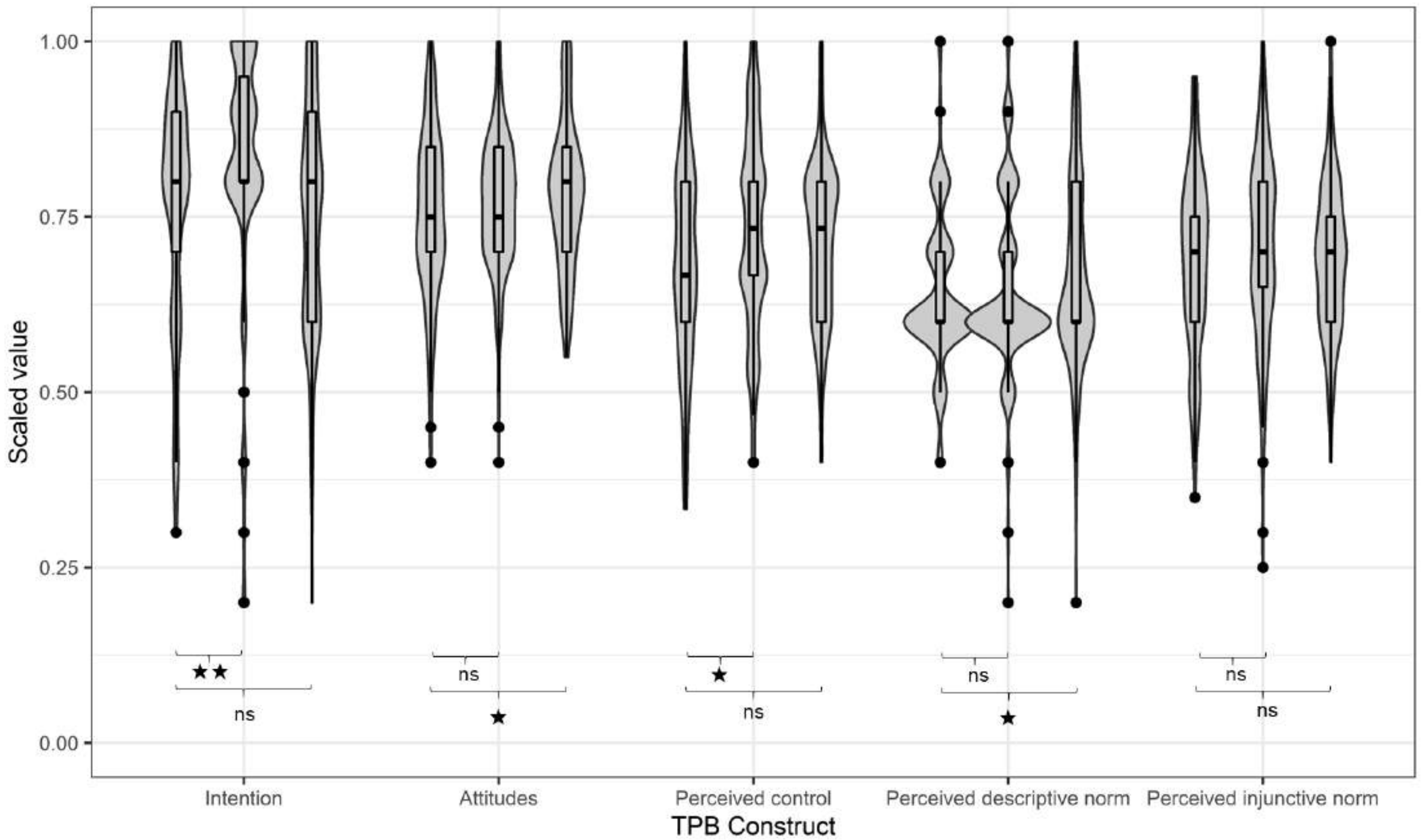


Figure 5.2 (previous page): Changes in the measured values for each construct from the Theory of Planned Behaviour. From left to right: intention to report poisoning, attitudes towards reporting, perceived control, perceived descriptive norms, and perceived injunctive norms. Each construct is constructed from a set of questions answered on a five-point Likert scale. The range of values for each construct differs, so they are scaled from 0-1 to enable visual comparison. Measurements in waves 1 (pre-intervention), 2 (two weeks post-intervention), and 3 (six months post-intervention), are coloured red, green, and blue respectively. The mean value is shown by a black stripe, the box indicates the standard deviation, and the whiskers represent the 95% confidence intervals. Outliers are shown by dots. Significance levels are shown for the differences between waves, estimated using linear mixed effect models (p<0.5, ** p<0.1, *** p<0.001, ns: not significant).*

5.4.1.4 The relationship between knowledge and psychological outcomes

In LMMs, knowledge was associated with higher behavioural intention (β_{kno}=0.14, SE=0.06, p=0.02), attitudes (β_{kno}=0.31, SE=0.08, p<0.01), perceptions of control (β_{kno}=0.23, SE=0.07, p<0.01), perceptions of descriptive norms (β_{kno}=0.09, SE=0.04, p=0.04), and perceptions of injunctive norms (β_{kno}=0.32, SE=0.09, p<0.01). In the imputed data, the effect of knowledge on intention and perceptions of descriptive norms were not significant. Modelling knowledge of each intervention component separately, the only significant correlation was between knowledge about the hotline and perceived injunctive norms (β_{hot}=0.38, SE=0.14, p<0.01).

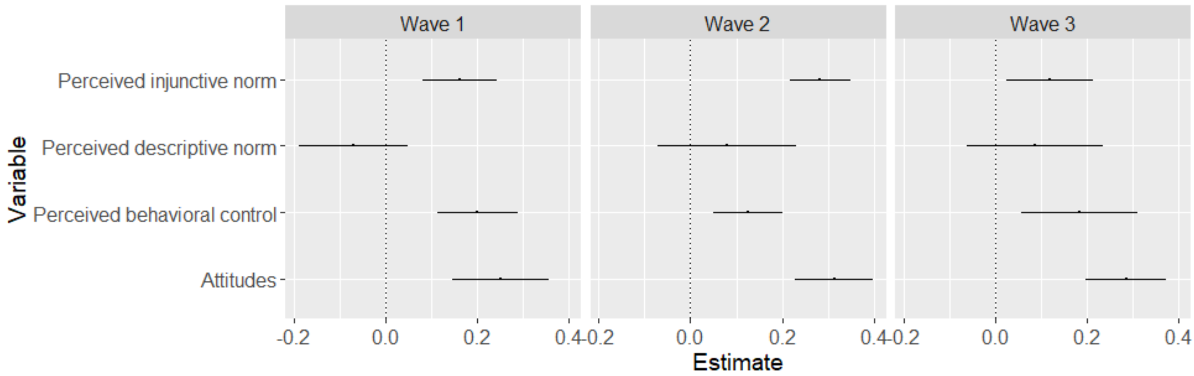


Figure 5.3: Relationship between attitude, descriptive and injunctive norms, and behavioural control and intention to report poisoning. The coefficients were estimated from Generalised Linear Models, using complete case data at each survey wave. Intention is positively correlated with attitudes, perceived injunctive norms, and with perceived behavioural control at all time points, but not with perceived descriptive norms. The relative importance of the perceived injunctive norm increases relative to perceived behavioural control in wave 2. 95% confidence intervals are shown.

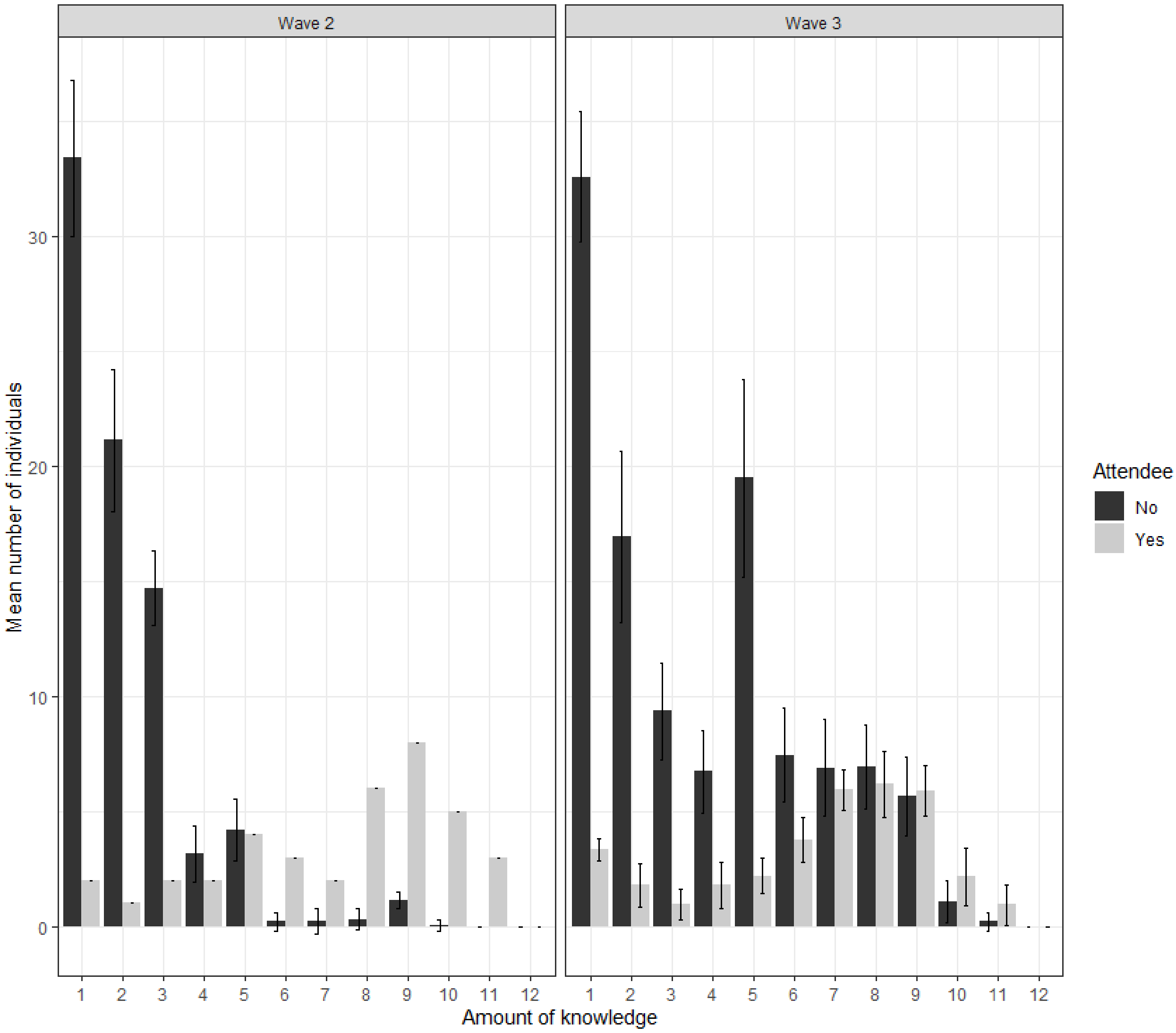


Figure 5.4: How does knowledge about the intervention change over time? The mean number of individuals with each level of knowledge (measured out of 12), across twenty imputation. Before the intervention, in wave 1, nobody has knowledge because the messages were designed to be unknowable to those not attending the event. Those who participated in the event are shown in grey, while those who did not are in black. Wave 2 (left) was measured two weeks following the intervention, while wave 3 (right) was measured after six months. The standard error bars show the variation between imputations. Individuals without any knowledge are not shown: 248 non-participants (SD=5.00) and 1 participant (SD=0.00) in wave 2, and 213 non-participants (SD=8) and 4 participants (SD=1) in wave 3.

5.4.2 The village social network

In total, the village social network comprised 1637 asymmetric ties, of which 650 (40%) were co-residence ties. For the overall habitual social contact network, residents had an average of 4.49 outgoing relationships, 57% of which were reciprocated, and graph transitivity was 0.27. One percent of all possible ties between residents were observed (network density). Using the assortativity coefficient (i.e., Pearson's *r*) we found that respondents tended to nominate others of the same gender for visiting ties (Pearson's *r* =+0.46), but age (+0.16), household wealth (+0.06) or participation in Ibis Rice (+0.07), were more variable.

5.4.3 Information flow

SAOMs showed that having an additional social tie with an individual knowledgeable of the intervention increased the probability that a respondent would become knowledgeable of the intervention by a factor of 1.39, SE=0.12 (i.e., the exponent of the effect size $= e^{0.332}$, Table A2.12). Models with separated ties showed that exposure within the household was significant, but exposure through other ties was not. Having an additional household member with knowledge of the intervention increased the probability that an individual would become knowledgeable by a factor of 1.87 ($e^{0.627}$, SE=0.26).

Table 5.1 (next page): Summary results from three Stochastic Actor Oriented Models modelling the effect of the social network on 1) intention to report poisoning, 2) perceived descriptive norms, and 3) perceived injunctive norms. For each effect the parameter estimates are presented as log-odds ratios, and the standard errors are shown. When an effect was not included in that model, this is indicated by a dash. The average covariate alter effect (row 2) was specified differently for model 2 and model 3. For model 2, this is the effect of peer intention. For model 3, this is the effect of peer attitudes. Significant effects are shown in bold. Model parameters are combined from estimates across twenty imputations.

Dependent variable:	**1. Change in Intention**		**2. Perceived descriptive norm**		**3. Perceived Injunctive norm**	
Effect	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
1. Average similarity	**+1.713**	**0.542**	-	-	-	-
2. Average covariate alter (intention or attitudes)	-	-	-0.004	0.036	-0.012	0.013
3. Intervention knowledge	+0.036	0.022	**+0.064**	**0.029**	**+0.047**	**0.015**
4. Period 2	**-0.222**	**0.048**	+0.099	0.068	-0.049	0.028
Interactions						
5. Social influence x Knowledge	+0.381	0.487	-0.011	0.029	+0.006	0.013
6. Social influence x Period 2	+0.448	0.699	+0.003	0.074	-0.036	0.027
Control effects						
7. Linear shape	+0.035	0.065	+0.039	0.091	-0.021	0.040
8. Quadratic shape	**-0.034**	**0.011**	**-0.180**	**0.015**	-0.048	0.003
9. In-degree	-0.001	0.009	+0.015	0.013	+0.014	0.005
10. Out-degree	+0.010	0.014	-0.010	0.019	-0.006	0.008
11. Age	+0.002	0.002	+0.002	0.002	-	-
12. Wealth	-0.021	0.023	-0.019	0.030	-	-
13. Gender	+0.0001	0.040	-0.013	0.062	-	-
14. Conservation agriculture	+0.040	0.040	**+0.140**	**0.068**	+0.029	0.031
15. Pesticide use	-0.007	0.047	+0.009	0.069	-	-

5.4.4 Network influences on psychology

SAOM estimates for social influence models are presented as log-odds ratios in Table 5.1. Changes in intention to report poisoning were predicted by the intentions of social peers, but not by knowledge of the intervention (Model 1, effects 1 & 3). Residents were 1.24 times more likely to adjust their intention towards the average intention of their peers than not to change (i.e., exponent of the effect size divided by the number of levels of the behaviour $= e^{\frac{1.713}{8}}$). This effect did not vary over time or with knowledge of the intervention (effects 5 & 6). There was also a tendency to reduce intention in the second period (i.e., between waves 2 and 3, effect 4), which was not accounted for by other effects, indicating a potential weakening of the intervention's effects over time.

Peer intentions and attitudes did not predict changes in perceived norms (Models 2 & 3, effect 2), but knowledge of the intervention did (effect 3). There was also a tendency for perceived injunctive norms to reduce in the second period (i.e., between waves 2 and 3). Participants in Ibis Rice were also more likely to increase their perceptions of descriptive norms (Table 5.1).

5.5 Discussion

Using state-of-the-art models of network-behaviour dynamics, longitudinal behavioural data collected across an entire village, and an innovative study design, we show how social networks shape the outcomes of an important conservation intervention. Specifically, we show that a social marketing event aiming to reduce wildlife poisoning by encouraging use of a reporting hotline had spill-over effects beyond the individuals targeted (i.e., the intervention participants) that were mediated by a village social network capturing habitual social contact. We observed a significant increase in intention to report poisoning throughout the entire village after two weeks, and information from the intervention spread widely through the village. However, despite lasting changes in some psychological outcomes, such as perceived behavioural control and attitudes, the intervention failed to change behavioural intentions in the long term. Evidence from SAOMs suggests that both the increase and subsequent decrease in intention were driven by the social influences of network peers, rather than by individuals learning about the intervention (Table 5.1). The social network may therefore have initially promoted and subsequently undermined the intervention as residents sought to match their intentions with their social peers.

The intervention included dissemination of information and materials to facilitate learning about poisoning and the hotline, as this was considered an essential precondition for behaviour change. This information flowed relatively well for a small intervention; after six months, the number of residents knowledgeable about the intervention more than tripled (Figure 5.4). Much of this flow could be predicted by household co-residence ties, not social visiting ties, suggesting that reaching at least one member of as many households as possible could be an effective information dissemination strategy in this context. Our measured social network did not adequately capture the interactions through which information might have spread between households. This highlights the difficulty in capturing and measuring the weak interactions through which information spreads in physical communities (Granovetter, 1973), which may include brief encounters with strangers, or even overhearing others' conversations.

Knowledge of the intervention was correlated with higher intentions, attitudes, perceived control, and perceptions of social norms in linear models. However, dynamic network models showed that learning about the intervention did not lead to changes in behavioural intention overall (Table 5.1). Instead, Individuals with more positive attitudes towards or perceptions of reporting may have actively sought out information or were better able to recall it (Valente, Paredes & Poppe, 1998). In support of this interpretation, we observed no increase in attitudes in the short term despite widespread dissemination of information. Instead, these models showed that the influences of network peers predicted changes in intention, as individuals increased or decreased their intention to be more similar to their peers. After learning about the hotline, residents may have sought out social cues to determine whether reporting was a socially appropriate behaviour (Prentice & Paluck, 2020). Rather than driving behavioural change, communication about the new behaviour may ultimately have reinforced the status quo, pushing residents to conform with existing levels of behaviour. This contradicts evidence from elsewhere that increased communication about a new conservation behaviour tends to increase behavioural change (Green *et al.*, 2019).

Although our models indicated that social influences were occurring, we could not establish the cognitive mechanisms underlying this effect as peer intentions did not appear to drive changes in perceptions of descriptive norms, nor did peer attitudes influence perceptions of injunctive norms (Cialdini, Kallgren & Reno, 1991). Perhaps individuals are mis-perceiving the attitudes or intentions of their peers because reporting poisoning is both a rare and potentially sensitive behaviour, which makes observation of others' behaviour or communication about the behaviour uncommon (Prentice & Miller, 1996). In the absence of clear social cues from their network peers, residents may have used other sources of information to evaluate social norms. This might explain why knowledge about the intervention tended to drive more positive norm perceptions, indicating that the intervention messages were appropriately framed (Kusmanoff *et al.*, 2020). For example, the short film and pledging ceremony were both designed to alter norm perceptions (Bicchieri, 2017a). But, our measures of the perceived descriptive norm had a low internal consistency, suggesting that we did not adequately measure the underlying construct.

The peer-influence effects we observed for behavioural intention may have occurred through other processes. For example, individuals may resolve ambiguity around reporting poisoning by deferring to the opinions of their peers, without updating their perceived norms (i.e. informational influence, Wooten & Reed II, 1998). Alternatively, there may be important but unobserved variables, such as personality traits, which tend to be similar for socially close individuals and which are challenging to discount in observational studies (Shalizi & Thomas, 2011). Alternatively, individuals' norm perceptions may be informed by individuals with whom they don't have direct ties represented in our social network (Shepherd, 2017). For example, they may be looking to local leaders, or others to whom they are weakly tied rather than their direct peers (Lee & Kronrod, 2020). Further research to understand which referent groups are salient in perceptions of norms is therefore critical (Prentice & Paluck, 2020).

Despite successfully diffusing information necessary for behaviour changes to occur (such as information about the hotline), and using appropriate message framings to influence norm perceptions, attitudes, and perceptions of control, our intervention did not succeed in changing intentions in the long-term. The countervailing effect of social influence indicates that use of the reporting hotline is a complex contagion, which, unlike information, requires social reinforcement for adoption (Centola & Macy, 2007). This is also likely to be the case for many conservation behaviours, which are often related to provision of public or common goods (Turaga, Howarth & Borsuk, 2010). The observed changes in knowledge and psychology provide the conditions necessary for future behaviour change to occur, perhaps because of further intervention or other exogenous events. However, to sustain these impacts and create behaviour change in the long-term, continued engagement with a community, consisting of repeated interventions, and other efforts at gradually influencing relevant social structures (Brooks, Waylen & Mulder, 2013) or exploiting social influences are needed (Centola, 2018; Valente, 2012). This could involve working with highly connected opinion leaders (Valente & Pumpuang, 2007), small groups of socially close individuals (Centola, 2018), or even forming new ties between receptive individuals (Contractor & DeChurch, 2014). In Cambodia, anti-poisoning interventions could be integrated with broader social interventions, such as the Ibis Rice conservation agriculture programme, that aim to influence agricultural and conservation decision-making (Clements *et al.*, 2020). Furthermore, such strategies may alter the structures of social networks in the long-term, potentially producing more enabling social contexts (Chapter 2).

Although conservation scientists are increasingly interested in relational processes, little research has looked at how these processes operate in real-world conservation contexts (Groce *et al.*, 2018; de Lange et al., 2019). Using an innovative network modelling approach (Greenan, 2015; Steglich, Snijders & Pearson, 2010), we interrogated the social influence processes that followed a conservation intervention. Our results highlight the critical importance of social relations in shaping conservation behaviours. In this case, network peers influenced one another's behaviour, but we could not identify the specific cognitive mechanisms through which this occurred. In keeping with the theory of complex contagions, we found that information flow occurs more easily than behaviour change, and does not lead straightforwardly to change in intention (Centola, 2018; Schultz, 2002). Furthermore, as conservation practitioners begin to incorporate relational insights into their intervention, such as the targeting of network-central individuals (Mbaru & Barnes, 2017), longitudinal studies such as this one will be needed to evaluate these approaches. This will support better understanding of the dynamic processes of social change, and the design of more effective intentions (Ferraro & Pattanayak, 2006; Chapter 3).

6. Combining simulation and empirical data to explore the scope for social network interventions in conservation

6.1 Abstract

Conservationists can use social network analysis to improve targeting for behaviour-change interventions, selecting individuals to target who will go on to inform or influence others. However, collecting sociometric data is expensive. Using empirical data from a case study in Cambodia and simulations we examine the conditions under which collecting this data is cost-effective. Our results show that targeting interventions using sociometric data can lead to greater dissemination of information and adoption of new behaviours. However, these approaches are not cost-effective for small interventions implemented in only a few communities, and it is an order of magnitude cheaper to achieve the same results by simply targeting more individuals in each community at random. For interventions across multiple communities, network data from one community could inform rules of thumb that can be applied to boost the effectiveness of interventions. In rural Cambodia, this approach is only worthwhile if it can inform interventions covering at least 31 villages. Our findings provide a framework for understanding how insights from network sciences, such as targeting clusters of individuals for interventions that aim to change behaviour, can make a practical contribution to conservation.

6.2 Introduction

Conservation interventions aiming to influence human behaviour are commonly targeted directly at the people they aim to influence (Jones *et al.*, 2019). An alternative perspective recognises that new behaviours tend to spread through social ties (Centola, 2018; Rogers, 2003), and suggests interventions should target influential individuals who may subsequently propagate the behaviour throughout the group (Chapters 3 & 5; Valente, 2012). This approach is little used in conservation, perhaps because it can be costly to collect the sociometric data necessary to identify such individuals (Eckles *et al.*, 2019). A potentially cheaper approach is to use 'rules-of-thumb', or other indicators of influence (Valente & Pumpuang, 2007; Mbaru & Barnes, 2017), but little research has been done to identify such indicators in conservation contexts. We use data from a case study in

Cambodia to a) determine the cost-effectiveness of targeting informed by sociometric data, and b) explore the potential for identifying effective rules-of-thumb.

Little information is available about how conservation behaviour change interventions are targeted in practice, but much research has been devoted to identifying individuals or groups whose behaviour needs to be changed, or who are most susceptible to change (Jones *et al.*, 2019). For example, research may identify frequent consumers of wildlife products, or those most willing to adopt alternative products (Doughty *et al.*, 2019; Davis *et al.*, 2016). Targeting is therefore based directly on observations of the behaviour that the intervention aims to change. However, many behaviours spread through less easily identifiable social processes such as information flow and social influence, which may be unrelated to the behaviour of concern (Borgatti *et al.*, 2009; Centola, 2018; Rogers, 2003). For example, bushmeat hunting in the Amazon may be driven by affective relations between friends and kin (Carignano Torres *et al.*, 2021). Understanding the social relationships within a group can therefore suggest ways to more effectively target an intervention (Chapter 3; Valente, 2012).

Sociometric data (i.e. data about social ties within a population) can enable researchers to identify an optimal set of target individuals to maximise the spread of new behaviours or information (Banerjee, Jenamani & Pratihar, 2020). In public health, a common approach is to target so-called 'key-players' using measures of importance in a social network (Valente & Pumpuang, 2007; Borgatti, 2006). For example, in information-sharing networks, individuals that are a source of information for many others (referred to as high *in-degree centrality*), tend to also be trusted and influential (Freeman, 1978). Randomised controlled trials in various contexts have shown that targeting interventions at such key-players can lead to greater adoption of new behaviours compared to other approaches (Kim *et al.*, 2015; Paluck, Shepherd & Aronow, 2016; Valente, 2012).

However, to robustly identify key-players spanning a network, it is desirable to have sociometric data covering as much of the target population as possible (Knoke & Yang, 2011; Borgatti, 2006; Costenbader & Valente, 2003). In conservation contexts, which are often rural, remote, and low-technology environments, collecting such data can require costly surveys (Eckles *et al.*, 2019). A potentially cheaper way to identify key-players is to use proxy attributes thought to correlate with influence, such as wealth, experience, or formal leadership positions (Valente & Pumpuang, 2007). For example, Mbaru & Barnes (2017) used sociometric data from several villages on the Kenyan coast to determine that formal leaders, but not experienced fisherman, tended to be key players. Therefore, targeting formal leaders could be a rule-of-thumb for better targeting within similar contexts. However, such rules of thumb are not universal (Valente & Pumpuang, 2007) and in some contexts suitable rules-of-thumb may simply not be identifiable (de Roo *et al.*, 2021).

Despite the evidence demonstrating the effectiveness of key-player targeting, approaches based on individual network positions may be insufficient when the adoption of behaviours depends on social reinforcement (Centola & Macy, 2007; Aral & Walker, 2012). The spread of these behaviours is referred to as “complex contagion” and exhibits different patterns to the spread of “simple contagions”, such as information, which can spread easily through single exposures (Centola & Macy, 2007). For individuals to adopt “complex” behaviours, multiple social peers need to adopt first, meaning a single key player may not succeed in promoting adoption (Centola, 2018). This suggests that interventions can better target clusters of mutually connected individuals. For example, rather than targeting two key players in different parts of a network, targeting a key player and one of their peers will enable them to collectively influence their mutual acquaintances (Centola, 2018; Beaman *et al.*, 2014). This approach could enable researchers to exploit network effects without needing to collect sociometric data.

For conservation practitioners to be able to target their interventions most effectively, we need to understand the cost-effectiveness of using sociometric data, and the possibility of identifying rules-of-thumb, across different intervention contexts. Here, we combine empirical and simulation approaches within a case study from Cambodia to make two contributions: First, to evaluate the cost-effectiveness of strategies informed by sociometric data and theory at spreading information or complex behaviours under different conditions, compared with more conventional targeting strategies. Second, to identify rules-of-thumb that might be used to identify key-players and target interventions more effectively in this context. We use data from the case study and a variety of possible strategies to generate sets of individuals to target for intervention and compare the composition of these sets to identify possible rules-of-thumb. We then use diffusion simulations to predict the effectiveness of these different targeting strategies and compare their cost-effectiveness.

6.3 Methods

6.3.1 Case study

Our case study uses data from a village located in a protected area in northern Cambodia. Most village households are engaged in rice-growing as a primary livelihood, but some also grow cash-crops such as cassava or cashew, participate in logging activities, or run small shops. The village has a village chief and sub-chief appointed by the state. The village is near critical wildlife habitat, and is involved in several long-term conservation initiatives, including a bird-nest protection scheme, a conservation agriculture programme, and community forestry (Chapter 2; Poffenberger, 2013; Clements et al., 2010). The community forests and conservation agriculture programmes are overseen by separate elected village committees. Furthermore, environmental education and conservation awareness-raising events are regularly implemented.

Currently, conservationists are concerned about several cases of wildlife poisoning that have been documented in the surrounding area. There is also widespread concern about this practice among residents, therefore one intervention approach being trialled by the Wildlife Conservation Society and local authorities is the introduction of a hotline for reporting poisoning events (Chapters 4 & 5). To promote the hotline, it is necessary to both disseminate information about the hotline (e.g., the phone number, the purpose of reporting) as widely as possible, and to overcome concerns residents may have about social conflict or disapproval from others (i.e. social barriers). An intervention might thus target individuals well positioned to disseminate information, or target communication in a way that maximises the social reinforcement needed for widespread adoption of the hotline to occur. To compare the cost-effectiveness of different targeting strategies and identify rules-of-thumb, we use sociometric, demographic, and behavioural data from this village to select individuals to target following a variety of selection strategies. We compare the composition of the sets of selected individuals to identify potential rules-of-thumb, then compare the cost-effectiveness of sociometric and rule-of-thumb strategies by simulating how information and behaviours diffuse through the village social network. All analysis was conducted in R 4.0.0 (R Core Team, 2017).

6.3.2 Data collection

We collected data using questionnaire surveys at two time points. All questionnaires were previously piloted and refined with individuals in another nearby village. The questionnaires were translated from English to Khmer and back to check accuracy, and conducted in Khmer by research assistants using tablets and Open Data Kit software (Brunette *et al.*, 2013). In September 2017, we conducted sociometric and demographic data, aiming to interview all consenting adults in the village. We recorded respondent's age, occupation, positions in the village, and an index of household wealth. To measure wealth, we used a Basic Necessities Survey previously developed for this region (Beauchamp *et al.*, 2018).

In January 2019, after the intervention objectives were established, we interviewed a sample of households to measure attitudes related to reporting of poisoning. We interviewed all adult residents of 93 randomly selected households (~60% of households, 155 individuals in total). We measured attitudes using four five-point scales, which were then summed to produce an attitude score out of 20 (see Appendix 3), as an indicator of the likelihood that an individual would adopt use of the hotline.

6.3.3 Social networks

We aimed to measure a social network that would capture the relations through which residents are likely to communicate about the hotline – a habitual social contact network. To better understand social interactions and identify the relevant ties, we first conducted qualitative research and reviewed the literature (see Appendix 3). In rural Cambodia, the household forms the core of social organisation (Chapter 2; Ovesen, Trankell & Ojendal, 1996). Individuals within a household are likely to spend significant time together and share information about many topics (Chapter 5). We therefore recorded the names of individuals in each household and included bi-directional ties between all co-residents, assuming homogenous mixing within the household. We also identified household visits as an important form of interaction and communication with peers outside of the household, and asked respondents to nominate others that they have regularly visited at home in the past year. We allowed respondents to freely recall as many names as they wished and prompted them until they declined to nominate further. We then included directional household visit ties (i.e., if person A nominates person B as a social contact, then information can only flow from B to A) in our network (see Appendix 3).

6.3.4 Intervention targeting

To identify plausible intervention targeting approaches, we reviewed the literature and drew on our own experiences, and then selected sets of individuals to target for interventions following each identified strategy. We did this for various levels intervention effort (number of individuals =n), selecting sets of 2, 10, 20, and 30 individuals to target. This reflects the range of intervention intensities we have observed carried out by WCS Cambodia in this context, where directly reaching more than 30 individuals at one time is challenging.

6.3.4.1 Sociometric targeting

For targeting strategies based on network theory, we used the sociometric data to identify key-players in the network, following the centrality measures used by Mbaru & Barnes (2017). These measures are in-degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality (Table 1). We used the Keyplayer algorithm, which selects a set of *n* individuals that optimally span the network based on each centrality measure (Borgatti, 2006). Since our network has disconnected sections, we used the harmonic measure of closeness centrality.

As clusters of connected individuals are predicted to better enable the spread of complex contagions, we also implemented clustered targeting strategies, by pairing key-players of each kind with social peers whom they visit outside the household. For example, to generate a set of size n=30, we selected 15 key-players and then included 15 of their social peers.

6.3.4.2 Non-sociometric targeting

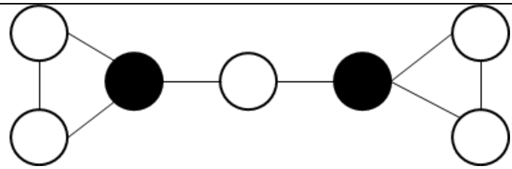
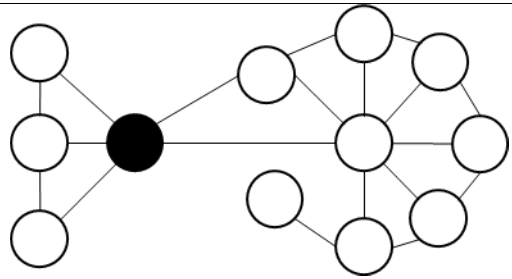
To identify possible non-sociometric targeting strategies currently used by conservationists we conducted a literature search. We searched the Web of Science database using the keywords: “intervention AND behavi*”, filtered by the “biodiversity conservation” category. We scanned over 200 resulting abstracts and selected papers describing real behaviour-change interventions. We searched these for information about targeting strategies and identified 15 papers with clear descriptions. We also drew on the papers cited in the following reviews: (Nilsson *et al.*, 2016a; Olmedo, Sharif & Milner-Gulland, 2017; Ryan *et al.*, 2020), and on our experiences collaborating with conservation practitioners. We identified nine commonly deployed and clearly definable targeting strategies (Table 6.2). For example, conservationists may target individuals in formal leadership positions with the expectation that they may be influential (Mbaru & Barnes, 2017), or target those with more positive attitudes towards the new behaviour (Metcalf *et al.*, 2018). We selected sets of target individuals in our village following each strategy, using the demographic and attitudinal data. The leadership and conservationist sets were not employed for effort level *n*=30, as there were not enough individuals meeting the criteria.

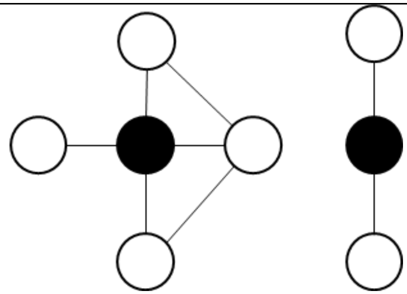
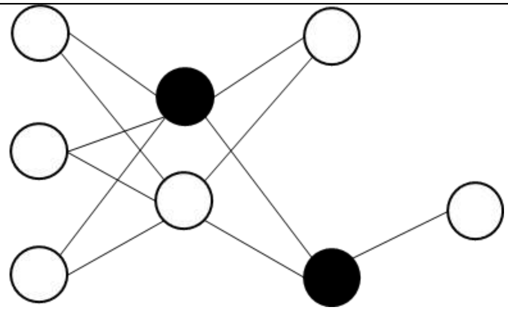
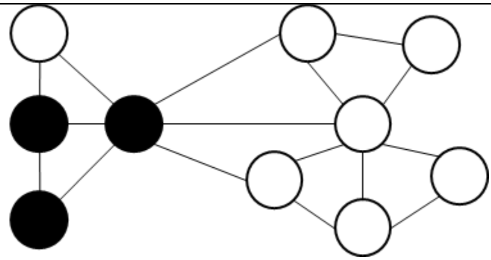
As a null comparator we generated 30 sets of randomly selected individuals at each level of intervention effort (i.e., size of target set). Furthermore, we created random sets of clusters, selecting random individuals, and a social peer for each. For example, to generate a set of size n=30, we selected 15 random individuals and selected 15 social peers.

6.3.5 Identifying rules-of-thumb

We used two approaches to identifying potential rules-of-thumb. First, we look for non-sociometric strategies that result in sets of targets that are very similar to strategies informed by network theory. To assess similarity between each pair of sets, we use the Jaccard similarity index (Jaccard, 1912). This is the proportion of individuals that occur in both of a pair of sets. Second, we look for other observable traits that can predict inclusion in a key-player set (at n=30), using binary logistic regression. We assessed correlation with wealth, leadership position, age, and gender.

Table 6.1: Targeting strategies informed by the network interventions literature. The first four are "key-players" approaches selecting individuals that span the networks, while the last two are clustering strategies selecting groups of connected individuals. Diagrams for key-players approaches (1 to 4) are adapted from Mbaru & Barnes (2017)).

Targeting strategy	**Case study rationale**	**Modelling strategy**	**Example**	**Diagram**
In-degree centrality	Identifies popular individuals who have many connections with others and are influential.	We select the individuals with the highest in-degree centrality, using the Key-players Algorithm	(Mbaru & Barnes, 2017)	
Betweenness centrality	Identifies individuals who can broker information between disconnected groups	We select the individuals with the highest betweenness centrality, using the Key-players Algorithm	(Mbaru & Barnes, 2017)	

Closeness centrality	Identifies individuals who can rapidly spread information	We select the individuals with the highest closeness centrality, using the Key-players Algorithm	(Mbaru & Barnes, 2017)	
Eigenvector centrality	Identifies individuals with influential friends, who can facilitate the spread of the hotline	We select the individuals with the highest eigenvector centrality, using the Key-players Algorithm	(Mbaru & Barnes, 2017)	
Clusters	Use of the hotline is socially sensitive so targeting groups of friends is more likely to result in adoption.	We select random individuals and then include all their nominated peers.	(Beaman *et al.*, 2014)	

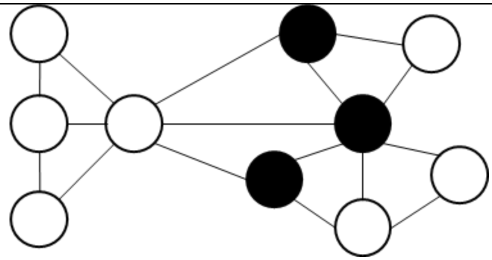
Combined approach	Groups of friends that are well-connected are more likely to adopt, and more likely to spread the hotline to others.	We select individuals with high centrality and include their connected peers.	-	

Table 6.2: Targeting strategies used in our simulated intervention, informed by a review of the conservation science literature.

