Tackling Small-Scale Fisheries Non-Compliance

Rodrigo Oyanedel

Wolfson College, University of Oxford

Supervised by

Professor E.J. Milner-Gulland and Professor Stefan Gelcich

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Declaration

I declare that this thesis is entirely my own work. Contributions by other authors are stated in section 1.3. None of the work has been submitted, in whole or in part, for any previous degree application.

Rodrigo Oyanedel

Dedication

To my mom, who was the first to believe in me

Acknowledgements

I want to start by acknowledging my supervisors, EJ and Stefan. There are no words to express my gratitude. You perfectly managed the balance between supervising and guiding and allowing me to explore and make mistakes. Thanks so much for your patience. I admire you both sincerely for constantly maintaining a positive vibe throughout this process. Not even for a second, I stop enjoying doing this with you. There was constant laughter in our meetings (I have the recordings to prove it!). I consider you both my friends, and I am sure life will reunite us. EJ: I still can't believe I got the chance to work with you. I admired you before arriving here but getting to know you multiplied that by ten. Your contribution to the field preceded you, but also your energy and human quality are such an inspiration. You were always kind and supportive and trusted in my skills way before I did. Your ability to push my boundaries was remarkable, and you certainly made me a more integral scientist and a better person. There are so many lessons I take from you: on how to do science, think, and most importantly, on how to work with people. Stefan: Thanks so much for supporting me for almost a decade now! Since I started in this academic journey you always talked to me as an equal, there was never a vertical distance between us. I admire your energy to always push for what's the right thing to do, even if it involves sacrifices. I am so happy that we have been able to work together throughout the years. I can't wait to see what's next and how we turn Matanzas into a research hub!

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Abstract

Sustainable wildlife trade is critical for biodiversity conservation, livelihoods, and food security. However, compliance with wildlife trade rules and regulations aimed at sustainability cannot be taken for granted. The ecological, economic, and social impacts of non-compliance with wildlife trade rules have been widely documented across diverse biomes and can be especially acute in small-scale wildlife use contexts, which usually involve poor management and limited enforcement capacity. In this DPhil, I aim to contribute to the scientific understanding of how non-compliance in small-scale wildlife use contexts can be studied and managed, through applying innovative and interdisciplinary approaches, using a small-scale fishery in Chile as a case study.

Data collection for the case study took place in the common hake (*Merluccius gayi gayi*) small-scale fishery in Chile's VII region. I used specialised survey techniques for assessing non-compliant behaviours, key-informant interviews, literature review, and analysed government-based datasets. I found that most of the common hake traded in the analysed region comes from non-compliant activities. I also found that fishers' motivations for non-complying are diverse, depend on the rule, and include normative (i.e., prescriptions commonly accepted in a group, supporting desirable behaviors and forbidding undesirable ones), legitimacy-based (i.e., acceptance of decision-making and its outcomes by citizens) and instrumental motivations (i.e., economic calculation of the costs and benefits of compliance). Moreover, I found that non-compliance in this fishery is highly influenced by the operation of the supply chain and market dynamics. Specifically, I found traders' (i.e., intermediaries) incentives to trade legal or non-compliant products help describe landings and the dynamics of the fishery. These incentives can be used to predict the effect of potential interventions to reduce non-compliant use.

Based on the evidence gathered, I provide policy recommendations and guidelines to reduce the extent of non-compliant behaviours in this small-scale fishery case study and beyond. Likewise, in this DPhil, I provide tools and frameworks that can be used to study non-compliance in other wildlife trade contexts and to prompt new ways of thinking about how to intervene when non-compliance in small-scale wildlife use contexts is present. These tools and frameworks can be used to compare and contrast between cases, learn from experiences, and connect researchers working in diverse social-ecological systems under a common umbrella. This research demonstrates the need to systematically tackle non-compliance in small-scale wildlife use contexts, considering the diversity of actors involved and their motivations, and the market and supply chain used to trade wildlife products.

Resumen

El comercio sustentable de vida silvestre es crítico para la conservación de la biodiversidad, como fuente de trabajo y para la seguridad alimentaria. Sin embargo, el cumplimiento con las reglas y regulaciones para el comercio de vida silvestre sustentable no puede darse por sentado. Los impactos ecológicos del incumplimiento se han documentado ampliamente en diversos ecosistemas y son especialmente críticos en contextos de uso a pequeña escala, que generalmente implican una gestión deficiente y una capacidad de vigilancia limitada. En este DPhil, mi objetivo es contribuir a la comprensión científica de cómo el incumplimiento en contextos de uso de vida silvestre a pequeña escala puede ser estudiado y manejado a través de enfoques innovadores e interdisciplinarios, utilizando una pesquería de pequeña escala en Chile como caso de estudio.

La recolección de datos se llevó a cabo en el caso de estudio de la pesca artesanal de merluza común (*Merluccius gayi gayi*) en la VII Región de Chile. Utilicé múltiples métodos, incluyendo técnicas de encuesta especializadas para evaluar comportamientos sensibles, entrevistas con informantes clave, revisión de literatura y análisis de bases de datos generados por el gobierno. Mis resultados indican que la mayor parte de la merluza común comercializada en la región analizada proviene de actividades relacionadas con incumplimiento. También encontré que las motivaciones de los pescadores para no cumplir son diversas, dependen de la regulación, e incluyen motivaciones normativas (es decir, prescripciones comúnmente aceptadas en un grupo, que apoyan conductas deseables y prohíben las indeseables), basadas en la legitimidad (es decir, aceptación de decisiones y sus resultados por parte de los ciudadanos) y motivaciones instrumentales (es decir, cálculo económico de los costos y beneficios del cumplimiento). Además, descubrí que el incumplimiento en esta pesquería está influenciado por el funcionamiento de la cadena de suministro y la dinámica del mercado. Específicamente, encontré que los incentivos de los comerciantes (es decir, intermediarios) para comercializar productos legales o ilegales ayudan a describir los desembarques y la dinámica de

la pesquería y pueden usarse para predecir el efecto de posibles intervenciones para reducir el incumpliendo.

En base en la evidencia recopilada, proporciono recomendaciones de política pública para reducir el alcance del incumplimiento para este caso de estudio, y para otros similares. Además, en este DPhil, proporciono herramientas que pueden usarse para estudiar el incumplimiento en otros contextos de comercio de vida silvestre para generar nuevas formas de pensar sobre cómo intervenir cuando existe incumplimiento. Estas herramientas y marcos conceptuales se pueden utilizar para comparar y contrastar casos, aprender de las experiencias y conectar a los investigadores que trabajan en diversos sistemas socio-ecológicos bajo un mismo paraguas. En este DPhil se demuestra la necesidad de abordar sistemáticamente el incumplimiento en el uso de vida silvestre a pequeña escala, considerando la diversidad de actores involucrados y sus motivaciones, y el mercado y la cadena de suministro utilizados para comercializar los productos.

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List of Acronyms and Abbreviations

BBM	Ballot Box Method
BLUPS	Best Linear Unbiased Predictors
CAPES	Centre for Applied Ecology and Sustainability
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLP	Chilean Pesos
COVID	Coronavirus 2019-nCoV
CRAVED	Concealable, Removable, Available, Valuable, Enjoyable, and Disposable
CUREC	Central University Research Ethics Committee
IUU	Illegal, Unreported and Unregulated
IUWT	Illegal and Unsustainable Wildlife trade
IWT	Illegal Wildlife trade
NGO	Non-governmental Organization
RFMO	Regional Fisheries Management Organizations
RGLFA	Revised General Law of Fishing and Aquaculture
RRT	Randomized Response Technique
SD	Standard Deviation
SDG	Sustainable Development Goals
SE	Standard Error
SNA	Social Norms Approach
SERNAPESCA	Chilean National Fisheries and Aquaculture Service
SUBPESCA	Chilean Undersecretary of Fisheries
TAC	Total Allowable Catch
TPB	Theory of Planned Behaviour
TURF	Territorial User Rights for Fisheries
UCT	Unmatched Count Technique
USD	United States Dollars

Chapter 1: Introduction

1.1. Problem statement

Moving towards a peaceful and prosperous global society requires coordinated efforts to simultaneously improve people's lives while maintaining the health of the natural world. This vision is at the forefront of one of humanities' most consolidated efforts: the adoption, by the United Nations, of the 17 Sustainable Development Goals (SDGs) (Figure 1.1.1.) (United Nations, 2015). Simultaneously adopting these goals is no easy task, as reconciling global agendas with local realities is challenging. A myriad of trade-offs, synergies, and feedbacks between and within SDGs further defy implementation (Booth et al., 2020; Herrera, 2019; Singh et al., 2018). On top of these challenges, the COVID-19 pandemic has thrown significant progress overboard. Not only have more than 4.8 million people died from a pandemic, but the SARS-CoV-2 virus has also disrupted livelihoods, sending millions into poverty (Hughes et al., 2021). Navigating towards the SDGs was a challenging task even before COVID-19. Now, the window of opportunity for global action is shrinking even faster, and action is needed on all fronts, with more urgency than ever.

Figure 1.1.1. United Nation's Sustainable Development Goals

The sustainable use and trade of wildlife can play a big part in getting us back on track with the SDGs (Booth et al., 2020; McNamara et al., 2020). The trade in wild fungi, for instance, can help fight poverty (SDG 1), decrease hunger (SDG 2) while reducing inequalities and providing a reliable income for women (SDGs 3 and 5) (Pérez-Moreno et al., 2021; Román et al., 2006). Similarly, the use and trade in bushmeat provides thousands with livelihoods (SDG 8) and contributes to food security worldwide (SDG 2) (Cawthorn & Hoffman, 2015). Blue foods (those captured or cultivated in marine or freshwater ecosystems) are also expected to have a critical role in providing nutritious food (SDG 2), livelihoods (SDGs 1 and 8) but this necessitates healthy marine and freshwater ecosystems (SDGs 14 and 15) (Gephart et al., 2021; Naylor et al., 2021). For wildlife trade to serve as an avenue towards the SDGs, sustainable wildlife management is required, which depends mainly on rules, laws, and regulations. However, compliance with wildlife conservation and management rules cannot be taken for granted (Keane et al., 2008). The ecological impacts of non-compliance with conservation rules have been widely documented across diverse biomes, obstructing the fulfilment of SDGs 13, 14, and 15 (Agnew et al., 2009; Maxwell et al., 2016; Raemaekers et al., 2011). Moreover, non-compliance can threaten institutions, and conservation and wildlife management efforts (hindering progress towards SDG 17), causing mistrust and tensions between wildlife users and regulators (Doumbouya et al., 2017; Faasen & Watts, 2007; Von Essen et al., 2014).

The impacts of non-compliance are especially acute in small-scale wildlife use contexts, which usually involve poor management and limited enforcement capacity (Biggs et al., 2017; Gelcich et al., 2017; McDonald et al., 2016). For instance, small-scale illegal logging has been recognized as one of the major threats to the conservation of forests worldwide (Ramcilovic-Suominen & Epstein, 2012; Tacconi, 2012). Similarly, bushmeat overhunting has been linked to adverse effects on biodiversity and driving species to the brink of extinction (Benítez-López et al., 2017; Effiom et al., 2013; Milner-Gulland et al., 2003; Ripple et al., 2016). Moreover, small-scale fishing non-compliance has been linked to the collapse of fishing stocks and habitat destruction (Cisneros-Montemayor et al., 2013; Plotnek et al., 2016; Slade & Kalangahe, 2015). Dealing with non-compliance in these contexts is further necessary because small-scale communities are often highly dependent on wildlife as a source of employment and food availability (FAO, 2018). Reducing non-compliance in small-scale user contexts is, therefore, a key challenge for advancing towards the SDGs.

Reducing non-compliance in the small-scale fisheries sector is of great importance for Chile. Chile is one of the largest producers of marine products globally, with average landings between 2005-2014 of 3.1 million tonnes (FAO, 2018). Along its more than 4,300 kilometers of coast, diverse fisheries operate, targeting a suite of species and directly providing livelihoods to around 90,000 small-scale fishers (Castilla & Fernández, 2015). Although progressive in applying innovative and science-based schemes, fisheries management in Chile suffers from chronic non-compliance. For instance, estimates for one of the most important small-scale benthic fisheries, the loco (*Concholepas concholepas*), suggest that between 70 and 85% of landings are illegal (Oyanedel et al., 2018). Similar figures have been obtained for other economically important species, which has driven growing attention to the issue (Donlan et al., 2020). Increasing compliance in Chile's fisheries is urgent for the sector to support progress towards the SDGs. Furthermore, lessons from studying non-compliance in small-scale fishing contexts can be drawn upon for advancing the understanding of non-compliance issues in small-scale wildlife use contexts more broadly.

Efforts to reduce non-compliance with rules are as old as rules themselves. Historically, compliance has been sought by governments through impositions of sanctions on offenders, primarily via enforcement programs and actions (Arias & Pressey, 2016; Critchlow et al., 2017a; Milner-Gulland & Leader-Williams, 1992). This approach assumes that wildlife users are rational decision-makers seeking to maximize their utility and that non-compliance occurs when benefits outweigh costs

(Becker, 1968). This forms the basis of the instrumental model, which aims to reduce non-compliant behaviors by increasing the cost of not complying and/or reducing the cost of behaving legally (Becker, 1968; Keane et al., 2008). However, two main problems arise when using the instrumental model for compliance, especially in small-scale contexts (Kuperan & Sutinen, 1998a). First, resources for enforcement are usually not at the required or optimal level, with governments from developing countries lacking the necessary tools, human capacities, and technologies to properly enforce rules (Davis et al., 2017; di Minin & Toivonen, 2015). Second, fines are not usually effective because of the difficulty of catching non-compliant wildlife users *in situ* and collecting robust evidence of their non-compliant actions. When imposed, the penalties are often not significant enough to make users comply (Kuperan & Sutinen, 1998a).

Moving beyond the instrumental model and expanding the suite of approaches to deal with the problem of non-compliance with wildlife management rules is greatly needed. Devising approaches and taking theories from other disciplines can aid in this task. Non-compliance is not exclusive to wildlife use; there is a large body of theory concerned with non-compliance behaviors and crimes more broadly, spanning many disciplines from criminology to economy and psychology (Berkowitz, 2005; Clarke, 2016; Keane et al., 2008; Nielsen, 2003). This presents a potential opportunity to apply some of these theories to expand the study of non-compliance in wildlife management contexts.

One way to expand the study of non-compliance is by accounting for the nuances of the governance of small-scale wildlife use contexts. In these contexts, management and conservation usually involve informally developed rules set voluntarily by local actors, independently of government or state laws (Epstein, 2017; Nakandakari et al., 2017). Benefits have been documented for these self-governance arrangements, especially in cases where state law is absent, laws are perceived as unfair and therefore lack legitimacy, and where subsistence need prevents compliance (Castilla & Gelcich, 2007; Ostrom, 1990). Thus, small-scale wildlife users can operate under diverse rule systems ranging from informal self-governance to national-level legal, institutional arrangements (Lindkvist et al., 2017; Ostrom, 2010). Recognizing these realities can provide two benefits. First, it means that researchers can build an understanding of non-compliance in contexts where no formal laws exist, but other informal rules exist. And second, simultaneously it enables them to assess non-compliance across the range of institutional arrangements that small-scale wildlife users operate. It also allows a more neutral framing, as the terms “offender” or “violator”, which are usually used in conservation literature to refer to law-breakers, is a negative framing. Instead, using “actor” recognizes that people may break the rules for what may, at least from some perspectives, be legitimate reasons.

A second way to expand the study of non-compliance in wildlife use contexts is by including in assessments not only harvesters but all actors involved in wildlife supply chains. To date, most of the research on non-compliance has focused exclusively on harvesters (e.g., fishers, hunters, loggers). Less attention has been directed to the other participants in wildlife supply chains, who are also vital in determining their sustainability (FAO, 2015; González-Mon et al., 2019). Traders, for instance (also referred to as middlemen or intermediaries), connect end-markets and consumers with wildlife harvesters, ultimately influencing how wildlife is used (Crona et al., 2010; González-Mon et al., 2019). Focusing the study of non-compliance exclusively on those who harvest wildlife, rather than integrating the diversity of actors who can influence how wildlife is used, can lead to only a partial understanding, which compromises our ability to intervene effectively and may risk unintended consequences (Larrosa et al., 2016). Expanding the study of non-compliance in wildlife use contexts by embracing a more nuanced definition of rules and regulations and including all actors involved in supply chains can shed new light to solve this perennial problem. This, in turn, can help to ensure that wildlife use and trade support, rather than hinder, progress towards the SDGs.

1.2. Aims and objectives

The overall aim of my thesis is to contribute to the scientific understanding of how non-compliance in small-scale wildlife use contexts can be studied and ultimately managed through innovative and interdisciplinary approaches, using a small-scale fishery in Chile as a case study.

The specific objectives of my thesis are to:

Objective 1: Assess and review diverse literature and approaches that can be applied to study and reduce non-compliance in fisheries and beyond.

Objective 2: Estimate rates of non-compliance with different rules and regulations, amounts of illegal extraction, and disentangle what underlies the heterogeneity of observed non-compliance behaviour of small-scale fishers.

Objective 3: Develop a framework to help guide better understanding of wildlife markets when there are unsustainable and illegal practices and identify potential interventions to reduce them.

Objective 4: Develop a simulation approach to understand what drives traders to trade legal or illegal wildlife products and identify which policy levers might change those incentives towards more legal trading.

1.3. Thesis outline

Chapter 1: Introduction

In this initial chapter, I provide a general introduction to the thesis, including the problem statement describing the current status and opportunities to expand the study of non-compliance in wildlife more broadly and the aims and objectives of my DPhil. This chapter also includes the thesis outline, other research done during my DPhil, and a research positionality statement.

Chapter 2: Background

In this chapter, I first describe the challenges of studying non-compliance and some methodologies developed to overcome them. I then briefly describe how fisheries supply chains are structured, including how food systems operate. Finally, I describe my study system (small-scale common-hake fishery in Chile), its history, governance structure, and market.

Chapter 3: A synthesis of (non-)compliance theories with applications to small-scale fisheries research and practice

In this chapter, I review two main approaches for studying non-compliant behaviors and crimes more broadly, spanning criminology, economics, and psychology. On the one hand, actor-based approaches address the underlying motivations for people to comply or not with regulations. On the other hand, opportunity-based approaches assume that non-compliance is not distributed randomly across space and time and focus on the role that the immediate environment plays in the performance of non-compliant behaviors. I discuss potential applications of actor-based and opportunity-based approaches in guiding small-scale fisheries non-compliance research. Moreover, I provide guiding principles for integrating these approaches in a complementary way, highlighting opportunities and challenges for building a better non-compliance research agenda for fisheries and beyond.

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Author contributions:

RO proposed, conceptualized, and drafted this chapter, with comments and supervision from SG and EJMG. All authors edited and reviewed the manuscript.

Chapter 4: Motivations for (non-)compliance with conservation rules by small-scale resource users

In this chapter, I assess compliance and its underlying motivations in a small-scale fishery in Chile. I adapt a framework originally developed for forestry to unpack compliance motivations at within-individual and between-individuals levels while accounting for contextual factors. I find that 92–100% of fishers comply with temporal or gear rules, while only 3% comply with the quota limit. Legitimacy-based motivations are more important in explaining why individual fishers comply with temporal/gear rules than they are for compliance with the quota. At the between-individuals level, I find that normative motivations are significantly related to the degree of non-compliance with the quota. Contextual factors such as quota levels are vital in explaining broader non-compliance patterns. Results suggest that considering compliance at appropriate analytical levels is necessary to unpack motivations, guide local and national natural resource management policies, and move toward a better compliance theory.

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Author contributions:

RO proposed, conceptualized, designed, collected, and analyzed the data, and drafted this chapter, with comments and supervision from SG and EJMG. All authors edited and reviewed the manuscript.