Targeting strategy	**Case study rationale**	**Modelling strategy**	**Example**
Negative attitudes to the behaviour	Changing the behaviour of those individuals least likely to support reporting of poisoning will be most effective	We select the individuals least likely to want to report poisoning from our sample	(Saypanya *et al.*, 2013; Jones *et al.*, 2019; Kamins *et al.*, 2015)
Positive attitudes to the behaviour	Targeting individuals already predisposed to using the hotline will be most effective.	We select the individuals most in favour of reporting poisoning from our sample	(Jones *et al.*, 2019; Metcalf *et al.*, 2018)
Wealth	Wealthy individuals are thought to be influential, and they will help to promote use of the hotline.	We select the heads of the wealthiest households	(Olmedo, Sharif & Milner-Gulland, 2017; Mbaru & Barnes, 2017)
Leadership	Local leaders are trusted, have good local knowledge, and will provide legitimacy to the hotline.	We select individuals occupying formal leadership positions in the community, such as the village chief and sub-chief, leaders & secretaries in the community forest committee.	(Saypanya *et al.*, 2013; Gibson & Marks, 1995; Mbaru & Barnes, 2017; Day *et al.*, 2014; Steinmetz *et al.*, 2014)
Gatekeeper	We have an existing relationship with the village chief. We can rely on his local knowledge and assume he has influential	We select individuals within our network connected to the village chief through	(Gibson & Marks, 1995)

	friends.	any kind of tie.	
Convenience	Hosting an event at the village hall is likely to attract an interested crowd and is convenient.	We select a random set of individuals, with a bias towards women and those living near the village hall, as we know these are more likely to attend.	(Cartwright, Wall & Placide Kaya, 2012; Saypanya *et al.*, 2013)
Conservationists	We have existing relationships with some individuals and know they are committed to conservation. We can rely on their local knowledge.	We select individuals known to be engaged in conservation activities in general, such as members of the community forest and Ibis Rice committees.	(Day *et al.*, 2014)
School students	School children are more easily influenced and may influence their parents.	Not considered in this study	(Damerell, Howe & Milner-Gulland, 2013; Freund *et al.*, 2020; Steinmetz *et al.*, 2014; Padua, 1994)
Random	Without specific information upon which to base our targeting we choose random residents in the village.	We select a random set of individuals.	(Jones *et al.*, 2019; Day *et al.*, 2014; Baruch-Mordo *et al.*, 2011; Saypanya *et al.*, 2013)

6.3.6 Comparing effectiveness using simulation

We compared the performance of each strategy using a simulation model. In each simulation, we initiate diffusion through a set of target individuals, and observe how information about the hotline, a simple contagion, and intention to use the hotline, a complex contagion, diffuse through the village social network. The model, described below, is adapted from that specified in (Dobson et al., 2019).

The diffusion model simulates the spread of information or behaviour through a network based on simple assumptions and rules. At any time, any individual (i) in the network has one of two possible states (β): indicating that they have received information or adopted a behaviour ($\beta_i = 1$), or that they have not ($\beta_i = 0$). Initially, at t=0, we assume that $\beta_i = 0$ for all individuals, except for those in the targeted intervention set, for whom $\beta_i = 1$. At subsequent time points (t=1, 2, …20) individuals are exposed (α) to the information or behaviour through their network connections to others who have already adopted it, either in their own household (X) or among those they visit (Y). Exposure through visits ties is weighted double, $Y_i = 2X_i$, as we assume that social peers explicitly nominated are likely to be more influential on an individual's behaviour than household co-residents, who are only linked because of the homogenous mixing assumption. Furthermore, stochasticity was introduced into the model through a 'communication probability', L: the probability that communication of the information or change in behaviour will occur following interaction between any pair of individuals at t, where L = 0.2 or 0.8. Therefore:

$$Equation\ 6.1: \alpha = L(\sum \beta_x + 2\sum \beta_y).$$

To compare the effectiveness of different strategies at different levels of intervention effort, we used each of the identified sets of targets to initiate diffusion. Further individuals will adopt the information/behaviour ($\beta_i = 0 \rightarrow 1$) if $\alpha \geq \lambda$, where λ is the exposure threshold. To compare the spread of information with the spread of behaviour, we repeated the simulations with λ = 1, 3. At λ=1 information can be passed from any single connection, while at λ =3, at least two connections outside the household are required for adoption of the behaviour, or three within the household, or some combination of these. Each simulation continued until t=20 and was repeated 20 times. Each time step represents an arbitrary period, during which individuals may communicate with their peers.

As a measure of intervention effectiveness in each simulation, we use the area under the diffusion curve (AUC, see Appendix 3) as a percentage of the maximum possible AUC (size of network x number of periods). Therefore, the AUC percentage reflects both the number of individuals knowing about the hotline or intending to use it, and the speed with which this change occurs. We calculated bootstrapped 95% confidence intervals across the 20 repeated simulations. For the clustered and random strategies, we combined results across all 30 sets giving 20x30=600 model simulations for each. We bootstrapped 95% confidence intervals for AUC across all 600 results.

6.3.7 Cost-benefit analysis

Finally, to compare the cost-effectiveness of each strategy at achieving diffusion, we estimated the financial costs of collecting the data required to identify targets for each strategy and to implement the hotline intervention, based on our experiences conducting simple information-provisioning or social marketing interventions (i.e. single events where persuasive information is presented to participants, see Appendix 3). The intervention takes a similar format regardless of the targeting strategy used, and cost is dependent only on the level of effort (i.e., the number of targets). This included travel, staff, and materials costs. For example, an intervention with two targets consists of two NGO staff meeting targets at their home and providing information materials. For interventions with twenty or thirty targets, multiple staff would take multiple days to prepare a venue, invite participants, and source additional materials, such as posters to display.

We summed the data-collection and intervention costs for each simulation and then linearly interpolated the cost required to arrive at a target AUC (using the 'approx' function in R). Assuming we can use our data to identify general rules of thumb applicable in other villages, we calculated the number of villages (N) an intervention must include in order for sociometric data collection to be cost-effective at achieving the target AUC. To do so, we used the formula $N = \frac{D}{C_{non} - C_{net}}$, where D is the cost of collecting sociometric data ($5160), C_{non} is the cost of the best performing non-sociometric strategy, and C_{net} is the cost of the best performing sociometric strategy. This assumes that the increase in efficacy and effort required remains proportional across villages.

6.4 Results

6.4.1 Description of the sample & network

The network included 365 adults from 155 households. We recorded 774 nominations for household visits, and after cleaning the data retained 701 ties. The final habitual social contact network included 1350 ties (see Table A3.1 for descriptive statistics).

6.4.2 Set comparisons & rules-of-thumb

Overall, the sets of individuals selected for targeting under different strategies were distinct and had a low degree of overlap (see Tables & Figures A3.2, A3.3 & A3.4). Of the key-player sets, only closeness and betweenness centrality had any overlap with non-sociometric sets (albeit low; *Jaccard* = 0.05), namely with the wealth and gatekeeper sets respectively. At the highest effort level, the greatest overlap between a key-player set and a conventional set was $J = 0.09$ for the gatekeeper and in-degree centrality sets.

Only one variable was significantly associated with inclusion in the key-player sets based on each centrality measure. In-degree centrality key-players tended to be older (effect size = 0.52 ± 1.74, $p < 0.01$), while closeness centrality key-players tended to be younger (effect =-0.80 ± 0.29, $p < 0.01$). For eigenvector centrality, women were more likely to be included than men (effect size = 1.05 ± 0.45, $p = 0.02$). Betweenness centrality, was not significantly associated with any variable.

6.4.3 Simulations

6.4.3.1 Diffusing information

For diffusing information, all strategies performed well, and there was diminishing return on effort (Figure 6.1). At higher effort and higher communication probability there was low variation in performance. For example, at effort n=30, even the worst-performing strategies achieved >80% AUC. Only sociometric strategies performed better than the 95% confidence interval for random targeting. In-degree centrality and betweenness centrality key-players performed best at all levels of effort, and clusters based on these two centrality measures also performed well. The best-performing conventional strategies were targeting through the gatekeeper and targeting those with less positive attitudes. These performed at the upper end of the random range. Other strategies performed similarly or worse than the median random strategy.

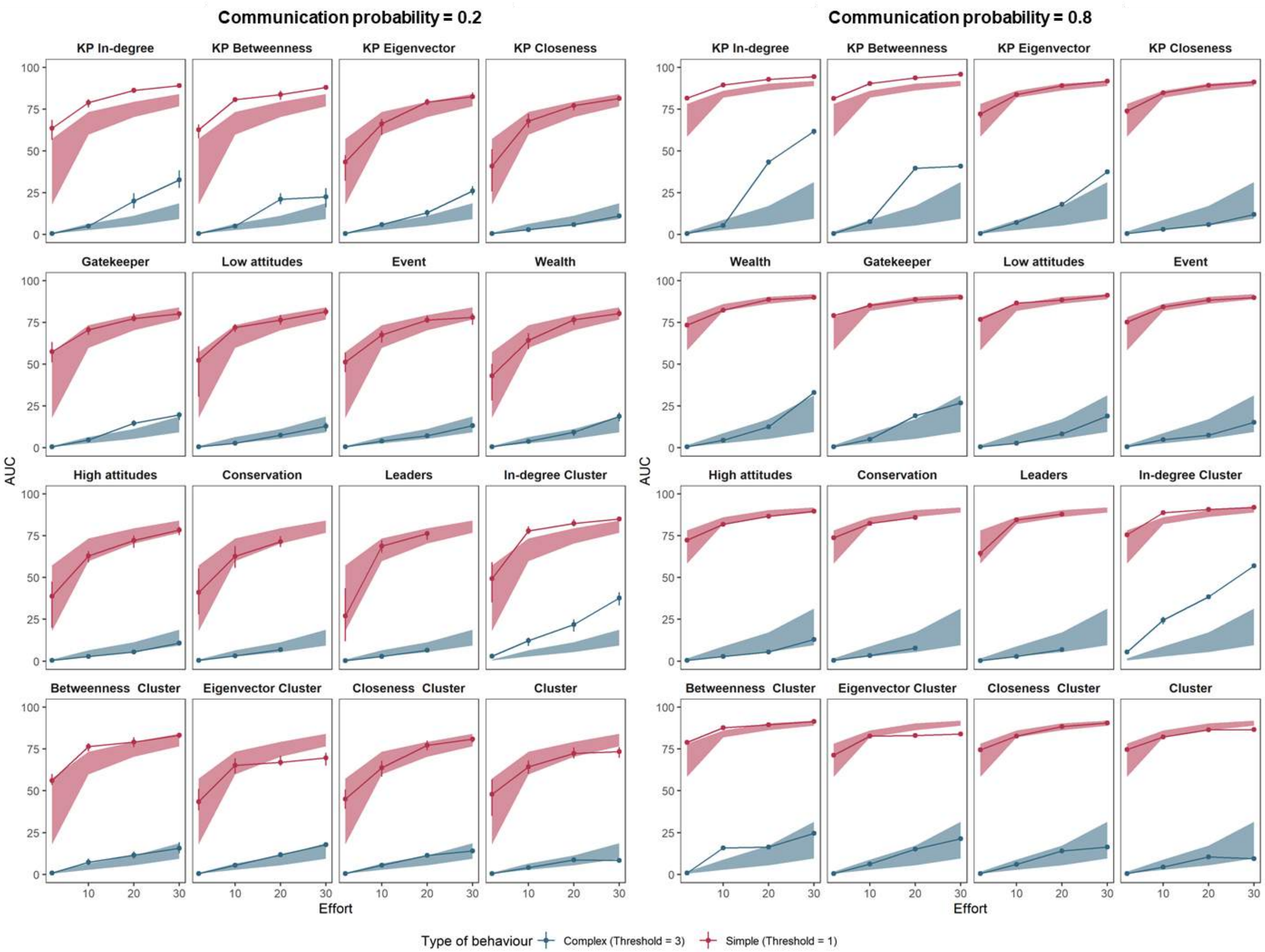

Communication probability = 0.2
Communication probability = 0.8
KP In-degree
KP Betweenness
KP Eigenvector
KP Closeness
Gatekeeper
Low attitudes
Event
Wealth
High attitudes
Conservation
Leaders
In-degree Cluster
Betweenness Cluster
Eigenvector Cluster
Closeness Cluster
Cluster
AUC
Effort
Type of behaviour
Complex (Threshold = 3)
Simple (Threshold = 1)

Figure 6.4 (previous page): Performance of different targeting strategies at diffusing an innovation, based on simulations using the measured social network. Each strategy is simulated at four levels of effort (2, 10, 20, & 30 targeted individuals) except for 'conservation' and 'leaders' which are not simulated at n=30, because not enough of these people existed within the network. Performance is measured as the area under the diffusion curve (AUC) as percentage of the maximum possible diffusion at time t=20. This captures both the speed and the scale of diffusion in one metric. Bootstrapped 95% confidence intervals are shown. The shaded area is the 95% confidence interval range for simulations on 30 randomly generated sets of targets, acting as a null comparator. If the line falls within the shaded area, its performance is within the bounds of random targeting. Colours indicate the threshold of diffusion: blue for complex contagions such as conservation behaviours, and red for simple contagions such as information. On the left are results when the communication probability (i.e., the probability of communication between two connected individuals) is low (0.2), and on the right it is high (0.8). See Table 6.2 for explanations of the strategies.

6.4.3.2 Diffusing complex behaviours

For the diffusion of behavioural changes (complex contagions), performance was much lower across all strategies and tended to increase linearly with effort (Figure 6.1). At low effort, only clustered strategies achieved any diffusion. Variation in performance increased with effort and communication probability. For example, at the highest effort level and communication probability, the median random set achieved 18% AUC while targeting clusters based on the in-degree centrality key-players achieved 62% AUC. This was the best performing strategy, and the only strategy to perform better than random at all levels of effort. At effort greater than 20 targets, targeting in-degree, betweenness or eigenvector centrality key-players also performed well (Figures 6.1 & 6.2). Targeting clusters based on these key-players tended to perform at the upper random range or slightly better. Of the conventional strategies, only targeting through the gatekeeper performed better than random, at higher levels of effort. Targeting wealthy households performed at the upper limits of the random sets at high efforts (n>20, Figure 6.2). At low communication probability, targeting random clusters performed better on average than targeting random individuals.

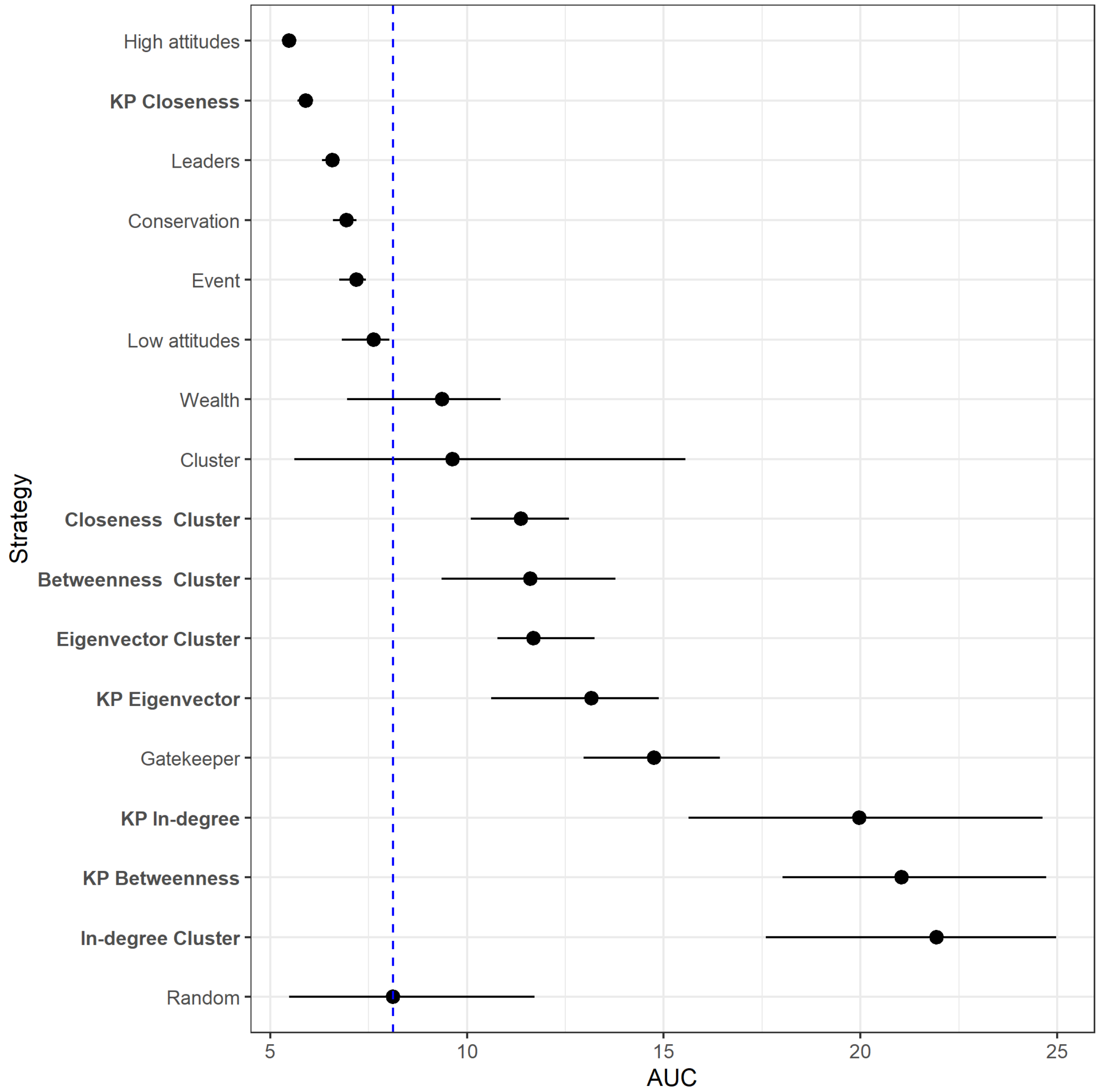


Figure 6.5: Strategy performance ordered by mean AUC. When targeting 20 individuals, only sociometric strategies (in bold) and targeting through the gatekeeper perform better than random at diffusing a complex contagion at low listening probability. The AUC represents the percentage of the maximum possible diffusion achieved within 20 time periods. Bootstrapped 95% confidence intervals are shown from 20 model runs. For Random, confidence intervals are bootstrapped for 20 runs across 30 randomly generated sets, and the median set is shown by the dotted line. See Table 6.2 for explanations of the strategies.

6.4.4 Cost-benefit analyses

Intervention costs increased as effort increased, from $52 for targeting two individuals to $502 for targeting 30 individuals (Table A3.5), though the cost per person targeted decreased as effort increased. The cost of collecting data for targeting was an order of magnitude greater: $5160 for sociometric data, and $2200 for other data (Table A3.6).

It was always more cost-effective to increase intervention effort and apply a conventional strategy than to collect data in order to use sociometric strategies, or other strategies for which data collection is needed (i.e., people with less positive attitudes, wealthy people). For example, to achieve AUC=15% for a complex contagion at low communication probability, it would cost approximately $318 using the gatekeeper strategy, $487 through random targeting, or $5276 for the best-performing sociometric strategy (in-degree clusters) (Table 6.3).

Table 6.3: Costs required to achieve a target AUC for four example strategies (one from each type), at a low communication probability. The costs are calculated based on interpolated effort levels. Missing costs indicate that it was not possible to achieve this target AUC using this particular strategy in our simulations. The costs are estimated based on the authors' experience in the study context. For explanations of the strategies, see Table 6.2.

Strategy	Target AUC for complex contagion			Target AUC for simple contagion		
	10%	15%	20%	60%	70%	80%
KP In-degree	$5349	$5475	$5488	-	$5269	$5330
Gatekeeper	$301	$353	-	$91	$153	$513
Wealth	$2555	$2682	-	$2340	$2402	$2712
Random	$379	-	-	$131	$178	$510

Targeting clusters based on in-degree centrality key-players was the best performing strategy for diffusing behavioural change at low listening probability, but was not cost-effective compared to other approaches, such as targeting through the gatekeeper. The cost of sociometric data collection would be justified if used to inform thirty-one interventions.

To cost the same as a randomly targeted intervention only 21 interventions are needed. For the diffusion of information, betweenness centrality key-players were most effective. To achieve 80% AUC at a comparable price to random targeting, the intervention must include 15 interventions, but to achieve 70% AUC at comparable price to random targeting, 75 interventions are required.

6.5 Discussion

Using simulations, our results confirm predictions from network theory (Mbaru & Barnes, 2017; Valente, 2012) and evidence from other disciplines (Paluck, Shepherd & Aronow, 2016; Kim et al., 2015), in showing that sociometric targeting is more effective at diffusing new behaviours than non-sociometric strategies. In particular, we demonstrate that targeting connected clusters of individuals is a highly effective strategy for diffusing behavioural change (Centola, 2018; Beaman et al., 2014). However, our results also show that, in our case study, the high costs associated with collecting sociometric data compared to the cost of the intervention itself mean it is rarely cost-effective, and that resources are usually better spent on targeting more individuals.

The value of sociometric data increases as diffusion becomes more challenging (Akbarpour, Malladi & Saberi, 2020). For example, it was relatively straightforward to effectively diffuse information (a simple contagion). By targeting 30 random individuals it was possible to reach over 80% of the 365 villagers in our case study. However, when adoption of a behaviour requires social reinforcement, targeting choices become more important and the best performing approaches were those informed by sociometric data. Within the range of interventions simulated, only sociometric targeting achieved diffusion greater than 20% of the theoretical maximum. Similarly, sociometric strategies performed relatively better when the probability of communication between individuals was lower. In some cases, the probability of individuals communicating about the conservation behaviour may be lower than we have modelled, such as when the behaviour is sensitive, meaning we may be underestimating the importance of targeting.

Despite the higher performance of sociometric strategies for diffusing complex behaviours, they were never a cost-effective option. For example, to achieve 15% of maximum diffusion, it was an order of magnitude cheaper to use the best performing conventional strategy whilst targeting more people, than to collect sociometric data and precisely target a smaller number of key-players. This result is in agreement with predictions from other simulation studies (Akbarpour, Malladi & Saberi, 2020).

However, it may be worth collecting sociometric data if this one-time investment could be leveraged to generate rules of thumb that can be applied to improve intervention outcomes beyond the study site. For example, if a more easily observed variable such as wealth is strongly correlated with network centrality. According to our analysis, an investment in sociometric data collection would become cost-effective if such an approach could be applied across 21 villages (compared to random targeting and assuming the rule of thumb performs just as well as the sociometric strategy). This is a large number, but it is feasible within our case study area, where there are 28 further villages with community protected areas. Social networks are dynamic (Bignami-Van Assche, 2005), but within a particular timeframe these data could also be used to guide multiple interventions within the same villages assuming the measured networks are relevant. For more expensive forms of intervention, requiring prolonged engagement with targets (e.g., a farmer field school), or financial incentives, it is likely to be more cost-effective to collect sociometric data and work in fewer villages (Akbarpour, Malladi & Saberi, 2020). A formal analysis of the value of information could be used to guide decision-making around data collection (Canessa et al., 2015).

Our analyses did not suggest any particularly promising rules of thumb, with effect sizes much smaller than those found by Mbaru & Barnes (2017) but do suggest that older individuals tend to be better connected (in-degree centrality), while closeness-centrality key-players tended to be younger. As found in other studies in rural developing country contexts, the results suggests that central individuals in our network are not necessarily those with the highest wealth or social status (de Roo et al., 2021). At higher effort levels there was some overlap between the gatekeeper and in-degree centrality key-player sets, and the gatekeeper strategy also performed relatively well in our simulations, indicating that targeting through the gatekeeper may be an effective rule of thumb. Nevertheless, this strategy was much less effective than the best sociometric strategy, more villages would need to be included in the intervention to justify investment in sociometric data collection.

Our results probably underestimate the power of village chiefs (the gatekeepers in our case study) for diffusing behaviours as they can access further resources, networks, and use their social capital to reach others (Ledgerwood & Vijghen, 2002; Marston, 2011). For example, we know that some village chiefs have organised meetings on their own initiative to discuss the issue of wildlife poisoning (Chapter 4). Replicating our study in other villages could provide confidence that this strategy is effective across rural Cambodia, and qualitative local knowledge may help determine the appropriateness of this strategy in each village. An assessment of the best approach also needs to take other social and ethical considerations into account. For example, interventions working through a gatekeeper may lead to elite capture of the benefits of the intervention, further marginalising other groups (Lucas & Lucas, 2016).

If sociometric data have already been collected, diffusion simulations can be applied to select optimal sets of intervention targets (Beaman et al., 2014; Banerjee et al., 2013). Our model provides a framework for achieving this but could be refined to better capture real world dynamics. Firstly, individuals vary in their contribution to conservation behaviours. For example, we could weight our valuation of the behavioural change (adoption of the hotline) if undertaken by individuals thought more likely to have knowledge of wildlife poisoning, as this would be a greater gain for conservation than its use by others. This is the logic behind strategies such as targeting individuals with more or less positive attitudes towards the behaviour of concern. Secondly, one could use behavioural data to parametrise a distribution of adoption thresholds (Valente, 1996), reflecting the varying propensities of individuals to adopt new behaviours. Thirdly, one could include more types of tie in a multiplex network to better capture the dynamics of social influence and information sharing. Finally, our model output, the area under the diffusion curve, captures both the speed and the extent of diffusion. If intervention objectives require behaviours to diffuse within a particular timeframe, simulations can examine the performance of these parameters separately (Akbarpour, Malladi & Saberi, 2020).

Network theory more generally suggests some universal improvements to intervention design which are supported by our results. In particular we show that selecting targets in clusters is more likely to result in diffusion of complex behaviours than targeting individuals from across a network (Centola, 2018; Beaman et al., 2014). Conservationists could easily apply this insight. For example, if only a small number of individuals can be targeted in each village, one could select them using a rule of thumb (such as selecting the village chief) and ask them to invite their close connections to participate in the intervention. In Cambodia, anecdotal evidence suggests that after switching from village-wide meetings to small meetings with groups of related farmers, a 50% increase in recruitment to a conservation agriculture scheme was achieved in one village (Chapter 3).

Our study shows that network analysis has the potential to improve conservation interventions on three levels. First, the collection of sociometric data can identify optimal sets of targets for diffusing complex behaviours that greatly outperform other strategies. However, this is unlikely to be cost-effective for small or cheap interventions. Instead, resources are better spent targeting more individuals, selected via cheaper means. Second, sociometric data can be used in combination with other knowledge to produce generalised rules of thumb for targeting interventions. Our results suggest these are likely to be context specific. This approach may be valuable for refining large-scale interventions; in our case, collecting sociometric data is only cost-effective if a very large number of villages are included in the intervention (although the absolute cost of data collection is still low). Simple calculations of the value of information combined with simulations can help to guide these intervention-design decisions (Rhodes et al., 2020; Akbarpour, Malladi & Saberi, 2020; Canessa et al., 2015). Third, the large literature on network interventions (Valente, 2012) can suggest improvements to intervention design that apply across contexts, such as the use of clustered targeting strategies (Centola, 2018). Given the relative cost of collecting sociometric data, this is likely to be the most generally useful contribution of network data to conservation practice. Conservationists should continue to incorporate these insights into their interventions (Groce et al., 2018), while further research on social networks within different conservation contexts is needed to identify further applicable insights.

7. Discussion

7.1 Summary of thesis contributions

7.1.1 Context

Conservation scientists are increasingly interested in adopting methods and tools from the behavioural sciences to design more effective interventions that influence human behaviour and protect biodiversity (St. John, Keane & Milner-Gulland, 2012; Schultz, 2011). To this end, substantial amounts of conservation research have been published examining tools such as social marketing (Wright *et al.*, 2015) or generating insights into the behaviours and attitudes of individuals in a population (Jones *et al.*, 2019; St. John *et al.*, 2012). An aspect of behaviour change that has not yet been widely studied by conservation scientists is the social relational processes that shape individual behaviour, such as communication through social networks and the production of social norms (Ernstson, 2011). Scholars in the social and behavioural sciences have developed a rich body of theory and practice incorporating these social processes into the design of interventions. Integrating these insights into conservation practice could help to achieve conservation goals (Borgatti *et al.*, 2009; Valente, 2012; Centola, 2018; Prentice & Paluck, 2020).

In this thesis, I aimed to contribute to more effective design of conservation interventions by furthering understanding of the role of social networks in conservation behaviours, focussing on a case study intervention of wildlife poisoning. To do so I first synthesised the literature on network interventions from other disciplines. I then carried out a series of studies following the project management cycle of an intervention, starting with formative research to inform intervention design, and ending with an evaluation of the intervention's effectiveness. I used the Theory of Planned Behaviour to conceptualise and measure behaviour throughout. First, I used a mixed method approach to better understand the phenomenon of wildlife poisoning. I then facilitated the design of a social marketing intervention together with WCS Cambodia and the Department of Environment in Preah Vihear province. I collected longitudinal data on behaviour and knowledge and modelled these in conjunction with a measured social network, to understand how social relations shaped responses to the intervention. Finally, I used simulations of diffusion in the social network to explore the cost-effectiveness of targeting strategies informed by network theory.

7.1.2 Key contributions

Overall, this thesis has furthered the integration of methods and insights from the behavioural sciences into conservation. Firstly, by synthesising the literature on 'network interventions', and secondly by applying these insights to a real conservation problem. Here, I discuss the key contributions made towards each objective.

7.1.2.1 Objective 1: Synthesising knowledge on social networks.

Chapter three synthesised the literature from disciplines such as sociology, social psychology, and public health, on the role of social relations/networks in shaping human behaviour and discussed approaches to 'network intervention' in the context of conservation. I discussed evidence and theory about the importance of information of various types in human decision-making and highlight the particular importance of social information. I described a methodological framework through which researchers can collect data about the social networks that are relevant to an intervention and identify important structural features. I introduced the concept of simple and complex contagions to conservation. Finally, I provided an overview of the various intervention options available that exploit or leverage knowledge about social network, such as more effective targeting of intervention, or altering network structures, relating examples from fields such as public health and marketing to conservation.

7.1.2.2 Objective 2: Understanding wildlife poisoning.

Chapter four presented a study into wildlife poisoning practices in Northern Cambodia. Wildlife poisonings were first documented in this area in 2015 and were recognised as a potentially critical threat to conservation (Loveridge *et al.*, 2019). To inform intervention design, we carried out a mixed method study across ten villages in the landscape, aiming to understand the prevalence of this practice, identify the groups involved and their motivations, and understand the attitudes and perceptions of others in the villages. We found that wildlife poisoning is a deliberate practice used by hunters to catch wildlife during the dry season and that there are widespread misperceptions about the health risks of this behaviour. Nevertheless, over 75% of respondents reported perceived negative social norms, and 87% perceived it as an unsafe method. Concerns for safety were given as the predominant reason by hunters (63%) for not using poison. We documented actions taken against poisoning by authorities in five villages, particularly in those villages where norms were perceived most negatively. These actions included disciplining of individual hunters, and village meetings to discuss poisoning.

7.1.2.3 Objective 3: Understanding how social networks influence behaviour change interventions

Chapter five presented a study of the mechanisms through which social relations influenced the outcomes of an intervention. The intervention aimed to promote the use of a hotline for reporting poisoning and consisted of an event attended by 41 individuals. We measured network ties among 365 adults in the village, and measured their knowledge of the intervention, and their psychological outcomes in three survey waves before and after the intervention. We then used linear models and stochastic actor-oriented models, a kind of dynamic network-behaviour model, to determine the relation between social networks and intervention outcomes. We found that information flowed following our intervention largely within households, and that 144 individuals (~40%) were knowledgeable about the intervention after six months. However, as predicted by the theory of complex contagions, dynamic network models showed that changes in behaviour throughout the village were largely driven by social influences, and not by information flow.

7.1.2.4 Objective 4: Exploring the potential use of network data for targeting an intervention

Chapter six presented a study exploring the scope and cost-effectiveness of network-informed interventions using sociometric (data about the social ties or relationships between individuals), demographic, and behavioural data for all residents of one village in northern Cambodia. Using different intervention strategies, including those from the literature, strategies informed by network theory, and random selection, we generated sets of individuals to target for an intervention. We compared the composition of these sets and compared their effectiveness by simulating the diffusion of behaviour and information through the social network. We then determined the cost-effectiveness of each approach based on our own experiences of intervening in this context. We found that targeting strategies informed by network theory and data were approximately twice as effective as the best-performing of the other strategies, based on individual characteristics such as wealth or attitudes. Furthermore, most of the conventional strategies did not perform better than random. This difference was greater for diffusion of behaviour compared with the diffusion of information, as expected under the theory of complex contagions. However, this improved efficacy did not justify the costs required to collect network data, which were an order of magnitude greater than targeting costs in this context. In all cases we examined, it was more cost-effective to target a greater number of people randomly, than to target specific network-informed individuals.

7.2 Cross-cutting themes

This thesis followed the project cycle of an intervention; from formative research, through intervention design, and finally to evaluation and learning from intervention outcomes. To meet the research objectives described, I paid close attention to the role of social relations and social networks throughout this process. Therefore, reviewing this thesis in its entirety, several key insights and themes emerge. First, I briefly discuss the ways in which residents communicate and learn about new behaviours, and what this means for information transfer. Then, I highlight the ways in which individuals in our case study influenced one another regarding wildlife poisoning, as well as in the context of our hotline intervention. Recognising the important role of social influence in conservation behaviour opens new ways of thinking about intervention design, which I describe with reference to literature from other disciplines. Finally, I discuss the key implications of this research for efforts to reduce wildlife poisoning in Cambodia, connecting our results with broader literatures on the political economy of pesticide use.

7.2.1 Learning and information flows

Information about the world is a central input to human cognition and plays a key role in human decision-making (Schlüter *et al.*, 2017). Chapters three and five show that the transfer of information is a necessary, but not sufficient, component of any intervention which aims to change behaviour.

In the Northern Plains we found a striking lack of communication within the communities about problems such as pesticide use (Chapter 4). Most farmers reported a preference for learning from market sellers. Typically, farmers would go to market to seek advice on specific problems they faced, or if they observed other farmers using a new tool, they would go to the market to seek further information. Shopkeepers within the village were also an important conduit as they have links with market traders, and we know of at least two who were distributing and promoting poisons in their villages. These patterns, together with a reliance on personal experimentation and observation, meant that farmers tended to have poor access to information about pesticides as packaging and labelling is often absent or unclear, while market sellers are not likely to provide objective information. This has resulted in misinformation and misperceptions about the risks of pesticide use, which may have contributed to wildlife poisoning behaviours.

It is against this background that our intervention was planned. As is typical, we were only able to directly target a relatively small proportion of the intended audience for the conservation messages (~10%). We therefore relied on information flow to amplify the effect of the intervention. Sociometric data showed that, in general, the village was sparsely connected (Chapter 5). Most villagers only had two or three people outside of their own household with whom they regularly and intentionally spent time, and these tended to be relatives. Consistent with anthropological observations elsewhere in Cambodia, we found that communication and interaction among unrelated households tends to be quite minimal, even amongst those living in close proximity (Marston, 2011). Accordingly, we found that information about the intervention flowed relatively easily but tended to flow most within households (Chapter 5). This suggests that strategies which aim to reach at least one individual from each household (i.e., by inviting a representative to attend information sessions) are likely to be most successful for disseminating information. This was in contrast to the findings from simulations of information flow, which suggested that information dissemination is relatively straightforward, and that high levels of diffusion can be achieved simply by targeting a small number of random individuals (Chapter 6).

7.2.2 The role of social relations in conservation behaviour

Although information about new behaviour is essential for human decision making, and information flows relatively easily, providing information is not sufficient to change behaviour, because the causal links between knowledge about an issue and behaviour changes are complex and mediated by social and material processes (Valente, Paredes & Poppe, 1998). Nevertheless, many conservation interventions still rely on the assumption that providing information will lead to behaviour change, the so-called ‘information deficit model’ (Monroe, 2003). This model does not account for motivations, barriers, and the other material and psychological factors that can encourage or discourage behavioural changes (Schultz, 2002; Monroe, 2003; McKenzie-Mohr & Schultz, 2014).

In the last decade, conservation scientists have adopted theory and tools from the behavioural sciences to better understand conservation behaviours and design effective interventions (St. John, Edwards-Jones & Jones, 2010; St. John, Keane & Milner-Gulland, 2013; Schultz, 2011). For example, behaviour change frameworks such as social marketing (Green *et al.*, 2019) recognise the limitations of the information deficit model and are increasingly adopted in conservation (Wright *et al.*, 2015; Smith, Verissimo & Macmillan, 2010). But often these efforts are still focussed on the behaviours, or even attitudes, of individuals, and neglect the dynamic social cues that are essential for behaviour change to occur throughout a population (Prentice & Paluck, 2020; Ernstson, 2011). Another body of literature examining the collective, group-level, or relational, processes through which societies change (Prentice & Paluck, 2020) has been largely absent from conservation science (Carignano Torres *et al.*, 2021; Naito, Zhao & Chan, 2021). This perspective emphasises the ways in which individuals interact and communicate with one another to arrive at shared understandings, or social norms, which shape their behaviour (Schultz *et al.*, 2016; Prentice & Paluck, 2020; Miller & Prentice, 2016). Recognising this, researchers must attend to social structures, using tools such as social network analysis, and consider social relations instead of just individual beliefs when designing interventions (Valente, 2012).

In this thesis, I attempted to model this perspective. I studied both individual and social influences on the phenomenon of wildlife poisoning. I used the Theory of Planned Behaviour to conceptualise and measure behaviour. Although this theory focuses on the micro-scale individual cognitive determinants of behaviour, it measures beliefs about external factors, such as perceptions of control and perceived norms. I expanded on this by interpreting behavioural data in conjunction with qualitative data (Chapter 4), and social network data (Chapter 5). In particular, I model changes in individual measures of behaviour and link them to others by taking account of social structure (Chapter 5). The behaviours I studied were not directly observable, making it challenging to validate whether the theory is accurately identifying predictors of behaviour. For example, it is possible that measured intentions to report poisoning do not accurately predict reporting if the context of reporting differs from that described during questioning. Nevertheless, the Theory of Planned

Behaviour provided a practical and convenient framework through which to assess and compare theoretically-important determinants of behaviour across the population, and from which to plan the interventions carried out (Chapter 2). Qualitative data corroborated the importance of norms, attitudes, and perceptions of control as important factors in the behaviours studied.

I found that individual beliefs about the efficacy of hunting with poisons, or of the possible health impacts of consuming poisoned meat certainly played a role in decisions to use poison. However, I also found a variety of social factors which enable or constrain poisoning behaviours (Chapter 4). The myriad negative impacts that poisoning can have on other members of the community have generated widely shared negative attitudes, and perceptions that anti-poisoning norms are widespread. These norms were likely an enabling factor for village authorities to act against poisoning in some villages, and pre-existing norms against poisoning are likely to be an important factor in the success of future interventions as well (Bicchieri, 2017a). On the other hand, the ease with which poisoning can be carried out in secret, and wider cultural norms favouring conflict avoidance, enable hunters to use poison without credible fear of social repercussions (Saypanya *et al.*, 2013). Social structures may also insulate hunters from wider village norms. For example, one village chief pointed out that there were many people using poison in the village but that they were not in his friendship circles. There were also differences in perceptions of norms between different age groups. Understanding these social structures might therefore also suggest more effective ways to intervene.

The intervention we piloted was designed with these insights in mind. We promoted the use of a reporting hotline because this might tap into existing anti-poisoning norms to generate action by residents, and potentially raise the salience of these norms for hunters who are otherwise socially insulated from them (Saypanya *et al.*, 2013). We targeted the parents of youth in a vulnerable age group because of the potential influence they could exert on their children. However, we knew that fears of social conflict or upset neighbours might be significant barriers to reporting. We therefore used normative messaging and encouraged individuals to make a public pledge to use pesticides responsibly and to be vigilant against poisonings (Bicchieri, 2017a). The materials we disseminated were designed to enable these individuals to communicate this stance with others in the community, which we hoped would catalyse a shift in the beliefs about social responses to poisoning (Prentice & Paluck, 2020). Chapter five evaluated this intervention in detail. We found that our key messages did spread through the community, likely through weak social ties. But social influences were an important predictor of changes in intention, and probably contributed to a failure to increase intention in the long term as individuals sought to conform with norms in their immediate social circles.