Chapter 5: A framework for assessing and intervening in markets driving unsustainable wildlife use

In this chapter, I propose a framework to better assess and intervene in wildlife markets that integrates three analytical levels. The first level, "actor", assesses the underlying motivations and mechanisms that allow or constrain how actors benefit from wildlife markets. The second level, "inter-actor", assesses the configuration of wildlife product supply-chains and the type of competition between actors participating in wildlife markets. The third level, "market", evaluates supply-demand dynamics, quantity and price determinants, and the presence and effect of illegal products flowing into markets. I showcase the framework's utility in a data-limited small-scale fishery case study (common hake, *Merluccius gayi gayi* in Chile); the mixed-method analysis provided relevant, tailored management recommendations for improving sustainability. Tackling markets driving unsustainable wildlife use needs integrated approaches that bring together the diversity of factors affecting wildlife market dynamics.

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Chapter 6: A dynamic simulation model to support reduction in illegal trade within legal wildlife markets

In this chapter, I present a dynamic simulation model to support reduction in illegal wildlife trade within legal markets by focusing on the incentives to trade legal or illegal products faced by traders. I use an Approximate Bayesian Computation approach to infer illegal trading dynamics and parameters that might be unknown (e.g., price of illegal products). I showcase the approach's utility with a small-scale fishery case study in Chile, where I disentangle within-year legal and illegal trading dynamics and show that most traded fish is illegal. Moreover, I utilized the model to assess the effect of policy interventions to improve the fishery's sustainability and explore the trade-offs between ecological, economic, and social goals. Scenario simulations show that even significant increases (over 200%) in parameters proxying for policy levers enable only moderate improvements in ecological and social sustainability, at a substantial economic cost, exposing how unbalanced trader's incentives are towards trading illegal over legal products in this fishery. This model is a novel tool for promoting sustainable wildlife trade in data-limited settings, which explicitly considers traders as critical players in wildlife markets.

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Author contributions: RO proposed, conceptualized, designed, collected, and analyzed the data, and drafted this chapter, with comments and supervision from Emile Mathieu, SG, and EJMG. All authors edited and reviewed the manuscript.

Chapter 7: Discussion and Conclusion

In this final chapter, I provide a summary of my thesis linking it to the objectives posed. Then, I propose several interventions for the common-hake fishery based on my findings and considering a broader perspective in which I draw parallels with what has been found in other wildlife trade contexts. Next, I discuss how conservation researchers need to reflect on their process for proposing interventions for improving sustainability. I finish providing cross-cutting themes and recommendations for further research, as well as personal reflections of my process as a DPhil researcher.

1.4. Other research

Throughout my DPhil, I led and contributed to other research projects related and unrelated to my main research topic. These efforts are published or have been accepted as the following papers or book chapters:

1. Hannah, L., Costello, C., Elliot, V., Owashi, B., Nam, S., **Oyanedel, R**., ... & McDonald, G. (2019). Designing freshwater protected areas (FPAs) for indiscriminate fisheries. *Ecological Modelling*, *393*, 127-134.
2. Muller, M. R., **Oyanedel, R**., & Monteferri, B. (2019). Marine and Fisheries Policies in Latin America: A Comparison of Selected Countries. *Routledge*.
3. **Oyanedel, R**. (2019). Illegal fishing and non-compliance. In *Marine and Fisheries Policies in Latin America* (pp. 45-54). Routledge.
4. Booth, H., Arias, M., Brittain, S., Challender, D. W., Khanyari, M., Kuiper, T., Li, Y., Olmedo, A., **Oyanedel, R**., Pienkowski, T. & Milner-Gulland, E. J. (2021). "Saving lives, protecting

livelihoods, and safeguarding nature": risk-based wildlife trade policy for sustainable development outcomes post-COVID-19. *Frontiers in Ecology and Evolution*, *9*, 99

5. Torres, Felipe., **Oyanedel, Rodrigo**. & Gelcich, Stefan. Adoption and impacts of fishing gear innovations: Insights from a small-scale fishery in Chile. *Fisheries Research (accepted)*.

6. Snyder, Hunter T**., Oyanedel, Rodrigo**., Sneddon, Christopher S. & Scheld, Andrew M. Attitudes and behaviors for understanding compliance in Greenland's Atlantic salmon (Salmo salar) fishery*. Conservation Science and Practice (accepted).*

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1.5. Research Positionality

My journey towards this DPhil started quite some time ago while exploring the coast of Chile with my parents as a kid. I remember very well the excitement of waiting for the small wooden boats with their mystic-beard fishers to land on the shore and see what they might bring. What I saw, trying to lean over the side of the boat, were my first glimpses of what the ocean had beneath its surface. The fishers' stories were my first interactions with small-scale fishers' complicated, erratic, and beautiful culture. Several years later, while doing my undergraduate degree in Marine Biology, these stories and memories would come back, though in a different shape. While studying the diversity of conservation challenges that the oceans faced, I quickly realized that conservation had to do much more with those using nature than the species being used. This brought small-scale fishers into focus again: it was them who I needed to understand if I wanted to have a positive impact in protecting the ocean.

That drive quickly turned into action. After my Master's degree, I started working as a consultant for NGOs and Foundations to improve the sustainability of small-scale fisheries in Chile and Peru. This work allowed me to travel all along Chile and Peru's coast, talking to fishers, understanding projects that were being developed, and deep dive into the role of governments in trying to enhance (hinder) sustainability. And while we were making some progress with the NGOs and Foundations I was working with, I grew disenchanted by the superficiality of the discussions and the weak basis on which decisions were being made. This was especially apparent with the most significant threat to our work: non-compliance. While ample funding was being put into different solutions to reduce non-compliance, there was a profound lack of understanding of the causes of the problem itself. Instead, solutions were being proposed (and funded!) based on spurious assumptions at best. It became clear to me that I was in the wrong job, and I needed to understand better what was causing small-scale fishers not to comply with regulations and what could be done (with data) to inform better interventions to reduce the extent of the problem.

As a natural scientist I was surely biased towards understanding and conceptualizing these issues with quantitative rather than qualitative methods and focusing on the people who interact directly with nature, in this case fishers. This bias permeated the decisions I made, early on in my DPhil, about the approaches and methods I was going to use in the first chapters of my thesis. In that sense, planning my first empirical chapter with quantitative methods and with fishers as study objects was a continuation of my previous work and experience and highly influenced by my background. The fieldwork campaign for that first chapter, however, shook the foundations of what I had planned for my DPhil. It made me realize that I needed to factor in how the way I related to fishers might influence my research process. Fishers undoubtedly saw me as an outsider from their own culture and socio-economic status, and because I was coming from an internationally renowned University, as a qualified professional. This created some distance between me and them, but also a sense of responsibility to "help them". I have taken on this responsibility with caution though, trying to avoid making it personal to the level where it might influence the interpretation of my findings. While on fieldwork, I also realized that fishers were undoubtedly not the only ones involved in non-compliance operations; there was a larger system and set of people around this activity that needed to be considered. This required shifting gears and the focus of my studies. In the Discussion section, I come back to this point and how I tried, during my thesis, to overcome my own path-dependency as a researcher in order to better assess what influences the occurrence of non-compliance in my case study.

Because I needed to broaden the way I was looking at the non-compliance issue, I had to push my curiosity, move away from my comfort zone, and explore methods and literature that I didn't even know existed before enrolling in this program. This created uncertainty, and a void of intellectual identity in me, as I lost track of my strengths and capacities while venturing into new terrains. It wasn't all dark, of course, on the contrary. Doing a DPhil is an extraordinarily privileged opportunity to take the necessary time to learn, explore, make mistakes, and treasure little victories from time to time. Opening to new ideas and worldviews has been crucial in my formation and has allowed me to diversify the suites of tools to study sustainability problems. My intellectual identity, I realized, doesn't need to be fixed or intrinsically related to what I have done in the past. As Professor Richard

Feynman once said, “You are under no obligation to remain the same person you were a year ago, a month ago, or even a day ago. You are here to create yourself, continuously.” Indeed, I see my work and research now as a constantly changing, ever-evolving process, rather than the static certainty-seeking enterprise I visualized when I started. In retrospect, this realization by itself is worth the effort I have put into this DPhil.

Chapter 2: Background

2.1. Studying non-compliance

Studying non-compliance in wildlife use contexts is challenging given its sensitive and even cryptic nature, which defies the application of many of the other methodologies used to assess conservation problems (Gavin et al., 2009; Nuno & St John, 2015). This has ignited interest in developing and testing methods and approaches that can help estimate the extent of non-compliance, trends, and underlying drivers (Blank & Gavin, 2009; Conteh et al., 2015; Hinsley et al., 2019). Below, I present 3 out of the many approaches that can be used to study non-compliance in wildlife use context: asking people that might participate in the activity about it using sensitive questioning techniques; using predictive simulation models; and via encounter data models which estimate the detectability of non-compliance so as to infer its real extent. Each approach has advantages and limitations, and which one to use will depend on the context, the data availability, and local expertise. Moreover, the study of non-compliance is victim to some of the same perils of other conservation research topics; data collection is expensive, time-consuming, and even impractical (Dobson et al., 2020). This leads conservationists, governments, and scientists to sometimes rely on patchy and loosely structured data, which requires the underlying biases of the data to be anticipated and overcome (Dobson et al., 2020; Keane et al., 2008).

The challenges of studying non-compliance call for an interdisciplinary perspective, in which methodologies and approaches from several disciplines interact towards a common goal (Hicks et al., 2010). The advantage of interdisciplinarity is that knowledge, ideas, or methods can be transferred between disciplines, providing potential for the production of a more comprehensive understanding of the subject from the combined knowledge (Newing, 2010b). Interdisciplinary research is not without its barriers, and discrepancies between disciplines might challenge its application even when researchers have common goals (Hicks et al., 2010; von Essen et al., 2015). This is especially so when methods (or their underlying philosophies) are incompatible between disciplines, preventing progress. However, considering the diverse limitations that particular methodologies and approaches have for studying non-compliance, the potential benefits of using an interdisciplinary approach could incentivise researchers to embrace its use and overcome its challenges.

2.1.1. Sensitive questioning techniques

One way to study non-compliance is by directly asking those involved in the activity, using surveys or interviews. This approach is becoming increasingly important as a tool to understand non-compliance (Aronow et al., 2015; Fox & Tracy, 1986; Hinsley et al., 2019; Ibbett et al., 2021; Krumpal et al., 2018; Ulrich et al., 2012; Walzenbach & Hinz, 2019). The advantage of assessing non-compliance through surveys or interviews is that the extent or trends of non-compliance can be investigated alongside its behavioural drivers (Id et al., 2018; Thomas et al., 2016). However, because of the nature of non-compliance, those who participate in the activity might be reluctant to answer questions related to their activity. Moreover, even those who might participate in a survey will be biased towards understating their participation in illegal behaviours or behaviours perceived as socially unacceptable (social desirability bias) (Oyanedel et al., 2018).

As such, assessing non-compliance through surveys or interviews requires specialized techniques to overcome the biases generated by the sensitive nature of non-compliance. Several methods have been developed to this end (e.g., Ballot Box Method, Unmatched Count Technique, Randomized Response Technique (Arias, 2021; Bova et al., 2018; Fox & Tracy, 1986; Hinsley et al., 2019)). These methods share the use of different ways to protect the anonymity of the respondent, reducing potential bias. The Randomized Response Technique (RRT), for instance, uses a randomized device or process (e.g., throwing a die) to determine whether the respondent has to answer truthfully or not to a sensitive question (Fox, 2012; Lensvelt-Mulders et al., 2005). This guarantees the anonymity of the interviewee because the interviewer does not know the results of the randomized process, and therefore if the interviewee is answering truthfully or not. This technique has been used widely in sociological and psychological research to assess sensitive issues such as drug abuse (Fox & Tracy, 1986), and lately also in wildlife use contexts (Blank & Gavin, 2009; Gavin et al., 2009; St John, Edwards-Jones, et al., 2010). While the "classic" RRT can assess binary responses to a sensitive question (Yes/No), a variation of the RRT can be used to quantify the extent of non-compliance activities (Conteh et al., 2015). Proposed by (Greenberg et al., 1971), the quantitative RRT can be used to estimate the amount of wildlife being extracted through non-compliant activities, therefore providing a valuable tool to assess the consequences of non-compliance behaviours quantitatively.

2.1.2. Predictive simulation models

Predictive simulation models allow experimentation and hypothesis-testing in a "virtual world" constructed to assess a complex system through a series of explicit equations that transparently lay out the assumptions being made to describe the system (Milner-Gulland & Rowcliffe, 2013). As such, predictive simulation models can complement the study of non-compliance as a powerful tool for assessing how different sectors of wildlife supply chains might be affected by changes in rules or regulations. This can then help to understand the cost-effectiveness of potential interventions to reduce non-compliance. Moreover, simulation models can accommodate different outcomes in cost-effectiveness assessments, such as ecological, economic, and social (e.g., change in wildlife used, profit generated, and non-compliance levels given the intervention, respectively). Using predictive models to assess the impacts of interventions considering the three pillars of sustainability (social, ecological, and economic) in wildlife use context can help avoid unintended consequences, shedding light on where to direct efforts and which interventions to refrain from (Larrosa et al., 2016).

Predictive simulations models for aiding the study of non-compliance can take several forms. For instance, agent-based models can simulate the strategic decision-making of a set of individuals (e.g., hunters) while simultaneously modelling the behaviour of wildlife and the feedback between the model components (Neil et al., 2020). Another approach is Approximate Bayesian Computation (ABC) models, which are especially useful in cases when only some of the data that generates a process (e.g., non-compliance) are available (Beaumont, 2010). The ABC approach models how the available data are generated from some partially unobserved (latent) variables. It then helps find the latent variable values, or their distributions in a probabilistic setting, that would approximately generate the observed data.

2.1.3. Encounter data models

Encounter data models try to estimate the extent of non-compliance through analysis of the data obtained from monitoring of encounters: these datasets can be generated through encountering the evidence of non-compliance (e.g., carcasses) or the activity itself. This approach is probably the most common approach to assessing non-compliance because it feeds off from the activity and reports of rangers patrolling protected areas (Kuiper, 2020), community-based efforts (Biggs et al., 2017), government officials enforcing laws (Donlan et al., 2020), or data generated by international trade agreements such as CITES (Underwood et al., 2013). Therefore, this approach can provide data and information from a broad range of contexts, helping to shed light on non-compliance trends, their extent, and their effect on target populations (Keane et al., 2011). Indeed, encounter data models have been used to assess non-compliance in bushmeat hunting contexts (Ibbett et al., 2020), poaching in terrestrial protected areas (Moore et al., 2021), and non-compliance with fisheries and marine protected areas regulations (Thiault et al., 2020).

However, encounter models might suffer from unquantifiable biases in wildlife use contexts because identifying the time and space where non-compliance occurs is challenging (Gavin et al., 2009; Keane et al., 2011). This is especially so when only enforcement and infringement records are used, as they are not always good indicators of where and when non-compliance occurs (Critchlow et al., 2017a; Keane et al., 2011; O'Kelly et al., 2018a). This is because enforcement is reactive and non-random; therefore, data from this activity is inherently biased (Keane et al., 2008; O'Kelly et al., 2018b). The second source of bias arises because enforcement acts as a deterrent, subsequently changing resource user behaviours and further reducing the ability of enforcement records to detect true non-compliance occurrences (Keane et al., 2011). But, advances in encounter data analysis and modelling have proven useful to disentangle inherent co-founding factors and biases, leading to better interpretation of infringement records (Critchlow et al., 2015; Underwood et al., 2013). This, in turn, can help to identify hotspots and temporal trends of non-compliance. Examples of the application of these models can be found for snare detection (O'Kelly et al., 2018b), elephant carcasses (Burn et al., 2011) and ivory seizure data (Underwood et al., 2013).

2.2. Ethical considerations

As with any study involving human participants, there are important ethical considerations when studying non-compliance. First, clear protocols and good practices are needed to ensure that those individuals who participate in research projects do not suffer adverse consequences from doing so (Newing, 2010a). This is of particular concern when dealing with people who might have been involved in non-compliant behaviours, as admitting to doing so could carry legal or social implications (Hinsley et al., 2019). While there is always a potential risk of consequences for research participants, researchers must minimize these. This can be done by ensuring truly anonymized methods (such as those presented above) so that interviewees cannot be linked back to their responses (Ibbett et al., 2021). Another way to minimize this risk is through seeking informed consent from participants to ensure voluntary participation and the right to withdraw. While protecting participants at the individual level, those studying non-compliance should also consider the effect that research results and policy recommendations might have on communities at the aggregate level (St John et al., 2016). Maintaining anonymity at the group level is a way to get around this, while also not disclosing identifiable features of the research locations. This, however, also could have its issues, because it impedes scientific replicability and limits informative reporting to local authorities interested in reducing non-compliance. In any case, researchers should always obtain ethical approval from authorized, ethical review boards at their institutions, which is unfortunately not as common as it should be (Brittain et al., 2020).

2.3. Wildlife beyond harvest

The harvest of wildlife products is only the first step in a series of events that finishes in the product being used or consumed. Markets combine institutions, processes, infrastructure, and social relations where parties engage in exchange. Assessing and understanding wildlife markets can aid in the study of non-compliance because market dynamics ultimately influence how wildlife is used (Bennett et al., 2021; Cinner et al., 2020a; Crookes & Milner-Gulland, 2006). For instance, in systems where markets are demand-driven, wildlife users' activity responds closely to changes in prices, which in turn depends on demand. As such, in demand-driven markets, consumers' preferences and behaviour play a crucial role in determining how much and when wildlife is harvested. In supply-driven markets, on the contrary, suppliers (wildlife users) participate in markets independently of price signals. In these markets, suppliers' operations are defined mainly by natural variability or alternative income streams (McNamara et al., 2016). Assessing market characteristics, such as whether it is supply or demand-driven, can inform decision-making about the type and target (e.g. suppliers or consumers) of interventions that might potentially reduce non-compliant practices (McNamara et al., 2016).

Researchers from several disciplines have investigated wildlife markets to understand their operation in general and the presence and impacts of non-compliance in particular. This is because, for several species, markets have been identified as the drivers of non-compliance (Crookes & Milner-Gulland, 2006; Lunstrum & Givá, 2020; Marshall et al., 2020). For instance, previous work has looked at motivations for the use and consumption of wildlife products (Thomas-Walters et al., 2020), provided frameworks for analysing illegal wildlife trade (Phelps et al., 2016) and theorized about how wildlife supply and demand might change under different scenarios (Bulte & Van Kooten, 1999; Chen & 't Sas-Rolfes, 2021; Crookes, 2017; Crookes & Blignaut, 2015; Damania et al., 2005). The diversity of work in this area has prompted an intense debate about regulating wildlife markets and whether there should be trade in wildlife at all. Proponents of "blanket bans" argue that, in addition to ethical concerns, all wildlife trade should be banned because the existence of a legal market allows for smuggling illegal products, especially in cases where demand cannot be met by legal products alone (Bennett et al., 2021). On the other side, those who argue for wildlife markets to operate do so on the basis that conservation of wildlife is possible if it has a legitimate economic value, to incentivize local people to conserve, and because the earnings from wildlife trade can help support conservation (Bennett et al., 2021). These issues are complex, intricate, and context-dependent: more research is undoubtedly needed to disentangle the role of markets in hindering or incentivizing non-compliance and sustainability at the local level.

Given the role that markets have in influencing how wildlife is used, it is necessary to characterize and assess the heterogeneity in actors' roles within markets and their part in hindering or incentivizing non-compliance. For my thesis, I categorize actors in the market into four categories: harvesters (those who directly interact with wildlife and extract it from nature through fishing, hunting, snaring, logging, mushroom picking, etc.); traders or intermediaries (those who transform and transport wildlife from its harvest point to selling point); vendors (those who are involved in selling wildlife products to consumers); and consumers (end-users of wildlife products). Within these categories, there is also heterogeneity in the actors that compose each group, which requires the creation of context-based typologies to ultimately understand how actors influence wildlife markets.

2.4. Study system

2.4.1. Common hake

The common hake (*Merluccious gayi gayi*) is a fish species that plays a critical trophic role in the upwelling ecosystem off central Chile's coast (Neira & Arancibia, 2013; San Martín et al., 2013). It inhabits the upper continental slope, ranging from 50 to 500 meters in depth. It exhibits age-dependent habitat differentiation, with juveniles mostly found closer to the coast in shallower waters and adults moving down the continental slope to deeper waters as they grow (Alarcón et al., 2008). Adults come back closer to the coast to spawn throughout the year, but higher spawning levels are concentrated between July and November (peaking in August-September), and to a lesser extent, between December and February (SUBPESCA, 2016). A long-lived species, the common hake's lifespan is 17 to 21 years in females and 11 to 15 years in males. Similar to other cod-like species, it is resilient to significant variations in environmental conditions and has high fecundity rates. Mortality is driven mainly by human pressure through fishing, which can cause stock collapse if the population structure is altered beyond ecological tipping points (SUBPESCA, 2016).

Figure 2.4.1. Common hake (Subpesca)

2.4.2. The fishery

The fishery is composed of an industrial and a small-scale fleet, which operate between the IV region (central-north) and the X (central-south) region in Chile. The bottom-trawling industrial fleet consists of vessels larger than 18 m that cannot operate within 5 miles of the coast. The small-scale fleet consists of approximately ~900 vessels, most less than 12 m lengths and some up to 16 m, using handlines, long-lines, and gillnets (Plotnek et al., 2016; SUBPESCA, 2016). Catch landed by both fleets is mostly destined for domestic direct human consumption, mainly as fresh and frozen fillets, and some industrial catch being exported. Common hake is one of the most valuable fisheries in Chile in terms of income and jobs, employing more than 3,000 fishers directly only in the small-scale sector (supporting SDGs 1 and 8) (Arancibia & Neira, 2008). Moreover, common hake is, arguably, the most accessible fish resource in Chile. As such, it plays a vital role in food security and nutrition for low- and mid-income families (SDGs 2 and 3). Additionally, it plays a critical socio-cultural role for consumers because of its importance in festivities, such as in Easter, when consumption increases considerably (*Personal observation*).

The common hake fishery has a long-term history of over-exploitation and recovery cycles. The fishery (composed only of an industrial fleet) started developing in the early 1940s, building up to full exploitation in the mid-1950s, when landings were around 80,000 tons (Figure 2.4.2.). Increased demand kept boosting landings, which peaked at 130,000 tons by 1968. However, estimates of discards and unreporting suggest that the actual catch could have been as high as 160,000 tons in that year (Arancibia & Neira, 2008). A sharp decline followed this peak, with landings stabilising during the 1980s at around 30,000 tons. During this period, demand decreased because the use of common hake for fishmeal ceased. Throughout the 1980s, the small-scale fleet started playing a more significant role in total catches.

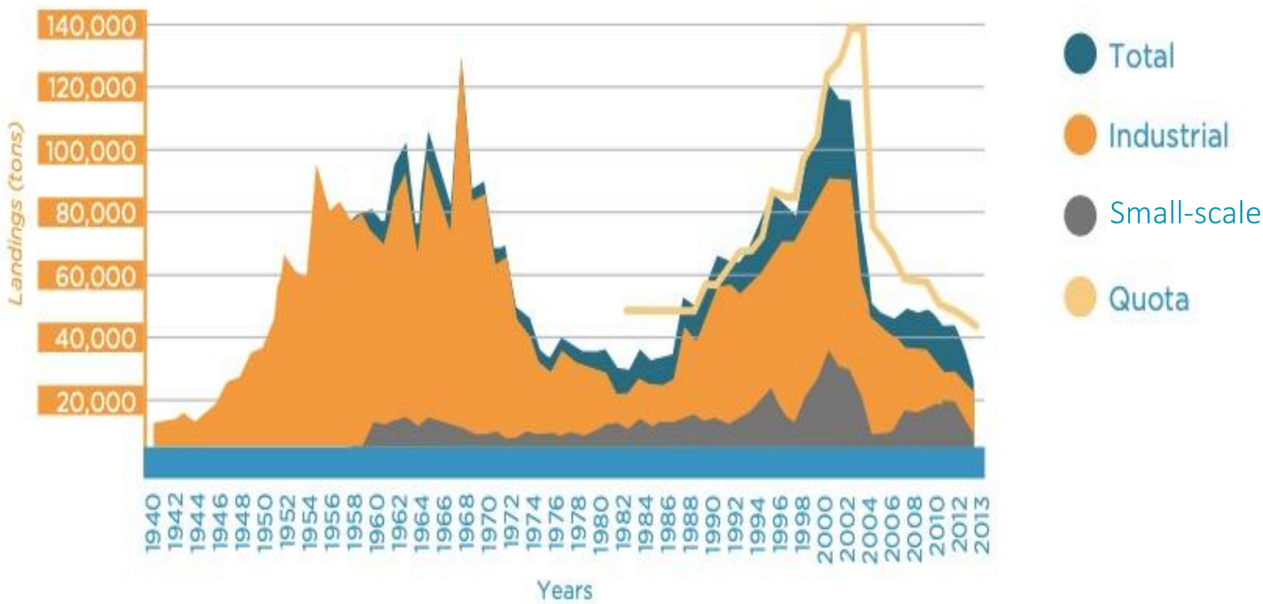


Figure 2.4.2. Landings of common hake by sector and TAC (line) (from Encourage Capital, 2015).

During the 1990s and early 2000s, the fishery saw another dramatic increase in landings, which led to a peak of 120,000 tons landed in 2001. A substantial collapse followed, where the biomass is estimated to have reached 10% of its virgin biomass (Arancibia & Neira, 2008). This collapse is thought to have been caused by a combination of the increased fishing pressure and and unprecedented rise in jumbo squid (*Dosidicus gigas*) populations. This species preys on common hake, but there is controversy on its actual role in the fishery collapse (Ibáñez, 2013). The prolonged depletion that followed through the 2000s and 2010s had dramatic consequences for stock dynamics and for the fishery (Plotnek et al., 2016): Between 2004 and 2010, the average individual length decreased from 46 to 33 cm, preventing fishery recovery (Tascheri, 2015). By 2013, the overall quota was set at 40,000 but then declined to 25,000 tons in 2017. Since then, slow biomass recovery has led to steady increases in overall quota, reaching 37,000 tons for 2020.

2.4.3. Management

Since 2013, the Revised General Law of Fishing and Aquaculture (RGLFA) has been the legal body that governs fisheries management in Chile. As for all commercial fisheries, this law mandates the creation of a Management Committee for the common hake (Gelcich, 2014). This committee comprises representatives of the supply chain, small-scale and industrial fishers, and government officials. The committee enacts the principal management regulations for the fishery in the form of a Management Plan, which becomes mandatory after approval by the government. In setting the overall quota, however, it has to follow the recommendations of an independent Scientific Committee, formed by fishery experts, which does not allow representation from fishery users. The Scientific Committee proposes a range of possible annual quotas based on the best available evidence from stock assessments. The Management Committee then sets the overall annual quota within this range.

The RGLFA sets the fraction of the annual quota apportioned between small-scale and industrial fleets for commercial fisheries, which can only be changed through a new law. For the common hake fishery, 60% of the annual quota is allocated to the industrial sector and 40% to the small-scale fleet. The industrial sector operates under an individual transferable quota system (ITQ) (Chavez & Salgado, 2005). Allocation of quota in the small-scale sector can take three forms: to a specific area within a region, a fishers' organisation, or individual fishers. In each case, the fixed fraction of the quota that each beneficiary gets corresponds to historical landings before the quota allocation system began. Moreover, the fishery has a reproductive ban and gear restriction regulations. The reproductive ban during September each year prohibits any targeted landings of common hake in both fleets. This ban is intended to protect one of the reproductive peaks. While there is no size limit set for this fishery, there are minimum mesh sizes for bottom-trawling and gillnet gears.

The most critical challenge for the sustainable management of the common hake fishery is unreported fishing, where quota limits are exceeded and fishers fail to report catches accordingly (Plotnek et al., 2016; SUBPESCA, 2016). Unreporting is an issue that compromises the stock's future, creates tensions between fishers and the government, and threatens the management system. Anecdotal evidence and enforcement records from the Chilean National Fisheries and Aquaculture Service (SERNAPESCA) indicate that this problem is more severe in the small-scale sector and particularly in the VII region of the country, where the majority of the catch is unreported.

2.4.4. Market

All landings coming from the small-scale sector are consumed domestically (SUBPESCA 2016). A small fraction of landings stays in the ports where it was landed, and is sold locally, but it is estimated that around 90% of landings are sold at the main fishing terminal in Santiago (Chile's capital) (Encourage Capital, 2015). This terminal is the central hub where marine products from all over Chile are sold. From this terminal, common hake is mostly commercialised through open-air markets spread across the country. These open-air markets can account for up to 60% of marine-based product consumption in the country, and common hake is no exception.

There is little available information on how trade in this fishery is structured or how it operates. An important amount of the product is wasted across the supply chain as it is not kept on ice. Moreover, there is little to no processing but high mark-up prices from the port to the end consumer, as the price of the product increase along the supply chain (*Personal observation*). Moreover, the supply chain in this fishery is an important driver for its overexploited state because it is used for trading both legal and unreported (illegal) products. The market for this fishery operates in a mixed fashion; legal and unreported products are traded in the same trucks and sold in the same markets. Fishers are the quota holders. By reporting a given amount of catch they provide the trader with a legal permit for that catch which is subtracted from their quota. Landings that are not reported are sold to traders without this permit and are therefore illegal to trade. This creates product and price differentiation; traders pay for the permit for legal units (27-30 kgs. boxes) to fishers and, similarly, receive a “price premium” at the market for those legal units.

Chapter 3: Studying small-scale fisheries illegality: Bringing together actor-based and opportunity-based approaches

Abstract

Illegal fishing is a persistent challenge for the conservation and sustainable management of the oceans and has particularly acute impacts in small-scale fisheries contexts. Small-scale fisheries often suffer from chronic overexploitation, poor management, lack of enforcement and illegality, but small-scale fishers are highly dependent on the ocean as a source of employment and food. Improving our understanding of the determinants of illegal behaviours in small-scale fisheries can help develop strategies to prevent and reduce its consequences. Here, we review two main approaches for the study of non-compliance behaviours and crimes more broadly, spanning criminology, economics and psychology. On the one hand, actor-based approaches address the underlying motivations for people to comply or not with regulations. Opportunity-based approaches, on the other hand, assume that illegality is not distributed randomly across space and time and focuses on the role that the immediate environment plays in the performance of illegal behaviours. We discuss potential applications of actor-based and opportunity-based approaches in guiding small-scale illegal fishing research. Moreover, we provide guiding principles for integrating these approaches in a complementary way, highlighting opportunities and challenges for building a better small-scale illegal fishing research agenda. Addressing illegality is a common challenge for natural resource management in multiple ecosystems. Integrating these two perspectives has the potential to improve both research and practice.

3.1. Introduction

Illegality in the fisheries sector is one of the greatest challenges for the sustainable management of the oceans (Agnew et al., 2009; Sumaila et al., 2006). Illegal fishing affects the sustainability of stocks and the marine ecosystem, undermines management regimes and creates tensions between resource users and regulators (Arias, 2015; Cisneros-Montemayor et al., 2013; Lewis, 2015). Small-scale or artisanal fisheries are particularly exposed to the detrimental impacts of illegal practices (Battista et al., 2018; Hauck, 2008). Small-scale fishing communities are often located in developing countries that are highly dependent on the ocean as a source of employment and food, but small-scale fisheries also often suffer from chronic overexploitation, poor management and lack of enforcement capacity (Gelcich et al., 2017; McDonald et al., 2016; Song et al., 2020).

Reducing the level of illegal activity in small-scale fisheries can help in securing livelihoods in the sector and contribute to food security worldwide (Arias & Pressey, 2016; Cohen et al., 2019). As such, understanding how to prevent and reduce illegality in small-scale contexts is a key topic in the fisheries management research agenda. The study of illegality, however, is not exclusive to fisheries: there is a large body of theory concerned with non-compliance behaviours and crimes more broadly, spanning many disciplines from criminology to economics and psychology (Becker, 1968; Clarke, 1980; Keane et al., 2008; Nielsen, 2003; Petrossian & Pezzella, 2018). This presents a potential opportunity to apply these approaches to studying illegality in the small-scale fisheries sector. However, current literature is scattered and isolated within disciplinary silos advancing along different trajectories, preventing proper identification of knowledge gaps and biases. This limits the potential of insights from other disciplines to advance the theory and practice of small-scale illegal fishing research.

Illegality can be framed as the interaction of a motivated actor and an opportunity (Figure 3.1.1) (Clarke, 1980). On the one side, researchers have concentrated on understanding the underlying motivations for people to comply or not with regulations. These approaches draw mostly on economic (Becker, 1968) and behavioural and psychological theories (Cialdini & Trost, 1998; Ostrom, 1990; Tyler, 1990). In fisheries, one of the first models used to understand motivations for compliance was put forward by (Sutinen & Andersen, 1985) to analyse the effect of imperfect enforcement on fishers behaviour. This instrumental vision of fishers' motivations is rooted in Becker's (1968) economic theory of crime and punishment. Building upon this model, fisheries compliance research has focused on accounting for non-economic factors that may influence motivations for compliance, such as legitimacy of regulations (Hatcher et al., 2000; Kuperan & Sutinen, 1998b; Nielsen, 2003) and normative factors (Bergseth & Roscher, 2018; Mackay et al., 2018; Thomas et al., 2016).

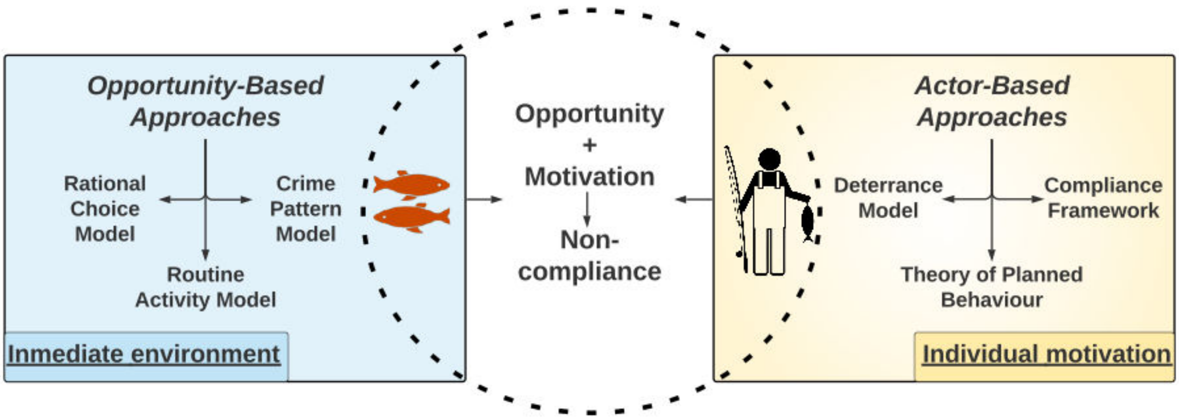


Figure 3.1.1. Actor-based and opportunity-based approaches for studying non-compliance in small-scale fisheries.

Approaching the study of illegality through understanding actors' motivations has shortcomings, though. First, by focusing exclusively on the individual as the object of study, these theories and approaches don't pay enough attention to the different kinds of illegal act. For instance, while committed by the same individual, and even for the same reasons, fishing over the quota or using prohibited fishing gears are very different illegal acts that need to be understood differently (Oyanedel et al., 2020b). Failing to account for this diversity can result in poorly tailored preventive measures (Clarke, 1980; Clarke & Felson, 2004; Cornish & Clarke, 1987). Second, the applicability of actor-based theories and approaches for illegality prevention is limited by the difficulty of crafting interventions that change the underlying motivations that drive behaviour (Cornish & Clarke, 1987). For instance, while normative motivations have been identified as key predictors for compliance in fisheries (Oyanedel et al., 2020b; Thomas et al., 2016), changing a group's normative beliefs is challenging or even unfeasible (Cialdini, 2003).

The shortcomings of actor-oriented approaches to studying and preventing illegal activities have fuelled alternative ways to think about illegality and crimes more broadly (Clarke, 2016). As such, there has been a growing effort in the criminological literature to examine the situational opportunities that affect the occurrence of illegal behaviours, with the underlying premise (whether explicit or not) that illegality is largely a product of opportunity rather than underlying motivation (Brantingham & Brantingham, 1981; Clarke & Felson, 2004; Wortley & Townsley, 2016).

Opportunity-based approaches assume that illegality is not distributed randomly across space and time and focus on the role that the immediate environment plays in the performance of illegal behaviours (Wortley & Townsley, 2016). Evidence from different studies suggests that, in fact, illegal use of, and trade in, natural resources concentrates at specific places, facilities, times and products (Kurland et al., 2017; Kurland & Pires, 2017; Moreto & Lemieux, 2015). This presents a potential opportunity to apply opportunity-based theories and approaches for studying illegal use of natural resources more generally, and fisheries specifically.

Some studies have applied opportunity-based approaches to guide the study of commercial and recreational illegal fishing (Davis & Harasti, 2020; Marteache et al., 2015; Petrossian, Marteache, et al., 2015; Thiault et al., 2020; Weekers & Zahnow, 2018). However, efforts to apply opportunity-based approaches in small-scale fisheries contexts are lacking. Including an opportunity-based approach into small-scale fisheries management research and practice has the potential to provide new insights, methods and approaches that can complement the predominant actor-based focus, thereby enabling researchers to better understand illegality in small-scale fisheries contexts.

Here, we aim to bridge the gap between opportunity-based and actor-based approaches to studying illegality in small-scale fisheries. We structure our paper according to the analytical focus. First, we consider actor-based approaches, which try to explain the underlying motivations for illegality. Next, we describe opportunity-based theories, models and frameworks to study illegality more broadly. We then discuss how opportunity-based and actor-based approaches to study illegality can be applied in the context of small-scale fisheries. We finish by providing guiding principles on how to bring these approaches together in a complementary way. By doing so, we hope to point to the most pressing opportunities for building a better small-scale illegal fishing research agenda.

3.2. Actor-Based Approaches

Several theories and models have been proposed to explain the underlying motivations for actors to comply or not with rules and regulations (Becker, 1968; Cialdini & Trost, 1998; Ishoy, 2016; Ostrom, 1990; Tyler, 1990). Consequently, fisheries scientists and conservationists have drawn from these theories in order to better understand why fishers comply or not with conservation and management regulations (Arias et al., 2015; Bergseth & Roscher, 2018; Bova et al., 2017; Kuperan &

Sutinen, 1998b). Ideally, better understanding what motivates illegal fishing behaviours can inform and guide targeted interventions aimed at reducing the incidence of illegal fishing (Bergseth & Roscher, 2018; Mackay et al., 2018; Nielsen & Mathiesen, 2003).

Generally speaking, the behavioural, psychological and economic approaches that have been applied for understanding fishers' motivations for engaging in illegal activities assume decision-making are similar to the approaches used for compliance with rules more generally (Gezelius, 2002; Keane et al., 2008; Sutinen & Kuperan, 1999). As such, research efforts have been aimed at understanding the diversity of factors that influence decision-making in the context of fisheries, with the underlying premise that reductions in illegal fishing can be obtained through manipulating these factors in favour of compliance (Bova et al., 2017; Oyanedel et al., 2020b). Below, we describe three common approaches that have been used to assess and understand why people engage in illegal fishing, namely; the Instrumental Model, Compliance Framework and the Theory of Planned Behaviour (Table 3.2.1). This is by no means an exhaustive list, but provides parallel, although sometimes overlapping, ways of thinking about why people engage in illegal activities.