While transfer of information may have laid the groundwork for future behaviour change, a sustainable shift in behaviour across the population requires more attention be paid to these social relations. The socially sensitive nature of reporting poisoning meant that expectation about the beliefs and responses of others in an individuals' social network (i.e. "social proof") are critical in deciding whether or not to report (Prentice & Paluck, 2020). Unless these expectations are changed the best-crafted intervention messages are unlikely to succeed at influencing behaviour (Bicchieri, 2017a), and these changes will likely only occur through communication between the individuals concerned, or through observations of behaviour of referent groups (Prentice & Paluck, 2020; Bicchieri & Xiao, 2009). It is therefore essential to understand the social structure of the group, and to identify who it is that individuals are referring to for these social cues. This knowledge can then be used to work with these individuals and leverage their influence (Valente & Pumpuang, 2007; Paluck, Shepherd & Aronow, 2016).

I explored one possible way of doing this; namely by targeting communications at key-players in the social network (Valente & Davis, 1999; Mbaru & Barnes, 2017). I showed that social visiting and household co-residence ties were important for influencing decisions to report poisoning (Chapter 5), and that adoption of the hotline by individuals at the centre of these social networks could lead to much more widespread diffusion of the behaviour than initial adoption by others. But, despite the considerably higher expense of collecting the data for identifying these key-players, overall adoption rates were still low (Chapter 6). The key-player approach can therefore be an important tool for intervention, but it is not a silver bullet or a shortcut to influence. Furthermore, in reality, key-players can often be reluctant to adopt new behaviours that might risk their social status, making them challenging targets for intervention (Aral & Walker, 2012).

The relational perspective shows us that the challenge of behaviour change is formidable. There is a natural 'inertia' and resistance to change within social groups because deviating from existing group norms is risky, costly, and potentially undesirable (Centola, 2018). Furthermore, in many cases the key-players whose influence we would like to tap into to create change are also those most resistant to changing the status-quo (Aral & Walker, 2012). However, once disabused of the illusion that the social network provides shortcuts to influencing behaviour, we can start to understand the possibilities in a more realistic sense. I propose three key insights for designing effective interventions.

Firstly, we must recognise that there are no silver bullets. Societies are complex, individuals and groups vary in intersectional ways, relate to one another in diverse ways, and therefore respond to information, incentives, and other stimuli differently. For this reason, social marketing interventions typically segment audiences based on key characteristics (Kotler & Lee, 2008). Conservationists have also begun to do this, such as identifying groups of hunters with the highest impact on important species (Jones *et al.*, 2019). For interventions to be effective across a population, they will need to be multi-faceted, tailoring different approaches to each segment. Knowledge or data (such as sociometric data) about social relations can be a useful, and complementary, way to segment audiences based on their social positions and social influence (Valente, 2012).

Second, behaviour change has a socio-temporal quality (rather than spatio-temporal), as new behaviours spread through social networks over time (Rogers, 2003). One-shot interventions are unlikely to succeed, as our experience in Chapter five demonstrates. The population segments that initially adopt the behaviour will perceive different barriers to behaviour change and respond to different interventions than those who might adopt later. Therefore, conservationists should recognise that repeated interventions will be needed, and that strategies and targeting must adapt as beliefs and behaviours change throughout a social network. In the classic theory of 'Diffusion of Innovations', Rogers (2003) segments the population based on the speed with which they adopt and proposes unique forms of intervention at each stage. Conservationists therefore need strategic patience, recognising that their first efforts might be more impactful if they aim to gradually change beliefs and perceptions within certain parts of a population, rather than aiming to change behaviour all at once. In this way, they can build the critical mass required to drive change in social norms in the long term (Centola, 2018; Valente, 1996).

Third, social influences are more important for later adopters than for early adopters. This temporal perspective opens up opportunities for later interventions to build on and leverage early gains, as early adopters become valuable social resources that can drive further adoption through their social networks (Valente, 2012). For example, early adopters may be peripheral in a social network, and therefore feel less social constraint, but they can build the momentum needed for central key-players to adopt. Once key-players adopt, behaviour change is likely to accelerate (Valente & Davis, 1999; Valente *et al.*, 2007). Interventions should explicitly account for social influence within the theory of change by identifying referent groups and other individuals likely to influence each of their audience segments (Prentice & Paluck, 2020). As behaviour change progresses through the population and intervention effort turns to different social groups, their respective referent and influential groups will also come into play as resources for intervention. Viewed from the other end, as different segments of the population undergo behavioural change, they also become potential influencers for the next segment. To capitalise on this, conservationists could identify those who are already behaving in the desired way and work with them as change agents, equipping and motivating them to reach out to others in their social networks (Crona & Bodin, 2010; Valente, 2012). This can involve recruitment into organizations and co-design of interventions (Paluck, Shepherd & Aronow, 2016), providing incentives to recruit others, or simply creating opportunities for social signalling, such as providing materials that enable them to display their behaviour to others (Niemiec *et al.*, 2019, 2021).

At present, there are still many existing ideas and strategies that have not been used by conservationists, and there is no need for us to reinvent the wheel of behavioural intervention. Indeed, the ideas discussed here are widely accepted in various behavioural science disciplines, and applied by communities of practice such as in public health (Prentice & Paluck, 2020; Valente, 2012). Although it is still rare to see conservationists considering social influence processes, one programme which exemplifies the practical application of these insights is the Lands for Life project implemented by Rare in Colombia, which aims to promote climate-smart agriculture amongst smallholder farmers (Bujold & Karak, 2021).

According to Rare, social proof (i.e. observing adoption of the behaviour by other farmers) and social pressures are key for farmer's decision making (Rodriguez *et al.*, 2009), and "previous efforts to change behaviour failed because they didn't incorporate either of these social variables […]" (Bujold & Karak, 2021). The programme they developed in response aimed to use these social processes. First, they segmented farmers by how resistant they might be to adoption and recruited low-resistance farmers into their programme. These farmers became social proof and helped to influence more resistant farmers. Rare, facilitated this process through peer-to-peer workshops and radio interviews. Finally, once substantial numbers of farmers were participating, they pressured the most resistant farmers, which Rare facilitated using social marketing and community events. There is no formal evaluation of this programme in the peer-reviewed literature, but there is sufficient evidence from other disciplines, and in this thesis, to suggest that conservationists can leverage the processes of social influence in similar ways to achieve conservation outcomes. Perhaps Rare, as early adopters, will help to catalyse a broader shift in how conservation is done. It is my hope that this thesis can play a similar role.

7.2.3 The political economy of wildlife poisoning

Chapter four looks in detail at the behavioural drivers of deliberate poisoning for harvesting wild meat, with an eye to local intervention. But wildlife poisoning can have numerous causes, ranging from unintentional spill over from agricultural practices to deliberate targeting of wildlife using poisoned baits (Carson, 1962; Odino, 2011; Ogada, Keesing & Virani, 2012; Ogada, 2014; Ogada, Botha & Shaw, 2016; Lalah *et al.*, 2011). In the Northern Plains of Cambodia, we also found a diversity of poisoning practices carried out by different actors. Conservation problems are driven by overlapping political, economic, cultural, and social systems (IPBES, 2019). Behaviour change interventions are a valuable tool for driving transformative social change, but it is vital that they are used strategically together with broader efforts to drive change at all levels (Naito, Zhao & Chan, 2021). In the case of wildlife poisoning, this means recognising the underlying political economies that are driving pesticides to become ubiquitous in Cambodia.

Globally, use of pesticides is increasing, but particularly in countries such as Cambodia where agriculture is fast intensifying (Schreinemachers & Tipraqsa, 2012; Environmental Justice Foundation, 2002). This has both demand and supply side drivers (Shattuck, 2021).

On the demand side, wildlife poisoning is a product of the changing forms of agricultural production in rural Cambodia. As smallholders are increasingly integrated into markets there is pressure to generate surplus production (Scheidel, Giampietro & Ramos-Martin, 2013). This requires intensification and/or extensification of production, and farmers often turn to pesticides to achieve this. Studies in various locations have also found pesticide use linked with access to credit, labour-shortages due to rural-urban migration and increased wages, and cash crop booms (Shattuck, 2021) – all processes occurring in Northern Cambodia (Beauchamp, Clements & Milner-Gulland, 2018b, 2019; Riggs *et al.*, 2020; Kong *et al.*, 2019). We documented several forms of pesticide misuse for protecting crops by smallholder farmers which exemplify these changes (Chapter 4). For example, many farmers lack the labour necessary to transplant rice (i.e., grow the stalk in a nursery and then plant it in the field) at the scale required to produce profitable surpluses. As a result, many have switched to broadcasting (i.e., scattering seeds across the field) which promotes growth of weeds and the spread of pests. To compensate, they scatter granular pesticides on the rice fields. Farmers were also more likely to use pesticides on cash crops than on rice grown for their own consumption (unpublished data).

The ownership of land has also changed drastically in the Northern Plains, as large areas of rural land have been transferred to industrial plantations (Beauchamp, Clements & Milner-Gulland, 2019; Davis *et al.*, 2015). This has spill-over effects on the technologies and chemicals available to nearby smallholders as well as on the way they manage their land (Anti, 2021). For example, market sellers set up to serve the plantations were a key promotor of pesticide use for smallholders. Moreover, these land transfers generate severe conflicts (Baird, 2017). In recent years, WCS has documented several cases of poisoning where large amounts of pesticide were placed on land belonging to or adjacent to large concessions (e.g., Heng Yue, Rui Feng sugarcane) and it is likely that these poisonings were carried out by labourers, perhaps on the order of their employers, to deter encroachment of cattle onto company land.

On the supply side, as patents have expired, pesticides are increasingly manufactured in Asia and at lower costs (Shattuck, 2021). They are thus more available and more accessible than ever before in Cambodia. In 2002, the Environmental Justice Foundation described Cambodia as a ‘dumping ground’ for unwanted chemicals (Environmental Justice

Foundation, 2002), because unscrupulous chemical manufacturers in neighbouring countries can offload their unwanted product onto the weakly regulated marketplace in Cambodia. Besides the ubiquity of these products, they are also often poorly labelled and packaged. In Chapter four, we found that market sellers stocked a wide variety of different chemicals, which vary in their toxicity. Often, they are labelled in foreign languages, or repackaged so that safety information is missing. The market traders themselves also have little knowledge of what they are selling and are prone to misleading their customers. Most concerning was the availability and use of carbamates, including carbofuran (Richards, 2011), which are banned by the international Rotterdam convention (Rotterdam Convention, 2013). Our attempts to trace the supply chains of these pesticides did not go beyond local shops, but it was clear that these dangerous chemicals were sold and used interchangeably with other, much less harmful, chemicals such as fipronil and abamectin.

We documented an interesting example of a local effort at resistance when one village chief tried to pronounce a ban on the sale of certain chemicals by shops within his community (Chapter 4). Although, we do not know what effect this ban had, and the pesticides have again become available since, such efforts should be supported. Much of the data presented in this thesis focuses on the beliefs and behaviours of local community members, but one motivation for establishing a reporting hotline was to enable residents to participate in efforts to protect their environment and their own health. Generating collective actions like this may be key, as communities are both more likely to detect poisoning events (compared to government patrols), and may have stronger motivations to prevent poisoning (Cooney *et al.*, 2017). Furthermore, generating political support for an alternative development model that does not rely on pesticide use, will require organizing local communities so that they can advocate for their own interests, and demonstrating that such a model can be viable and profitable. The Ibis Rice conservation agriculture project may be a key lever in this process (see Chapter 2).

Besides interventions aiming to influence the practices of local farmers and hunters, reducing the burden of poisoning on wildlife and local communities will require efforts to counteract the interests of 'petro-chemical capital' at global and national scales, including stronger regulation of trade, combating misinformation, and resisting agro-industrial land grabs (Faber, 2020). A 2002 report by the Environmental Justice Foundation (EJF, 2002) provided many recommendations for Cambodia to grapple with pesticides, of which I highlight a few:

- Cambodia should accede to the Rotterdam Convention procedures, placing the onus on exporter countries to control trade in restricted chemicals.
- The government should inspect markets for restricted pesticides and residues on food products.
- They should ban advertising of pesticides and develop communication and education campaigns to deter pesticide use and promote alternatives such as integrated pest management.
- The donor community can encourage and facilitate these actions by funding the activities described above and supporting capacity building within the relevant ministries.
- Donors should also recognise pesticide-problems as a public health crisis comparable to HIV and malaria.
- The agro-chemical industry and their financiers must recognise the reputational and regulatory risks in continuing to produce and market unsafe chemicals and should ensure that products sold in Cambodia are labelled with safety information in Khmer.
- Finally, the European Union and United States should end exports of chemicals that are not permitted for use within their own borders.

In 2012, the Cambodian government passed a law on pesticides which established a list of restricted chemicals, standards of use and disposal and mandated the Ministry of Agriculture, Forestry and Fisheries to regulate these and carry out education campaigns (Royal Government of Cambodia, 2012). This is an important step, but in regions such as the Northern Plains, these regulations are rarely enforced, and further efforts are required.

7.3 Future research directions

7.3.1 Cheap methods of learning about social structure

A key theme in this thesis is the importance of accounting for social relations when designing behaviour change intervention. Chapter three describes a variety of intervention approaches used in other disciplines that do so, including targeting of individuals occupying important positions in the network. Chapter six explores this strategy further using simulations and finds that these approaches are promising but that the cost of collecting network data can be prohibitive. There is thus a clear need for methods for gathering robust information about a social network, such as identifying important individuals or delineating social groups, which do not necessitate expensive name generator surveys across an entire population.

Valente & Pumpuang (2007) reviewed the literature and found a variety of techniques used in interventions to identify 'opinion leaders'; individuals thought to be influential within a group. Many of these approaches aim to determine which individuals are highly connected in a group using methods of varying robustness, such as by collecting sociometric data through name-generator surveys. One way to reduce the cost of such surveys is to simply sample a proportion of the population. The cost of data collection will decrease in proportion to the sampling factor, but the costs of analysing the data are likely to remain constant. Furthermore, as the sample coverage of the population decreases, robustness will also decrease (Eckles *et al.*, 2019). The nature of this trade-off varies depending on the structure of the network and the type of centrality measures being used. For example, simulation studies have shown that in-degree centrality is relatively robust to missing data, whereas betweenness centrality is not. Identifying influencers using in-degree centrality may even be robust with up to half of the network missing at random, representing real potential for cost saving (Costenbader & Valente, 2003). Nevertheless, the cost-benefit analyses we conducted in Chapter six suggest even a 50% reduction in cost is unlikely to be enough to justify data collection for sociometric analysis.

Other sociometric methods are peer-nomination surveys, where a sample in the population is asked to nominate individuals they perceive as influential, or qualitative techniques such as expert identification or ratings by key informants (Valente & Pumpuang, 2007). These methods could potentially be applied to much smaller samples of the population and are low-cost and simple to implement. Given that there are few published examples of conservationists targeting opinion leaders, these methods could be valuable simple additions to the conservation toolbox, even if they do not identify optimal targets in the network. Future research could assess the reliability of these approaches by comparing the elicited nominations with key players identified using complete sociometric data.

Furthermore, little research has been done to identify other network features without complete sociometric data, such as the delineation of social groups, which can be important in different intervention scenarios (Valente, 2012). Future research could examine the robustness of group-delineation algorithms to sampling sizes. As in Costenbader & Valente's (2003) study of centrality measure stability, researchers could sample network data at varying levels of completeness and compare the results produced using different group-detection algorithms. Further research could assess the reliability of cheaper group-identification methods, such as expert elicitation or informant interviews, by comparing the results with sociometric data in varying contexts.

Other methods identified by Valente & Pumpuang (2007) aim to identify influential individuals based on other criteria thought to indicate influence. This includes selection of individuals occupying specific organisational or institutional positions, allowing opinion leaders to self-identify, and targeting celebrities. The 'rule of thumb' represents a promising approach because it is low-cost and allows network data collected in one place to inform robust strategies that apply more broadly. In the context of a Kenyan fishery, Mbaru & Barnes (2017) used network data to identify possible rules of thumb that could be used to reliably identify individuals occupying important positions in six village social networks. They found that formal leaders, those elected to manage coastal resources, tended to also be important according to three of the four network measures they assessed. In Chapter six, I replicated their analyses in a very different conservation context, and did not find that formal leadership, or any other of the variables assessed by Mbaru & Barnes, predicted importance in the network. Further research to identify rules of thumb that work (or do not) in different contexts would be extremely valuable. For example, a database of network studies identifying rules of thumb in a variety of different contexts could allow researchers to tease out the factors that predict which sorts of individuals are likely to be socially important. Conservationists working in diverse settings could potentially draw on these syntheses in combination with their local knowledge to reliably select well-informed and appropriate intervention approaches.

7.3.2 Disentangling the mechanisms of social influence

Chapter five demonstrates the importance of social influence for psychological outcomes. Social influence can occur through a wide variety of mechanisms. For example, individuals can directly influence one another through pressure and persuasion (Wood, 2000), or seek to comply and conform with social norms by taking cues from referent individuals (Cialdini & Goldstein, 2004; Prentice & Paluck, 2020). In our case study, the intentions of an individual's social peers were a strong predictor of changes in the individual's behavioural intention. However, these influences did not operate through altering perceived social norms. Furthermore, perceptions of descriptive norms did not seem to play an important role in determining intention. Instead, it is likely that individuals were seeking social cues from their direct contacts and responding to them through interpersonal mechanisms like contagion or conformity, rather than looking for information about what the prevailing social norms were within the community. To get a firmer understanding of what was happening, future research could complement quantitative data on behaviour and perceptions of social norms with qualitative approaches. For example, group discussions could be used to understand how some behaviours are governed by broader norms (see Chapter 2).

Differences in the mechanisms of social influence are likely to have important implications for intervention design. For example, where behaviours are shaped by perceptions of societal norms which are informed by cues from weak social ties (Lee & Kronrod, 2020), interventions might use media to communicate messages crafted to shift these perceptions (Bicchieri, 2017a). Conversely, where behaviours are shaped more strongly by interaction between socially close individuals, such as in our case study, interventions may require more intensive collaboration with influential individuals in the social network (Paluck, Shepherd & Aronow, 2016; Beaman *et al.*, 2014). Furthermore, different segments within a population are likely to respond to different forms of influence.

Further research to understand the different social mechanisms operating on different conservation behaviours in different contexts could be useful for informing intervention design. A variety of research methods can be used to elucidate social influence mechanisms, such as qualitative or ethnographic approaches, or questionnaire surveys designed to assess discrepancies between perceived norms and group behaviour (Borsari & Carey, 2003). Such studies can evaluate the impacts of conservation interventions or analyse existing conservation behaviours, as we have done in Chapter four. However, the most robust methodologies will take a longitudinal perspective, and will combine observations of both behaviour and social interaction. Modelling these two types of data in conjunction, as we have done in Chapter five, could enable researchers to investigate a variety of social influence mechanisms, and discount confounding processes such as changing social ties (Steglich, Snijders & Pearson, 2010). For example, the Stochastic Actor-Oriented models which we used, support the modelling of contagion processes (Greenan, 2015), the influence of group-level behaviours, and a wide variety of interpersonal mechanisms (Ripley *et al.*, 2020).

The data collection required for these types of studies is resource intensive but analysing several case studies in different contexts could provide robust evidence, and enable commonalities and differences to be teased out, which could be used to inform intervention design more generally. For example, a large body of such evidence now exists for adolescent school networks and harmful behaviours such as smoking and alcohol abuse. A systematic review of forty studies found that both alcohol and tobacco shape social networks, as adolescents prefer to socialise with peers with similar consumption habits. Adolescents also tended to become more similar to their peers in terms of alcohol consumption, but this effect was weaker for tobacco consumption (Henneberger, Mushonga & Preston, 2021). This suggests that interventions which aim to disrupt friend formation between smokers and influence network structures (e.g., by reducing the social appeal of smoking) would probably be more successful than interventions using traditional social influence approaches (e.g., equipping adolescents to resist peer influence) or those which aim to change perceptions of descriptive norms. This is an important finding given that most interventions do focus on social influence rather than peer selection (Henneberger, Gest & Zadzora, 2019).

7.3.3 Network alteration

Social networks are constantly evolving as people develop new relationships and allow existing ties to fade (Palla, Barabási & Vicsek, 2007). Social networks not only shape behaviour, but their evolution is also influenced by the changing behaviours of individuals (Steglich, Snijders & Pearson, 2010). For example, individuals often seek to form relationships with others who are similar to them (a process known as homophily) (Mcpherson, Smith-lovin & Cook, 2001). As conservation interventions influence individual behaviour, they can inadvertently alter the structures of social networks. For example, Indonesian farmers who were taken for training and networking outside of their villages became more influential in their village social networks (Matous & Wang, 2019).

Other interventions deliberately aim to influence or alter network structures, as described in Chapter three. These interventions may try to disrupt ties that facilitate negative behaviours, such as those between actors involved in illegal wildlife trade (Sánchez-Mercado *et al.*, 2020). Or they may attempt to form network structures that reinforce and facilitate positive conservation action, such as bringing farmers together to facilitate social learning (Matous & Todo, 2018), or bringing resource users together to facilitate collective action for managing natural resources (Ernstson, 2011). For example, in Ethiopia, providing farmers with mobile phones allowed them to communicate and seek information more frequently from acquaintances living further away than they did previously (Matous, Todo & Ishikawa, 2014).

This thesis focussed on interventions exploiting existing networks to diffuse new information or behaviours, but there is great scope to a): study the ways in which conservation interventions lead to changes in social networks; and b) explore the feedbacks between evolving networks and behaviours. For example, farmers participating in a conservation agriculture scheme may find more opportunities to interact and communicate with one another, leading to the formation of new social ties. This could then reinforce their participation in the scheme, but it could also reduce their connection with other farmers and reinforce non-participation in other groups. Collection of network and behavioural data at multiple time points before and after intervention, and dynamic network modelling, can tell us about the degree to which change occurs and about the mechanisms shaping this coevolution (Steglich, Snijders & Pearson, 2010).

When interventions explicitly aim to alter network structures, network modelling can form an important part of intervention evaluation strategies. Such research carried out in different contexts could help conservationists to predict when network alteration might be beneficial and provide evidence on the best approaches to take given the objectives and intervention context. More generally, network modelling could offer important insights into the ways in which existing conservation interventions are impacting communities. For example, do institution-building efforts, such as the establishment of community forestry management, rewire social ties in a way that further promotes collective action? Do they improve the social capital and influence of some actors over that of others? These approaches are also likely to have important impacts on the wellbeing of different groups, potentially affecting feelings of agency or belonging, which should be carefully considered and evaluated from an ethics perspective (Matous, Wang & Lau, 2021). Conversely, a network approach could help to shed light on why some groups, such as women, might be marginalised and suggest strategies of empowerment (Adams, Madhavan & Simon, 2002).

7.3.4 New communication technologies

Conservation efforts are taking place against a backdrop of rapid societal and technological change. New communication technologies are rapidly reshaping the ways in which individuals communicate, receive information, and influence one another (Aral & Nicolaides, 2017; Centola, 2011). In the Northern Plains of Cambodia, communities that were long cut off from markets, roads, and the wider world, are now starting to receive mobile internet coverage and electricity to power satellite televisions. This is likely to have profound implications for the information they receive and therefore on conservation behaviours (Matous, Todo & Ishikawa, 2014). For example, in the context of wildlife poisoning, farmers could be further exposed to predatory marketing practices from pesticide traders, leading to further uptake and misuse of pesticides. Conversely, farmers could use the internet to gain more trustworthy information about pesticides, bypassing market traders. Further research will be required to understand the ways in which these developments impact village networks and conservation behaviours.

These technologies also provide opportunities for more effective conservation intervention. In villages with good mobile internet coverage, social media channels could be used to communicate directly with residents, bypassing the cumbersome village meetings and ensuring messages penetrate widely within the community (Bennett & Manheim, 2006). These channels also enable messages to be generated and delivered that are more closely targeted to specific ‘micro’ audiences (Metcalf *et al.*, 2018). Communication technologies also provide opportunities for rewiring networks in ways that support conservation. For example, by enabling community patrol teams to share information with each other and with authorities and to coordinate their actions, or to allow farmers participating in conservation agriculture schemes to seek advice from one another (Matous, Todo & Ishikawa, 2014). More broadly, conservation agriculture programmes might produce new social networks allowing farmers to communicate and share information across a landscape using mobile phones, rather than relying on extension agents. For example, WeFarm is a global peer-to-peer knowledge sharing platform for smallholder farmers in the global south with over 2 million members (Wefarm, 2021).

Future research examining the ways in which communication technologies are altering farmer's social networks and access to information would be useful for anticipating these opportunities, or potential threats, and intervention strategies that use online or offline social networks to communicate conservation messages could be compared. Researchers could test this experimentally, as Matous, Todo & Ishikawa did in Ethiopia (2014), by mapping farmers' social networks and then providing mobile phones and observing how the networks changed over time. These changes could then be modelled in conjunction with measurements of conservation-related beliefs or behaviour to understand the implications for conservation outcomes (Steglich, Snijders & Pearson, 2010). Communication using internet technologies can also be manipulated to serve experimental purposes. For example, Centola (2010) created an online social network where participants were placed into specific network structures, and observed that the spread of health-related behaviours was dependent on this structure. Similar platforms geared towards populations of conservation interest, such as WeFarm, could provide large amounts of data about both communication and behaviour and provide opportunities for experimental research.

7.4 Recommendations for WCS

This thesis was carried out in collaboration with WCS Cambodia, with the aspiration of supporting their interventions in the study area. Therefore, I offer some recommendations aimed at WCS to help them to reduce wildlife poisoning in the Northern Plains and improve the effectiveness of their future interventions. These are:

- We found that poisoning has multi-faceted impacts on human health, animal health, the environment, and wildlife (Chapter 4). Addressing poisoning will require an equally multi-faceted response combining messaging from trusted messengers around health risks (e.g., doctors or health officials), normative messaging within the community, promotion of safer agricultural practises, and efforts at regulating the availability of restricted pesticides. Therefore, collaboration between different ministries and organisations will be key. To facilitate this, WCS could convene a provincial working group on pesticide poisoning, including the departments of agriculture, health, and environment. This working group can be used to coordinate action against pesticide misuse. Furthermore, raising awareness of pesticide poisoning as a public health and conservation issue among officials, could help to generate support for action at higher political levels. Similarly, WCS could collaborate with other civil society organisations and donors, from across multiple sectors, to campaign for greater awareness of pesticide poisoning and push for government action at a national level.

- Pesticide use is likely to increase if current development trajectories continue in Preah Vihear province, as these promote intensification of agriculture, large-scale industrial agriculture, and integration of smallholders into the market economy. An alternative trajectory is possible drawing on Preah Vihear's abundant natural resources and traditional agro-ecological practices. WCS should continue to develop and promote alternative models of sustainable development using the Ibis Rice programme, which requires participants to stop chemical use. This programme is a key lever for farmers and communities to build political capital for greener development pathways, and provides important wellbeing value sfor farmers and citizens. Furthermore, WCS could use behavioural insights and leverage social influences to drive further recruitment of farmers (see final point).
- We found that there is widespread disapproval of wildlife poisoning in the Northern Plains, and that village authorities in some areas are motivated to implement interventions to reduce poisoning. Furthermore, poisoning is difficult to detect and more widespread than previously understood (Chapter 4). For these reasons, we trialled the introduction of a reporting hotline, intended to be a key tool for gathering data about poisoning, responding quickly to poisoning events, and providing normative messaging for future social marketing campaigns. We found that there is great potential for adoption of the hotline by local communities given further intervention (Chapter 5). WCS should work to implement the reporting hotline across the northern plains landscape, and to formalise this in partnership

with the department of environment. They should ensure robust response protocols are in place when reports are made, in coordination with community protected area committees. WCS can promote the hotline in local communities and continue to develop social marketing campaigns to enable uptake (see next point).

- In Chapter five, I evaluated a pilot intervention, which used a combination of normative messaging and messaging about the health risks of pesticide misuse, to promote adoption of the reporting hotline. We found that this pilot was successful at disseminating information and influenced residents' beliefs about behavioural control and social norms. However, social influences and a lack of long-term engagement may have contributed to the failure of widespread behaviour change in the long term. The intervention might therefore serve as the basis for further intervention but should be repeated and further tailored to reach different segments in the villages. For example, WCS could collaborate with local schools to deliver health-focused pesticide-information geared towards children and parents, including the short-film, through the school curriculum. Furthermore, in the absence of clear rules-of-thumb that can be used to identify key influencers in the Northern Plains and given the expense of collecting further sociometric data (Chapter 6), further intervention could capitalise on the early successes of the pilot by leveraging the social influence of early adopters. For example, WCS could collaborate with local early adopters, such as those residents who took the safe pesticide use pledge, and other motivated local influencers, such as Ibis Rice farmers or Community Protected Area committee members. WCS could work with these groups to design further interventions and equip them to conduct further promotion efforts in their villages. For example, Ibis Rice farmers may be concerned about possible pesticide contamination on their organic crops and could help to exert social pressure on neighbouring farmers to reduce their pesticide use. WCS should also recognise the potential marginalising impacts this could have on certain social groups. This could be ameliorated by ensuring interventions are not coercive, and that poorer households can access benefits from participating in conservation.

- I have examined in detail the complex personal, social, and behavioural factors underlying an important conservation behaviour and influencing intervention outcomes (Chapters 3, 4 & 5). I highlight the important role of social influences, and in this chapter (see section 7.2) I discuss the implications of this insight for conservation interventions. Furthermore, this thesis demonstrates the value of both formative and evaluative research for designing and refining interventions (Chapters 4, 5 & 6). To improve the effectiveness of their interventions, and ensure continued learning, WCS should mainstream the social and behavioural sciences in their programmes, by further collaborating with social scientists. They should abandon initiatives not founded on a clear theory of change, such as the awareness-raising and education sessions, and replace them with targeted social marketing interventions built on sound behavioural science. This means working with local stakeholders to define clear behaviour change objectives, identifying specific audiences for intervention, considering how social networks might influence intervention outcomes, and building on their understanding of the audience to craft clear and motivating messages. Furthermore, they should plan for long-term engagement, iteratively adapting and refining their interventions based on learning from formal evaluation and experimentation. The process documented and described in this thesis could serve as a model for future work.

7.5 Conclusion

As conservationists continue to adopt insights from the behavioural sciences when designing behaviour-change intervention, they need to think beyond the beliefs, attitudes, and behaviours of individuals. People are social animals, and much of what we do is shaped by the relationships we have with others. Within this thesis, I explored some of the ways in which this is important for conservation practice. I demonstrated the importance of social ties using both a synthesis of evidence and theory from other disciplines, and an empirical study of an intervention taking place in Cambodia. The research methods used in this thesis, including the use of dynamic network models, can be built upon to further understand how interventions are influencing people’s behaviour. Furthermore, I describe a wide variety of intervention approaches that conservationists can use to improve their interventions, through a review of literature from other disciplines, and by exploring their feasibility in a conservation context. The thesis will therefore be of interest to researchers, as well as conservation practitioners interested in using insights about human behaviour to improve their practice.

Bibliography

Adams, A.M., Madhavan, S. & Simon, D. (2002) Women's social networks and child survival in Mali. Social Science & Medicine. 54 (2), 165–178. doi: https://doi.org/10.1016/S0277-9536(01)00017-X.

Adams, W. (2007) Thinking like a human: science and the two cultures problem. Oryx. 41 (3), 275–276. doi: https://doi.org/10.1017/S0030605307004131.

Agrawal, A. & Gibson, C.C. (1999) Enchantment and disenchantment: The role of community in natural resource conservation. World Development. 27 (4), 629–649. doi: 10.1016/S0305-750X(98)00161-2.

Ajzen, I. (1991) The theory of planned behavior. Organizational Behavior and Human Decision Processes. 50, 179–211. doi: 10.1016/0749-5978(91)90020-T.

Andrews, M. & Manning, N. (2016) A Guide to Peer-to-Peer Learning. Available from: https://www.effectiveinstitutions.org/media/The_EIP_P_to_P_Learning_Guide.pdf.

Anti, S. (2021) Land grabs and labor in Cambodia. Journal of Development Economics. 149, 102616. doi: https://doi.org/10.1016/j.jdeveco.2020.102616.

Aral, S. & Nicolaides, C. (2017) Exercise contagion in a global social network. Nature Communications. 8, 1–8. doi:10.1038/ncomms14753.

Aral, S. & Walker, D. (2012) Identifying influential and susceptible members of social networks. Science. 337 (July), 337–341. doi:10.1126/science.1215842.

Armitage CJ, Conner M. Efficacy of the Theory of Planned Behaviour: a meta-analytic review. Br J Soc Psychol. 2001 Dec;40(Pt 4):471-99. doi: 10.1348/014466601164939

Baird, I. (2017) Resistance and Contingent Contestations to Large-Scale Land Concessions in Southern Laos and Northeastern Cambodia. Land. 6 (1), 16. doi:10.3390/land6010016.

Banerjee, A., Chandrasekhar, A.G., Duflo, E. & Jackson, M.O. (2013) The diffusion of microfinance. Science. 341 (6144). doi:10.1126/science.1236498.

Banerjee, S., Jenamani, M. & Pratihar, D.K. (2020) A survey on influence maximization in a social network. Knowledge and Information Systems. 62 (9), 3417–3455. doi:10.1007/s10115-020-01461-4.

Barnes, M.L., Kalberg, K., Pan, M. & Leung, P.S. (2016a) When is brokerage negatively associated with economic benefits? Ethnic diversity, competition, and common-pool resources. Social Networks. 45, 55–65. doi: 10.1016/j.socnet.2015.11.004.

Barnes, M.L., Lynham, J., Kalberg, K. & Leung, P. (2016b) Social networks and environmental outcomes. Proceedings of the National Academy of Sciences. 201523245. doi:10.1073/pnas.1523245113.

Baruch-Mordo, S., Breck, S.W., Wilson, K.R. & Broderick, J. (2011) The Carrot or the Stick? Evaluation of Education and Enforcement as Management Tools for Human-Wildlife Conflicts. PLOS ONE. 6 (1), e15681. Available from: https://doi.org/10.1371/journal.pone.0015681.

Baylis, K., Honey-Rosés, J., Börner, J., Corbera, E., et al. (2016) Mainstreaming Impact Evaluation in Nature Conservation. Conservation Letters. 9 (1), 58–64. doi: 10.1111/conl.12180.

Beaman, L., Benyishay, A., William, C. & Mobarak, A.M. (2014) Can Network Theory based Targeting Increase Technology Adoption? NBER Working paper. Available from: https://www.nber.org/papers/w24912.

Beauchamp, E., Clements, T. & Milner-Gulland, E.J. (2018a) Assessing Medium-term Impacts of Conservation Interventions on Local Livelihoods in Northern Cambodia. World Development. 101, 202–218. doi: 10.1016/j.worlddev.2017.08.008.

Beauchamp, E., Clements, T. & Milner-Gulland, E.J. (2018b) Exploring trade-offs between development and conservation outcomes in Northern Cambodia. Land Use Policy. 71 (December 2017), 431–444. doi: 10.1016/j.landusepol.2017.11.021.

Beauchamp, E., Clements, T. & Milner-Gulland, E.J. (2019) Investigating Perceptions of Land Issues in a Threatened Landscape in Northern Cambodia. Sustainability. 11 (21), 5881. doi:10.3390/su11215881 [Accessed: 7 November 2019].

Beauchamp, E., Woodhouse, E., Clements, T. & Milner-Gulland, E.J. (2018) “Living a good life”: conceptualizations of well-being in a conservation context in Cambodia. Ecology & Society. 23 (2). doi:10.5751/ES-10049-230228.

Beban, A., Schoenberger, L., Lamb, V., Beban, A., et al. (2019) Pockets of liberal media in authoritarian regimes: what the crackdown on emancipatory spaces means for rural social movements in Cambodia movements in Cambodia *. Journal of Peasant Studies. doi: 10.1080/03066150.2019.1672664.

Beck, L., & Ajzen, I. (1991). Predicting dishonest actions using the theory of planned behavior. Journal of Research in Personality, 25, 285-301.

Beier, P., Hansen, L.J., Helbrecht, L. & Behar, D. (2017) A How-to Guide for Coproduction of Actionable Science. Conservation Letters. 10 (3), 288–296. doi: https://doi.org/10.1111/conl.12300.

Bennett, N.J., Roth, R., Klain, S.C., Chan, K., et al. (2017) Conservation social science: Understanding and integrating human dimensions to improve conservation. Biological Conservation. 205, 93–108. doi: 10.1016/j.biocon.2016.10.006.

Bennett, W.L. & Manheim, J.B. (2006) The one-step flow of communication. Annals of the American Academy of Political and Social Science. 608 (November), 213–232. doi: 10.1177/0002716206292266.

Berny, P. (2007) Pesticides and the intoxication of wild animals. Journal of Veterinary Pharmacology and Therapeutics. 30 (2), 93–100. doi: 10.1111/j.1365-2885.2007.00836. x.

Bicchieri, C. (2017a) Norms in the Wild: How to Diagnose, Measure, and Change Social Norms. Oxford, Uk, Oxford University Press.

Bicchieri, C. (2017b) Tools for Change. In: Norms in the Wild: How to diagnose, measure, and change social norms. New York, Oxford University Press. pp. 45–66. doi: 10.1093/acprof:oso/9780190622046.001.0001.

Bicchieri, C. & Xiao, E. (2009) Do the right thing: but only if others do so. Journal of Behavioral Decision Making. 22 (2), 191–208. doi:10.1002/bdm.621.

Biddulph, R. (2015) In whose name and in whose interests? An actor-oriented analysis of community forestry in Bey, a Khmer village in Northeast Cambodia. In: S Milne & S Mahanty (eds.). Conservation and Development in Cambodia. Abingdon, UK, Routledge. pp. 160–176.

Le Billon, P. (2002) Logging in muddy waters: The politics of forest exploitation in Cambodia. Critical Asian Studies. 34 (4), 563–586. doi: 10.1080/1467271022000035938.

Le Billon, P. (2000) The Political Ecology of Transition in Cambodia 1989 ± 1999: War, Peace and Forest Exploitation. 31 (1998), 785–805.

Blair, G. & Imai, K. (2010) list: Statistical Methods for the Item Count Technique and List Experiment.

Blair, G. & Imai, K. (2012) Statistical analysis of list experiments. Political Analysis. 20 (1), 47–77. doi: 10.1093/pan/mpr048.

Block, P., Stadtfeld, C. & Snijders, T.A.B. (2016) Forms of Dependence: Comparing SAOMs and ERGMs From Basic Principles. Sociological Methods & Research. 48 (1), 202–239. doi: 10.1177/0049124116672680.

Bodin, Ö., Crona, B.I. & Ernstson, H. (2006) Social networks in natural resource management: what is there to learn from a structural perspective? Ecology and Society. 11 (2), r2. Available from: http://www.ecologyandsociety.org/vol11/iss2/resp2/%5Cnhttp://www.ecologyandsociety.org/vol11/iss2/resp2/ES-2006-1808.pdf.