Table 3.2.1. Actor-based approaches: Instrumental model, compliance framework and the theory of planned behaviour

Approach	Sub-Component	Description	References in fisheries	References in other natural resources
Instrumental Model	Probability of detection	An actor's compliance decision is based on the calculated potential costs and benefits of the non-	(Arias & Sutton, 2013; King & Sutinen, 2010; Kuperan &	(Bulte & Van Kooten, 1999; Damania et al., 2005; Milner-
	Severity of Sanction			

	Expected Revenue	compliance behaviour and will decide to engage in non-compliance when benefits outweigh costs.	Sutinen, 1998b; Nielsen & Mathiesen, 2003)	Gulland & Leader-Williams, 1992)
Compliance Framework	Normative Motivations Instrumental Motivations Legitimacy-based Motivations	An actor's compliance decision is defined by normative, instrumental and legitimacy-based motivations, as well as context-specific economic, social, cultural and institutional variables	(Hatcher et al., 2000; Nielsen & Mathiesen, 2003; Oyanedel et al., 2020b)	(Ramcilovic-Suominen & Epstein, 2012, 2015; Ramcilovic-Suominen & Hansen, 2012)
Theory of Planned Behaviour	Attitudes towards the behaviour Perceived behavioural control Subjective Norms	An actor's decision-making is defined by their intention to perform a behaviour. Intention is shaped by attitudes toward the behaviour, subjective norms and perceived behavioural controls.	(Bergseth & Roscher, 2018; Thomas et al., 2016)	(Fairbrass et al., 2016; Shrestha et al., 2012)

3.2.1. Instrumental or Deterrence Model

The instrumental model (also known as the deterrence model) of compliance has its roots in the economic theory of law, first proposed by Becker (1968). It assumes that, as individuals, actors will calculate the potential costs and benefits of non-compliance behaviours, and will engage in non-compliance when benefits outweigh costs. This calculation is essentially the same than for any actor attempting to maximize utility subject to budget constraints (Sumaila et al., 2006). As such, the level of illegal fishing in which a utility-maximiser actor will engage is calculated from the expected reward from fishing illegally minus the costs, computed as the probability of detection and sanction multiplied by the severity of the resulting punishment (1) (Becker, 1968).

$$EU = pU(b-f) + (1-p)U(b) \qquad (1)$$

Where; EU is expected utility, p is the probability of capture and punishment, U is utility, b is income if undetected, and b − f income if punished (Garoupa, 1997).

Sutinen & Andersen (1985) first adapted Becker's model to understand the effect of imperfect enforcement on fisher behaviour. From there, this model has been largely applied in fisheries management in order to understand how to increase compliance (Arias, 2015; Doumbouya et al., 2017; King & Sutinen, 2010; Sumaila et al., 2006). Two main mechanisms by which to increase compliance can be deduced from this model. The first involves increasing the actual probability of detection. This requires increases in law enforcer numbers, or patrol effort or effectiveness, which are usually costly and can prove ineffective in raising the probability of detection to significant levels if not well-funded (Paternoster, 2010). As such, increasing the real probability of detecting illegal fishing can prove challenging or logistically unfeasible, especially in small-scale fisheries contexts that lack proper enforcement capacities or budgets (Muller et al., 2019). An alternative approach involves increasing the perceived probability of detection, by means of targeted and fear-arousing communication highlighting enforcement capabilities by authorities, such as publicising technological advances for illegal detection (drones, vessels, etc) (Bergseth & Roscher, 2018). This could, potentially, be a cost-effective mechanism because such communication campaigns are lower-cost. However, the long-term effectiveness of increasing the perceived probability of detection has not been tested empirically in fisheries. Moreover, evidence from other contexts suggests that this strategy has limited long-term effect if perceptions are not aligned with the truth (Milner-Gulland & Clayton, 2002).

The second mechanism involves increasing penalties. Since increasing detection is usually costly, a more straightforward enforcement strategy is to raise the size of the penalty as to maintain low levels of illegality. However, severe penalties might have negative effects on compliance. For instance, if penalties are perceived as too harsh or unfair, there is a risk of alienating fishers and the emergence of a defiance response from actors that could further increase the prevalence of illegal behaviours (Bergseth & Roscher, 2018; Von Essen et al., 2014). Moreover, theoretical modelling of penalties and probability of detection suggest that the effectiveness of increasing penalties is very limited without improvements in detection (Leader-Williams & Milner-Gulland, 1993).

3.2.2. Compliance Framework

The compliance framework was first proposed for forestry contexts in an effort to integrate different theoretical models of individual motivations for rule compliance into one analytical framework (Ramcilovic-Suominen & Epstein, 2012). It also includes context-specific economic, social, cultural and institutional variables that might influence individual motivations. This framework compiles different theoretical perspectives of what motivates compliance into three dominant components: instrumental (which relates to the instrumental model described in 3.2.1), legitimacy-based and normative (described below). By doing so, it allows for simultaneous evaluation and comparison of their role in motivating compliance, as well as permitting to include context-specific explanatory variables.

Legitimacy-based Motivations

Legitimacy-based motivations relate to how the acceptance of decision-making and its outcomes motivate actors to comply with regulations (Levi et al., 2009; Ramcilovic-Suominen & Epstein, 2012). Legitimacy can play a key role in motivating compliance, and can also make governance easier and more effective (Jentoft, 1989). There are several and evolving ways to conceptualize and measure legitimacy, but these can be categorised into procedural legitimacy, legitimacy of authorities, and outcome legitimacy.

Procedural legitimacy deals with how collective decision-making processes affect individual motivations for compliance (Tyler, 1990). When decision-making is participatory, transparent and accountable, individuals are more likely to comply (Levi et al., 2009; Ramcilovic-Suominen & Epstein, 2012). Legitimacy of authority has to do with how leaders are perceived, including their perceived capability as decision-makers, and in turn, how that affects individual compliance (Levi et al., 2009). Finally, outcome legitimacy considers the fairness and appropriateness of rules as perceived by those who are affected by them. Rules that are perceived as fair and effective are much more likely to be complied with (Jentoft, 1989; Kuperan & Sutinen, 1998b; Nielsen, 2003)

Normative Motivations

The normative component emphasizes social and personal norms as motivations for compliance. Norms are defined as prescriptions commonly accepted in a group, supporting desirable behaviours and forbidding undesirable ones (Gezelius, 2002; Ramcilovic-Suominen & Epstein, 2015). Norms can have a significant effect in reinforcing non-compliance or strengthening adherence to fisheries rules (de la Torre-Castro, 2006) .The role of norms as a motivation for compliance has been a topic of increasing interest in the illegal fishing literature, especially in recreational (Arias &

Sutton, 2013; Bergseth & Roscher, 2018; Bova et al., 2017; Thomas et al., 2016) and small-scale fisheries contexts (Arias & Pressey, 2016; Battista et al., 2018; Oyanedel et al., 2020b). Normative motivations and the way they affect compliance can be classified in three main categories: personal norms (e.g. individual values regarding the behaviour), injunctive norms (e.g. perceived moral values of a group) and descriptive norms (e.g. perception of what others do) (Cialdini & Trost, 1998; Hatcher et al., 2000; Thomas et al., 2016).

Oyanedel et al. (2020) provide an example of how the application of the compliance framework can aid in understanding small-scale fisheries non-compliance. They assessed non-compliance rates and the motivations behind these behaviours in a small-scale fishery in Chile. They found that while 93-100% of fishers complied with gear or temporal restrictions, only 3% did so for the fishery's quota limit. Legitimacy-based motivations were more important than other motivations in explaining this diversity of fishers' responses towards regulations. Similarly, they found that normative motivations best predicted the degree of non-compliance with the quota limit, and contextual factors such as the per-fisher quota level (which relates to the instrumental component) explained broader non-compliance patterns.

3.2.3. Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) is an extension of the Theory of Reasoned Action (Hill et al., 1977) and seeks to predict an individual's behaviour (Ajzen, 2011). It focuses on the individual's deliberative decision-making process by understanding their intention to perform a behaviour (Bergseth & Roscher, 2018). It assumes that the stronger the intention, the more likely it is that the individual will perform the behaviour (Ajzen, 2011). Intention in the TPB is shaped by three socio-cognitive factors: Attitudes toward the behaviour (e.g. what someone believes about the behaviour), Subjective Norms (e.g. social pressures associated to the specific behaviour) and Perceived

Behavioural Control (e.g. the perception of the difficulty of performing the behaviour). The TPB has been used to understand and predict illegality in the context of natural resource management in general, and fisheries specifically (Bergseth & Roscher, 2018; Fairbrass et al., 2016; Shrestha et al., 2012; Thomas et al., 2016).

3.3. Opportunity-based Approaches

Here, we review opportunity-based approaches to studying illegality more broadly, which gather around the Environmental Criminology (or crime science) school of thought. These scholars focus on the environmental factors that influence the immediate decision to perform an illegal behaviour (Brantingham & Brantingham, 1981; Clarke & Felson, 2004). Environmental criminologists have an applied mission and they guide their studies towards the development of opportunity-reducing strategies, with the premise that by manipulating crime-causing situations, effective prevention and disruption of illegal activities can be obtained (Clarke, 1980, 2016). Environmental Criminology and Crime Analysis have three main operational models, described below: Rational Choice, Crime Pattern and Routine Activity. These models were conceived and initially developed in isolation, but they have similarities and overlaps. As such, they are not exclusive, and their application in practice involves convergence (Wortley & Townsley, 2016).

3.3.1. Rational Choice Model

The rational choice model is built upon the principle that “specific crimes are chosen and committed for specific reasons” (Cornish & Clarke, 1987). In this theory-based model, the premise is that several factors are considered in the actor's decision to engage into a crime. These factors are viewed as *properties* of the circumstances and include the possible payoff, perceived risk or skills needed in the context of the user's motives, experience, expertise and ability (Cornish & Clarke, 1987). The implication of this model is that the "environmental" data that the actor uses can be modified to change their decision to commit a crime.

While this model is similar to (Becker, 1968) (see section 3.2.1), in that it asserts that crimes occur when the anticipated benefits outweigh costs, there are two main differences between these models in how costs and rewards are calculated. First, the Rational Choice Model defines rewards not only in economic terms but also considers the emotional or psychological benefits of a criminal act (Clarke, 1980). Second, the Rational Choice Model does not consider costs only in terms of the probability of detection and sanction, but also with respect to the particular properties of the crime that can make it costly to perform (such as the level of skill or physical fitness required). The rational choice model is built on the evidence that societies, in general, are extremely inefficient at delivering economic punishment and therefore making crimes costly (Cornish & Clarke, 1987). In this sense, (Cornish & Clarke, 1987) assert that Becker's model might be effective in some particular circumstances, but fails to explain most crimes as it does not consider the opportunistic nature of many kinds of crimes and the non-economic motivations and barriers that potential criminals face.

3.3.2. Routine Activity Model

The routine activity model has its empirically-based roots in the evidence that crime rate trends and cycles are influenced by structural changes in routine activity patterns. This occurs when changes in routine activities affect the convergence in space and time of the three minimal elements for crime: a) motivated actors, b) suitable targets, and c) the absence of capable guardians (Cohen & Felson, 1979). If any of these elements is missing, crimes do not take place. This model implies that even when the number of motivated offenders is constant, crime rates can change due to changes in suitable targets or the absence of guardians (note: guardians not only means police but could also be regular citizens). Therefore, this model takes user motivations towards illegality as a given and studies the manner in which spatial-temporal factors of the organization of daily life can help convert criminal inclination into action (Cohen & Felson, 1979).

3.3.3. Crime Pattern Model

The Crime Pattern model's objective is to empirically measure and account for the non-uniformity and non-randomness observed in crime patterns (Brantingham & Brantingham, 1984) . This model is based on the idea that people develop a pattern of repetitive activity in their normal life. Understanding the factors that determine the specific spatial patterns of crime is therefore necessary to prevent it. This pattern includes nodes (such as the workplace, home, shopping, etc) and routes between them. Offenders behave in this same way as everyone else, and will be more comfortable committing crimes closer to the areas they frequent (Brantingham et al., 2017). Therefore, the routes and nodes that shape non-criminal activities, influence how criminal activities are shaped as well.

3.3.4. Methods and tools used in environmental criminology and crime analysis

Several analytical methods have arisen that seek to operationalize and combine the abovementioned models, breaking crime down into specific analysable components, in order to propose and design prevention measures. Here we review some of these methods, with a specific focus on those that have been used in fisheries or other natural resource contexts (Figure 3.3.1).

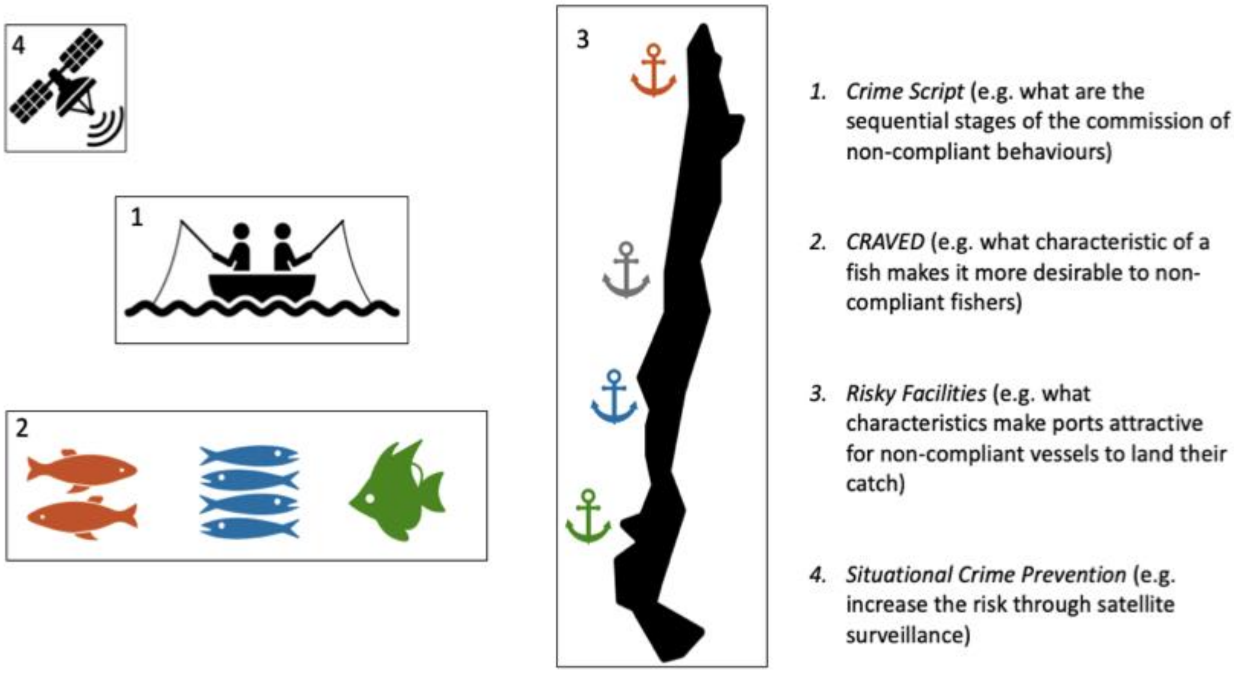


Figure 3.3.1. Examples of the application of methods and tools from Environmental Criminology and Crime Analysis in the study of small-scale fisheries non-compliance.

Crime Script Analysis

Crime script analysis was first proposed by Cornish (1994), based on the premise that crimes are discrete events in space and time, but the realization of the crime itself takes place within a context of many other events. The crime itself is usually the object of study, typically overlooking certain other stages in the crime-commission process (e.g. getting the necessary tools or exiting the setting). Script refers to an "event" schema where there is a causal effect from early to later events; that is, one event in the script enables the occurrence of a later event (Cornish, 1994). By concentrating on the way that events unfold through time, the crime script analysis provides researchers and practitioners with an analytical tool to understand a series of rational, goal-oriented actions (Cornish, 1994). Crime script can operate at different levels of analysis; from specific crime situations where rich information is available, to analysing larger-level scripts or more general crimes.

Crime Script Analysis has been applied to study illegality in fishing and seafood fraud. (Petrossian & Pezzella, 2018) separated the scripts of illegal fishing and the seafood fraud process to shed light on the regulations needed to address these crimes. Based on Clarke & Eck, 2005, they divided the processes of illegal fishing and seafood fraud into the following sequential stages: (a) *preparation* (getting the necessary tools and selecting the target); (b) *entry into the area*; (c) *precondition* (steps toward creating the enabling conditions); (d) *instrumental initiation* (target approach); (e) *doing or carrying out the crime*; (f) *exiting the crime scene*; and (g) *aftermath* (disposing of incriminatory elements or steps to reduce risk of apprehension). By breaking the process into smaller sequential discrete actions, the authors proposed policy responses that act upon these specific stages of the script, such as disrupting the *preparation* stage by providing insurance companies with a list of blacklisted vessels. They argued that these responses required very little involvement from the criminal justice sector. Instead, they stressed the need for collaboration amongst national and international agencies in order to tackle some of the situational factors at the different stages of illegal fishing and seafood fraud.

Risky Facilities Framework

The risky facilities framework builds on the premise that "for any group of similar facilities (e.g. taverns, parking lots, or bus shelters), a small proportion of the group accounts for the majority of crime experienced by the entire group" (Eck et al., 2007). While several authors have analysed hotspots and map them, the comparison between facilities of the same sort allows identification of specific characteristics that could explain their risk, providing the base to design preventive actions. In a more practical way, this framework allows concentrating of efforts in certain facilities where most crime occurs, instead of targeting a broad number of facilities where little crime occurs. Some of the variables identified to influence a facility's risk are size, number and quantity of "hot products" in the facility, location, management effectiveness and design and layout.

Petrossian et al. (2015) applied this framework to study what characteristics make ports attractive for vessels to land their illegal catch. To do this, they analysed data on the ports used by vessels that were listed as performing illegal fishing by Regional Fisheries Management Organizations (RFMO). They identified a total of 120 ports in 70 countries where these vessels had operated between 2004 and 2009. They found that larger ports that had higher vessel traffic were more visited by illegal vessels. Also, ports in countries where illegal fishing is more common, corruption is higher and catch inspection schemes were less effective were also more visited. This points out the variables that could be modified to disrupt illegal vessel fishing operations.

CRAVED Framework

The CRAVED framework was first proposed by (Clarke & Webb, 1999) with the goal of analysing what makes some products more attractive for theft than others. CRAVED stands for: Concealable, Removable, Available, Valuable, Enjoyable and Disposable. These six attributes of a product are hypothesised to make a product more attractive (Clarke & Webb, 1999). For the application of CRAVED, the indicators for each of the attributes must be fitted to the specific crime and product being studied. An indicator of Removable will vary dramatically depending on, for example, the species being studied (Petrossian & Clarke, 2014). This framework helps users to compare the attributes between products and explain changing patterns in crime targets. This framework has been used for studying wildlife products (Moreto & Lemieux, 2015) and fish more specifically (Petrossian, Weis, et al., 2015; Petrossian & Clarke, 2014). Petrossian, Weis, & Pires (2015) for instance, found that crab and lobster species that were subject to higher levels of illegal fishing were those that were more Abundant, Valuable and Enjoyable. From this, they provide guidance on how to reduce illegal fishing through prioritizing and targeting those identified attributes.

Situational Crime Prevention

Situational crime prevention (SCT) was first suggested by (Clarke, 1980). SCT is a framework that offers a suite of techniques that can help build solutions to prevent crime. SCT techniques are based on an understanding of the processes undertaken to commit a crime. By disentangling the situational features that enable crimes, SCT techniques aim to influence an actor's choice to engage in it. SCT techniques are organized into 5 categories: increase the effort, increase the risk, reduce the reward, reduce provocations and remove excuses. (Petrossian, 2015) applied the SCT framework to study the relationship between illegal fishing in 53 countries and local situational factors. She found that illegal fishing risk was higher in countries with more commercially important fisheries that were closer to ports of convenience. Similarly, she found that countries with higher management and enforcement capacities had lower levels of illegal fishing.

3.4. Bringing actor-based and opportunity-based approaches together to advance small-scale illegal fishing research

Small-scale fisheries operate in diverse economic, social and cultural contexts (Cohen et al., 2019), preventing bullet-proof solutions to the illegality problem (Boonstra et al., 2017; Mahon et al., 2008; Oyanedel et al., 2020b; Song et al., 2020). However, one characteristic that small-scale fisheries share is that their operation depends on both social and ecological factors (Basurto et al., 2013; Lindkvist et al., 2017). Considering the socio-ecological nature of small-scale fisheries, we provide an overview of three challenges for doing research on illegality that can be better framed and tackled through bringing actor- and opportunity-based approaches together.

3.4.1. Illegality in small-scale fisheries emerges from both the social and ecological realms

Small-scale fishers behaviour, and also illegal acts, are strongly determined by the social and economic context in which fisheries operate, which has been described extensively (Gezelius & Hauck, 2016; Hauck, 2008; Mahon et al., 2008; Nielsen & Mathiesen, 2003; Oyanedel et al., 2020b; Sutinen & Kuperan, 1999). But the ecological characteristics of small-scale fisheries are also key determinants of the availability of opportunities for illegality. The inherent spatial and temporal variability of ocean ecosystems makes it highly likely that opportunities for illegality vary over a range of temporal and spatial scales. There is growing evidence that this variability results in non-randomly distributed opportunities for illegal fishing, which is concentrated in hotspots (Davis & Harasti, 2020; Thiault et al., 2020; Weekers et al., 2019). Identifying these hotspots, and how they vary over time and space, is of crucial importance to understand how environmental context-specific variables produce emergent opportunities for illegality. Ignoring the dynamic ecological features of small-scale fisheries contexts will result in an incomplete understanding of why, how and when illegal fishing could emerge (Petrossian, 2018). As such, combining actor-based and opportunity-based approaches for researching illegality in small-scale fisheries can produce more robust results by incorporating both the social and the ecological features that determine illegal fishing dynamics.

3.4.2. Choose your battles wisely: improving identification for prioritisation in diverse socio-ecological systems

Small-scale fisheries management usually comes with budget constraints affecting the design, implementation and enforcement of rules, from which situations conducive to illegality can emerge (Arias et al., 2015; Gelcich et al., 2017). In the low-governance, budget-limited situation of small-scale fisheries it is of utmost importance to prioritize efforts to effectively reduce illegality. Here, combining actor-and opportunity-based approaches can aid in the identification of the most pressing facilities, resources and locations where illegality is likely to concentrate. For instance, the Risky Facilities Framework can help identify the ports where illegal vessels land their catches (Marteache et al., 2015), or researchers can use the CRAVED model to understand which species are more attractive to illegal fishers and which attributes makes them so (Figure 3.3.1). Further, research can focus in understanding the social characteristics of places where illegality develops. Social disorganization models, for instance, focus on the effectiveness of communities at preventing illegality through informal control mechanisms (Sampson & Groves, 1989). Understanding fishers' perception of the legitimacy of rules at the local scale can help predict compliance levels and informal control mechanism that might help prevent illegality (Oyanedel et al., 2020b; Sampson & Groves, 1989).

3.4.3. Neither the actor- or opportunity-based approach on its own fully explains illegality in socio-ecological systems such as small-scale fisheries

Understanding the interaction of actor- and opportunity-based approaches when studying illegality in small-scale fisheries can provide useful insights into the socio-ecological nature of illegality. For instance, (Oyanedel et al., 2018) describe a quite unexpected form of illegality that could be better understood based on the interaction of actor-based and opportunity-based approaches. Using the randomized response technique (Fox & Tracy, 1986; Lensvelt-Mulders et al., 2005), they empirically assessed the proportion of divers that violated several rules of a territorial user right for fisheries (TURF) system in a small-scale context in Chile. They found that 46% of fishers who belonged to unions with user rights fished illegally with the consent of their union leaders (this catch was illegal as it was not reported to authorities). On the one hand, normative and legitimacy-based motivations were aligned for these fishers to fish illegally, as they were authorized by their own leaders to do so. On the other hand, there is evidence that TURF areas are more prolific fishing grounds, and as such are more attractive for fishers, which provides an opportunity-based account for this behaviour

(Gelcich et al., 2008, 2017). Further, the authors provide an explanation for this behaviour that can help complement the understanding of this form of illegality: "Because fisher unions find it too complicated, costly, or useless to officially report their catches, they are not reporting to authorities, even if they fish within legal margins (respecting the minimum size and closures)" (Oyanedel et al., 2018). As such, this form of illegality could be prevented through opportunity-based approaches such as those found in Situational Crime Prevention, more specifically, "removing the barrier".

3.5. Guiding principles for applying actor-based and opportunity-based approaches for advancing research on small-scale illegal fishing

Here, we propose three guiding principles to help bridge the gap between these two types of approaches, in order to advance research on small-scale illegal fishing.

3.5.1. Analyse which approach better suits what's being studied and the possible policy levers

One fundamental difference between actor-based and opportunity-based approaches is that the former puts the individual at the centre of the study while the latter does exactly the opposite (Clarke & Felson, 2004; Cornish & Clarke, 1987; Keane et al., 2008; Kurland et al., 2017). The socio-ecological setting of small-scale fisheries allows for a variety of actors, processes and circumstances to converge. As such, some of the vast array of research questions that can be framed around the problem of illegality in small-scale fisheries could be better fitted to actor-based approaches, and some to opportunity-based approaches. However, it is important to also consider the applied consequences of the research questions; the type of policy levers available and the context the research is trying to inform (Ramcilovic-Suominen & Epstein, 2015; St John et al., 2013). In contexts where changing the properties of the products or situations that give rise to opportunities for illegality might be challenging or unfeasible, research needs to focus on actors' motivations for non-compliance. A situation like this can arise in cases where fishers are easy to locate, organized and geographically attached, but where external market or ecological dynamics provide extensive opportunities for illegality. In such cases, research can focus on the behavioural motivations that influence small-scale fishers to comply or not with regulations. Since in these cases it is possible to locate and identify fishers, potential interventions to change motivations are feasible.

Conversely, there are cases where changing actors' motivations might be too challenging, and interventions will be better focused at the attributes that give rise to illegality opportunities. In these cases, research will be of better use if it focusses on the properties of places, products or circumstances that give rise to illegality opportunities. For instance, there are contexts where there is no register of fishers, or high mobility of vessels that prevents the proper identification of motivations for compliance or eventual interventions to address them. In such cases, research might be better directed at identifying which species are the most targeted by illegal fishers and what attributes makes these species attractive (CRAVED model). Similarly, research can focus on identifying the *modus operantis* of the illegal activity and the several steps needed for the illegal process to develop (Crime Script Analysis) (Petrossian & Pezzella, 2018). Insights from research on these topics can help inform policies that might reduce illegality without having to intervene with the actors involved, but instead focus on the opportunities for illegality.

3.5.2. Explicitly consider each approach's shortcomings and methodological challenges

Actor-based and opportunity-based approaches have different ways to study illegality, and each has limitations in how they could be applied in the context of small-scale fisheries. On the one hand, opportunity-based approaches rely heavily on managers' ability to identify the products and discrete locations in time and space where illegality occurs (Brantingham et al., 2017; Brantingham & Brantingham, 1981, 1984; Clarke & Webb, 1999). However, this can be challenging in natural resource contexts, which poses an important limitation for applying opportunity-based approaches to small-scale fisheries (Gavin et al., 2009; Keane et al., 2011). While enforcement and infringement records are sometime available in small-scale fisheries, they are not always good indicators of where and when illegality occurs (Critchlow et al., 2017b; Keane et al., 2011; O'Kelly et al., 2018a). This is because enforcement is reactive and non-random in nature, therefore data from this activity is inherently biased (Keane et al., 2008; O'Kelly et al., 2018b). A second source of bias arises because enforcement acts as a deterrent, subsequently changing resource user behaviours and further reducing the ability of enforcement records to detect true illegality trends (Keane et al., 2011) . However, advances in encounter data analysis and modelling has proven useful to disentangle confounding factors and biases, leading to better interpretation of infringement records (Critchlow et al., 2015; Underwood et al., 2013). This, in turn, can help to identify hotspots and temporal trends in illegality. Examples of the application of these models can be found for snare detection (O'Kelly et al., 2018b), elephant carcasses (Burn et al., 2011) and ivory seizure data (Underwood et al., 2013). Properly accounting for and dealing with these biases is key for applying opportunity-based approaches in small-scale fisheries.

On the other side, one of the major limitations of actor-based approaches for understanding illegality in small-scale fisheries relates to the difficulty of approaching fishers who are involved in illegality (Kuk, 1990; Oyanedel et al., 2018; Solomon et al., 2015). Illegal fishing is a sensitive behaviour, and it is to be expected that people involved in the activity will be reluctant to participate in research projects aimed at reducing its incidence. This poses a major challenge for applying actor-based approaches, since for the Compliance Framework and the Theory of Planned Behaviour (and to a lesser extent the instrumental model), methods rely on surveys or questionnaires that require fisher participation (Fairbrass et al., 2016; Oyanedel et al., 2020b; Ramcilovic-Suominen & Epstein, 2012). The difficulty is especially prevalent in small-scale fisheries where mistrust in scientists can be common (Shirley & Gore, 2019). However, there are ways to get around this problem and induce participation, such as protecting fishers' confidentiality thereby reducing non-response rates and social desirability bias (e.g. under-reporting of behaviours that are socially undesirable or over-reporting those that are desirable) (Bova et al., 2018). These include doing electronically-based surveys (Thomas et al., 2016), the randomized response technique (Blank & Gavin, 2009; Fox & Tracy, 1986; Oyanedel et al., 2018), the unmatched count technique (Hinsley et al., 2019; Lavender & Anderson, 2009) and the ballot box method (Bova et al., 2018). While none of these methods can assure full participation or completely honest responses, they do increase responses rates and can provide more transparent assessments of illegal behaviour and its motivations. Further, by using these confidential methods, retaliation or negative consequences for research participants can be prevented if methods are appropriately applied and presented (e.g. not reporting port-level aggregate results that might cause fishers from a particular port to be targeted).

3.5.3. Consider the appropriate timescales at which changes can be detected

The time scales at which research on actor- and opportunity-based approaches need to be conceptualized and performed differ. This is because the interventions proposed by actor- and opportunity-based approaches have different time horizons. As such, actor- and opportunity-based approaches can complement each other through the temporal scale of the interventions that are put in place to address illegality. By bringing together these two approaches, the underlying causes of illegality in fisheries can be tackled, while also providing shorter-term gains in compliance.

On the one hand, altering the underlying motivations that drive behaviour is a long-term effort (Clarke, 1980). As such, research aiming to understand trends in how actor-based approaches might affect illegality must incorporate into its design the time horizon at which some of these underlying motivations might start to change. For instance, the social norms approach (SNA) has been proposed as a way to increase compliance with recreational fisheries regulations (Bova et al., 2017). The SNA uses targeted advertising campaigns to correct misconceptions of the proportion of people that engage with undesirable or illegal behaviours (Berkowitz, 2005). By doing so, it aims to change descriptive norms (e.g. perception of what others do) as a way to motivate compliance. However, for this approach to be effective, at least half of the population should exhibit the appropriate (legal) behaviour (Bova et al., 2017; Perkins & Berkowitz, 1986). As such, the time horizon needed for these advertising campaigns to have the intended effect might be significant, because of the need to assess and bring compliance levels up to the point where the SNA can be applied.

On the other hand, from their inception opportunity-based approaches have relied on short-term, trial and error assessment of interventions to prevent illegality (Kurland et al., 2017; Weisburd, 2018). As such, research guided by opportunity-based approaches can help to design interventions that can be implemented in short timeframes. Techniques from Situational Crime Prevention allow for empirically based analysis of potential changes in illegality that can be detected over short time periods. (Petrossian & Marteache, 2018) provides a good account of the type of interventions that can be informed by Situational Crime Prevention and its application in fisheries, its time frames and potential results.

3.6. Conclusion

Sustaining fisheries and other natural resources into the future requires the reduction of illegal use. This is especially pressing in small-scale fisheries settings, where the impacts of illegality can be more acute because of poor management, lack of enforcement capacity and the high dependence of fishers on natural resources for employment and food. Addressing issues of the illegal use of natural resources requires us to push research frontiers so as to provide frameworks and insights that translate into practical actions and plans. Understanding how the transition from theory to practice has been achieved in other disciplines dealing with illegal activities can make this easier to achieve.

Here, we have shown how integrating actor-based and opportunity-based approaches can trigger new ways to explore illegality in small-scale fisheries. Moreover, these principles and approaches are generalizable to other natural resources and contexts, such as the illegal wildlife trade. Illegal wildlife trade has similarities with small-scale fisheries in that they both operate in the intersection of social and ecological systems. The diversity of ways that natural resources are used and managed precludes simple solutions to curtailing illegal exploitation (t Sas-Rolfes et al., 2019). However, acknowledging that illegality can be framed as the interaction of a motivated actor and an opportunity serves as a starting point for broader applicability of our approach to other contexts and settings.

As demonstrated here, building a better research agenda on illegal issues in small-scale fishing should include active engagement with experiences and approaches from other natural resource management settings. The theoretical underpinnings of actor-based and opportunity-based approaches, as well as their integrated application, are the same whether the social-ecological system is terrestrial or marine. As such, these approaches provide a bridge through which collaboration between researchers studying illegal use of natural resources in a range of settings can be promoted. The application of these approaches can provide cross-learning opportunities and better identification of knowledge gaps and biases. Thereby, it could unleash the potential of collaborative studies for advancing the theory and practice of natural resource illegal use research. Understanding the commonalities and specificities of contexts where illegality occurs could be a key step towards better managing and maintaining the natural resources we depend on.

Chapter 4: Motivations for (non-) compliance with conservation rules by small-scale resource users

Abstract

Understanding compliance with conservation rules is key for biodiversity conservation. Here, we assess compliance and its underlying motivations in a small-scale fishery in Chile. We adapt a framework originally developed for forestry to unpack compliance motivations at within-individual and between-individuals levels while accounting for contextual factors. We find that 92-100% fishers comply with temporal or gear rules, while only 3% comply with the quota limit. Legitimacy-based motivations are more important in explaining why individual fishers comply with temporal/gear rules than they are for compliance with the quota. At the between-individuals level, we find that normative motivations are significantly related to the degree of non-compliance with the quota. Contextual factors such as quota levels are key in explaining broader non-compliance patterns. Our results suggest that considering compliance at appropriate analytical levels is necessary to unpack motivations, guide local and national natural resource management policies, and move towards a better theory of compliance.

4.1. Introduction

The conservation and sustainable management of natural resources depends on people complying with conservation rules. However, rules are not always appropriate or fair in how costs and benefits are distributed, or could be out-dated (Wells, 1992). As such, compliance cannot and should not be taken for granted (Keane et al., 2008). The ecological, economic and social impacts of non-compliance with conservation rules have been widely documented across diverse settings (Maxwell et al., 2016). Yet, research is still needed that informs policies and interventions to address the potential threat to biodiversity of non-compliance. Effectively addressing non-compliance first requires disentangling resource users' underlying motivations (Travers, Archer, et al., 2019).

Researchers from different disciplines emphasise how social, institutional, behavioural and economic motivations affect compliance with rules (Becker, 1968; Boonstra et al., 2017; Nielsen, 2003; Ostrom, 1990). However, it is challenging to discern between such diverse motivations for non-compliance with conservation rules at the local level, which is necessary for developing effective strategies to address it. Frameworks combining these motivations can guide the study and understanding of compliance and unpack heterogeneous motivations. (Ramcilovic-Suominen & Epstein, 2012) provide one such analytical framework, originally designed to study forest law compliance (hereafter the "Compliance Framework"). This framework has the advantage of combining different motivations into three dominant components: instrumental, normative and legitimacy-based (Table 4.1.1.). Categorizing motivations into these discrete components allows simultaneous evaluation of their relative importance, enabling the assessment of what motivates compliance at different analytical levels, with the potential to guide the study of compliance motivations in other settings, such as fisheries. This can then help in building an empirically-informed theory of compliance for conservation.

Table 4.1.1. Individual motivations from the Analytical Framework for Compliance (Ramcilovic-Suominen & Epstein 2012) adapted for the context of our case study. Table shows individual motivations for compliance with the sub-components assessed in this study and the rationale behind these sub-components.

Motivation	Sub-Component Assessed	Rationale	References

Instrumental	Perceived probability of detection Perceived probability of sanction	Perceived probability of detection and sanction relate to the cost (deterrent) component of the instrumental motivation. We could not include the benefit side as a motivation because of the difficulty to assess perceived benefits of non-compliance across different conservation rules which provide benefits not easily accountable or comparable.	(Arias & Sutton, 2013; Becker, 1968; King & Sutinen, 2010; Kuperan & Sutinen, 1998a; Nielsen & Mathiesen, 2003)
Normative	Feeling of Guilt Colleague Disapproval Perceived colleagues non-compliance	Normative motivations can influence behaviour through three distinct mechanisms: personal norms (feeling of guilt), or a person's own values regarding the behaviour; social injunctive norms (colleague disapproval), or perceived moral values of a group; and descriptive norms (perceived colleagues non-compliance) or the perception of what others do.	(Bergseth & Roscher, 2018; Cialdini et al., 1998; Hatcher et al., 2000; Thomas et al., 2016)
Legitimacy-based	Legitimacy of authorities Equity of rules Effectiveness of rules	Legitimacy can act as a motivation for compliance when resource users perceived that authorities and decision-makers are trustworthy and act honestly (legitimacy of authorities) and when rules outcome are fair and effective.	(Levi et al., 2009; Nielsen, 2003; Thomas et al., 2016)

The instrumental component in the Compliance Framework highlights that one motivation for compliance relates to an economic calculation of the costs and benefits of complying. This balances the potential benefits of non-compliant behaviour (such as higher catches) against the potential costs (including the probability of detection and severity of sanctions). This utilitarian understanding of compliance has roots in the economic theory of law (Becker, 1968) and has been used to explain compliance with natural resource rules (e.g. for fisheries (Sutinen & Kuperan, 1999), and rhino poaching (Milner-Gulland & Leader-Williams, 1992)). The normative component emphasizes social and personal norms as motivations for compliance. Norms are defined as prescriptions commonly accepted in a group, supporting desirable behaviours and forbidding undesirable ones (Ramcilovic-Suominen & Epstein, 2012). Norms can have a significant effect in reinforcing non-compliance or strengthening adherence to conservation rules, depending on the specific rule and its outcomes for the person's reference group (Cialdini & Trost, 1998). Finally, the legitimacy-based component assesses how the acceptance of decision-making and its outcomes by citizens motivates compliance (Levi et al., 2009). Higher legitimacy has been linked with enhanced compliance, making governance easier and more effective (Jentoft, 1989).

The relative influence of these motivations (instrumental, normative and legitimacy-based) on actual compliance, and their interaction, is influenced by both the contextual factors (e.g. economic, social, cultural) in which decisions are made and the types of rules in place (Ramcilovic-Suominen & Epstein, 2012). For instance, locally crafted and enforced rules tend to give resource users a sense of ownership over decision-making processes, enhancing legitimacy and motivating compliance (Nielsen & Mathiesen, 2003). By contrast, conservation rules that are imposed on resource users by external authorities can backfire, by aligning normative motivations against compliance (Hatcher et al., 2000). Different rule-types can co-occur within one context, creating heterogeneity in an individual's compliance responses. This is especially the case in many small-scale fisheries, which operate under diverse institutional arrangements, combining self-governance, co-management and top-down systems each with different rule-types attached (Lindkvist et al., 2017; Ostrom, 2010). Small-scale fisheries, therefore, provide an interesting setting to disentangle the effect that contextual factors and rule-types have in motivating compliance with conservation rules.