Bodin Ö & Prell C (eds.) (2011) Social Networks and Natural Resource Management. Cambridge, UK, Cambridge University Press.

Borgatti, S.P. (2006) Identifying sets of key players in a social network. Computational and Mathematical Organization Theory. 12 (1), 21–34. doi: 10.1007/s10588-006-7084-x.

Borgatti, S.P. & Everett, M.G. (2000) Models of core /periphery structures. Social networks. 375–395. doi: 10.1016/S0378-8733(99)00019-2.

Borgatti, S.P., Mehra, A., Brass, D.J. & Labianca, G. (2009) Network Analysis in the Social Sciences. Science. 323 (5916), 892–895.

Borgatti, S.P. & Molina, J.-L. (2005) Toward Ethical Guidelines for Network Research in Organizations. Social Networks. 27 (2), 107–117.

Borsari, B. & Carey, K.B. (2003) Descriptive and injunctive norms in college drinking: a meta-analytic integration. Journal of studies on alcohol. 64 (3), 331–341. doi: 10.1016/j.biotechadv.2011.08.021.Secreted.

Brittain, S., Ibbett, H., de Lange, E., Dorward, L., et al. (2020) Ethical considerations when conservation research involves people. Conservation Biology. 34 (4), 925–933. doi: https://doi.org/10.1111/cobi.13464.

Broadhead, R.S., Heckathorn, D.D., Weakliem, D.L., Anthony, D.L., et al. (1998) Harnessing peer networks as an instrument for AIDS prevention: Results from a peer- driven intervention. Public Health Reports. 113 (Supplement 1), 42–57.

Brooks, J., Waylen, K.A. & Mulder, M.B. (2013) Assessing community-based conservation projects: A systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. Environmental Evidence. 2 (1), 2. doi: 10.1186/2047-2382-2-2.

Brown, H.C.P. & Lassoie, J.P. (2010) Institutional choice and local legitimacy in community-based forest management: Lessons from Cameroon. Environmental Conservation. 37 (3), 261–269. doi: 10.1017/S0376892910000603.

Brunette, W., Sundt, M., Dell, N., Chaudhri, R., et al. (2013) Open Data Kit 2.0: Expanding and Refining Information Services for Developing Regions. Available from: http://dl.acm.org/citation.cfm?id=2444790.

Bryants, J. & Heath, R.L. (2000) Human Communication Theory and Research. Mahwah, New Jersey, Lawrence Erlbaum associates.

Buechley, E.R. & Şekercioğlu, Ç.H. (2016) The avian scavenger crisis: Looming extinctions, trophic cascades, and loss of critical ecosystem functions. Biological Conservation. 198, 220–228. doi: 10.1016/j.biocon.2016.04.001.

Bujold, P. & Karak, M. (2021) To scale behavior change: target early adopters, then leverage social proof and social pressure. Behavioral Scientist. Available from: https://behavioralscientist.org/to-scale-behavior-change-target-early-adopters-then-leverage-social-proof-and-social-pressure/.

Butler, P., Green, K. & Galvin, D. (2013) The Principles of Pride: The science behind the mascots. Available from: https://www.rare.org/sites/default/files/Principles%2520of%2520Pride%25202013%2520lo%2520res.pdf.

van Buuren, S. (2018) Flexible Imputation of Missing Data. 2nd edition. CRC Press. Available from: https://stefvanbuuren.name/fimd/.

van Buuren, S. & Groothuis-Oudshoorn, K. (2011) mice: Multivariate Imputation by Chained Equations in R. Journal of Statistical Software. 45 (3), 1–67. Available from: https://www.jstatsoft.org/v45/i03/.

Cai, J., De Janvry, A. & Sadoulet, E. (2015) Social Networks and the Decision to Insure. American Economic Journal: Applied Economics. 7 (2), 81–108. doi: http://dx.doi.org/10.1257/app.20130442.

Carignano Torres, P., Morsello, C., Parry, L. & Pardini, R. (2021) Forest cover and social relations are more important than economic factors in driving hunting and bushmeat consumption in post-frontier Amazonia. Biological Conservation. 253, 108823. doi: https://doi.org/10.1016/j.biocon.2020.108823.

Carson, R. (1962) Silent Spring. New York, Houghton Mifflin.

Cartwright, B.J., Wall, J.E. & Placide Kaya, J.A. (2012) Conservation Education and Environmental Communication in Great Ape Re-Introduction Projects: Two Cases from the

Republic of Congo. The Journal of Environmental Education. 43 (4), 241–258. doi: 10.1080/00958964.2011.652694.

Centola, D. (2011) An Experimental Study of Homophily in the Adoption of Health Behavior. Science. 334 (6060), 1269 LP – 1272. doi: 10.1126/science.1207055.

Centola, D. (2018) How Behaviour Spreads: The Science of Complex Contagions. Princeton, NJ, Princeton University Press.

Centola, D. (2010) The Spread of Behavior in an Online Social Network Experiment. Science. 329 (5996), 1194–1197. doi: 10.1126/science.1185231.

Centola, D. & Macy, M. (2007) Complex Contagions and the Weakness of Long Ties. American Journal of Sociology. 113 (3), 702–734.

Chandler, D. (2018) A History of Cambodia. 4th edition. Routledge.

Chann, S. (2021) Climate change migration in the post-conflict state: understanding Cambodian migration narratives through geopolitical history and land struggles. Area. doi: 10.1111/area.12697.

Chann, S. (2020) Making place and creating frontiers: Examining land and resource struggles in Cambodian post-conflict resource landscapes. The Geographical Journal. 186 (3), 262–275. doi: https://doi.org/10.1111/geoj.12340.

Cialdini, R.B. (2015) Crafting Normative Messages to Protect the Environment. Current Directions in Psychological Science. 12 (4), 105–109.

Cialdini, R.B. & Goldstein, N.J. (2004) Social Influence: Compliance and Conformity. Annual Review of Psychology. (1974), 591–621. doi: 10.1146/annurev.psych.55.090902.142015.

Cialdini, R.B., Kallgren, C.A. & Reno, R.R. (1991) A Focus Theory of Normative Conduct: A Theoretical Refinement and Reevaluation of the Role of Norms in Human Behavior. In: Mark P B T - Advances in Experimental Social Psychology Zanna (ed.). Academic Press. pp. 201–234. doi: https://doi.org/10.1016/S0065-2601(08)60330-5.

Clements, T., John, A., Nielsen, K., An, D., et al. (2010) Payments for biodiversity conservation in the context of weak institutions: Comparison of three programs from Cambodia. Ecological Economics. 69 (6), 1283–1291. doi: 10.1016/j.ecolecon.2009.11.010.

Clements, T. & Milner-Gulland, E.J. (2015) Impact of payments for environmental services and protected areas on local livelihoods and forest conservation in northern Cambodia. Conservation Biology. 29 (1), 78–87. doi: 10.1111/cobi.12423.

Clements, T., Neang, M., Milner-Gulland, E.J. & Travers, H. (2020) Measuring impacts of conservation interventions on human wellbeing and the environment in Northern Cambodia. Available from: https://www.3ieimpact.org/sites/default/files/2020-03/IE106-DPW1.1045-Cambodia-PES.pdf.

Clements, T., Rainey, H., An, D., Rours, V., et al. (2013) An evaluation of the effectiveness of a direct payment for biodiversity conservation: The Bird Nest Protection Program in the Northern Plains of Cambodia. Biological Conservation. 157, 50–59. doi: 10.1016/j.biocon.2012.07.020.

Clements, T., Suon, S., Wilkie, D.S. & Milner-Gulland, E.J. (2014) Impacts of Protected Areas on Local Livelihoods in Cambodia. World Development. 64, S125–S134. doi: https://doi.org/10.1016/j.worlddev.2014.03.008.

Coad, L., Lim, S. & Nuon, L. (2019) Wildlife and Livelihoods in the Cardamom Mountains, Cambodia. Frontiers in Ecology and Evolution. 7 (296). doi: 10.3389/fevo.2019.00296.

Cock, A. (2016) Governing Cambodia's Forests: The International Politics of Policy Reform. NIAS Press.

Contractor, N.S. & DeChurch, L.A. (2014) Integrating social networks and human social motives to achieve social influence at scale. Proceedings of the National Academy of Sciences. 111 (Supplement 4), 13650 LP – 13657. doi: 10.1073/pnas.1401211111.

Cook, C.N., Hockings, M. & Carter, R.W. (Bill) (2010) Conservation in the dark? The information used to support management decisions. Frontiers in Ecology and the Environment. 8 (4), 181–186. doi:10.1890/090020.

Cooney, R., Roe, D., Dublin, H., Phelps, J., et al. (2017) From Poachers to Protectors: Engaging Local Communities in Solutions to Illegal Wildlife Trade. Conservation Letters. 10 (3), 367–374. doi: https://doi.org/10.1111/conl.12294.

Costenbader, E. & Valente, T.W. (2003) The stability of centrality measures when networks are sampled. Social Networks. 25 (4), 283–307. doi: https://doi.org/10.1016/S0378-8733(03)00012-1.

Craig, D. & Kimchoeun, P. (2011) Party Financing of Local Investment Projects. In: Caroline Hughes & Kheang Un (eds.). Cambodia's Economic Transformation. Copenhagen, Nordic Institute of Asian Studies. pp. 219–244.

Crochet, S. (2011) Catching facts or sketching the elephant? Village monographs in Cambodia, yesterday, today, tomorrow. In: John Marston (ed.). Anthropology and community in Camodia2. Caulfield, Monash University Press. pp. 131–152.

Crona, B. & Bodin, Ö. (2010) Power Asymmetries in Small-Scale Fisheries: A Barrier to Governance Transformability? Ecology and Society. 15 (4).

Crona, B. & Bodin, Ö. (2006) What You Know is Who You Know? Communication Patterns Among Resource Users as a Prerequisite for Co-management. Ecology and Society. 11 (2), 7. doi: 10.1038/nature09798.

Crona, B.I. & Bodin, Ö. (2011) Friends or neighbors? Subgroup heterogeneity and the importance of bonding and bridging ties in natural resource governance. Social Networks and Natural Resource Management: uncovering the social fabric of environmental governance. 206–233. doi: 10.1017/CBO9780511894985.010.

Cross, R., Borgatti, S.P. & Parker, A. (2002) Making Invisible Work Visible: Using Social Network Analysis to Support Strategic Collaboration. California Management Review. 44 (2), 25–46.

Csardi, G. & Nepusz, T. (2006) The igraph software package for complex network research. InterJournal. Complex Sy, 1695. Available from: https://igraph.org/.

Damerell, P., Howe, C. & Milner-Gulland, E.J. (2013) Child-orientated environmental education influences adult knowledge and household behaviour. Environmental Research Letters. 8, 015016. doi: 10.1088/1748-9326/8/1/015016.

Damerell, P.J. (2010) From knowledge to behaviour: can environmental education realise its potential? Available from: http://www.iccs.org.uk/wp-content/thesis/consci/2009/Damerell.pdf.

Davis, E.O., O'Connor, D., Crudge, B., Carignan, A., et al. (2016) Understanding public perceptions and motivations around bear part use: A study in northern Laos of attitudes of Chinese tourists and Lao PDR nationals. Biological Conservation. 203, 282–289. doi: 10.1016/j.biocon.2016.09.009.

Davis, K.F., Yu, K., Rulli, M.C., Pichdara, L., et al. (2015) Accelerated deforestation driven by large-scale land acquisitions in Cambodia. Nature Geoscience. 8 (10), 772–775. doi: 10.1038/ngeo2540.

Day, B.A., DeWan, A., Cadiz, F.C., Jakosalem-Balane, J., et al. (2014) Rare Social Marketing for Sustainable Fishing in Cortes, Surigao del Sur, Philippines. Applied Environmental Education & Communication. 13 (1), 56–65. doi: 10.1080/1533015X.2014.916585.

Delisle, A., Kiatkoski Kim, M., Stoeckl, N., Watkin Lui, F., et al. (2018) The socio-cultural benefits and costs of the traditional hunting of dugongs Dugong dugon and green turtles Chelonia mydas in Torres Strait, Australia. Oryx. 52 (2), 250–261. doi: 10.1017/S0030605317001466.

Diepart, J.C. & Dupuis, D. (2014) The peasants in turmoil: Khmer Rouge, state formation and the control of land in northwest Cambodia. Journal of Peasant Studies. 41 (4), 445–468. doi: 10.1080/03066150.2014.919265.

Doughty, H., Veríssimo, D., Tan, R.C.Q., Lee, J.S.H., et al. (2019) Saiga horn user characteristics, motivations, and purchasing behaviour in Singapore. PLOS ONE. 14 (9), e0222038. Available from: https://doi.org/10.1371/journal.pone.0222038.

Drury, R., Homewood, K. & Randall, S. (2011) Less is more: The potential of qualitative approaches in conservation research. Animal Conservation. 14 (1), 18–24. doi: 10.1111/j.1469-1795.2010.00375.x.

Duvall, J. & Zint, M. (2007) A Review of Research on the Effectiveness of Environmental Education in Promoting Intergenerational Learning. The Journal of Environmental Education. 38 (4), 37–41. doi: 10.3200/JOEE.38.4.14-24.

Ear, S. (2007) The Political Economy of Aid and Governance in Cambodia. Asian Journal of Political Science. 15 (1), 68–96. doi: 10.1080/02185370701315624.

Ebihara, M.M. (1968) Svay: A Khmer Village in Cambodia. Ithaca, NY, Cornell University Press.

Eckles, D., Esfandiari, H., Mossel, E. & Rahimian, M.A. (2019) Seeding with Costly Network Information. Available from: http://arxiv.org/abs/1905.04325 [Accessed: 6 November 2020].

Environmental Justice Foundation (2002) Death in Small Doses: Cambodia's Pest Problems and Solutions.

Ernstson, H. (2011) Transformative collective action: a network approach to transformative change in ecosystem-based management. doi: 10.1017/CBO9780511894985.012.

Essen, E. & Allen, M. (2017) Interspecies Violence and Crimes of Dissent: Communication Ethics and Legitimacy in Message. Critical Criminology. 25 (2), 261–274. doi: 10.1007/s10612-017-9358-7.

Everton, S.F. (2012) Disrupting Dark Networks. 1st edition. New York, USA, Cambridge University Press.

Ewaso Lions (2018) Mama Simba. 2018. Available from: http://ewasolions.org/conservation/mamasimba/ [Accessed: 29 January 2018].

Faber, D. (2020) Poisoning the World for Profit: Petro-Chemical Capital and the Global Pesticide Crisis. Capitalism Nature Socialism. 31 (4), 1–17. doi: 10.1080/10455752.2020.1829794.

Fairbrass, A., Nuno, A., Bunnefeld, N. & Milner-Gulland, E.J. (2016) Investigating determinants of compliance with wildlife protection laws: bird persecution in Portugal. European Journal of Wildlife Research. 62 (1), 93–101. doi: 10.1007/s10344-015-0977-6.

Faraji-Rad, A., Samuelsen, B.M. & Warlop, L. (2015) On the Persuasiveness of Similar Others: The Role of Mentalizing and the Feeling of Certainty. Journal of Consumer Research. 42 (3), 458–471. doi: 10.1093/jcr/ucv032.

Ferraro, P.J. & Pattanayak, S.K. (2006) Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments. PLOS Biology. 4 (4), e105. Available from: https://doi.org/10.1371/journal.pbio.0040105.

Fishbein, M. & Ajzen, I. (2010) Predicting and Changing Behavior: The Reasoned Action Approach. Routledge, UK. ISBN: 9781138995215

Flyvbjerg, B. (2006) Five Misunderstandings About Case-Study Research. 219–245.

Fox, J. & Weisberg, S. (2019) An R Companion to Applied Regression. 3rd edition. Thousand Oaks, CA, Sage. Available from: https://socialsciences.mcmaster.ca/jfox/Books/Companion/.

Freeman, L.C. (1978) Centrality in social networks conceptual clarification. Social Networks. 1 (3), 215–239. doi: https://doi.org/10.1016/0378-8733(78)90021-7.

Freund, C.A., Achmad, M., Kanisius, P., Naruri, R., et al. (2020) Conserving orangutans one classroom at a time: evaluating the effectiveness of a wildlife education program for school-aged children in Indonesia. Animal Conservation. 23 (1), 18–27. doi:10.1111/acv.12513.

Friedkin, N.E. & Johnsen, E.C. (2011) Models of Group Decision-Making. In: Social Influence Network Theory. New York, Cambridge University Press. pp. 235–258.

Galeotti, A. (2009) Influencing the influencers: a theory of strategic diffusion. The RAND Journal of Economics. 40 (3), 509–532.

Gibson, C.C. & Marks, S.A. (1995) Transforming rural hunters into conservationists: An assessment of community-based wildlife management programs in Africa. World Development. 23 (6), 941–957. doi: https://doi.org/10.1016/0305-750X(95)00025-8.

Gidley, R. (2017) The Political Construction of Narrative and Collective Memory in Cambodia. Situations. 10 (1), 99–118.

Granovetter, M. (1973) The Strength of Weak Ties. American Journal of Sociology. 78 (6) pp.1360–1380. doi: 10.1086/225469.

Grantham, H.S., Bode, M., McDonald-Madden, E., Game, E.T., et al. (2010) Effective conservation planning requires learning and adaptation. Frontiers in Ecology and the Environment. 8 (8), 431–437. doi: https://doi.org/10.1890/080151.

Green, K.M., Crawford, B.A., Williamson, K.A. & Dewan, A.A. (2019) A Meta-Analysis of Social Marketing Campaigns to Improve Global Conservation Outcomes. Social Marketing Quarterly. 25 (1), 69–87. doi: 10.1177/1524500418824258.

Green, W.N. (2020) Regulating Over-indebtedness: Local State Power in Cambodia's Microfinance Market. Development and Change. 51 (6), 1429–1453. doi: 10.1111/dech.12620.

Greenan, C.C. (2015) Diffusion of innovations in dynamic networks. Journal of the Royal Statistical Society: Series A (Statistics in Society). 178 (1), 147–166. doi: https://doi.org/10.1111/rssa.12054.

Groce, J.E., Farrelly, M.A., Jorgensen, B.S. & Cook, C.N. (2018) Using social-network research to improve outcomes in natural resource management. Conservation Biology. 1–52. doi: 10.1111/cobi.13127.

Groh, D.R., Jason, L.A. & Keys, C.B. (2008) Social network variables in alcoholics anonymous: A literature review. Clinical Psychology Review. 28 (3), 430–450. doi: 10.1016/j.cpr.2007.07.014.

Gurney, G.G., Cinner, J.E., Sartin, J., Pressey, R.L., Ban, N.C., Marshall, N., & Prabuning, D. (2016) Participation in devolved commons management: Multiscale socioeconomic factors related to individuals' participation in community-based management of marine protected areas in Indonesia. *Environmental Science & Policy*. 61, 212-220. doi: 10.1016/j.envsci.2016.04.015

Hagger, M. S., Chatzisarantis, N. L., & Biddle, S. J. (2002). A Meta-Analytic Review of the Theories of Reasoned Action and Planned Behavior in Physical Activity: Predictive Validity and the Contribution of Additional Variables, *Journal of Sport and Exercise Psychology*, *24*(1), 3-32. doi: 10.1123/jsep.24.1.3

Hardeman, W., Johnston, M., Johnston, D., Bonetti, D., et al. (2002) Application of the Theory of Planned Behaviour in Behaviour Change Interventions: A Systematic Review. Psychology & Health. 17 (2), 123–158. doi: 10.1080/08870440290013644a.

Henneberger, A.K., Gest, S.D., Zadzora, K.M. (2019) Preventing adolescent substance use: a content analysis of peer processes targeted within universal school-based programs The Journal of Primary Prevention. 40 (2), 213-230. doi: 10.1007/s10935-019-00544-5

Henneberger, A.K., Mushonga, D.R., Preston, A.R. (2021) Peer influence and adolescent substance use: a systematic review of dynamic social network research. Adolescent Research Review. 6 (1), 57-73, doi: 10.1007/s40894-019-00130-0

Hilbert, M., Vásquez, J., Halpern, D., Valenzuela, S., et al. (2017) One Step, Two Step, Network Step? Complementary Perspectives on Communication Flows in Twittered Citizen Protests. Social Science Computer Review. 35 (4), 444–461. doi: 10.1177/0894439316639561.

Hinsley, A., Keane, A.M., St. John, F.A.V., Ibbett, H., et al. (2019) Asking sensitive questions using the Unmatched Count Technique: Applications and guidelines for conservation. Methods in Ecology and Evolution. 10 (3), 308–319. doi: 10.1111/2041-210X.13137.

Hollstein, B. (2016) Mixed Methods Social Networks Research: An Introduction. Cambridge University Press, Cambridge UK. ISBN: 9781139227193

Hughes, C. & Un, K. (2011) Cambodia's Economic Transformation: Historical and Theoretical Frameworks. In: Caroline Hughes & Kheang Un (eds.). Cambodia's Economic Transformation. Copenhagen, Nordic Institute of Asian Studies. pp. 1–26.

Huisman, M. & Steglich, C. (2008) Treatment of non-response in longitudinal network studies. Social Networks. 30 (4), 297–308. doi: https://doi.org/10.1016/j.socnet.2008.04.004.

Ibbett, H., Keane, A., Dobson, A.D.M., Griffin, O., et al. (2020) Estimating hunting prevalence and reliance on wild meat in Cambodia's Eastern Plains. Oryx. 1–11. doi: DOI: 10.1017/S0030605319001455.

Ibbett, H., Lay, C., Phlai, P., Song, D., et al. (2017) Conserving a globally threatened species in a semi-natural, agrarian landscape. Oryx. 1–11. doi: 10.1017/S0030605316001708.

IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Available from: https://ipbes.net/global-assessment.

Isaac, M.E., Erickson, B.H., Quashie-Sam, S.J. & Timmer, V.R. (2007) Transfer of knowledge on agroforestry management practices: The structure of farmer advice networks. Ecology and Society. 12 (2). doi: 32.

St. John, F.A.V., Edwards-Jones, G. & Jones, J.P.G. (2010) Conservation and human behaviour: lessons from social psychology. Wildlife Research. 37 (Persky 1995), 658–667. doi: 10.1071/WR10032.

St. John, F.A.V., Keane, A.M., Edwards-Jones, G., Jones, L., et al. (2012) Identifying indicators of illegal behaviour: carnivore killing in human-managed landscapes. Proceedings of the Royal Society B: Biological Sciences. 279 (1729), 804–812. doi: 10.1098/rspb.2011.1228.

St. John, F.A.V., Keane, A.M. & Milner-Gulland, E.J. (2013) Effective conservation depends upon understanding human behaviour. In: David W Macdonald & Katherine J Willis (eds.). Key Topics in Conservation Biology 2. John Wiley & Sons. p.

St. John, F.A.V., Linkie, M., Martyr, D.J., Milliyanawati, B., et al. (2018) Intention to kill: Tolerance and illegal persecution of Sumatrantigers and sympatric species. Conservation Letters. doi: 10.1111/conl.12451.

Johnston, L.G. & Sabin, K. (2010) Sampling Hard-to-Reach Populations with Respondent Driven Sampling. Methodological Innovations Online. 5 (2), 38.1-48. doi: 10.4256/mio.2010.0017.

Jones, S., Keane, A., St. John, F.A.V., Vickery, J., et al. (2019) Audience segmentation to improve targeting of conservation interventions for hunters. Conservation Biology. doi:10.1111/cobi.13275.

Kadushin, C. (2005) Who benefits from network analysis: Ethics of social network research. Social Networks. 27 (2), 139–153. doi: 10.1016/j.socnet.2005.01.005.

Kamins, A.O., Rowcliffe, J.M., Ntiamoa-Baidu, Y., Cunningham, A.A., et al. (2015) Characteristics and Risk Perceptions of Ghanaians Potentially Exposed to Bat-Borne Zoonoses through Bushmeat. EcoHealth. 12 (1), 104–120. doi: 10.1007/s10393-014-0977-0.

Kaplan, A.M. & Haenlein, M. (2011) Two hearts in three-quarter time: How to waltz the social media / viral marketing dance. Business Horizons. 54 (3), 253–263. doi: 10.1016/j.bushor.2011.01.006.

Kareiva, P. & Marvier, M. (2012) What Is Conservation Science? BioScience. 62 (11), 962–969. Available from: http://dx.doi.org/10.1525/bio.2012.62.11.5.

Keane, A.M., Jones, J.P.G., Edwards-Jones, G. & Milner-Gulland, E.J. (2008) The sleeping policeman: understanding issues of enforcement and compliance in conservation. Animal Conservation. 11 (2), 75–82. doi: 10.1111/j.1469-1795.2008.00170.x [Accessed: 14 September 2016].

Ken, S., Entani, T., Tsusaka, T.W. & Sasaki, N. (2020) Effect of REDD+ projects on local livelihood assets in Keo Seima and Oddar Meanchey, Cambodia. Heliyon. 6 (4), e03802. doi: https://doi.org/10.1016/j.heliyon.2020.e03802.

Kidd, L.R., Garrard, G.E., Bekessy, S.A., Mills, M., et al. (2019) Messaging matters: A systematic review of the conservation messaging literature. Biological Conservation. 236, 92–99. doi: 10.1016/J.BIOCON.2019.05.020 [Accessed: 27 May 2019].

Kim, D.A., Hwong, A.R., Stafford, D., Hughes, D.A., et al. (2015) Social network targeting to maximise population behaviour change: A cluster randomised controlled trial. The Lancet. 386 (9989), 145–153. doi: 10.1016/S0140-6736(15)60095-2.

Kincaid, L.D. (2004) From Innovation to Social Norm: Bounded Normative Influence. Journal of Health Communication. 9 (March), 37–57. doi: 10.1080/10810730490271511.

Klovdahl, A.S. (2005) Social network research and human subjects protection: Towards more effective infectious disease control. Social Networks. 27 (2), 119–137. doi: 10.1016/j.socnet.2005.01.006.

Knoke, D. & Yang, S. (2011) Social Network Analysis. SAGE Publications. doi: http://dx.doi.org/10.4135/9781412985864.

Kong, R., Diepart, J.-C., Castella, J.-C., Lestrelin, G., et al. (2019) Understanding the drivers of deforestation and agricultural transformations in the Northwestern uplands of Cambodia. Applied Geography. 102, 84–98. doi: https://doi.org/10.1016/j.apgeog.2018.12.006.

Kotler, P. & Lee, N.R. (2008) Segmenting, evaluating and selecting target audiences. In: Social Marketing: Changing Behaviors for Good. SAGE Publications. pp. 122–152.

Kramon, E. & Weghorst, K. (2019) (Mis)Measuring Sensitive Attitudes with the List Experiment: Solutions to List Experiment Breakdown in Kenya. Public Opinion Quarterly. 83 (S1), 236–263. doi: 10.1093/poq/nfz009.

Krause, R.W., Huisman, M. & Snijders, T.A.B. (2018) Multiple imputation for longitudinal network data. Statistica Applicata - Italian Journal of Applied Statistics. 30 (1), 33–57. doi: doi.org/10.26398/IJAS.0030-002.

Kuhn, T.S. (1987) What are scientific revolutions? In: L Kruger, L. J. Daston, & M. Heidelberger (eds.). The probabilistic revolution, Vol. 1: Ideas in history. Cambridge, MA, MIT Press. pp. 7–22.

Kumar, V. & Mirchandani, R. (2012) Increasing the ROI of Social Media Marketing. MIT Sloan Management Review. 54 (1), 54–61.

Kusmanoff, A.M., Fidler, F., Gordon, A., Garrard, G.E., et al. (2020) Five lessons to guide more effective biodiversity conservation message framing. Conservation Biology. 34 (5), 1131–1141. doi: https://doi.org/10.1111/cobi.13482.

Kurz, T., Gardner, B., Verplanken, B. and Abraham, C. (2015), Habitual behaviors or patterns of practice? Explaining and changing repetitive climate-relevant actions. WIREs Clim Change, 6: 113-128. https://doi.org/10.1002/wcc.327

LACANET (2016) Carbofuran poisoning at the interface between wildlife, livestock, and humans.

Lalah, J.O., Otieno, P.O., Richards, N., Odino, M., et al. (2011) A Chronicling of Long-Standing Carbofuran Use and its Menace to Wildlife in Kenya. Carbofuran and Wildlife Poisoning: Global Perspectives and Forensic Approaches. 39–98. doi: 10.1002/9781119998532.ch3.

Lasker, R.D., Humphreys, B.L. & Braithwaite, W.R. (1995) Making a Powerful Connection: The Health of the Public and the National Information Infrastructure. Available from: https://www.nlm.nih.gov/pubs/staffpubs/lo/makingpd.html.

Leach, M., Mearns, R. & Scoones, I.A.N. (1999) Environmental Entitlements: Dynamics and Institutions in Community-Based Natural Resource Management. World Development. 27 (2), 225–247.

Ledgerwood, J. (2012a) A tale of two temples: communities and their wats. In: John Marston (ed.). Anthropology and community in Camodia. Monash University Press. pp. 105–130.

Ledgerwood, J. (2012b) Buddhist ritual and the reordering of social relations in Cambodia. South East Asia Research. 20 (2), 191–205. doi: 10.5367/sear.2012.0100.

Ledgerwood, J. & Vijghen, J. (2002) Decision making in rural Khmer villages.

Ledgerwood, J.L. (1995) Khmer Kinship: The Matriliny/Matriarchy Myth. Journal of Anthropological Research. 51 (3), 247–261. Available from: http://www.jstor.org/stable/3630360.

Lee, J.K. & Kronrod, A. (2020) The Strength of Weak-Tie Consensus Language. Journal of Marketing Research. 57 (2), 353–374. doi: 10.1177/0022243720904957.

Littlejohn, S.W. & Foss, K.A. (2011) Theories of Human Communication. 10th edition. Long Grove, IL, Waveland Press.

Lospinoso, J.A., Schweinberger, M., Snijders, T.A.B. & Ripley, R.M. (2011) Assessing and accounting for time heterogeneity in stochastic actor-oriented models. Advances in Data Analysis and Classification. 5 (2), 147–176. doi: 10.1007/s11634-010-0076-1.

Loughlin, N. & Milne, S. (2020) After the Grab? Land Control and Regime Survival in Cambodia since 2012. Journal of Contemporary Asia. 00 (00), 1–23. doi: 10.1080/00472336.2020.1740295.

Loveridge, R., Ryan, G.E., Sum, P., Grey-Read, O., et al. (2019a) Poisoning causing the decline in South-East Asia’s largest vulture population. Bird Conservation International. 29 (1), 41–54. doi: 10.1017/s0959270918000126.

Luco, F. (2002) Between a tiger and a crocodile. Management of local conflicts in Cambodia: an anthropological approach to traditional and new practices. Available from: http://unesdoc.unesco.org/images/0015/001595/159544e.pdf.

Margoluis, R., Stem, C., Salafsky, N. & Brown, M. (2009) Using conceptual models as a planning and evaluation tool in conservation. Evaluation and Program Planning. 32 (2), 138–147. doi: https://doi.org/10.1016/j.evalprogplan.2008.09.007.

Marston, J.A. (ed) (2011) Anthropology and Community in Cambodia: reflections on the work of May Ebihara. John A Marston (ed.). Monash University Press.

Mastrangelo, M.E., Gavin, M.C., Laterra, P., Linklater, W.L., et al. (2014) Psycho-Social Factors Influencing Forest Conservation Intentions on the Agricultural Frontier. Conservation Letters. 7 (2), 103–110. doi: 10.1111/conl.12033.

Matous, P. & Todo, Y. (2018) An experiment in strengthening the networks of remote communities in the face of environmental change: leveraging spatially distributed environmental memory. Regional Environmental Change. (Letina 2016), 1–12. doi: 10.1007/s10113-018-1307-9.

Matous, P., Todo, Y. & Ishikawa, T. (2014) Emergence of multiplex mobile phone communication networks across rural areas: An Ethiopian experiment. Network Science. 2 (02), 162–188. doi: 10.1017/nws.2014.12.

Matous, P. & Wang, P. (2019) External exposure, boundary-spanning, and opinion leadership in remote communities: A network experiment. Social Networks. 56, 10–22. doi: 10.1016/j.socnet.2018.08.002.

Matous, P., Wang, P. & Lau, L. (2021) Who benefits from network intervention programs? TERGM analysis across ten Philippine low-income communities. Social Networks. 65, 110–123. doi: https://doi.org/10.1016/j.socnet.2020.12.008.

Matsukawa, M., Ito, K., Kawakita, K. & Tanaka, T. (2016) Current status of pesticide use among rice farmers in Cambodia. Applied Entomology and Zoology. 51 (4), 571–579. doi: 10.1007/s13355-016-0432-5.

Mbaru, E.K. & Barnes, M.L. (2017) Key players in conservation diffusion: Using social network analysis to identify critical injection points. Biological Conservation. 210 (March), 222–232. doi: 10.1016/j.biocon.2017.03.031.

McDonald, R.I. & Crandall, C.S. (2015) Social norms and social influence. Current Opinion in Behavioral Sciences. 3, 147–151. doi: 10.1016/j.cobeha.2015.04.006.

Mckenzie-Mohr, D. (2000) Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing. Journal of Social Issues. 56 (3), 543–554. doi: 10.1111/0022-4537.00183.

McKenzie-Mohr, D. & Schultz, P.W. (2014) Choosing effective behavior change tools. Social Marketing Quarterly. 20 (1), 35–46. doi: 10.1177/1524500413519257.

Mcpherson, M., Smith-lovin, L. & Cook, J.M. (2001) Birds of a Feather: Homophily in Social Networks. Annual Review of Sociology. 27, 415–444. doi: 10.1146/annurev.soc.27.1.415.

Metcalf, A.L., Angle, J.W., Phelan, C.N., Muth, B.A., et al. (2018) More “Bank” for the Buck: Microtargeting and Normative Appeals to Increase Social Marketing Efficiency. Social Marketing Quarterly. 25 (1), 26–39. doi: 10.1177/1524500418818063.

Michie, S., Johnston, M., Francis, J., Hardeman, W., et al. (2008) From Theory to Intervention: Mapping Theoretically Derived Behavioural Determinants to Behaviour Change Techniques. Applied Psychology. 57 (4), 660–680. doi: 10.1111/j.1464-0597.2008.00341.x.

Miller, D.T. & Prentice, D. a. (2016) Changing norms to change behavior. Annual Review of Psychology. 67, 339–361. doi: 10.1146/annurev-psych-010814-015013.

Milne, S. (2015) Cambodia’s Unofficial Regime of Extraction: Illicit Logging in the Shadow of Transnational Governance and Investment. Critical Asian Studies. 47 (2), 200–228. doi: 10.1080/14672715.2015.1041275.

Milner-Gulland, E.J. (2012) Interactions between human behaviour and ecological systems. Philosophical Transactions of the Royal Society B: Biological Sciences. 367 (1586), 270–278. doi: 10.1098/rstb.2011.0175.

Milner-Gulland, E.J., Bennett, E.L., Abernethy, K., Bakarr, M., et al. (2003) Wild meat: The bigger picture. Trends in Ecology and Evolution. 18 (7), 351–357. doi: 10.1016/S0169-5347(03)00123-X.

Monroe, M. (2003) Two Avenues for Encouraging Conservations Behaviors. Human Ecology Review. 10 (2), 113–125. doi: 10.1177/1086026601141001.

Morgenbesser, L. (2019) Cambodia’s Transition to Hegemonic Authoritarianism. Journal of Democracy. 30 (1), 158–171.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B. d., et al. (2000) Biodiversity hotspots for conservation priorities. Nature. 403 (February), 853–858.

Myneni, S., Fujimoto, K., Cobb, N. & Cohen, T. (2015) Content-Driven Analysis of an Online Community for Smoking Cessation: Integration of Qualitative Techniques, Automated Text Analysis, and Affiliation Networks. American Journal of Public Health. 105 (6), 1206–1212. doi: 10.2105/AJPH.2014.302464.

Naito, R., Zhao, J. & Chan, K.M.A. (2021) An integrative framework for transformative social change: A case in global wildlife trade. SocArxiv. doi: 10.31235/osf.io/5zmxd.

Nakano, Y., Tsusaka, T.W., Aida, T. & Pede, V.O. (2018) Is farmer-to-farmer extension effective? The impact of training on technology adoption and rice farming productivity in Tanzania. World Development. 105, 336–351. doi: 10.1016/j.worlddev.2017.12.013.

Neumann, R.P. (2005) Making Political Ecology. Hodder Education.

Nguyen, C.D., Carlin, J.B. & Lee, K.J. (2017) Model checking in multiple imputation: An overview and case study. Emerging Themes in Epidemiology. 14 (1), 1–12. doi: 10.1186/s12982-017-0062-6.

Nicolescu, B. (2014) Methodology of Transdisciplinarity. World Futures. 70 (3–4), 186–199. doi: 10.1080/02604027.2014.934631.

Niemiec, R., Jones, M.S., Lischka, S. & Champine, V. (2021) Efficacy-based and normative interventions for facilitating the diffusion of conservation behavior through social networks. Conservation Biology. n/a (n/a). doi: https://doi.org/10.1111/cobi.13717.

Niemiec, R.M., Willer, R., Ardoin, N.M. & Brewer, F.K. (2019) Motivating landowners to recruit neighbors for private land conservation. Conservation Biology. 33 (4), 930–941. doi: https://doi.org/10.1111/cobi.13294.

Nilsson, D., Baxter, G., Butler, J.R.A. & Mcalpine, C.A. (2016a) How do community-based conservation programs in developing countries change human behaviour? A realist synthesis. BIOC. 200, 93–103. doi: 10.1016/j.biocon.2016.05.020.

Nilsson, D., Gramotnev, G., Baxter, G., Butler, J.R.A., et al. (2016b) Community motivations to engage in conservation behavior to conserve the Sumatran orangutan. Conservation Biology. 30 (4), 816–826. doi: 10.1111/cobi.12650.

Nisbet, M.C. & Kotcher, J.E. (2009) A Two-Step Flow of Influence?: Opinion-Leader Campaigns on Climate Change. Science Communication. 30 (3), 328–354. doi: 10.1177/1075547008328797.

Norgrove, L. & Hulme, D. (2006) Confronting Conservation at Mount Elgon, Uganda. Development and Change. 37 (5), 1093–1116.

Nuno, A. & St. John, F.A.V. (2015) How to ask sensitive questions in conservation: A review of specialized questioning techniques. Biological Conservation. 189, 5–15. doi: 10.1016/j.biocon.2014.09.047.

Nyumba, T.O., Wilson, K., Derrick, C.J. & Mukherjee, N. (2018) The use of focus group discussion methodology: Insights from two decades of application in conservation. Methods in Ecology and Evolution. 9 (1), 20–32. doi: 10.1111/2041-210X.12860.

Odino, M. (2011) Measuring the conservation threat that deliberate poisoning poses to birds in Kenya: The case of pesticide hunting with Furadan in the Bunyala Rice Irrigation Scheme. In: Ngaio Richards (ed.). Carbofuran and Wildlife Poisoning: Global Perspectives and Forensic Approaches. Wiley-Blackwell. pp. 53–69.

Ogada, D., Botha, A. & Shaw, P. (2016) Ivory poachers and poison: Drivers of Africa's declining vulture populations. Oryx. 50 (4), 593–596. doi: 10.1017/S0030605315001209.

Ogada, D.L. (2014) The power of poison: Pesticide poisoning of Africa's wildlife. Annals of the New York Academy of Sciences. 1322 (1), 1–20. doi: 10.1111/nyas.12405.

Ogada, D.L., Keesing, F. & Virani, M.Z. (2012) Dropping dead: causes and consequences of vulture population declines worldwide. Annals of the New York Academy of Sciences. 1249, 57–71. doi: 10.1111/j.1749-6632.2011.06293.x [Accessed: 22 August 2016].

Olmedo, A., Sharif, V. & Milner-Gulland, E.J. (2017) Evaluating the Design of Behaviour Change Interventions: A Case Study of Rhino Horn in Vietnam. Conservation Letters. doi: 10.1111/conl.12365.

Ostrom, E. (1990) Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press.

Ovesen, J., Trankell, I.-B. & Ojendal, J. (1996) When every household is an island: social organization and power structures in rural Cambodia. Uppsala, Sweden, Department of Cultural Anthropology, Uppsala University.

Padua, S.M. (1994) Conservation Awareness through an Environmental Education Programme in the Atlantic Forest of Brazil. Environmental Conservation. 21 (2), 145–151. doi: DOI: 10.1017/S0376892900024577.

Paley, R. (2015) Managing protected areas in Cambodia. In: Sarah Milne & Sango Mahanty (eds.). Conservation and Development in Cambodia2. Routledge. pp. 141–159.

Palla, G., Barabási, A.-L. & Vicsek, T. (2007) Quantifying social group evolution. Nature. 446 (7136), 664–667. doi: 10.1038/nature05670.

Paluck, E.L., Shepherd, H.R. & Aronow, P.M. (2016) Changing climates of conflict: a social network experiment in 56 schools. Proceedings of the National Academy of Sciences of the United States of America. 113 (3), 566–571. doi: 10.1073/pnas.1514483113.

Pei, S., Morone, F. & Makse, H.A. (2018) Theories for Influencer Identification in Complex Networks. In: S Lehmann & Y.Y. Ahn (eds.). Complex Spreading Phenomena in Social Systems: Influence and Contagion in Real-World Social Networks. Cham: Springer International Publishing. pp. 125–148.

Pepinsky, T.B. (2018) A Note on Listwise Deletion versus Multiple Imputation. Political Analysis. 26 (4), 480–488. doi: DOI: 10.1017/pan.2018.18.

Perkins, J.M., Subramanian, S. V. & Christakis, N.A. (2015) Social networks and health: A systematic review of sociocentric network studies in low- and middle-income countries. Social Science and Medicine. 125, 60–78. doi: 10.1016/j.socscimed.2014.08.019.

Peterson, M.N., Essen, E. Von & Hansen, H.P. (2017) Illegal fishing and hunting as resistance to neoliberal colonialism. Crime, Law, and Social Change. 67, 401–413. doi: 10.1007/s10611-016-9664-0.

Petroczi, A., Nespusz, T., Cross, P., Taft, H., et al. (2011) New non-randomised model to assess the prevalence of discimination behavious: A pilot study on mephedrone. Substance abuse treatment, prevention, and policy. 6 (20), 1–18. doi: 10.1186/1747-597X-6-20.

Pin, C., Ngoprasert, D., Gray, T.N.E., Savini, T., et al. (2018) Utilization of waterholes by globally threatened species in deciduous dipterocarp forest of the Eastern Plains Landscape of Cambodia. Oryx. 1–11. doi: 10.1017/S0030605318000455.

Poffenberger, M. (2013) Cambodia's contested forest domain: the role of community forestry in the new millenium. Mark Poffenberger (ed.). Manila, Ateneo de Manila University Press.

Pooley, S.P., Mendelsohn, J.A. & Milner-Gulland, E.J. (2013) Hunting Down the Chimera of Multiple Disciplinarity in Conservation Science. Conservation Biology. 28 (1), 22–32. doi: 10.1111/cobi.12183.

Pornpitakpan, C. (2004) The Persuasiveness of Source Credibility: A Critical Review of Five Decades Evidence. Journal of Applied Social Psychology. 34 (2), 243–281. doi: 10.1111/j.1559-1816.2004.tb02547.x.

Prentice, D. & Paluck, E.L. (2020) Engineering social change using social norms: lessons from the study of collective action. Current Opinion in Psychology. 35, 138–142. doi: https://doi.org/10.1016/j.copsyc.2020.06.012.

Prentice, D.A. & Miller, D.T. (1996) Pluralistic Ignorance and the Perpetuation of Social Norms by Unwitting Actors. Advances in Experimental Social Psychology. 28 (C), 161–209. doi: 10.1016/S0065-2601(08)60238-5.

Presseau, J., McCleary, N., Lorencatto, F. *et al.* Action, actor, context, target, time (AACTT): a framework for specifying behaviour. *Implementation Sci* **14,** 102 (2019). https://doi.org/10.1186/s13012-019-0951-x

Pretty, J. & Ward, H. (2001) Social Capital and the Environment. World Development. 29 (2), 209–227.

QSR International (2015) NVivo.

R Core Team (2017) R: A Language and Environment for Statistical Computing. Available from: https://www.r-project.org.

Reddy, S.M.W., Montambault, J., Masuda, Y.J., Gneezy, A., et al. (2016) Advancing Conservation by Understanding and Influencing Human Behavior. Conservation Letters. 00 (May), 1–9. doi: 10.1111/conl.12252.

Royal Government of Cambodia (2012) Law on the Management of Pesticides and Fertilizers. Available from: http://extwprlegs1.fao.org/docs/pdf/cam151539.pdf.

Rhodes, J.R., Guerrero, A., Bodin, Ö. & Chadès, I. (2020) Fundamental insights on when social-network data are most critical for conservation planning. Conservation Biology. doi: 10.1111/cobi.13500.

Richards, N. (2011) Carbofuran and Wildlife Poisoning: Global Perspectives and Forensic Approaches. 1st edition. Ngaio Richards (ed.). Chichester, Wiley-Blackwell. doi: 10.1002/9781119998532.

Riggs, R.A., Langston, J.D., Beauchamp, E., Travers, H., et al. (2020) Examining Trajectories of Change for Prosperous Forest Landscapes in Cambodia. Environmental Management. 66 (1), 72–90. doi: 10.1007/s00267-020-01290-9.

Riggs, R.A., Langston, J.D. & Phann, S. (2020) Actor network analysis to leverage improvements in conservation and development outcomes in Cambodia. Ecology and Society. 25 (4). doi: 10.5751/ES-11854-250428.

Ríos-Saldaña, C.A., Delibes-Mateos, M. & Ferreira, C.C. (2018) Are fieldwork studies being relegated to second place in conservation science? Global Ecology and Conservation. 14, e00389. doi: https://doi.org/10.1016/j.gecco.2018.e00389.

Ripley, R.M., Snijders, T.A.B., Boda, Z., Voros, A., et al. (2020) Manual for SIENA version 4.0. Available from: http://www.stats.ox.ac.uk/~snijders/siena/RSiena_Manual.pdf.

Robins, G. (2015) Doing Social Network Research: Network-Based Research Design for Social Scientists. SAGE Publications.

Rodriguez, J.M., Molnar, J.J., Fazio, R.A., Sydnor, E., et al. (2009) Barriers to adoption of sustainable agriculture practices: Change agent perspectives. Renewable Agriculture and Food Systems. 24 (1), 60–71. Available from: http://www.jstor.org/stable/44490690.

Rogers, E.M. (2003) Diffusion of Innovations. 5th edition. New York, Free Press.

de Roo, N., Amede, T.T., Elias, E., Almekinders, C., et al. (2021) Opinion leadership under imperfect market conditions: the case of malt barley technology in South Ethiopia. International Journal of Agricultural Education and Extension.

Rotterdam Convention (2013) Cambodia. 2013.

Ryan, J., Mellish, S., Dorrian, J., Winefield, T., et al. (2020) Effectiveness of biodiversity-conservation marketing. Conservation Biology. 34 (2), 354–367. doi: 10.1111/cobi.13386.

Sales, A.E., Estabrooks, C.A. & Valente, T.W. (2010) The impact of social networks on knowledge transfer in long-term care facilities: Protocol for a study. Implementation Science. 5 (1), 49. doi: Artn 49\rDoi 10.1186/1748-5908-5-49.

Sánchez-Mercado, A., Cardozo-Urdaneta, A., Moran, L., Ovalle, L., et al. (2020) Social network analysis reveals specialized trade in an Endangered songbird. Animal Conservation. 23 (2), 132–144. doi: https://doi.org/10.1111/acv.12514.

Sandbrook, C., Adams, W.M., Buscher, B. & Vira, B. (2013) Social Research and Biodiversity Conservation. Conservation Biology. 27 (6), 1487–1490. doi: https://doi.org/10.1111/cobi.12141.

Saroeun, B. (1999) Pesticides killing Great Lake. The Phnom Penh Post. May.

Saypanya, S., Hansel, T., Johnson, A., Bianchessi, A., et al. (2013) Effectiveness of a social marketing strategy, coupled with law enforcement, to conserve tigers and their prey in Nam Et Phou Louey National Protected Area, Lao People's Democratic Republic. Conservation Evidence. 10 (2013), 57–66.

Scheidel, A., Giampietro, M. & Ramos-Martin, J. (2013) Self-sufficiency or surplus: Conflicting local and national rural development goals in Cambodia. Land Use Policy. 34, 342–352. doi: 10.1016/j.landusepol.2013.04.009.

Schlüter, M., Baeza, A., Dressler, G., Frank, K., et al. (2017) A framework for mapping and comparing behavioural theories in models of social-ecological systems. Ecological Economics. 131, 21–35. doi: 10.1016/j.ecolecon.2016.08.008.

Schneider, C.R., Zaval, L., Weber, E.U. & Markowitz, E.M. (2017) The influence of anticipated pride and guilt on pro-environmental decision making. PLoS ONE. 12 (11), 1–14. doi: 10.1371/journal.pone.0188781.

Schoenberger, L. & Beban, A. (2018) "They Turn Us into Criminals": Embodiments of Fear in Cambodian Land Grabbing. Annals of the American Association of Geographers. 108 (5), 1338–1353. doi: 10.1080/24694452.2017.1420462.

Schoenberger, L. & Beban, A. (2017) What is academic research on the Cambodian frontier? Critical Asian Studies. 49 (3), 437–440. doi: 10.1080/14672715.2017.1339446.

Schreinemachers, P. & Tipraqsa, P. (2012) Agricultural pesticides and land use intensification in high, middle and low income countries. Food Policy. 37 (6), 616–626. doi: https://doi.org/10.1016/j.foodpol.2012.06.003.

Schultz, P.W. (2011) Conservation Means Behavior. Conservation Biology. 25 (6), 1080–1083. doi: 10.1111/j.1523-1739.2011.01766.x.

Schultz, P.W., Nolan, J.M., Cialdini, R.B., Goldstein, N.J., et al. (2016) The Constructive, Destructive, and Reconstructive Power of Social Norms. 18 (5), 429–434.

Schultz, P.W.W. (2002) Knowledge, information, and household recycling: Examining the knowledge-deficit model of behavior change. In: Paul Stern & Thomas Dietz (eds.). New Tools for Environmental Protection: Education, Information, and Voluntary Measures. National Academy Press. pp. 67–82.

Scott, J.C. (2009) The Art of Not Being Governed. Yale University Press.

Sedara, K. (2011) Reciprocity: informal patterns of social interaction in a Cambodian village. In: John A. Marston (ed.). Anthropology and community in Camodia. Victoria, Australia, Monash University Press. pp. 153–170.

Selinske, M.J., Cooke, B., Torabi, N., Hardy, M.J., et al. (2017) Locating financial incentives among diverse motivations for long-term private land conservation. Ecology and Society. 22 (2), art7. doi: 10.5751/ES-09148-220207.

Shakya, H.B., Christakis, N.A. & Fowler, J.H. (2017) An exploratory comparison of name generator content: Data from rural India. Social Networks. 48, 157–168. doi: 10.1016/j.socnet.2016.08.008.

Shalizi, C.R. & Thomas, A.C. (2011) Homophily and Contagion Are Generically Confounded in Observational Social Network Studies. Sociological Methods & Research. 40 (2), 211–239. doi: 10.1177/0049124111404820.

Shattuck, A. (2021) Generic, growing, green?: The changing political economy of the global pesticide complex. The Journal of Peasant Studies. 1–23. doi: 10.1080/03066150.2020.1839053.

Shepherd, H.R. (2017) The Structure of Perception: How Networks Shape Ideas of Norms. Sociological Forum. 32 (1), 72–93. doi: 10.1111/socf.12317.

Smith, P.K. & Magee, J.C. (2015) The interpersonal nature of power and status. Current Opinion in Behavioral Sciences. 3, 152–156. doi: 10.1016/j.cobeha.2015.04.007.

Smith, R.J., Veríssimo, D., Leader-Williams, N., Cowling, R.M., et al. (2009) Let the locals lead. Nature. 462 (7271), 280–281. doi: 10.1038/462280a.

Smith, R.J., Verissimo, D. & Macmillan, D.C. (2010) Marketing and Conservation: How to Lose Friends and Influence People. Trade-Offs in Conservation: Deciding What to Save. 215–232. doi: 10.1002/9781444324907.ch12.

Snijders, T.A.B. (2017) Stochastic Actor-Oriented Models for Network Dynamics. Annual Review of Statistics and Its Application. 4 (1), 343–363. doi: 10.1146/annurev-statistics-060116-054035.

Snijders, T.A.B., van de Bunt, G.G. & Steglich, C.E.G. (2010) Introduction to stochastic actor-based models for network dynamics. Social Networks. 32 (1), 44–60. doi: https://doi.org/10.1016/j.socnet.2009.02.004.

Snijders, T.A.B. & Steglich, C.E.G. (2015) Representing Micro–Macro Linkages by Actor-based Dynamic Network Models. Sociological Methods & Research. 44 (2), 222–271. doi: 10.1177/0049124113494573.

Soda, G. & Zaheer, A. (2012) A network perspective on organizational architecture: performance effects of the interplay of formal and informal organization. Strategic Management Journal. 33, 751–771. doi: 10.1002/smj.1966.

Sokphea, Y. (2016) Movement of indigenous communities targeting an agro-industrial investment in north-eastern Cambodia. Asian Journal of Social Science. 44 (1–2), 187–213. doi: 10.1163/15685314-04401008.

Sokpheng, H. (2015) A man suicides by drinking poison, as his wife refuses to sleep with him. Koh Santepheap Daily. 21 June. Available from: https://kohsantepheapdaily.com.kh/article/122566.html.

Sommerville, M., Rahajaharison, M. & Jones, J.P.G. (2010) Impact of a Community-Based Payment for Environmental Services Intervention on Forest Use in Menabe, Madagascar. 24 (6), 1488–1498. doi: 10.1111/j.1523-1739.2010.01526.x.

Soulé, M.E. (1985) What is Conservation Biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems. BioScience. 35 (11), 727–734. Available from: http://dx.doi.org/10.2307/1310054.

Springer, S. (2009) Violence, Democracy, and the Neoliberal “Order”: The Contestation of Public Space in Posttransitional Cambodia. Annals of the Association of American Geographers. 99 (1), 138–162. doi: 10.1080/00045600802223333.

Starkey, F., Audrey, S., Holliday, J., Moore, L., et al. (2009) Identifying influential young people to undertake effective peer-led health promotion: The example of A Stop Smoking in Schools Trial (ASSIST). Health Education Research. 24 (6), 977–988. doi: 10.1093/her/cyp045.

Steglich, C., Snijders, T.A.B. & Pearson, M. (2010) Dynamic Networks and Behavior: Separating Selection from Influence. Sociological Methodology. 40 (1), 329–393. doi: 10.1111/j.1467-9531.2010.01225.x.

Steinmetz, R., Srirattanaporn, S., Mor-Tip, J. & Seuaturien, N. (2014) Can community outreach alleviate poaching pressure and recover wildlife in South-East Asian protected areas? Journal of Applied Ecology. 51 (6), 1469–1478. doi: 10.1111/1365-2664.12239.

Strangio, S. (2014) Hun Sen’s Cambodia. New Haven, Yale University Press.

Swift, P. (2013) Changing ethnic identities among the Kuy in Cambodia: Assimilation, reassertion and the making of Indigenous identity. Asia Pacific Viewpoint. 54 (3), 296–308. doi: 10.1111/apv.12025.

Swift, P. & Cock, A. (2015) Traditional Khmer Systems of Forest Management. Journal of the Royal Asiatic Society. 25 (1), 153–173. doi: 10.1017/S13561863140003.

Thøgersen, J. (2005) How may consumer policy empower consumers for sustainable lifestyles? Journal of Consumer Policy. 28 (2), 143–177. doi: 10.1007/s10603-005-2982-8.

Travers, H., Archer, L.J., Mwedde, G., Roe, D., et al. (2019) Understanding complex drivers of wildlife crime to design effective conservation interventions. Conservation Biology. doi: 10.1111/cobi.13330.

Travers, H., Clements, T., Keane, A.M. & Milner-Gulland, E.J. (2011) Incentives for cooperation: The effects of institutional controls on common pool resource extraction in Cambodia. Ecological Economics. 71 (1), 151–161. doi: 10.1016/j.ecolecon.2011.08.020.

Turaga, R.M.R., Howarth, R.B. & Borsuk, M.E. (2010) Pro-environmental behavior. Annals of the New York Academy of Sciences. 1185 (1), 211–224. doi: https://doi.org/10.1111/j.1749-6632.2009.05163.x.

Valente, T.W. (2012) Network Interventions. Science. 337 (6090), 49–53. doi: 10.1126/science.1217330.

Valente, T.W. (1996) Social network thresholds in the diffusion of innovations. Social Networks. 18 (1), 69–89. doi: 10.1016/0378-8733(95)00256-1.

Valente, T.W. & Davis, R.L. (1999) Accelerating the Diffusion of Innovations Using Opinion Leaders. Annals of the American Academy of Political and Social Science. 566 (1), 55–67.

Valente, T.W. & Fujimoto, K. (2010) Bridging: Locating critical connectors in a network. Social Networks. 32 (3), 212–220. doi: 10.1016/j.socnet.2010.03.003.

Valente, T.W., Paredes, P. & Poppe, P.R. (1998) Matching the Message to the Process: the relative ordering of knowledge, attitudes, and practices in behavior change research. Human Communication Research. 24 (3), 366–385. doi: 10.1177/0093650211427140.

Valente, T.W. & Pumpuang, P. (2007) Identifying Opinion Leaders to Promote Behavior Change. Health Education & Behavior. 34 (6), 881–896. doi: 10.1177/1090198106297855.

Valente, T.W., Ritt-Olson, A., Stacy, A., Unger, J.B., et al. (2007) Peer acceleration: Effects of a social network tailored substance abuse prevention program among high-risk adolescents. Addiction. 102 (11), 1804–1815. doi: 10.1111/j.1360-0443.2007.01992.x.

van der Pligt, J., Zeelenberg, M., van Dijk, W.W., de Vries, N.K., & Richard, R. (1997) Affect, Attitudes and Decisions: Let's Be More Specific, European Review of Social Psychology, 8:1, 33-66, DOI: 10.1080/14792779643000074

Varughese, G. & Ostrom, E. (2001) The contested role of hetrogenity in collective action: Some evidence from community forestry in Nepal. Word Development. 29 (5), 747–765.

Veríssimo, D., Schmid, C., Kimario, F.F. & Eves, H.E. (2018) Measuring the impact of an entertainment-education intervention to reduce demand for bushmeat. Animal Conservation. 1–8. doi: 10.1111/acv.12396.

Verkoren, W. & Ngin, C. (2017) Organizing against Land Grabbing in Cambodia: Exploring Missing Links. Development and Change. 48 (6), 1336–1361. doi: 10.1111/dech.12346.

Wakefield, M.A., Loken, B. & Hornik, R.C. (2010) Use of mass media campaigns to change health behaviour. The Lancet. 376 (9748), 1261–1271. doi: 10.1016/S0140-6736(10)60809-4.

Wang, C., Butts, C.T., Hipp, J. & Lakon, C.M. (2020) Model Adequacy Checking/Goodness-of-fit Testing for Behavior in Joint Dynamic Network/Behavior Models, with an Extension to Two-mode Networks. Sociological Methods & Research. 0049124120914933. doi: 10.1177/0049124120914933.

Ward, C., Holmes, G. & Stringer, L. (2018) Perceived barriers to and drivers of community participation in protected-area governance. Conservation Biology. 32 (2), 437–446. doi: 10.1111/cobi.13000.

Wasserman, S. & Faust, K. (1994) Social network analysis: Methods and applications. Cambridge, Cambridge University Press. doi: 10.1017/CBO9780511815478.

Weenig, M.W.H. (1999) Communication Networks in the Diffusion of an Innovation in an Organization. Journal of Applied Social Psychology. 29 (5), 1072–1092. doi: 10.1111/j.1559-1816.1999.tb00141.x.

Wefarm (2021) wefarm. 2021. Available from: https://wefarm.co/ [Accessed: 4 March 2021].

Weimann, G. (1994) Typologies of Opinion Leadership. In: The Influentials: People who influence people. Albany, State University of New York Press. pp. 53–70.

Wharton, C.H. (1966) Man, fire and wild cattle in northern Cambodia. Proc. Annu. Tall Timbers Fire Ecol. Conf. 5 (1940), 23–65.

Wood, W. (2000) Attitude Change: Persuasion and Social Influence. Annual Review of Psychology. 51 (1), 539–570. doi: 10.1146/annurev.psych.51.1.539.

Wooten, D.B. & Reed II, A. (1998) Informational Influence and the Ambiguity of Product Experience: Order Effects on the Weighting of Evidence. Journal of Consumer Psychology. 7 (1), 79–99. doi: https://doi.org/10.1207/s15327663jcp0701_04.

World Resources Institute (2014) Global Forest Watch. 2014. Available from: http://www.globalforestwatch.org/ [Accessed: 22 December 2020].

Wright, A.J., Verissimo, D., Pilfold, K., Parsons, E.C.M., et al. (2015) Competitive outreach in the 21st century: Why we need conservation marketing. Ocean and Coastal Management. 115, 41–48. doi: 10.1016/j.ocecoaman.2015.06.029.

Wright, J.H., Hill, N.A.O., Roe, D., Rowcliffe, M., et al. (2016) Reframing the concept of alternative livelihoods. Conservation Biology. 30 (1), 7–13. doi: 10.1111/cobi.12607.

Wu, C. & Shaffer, D.R. (1987) Susceptibility to Persuasive Appeals as a Function of Source Credibility and Prior Experience with the Attitude Object. Journal of Personality and Social Psychology. 52 (4), 677–688. doi: 10.1037/0022-3514.52.4.677.

Yin, R.K. (2014) Case study research: design and methods. SAGE Publications.

Young, S. (2019) Social movements in Cambodia: why they succeed or fail. Journal of International Relations and Development. (0123456789). doi: 10.1057/s41268-019-00175-7.

Zwijze-Koning, K.H. (2005) Auditing Information Structures in Organizations: A Review of Data Collection Techniques for Network Analysis. Organizational Research Methods. 8 (4), 429–453. doi: 10.1177/1094428105280120.

Appendix 1: Supplementary material for Chapter 4

A1.1 Hunting

168 respondents (36%) stated that they hunted wildlife in the past year. The most common method of hunting was using traps (56% of 168 hunters), followed by slingshots (12%). Twenty-four (1%) hunters used nets and 23 (1%) used dogs. Finally, four hunters stated that they used cross bows, and three hunters stated that they used guns to hunt, but this may refer to the homemade air guns commonly found. Most hunters used a single method, but 44 (26%) reported using a combination of methods. Younger respondents were more likely to hunt (effect = -0.04, $z = -4.19$, $p < 0.01$, Supplementary Table 3), but no effect was found for wealth or other variables.

A1.2 Agricultural Pesticide usage

Pesticides were reported as used in all villages except one. Overall, 15% of households surveyed stated in response to a direct question that they had used pesticides in the past year, but this varied by village between 0 and 47% (median 8%). Interviews with village chiefs and FGD data suggest that usage varies from year to year and usually occurs in response to observations of pests on crops intended for commercial sale, but not on rice grown for home consumption. According to informants, irregularly occurring 'worm' (ដង្កូវ) outbreaks are a major driver of usage, but this did not occur in the year of our study. These 'worms' are in fact a kind of caterpillar which occurs seasonally. Pesticides are also mixed with water in the wet rice paddy to kill crabs which may then be consumed.

Twenty-one different pesticide products were identified by respondents as used for these purposes. Farmers typically report learning how to use pesticides from sellers at local markets when seeking advice on pest management, or from agricultural middlemen. We found no relation between respondent age and pesticide use, but wealthier households were more likely to use pesticides (effect size = 0.25, $z = 2.06$, $p = 0.04$, Supplementary Table 3). 'Termite poisons' are also used to prevent termite damage by soaking the roots of cassava or cashew crops before planting.

A1.3 Rice field poisoning

In addition to waterhole poisoning, several other practices make use of poisons or pesticides to kill wildlife. Firstly, following a traditional method, poison produced from tree bark is placed in a water source to stun fish. This is a common method but is not believed to be harmful to wildlife due to the weak effect of the poison. Secondly, poisons are sprayed on fruit trees to kill birds, but this was only reported in one village. Third, granular-form pesticides are mixed or boiled with rice and scattered in the rice field to kill birds that eat the rice crop. Poisoning at rice fields was thought by respondents across all types of questioning to affect only doves, parakeets, and sparrows. This was reported in six villages, and we included this practice in our UCT questionnaire. The proportion of respondents allocated the treatment and control cards in this round did not differ significantly from 1:1 ($\chi^2 = 2.1$, df = 1, $p = 0.15$). The UCT results indicated that the proportion of households engaging in rice-field poisoning across 10 villages was not significantly different from zero with no design effect ($p = 0.42$, Supplementary Table 1). However, 4 respondents (1.7%) gave a maximal response for rice-field poisoning and when questioned directly, 10 respondents (2.2%) admitted to poisoning rice fields in the past year.

Table A1.1: Summary of prevalence estimates for different behaviours using the Unmatched Count Technique, a method used to estimate prevalence of sensitive behaviours. This includes the results for the practice round which focused on fruit eating, and direct questioning estimates for poisoning practices. A significant design effect indicates sensitivity of the practice.

Behaviour	**Practice: fruit eating**	**Poisoning in rice field**	**Poisoning at waterholes**
Size of treatment group (total = 462)	221	241	254
Estimate % ± SE (p)	32% ± 14 (0.02)	-10% ± 12 (0.40)	-40% ± 12 (<0.001)
Design effect (p value)	0.67	0.42	**<0.01**
No. of maximal responses in treatment group (%)	22 (10.0 %)	4 (1.7 %)	6 (2.4 %)
Positive responses to direct question	NA	10 (2.2%)	6 (1.3%)

Table A1.2: Poisoned wildlife observed by informants, showing the number of informants who have observed the species poisoned.

Wildlife Species	**IUCN Redlist status**	**No. Reports**
“Egrets”		13
“Doves”		11
“Parakeet”		9
“Civets”		5
“Doves”		3
Red junglefowl *Gallus gallus*	Least concern	3
Black-winged kite *Elanus caeruleus*		3
Green imperial pigeon *Ducula aenea*	Least concern	3
Sarus crane *Antigone antigone*	Vulnerable	2
“Sparrows”		2
Chinese francolin *Francolinus pintadeanus*	Least concern	3
Giant ibis *Thaumatibis gigantea*	Critically endangered	2
Wild boar *Sus scrofa*	Least concern	1
“Monkeys”		1
“Cobras”		1
Lesser Mouse deer *Tragulus kanchil*	Least concern	1
“Storks”		1
Green peafowl *Pavo muticus*	Endangered	1
Lesser adjutant *Leptoptilos javanicus*	Vulnerable	1
“Eagles”		1
“Snakes”		1
“Drongo”		1

Table A1.3: Fixed effect coefficients from linear mixed models. Effect size estimates are given relative to the intercept. Bolded variables have effect sizes larger than two times the standard error, or for generalised models have a p-value less than 0.05.

Model	Descriptive norms Linear mixed model					Injunctive norms Linear mixed model					Combined norms Linear mixed model				
Variable/Coefficient	Estimate	Std. Error	T-value	95% C.I. lower bound	95% C.I. upper bound	Estimate	Std. Error	T-value	95% C.I. lower bound	95% C.I. upper bound	Estimate	Std. Error	T-value	95% C.I. lower bound	95% C.I. upper bound
Intercept	3.878	0.335	11.57	3.223	4.508	4.612	0.320	14.41	3.995	5.229	8.478	0.514	16.49	7.477	9.479
Age (Years / SD)	-0.052	0.081	-0.649	-0.210	0.103	**-0.231**	**0.077**	**-2.978**	**-0.380**	**-0.079**	**-0.283**	**0.125**	**-2.261**	**-0.527**	**-0.039**
Agricultural Pesticide use	0.093	0.202	0.461	-0.300	0.481	**-0.258**	**0.194**	**-1.330**	**-0.641**	**0.109**	-0.175	0.313	-0.560	-0.784	0.433
Residence time (years / SD)	-0.042	0.082	-0.509	-0.199	0.118	-0.010	0.079	-0.123	-0.165	0.139	-0.053	0.127	-0.420	-0.300	0.193
Native Intervention village	0.136	0.162	0.836	-0.153	0.424	**-0.484**	**0.151**	**-3.199**	**-0.766**	**-0.205**	**-0.346**	**0.231**	**-1.500**	**-0.796**	**0.103**
VMN member	-0.164	0.176	-0.933	-0.496	0.184	-0.016	0.168	-0.092	-0.339	0.314	-0.169	0.272	-0.620	-0.698	0.361
Wealth score	**0.150**	**0.060**	**2.526**	**0.039**	**0.270**	-0.035	0.057	-0.621	-0.145	0.076	**0.121**	**0.092**	**1.310**	**-0.059**	**0.300**
Protected area (Kulen Promtep)	**-1.129**	**0.167**	**-6.752**	**-1.433**	**-0.828**	**-0.756**	**0.157**	**-4.822**	**-1.051**	**-0.470**	**-1.891**	**0.242**	**-7.819**	**-2.362**	**-1.420**

Model	Attitudes Linear mixed model					Pesticide usage Generalised linear mixed model				Hunting Generalised linear mixed model			
Variable/Coefficient	Estimate	Std. Error	T-value	95% C.I. lower bound	95% C.I. upper bound	Estimate	Std. Error	z-value	P-value	Estimate	Std. Error	z-value	P-value
Intercept	4.083	0.381	10.71	3.401	4.837	-2.673	0.865	-3.091	0.002	0.758	0.484	1.566	0.117
Age (Years / SD)	**-0.121**	**0.088**	**-1.379**	**-0.317**	**0.036**	0.322	0.168	1.924	0.054	**-0.522**	**0.128**	**-4.068**	**<0.001**
Agricultural Pesticide use	**0.394**	**0.222**	**1.773**	**-0.048**	**0.782**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Residence time (years / SD)	0.052	0.090	0.581	-0.084	0.251	-0.218	0.177	-1.234	0.217	0.176	0.126	1.397	0.1624
Native Intervention village	**-0.294**	**0.229**	**-1.284**	**-0.619**	**-0.009**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
VMN member	-0.010	0.191	-0.052	-0.397	0.322	**-1.132**	**0.477**	**-2.372**	**0.018**	-0.367	0.264	-1.392	0.164
Wealth score	**-0.216**	**0.065**	**-3.335**	**-0.337**	**-0.093**	0.250	0.138	1.816	0.069	0.057	0.088	0.654	0.513
Protected area (Kulen Promtep)	-0.114	0.227	-0.502	-0.433	0.206	**-1.400**	**0.658**	**-2.127**	**0.033**	-0.322	0.218	-1.478	0.139

Table A1.4: Fixed effect coefficients from Cumulative Linked logistic mixed models for perceived behavioural control. Bold indicates an effect size greater than the two times standard error, or a p-value below 0.05.

Model:	Perceived behavioural control 1: Effective Cumulative linked (logit) mixed model				Perceived behavioural control 2: Easy Cumulative linked (logit) mixed model			
Variables/Coefficients	Estimate	Std. Error	Z Value	P Value	Estimate	Std. Error	Z Value	P Value
Age (Years / SD)	-0.166	0.109	-1.524	0.128	**-0.289**	**0.108**	**-2.674**	**0.008**
Agricultural Pesticide use	**0.609**	**0.281**	**2.170**	**0.030**	**0.817**	**0.253**	**3.233**	**0.001**
Residence time (Years / SD)	0.013	0.112	0.116	0.908	-0.141	0.111	-1.262	0.207
VMN member	0.091	0.247	0.366	0.714	**0.519**	**0.231**	**2.244**	**0.025**
Wealth score	-0.025	0.081	-0.306	0.760	0.113	0.080	1.402	0.161
Protected Area (Kulen Promtep)	**1.634**	**0.501**	**3.258**	**0.001**	-0.130	0.211	-0.617	0.537
Class membership: 1|2	**-1.299**	**0.569**	**-2.284**	**0.022**	-0.510	0.438	-1.164	0.244
Class membership: 2|3	-0.722	0.564	-1.279	0.201	0.136	0.437	0.312	0.755
Class membership: 3|4	-0.224	0.563	-0.397	0.691	0.801	0.439	1.824	0.068
Class membership: 4|5	**1.158**	**0.567**	**2.041**	**0.041**	**1.537**	**0.448**	**3.433**	**0.001**

Table A1.5: Random effect coefficients for models of attitudes, perceived norms, and perceived behavioural control. Bold indicates a value greater than two times the standard error or deviation. S.D. = standard deviation, S.E. = standard error.

MODEL:	COMBINED NORMS LINEAR MIXED EFFECT MODEL		DESCRIPTIVE NORMS LINEAR MIXED EFFECT MODEL		INJUNCTIVE NORMS LINEAR MIXED EFFECT MODEL		ATTITUDES LINEAR MIXED EFFECT MODEL		PERCEIVED BEHAVIOURAL CONTROL 1: EFFECTIVE CUMULATIVE LINKED (LOGIT) MIXED MODEL		PERCEIVED BEHAVIOURAL CONTROL 2: EASY CUMULATIVE LINKED (LOGIT) MIXED MODEL	
VARIABLES/COEFFICIENTS	VALUE	S.D.	VALUE	S.D.	VALUE	S.D.	VALUE	S.D.	VALUE	S.E.	VALUE	S.E.
Village 1	0.000	0.000	-0.001	0.084	-0.014	0.068	0.114	0.152	**-0.575**	**0.061**	**-0.055**	**0.009**
Village 2	0.000	0.000	0.014	0.087	0.020	0.069	0.283	0.169	0.092	0.092	**0.025**	**0.009**
Village 3	0.000	0.000	-0.008	0.087	0.009	0.069	0.040	0.169	-0.087	0.081	0.0002	0.010
Village 4	0.000	0.000	0.054	0.084	0.0003	0.068	0.017	0.153	**1.191**	**0.076**	**0.041**	**0.010**
Village 5	0.000	0.000	-0.037	0.087	0.038	0.069	-0.164	0.171	-0.062	0.068	**0.021**	**0.009**
Village 6	0.000	0.000	-0.046	0.086	-0.009	0.068	-0.058	0.160	**-1.252**	**0.070**	**-0.062**	**0.010**
Village 7	0.000	0.000	0.038	0.084	0.011	0.068	0.097	0.152	**-0.400**	**0.051**	**-0.034**	**0.009**
Village 8	0.000	0.000	-0.033	0.089	0.0002	0.070	-0.128	0.181	**0.572**	**0.054**	**0.031**	**0.010**
Village 9	0.000	0.000	0.017	0.087	-0.035	0.069	-0.192	0.167	**0.593**	**0.060**	**0.037**	**0.010**
Village 10	0.000	0.000	0.003	0.087	-0.020	0.069	-0.010	0.166	-0.112	0.075	-0.002	0.010

Appendix 2: Supplementary material for Chapter 5

Contents

A2.1. Context & Study site

A2.1.1 Study site

Preah Vihear province in northern Cambodia contains some of the largest remaining stretches of the lowland forests which used to cover much of mainland Southeast Asia. The forests consist of a complex mosaic of evergreen rainforest, deciduous dry forests, and grasslands. They are home to at least 28 species listed as Endangered or Critically Endangered (Clements *et al.*, 2010). Many of these species rely on seasonal waterholes for food and water throughout the dry season (Pin *et al.*, 2018).

Conservation efforts in this region have focused on three protected areas: Chheb, Prey Preah Rokha, and Kulen Promtep Wildlife Sanctuaries, managed by the Ministry of Environment. Several villages are located within the protected areas, comprised largely of rice farmers. A challenge is therefore to balance conservation with the development and livelihood aspirations of local communities. Several interventions have been implemented to meet these goals (Riggs *et al.*, 2020). Most notably, a conservation agriculture programme, which enables participating farmers to achieve higher prices for their produce if they comply with conservation rules (Beauchamp, Clements & Milner-Gulland, 2018a).

A2.1.2 Wildlife Poisoning

Wildlife poisoning was first reported here in 2015. This method of hunting seems to be increasingly common and has severe implications for threatened wildlife and human health. Hunters place carbamate pesticides near waterholes in the dry season to catch wildlife, largely for home consumption. It is not clear whether this practice is related to food insecurity, but there is a clearer link with attitudes and (mis)-perceptions of the health risks involved in consuming poisoned meat. Poisoning has negative impacts on other residents, their livestock, and access to fisheries and clean water sources. Most residents have strongly negative attitudes towards poisoning, and in several villages local authorities have attempted to act against poisoning, such as by holding village meetings, disciplining poison hunters, or even informally banning sale of carbamates (Chapter 4).

A2.1.3 Case study intervention

To support these local efforts, the Wildlife Conservation Society is trialling the introduction of a reporting hotline to enable residents to anonymously report poisoning. Such a report would enable authorities to respond to poisoning more quickly, by removing the contamination, and would enable communities to display clear anti-poisoning norms and reduce the likelihood of poisoning. To promote this hotline, we co-designed a social marketing intervention and piloted this in one community. The intervention consisted of a half-day event. For the pilot, and for the purposes of this study, forty-one adults, chosen because they have children aged 10 to 15, were invited to the village hall.

At the event, officials from provincial government departments (agriculture, health, and environment) and local NGOs talked about different aspects and consequences of wildlife poisoning. Residents of a neighbouring village who had lost cattle to poisoning also gave testimony, with graphic evidence, and the audience was given the opportunity to ask questions. NGO staff then introduced and explained the hotline, and a short film was shown. This film dramatizes a poisoning event in a local village which ends happily after the hotline is used by the protagonist and his family (Figure 2.6). Finally, participants were invited to make a public pledge of 'good citizenship', pledging to use pesticides responsibly and be vigilant to report misuse. Pledgees were given a certificate by the commune chief. All participants received various materials aimed at reinforcing the event's key messages and enabling them to share the messages in their social networks (Figure 2.6). Our study focused on three key messages from the event relating to the 1) details about the hotline, 2) the short film plot, and 3) participants and details in the pledge.