Here, we empirically assess what motivates compliance in the common hake (*Merluccious gayi gayi*) small-scale fishery of south-central Chile. A suite of conservation rule-types are in place for this fishery, emerging from different institutional arrangements. High levels of non-compliance with the fishery's quota limit have been documented (Plotnek et al., 2016), but there is no understanding of what motivates this behaviour or the heterogeneity in compliance between rule-types and fishers. We adapted the Compliance Framework from its original use in forestry to first characterize the diversity of compliance responses and motivations for the main conservation rules for this fishery. Then, we assessed the relative role that instrumental, normative and legitimacy-based motivations play in explaining the degree of non-compliance with the quota limit. Finally, we discuss the implications of these findings for conservation more broadly.

4.2. Methods

4.2.1. Research Setting

The common hake plays a key ecological and economic role in the upwelling ecosystem off central Chile’s coast but underreported fishing, in excess of quota limits, is threatening the conservation of the stock and the >3,000 livelihoods it supports (Plotnek et al., 2016). Anecdotal evidence and enforcement records from Chile’s National Fisheries and Aquaculture Service

(SERNAPESCA) indicate that underreporting is particularly serious in Chile's VII region (see Figure 4.2.1b for a map). In this region around 300 boats, operating with 3-4 crew and averaging 9.5 meters in length, are registered as part of the hake fishery.

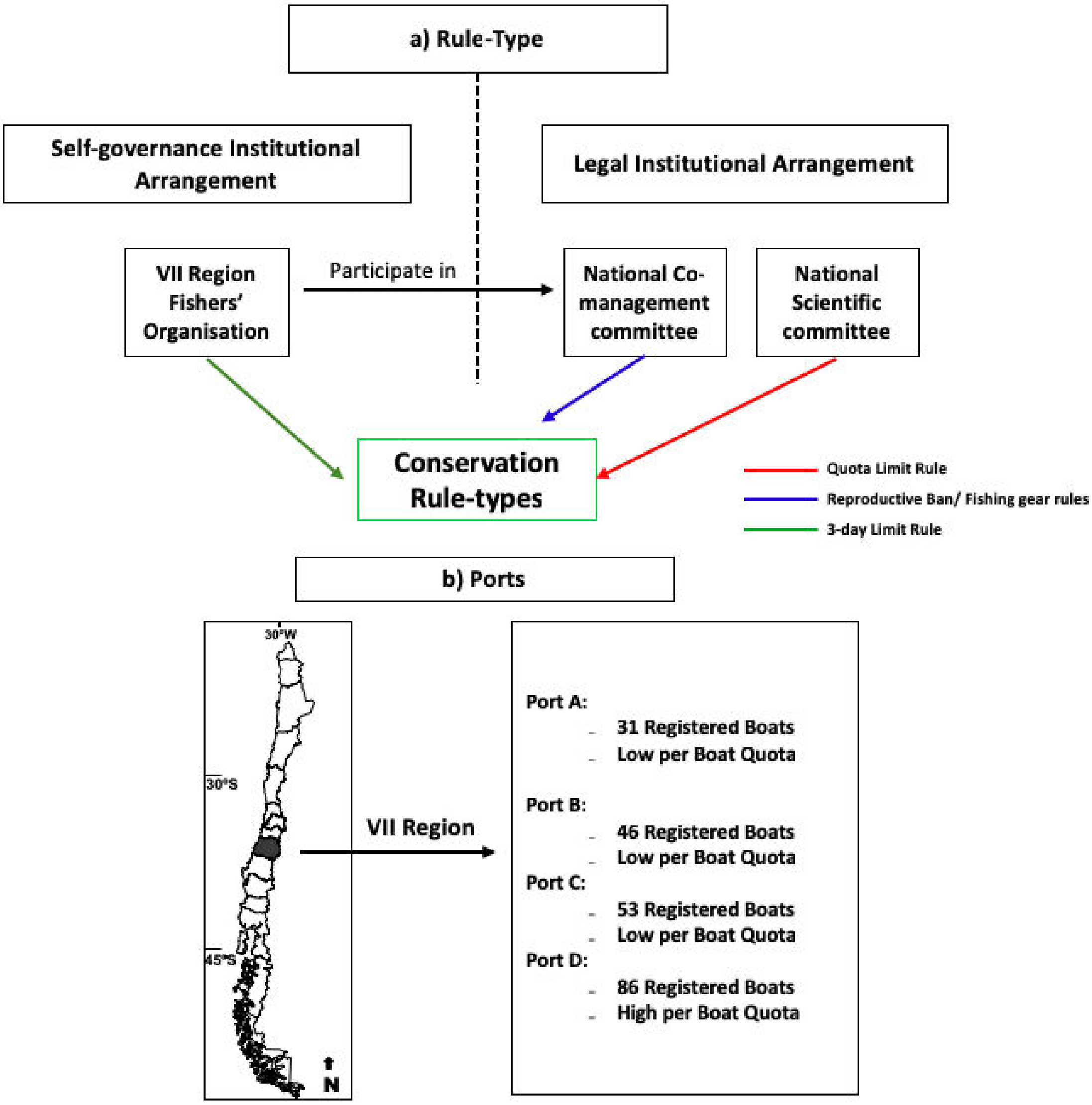


Figure 4.2.1. Contextual factors from the Analytical Framework for Compliance (Ramcilovic-Suominen & Epstein 2012), adapted for the context of the common-hake small-scale fishery of south-central Chile. a) is a conceptual framework of the conservation rule-types for the fishery. (b) A map of the study area and information of the four ports assessed.

A suite of nested, interrelated conservation rule-types governs the fishery in the VII region (Figure 4.2.1a). The four main rules are: a) a yearly quota-limit, set by a national-level scientific committee and allocated in fixed proportions to boat owners or fishers' associations; b) a national-level reproductive ban to protect hake's spawning peak during September; and c) a minimum mesh size for fishing gear, managed by a national co-management committee in which fishers participate; and d) a 3-day a week fishing limit, set voluntarily by fishers' organizations of the VII region.

4.2.2. Survey Instrument

After piloting and revision of the survey instrument, data were gathered in March-April 2019 in 4 ports (A, B, C and D for anonymity) of Chile's VII region (Figure 4.2.1b). We used snowballing sampling, after getting endorsement for the study from leaders of the main fishers' associations in these ports. In total, we surveyed 159 fishers (limited to one fisher per boat), representing 53% and 74% of the total number of boats registered in the region and in these 4 ports, respectively. Before each survey, we informed fishers that participation was voluntary and that they could refuse to answer any particular question. The study complied with Oxford University's ethical requirements (approval number R61136/RE001).

Because we assessed behaviours that might be sensitive, we used the randomized response technique (RRT) (Boruch, 1971) and direct questions (DQ) to assess non-compliance with conservation rules and estimate quantities of underreporting (questions in Supplementary Material). Based on the Compliance Framework, we assessed instrumental, normative and legitimacy-based motivations for compliance using a Likert scale to measure agreement/disagreement with 2-3 statements per component for each rule. The scores for each statement were averaged to get a measure of the strength of agreement with each component for each rule, after having checked for consistency between statements with Cohen's Kappa test (for normative and instrumental components that had two statements) and Fleiss's Kappa test (for the legitimacy-based component that had three statements). Descriptive norms were dropped from the normative motivation component of the analysis due to low variance which prevented consistency analysis. We framed statements so that agreement meant fishers perceived the statement as a motivation for compliance (Table 9.1.1 in Supplementary Material).

4.2.3. Data Analysis

Data were analysed using R Studio v1.1.456 (R Development Core Team, 2011). To understand what motivates compliance with conservation rules, we assessed heterogeneity in compliance at three levels: a) *within-individual*, regarding how fishers respond to different rule-types and what motivates these responses; and at two levels regarding the degree of non-compliance with the quota limit; b) *between-individuals* and c) *between-ports*.

For (a) we calculated (i) the proportion of fishers admitting non-compliance by adapting (Boruch, 1971) forced RRT response model (Figure 9.1.1 in Supplementary Material), and (ii) per-trip underreporting rates using a quantitative adaptation of the RRT (Figure 9.1.2 and Table 9.1.2, Supplementary Material), following (Oyanedel et al., 2018)). To assess heterogeneity at levels (b) and (c) we fitted an ordinal mixed-effects model, using the R package *Ordinal* (Christensen, 2015), where the degree of underreporting was expressed as a 5-category response variable (from the direct question data, see results). We only considered this response variable because the other compliance estimates were consistently close to 0% or 100%, and therefore unsuitable for modelling because of class imbalance. For this model we considered the motivational component scores as fixed effects, having checked for collinearity, and used Port as random effect. Given the anonymity of our survey, port was the only contextual factor we could control for. However, data from SERNAPESCA is available on the quotas that boats in each port receive, therefore port captures the effect of quota level on non-compliance (Figure 4.2.1b). To analyse the effect of port on non-compliance levels we estimated best linear unbiased predictors (BLUPs) from the model.

4.3. Results

Estimates of the proportion of respondents admitting non-compliance from direct questions fall within the 95% confidence interval of RRT estimates, suggesting fishers answered the questions honestly (Figure 4.3.1). For three of the four conservation rules, estimates of non-compliance were low and not significantly different from zero (fishing gear ($t=-0.107$, $df=158$, $p=0.91$), reproductive ban ($t=0.9$, $df=158$, $p=0.36$) and 3-day rule ($t=1.62$, $df=158$, $p=0.106$)). For the quota limit, non-compliance estimates were much higher, in contrast to the other rules (RRT=97% (87-100%), Direct=93%).

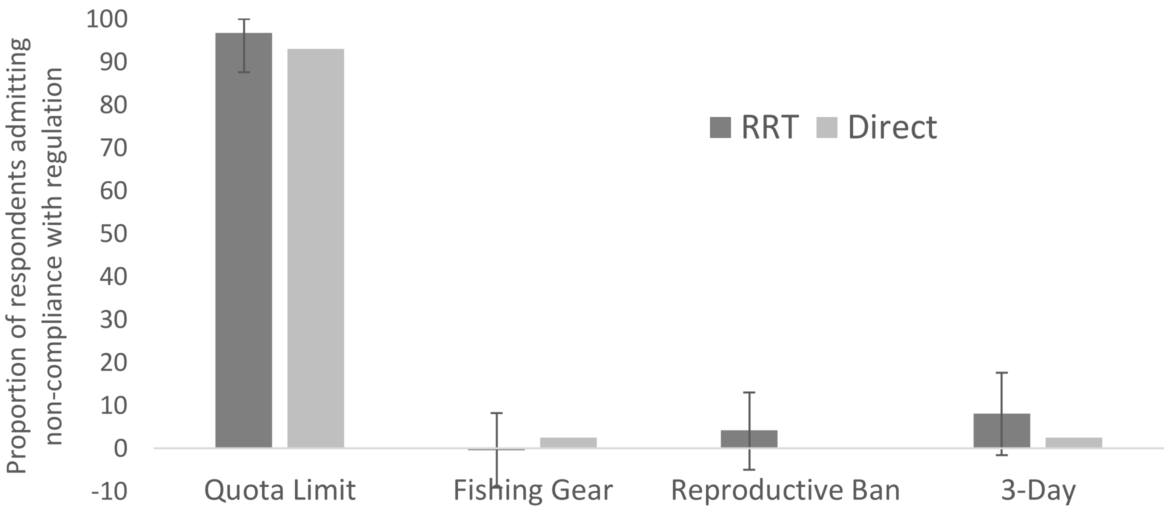
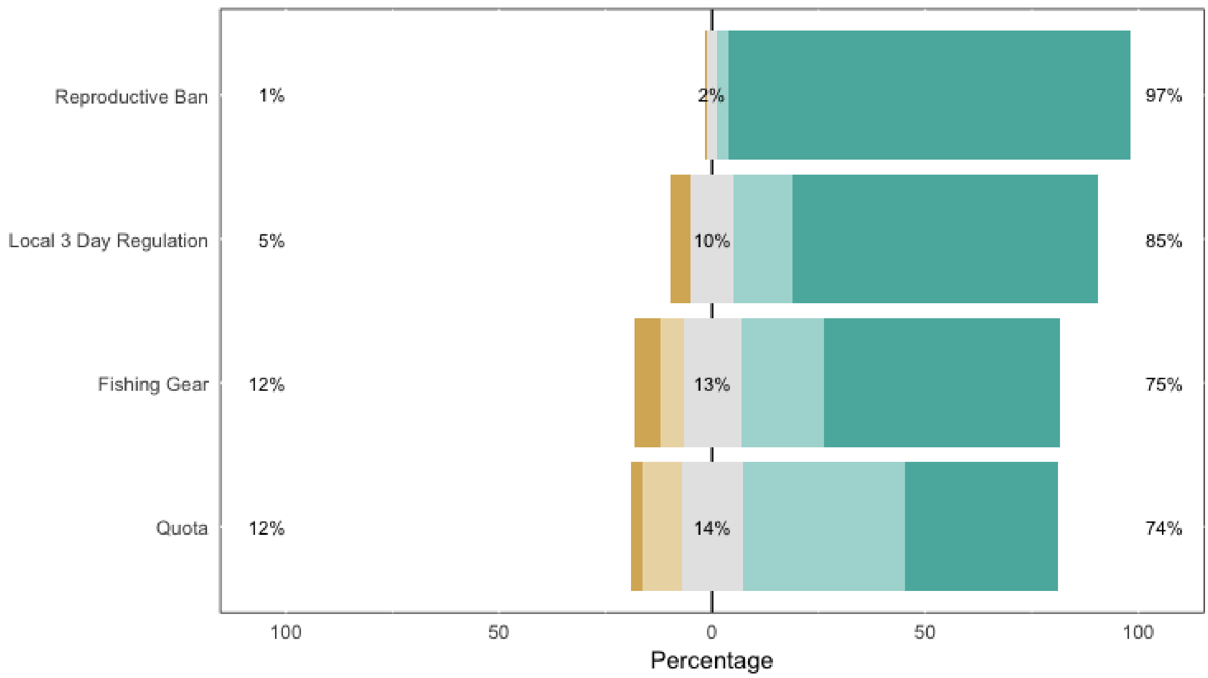


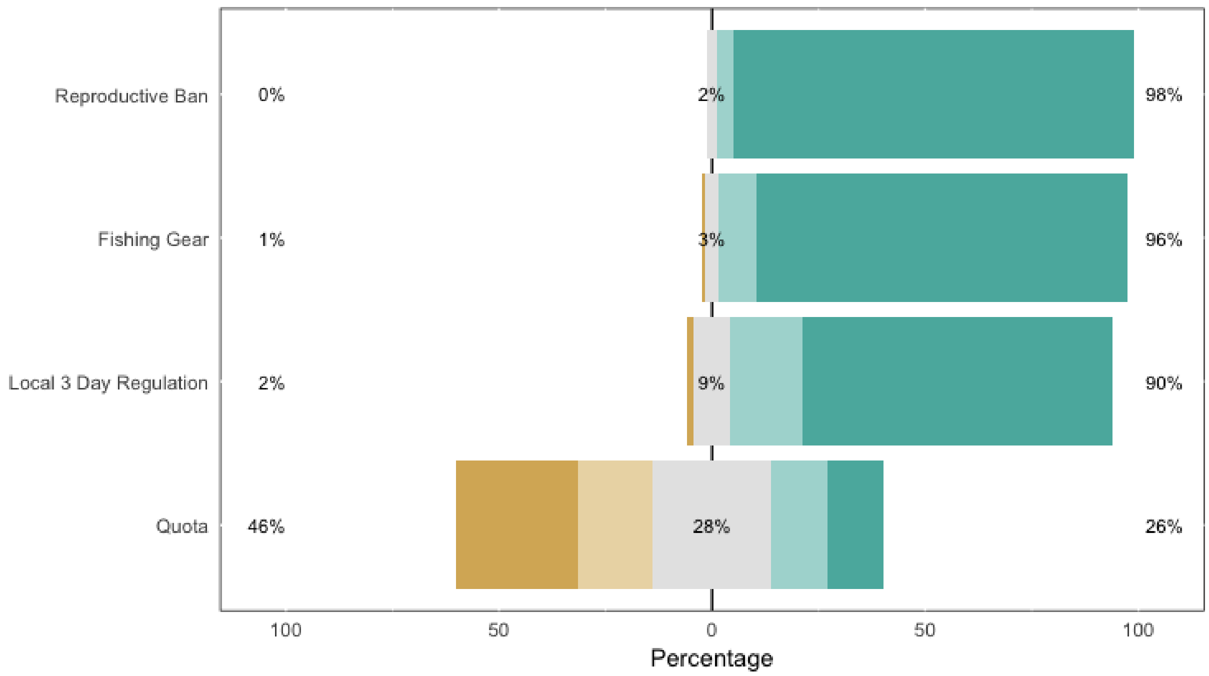
Figure 4.3.1. Estimates of non-compliance with 4 conservation rules using the Randomized Response Technique (RRT) and direct questions (Direct). Bars represent 95% confidence intervals on the RRT estimate.

Between 74% and 97% of fishers agreed or strongly agreed with statements reflecting instrumental motivations for compliance with the four assessed conservation rules (Figure 4.3.2a). Similarly, 90% of respondents agreed or strongly agreed with statements reflecting normative motivations for compliance with the fishing gear, reproductive ban and 3-day rules. However, agreement with statements reflecting normative motivations for compliance was lower for the quota limit (26% agreed or strongly agreed, Figure 4.3.2b). Between 55% and 87% of respondents agreed or strongly agreed with statements reflecting legitimacy-based motivations for compliance with the fishing gear, reproductive ban and 3-day rules. Conversely, most fishers disagreed with statements reflecting legitimacy-based motivations for compliance with the quota limit (95% disagreed or strongly disagreed, Figure 4.3.2c).