A2.1.4 Study village

Our study takes place in the village targeted for this pilot intervention. The village was selected because it is situated close to important wildlife habitat, poisoning has occurred there in the past, and the village chief has previously attempted to act against poisoning. Furthermore, the village was a feasible choice for this study because of its moderate size and easy access by road. Like other villages in the landscape, the village consists largely of rice farmers, but increasingly residents also grow cash crops, such as cassava or cashew. Gathering of forest products, such as mushrooms and resin, are also important livelihood activities, as are fishing and, to a lesser extent, hunting. A small group are engaged in illegal logging of luxury hardwoods. A further small number of households spread throughout the village run business like small shops, or a garage.

The village was settled in the first half of the twentieth century, within memory of some older residents. It is in a large expanse of forest and was relatively isolated for decades. Since the end of fighting with the Khmer Rouge in 1999, the Cambodian state has steadily consolidated its control over the area through infrastructure development and patronage schemes. In 2014 a good quality dirt road was built, passing by the village, and the roads within the village were formalised into a grid. This has enabled increasing migration of people from other provinces into the village and prompted many villagers to relocate their homes to better access the road. The village is thus comprised of two sections with roughly equal population: an older core, laid out in a grid and inhabited mainly by long-term residents, and a short distance away, households arranged along the road.

The village has a chief appointed by the state with the consent of village elites. He is responsible for bureaucratic functions such as signing marriage certificates and approving land transfers. He also has a deputy. Furthermore, there is a community forest, managed and patrolled by a small committee of elected residents, and a village market network which regulates enrolment in the conservation agriculture project and is also managed by an elected committee.

A2.2. Data collection

All data was collected using questionnaire surveys administered verbally by a research assistant in Khmer. The questionnaires were translated from English, and then translated back to English, to ensure accuracy. Research assistants were trained in questionnaire protocols, and each questionnaire used was piloted in another village, or among a small sample of households in the study village, which were then excluded from the data if any subsequent changes were made. The questions were asked verbally, and verbal responses were recorded on tablets using the Open Data Kit software (Brunette *et al.*, 2013). Each survey was delivered by two research assistants under the supervision of the lead author. Prior to each survey, consent was received from the village chief, and each respondent provided their informed consent prior to the interview. These protocols were approved by the University of Edinburgh, School of Geosciences, Ethics committee (No. 132, 2017, & No. 191, 2018).

A2.2.1 Data types

A2.2.1.1 Network data

In 2017, we conducted a qualitative exploratory study to understand which social interactions may be important for communicating about topics such as agriculture, conservation, poisoning, or other village events. We organised focus group discussions in 12 villages with men and women separately, interviewed key informants, and observed social interaction over a month spent in the villages. We determined that information related to the intervention was not likely to flow through interactions specific to this topic, but instead would flow through general every-day interactions. We determined that most time is spent interacting with members of one's household, but that villagers also visit one another at home.

We then collected data on these social ties using a name generator questionnaire in free-recall format. We asked respondents to nominate those individuals whom they a) visited at home during their spare time, or b) received as visitors at their home. Respondents would typically provide one or two names, and the research assistant would then prompt them for more names until they declined to provide more names. We collected data on household co-residence through an initial household survey. One adult in each household was asked to describe and name all individuals living in the household. We then returned to the household for the individual interviews and verified their identities.

We employed several strategies to ensure the social tie data collected was reliable and could be used to produce a social network. Firstly, the research team manually corroborated and corrected respondent names against a village census provided by the village chief. Secondly, we used fuzzy matching in R to identify all names in the data that differed from other names by less than three characters. Third, we generated a list of names that occurred only once in our dataset. Having compiled a set of potentially problematic cases using these two methods, we manually checked each name to see if there were obvious identity confusions, or if nicknames were used. We used kinship data we had collected to create a genealogy, which served as a reference to check and correct possible misspellings. For example, if Rob Franks had nominated Tim Franks and Mary Franks as siblings, but Mary had nominated Rob and Tom as siblings, we presumed Tim and Tom were alternate spellings of the same person. We selected one option and corrected any occurrences of this name in the dataset. This is a conservative strategy given that illiteracy is prevalent, and many possible spellings exist for any name in Khmer.

A2.2.1.2 Demographic & household data

During the household survey we collected data about the livelihood strategies employed by the household, pesticide usage, participation in the conservation agriculture programme, and household wealth. We corroborated data on participation in the conservation agriculture programme with data provided by Sansum Mlup Prey, the administering organisation. Household wealth was measured in a 6-point scale adapted from the Basic Necessities Survey previously developed in this area (Beauchamp *et al.*, 2018).

A2.2.1.3 Psychological outcomes

We measured five variables from the Theory of Planned Behaviour (Ajzen, 1991): intention to report poisoning, attitudes towards reporting poisoning, perception of behavioural control, perceptions of descriptive norms, and perceptions of injunctive norms. We used multiple questions for each variable, measured using 5-point Likert scales, and summed these to provide a value for that variable. Each five-point scale consisted of Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree. ‘Don’t know’ was also an option, and these responses were excluded from the data. Questions were worded both negatively and positively and were ordered randomly. The questions are grouped by variable below.

INTENTION

Next time I see a trapeang with poison I will keep it to myself and not report it.

តើអ្នកយល់ស្របដែរឬទេថា,លើកក្រោយអ្នកឃើញត្រពាំងមានការបំពុល អ្នកនឹងមិនរាយការណ៍ទៅអាជ្ញាធរទេ ?

I will report poisoning if I see it.

តើអ្នកយល់ស្របដែរឬទេថា,អ្នកនឹងរាយការណ៍ពីការបំពុល ប្រសិនបើអ្នកបានឃើញ ?

ATTITUDES

If you see poisoning, it is good to keep it to yourself and not report it.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុល វាជារឿងល្អដែលអ្នកគួរលាក់ទុកហើយមិនធ្វើការរាយការណ៍ទៅអាជ្ញាធរ ?

If I see poisoning and report it, the village will be safer.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុលហើយរាយការណ៍ តើអ្នកភូមិនឹងមានសុវត្ថិភាពជាងមុនដែរឬទេ?

Reporting poisoning is a good way to keep livestock safe.

តើអ្នកយល់ស្របដែរឬទេថា,ការរាយការណ៍ពីការបំពុលជាវិធីសាស្ត្រដ៏ល្អមួយដើម្បីបាននូវសុវត្ថិភាពជីវិតសត្វ?

If I see poisoning and report it, no one will come to clean the environment.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញការបំពុលហើយរាយការណ៍ គ្មាននរណាម្នាក់នឹងមកសម្អាតបរិស្ថានរបស់អ្នកទេ ?

PERCEIVED BEHAVIORAL CONTROL

If I see a poisoned trapeang, I know how I can report it.

តើអ្នកយល់ស្របដែរឬទេថាប្រសិនបើអ្នកបានឃើញមានការបំពុល អ្នកដឹងពីវិធីដែលអ្នកអាចធ្វើការរាយការណ៍ពីការបំពុល?

Reporting poisoning takes a lot of effort and time.

តើអ្នកយល់ស្របដែរឬទេថាការរាយការណ៍ពីការបំពុលគឺចំណាយការខំប្រឹងនិងពេលវេលាច្រើន ?

It’s easy to report trapeang poisoning.

តើអ្នកយល់ស្របដែរឬទេថាវាមានលក្ខណៈងាយស្រួលក្នុងការរាយការណ៍ពីការបំពុល?

PERCEIVED INJUNCTIVE NORMS

It’s better not to report poisoning, because it will cause conflict in the village.

តើអ្នកយល់ស្របដែរឬទេថាវាជារឿងល្អដែលមិនរាយការណ៍ពីការបំពុល   ពីព្រោះវាអាចបណ្តាលអោយអ្នកមានជំលោះនៅក្នុងភូមិ ?

If I see poisoning and report it, other people in the village will argue with with me.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញការបំពុលហើយរាយការណ៍ តើប្រជាជនផ្សេងទៀតនៅក្នុងភូមិមានការអន់ចិត្តជាមួយអ្នកដែរឬទេ?

If I see poisoning and report it, most villagers will be happy with me.

តើអ្នកយល់ស្របដែរឬទេថាប្រសិនបើអ្នកឃើញមានការបំពុលហើយរាយការណ៍ប្រជាជនភាគច្រើននឹងសប្បាយចិត្តជាមួយអ្នក ?

The village authorities expect me to report poisoning if I see it.

តើអ្នកយល់ស្របដែរឬទេថា,អាជ្ញាធររំពឹងទុកថាអ្នកនឹងរាយការណ៍ពីការបំពុលប្រសិនបើអ្នកបានឃើញពីការបំពុល?

PERCEIVED DESCRIPTIVE NORMS

Normal people will report poisoning if they see it

តើអ្នកយល់ស្របដែរឬទេថា, ប្រជាជនធម្មតានឹងធ្វើការរាយការណ៍ពីការបំពុលប្រសិនបើពួកគាត់បានឃើញ មានការបំពុល ?

Most people in the village will not report poisoning if they see it

តើអ្នកយល់ស្របដែរឬទេថា, ប្រជាជនភាគច្រើននៅក្នុងភូមិនឹងមិនរាយការណ៍ពីការបំពុលប្រសិនបើពួកគេឃើញមានការបំពុល?

A2.2.1.4 Internal consistency checks

The questions for each variable were all internally consistent (Cronbach's alpha > 0.5), except for perceived behavioural control (Table A2.1).

Table A2.1: internal consistency checks for TPB constructs, measured using Cronbach's alpha.

Variable	Wave 1	Wave 2	Wave 3	**Overall**
Intention	0.57	0.80	0.40	**0.64**
Control	0.42	0.48	0.47	**0.45**
Attitudes	0.64	0.52	0.62	**0.58**
Injunctive norms	0.48	0.66	0.43	**0.53**
Descriptive norms	0.15	0.39	0.33	**0.32**

A2.2.1.5 Knowledge & information

In survey waves following the intervention we used 12 questions about aspects of the intervention to assess respondent's knowledge of key messages. These questions were designed so that they did not give away the relevant information for future interviews. We asked about knowledge which no respondent could have had access to prior to the intervention. Furthermore, knowledge was grouped around three themes of the intervention: 1) details of the reporting hotline; 2) the plot of the short story; and 3) information about the pledge taken by some event attendees. Questions were posed in an open-ended way, but each question had a single correct answer, so we coded responses into binary variables for correct/false.

A2.3. Missingness & imputation strategies

A2.3.1 Missingness

There is considerable missingness in our data (Table A2.2). In Wave two, missingness is largely because we excluded a randomly select half of households from the survey, in order to be able to control for the effect of the survey on later changes in behaviour and knowledge.

Table A2.2: Summary of data-collection waves

Survey wave	Description	Data Collected	Completeness (% individuals of 365)	Completeness (% households of 154)
Preliminary	Preliminary surveys of individuals and households	Network	100	100
One	Baseline measurements	Behaviour	50	60
Two	Post-intervention measurements	Behaviour	77	93
Three	Final medium-term follow-up	Network* & Behaviour	53	72

In wave 3 (Table A2.2), we recorded the reasons for non-responses (Table A2.3). We are confident that at least 10 respondents were missing at random, for reasons unrelated to our research, such as the travel for health reasons or work. We received these explanations from other household members encountered. A further 25 respondents were encountered but refused consent to participate in the study. These non-responses are likely not random with respect to the data, as respondents will have been aware of the research topic from previous waves. The largest number of non-responses, 62, were for unknown reasons. Often, this is because the entire household was absent from the village. We can assume that a large portion of these non-responses will have been at random, perhaps because of travel to other places, or temporary relocation to the rice fields for work. However, it is a possibility that some households decided to leave the village when they became aware that the research team was present. These households will therefore not be missing at random.

Table A2.3: Reasons recorded for non-response of respondents in wave 3.

Reason for non-response	No. of respondents
Travel to other places	10
Refused consent	25
Unknown	62

A2.3.2 Complete case analyses

Only 24% of individual respondents were present in all four waves, while 62% were present in at least three waves (including the network data in wave one). Complete-case analysis across all four waves would therefore reduce the amount of data available to an unreasonable level. For generalised linear models, we therefore undertook analysis on a period-by-period basis, to maximise retention of data. We also conducted network analyses on complete cases using the handling of missingness built-in to the SIENA algorithm (see section 5).

A2.3.3 Knowledge

We manually imputed missing data on knowledge about information from the intervention. As the modal state for any question about knowledge at each time point was zero (i.e., no knowledge), we set any missing values to zero. However, if the respondent had answered the question correctly at the previous wave, we carried this correct answer forward, assuming that they would still be able to recall the information. This is a conservative assumption as of the 266 'bits' of knowledge recorded in wave two, only 34 (13%) were not recalled again in wave three.

A2.3.4 Behavioural variables

To impute the five variables from the Theory of Planned Behaviour, we used the multiple imputation using chained equations algorithm (van Buuren & Groothuis-Oudshoorn, 2011) in R (R Core Team, 2017). We generated twenty imputations used the predictive mean matching method and included the following variables in the imputation algorithm (Table 3). These imputed variables were used in generalised linear models.

Table A2.4: List of variables used in imputation using mice.

Variable	**Type**
Attendance at the event	Binary
Household number (ID)	integer
Household pesticide use	binary
Household participation in conservation agriculture programme	binary
Gender	binary
Age (normalised)	integer
Household wealth score	integer (1-5)
Inclusion in the baseline survey	binary
Network in-degree	integer
Average intention of network alters in wave 1	integer
Average intention of network alters in wave 2	integer
Average intention of network alters in wave 3	integer
Average attitudes of network alters in wave 1	integer

Average attitudes of network alters in wave 2	integer
Average attitudes of network alters in wave 3	integer
Baseline knowledge (0)	integer
Wave 2 knowledge of hotline	integer
Wave 3 knowledge of hotline	integer
Wave 2 knowledge of story	integer
Wave 3 knowledge of story	integer
Wave 2 knowledge of pledge	integer
Wave 3 knowledge of pledge	integer
Baseline intention	integer
Baseline attitudes	integer
Baseline perceived control	integer
Baseline perceived descriptive norms	integer
Baseline perceived injunctive norms	integer
Wave 2 intention	integer
Wave 2 attitudes	integer
Wave 2 perceived control	integer
Wave 2 perceived descriptive norms	integer
Wave 2 perceived injunctive norms	integer
Wave 3 intention	integer
Wave 3 attitudes	integer
Wave 3 perceived control	integer
Wave 3 perceived descriptive norms	integer
Wave 3 perceived injunctive norms	integer

We observe the following output plots. Figure A2.1 shows the values for each of the missing variables across the twenty imputations. There are no clear patterns, trends, or outliers in the imputed variables, indicating a reasonable imputation. Figure A2.2 shows the imputed distributions for each variable in red, and the observed distribution in blue. There are no obviously concerning discrepancies between the observed and imputed distributions. However, there is high variation between the imputed values.

A2.3.5 Network imputation

Network data was complete for 365 individuals in the preliminary wave, was not collected in wave one or two, and was 52% complete in wave three. We modelled the data with network measured in the preliminary wave held constant across all waves and modelled changes in behaviour with reference to this network. We used a joint network-behaviour multiple imputation to impute the missing behavioural data. This approach assumes that social interactions are unlikely to change significantly within the two-year period of the research study. For household co-residence ties this is a very plausible assumption. The partial re-measurement of network data in wave 3 was incomplete and not sufficient for dynamic network modelling. However, assuming that both network measurements represent observations of the same underlying social network, we perform a robustness check by repeating our models using the updated network. In this network, individuals not surveyed in wave 3 retain their network ties from wave 1. The updated network had 1604 ties, of which 954 were visit ties between members of different households. Among ties outside of the household, there was assortment by wealth (+0.48) and participation in conservation agriculture (+0.43), but not by age (+0.08) or gender (+0.09). Mean out-degree = 4.40, Reciprocity = 0.54, Transitivity = 0.23, Density = 0.01.

RSiena In-built handling of missingness

RSiena treats missing data as 'non-informative' and attempts to reduce the influence of missing data on results (Ripley *et al.*, 2020). The method is thought to be robust to missingness of around 20% depending on the informativeness of the missing data (Huisman & Steglich, 2008), far lower than the missingness in our dataset. To do this, the model carries out simulations over all variables by imputing missing values. Missing data on network ties is set to '0', i.e., assuming no ties are present, but in following waves, data is carried forward. In other words, if an individual has reported tie data in wave one but is missing from wave two, their ties will be assumed to remain constant from wave one to wave two. Behavioural data is also imputed. If the data point was measured in the previous wave, it is simply assumed to be unchanged. If it is not present in the previous wave, but is present in the following wave, it is also imputed and assumed unchanged. If this is also absent, then the observed mode of that variable is imputed. Individual covariates are imputed with the mean of that variable. Imputed data is treated as non-informative, so its effects on parameter estimates is minimised. For any period where an actor has missing data that is required for calculating a statistic, this actor in that period does not contribute to that statistic.

Joint multiple imputation of network and behaviour

Because of the higher missingness in our data, we used the joint network-behaviour multiple imputation strategy described by (Krause, Huisman & Snijders, 2018). A walkthrough script is available online at the link below, which we adapted to our purposes. We implemented this procedure separately for each model specification (see section A2.5).

http://www.stats.ox.ac.uk/~snijders/siena/MultipleImputationNetworkAndBehavior.html#imputing-the-behavior-with-mice.

Following multiple imputation with mice, we estimate a stationary stochastic actor-oriented model (SAOM). This is an analysis of cross-sectional network data using the SAOM model, which is usually applied to dynamic networks (Snijders & Steglich, 2015). In the cross-sectional SAOM, we fixed the network rate function at a low value (0.01), in effect assuming that the network is in a "stochastically stable state" (Krause, Huisman & Snijders, 2018). We also fixed the behavioural rate function at a low value (4). This allows the model simulations to produce some variation from the behavioral values imputed by mice in wave 1. We included all network and behavioural effects that were included in the final estimation model and estimated the model over the constant network from wave one, with all twenty behavioral imputations. The observed behaviour at wave 2 was also included as a covariate. Once the model was estimated we imputed 20 sets of behaviour values for wave one using a maximum likelihood simulation. (note: this required creating one random change in the network).

We used each of the 20 imputed values in wave one to impute behaviour and/or network data for waves 2 and 3 sequentially. Again, all the effects to be included in the final estimation were included here. The variable 'knowledge' was not included in the initial stationary SAOM because at wave one knowledge values for all individuals are zero. As the network was kept constant, each wave was treated as a stationary SAOM with respect to the network, meaning that the network rate function was fixed at 0.01, and network effects were not included. Finally, the 20 sets of imputed values for all waves were used in the final SAOM estimation, including the same effects. The results were then combined using Rubin's Rules (Krause, Huisman & Snijders, 2018).

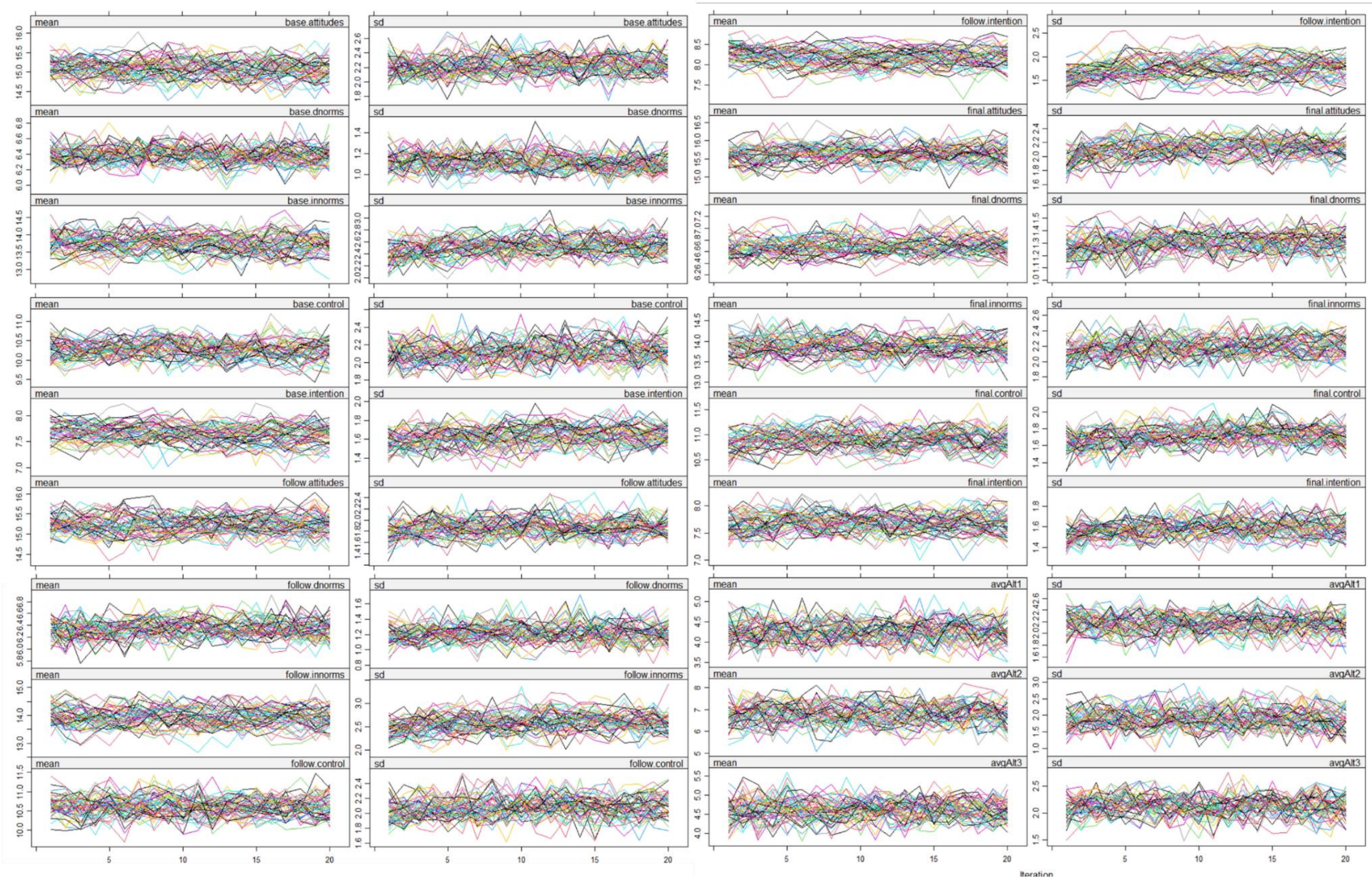


Figure A2.6: Mean imputed values and standard deviations for 20 imputations of each of 36 variables with missing data

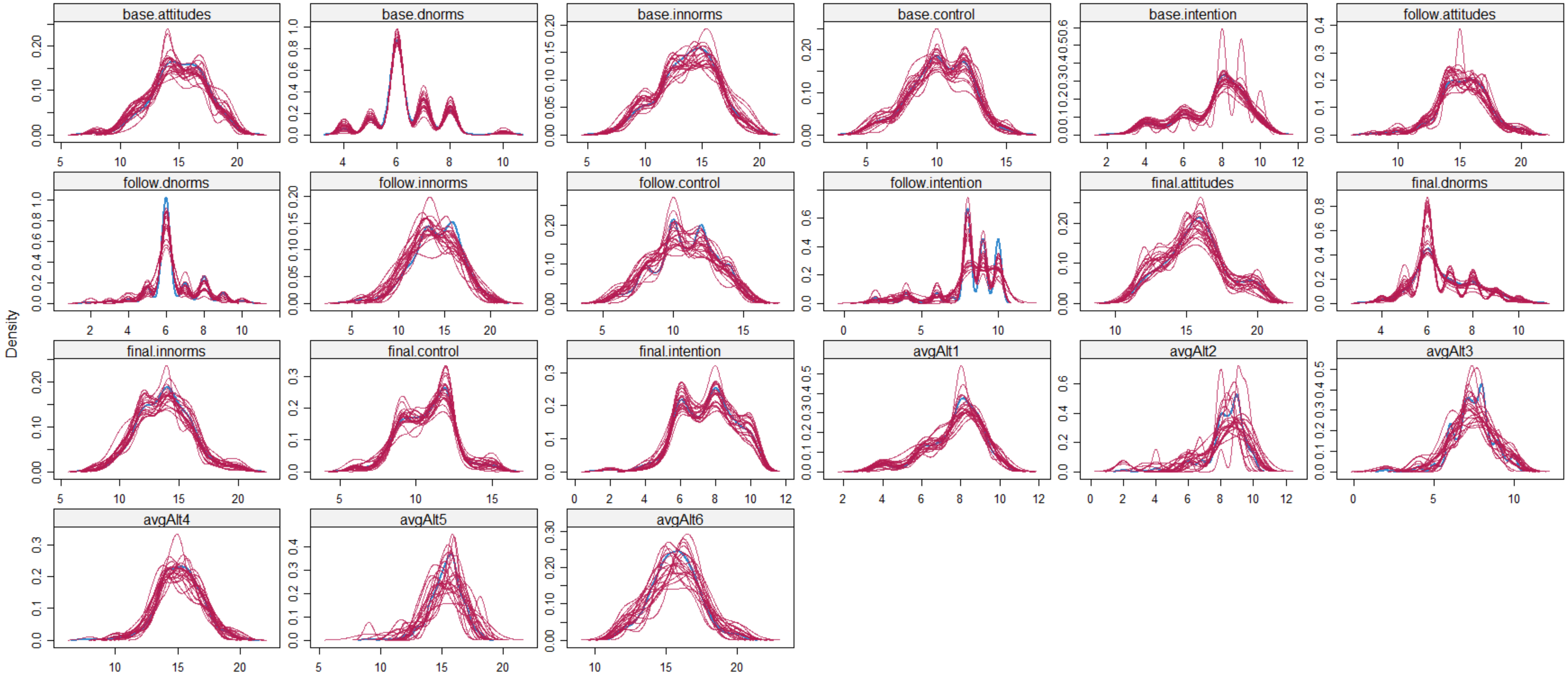


Figure A2.7: Density plot showing the distributions of imputed values (red) and the observed values (blue) for each variable with missing data

A2.4. Stochastic Actor Oriented Models

The stochastic actor-oriented model (SAOM) is an agent-based model of network and behaviour co-evolution (Snijders, van de Bunt & Steglich, 2010; Steglich, Snijders & Pearson, 2010). The rate function determines how many opportunities each actor has to alter their behaviour or ties. At each opportunity, individuals in the network can increase, decrease, or maintain their behaviour, and they can maintain, remove, or form new social ties. These decisions are simulated, and at the end of each period, are compared with the observed data provided. The decisions are also influenced by specified effects which can be the effects of individual or dyadic covariates, the effects of network on behaviour, behaviour on network choices, or more complex interactions. Please see the manual for more details (Ripley *et al.*, 2020).

Our primary research interest was to do with the effects of network ties on behaviour and information diffusion, not the evolution of the social network. Because we only have partial network data available for the latter waves, we therefore estimated SAOMs with the network kept constant throughout all periods. This enabled us to model how the behaviours changed in relation to the network. We did this by setting the rate parameter for the network to a low value (=0.01, personal communication from Professor Tom Snijders). As a robustness check to account for noise in the network measurements, we also fitted models with the updated network ties in wave 3.

A forward model selection approach is advised with SAOMs because of difficulties in achieving model convergence. This means that models are built step by step, adding additional effects one by one so long as the model achieves a good convergence ratio (<0.2 in our case). We applied this approach to building our models. For the models with network held constant, we began with the effect of interest (i.e., social influence), and then added control effects. For the dynamic network models, we started with fundamental network mechanisms, such as reciprocity. The final models presented here may therefore not include all the effects that would ideally be included, but they are the best fitting models that converge.

Here follows a description of the different effects.

The *rate parameters* represent the number of stochastically determined opportunities for actors to change their network ties or their behaviour. For the network ties, these are fixed by us at 0.01, limiting the opportunities for changes in the network at close to zero (however, a zero value is not tolerated by the algorithm).

Outdegree (density) must always be included but is not of interest given the fixed rate parameter for the network ties. The negative value simply indicates that individuals in the network do not tend to create new outgoing network ties.

Linear shape expresses the basic tendency for the behaviour to increase over time. However, this effect cannot be easily interpreted in relation to the other effects in the model and is residual on the other effects.

Quadratic shape is the effect of the behaviour on itself. A positive effect expresses the tendency for those at high levels of the behaviour to further increase their behaviour. A negative effect indicates a negative feedback. This is also a difficult effect to interpret with similarity effects included in the model.

In-degree and out-degree effects express the tendency for individuals with higher numbers of incoming and outgoing network ties respectively to increase their behaviour.

Effects from covariates, including age, gender, wealth, pesticide use, and participation in conservation agriculture, indicate the tendency for individuals with higher variates of these covariates to increase their behaviour. For changing covariates, such as the time dummy or knowledge, this expresses the tendency for individuals with higher values of the covariate in a given period to subsequently increase their behaviour.

Average similarity effects express the tendency for individuals to increase or decrease their behaviour in the direction of the average (mean) of their peer's behaviour.

Average alter covariate effects express the tendency for individuals whose peers have a higher average value for a covariate, *x*, to increase their level of the behaviour. For example, we model the tendency for those whose alters have higher intention to report poisoning to subsequently increase their perceived descriptive norms.

Additionally, to model the flow of information or knowledge about the intervention, we use the diffusion of innovations extension (Greenan, 2015). This models the spread of knowledge as a binary variable (i.e., knowledgeable or not), and non-decreasing (i.e. individuals cannot forget). As knowledge is a simple contagion (Granovetter, 1973), it can be transmitted through any single contact. The effect used to model this spread is the *total exposure effect*, which expresses the likelihood of an individual 'adopting' knowledge as a function of the total number of their network peers who have previously become knowledgeable. A higher value thus indicates that individuals are more likely to become knowledgeable with each additional knowledgeable peer.

A2.5. Model results

Table A2.5: Linear mixed effect models for intention to report.

	Event participation				Intervention knowledge (combined)			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	7.750	0.439	7.605	0.382	7.715	0.427	7.584	0.376
Wave 2 (β_{w2})	0.559	0.184	0.546	0.194	0.560	0.176	0.557	0.189
Wave 3 (β_{w3})	-0.077	0.195	-0.130	0.172	-0.216	0.190	-0.224	0.178
Participation in the event (β_{par})	0.065	0.374	0.052	0.330	-	-	-	-
Combined knowledge of the intervention normalised (β_{know})	-	-	-	-	0.144	0.062	0.105	0.066
- Knowledge of the pledge (β_{pledge})	-	-	-	-	-	-	-	-
- Knowledge of the hotline ($\beta_{hotline}$)	-	-	-	-	-	-	-	-
- Knowledge of the story (β_{story})	-	-	-	-	-	-	-	-
Gender (β_{gen})	0.202	0.167	0.178	0.154	0.185	0.164	0.168	0.153
Age (normalised) (β_{age})	0.069	0.089	0.114	0.186	0.085	0.084	0.098	0.078
Participation in conservation agriculture (β_{SMP})	0.191	0.180	0.090	0.080	0.177	0.177	0.108	0.185
Household wealth (β_{wea})	-0.098	0.088	-0.053	0.088	-0.098	0.087	-0.051	0.088
Participation in baseline survey (β_{base})	-0.045	0.178	-0.047	0.165	-0.023	0.174	-0.035	0.163
Household pesticide use (β_{pest})	-0.135	0.200	-0.115	0.222	-0.148	0.198	-0.120	0.222
Participation in the event * wave 2 (β_{par*w2})	0.628	0.422	0.615	0.390	-	-	-	-
Participation in the event * wave 3 (β_{par*w3})	-0.159	0.460	-0.114	0.400	-	-	-	-

Table A2. 6: Linear mixed effect models for attitudes

	Event participation				Intervention knowledge (combined)				Intervention knowledge (split)			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations		5. Complete cases		6. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	15.643	0.525	15.655	0.449	15.712	0.501	15.667	0.437	15.719	0.501	15.670	0.436
Wave 2 (β_{w2})	0.157	0.236	0.217	0.238	-0.025	0.224	0.087	0.234	-0.046	0.227	0.070	0.231
Wave 3 (β_{w3})	0.579	0.250	0.523	0.227	0.278	0.241	0.273	0.226	0.298	0.242	0.281	0.231
Participation in the event (β_{par})	0.431	0.462	0.267	0.426	-	-	-	-	-	-	-	-
Combined knowledge of the intervention normalised (β_{know})	-	-	-	-	0.306	0.075	0.330	0.095	-	-	-	-
- Knowledge of the pledge(β_{pledge})	-	-	-	-	-	-	-	-	0.272	0.157	0.215	0.151
- Knowledge of the hotline ($\beta_{hotline}$)	-	-	-	-	-	-	-	-	0.097	0.074	0.155	0.153
- Knowledge of the story (β_{story})	-	-	-	-	-	-	-	-	0.128	0.140	0.111	0.082
Gender (β_{gen})	0.509	0.196	0.412	0.199	0.483	0.189	0.394	0.197	0.481	0.190	0.390	0.200
Age (normalised) (β_{age})	-0.074	0.105	0.282	0.202	-0.066	0.097	0.260	0.199	-0.070	0.092	0.262	0.198
Participation in conservation agriculture	0.322	0.211	-0.028	0.098	0.282	0.205	-0.023	0.093	0.281	0.205	-0.023	0.094

(β_{SMP})												
Household wealth (β_{wea})	-0.156	0.104	-0.192	0.103	-0.156	0.101	-0.188	0.100	-0.154	0.101	-0.187	0.100
Participation in baseline survey (β_{base})	-0.182	0.212	-0.181	0.188	-0176	0.204	-0.171	0.180	-0.177	0.204	-0.173	0.179
Household pesticide use (β_{pest})	0.094	0.237	0.106	0.234	0.075	0.229	0.100	0.232	0.078	0.229	0.100	0.230
Participation in the event * wave 2 (β_{par*w2})	0.228	0.542	0.413	0.521	-	-	-	-	-	-	-	-
Participation in the event * wave 3 (β_{par*w3})	-0.214	0.589	0.076	0.571	-	-	-	-	-	-	-	-

Table A2.7: Linear mixed effect models for perceived behavioural control

	Event participation				Intervention knowledge (combined)				Intervention knowledge (split)			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations		5. Complete cases		6. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	10.246	0.522	10.169	0.492	10.215	0.507	10.138	0.481	10.217	0.506	10.138	0.480
Wave 2 (β_{w2})	0.786	0.208	0.666	0.261	0.726	0.198	0.621	0.237	0.680	0.201	0.577	0.235
Wave 3 (β_{w3})	0.666	0.222	0.525	0.261	0.461	0.214	0.351	0.247	0.489	0.216	0.365	0.248
Participation in the event (β_{par})	0.220	0.437	0.340	0.415	-	-	-	-	-	-	-	-
Combined knowledge of the intervention normalised (β_{know})	-	-	-	-	0.233	0.072	0.205	0.078	-	-	-	-
- Knowledge of the pledge(β_{pledge})	-	-	-	-	-	-	-	-	0.253	0.146	0.180	0.149
- Knowledge of the hotline ($\beta_{hotline}$)	-	-	-	-	-	-	-	-	0.019	0.069	0.207	0.132
- Knowledge of the story (β_{story})	-	-	-	-	-	-	-	-	0.176	0.130	0.003	0.069
Gender (β_{gen})	0.395	0.200	0.328	0.207	0.372	0.196	0.307	0.206	0.356	0.196	0.287	0.207
Age (normalised) (β_{age})	-0.093	0.106	0.091	0.241	-0.071	0.100	0.079	0.240	-0.069	0.101	0.081	0.239

Participation in conservation agriculture (β_{SMP})	0.126	0.215	-0.072	0.101	0.101	0.213	-0.051	0.097	0.101	0.212	-0.044	0.098
Household wealth (β_{wea})	-0.070	0.106	-0.006	0.096	-0.067	0.104	0.000	0.095	-0.066	0.104	-0.001	0.095
Participation in baseline survey (β_{base})	0.195	0.211	0.120	0.206	0.221	0.207	0.151	0.203	0.216	0.206	0.143	0.201
Household pesticide use (β_{pest})	-0.023	0.241	-0.039	0.245	-0.040	0.237	-0.052	0.242	-0.043	0.237	-0.060	0.239
Participation in the event * wave 2 (β_{par*w2})	0.628	0.479	0.595	0.486	-	-	-	-	-	-	-	-
Participation in the event * wave 3 (β_{par*w3})	-0.077	0.523	-0.138	0.506	-	-	-	-	-	-	-	-

Table A2.8: Linear mixed effect models for perceived descriptive norms

	Event participation				Intervention knowledge (combined)				Intervention knowledge (split)			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations		5. Complete cases		6. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	6.255	0.306	6.196	0.299	6.259	0.298	6.206	0.297	6.251	0.298	6.203	0.296
Wave 2 (β_{w2})	0.106	0.136	0.076	0.142	0.091	0.128	0.049	0.136	0.071	0.130	0.041	0.133
Wave 3 (β_{w3})	0.419	0.144	0.382	0.172	0.364	0.138	0.314	0.166	0.367	0.139	0.313	0.167
Participation in the event (β_{par})	-0.182	0.268	-0.132	0.276	-	-	-	-	-	-	-	-
Combined knowledge of the intervention normalised (β_{know})	-	-	-	-	0.093	0.044	0.112	0.059	-	-	-	-
- Knowledge of the pledge(β_{pledge})	-	-	-	-	-	-	-	-	0.011	0.091	0.005	0.088
- Knowledge of the hotline ($\beta_{hotline}$)	-	-	-	-	-	-	-	-	0.005	0.043	0.128	0.078
- Knowledge of the story (β_{story})	-	-	-	-	-	-	-	-	0.158	0.082	0.030	0.053
Gender (β_{gen})	-0.104	0.114	-0.118	0.119	-0.102	0.114	-0.119	0.118	-0.120	0.114	-0.129	0.119
Age (normalised) (β_{age})	0.020	0.061	0.147	0.120	0.009	0.058	0.138	0.119	0.019	0.059	0.139	0.118

Participation in conservation agriculture (β_{SMP})	0.194	0.123	0.012	0.074	0.182	0.123	0.005	0.069	0.185	0.123	0.010	0.069
Household wealth (β_{wea})	-0.028	0.061	0.013	0.055	-0.028	0.060	0.013	0.055	-0.028	0.060	0.012	0.055
Participation in baseline survey (β_{base})	0.170	0.123	0.114	0.117	0.166	0.121	0.105	0.116	0.160	0.122	0.102	0.114
Household pesticide use (β_{pest})	0.084	0.138	0.059	0.144	0.083	0.137	0.062	0.144	0.074	0.137	0.057	0.145
Participation in the event * wave 2 (β_{par*w2})	0.317	0.313	0.297	0.304	-	-	-	-	-	-	-	-
Participation in the event * wave 3 (β_{par*w3})	0.152	0.340	0.185	0.361	-	-	-	-	-	-	-	-