(a)



(b)


Reproductive Ban
Fishing Gear
Local 3 Day Regulation
Quota
0%
2%
98%
1%
3%
96%
2%
9%
90%
46%
28%
26%
100
50
0
50
100
Percentage

(c)

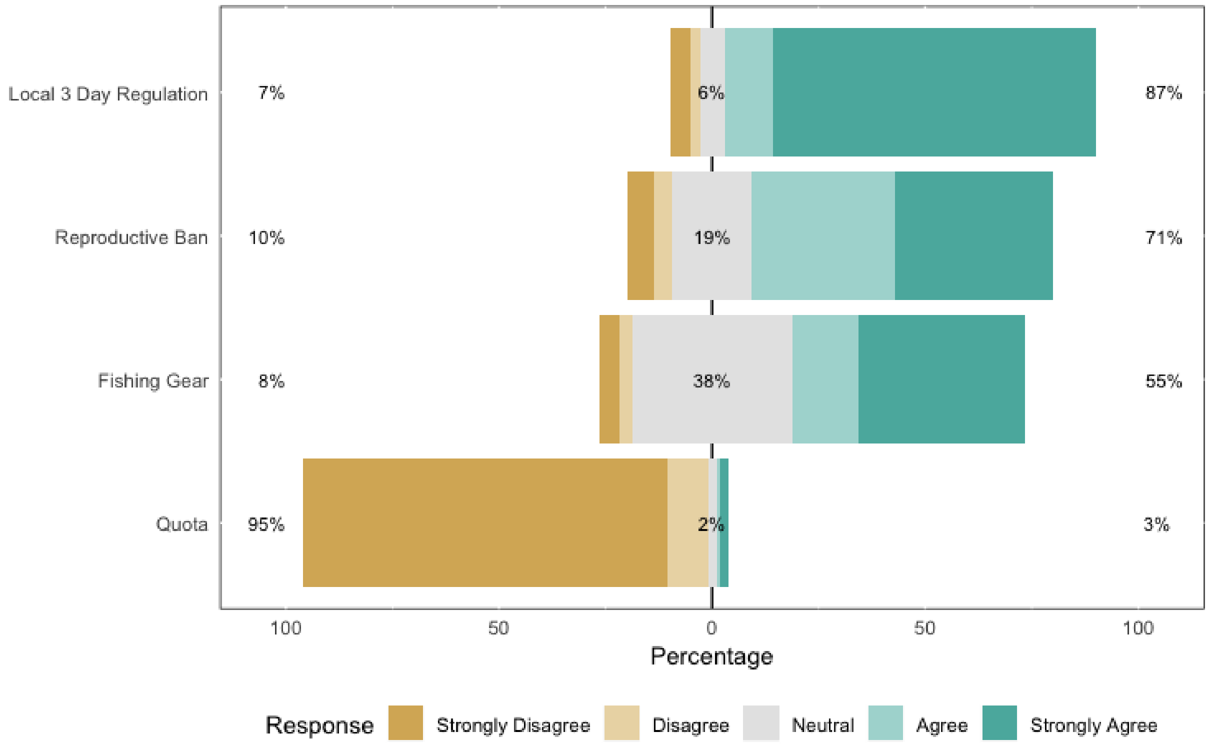

Local 3 Day Regulation
Reproductive Ban
Fishing Gear
Quota
7%
6%
87%
10%
19%
71%
8%
38%
55%
95%
2%
3%
100
50
0
50
100
Percentage
Response
Strongly Disagree
Disagree
Neutral
Agree
Strongly Agree

Figure 4.3.2. Likert scores of respondents' agreement with statements regarding their (a) instrumental, (b) normative, and (c) legitimacy-based motivations for complying with the 4 conservation rules (e.g. for a normative motivation statement, fishers were asked to to indicate how much they agreed with the following: "I would feel guilty if I violate this (conservation rule)", see Table 9.1.2). The percentage on the right side of each panel represents the sum of agree and strongly agree responses, the percentage in the middle represents neutral responses and the percentage on the left represents the sum of disagree and strongly disagree responses.

We used direct question data as response variables in our model, since estimates from RRT and direct questions were similar for the quantitative estimates of underreporting (RRT=20.31 (SE=2.46); Direct question=22.02 (SE=1.25)). Fishers that scored instrumental, normative and legitimacy-based motivations higher, underreported less (Table 4.3.1). However, the relative role of these components differs importantly between individuals. In particular, individual differences in the normative component were significantly related to the degree of non-compliance with the quota limit (β=-0.158 (0.06), p=0.014). Instrumental motivations were nearly significantly related to the degree of non-compliance with the quota limit (β=-0.145 (0.07), p=0.059). Legitimacy-based motivations had a low and non-significant effect on the degree of non-compliance with the quota limit.

Table 4.3.1. Result from multiple regression mixed effect model. Estimates of the effect that motivational components (fixed effects) and ports (random effect, estimates from BLUPs) have on the degree of non-compliance with the quota limit (Ordinal Model). * Indica Indicate significant variables at p < 0.05.

		Degree of non-Compliance with Quota Limit	
		β (Std Error)	p
Motivation	Instrumental	-0.145 (0.07)	0.059
	Normative	-0.158 (0.06)	0.014*
	Legitimacy-based	-0.056 (0.10)	0.584
Port	A	0.789 (0.17)	<0.0001*
	B	0.367 (0.09)	0.0002*

	C	-0.03 (0.08)	0.976
	D	-1.117 (0.04)	<0.0001*

The port that a fisher is based in had a large effect on the degree of non-compliance with the quota limit. Ports A (β=0.789 (0.17), p=<0.0001) and B (β=0.367 (0.09), p=0.0002) had significantly more underreporting, port C had a negative, non-significant coefficient (β=-0.03 (0.08), p=0.976), while port D was strongly significantly less likely to under-report (β=-1.117 (0.04), p=<0.0001).

4.4. Discussion

Our results support previous estimates of substantial levels of non-compliance with the quota limit in the Chilean common-hake fishery (Plotnek et al., 2016). However, our results also shed light on the diversity of motivations for compliance across rule-types and fishers. At *within-individual* level we found that fishers comply with temporal and gear restrictions, but not the quota limit (Figure 4.3.1). These distinct compliance responses are associated with heterogeneity in what motivates compliance with each conservation rule, especially reflecting the importance of legitimacy-based motivations to comply with temporal and gear restrictions but not the quota limit (Figure 4.3.2c).

At the *between-individuals* level, we found normative motivations best explained the degree of non-compliance with the quota limit, followed by instrumental motivations (Table 4.3.1). As such, our results sit between previous work that highlights the role of instrumental motivations for compliance in commercial fisheries (King & Sutinen, 2010; Nielsen & Mathiesen, 2003; Sutinen & Andersen, 1985) and the role of normative motivations for compliance in recreational fisheries (Bergseth & Roscher, 2018; Bova et al., 2017; Thomas et al., 2016). However, previous work that emphasizes the role of normative motivations was carried out in high compliance contexts. For instance, Bergseth and Roscher (2018), found that most recreational fishers in the Great Barrier Reef Marine Park in Australia had strong normative motivations for compliance. But, contrary to our case study, non-compliance among fishers was 3-18% (Bergseth et al., 2017). As such, our results expand on previous work by demonstrating that normative motivations can have a role in motivating compliance even in high non-compliance contexts.

Further, by assessing the degree of non-compliance with the quota limit (i.e. by *how much* fishers exceeded their quotas) as a response variable at the *between-individuals* level, we expand on previous studies using dichotomous assessments of non-compliance as response variables (i.e. whether fishers violate rules or not), (Arias & Sutton, 2013; Bergseth et al., 2015; Bergseth & Roscher, 2018; Thomas et al., 2016). Our results reveal how motivations affect not only the decision to engage in non-compliance but also the degree or extent of non-compliance. As such, this study allowed us to unpack the previously unidentified role of normative factors in motivating the extent of fishers' non-compliance. Moving from a dichotomous framing of compliance towards a holistic understanding of the diversity and extent of non-compliance responses and their motivations can aid in better managing and predicting non-compliance (Arias, 2015; Boonstra et al., 2017).

The high heterogeneity we found *between-ports* show that port D fishers, who have high quotas, were more likely to comply. Our finding that fishers from lower quota ports comply less suggests that underreporting in this region is partially caused by the low quotas assigned to fishers, which relates to the instrumental motivation (i.e. economic factors). However, our results also reveal an important geographical pattern in compliance responses, with differences between the low-quota ports A, B and C, indicating that port-level factors beyond the quota were important determinants of compliance. More research is needed to understand the role that context-specific variables such as local market pressure, culture, equity, poverty and corruption might have in influencing compliance and the relative role of different motivations (Ramcilovic-Suominen & Epstein, 2012).

Unpacking fishers' underlying motivations for compliance with different conservation rule-types, at different analytical levels, can help guide tailored interventions at the appropriate level (Arias, 2015; Thomas et al., 2016). Fisheries are complex adaptive systems, and diverse motivations for compliance need to be addressed differently by managers (Mahon et al., 2008). For instance, the *within-individual* heterogeneity suggests that allowing more participation by fishers in decision-making about quota limits could increase their legitimacy, ultimately improving compliance (Pares et al., 2015). *Between-individuals*, our results suggest that compliance could be improved by tapping into fishers' normative motivations. For instance, interventions could correct negative interpretations of how others are responding to rules, and highlight positive behaviours, such as through targeted advertising campaigns (Berkowitz, 2005; Bova et al., 2017). Similarly, block leaders could be empowered to shape port-level normative perceptions towards the need to comply with the quota limit (Bergseth & Roscher, 2018). Since fishers are well-organized in our case study, existing leaders could potentially fulfil this role. Heterogeneity *between-ports* suggests that higher quotas motivate fishers to comply. Auctioning and re-distribution programs could be designed to deal with the problems of initial quota allocation and their equity implications (Sumaila, 2018). This way, quota could be better allocated without increasing pressure on the overexploited stock.

Conservationists have two ways to deal with issues of compliance. One involves using technical fixes, such as increasing fines or the (real or perceived) probability of getting caught and sanctioned, to incentivise compliance (our instrumental component) (Becker, 1968). This has been the primary approach because it makes use of empirical data to estimate the effect of enforcement on compliance levels (Doumbouya et al., 2017; Hilborn et al., 2006) and relies on the assumption that human behaviour is governed by profit-maximising self-interest (Schill et al., 2019). However, empirical evidence is mounting that non-economic factors play an important role in motivating compliance (our normative and legitimacy-based components) (Bergseth & Roscher, 2018; Bova et al., 2017; Thomas et al., 2016). The tension between these approaches cannot be resolved without digging deeper into the heterogeneity of compliance responses, the motivations behind them, and how they vary between scales. This is especially necessary in small-scale resource user systems, because their diversity and dynamism precludes simple generalisations (Mahon et al., 2008; Waylen et al., 2013). Ultimately, a robust and empirically-based theory of compliance should guide conservationists in understanding the circumstances and scales for which technical fixes can motivate compliance, and when other approaches that tap into non-economic motivations are needed. Creative ways to deal with compliance issues will emerge if combinations of policy instruments are used at nested levels, accounting for the heterogeneity of motivations and contextual factors that ultimately drive compliance at each level.

Chapter 5: A framework for assessing and intervening in markets driving unsustainable wildlife use

Abstract

Understanding how markets drive unsustainable wildlife use is key for biodiversity conservation. Yet most approaches to date look at isolated components of wildlife markets, hindering our ability to intervene effectively to improve sustainability. To better assess and intervene in wildlife markets, we propose a framework that integrates three analytical levels. The first level, “actor”, assesses the underlying motivations and mechanisms that allow or constrain how actors benefit from wildlife markets. The second level, “inter-actor”, assesses the configuration of wildlife product supply-chains and the type of competition between actors participating in wildlife markets. The third level, “market”, evaluates supply-demand dynamics, quantity and price determinants, and the presence and effect of illegal products flowing into markets. We showcase the utility of the framework in a data-limited small-scale fishery case study (common hake, *Merluccius gayi gayi* in Chile); our mixed-method analysis provided relevant, tailored management recommendations for improving sustainability. Tackling markets driving unsustainable wildlife use needs integrated approaches that bring together the diversity of factors affecting wildlife market dynamics.

5.1. Introduction

Unsustainable wildlife use is a significant concern for biodiversity conservation (Diaz et al., 2019; Fukushima et al., 2020; Maire et al., 2020). How the operation and structure of wildlife markets affects the sustainability of wildlife use is an under-researched topic (Cinner et al., 2020b; Jones et al., 2019; McNamara et al., 2016). While unsustainable use is not always market-driven (for example it could be due to subsistence needs or human-wildlife conflict), markets often are identified as the drivers of unsustainable use (Crookes & Milner-Gulland, 2006; Lunstrum & Givá, 2020; Marshall et al., 2020). Better understanding wildlife markets can help reduce unsustainable wildlife use by informing tailored and context-appropriate interventions. However, understanding how and when markets might drive unsustainable wildlife use encompasses many interrelated factors, which are challenging to disentangle (McNamara et al., 2019; O'Neill et al., 2018).

Markets are the combination of institutions, processes, infrastructure and social relations where parties engage in exchange. Several studies have analysed different components of wildlife markets, in efforts to understand and intervene in them to improve sustainability (Damania et al., 2005; Ling & Milner-Gulland, 2006; McNamara et al., 2016; Milner-Gulland & Clayton, 2002; O'Neill et al., 2018; Purcell et al., 2017; Wamukota et al., 2014). However, this focus on particular components of wildlife markets, rather than integrating their complexity and interactions across different scales, can lead to only a partial understanding, which then compromises our ability to intervene effectively and may risk unintended consequences (Larrosa et al., 2016). Improving our understanding of how markets drive unsustainable wildlife use requires integrated frameworks that bring together the different market components affecting wildlife use dynamics.

Wildlife markets, at their core, are composed of actors. Actors are the individuals, groups or firms that participate in these markets. Assessing and intervening in markets driving unsustainable wildlife use requires an understanding of the underlying motivations that drive actors' behaviour, as well as the mechanisms that allow or constrain how actors operate in and benefit from wildlife markets (Maire et al., 2020; Nuno et al., 2013; Oyanedel et al., 2020a; Peluso & Ribot, 2020; Ribot & Peluso, 2003). Actors' motivations and how they benefit from wildlife markets vary depending on the type of actor, where in the market they operate, context-specific variables and market signals such as price (Damania et al., 2005; Ramcilovic-Suominen & Epstein, 2012). Assessing and intervening in wildlife markets also requires an inter-actor analysis, exploring how actors interact (O'Neill et al., 2018). Repeated actor interactions in markets creates supply-chain structures that are used for trading products and information. The configuration of these supply-chains and the type of interaction between actors can have substantial impacts on how wildlife markets operate, and ultimately on wildlife sustainability (Crona et al., 2010; González-Mon et al., 2019; Ribot, 1998). The emergent properties of actors' interactions and the flow of information, capital and products through supply-chains determine how wildlife markets, as a whole, operate (Damania et al., 2005; McNamara et al., 2016; Milner-Gulland, 1993). Market-level analyses can point to which processes define supply-demand dynamics, what determines quantities being traded and their prices, as well as the presence and effect of illegal products flowing into the market (McNamara et al., 2016, 2019; Oyanedel et al., 2018).

Previous work has looked at motivations for the use and consumption of wildlife products (Thomas-Walters et al., 2020), provided frameworks for analysing illegal wildlife trade (Phelps et al., 2016) and theorized on how wildlife supply and demand might change under different scenarios (Bulte & Van Kooten, 1999; Chen & 't Sas-Rolfes, 2021; Crookes, 2017; Crookes & Blignaut, 2015; Damania et al., 2005). To progress beyond sectoral analyses as the above, we here propose a framework for assessing and intervening in markets driving unsustainable wildlife use which integrates the actor, inter-actor and market levels. This framework is novel as it provides the first attempt to combine different levels of analysis used in wildlife markets into a comprehensive structure. The integration proposed in this framework is intended to enhance its applicability in different contexts and geographies, providing an adaptable and flexible tool to assess wildlife markets. This framework can assist in the identification of interventions to reduce unsustainable wildlife use, and pinpoint knowledge gaps, especially in incomplete or data-limited settings. We first describe the structure of the framework, specifying each of the components and how to integrate their interactions across different scales. We then apply the framework to a data-limited small-scale fishery case study, to showcase the utility of the approach. Insights from the application of the framework provided relevant, tailored management recommendations for improving sustainability in the fishery. We finish by offering recommendations on how to use the framework and discussing its relevance and limitations.

5.2. The Framework

5.2.1. Actor Analysis

In the framework, actors in wildlife markets are structured into four groups, which we refer to as components (Figure 5.2.1). The harvester component refers to those actors who directly interact with wildlife and extract it from nature through fishing, hunting, snaring, logging, mushroom picking, etc. The intermediary component refers to those who transform and transport wildlife from its harvest point to selling point, and vendors refers to those who are involved in selling wildlife products to consumers. Finally, consumers refer to the end users of wildlife products.

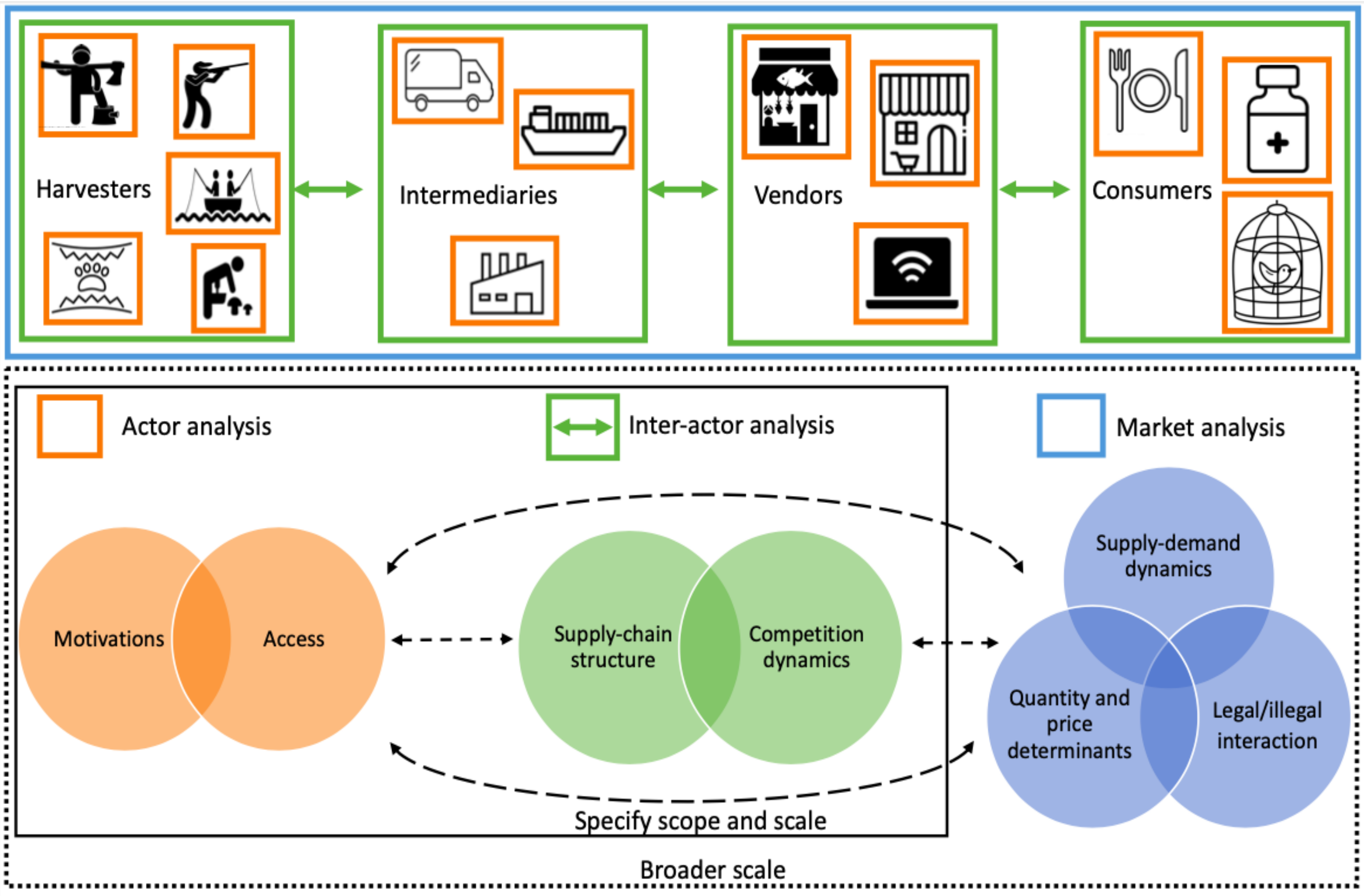


Figure 5.2.1. A framework for assessing and intervening in markets driving unsustainable wildlife use. The upper panel represents the four components (i.e. group of actors), and the lower panel the three analytical levels analysed in the framework.