Table A2.9: Linear mixed effect models for perceived injunctive norms

	Event participation				Intervention knowledge (combined)				Intervention knowledge (split)			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations		5. Complete cases		6. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	13.359	0.647	13.024	0.575	13.196	0.630	12.968	0.560	13.177	0.627	12.960	0.558
Wave 2 (β_{w2})	0.283	0.261	0.264	0.273	0.310	0.247	0.246	0.264	0.238	0.250	0.199	0.267
Wave 3 (β_{w3})	0.074	0.277	0.091	0.247	-0.082	0.268	-0.124	0.244	-0.066	0.269	-0.116	0.246
Participation in the event (β_{par})	-0.206	0.543	-0.086	0.476	-	-	-	-	-	-	-	-
Combined knowledge of the intervention normalised (β_{know})	-	-	-	-	0.322	0.090	0.337	0.103	-	-	-	-
- Knowledge of the pledge(β_{pledge})	-	-	-	-	-	-	-	-	0.114	0.181	0.125	0.173
- Knowledge of the hotline ($\beta_{hotline}$)	-	-	-	-	-	-	-	-	0.017	0.085	0.380	0.144
- Knowledge of the story (β_{story})	-	-	-	-	-	-	-	-	0.480	0.162	0.052	0.074
Gender (β_{gen})	0.231	0.247	0.319	0.239	0.211	0.243	0.295	0.242	0.157	0.243	0.264	0.240
Age (normalised) (β_{age})	0.175	0.131	-0.031	0.259	0.205	0.125	-0.053	0.257	0.232	0.125	-0.050	0.255

Participation in conservation agriculture (β_{SMP})	0.202	0.266	0.194	0.112	0.170	0.264	0.209	0.106	0.179	0.263	0.224	0.107
Household wealth (β_{wea})	-0.098	0.131	0.006	0.119	-0.092	0.129	0.012	0.118	-0.093	0.129	0.009	0.118
Participation in baseline survey (β_{base})	0.113	0.262	0.089	0.232	0.169	0.257	0.112	0.225	0.150	0.256	0.101	0.225
Household pesticide use (β_{pest})	0.344	0.298	0.118	0.314	0.326	0.295	0.107	0.310	0.301	0.293	0.092	0.308
Participation in the event * wave 2 (β_{par*w2})	1.476	0.599	1.493	0.537	-	-	-	-	-	-	-	-
Participation in the event * wave 3 (β_{par*w3})	0.629	0.655	0.446	0.567	-	-	-	-	-	-	-	-

Table A2.10: Linear mixed effect models for knowledge

	Event participation			
	1. Complete cases		2. 20 imputations	
Variable	Estimate	SE	Estimate	SE
Intercept	0.357	0.290	0.306	0.323
Wave 2 (β_{w2})	0.517	0.121	0.520	0.127
Wave 3 (β_{w3})	1.229	0.138	1.324	0.203
Participation in the event (β_{par})	0.152	0.271	0.151	0.295
Gender (β_{gen})	0.077	0.122	0.163	0.165
Age (normalised) (β_{age})	-0.117	0.063	0.146	0.163
Participation in conservation agriculture (β_{SMP})	0.123	0.132	-0.101	0.072
Household wealth (β_{wea})	-0.035	0.064	-0.039	0.070
Participation in baseline survey (β_{base})	-0.157	0.121	-0.154	0.145
Household pesticide use (β_{pest})	0.110	0.147	0.078	0.183
Participation in the event * wave 2 (β_{par*w2})	6.483	0.344	6.480	0.365
Participation in the event * wave 3 (β_{par*w3})	4.362	0.382	4.491	0.471

Table A2.11: Generalised linear models for the theory of planned behaviour

	Wave 1				Wave 2				Wave 3			
	1. Complete cases		2. 20 imputations		3. Complete cases		4. 20 imputations		5. Complete cases		6. 20 imputations	
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-1.860	0.680	-1.162	0.842	-1.860	0.680	-0.878	0.754	-0.535	0.797	-0.043	0.744
Perceived behavioural control (β_{con})	0.201	0.045	0.215	0.048	0.201	0.045	0.135	0.039	0.183	0.065	0.143	0.079
Attitudes (β_{att})	0.314	0.043	0.291	0.054	0.314	0.043	0.260	0.050	0.251	0.054	0.232	0.060
Perceived descriptive norms (β_{des})	0.086	0.076	0.009	0.093	0.086	0.076	-0.080	0.064	0.081	0.077	0.123	0.084
Perceived injunctive norms (β_{inj})	0.162	0.041	0.161	0.052	0.162	0.041	0.299	0.035	0.119	0.048	0.115	0.052

Stochastic actor-oriented models

Table A2.12: Information flow

	Network 1				Updated network			
	1. Combined network		2. Split network		3. Combined network		4. Split network	
Effect	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Network dynamics								
Rate constant (period 1)	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA
Rate constant (period 2)	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA
Density (Habitual social contact network)	-2.542	0.425	-	-	-2.541	0.424	-	-
- Density (Household co-residence)	-	-	-2.763	0.424	-	-	-2.764	0.423
- Density (Household visits)	-	-	-2.740	0.434	-	-	-2.755	0.435
- Density (Household visitors)	-	-	-2.810	0.466	-	-	-2.839	0.473
Behaviour dynamics								
Rate (period 1)	0.141	0.028	0.141	0.029	0.136	0.030	0.143	0.029
Rate (period 2)	0.090	0.024	0.091	0.023	0.087	0.024	0.094	0.025
Total exposure effect (Habitual social contact	0.332	0.088	-	-	0.373	0.090	-	-

network)								
- Total exposure effect (Household co-residence)	-	-	0.627	0.140	-	-	0.618	0.138
- Total exposure effect (Household visits)	-	-	0.115	0.185	-	-	0.084	0.208
- Total exposure effect (Household visitors)	-	-	0.114	0.209	-	-	0.117	0.239
Linear shape	2.231	1.090	2.340	1.044	2.202	1.125	2.368	1.136

Table A2.13: Psychological outcomes

Dependent variable:	**1. Change in Intention**				**2. Perceived descriptive norm**				**3. Perceived Injunctive norm**			
	Network 1		Updated network		Network 1		Updated network		Network 1		Updated network	
Effect	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
1. Average similarity	**+1.713**	**0.542**	+2.074	0.593	-	-	-	-	-	-	-	-
2. Average covariate alter (intention or attitudes)	-	-	-	-	-0.004	0.036	+0.033	0.038	-0.012	0.013	+0.001	0.014
3. Intervention knowledge	+0.036	0.022	+0.035	0.023	**+0.064**	**0.029**	0.056	0.032	**+0.047**	**0.015**	**+0.043**	**0.015**
4. Period 2	**-0.222**	**0.048**	**-0.207**	**0.053**	+0.099	0.068	+0.078	0.066	-0.049	0.028	-0.046	0.029
Interactions												
5. Social influence x Knowledge	+0.381	0.487	+0.270	0.505	-0.011	0.029	-0.006	0.034	+0.006	0.013	+0.007	0.013
6. Social influence x Period 2	+0.448	0.699	+0.349	0.969	+0.003	0.074	+0.003	0.100	-0.036	0.027	**-0.056**	**0.027**
Control effects												
7. Linear shape	+0.035	0.065	+0.001	0.060	+0.039	0.091	-0.082	0.094	-0.021	0.040	**-0.085**	**0.039**
8. Quadratic shape	**-0.034**	**0.011**	**-0.029**	**0.012**	**-0.180**	**0.015**	-0.185	0.020	**-0.048**	**0.003**	**-0.047**	**0.004**

9. In-degree	-0.001	0.009	+0.013	0.009	+0.015	0.013	+0.002	0.012	+0.014	0.005	+0.012	0.006
10. Out-degree	+0.010	0.014	+0.003	0.013	-0.010	0.019	+0.027	0.019	-0.006	0.008	+0.012	0.009
11. Age	+0.002	0.002	+0.001	0.001	+0.002	0.002	+0.002	0.002	-	-	-	-
12. Wealth	-0.021	0.023	-0.023	0.021	-0.019	0.030	-0.025	0.026	-	-	-	-
13. Gender	+0.0001	0.04	+0.045	0.042	-0.013	0.062	-0.046	0.057	-	-	-	-
14. Conservation agriculture	+0.04	0.04	+0.020	0.047	**+0.140**	**0.068**	**+0.127**	**0.067**	+0.029	0.031	+0.004	0.032
15. Pesticide use	-0.01	0.05	-0.016	0.048	+0.009	0.069	-0.007	0.067	-	-	-	-
Network dynamics												
16. Rate (period 1)	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA
17. Rate (period 2)	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA	0.010 (Fixed)	NA
18. Outdegree (density)	-2.539	0.435	-2.556	0.479	-2.541	0.422	-2.559	0.422	-2.539	0.431	-2.558	0.434

A2.6. Model diagnostics

All reported models had convergence ratios below 0.2. We checked the goodness of fit using the method described by (Wang *et al.*, 2020) for behavioural dependent variables. This was done for all 20 models, but only a single example is given below for each model. The figures show eight methods for checking model adequacy. In each panel, the observed outcome is shown by a red line, while the distribution of model predictions is given by the violin/box plots in blue. Figures on the panel indicate the observed values, and p-values for comparison of observed and predicted values are given underneath. From left to right, top to bottom, the panels are as follows: 1) the predicted frequency distribution of behavioural levels; 2) the distribution of transitions between each pair of behavioural values in the final period; 3) the magnitudes of the behavioural transitions; 4) the out-degree for individuals at each level of the behaviour; 5) the in-degree for individuals at each level of the behaviour. Indices 6-8 are combined onto the final panel. 6) the edgewise homophily (a measure of behavioural similarity among connected individuals); 7) Moran's I (a measure of network autocorrelation of the behaviour, i.e., do connected individuals tend to be more similar?); and 8) Geary's C (another measure of network autocorrelation, inverse to Moran's I).

Intention

The models for intention to report had a good fit on all aspects assessed.

Descriptive norms

The models for perceived descriptive norms had a good fit on all aspects assessed. The model appears to overestimate the in- and out-degree of individuals with very low levels of the behaviour (i.e., 2 & 3), but this is because there were no individuals at this level in the observed data.

Injunctive norms

The models for perceived injunctive norms had a good fit for most aspects. The same apparent issue for in-degree and out-degree is observed as for perceived descriptive norms (see above). The models underestimated edgewise homophily, but had a very good fit for the other measures of network autocorrelation. Although the model predicted levels of behaviour and changes in the magnitude of behaviour well, it did not adequately predict the specific transitions between behavioural levels.

Information diffusion

The models for information diffusion have adequate fit for all aspects.

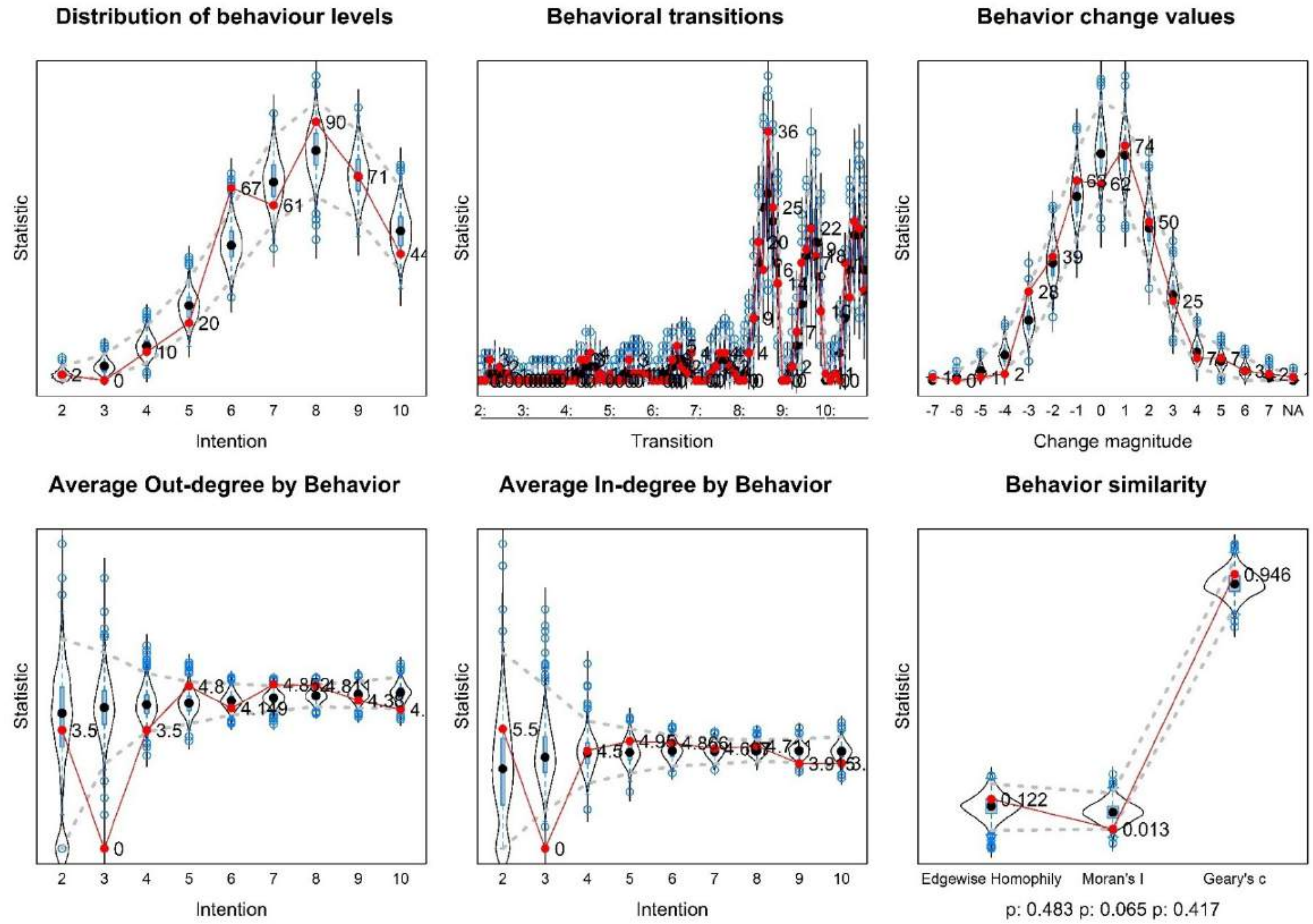


Figure A2.4: Intention

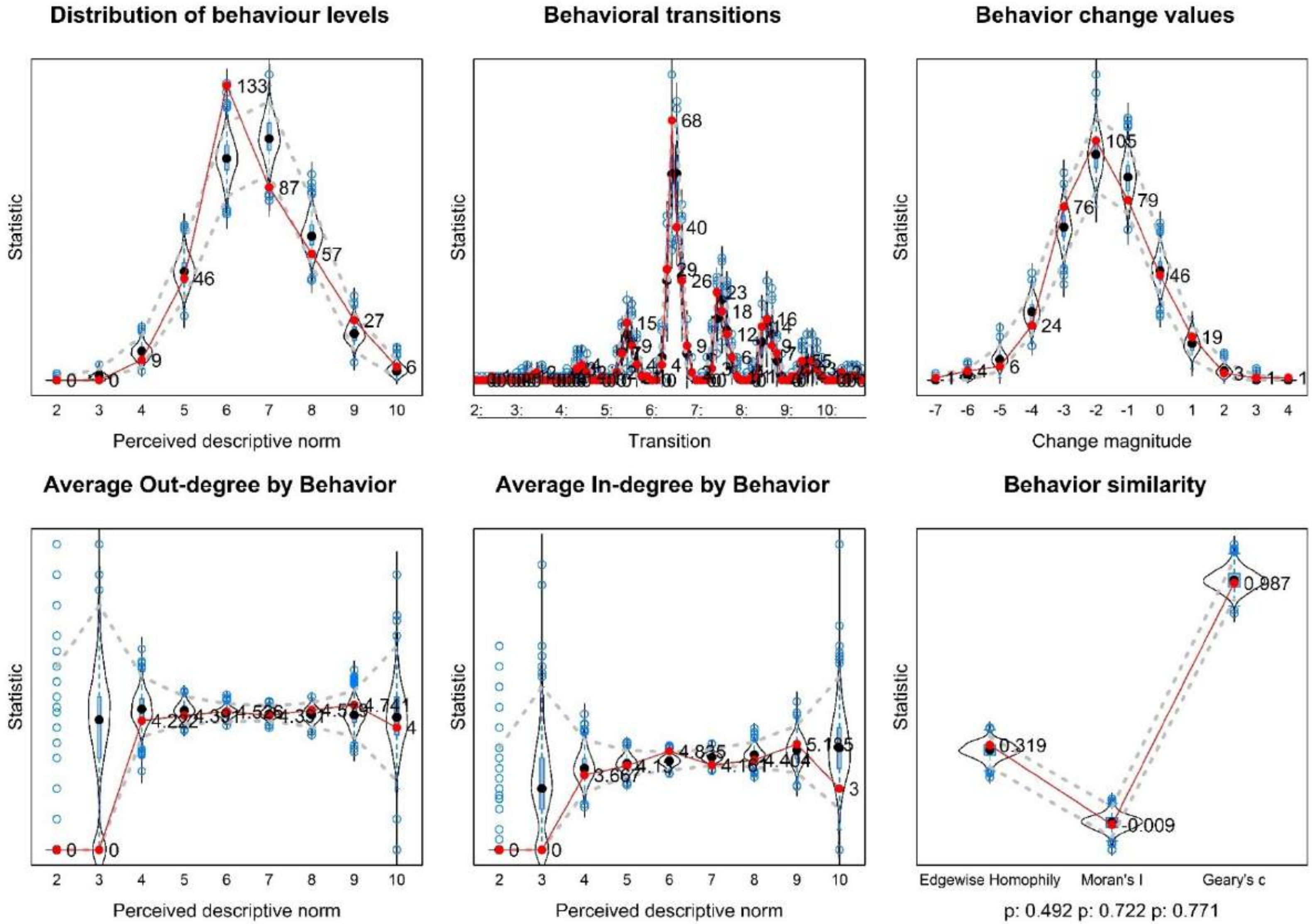


Figure A2.5: Descriptive norms

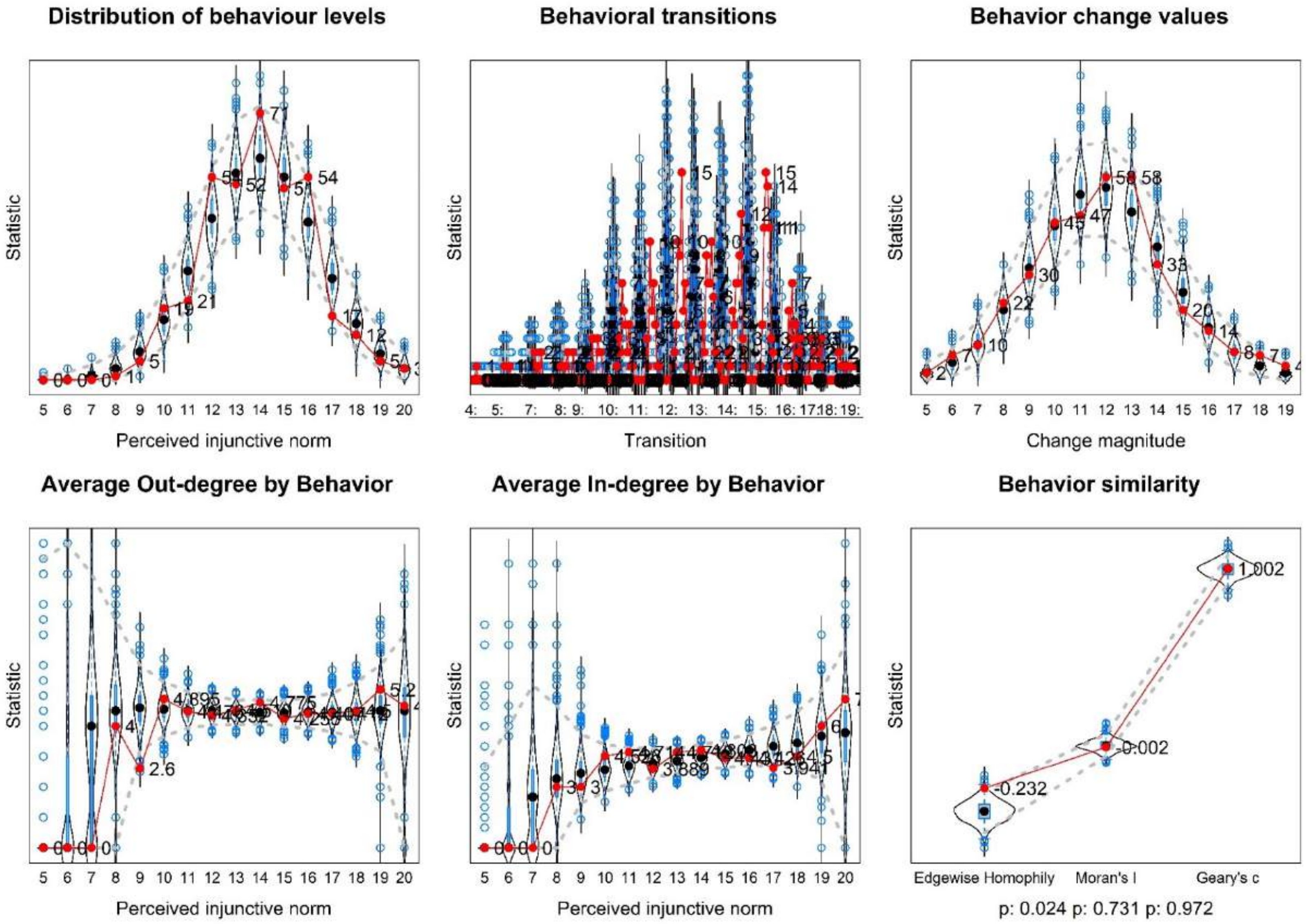


Figure A2.6: Injunctive norms

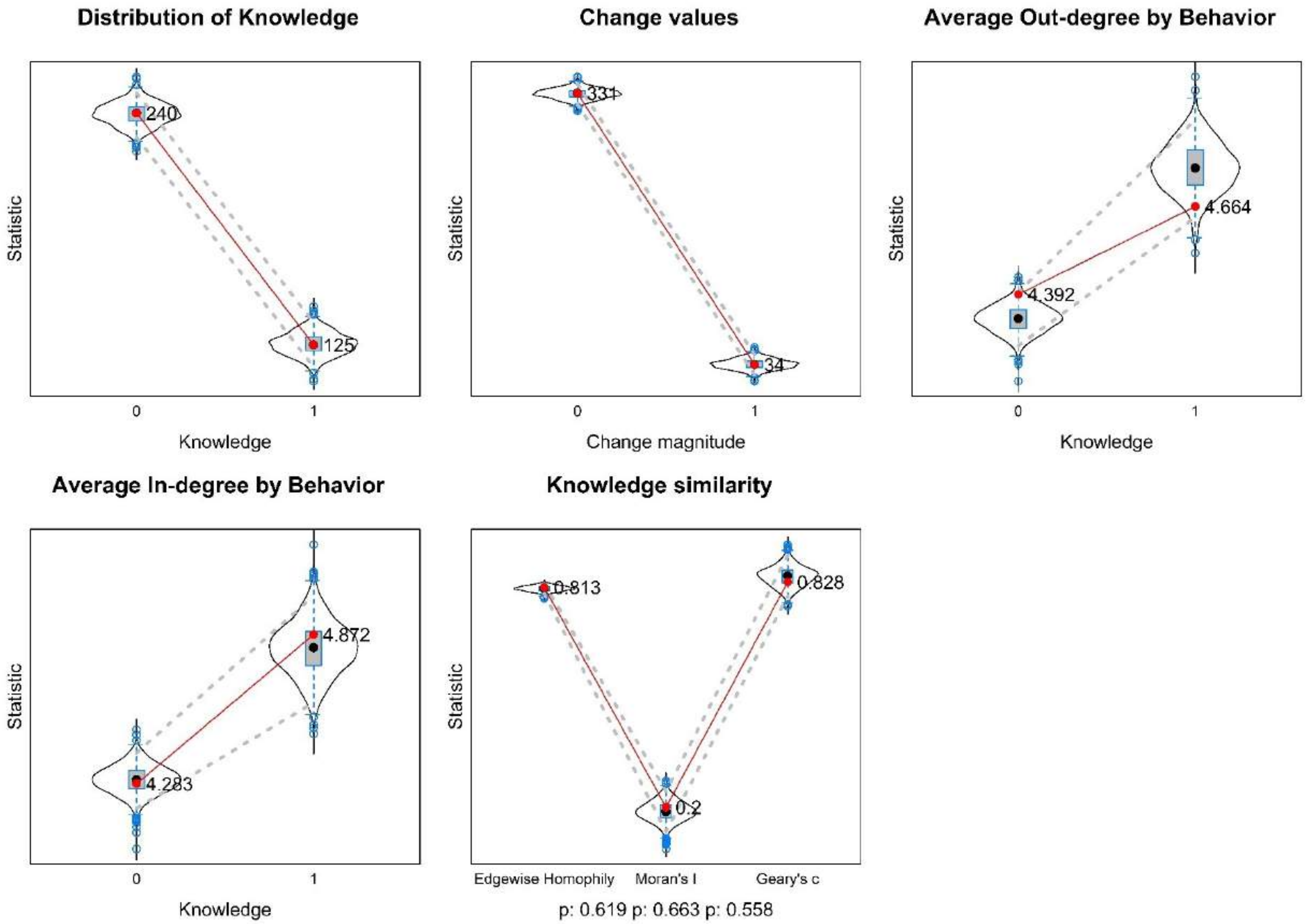


Figure A2.7: Information diffusion combined network

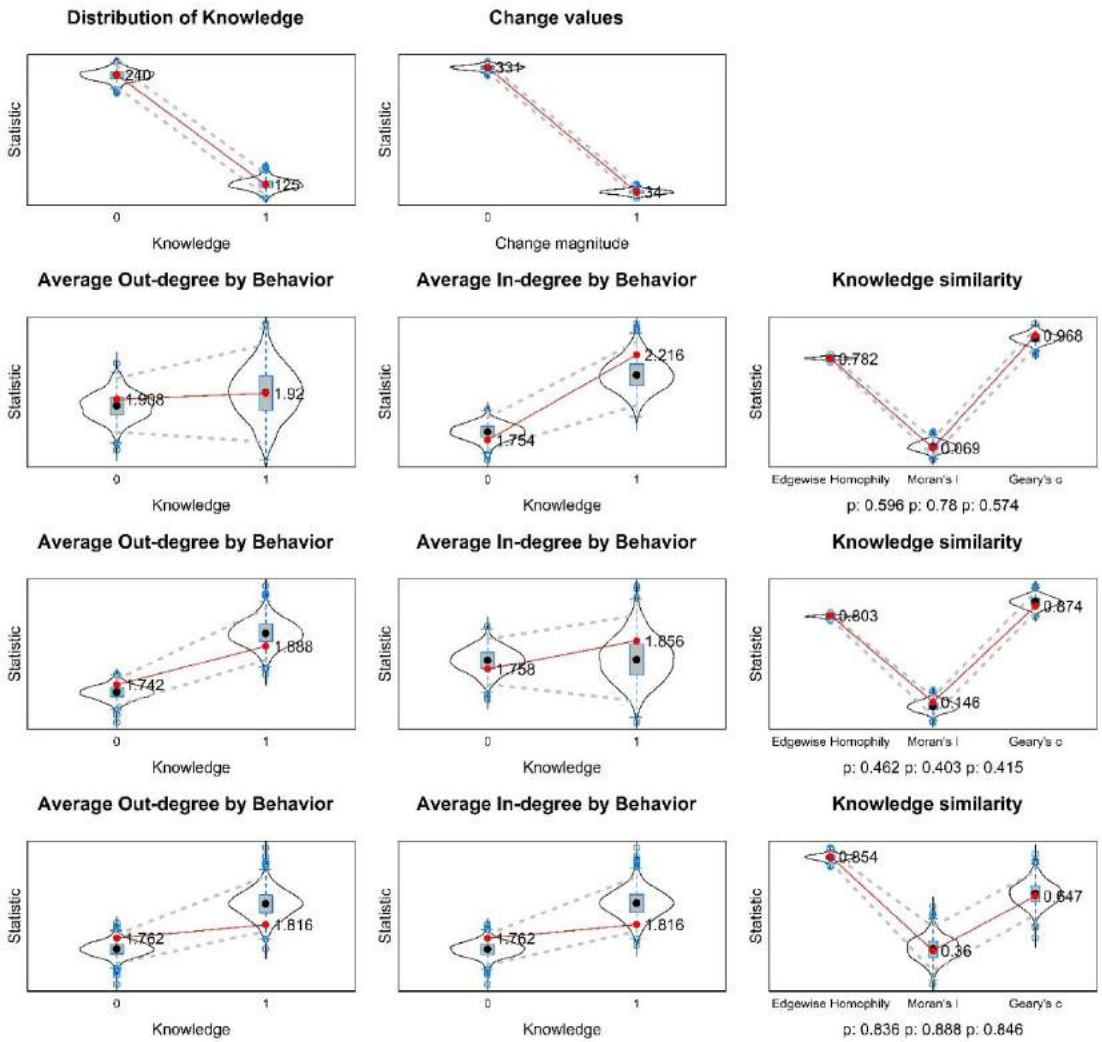


Figure A2.8: Information diffusion on multiple networks. Network-behaviour measures are shown for the three separate networks. From top to bottom: 1) household visits; 2) household visitors; and 3) household co-residence.

A2.7. Data and code

Data and code to replicate all the analyses described here are available on GitHub:

https://github.com/emieldelange/Social-Influence-Information-flow

A2.8. Questionnaire

Note: This is a copy of the questionnaire used in wave 3. In waves 1 and 2 the same questions were used.

Consent statement: **សេចក្តីថ្លែងការ**: ខ្ញុំជានិស្សិតនៅសាកលវិទ្យាល័យភូមិន្ទកសិកម្មដែលកំពុងធ្វើការជាមួយសាកលវិទ្យាល័យ *Edinburgh* នៅចក្រភពអង់គ្លេស ហើយយើងត្រូវការសម្ភាសន៍អ្នកដើម្បីស្វែងរកនូវបញ្ហាមួយចំនួនដែលពាក់ពាក់ព័ន្ធទៅនឹងកសិកម្ម និងការអភិរក្ស។ ការសិក្សាស្រាវជ្រាវនេះមានការអនុញ្ញាត្តពីរដ្ឋាភិបាល ហើយនិងប្រធានភូមិផងដែរ បើទោះបីជាយើងមិនបានធ្វើដើម្បីពួកគេ ឬ អង្គការក្រៅរដ្ឋាភិបាលណាមួយក៏ដោយ។ ប្រសិនបើអ្នកយល់ព្រមអោយពួកយើងសម្ភាសន៍ យើងនឹងកត់ត្រាទុកនូវឈ្មោះ និងចម្លើយរបស់អ្នក ប៉ុន្តែអ្នកកុំចែករំលែកការសម្ភាសន៍នេះជាមួយអ្នកផ្សេងទៀត។ អ្នកអាចបញ្ឈប់ការសម្ភាសន៍ពេលណាក៏បាន យល់ព្រមឬនៅ?

Date: _________

Name:________

Household no. ______

Age: _________

Gender: M/F

Are you married? ________________

What does it mean to be a good citizen? ____

តើធ្វើដូចម្តេចដើម្បីក្លាយជាពលរដ្ឋល្អ?

Follow-up survey: *Do you know about the good citizenship pledge?*

____

តើអ្នកដឹងឬទេពីកិច្ចសន្យាដើម្បីក្លាយជាពលរដ្ឋល្អ?

=> *Have you taken the pledge?* Y / N

តើអ្នកធ្លាប់បានចុះកិច្ចសន្យានេះដែរឬទេ?

=> *Do you have a certificate?* Y / N

តើអ្នកធ្លាប់បានទទួលសញ្ញាបត្រពីកិច្ចសន្យាដែរឬទេ?

=> How did you hear about this? From who? ___________________________________

តើអ្នកបានដឹងពីពត៍មាននេះដោយរបៀបណា? ពីនរណា?

=> When did you first talk about this? ____

តើអ្នកធ្លាប់បាននិយាយពីកិច្ចសន្យាលើកដំបូងនៅពេលណា?

=> About how many times [since the intervention] have you discussed this with someone?

តើប៉ុន្មានដង(ចាប់តាំងពីមានការផ្សព្វផ្សាយកិច្ចសន្យាជាពលរដ្ឋល្អ)តើអ្នកធ្លាប់បានពិភាក្សាជាមួយនរណាម្នាក់ដែរឬទេ?

=> Was it you who brought the subject up or them?

តើអ្នកជាអ្នកលើកយកមកនិយាយមុនគេ ឬគេជាអ្នកចាប់ផ្តើមនិយាយមុន?

=> Do you know other people who have taken this pledge? Who? Why/why not?

តើអ្នកដឹងថាមានអ្នកផ្សេងទៀត បានចុះកិច្ចសន្យានេះដែរឬទេ? អ្នកណា?

=> Why have other people decided to sign the contract? Or why not?

ហេតុអ្វីបានជាអ្នកផ្សេងទៀតបានសម្រេចចិត្តចុះកិច្ចសន្យា? ហេតុអ្វីបានជាពួកគាត់មិនសម្រេចចិត្តចុះកិច្ចសន្យា?

=> Why did you decide to take this pledge? _____________________________________

ហេតុអ្វីបានជាអ្នកសម្រេចចិត្តចុះកិច្ចសន្យានេះ?

What would you do if you saw a trapeang with poison?

____

តើអ្នកនឹងធ្វើអ្វី ប្រសិនបើអ្នកបានឃើញត្រពាំងមានការបំពុល?

Is there a way to report poisoning? Y/N ___________

តើមានមធ្យោបាយក្នុងការរាយការណ៍ដែរឬទេ?

=> Follow up survey: *Do you know about the WCS hotline?* Y/N

តើបានដឹងអំពីការទាក់ទងបន្ទាន់ទៅកាន់ WCSដែរឬទេ?

=> What is the phone number for the hotline? ________________________

តើលេខទូរស័ព្ទទាក់ទងបន្ទាន់មានលេខអ្វីខ្លះ?

=> What will happen if you call the hotline? __________________________

តើនឹងមានអ្វីកើតឡើង ប្រសិនបើអ្នកនឹងធ្វើការខលបន្ទាន់?

=> Can you tell me more about the hotline? __________________________

តើអ្នកអាចប្រាប់ខ្ញុំបន្ថែមបានទេពីការខលបន្ទាន់?

Do you agree with the following?

តើអ្នកយល់ស្របជាមួយនឹងអ្វីដែលមាននៅខាងក្រោមដែរឬទេ?

I dont know how I can report poisoning if I see it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថាអ្នកមិនដឹងពីវិធីដែលអ្នកអាចធ្វើការរាយការណ៍ពីការបំពុលប្រសិនបើអ្នកបានឃើញមានការបំពុល?

Next time I see a trapeang with poison I will keep it to myself and not report it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,លើកក្រោយអ្នកឃើញត្រពាំងមានការបំពុល អ្នកនឹងមិនរាយការណ៍ទៅអាជ្ញាធរទេ ?

It is easier not to report poisoning than to report it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ការមិនរាយការណ៍ពីការបំពុលគឺវាងាយស្រួលជាងការរាយការណ៍ពីការបំពុល ?

If you see poisoning, it is good to keep it to yourself and not report it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុល វាជារឿងល្អដែលអ្នកគួរលាក់ទុកហើយមិនធ្វើការរាយការណ៍ទៅអាជ្ញាធរ ?

If I report poisoning someone will come to solve the problem 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នករាយការណ៍ពីការបំពុល នរណាម្នាក់នឹងមកដោះស្រាយពីបញ្ហានេះ?

If I see poisoning and report it, the village will be safer 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុលហើយរាយការណ៍ តើអ្នកភូមិនឹងមានសុវត្ថិភាពជាងមុនដែរឬទេ?

If I see poisoning and report it, other people in the village will be upset with me 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញការបំពុលហើយរាយការណ៍ តើប្រជាជនផ្សេងទៀតនៅក្នុងភូមិមានការអន់ចិត្តជាមួយអ្នកដែរឬទេ?

If I see poisoning and report it, it will not help to improve our environment 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញការបំពុលហើយរាយការណ៍ វានឹងមិនធ្វើឱ្យបរិស្ថានរបស់យើងមានភាពប្រសើរឡើងទេ?

Most people in the village would report poisoning if they see it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រជាជនភាគច្រើននៅក្នុងភូមិនឹងរាយការណ៍ពីការបំពុលប្រសិនបើពួកគេឃើញមានការបំពុល?

I will report poisoning if I see it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,អ្នកនឹងរាយការណ៍ពីការបំពុល ប្រសិនបើអ្នកបានឃើញ ?

Reporting poisoning is a good way to keep livestock safe 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ការរាយការណ៍ពីការបំពុលជាវិធីសាស្រ្តដ៏ល្អមួយដើម្បីបាននូវសុវត្ថិភាពជីវិតសត្វ?

Other people never report poisoning if they see it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើប្រជាជនផ្សេងទៀតឃើញមានការបំពុល ពួកគាត់មិនដែលបានរាយការណ៍ទេ?

The authorities expect me to report poisoning if I see it 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,អាជ្ញាធររំពឹងទុកថាអ្នកនឹងរាយការណ៍ពីការបំពុលប្រសិនបើអ្នកបានឃើញពីការបំពុល?

I will phone WCS if I see a poisoned trapeang 5-1 DK

តើអ្នកយល់ស្របដែរឬទេថា,អ្នកនឹងខលទៅអង្គការWCSប្រសិនបើអ្នកបានឃើញការបំពុលទឹកត្រពាំង?

=> *How did you learn about the hotline?* ________________________________

តើអ្នកបានរៀនអំពីការខលបន្ទាន់តាមរយៈអ្វី?

=> *Who has talked to you about this (names)?* __________________________________

តើអ្នកណាធ្លាប់បាននិយាយជាមួយអ្នកអំពីរឿងនេះ (ឈ្មោះ)?

=> *when did you first hear about this?* _____________________________________

តើអ្នកធ្លាប់បានលឺអំពីរឿងនេះជាលើកដំបូងនៅពេលណា?

=> *About how many times [since the intervention] have you discussed this with someone?*

តើប្រហែលប៉ុន្មានដង(ចាប់តាំងពីមានការផ្សព្វផ្សាយពីលេខទំនាក់ទំនងបន្ទាន់) ដែលអ្នកបានពិភាក្សាជាមួយអ្នកផ្សេង?

=> *Was it you who brought the subject up or them?*

តើអ្នកជាអ្នកលើកឡើងពីប្រធានបទ ឬក៏ពួកគេជាអ្នកលើកឡើង?

Follow up: *Do you know the story about [Chan]?* Y / N

តើអ្នកបានដឹងអំពីសាច់រឿងរបស់ចាន់ដែរឬទេ?

=> *What did Chan see when he was playing with his friends?*

____

តើចាន់បានឃើញអ្វីនៅពេលដែលគាត់កំពុងលេងជាមួយមិត្តភក្តិរបស់គាត់?

If they don't know: *He saw a trapeang with dead animals around it.*

ប្រសិនបើគាត់មិនដឹង(ចម្លើយ៖គាត់បានឃើញត្រពាំងមួយជាមួយនឹងសាកសពសត្វនៅវិញត្រពាំង)

=> *How did XXX know there was poison in the trapeang?*

____

តើចាន់បានដឹងដោយរបៀបណា ថាទឹកត្រពាំងមានជាតិពុល?

If they don't know*: Because some of his friends became ill after drinking.*

ប្រសិនបើគាត់មិនដឹង(ចម្លើយ៖ដោយសារមិត្តភក្តិរបស់គាត់មួយចំនួនបានឈឺបន្ទាប់ពីផឹកទឹកត្រពាំងរួច)

=> *What do Chan, his parents, and his community decide to do?*

____

តើចាន់ ឪពុកម្តាយរបស់ចាន់ និងសហគមន៍របស់ចាន់បានសម្រេចចិត្តធ្វើម្តេច ដើម្បីដោះស្រាយបញ្ហាដែលជួបប្រទះ?

If they don't know: *They inform the chief and report it on the hotline.*

ប្រសិនបើគាត់មិនដឹង(ចម្លើយ៖ពួកគេបានរាយការណ៍ទៅកាន់លេខខលបន្ទាន់)

=> What happens after this?

____

តើនឹងមានអ្វីកើតឡើងបន្ទាប់ពីមានការរាយការណ៍រួច?

How did you hear about this story? From whom?

____

តើអ្នកបានដឹងពីរឿងនេះតាមរយៈអ្វី? ពីនរណា?

When did you hear about this first?

____

តើអ្នកបានលឺអំពីសាច់រឿងនេះជាលើកដំបូងនៅពេលណា?

Have you talked with anyone about this story?
(Name)_______________________________________

តើអ្នកធ្លាប់បាននិយាយជាមួយអ្នកណាខ្លះអំពីសាច់រឿងនេះ? (ឈ្មោះ)

About how many times [since the intervention] have you discussed this with someone?

តើប្រហែលប៉ុន្មានដង(តាំងពីមានការផ្សព្វផ្សាយសាច់រឿង) ដែលអ្នកធ្លាប់បានពិភាក្សាជាមួយអ្នកផ្សេង?

Was it you who brought the subject up or them?

តើអ្នកជាអ្នកលើកយកសាច់រឿងនេះមកនិយាយមុន ឬពួកគេជាអ្នកនិយាយមុន?

Now we would like to ask a few more questions about different topics.

If this is the first person surveyed in this household, ask them the following:

> Do the following people still live in this household? If not, where do they live? [Record any changes after comparing to the household list]
>
> Is there anyone not listed who lives in this household?

4. Wealth Indicators ការរស់នៅផងទ្រព្យសម្បត្តិ

4.1 Do you eat three meals a day? តើអ្នកហូបអាហារបីពេលរាល់ថ្ងៃឬទេ? YES / NO

4.2 What is the material of your roof? តើដំបូលផ្ទះរបស់អ្នកសាងសង់អំពីអ្វី? ->

Thatch ស្បូវ	
Palm leaf ស្លឹកត្នោត	
Wood ឈើ	
Metal/Zinc ដែក/ ស័ង្កសី	
Tile ក្បឿង	

4.3 Do you own a Kor-Yun តើអ្នកមានគោយន្តឬទេ?

YES / NO

4.4 Do you own a motorbike? តើអ្នកមានម៉ូតូឬទេ? YES / NO

4.5 Are you able to pay for healthcare without selling property? តើអ្នកអាចមានលទ្ធភាពចំណាយលើការថែរក្សាសុខភាពដោយគ្មានការលក់ទ្រព្យសម្បត្តិឬទេ? YES / NO

4.6 Do you have a toilet? តើអ្នកមានបង្គន់នៅផ្ទះឬទេ? YES / NO

5.1 Does your household own a TV? តើផ្ទះរបស់អ្នកមានទូរទស្សន៍ឬទេ? YES / NO

5.2 Does your household own a radio? តើផ្ទះរបស់អ្នកមានវិទ្យុឬទេ? YES / NO

7. Name generators Now we want to ask you some questions about who you talk with. Don’t worry, your answers will be kept secret.

➔ 7.A1 When you have some free time, who do you go to visit at their house?
នៅពេលអ្នកទំនេរ, តើអ្នកទៅលេងនរណា?

Number	Name	How many times a week?
1		
2		
3		
4		
5		

7.A2 How often do you visit this person? តើប៉ុន្មានដងក្នុងមួយសប្តាហ៍?

7.B1 Who visits your house when they have free time?

តើនរណាមកលេងផ្ទះរបស់អ្នកនៅពេលដែលពួកគេទំនេរ?

Number	Name	How many times a week?
1		
2		
3		
4		
5		

7.B2 How often does this person visit? តើប៉ុន្មានដងក្នុងមួយសប្តាហ៍?

Appendix 3: Supplementary material for Chapter 6

A3.1. Qualitative identification of relevant ties.

We conducted qualitative research to understand social interactions within our study area and to identify relevant ties to measure. We visited twelve villages (including the focal village) from June to September 2017 (Chapter 4), conducted two focus group discussions in each village (one or each gender), and interviewed informants such as those in official positions, shopkeepers, and others (see de Lange et. al 2020 in Oryx for further information about this study). In these discussions we asked participants where they received information about related topics such as agriculture, conservation, health, and hunting. We asked them to reflect on what makes certain information sources trustworthy and about influential relationships, such as individuals trusted to resolve conflicts, agricultural, or health issues. Additionally, we observed behaviour during our time in these villages, drew on our own experience working in rural Cambodia, consulted with local experts, and with the literature.

We then coded the data to identify discrete forms of interactions which could feasibly be measured and selected a set of ties to measure in consultation with local experts and NGO staff.

A3.2. Description of ties included in the network.

Household visits

Throughout the year, adult residents in Preah Vihear province spend much of the day working at their farms or gathering food in the forest. These activities are usually done in small groups from the same household, and because the farms are located far from the village, there is little opportunity for social contact with others, unless two farms happen to be located close to one another, which is rarely the case. At some parts of the year, farmers will stay in small huts at their farms for extended periods, further limiting opportunities for social contact. At other parts of the year, such as when the rains first start or when harvests are complete, all farmers will stay in the village to participate in social and religious festivals. However, for most of the year, adults will return home to the village each evening and return to the farm in the early morning. The evening is therefore an opportunity to relax, eat, and socialise. Residents will visit others at their homes to check in, catch up on gossip, and hang out. This applies to both men and women, although women are more likely to stay home during the day if they have young children and may visit with relatives and neighbours throughout the day. We asked respondents to name those who they visited at their homes during their free time. This is a directional tie, meaning the respondent visiting a nominated other does not necessarily mean the other also visits the respondent.

Household co-residence

The household is the core unit of social organisation in Khmer society. Multiple generations of adults may live in the same household as it is customary for the youngest daughter to remain at home and to care for the parents. When the youngest daughter marries, her husband will also join the household, and together they will eventually take over the running of the household and inherit the house. As members of the same household eat together every day, and work together on the farm, much communication occurs between them. We generated a census of each household in the village and generated co-residence ties between all members of the same household.

A3.3. Details of cleaning and verification procedures for network data

Firstly, the research team manually corroborated and corrected respondent names against a village census provided by the village chief. Secondly, we used fuzzy matching in R to identify all names in the data that differed from other names by less than three characters. Third, we generated a list of names that occurred only once in our dataset. Having compiled a set of potentially problematic cases using these two methods, we manually checked each name to see if there were obvious identity confusions, or if nicknames were used. We used kinship data we had collected to create a genealogy, which served as a reference to check and correct possible misspellings. For example, if Rob Franks had nominated Tim Franks and Mary Franks as siblings, but Mary had nominated Rob and Tom as siblings, we presumed Tim and Tom were alternate spellings of the same person. We selected on option and corrected any occurrences of this name in the dataset. This is a conservative strategy given that illiteracy is prevalent, and many possible spellings exist for any name in Khmer.

A3.4. Likert items for measuring attitudes towards reporting poisoning

If I see poisoning and report it, the village will be safer.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុលហើយរាយការណ៍ តើអ្នកភូមិនឹងមានសុវត្ថិភាពជាងមុនដែរឬទេ?

Strongly disagree 1 – 2 – 3 – 4 – 5 Strongly Agree – Don’t know

If you see poisoning, it is good to keep it to yourself and not report it.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញមានការបំពុល វាជារឿងល្អដែលអ្នកគួរលាក់ទុកហើយមិនធ្វើការរាយការណ៍ទៅអាជ្ញាធរ ?

Strongly disagree 1 – 2 – 3 – 4 – 5 Strongly Agree – Don’t know

Reporting poisoning is a good way to keep livestock safe.

តើអ្នកយល់ស្របដែរឬទេថា,ការរាយការណ៍ពីការបំពុលជាវិធីសាស្រ្តដ៏ល្អមួយដើម្បីបាននូវសុវត្ថិភាពជីវិតសត្វ?

Strongly disagree 1 – 2 – 3 – 4 – 5 Strongly Agree – Don’t know

If I see poisoning and report it, no one will come to clean the environment.

តើអ្នកយល់ស្របដែរឬទេថា,ប្រសិនបើអ្នកឃើញការបំពុលហើយរាយការណ៍ គ្មាននរណាម្នាក់នឹងមកសម្អាតបរិស្ថានរបស់អ្នកទេ ?

Strongly disagree 1 – 2 – 3 – 4 – 5 Strongly Agree – Don’t know

A3.5. Centrality measures used.

In-degree centrality

In-degree centrality is the number of incoming connections each individual has. For example, in the household visits network, this is the number of times an individual is nominated by others. Individuals with high in-degree centrality are therefore directly connected to many other individuals. They are able to rapidly diffuse contagions.

Betweenness centrality

Betweenness centrality is the number of times an individual falls on the shortest possible path between each other pair of individuals. It is a measure of the power an individual has to broker the exchange of information between others.

Closeness centrality

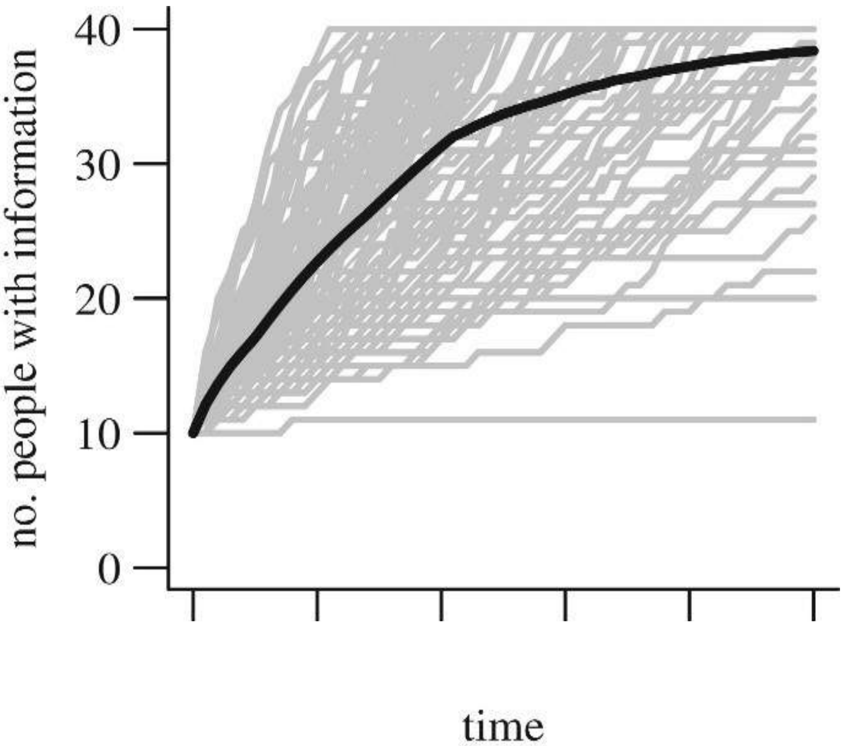
Closeness centrality is sum of the shortest distance from an individual to every other individual in the network. In other words, an individual with high closeness centrality has relatively few degrees of separation to all other individuals in the network and can therefore reach any other person relatively easily. They are able to spread information, or simple contagions, rapidly.

Eigenvector centrality

Eigenvector centrality is the extent to which an individual is connected to other individuals with high eigenvector centrality. It is a recursive measure, which indicates an individual’s ability to influence or inform other influential individuals.

5. Area under the diffusion curve (AUC)

At each time period more individuals in the network adopt the contagion. This can be visualised as a cumulative diffusion curve (adapted from Dobson et. al., 2019):



The area under this curve therefore gives an indication of both the scale and the rate of adoption.

Table A3.1: Descriptive statistics from the sample

Variable	Definition	Value
Gender	Male	159 (44%)
	Female	206 (56%)
Age	Mean age in years	34 (SD = ± 14)
Married	Yes	326 (89%)
	No	38 (11%)
Household size	Mean number of adults surveyed per household	2.4 (SD = ± 1.0)
Network statistics	Percentage of respondents nominating others in the household visit network	92%
	Mean out-degree (i.e., number of nominations) in the household visit network	1.92 (SD = ± 1.14)
	Mean in-degree (i.e., number of times nominated by others) in the household visit network	3.84 (SD = ± 2.54)
	Mean in-degree in the	7.40 (SD = ± 3.16)

	combined household visit and co-residence network	
	Density (i.e., the proportion of all possible ties that are observed) of the combined network.	0.01
	Number of components (i.e., disconnected parts) in the combined network	4
	Diameter (i.e., largest number of steps between any two individuals) of the largest component in the combined network	18 ties
	Transitivity (i.e., density of closed triangles) of the combined network	0.31
Attitude	Mean attitude towards reporting poisoning, where 20 is the most positive, and 4 is the most negative.	15.1 (SD = ± 2.22)

Table A3.2: Jaccard similarity index calculated for all sets of targets (n = 10)

	KP In-degree	KP Betweenness	KP Closeness	KP Eigenvector	Low attitudes	High attitudes	Wealth	Leaders	Gatekeeper	Event	Conservation
KP In-degree	1.000	0.250	0.111	0.176	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KP Betweenness	0.250	1.000	0.333	0.111	0.000	0.000	0.000	0.000	0.053	0.000	0.000
KP Closeness	0.111	0.333	1.000	0.053	0.000	0.000	0.053	0.000	0.000	0.000	0.000
KP Eigenvector	0.176	0.111	0.053	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Low attitudes	0.000	0.000	0.000	0.000	1.000	0.000	0.053	0.000	0.000	0.000	0.000
High attitudes	0.000	0.000	0.000	0.000	0.000	1.000	0.053	0.111	0.053	0.053	0.111
Wealth	0.000	0.000	0.053	0.000	0.053	0.053	1.000	0.000	0.000	0.000	0.000
Leaders	0.000	0.000	0.000	0.000	0.000	0.111	0.000	1.000	0.250	0.000	0.429
Gatekeeper	0.000	0.053	0.000	0.000	0.000	0.053	0.000	0.250	1.000	0.000	0.053
Event	0.000	0.000	0.000	0.000	0.000	0.053	0.000	0.000	0.000	1.000	0.000
Conservation	0.000	0.000	0.000	0.000	0.000	0.111	0.000	0.429	0.053	0.000	1.000

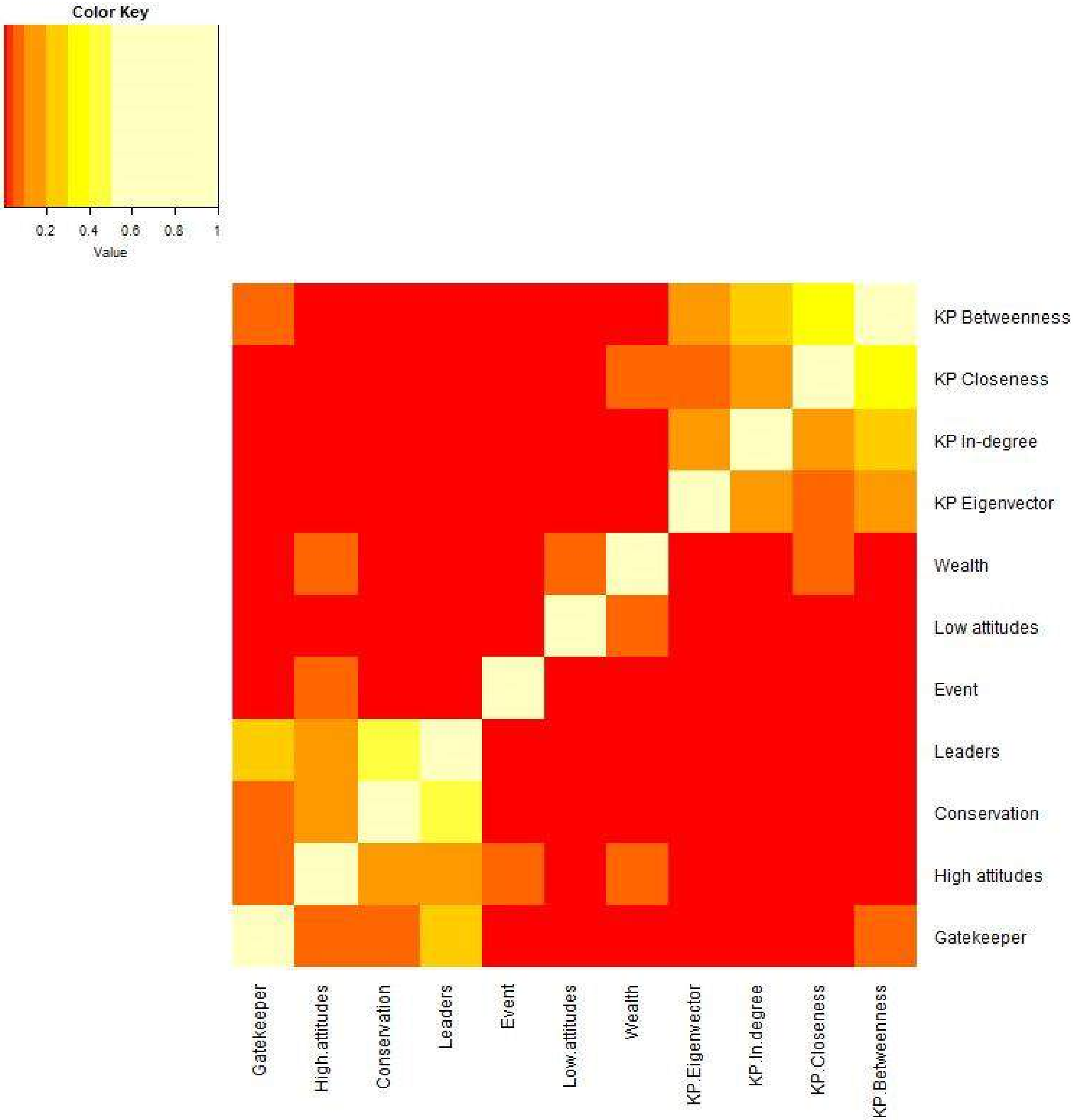


Figure A3.1: A heatmap showing the Jaccard similarity between each pair of target sets at size n=10. A lighter colour indicates greater similarity.

Table A3.3: Jaccard similarity index calculated for all sets of targets (n = 20)

	KP In-degree	KP Betweenness	KP Closeness	KP Eigenvector	Low attitudes	High attitudes	Wealth	Leaders	Gatekeeper	Event	Conservation
KP In-degree	1.000	0.143	0.000	0.143	0.053	0.026	0.053	0.053	0.111	0.000	0.000
KP Betweenness	0.143	1.000	0.053	0.081	0.000	0.000	0.053	0.053	0.053	0.026	0.000
KP Closeness	0.000	0.053	1.000	0.026	0.026	0.026	0.026	0.053	0.026	0.081	0.026
KP Eigenvector	0.143	0.081	0.026	1.000	0.053	0.026	0.026	0.143	0.111	0.081	0.026
Low attitudes	0.053	0.000	0.026	0.053	1.000	0.000	0.026	0.000	0.000	0.026	0.000
High attitudes	0.026	0.000	0.026	0.026	0.000	1.000	0.026	0.111	0.053	0.026	0.083
Wealth	0.053	0.053	0.026	0.026	0.026	0.026	1.000	0.053	0.026	0.000	0.000
Leaders	0.053	0.053	0.053	0.143	0.000	0.111	0.053	1.000	0.111	0.000	0.219
Gatekeeper	0.111	0.053	0.026	0.111	0.000	0.053	0.026	0.111	1.000	0.000	0.026
Event	0.000	0.026	0.081	0.081	0.026	0.026	0.000	0.000	0.000	1.000	0.000
Conservation	0.000	0.000	0.026	0.026	0.000	0.083	0.000	0.219	0.026	0.000	1.000

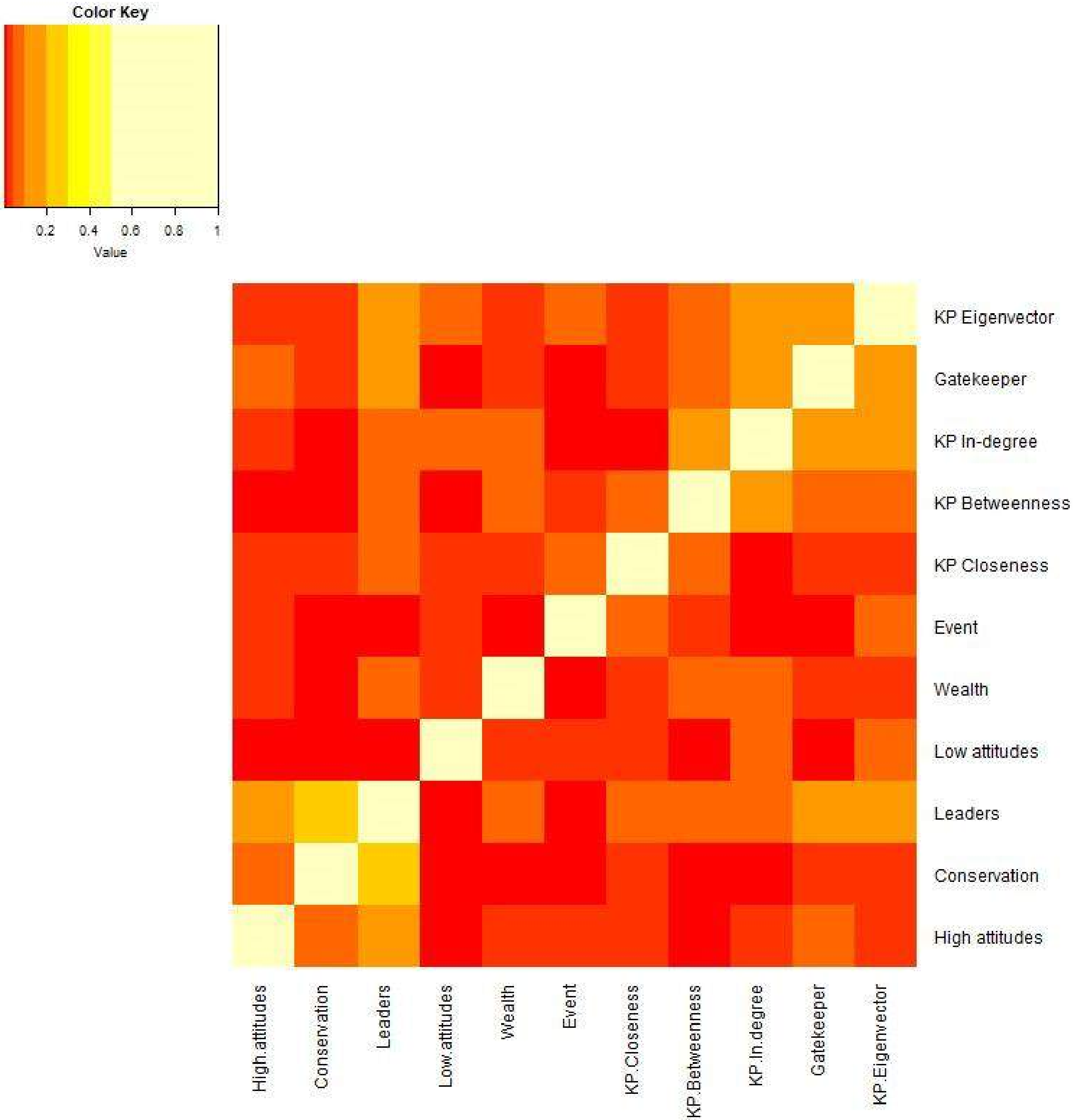


Figure A3.2: A heatmap showing the Jaccard similarity between each pair of target sets at size n=20. A lighter colour indicates greater similarity.

Table A3.4: Jaccard similarity index calculated for all sets of targets (n = 30)

	KP In-degree	KP Betweenness	KP Closeness	KP Eigenvector	Low attitudes	High attitudes	Wealth	Gatekeeper	Convenience
KP In-degree	1.000	0.176	0.000	0.200	0.017	0.053	0.034	0.000	0.094
KP Betweenness	0.176	1.000	0.132	0.111	0.034	0.053	0.034	0.000	0.055
KP Closeness	0.000	0.132	1.000	0.000	0.034	0.034	0.034	0.000	0.018
KP Eigenvector	0.200	0.111	0.000	1.000	0.017	0.017	0.034	0.000	0.074
Low attitudes	0.017	0.034	0.034	0.017	1.000	0.000	0.034	0.000	0.000
High attitudes	0.053	0.053	0.034	0.017	0.000	1.000	0.053	0.000	0.074
Wealth	0.034	0.034	0.034	0.034	0.034	0.053	1.000	0.000	0.074
Gatekeeper	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Convenience	0.094	0.055	0.018	0.074	0.000	0.074	0.074	0.000	1.000

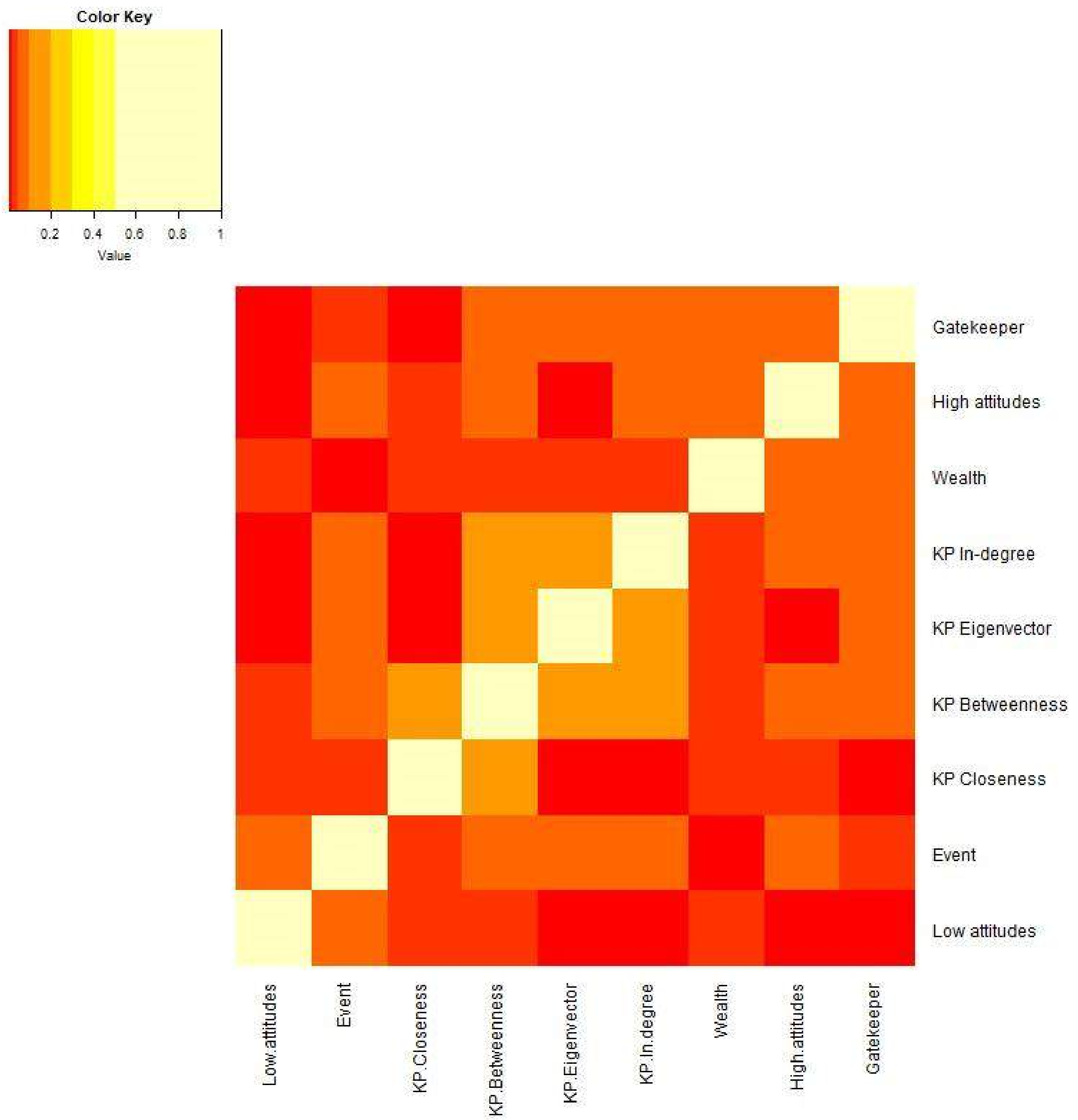


Figure A3.3: A heatmap showing the Jaccard similarity between each pair of target sets at size n=30. A lighter colour indicates greater similarity.

Table A3.5: Results of logistic regressions

Dependent variable: / Predictor variable:	In-degree centrality key-player			Betweenness centrality key-player			Closeness centrality key-player			Eigenvector centrality key-player		
	Estimate	S.E.	P-value	Estimate	S.E.	P-value	Estimate	S.E.	P-value	Estimate	S.E.	P-value
Intercept	-4.352	0.949	<0.001	-3.068	0.949	0.001	-1.418	0.965	0.142	-3.052	0.895	0.001
Age	0.516	0.174	0.003	-0.097	0.201	0.629	-0.803	0.287	0.005	0.208	0.183	0.254
Gender (male)	-0.652	0.421	0.121	0.487	0.385	0.206	0.494	0.393	0.209	-1.045	0.453	0.021
Wealth	0.234	0.198	0.237	0.185	0.204	0.364	0.127	0.204	0.533	0.127	0.194	0.513
Leadership positions	-15.189	983.031	0.988	-15.426	1014.778	0.988	-0.268	1.079	0.804	0.041	1.086	0.970

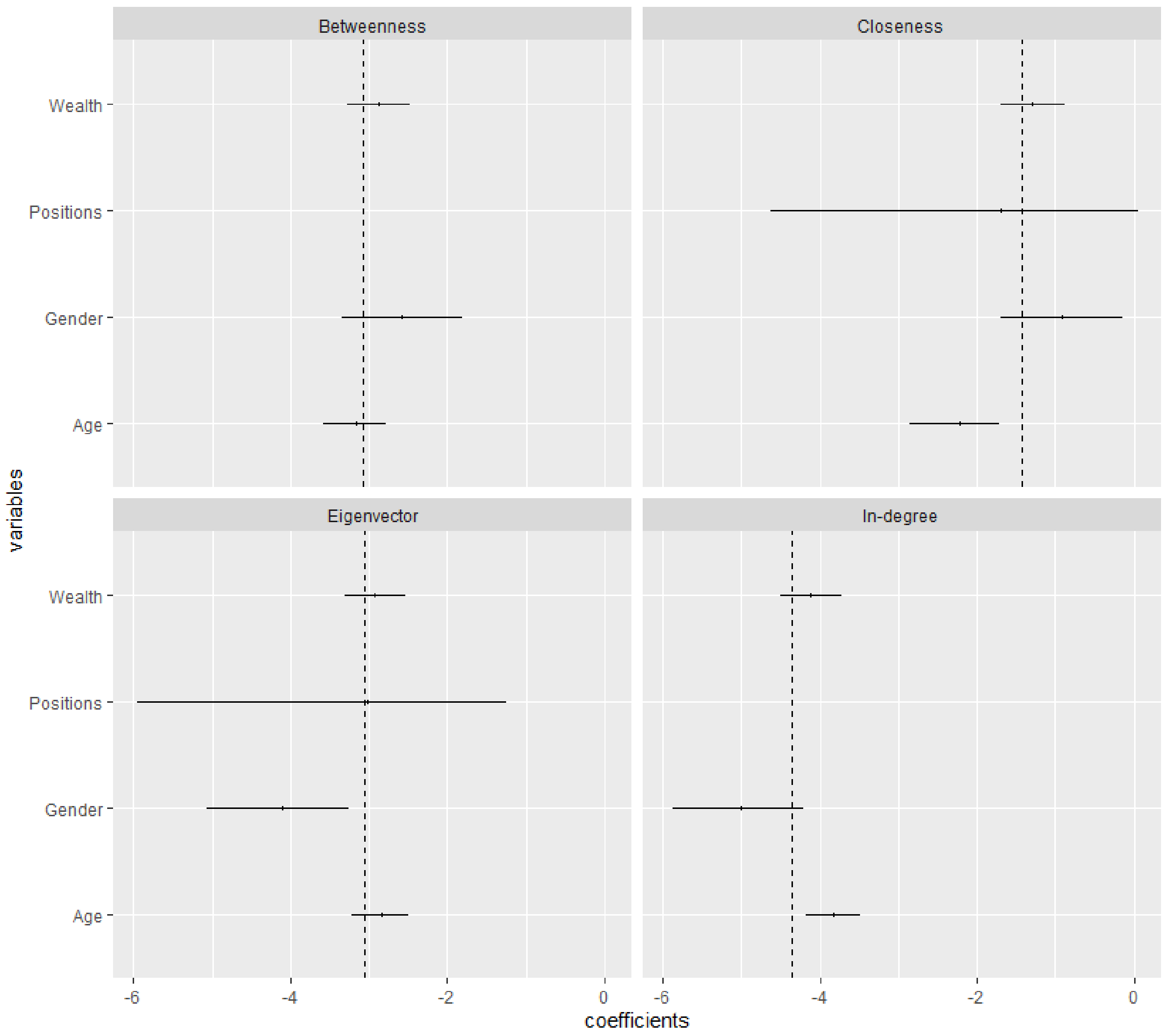


Figure A3.4: Results from logistic binary regressions testing (see supplementary table 5) for associations between some key individual attributes (wealth, formal leadership positions, gender, and normalised age) with inclusion in each of four key-players sets, size 30, calculated using the centrality measures: In-degree, Betweenness, Closeness, and Eigenvector. The effect sizes are shown bounded by the 95% confidence intervals. The intercept is shown as a dotted line. Formal leadership positions is omitted from the plot for In-degree and Betweenness centrality, as the confidence intervals exceeded the range of the graph.

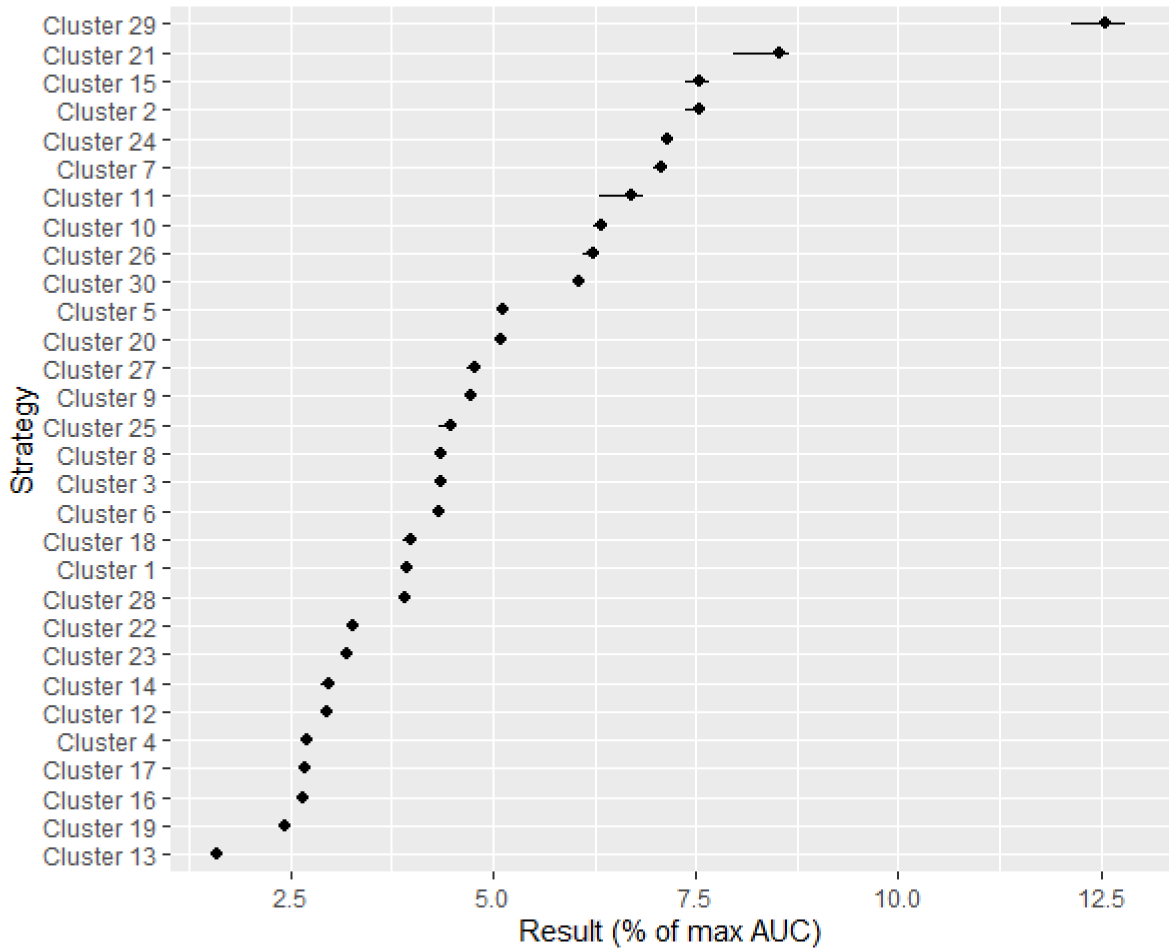


Figure A3.5: The result (as a percentage of the maximum AUC) of diffusion simulations for a complex contagion using 30 randomly generated sets of clusters (size = 10), communication probability = 0.2. Bootstrapped 95% confidence intervals are shown.

Table A3.5: A rough budget for each level of intervention effort. An intervention targeting two people could consist of a meeting with two NGO staff at the target's homes with provision of personal materials. An intervention with thirty targets requires coordination with the village chief to invite participants, provision of food and refreshments, and production of public materials to be displayed. At least five NGO staff will be required.

Item	Two targets	Ten targets	Twenty targets	Thirty targets
Staff costs	22	36	48	72
Material costs	20	90	200	280
Event costs	10	20	100	150
Total (USD)	**$52**	**$146**	**$348**	**$502**

Table A3.6: a rough budget for a research team of two junior Cambodian researchers to undertake six weeks of work collecting network data, or four weeks of work for other data, in our focal village. This includes time for preparation, training, and some preparatory qualitative work. For network data, this also include a consultancy fee for a network analyst to clean the data and identify the target sets. Conventional strategies requiring other data are 'wealth', 'relatively negative attitudes', and 'relatively positive attitudes'. Other conventional strategies did not require additional data collection and can be implemented using local knowledge

Item	**Network data (USD)**	**Other data (USD)**
Research staff costs	1200	800
Food & accommodation	1260	840
Equipment	200	200
Transport & fuel	200	160
Respondent gifts	200	200
Network analyst consultant	2000	-
Total	**$5160**	**$2200**