The first level of analysis, actor, assesses the characteristics of actors that participate in the market (Table 5.2.1). These can be individuals, groups or firms. The *motivation dimension* looks at the underlying motivations that drive an actor's behaviour. Understanding motivations can support better targeting of interventions to address unsustainable resource use through the identification of specific factors driving unsustainable behaviour (Damania et al., 2005; Jouffray et al., 2019; Milner-Gulland, 1993; Oyanedel et al., 2020b). How to assess these motivations depends on the type of actor. For individual motivations (e.g. a hunter or a consumer), several frameworks for evaluating behavioural motivations have been developed (e.g. the Theory of Planned Behaviour (Ajzen 1991) and the Compliance Framework (Ramcilovic-Suominen & Epstein, 2012)). Moreover, instrumental (i.e. calculation of economic costs and benefits) and/or normative (i.e. social and personal norms) approaches can be used to assess motivations (Fairbrass et al., 2016; Oyanedel et al., 2020a; St John, Edwards-Jones, et al., 2010; Thomas-Walters et al., 2020). Methodologies to assess these motivations include surveys, key-informant interviews and behavioural economic methodologies such as contingent valuation and choice experiments (Bova et al., 2017; Oyanedel et al., 2020b). For groups of individuals or firms (e.g. a group of vendors or a processing plant company) motivations might be assessed through risk profiles, cost benefit analysis or evaluating Environmental, Social and Governance commitments towards biodiversity impact reduction or certification programs (Addison et al., 2019; Jouffray et al., 2019).

The *access dimension* looks at the suite of mechanisms used by actors to benefit from wildlife markets (Ribot & Peluso, 2003). This includes not only formal mechanisms such as property rights but also informal mechanisms such as social ties or knowledge of demand (Ribot, 1998). The theory of access formalises these analyses and helps to guide methods to identify and describe the mechanisms used by actors to gain and maintain access to benefits (Peluso & Ribot, 2020). This then allows the identification of interventions that might disrupt specific mechanisms that maintain unsustainable wildlife use practices. For instance, when intermediaries concentrate access using mechanisms such as collusive price-fixing, prices paid to harvesters might be set intentionally low, driving overexploitation (Ribot, 1998).

For the actor level analysis, typologies can be empirically constructed to characterise participants in the market. Typologies refer to the systematic construction of types - which are unique combinations of dimensions of attributes that influence the relevant outcome. The motivations and access dimensions can be used to construct the typologies for each of the four market components (harvesters, intermediaries, vendors and consumers), thereby defining specific characteristics of actors for the case study. Following (Kluge, 2000) we divide the typology construction process into four steps: development of relevant analysis dimensions; grouping the cases and analysis of empirical regularities; analysis of meaningful relationships and type construction; and characterization of the constructed types (see Supplementary Material)

5.2.2. Inter-actor Analysis

Actors participating in wildlife markets interact to exchange wildlife products and information within and between market components. The *supply-chain structure dimension* assesses the configuration of actors' interactions when transporting and transforming wildlife products from the wild to consumers. Assessing these configurations requires mapping how products, information and resources travel through supply chains (Purcell et al., 2017). Methodologies for this include system mapping, key-informant interviews, social network analysis and literature review (González-Mon et al., 2019; Jena et al., 2017). Understanding these configurations can assist in identifying interventions by locating specific points in the supply chain that might be causing or maintaining unsustainable wildlife use practices (Phelps et al., 2016). A useful typology of supply-chain network configurations, created to assess illegal wildlife trade, can be found in Phelps et al., 2016. For instance, restricted supply chains where gatekeepers are present can cause specific actors to gain excessive market control, which in turn can exacerbate unsustainability if their motivations are not aligned with long-term sustainable management.

The *competition dynamics dimension* assesses the way actors interact, compete and prevent new actors coming into each component. Idealized categorizations of interactions include, but are not limited to: perfect competition (no particular actor controls supply or demand because many actors participate in the market), oligopoly (a few, powerful actors dominate market dynamics, reducing competition), monopoly (one actor supplies the product and as such has full control of the market) and monopsony (a single buyer controls the market by purchasing from different sellers). Recognising how actors within components interact can assist in assessing wildlife markets because this helps predict how wildlife is used. For instance, if the harvester component is characterised by a monopoly or oligopoly, in theory wildlife might be more likely to be used sustainably because harvesters can plan for the future (Clark, 1990). However, if a monopoly or oligopoly is present at the intermediary level, collusion might occur, driving prices paid to harvesters down, which can exacerbate unsustainable wildlife use (González-Mon et al., 2019; Jones et al., 2019).

5.2.3. Market Analysis

The market-level analysis assesses the emergent economic properties that result from the individual behaviours of, and interactions between, actors in the market. The *price and quantity determinants dimension* looks at the different factors that determine quantities supplied and demanded by the market and product prices. These factors include own price elasticity, income elasticity, cross-price elasticity, environmental or supply stochasticity and consumer preference (McNamara et al., 2019; Milner-Gulland, 1993; Rentsch & Damon, 2013). Methodologies for assessing this dimension include econometric analysis and regression models that try to disentangle how explanatory factors affect quantities demanded or supplied (McNamara et al., 2019).

The *supply-demand dynamics dimension* looks at whether the market is dominated by supply- or demand-driven processes. Supply-driven markets are those where suppliers participate in the market independently of price signals, while demand-driven markets are those where suppliers respond to price signals, among other factors (McNamara et al., 2016). A suite of methodologies is needed to disentangle whether the market under consideration is supply or demand-driven, including key-informant interviews, surveys and econometric analyses. Unravelling whether the market is supply or demand-driven can assist in identifying if interventions to reduce unsustainability should be targeted at consumers (in demand-driven markets) or suppliers (supply-driven markets) (McNamara et al., 2016).

The *legal/illegal interaction dimension* looks at the presence of illegal products going into the market and how they affect market dynamics. Illegal exploitation of wildlife can distort markets and affect competition. How illegality affects markets, however, depends on the way products are integrated into the supply chain. At one extreme, illegal products can be entirely integrated into the same markets as legal products, in which case they are difficult to distinguish (Oyanedel et al., 2020b). At the other extreme, illegal and legal products can be almost entirely separated in their markets – for instance they can be packed differently or sold in different places (Dutton et al., 2011). Assessing the presence and extent of illegal activities usually requires specialized research methods, as those involved in illegal activities might be reluctant to participate in research elucidating the extent and characteristics of their activities (Hinsley et al., 2019). Assessing the extent of illegal activities and how they are integrated in supply chains is necessary to complement legal market data, so that the true dynamics of the market as a whole can be revealed.

5.2.4. Applying the Framework: Select Sustainability Problem, Define Scope and Scale and Identify Interventions

Applying the framework firstly requires that a well-defined sustainability problem which involves markets is selected. A well-delimited sustainability problem helps to define the scope and scale of application of the framework and assist in better selecting interventions that might tackle the specific issue being analysed. Within this delimitation of the sustainability problem, the main components of the market to be analysed are also defined. This might include all four components of the market (harvesters, intermediaries, vendors and consumers), or the subset of these which contribute to the sustainability problem. We do not consider other actors which contribute to the wider environment within which the market operates, such as policy-makers, law enforcers or broader society.

To delimit the scope and scale at which the framework is most usefully applied, actor and inter-actor level analyses are defined based on one or more of the following: a specific product, species, selling channel and/or format. In some cases, the scope and scale of analysis will be easily identifiable, for instance, in fisheries where one product is sold in a well-defined channel without processing. In other cases, transformation and mixing of species into one product, or different products that are derived from the same species, might make the scope and scale of analysis harder to identify (e.g. scales from different pangolins species going into a generic pangolin scale product). For the market analysis level, a broader scale (e.g. a country) can be considered to account for factors, such as price, that might be defined at a larger scale than the scale and scope defined for actor/inter-actor analyses.

As part of the scale and scope delimitation, a time dimension must be also considered. Wildlife products vary in how they are used and transformed. Some perish fast (e.g. fresh fish), while others can be stored (e.g. ivory), some are highly seasonal (e.g. wild mushrooms) while others are harvested constantly over time (e.g. some timber products). The time scales in which wildlife products are used and transformed affects how actors participate in the market, the type of supply-chain needed to transport products, and ultimately, the way markets operate. As such, time has to be considered when defining the system being studied and how each analytical level is assessed, so that an appropriate time-scale is used that capture the diversity of processes affecting the market.

Applying the framework allows the user to transparently conceptualise a wildlife market system. This can then act as a guide for identifying interventions that address the specific characteristics of the market that might be driving unsustainable wildlife use. Identifying interventions involves integrating the results of the different analytical levels, considering the interactions within and between analytical levels. Selecting and predicting which of the set of feasible interventions will best assist in reducing the selected unsustainability problem is beyond the scope of the framework, but readers might want to look at cost-benefit analyses, participatory processes (Travers et al., 2016), or before-after-control-intervention analyses (Ferraro et al., 2019) for this purpose.

Table 5.2.1. Actor, inter-actor and market-level analysis and their dimensions for assessing and intervening in markets driving unsustainable wildlife use.

Level of analysis	Dimension	Description	Possible methodologies to assess the dimension	Examples of interventions	References
Actor	Motivations	The underlying motivations that drive actors' behaviour in the market	- Key informant interviews and surveys - Economic methods (e.g. choice experiments, contingent valuation) - Cost-benefit analysis - Risk profiles - Typology construction for creating actor types	- If instrumental motivations predominate at the individual or firm level, change negative incentives: improve enforcement, increase fines or reduce revenues from unsustainable practices. For positive incentives: performance-based rewards, alternatives or compensation -If individual normative motivations are aligned with unsustainable market practices, influence and modify social norms. - Promote certification or financial incentives for actors performing sustainable practices	(Cialdini & Trost, 1998; Ferrier, 2008; Jouffray et al., 2019; Milner-Gulland & Clayton, 2002; Newing, 2010a; Oyanedel et al., 2020a; Tyler, 1990)

	Access	The suite of mechanisms that define the ability of different actors that participate in the market to derive benefits from it	- Key-informant interviews - Literature review - Social network analysis - Access mechanisms mapping - Typology construction	- If access to information is disparate, provide information platforms for actors with less access - Provide training for unskilled actors or low-interest loans or equipment for actors that lack access to capital - If access to markets is a barrier, improve access to transport links - Regulate against collusive price fixing - Incentivise low access actors to organise into cooperatives or syndicates	(Kluge, 2000; Peluso & Ribot, 2020; Purcell et al., 2017; Ribot, 1998; Ribot & Peluso, 2003; Wamukota et al., 2014)
Inter-actor	Supply-chain structure	The configuration of actors' interactions between and within components for transporting and transforming wildlife	- System mapping - Key-informant interviews - Literature review - Social network analysis to map how actors interact	- When restrictive links are controlling the supply, incentivise direct sale links from harvesters to vendors or consumers - Diversify selling platforms when a limited number of intermediaries are driving unsustainable use	(Gaonkar & Viswanadham, 2007; González-Mon et al., 2019; Jena et al., 2017)

		products from the wild to consumers			
	Competition dynamics	The way that actors participating in each market component compete: oligopoly, perfect competition, monopoly or monopsony	- Key-informant interviews - Literature review	- If actors in a market component are organised as an oligopoly, monopsony or monopoly, reduce entry barriers to participation - Improve tenure rights and security if open access to resources is driving overexploitation - Develop and enforce competition regulations	(Purcell et al., 2017; Ribot, 1998)
Market	Quantity and price determinants	The diversity of factors that determine quantities supplied and demanded by the market and define product prices	- Key-informant interviews - Econometric analysis to determine elasticities and what influences quantities supplied/demanded	- If own demand is elastic, increase prices to reduce consumption - If own demand is inelastic, increase the availability of alternative products, considering the effect on demand for the focal product	(Loannides & Whitmarsh, 1987; McNamara et al., 2019; Pitt, 1981)

	Supply-demand dynamic	The interplay between different attributes that together suggest if the supply-demand dynamic is dominated by supply or demand-driven processes	- Key-informant interviews - Econometric analysis	If demand-driven: - Increase the availability of alternative products - Change consumer preferences - Introduce market regulations If supply-driven: - Reduce harvesters' dependence on resources - Improve enforcement at harvester component	(McNamara et al., 2016; Wright et al., 2016)
	Legal/illegal interaction	How illegal products enter and define the market and the total quantities traded	- Key informant interviews - Sensitive questioning surveys to assess and estimate illegal use	- Develop mechanisms to differentiate legal/illegal and sustainable/unsustainable products - Increase/improve monitoring and enforcement - Incentivise price premium for sustainable/legal products - Improve consumer awareness and demand for sustainable/legal products	(Agnew et al., 2009; Chen & ’t Sas-Rolfes, 2021; Nuno & St John, 2015; Oyanedel et al., 2018; Zeller et al., 2015)

5.3. Common hake fishery case study as an application of the framework

5.3.1. Select sustainability problem and define scope and scale

Common hake (*Merluccious gayi gayi*) is one of the most valuable fisheries in Chile in terms of income and jobs, employing more than 3,000 fishers directly just in the small-scale sector (vessels usually less than 12 meters in length) (Arancibia & Neira, 2008). The most critical challenge for the sustainable management of the fishery is unreported fishing, where quota limits are exceeded and fishers fail to report catches accurately (Oyanedel et al., 2020b; Plotnek et al., 2016; SUBPESCA, 2016). Anecdotal evidence, as well as enforcement records from the Chilean National Fisheries and Aquaculture Service (SERNAPESCA), indicate that this problem is more severe in the small-scale sector and particularly in the VII region of the country, where the majority of the catch is unreported (for an extended background on the fishery see (Oyanedel et al., 2020b)).

Accordingly, we define the sustainability problem as how the market drives common hake under-reporting and concentrate on the harvester, intermediary and vendor components. We define our scope and scale for actor and inter-actor analyses as the sale of fresh fish originating in the VII region of the country to open-air markets and the central fishing terminal in Santiago (Chile's capital). For the market analysis, we define the common hake fishery at the national level, so as to consider how own- and alternative product prices at this level affects unreported catch dynamics in the VII region. We consider a multi-year (2014-2019) time-scale to account for seasonal variability in landings and prices.

Four independent methodologies were used to characterize the different dimensions at each of the analytical levels of the framework (see Supplementary Material). First, key-informant interviews were used for the actor and inter-actor analytical levels as well as the legal/illegal interaction and supply-demand dynamics of the market. Then, a typology construction process was used to create actor types. For the market analysis level, a sensitive questioning survey analysis was performed to understand the legal/illegal product interaction, and an econometric model was used to assess the determinants of quantity and price.

5.3.2. Actor-level analysis

The typology construction methodology (see Supplementary Material for details) identified 6 actor-types: Type I "Low quota fisher", Type II "High quota fisher", Type III "Temporary intermediary", Type IV "Permanent intermediary", Type V "Fishing terminal vendor" and Type VI "Open-air market vendor" (Table 5.3.1).

Table 5.3.1. Characterisation of the actor-types constructed for each component of the common hake case study.

Component	Types	Characterisation
Harvesters	Type I "Low quota fisher"	Fishers from Type I are from ports where quota assignation is low, compared to other ports in the region. They are price takers, and so their primary mechanism to benefit from the fishery is through their quota. They have mixed motivations for participating in the fishery, including normative and instrumental.
	Type II "High quota fisher"	Fishers from Type II are from ports where quota assignation is high. They are price takers, and so their primary mechanism to benefit from the fishery is

		through their quota. They have mixed motivations for participating in the fishery, including normative and instrumental.
Intermediaries	Type III "Temporary intermediary"	Intermediaries from Type III are sporadically hired by permanent intermediaries when landings exceed permanent intermediaries' capacities. As such, these intermediaries are dependent on specific conditions when they are required and do not have permanent access to the benefits from the fishery. These intermediaries are mostly driven by instrumental motivations.
	Type IV "Permanent intermediary"	Intermediaries from Type IV work permanently in the fishery. These intermediaries have several mechanisms of access to the benefits of the fishery, such as capital, control of access to market, collusive price-fixing, price information control and ties with enforcers. These intermediaries are mostly driven by instrumental motivations.
Vendors	Type V "Fishing terminal vendor"	Vendors of Type V operate from the main fishing terminal in Chile. These vendors are well organised and have diverse mechanisms for accessing the benefits of the fishery such as knowledge of demand, relationship with intermediaries and infrastructure. These vendors are mostly driven by instrumental motivations.
	Type VI "Open-air market vendor"	Vendors from Type VI operate in spread-out open-air markets in Chile's major cities. These vendors have a central organisation and their mechanisms to benefit from the fishery include comprehensive knowledge of demand and direct access to consumers, syndicate membership, licence to operate in open-air markets and information on prices. These vendors are mostly driven by instrumental motivations.

Motivations dimension

Results from key-informant interviews indicate that instrumental motivations drive intermediaries' decisions to trade legal or unreported catch. Key-informants indicated that intermediaries always trade some legal catch to justify their operation for tax and registration purposes. This does vary, however, depending on perceived levels of enforcement activity or higher prices. Interview results indicate similar motivations for vendors. However, in their case variation in how much legal or unreported product they trade has to do mostly with enforcement probability and is not too sensitive to price. Sensitive questioning methods revealed that fishers' decisions to underreport had an instrumental component related to their quota level but was also highly influenced by normative motivations (see (Oyanedel et al., 2020b)).

Access dimension

Interviewees consistently identified intermediaries as the most significant economic beneficiaries of the fishery. Results from the interviews indicate that intermediaries use a suite of mechanisms to access and maintain benefits from the fishery. These include access to capital, markets and information on demand and supply. Moreover, they have social ties with enforcers, fishers and vendors and use collusive price-fixing. Vendors do share some of these access mechanisms, such as access to capital, knowledge of demand and social ties with intermediaries. However, vendors' primary access mechanism involved their access to a selling position, whether it was in the fishing terminal or open-air markets, through involvement in a syndicate organisation. Fishers (harvesters) have more limited access, mostly via their access to quota (formal mechanism), involvement in a syndicate organisation and their social identity as fishers. They also have moderate access to capital and social ties with some intermediaries.

5.3.3. Inter-actor level analysis

Supply-chain structure dimension

Responses from interviews were consistent in indicating that the structure of the supply-chain is constrained at the intermediary level. While there are high numbers of fishers and vendors participating in the market, the vast majority of the supply goes through a limited number of intermediaries, which control the routes between the different ports in the VII region, the main fishing terminal in Santiago, and the open-air markets. No major alternative pathways exist in the supply-chain structure, which makes the operation of the market highly dependent on a limited number of intermediaries.

Competition dynamics dimension

Respondents characterised the interaction between intermediaries as an oligopoly. According to key-informants, this maintains prices paid to fishers artificially low and prevents negotiation. Respondents indicated that the limited number of participants in this market component is maintained through high entry barriers (because of intermediaries' social ties with enforcers and fishers). We could not, from the interviews, disentangle the market structure within the vendor component. While barriers to entry do exist (e.g. syndicate membership, having an assigned selling point), responses from interviews were not consistent in indicating whether this market component was characterised as an oligopoly or perfect competition. At the fisher (harvester) component, the market structure was characterised as competitive, as no particular participant had influential market power and the products being supplied were identical. However, entry barriers do exist, as currently no new permits are being issued by the government to participate in the fishery.

5.3.4. Market level analysis

Quantity and price determinants dimension

The econometric analysis indicates that own-price elasticity was positively and significantly related to common hake reported landings (β=0.472 SE=0.23; Figure 5.3.1 and Supplementary Material), suggesting that a 1% increase in common hake price would lead to a 0.47% increase in reported supply. Pacific pomfret price elasticity (*Brama australis*, an important fishery in the VII region, in which common hake fishers participate) was negatively and significantly related to common hake supply (β=-0.752 SE=0.203), meaning that a 1% increase in pomfret price would lead to a 0.75% reduction in common hake supply. Enforcement was positively and significantly related to common hake supply (β=0.025 SE=0.008). Only year 2014 was significantly (negatively) related to supply compared to the baseline of 2019 (β=-0.508 SE=0.205). All seasons were negatively and significantly related to supply compared to the baseline of Aug-Dec (Season 1 (β=-1.026 SE=0.187), Season 2 (β=-0.614 SE=0.176) and Season 3 (β=-0.482 SE=0.17)). These results suggest that legal supply (reported landings) does respond to price signals, including from alternative products, and to enforcement levels. It is also seasonal, though whether this is due to bio-physical processes or changes in supplier behaviour (e.g. under-reporting, fishing effort) is unclear from this analysis.

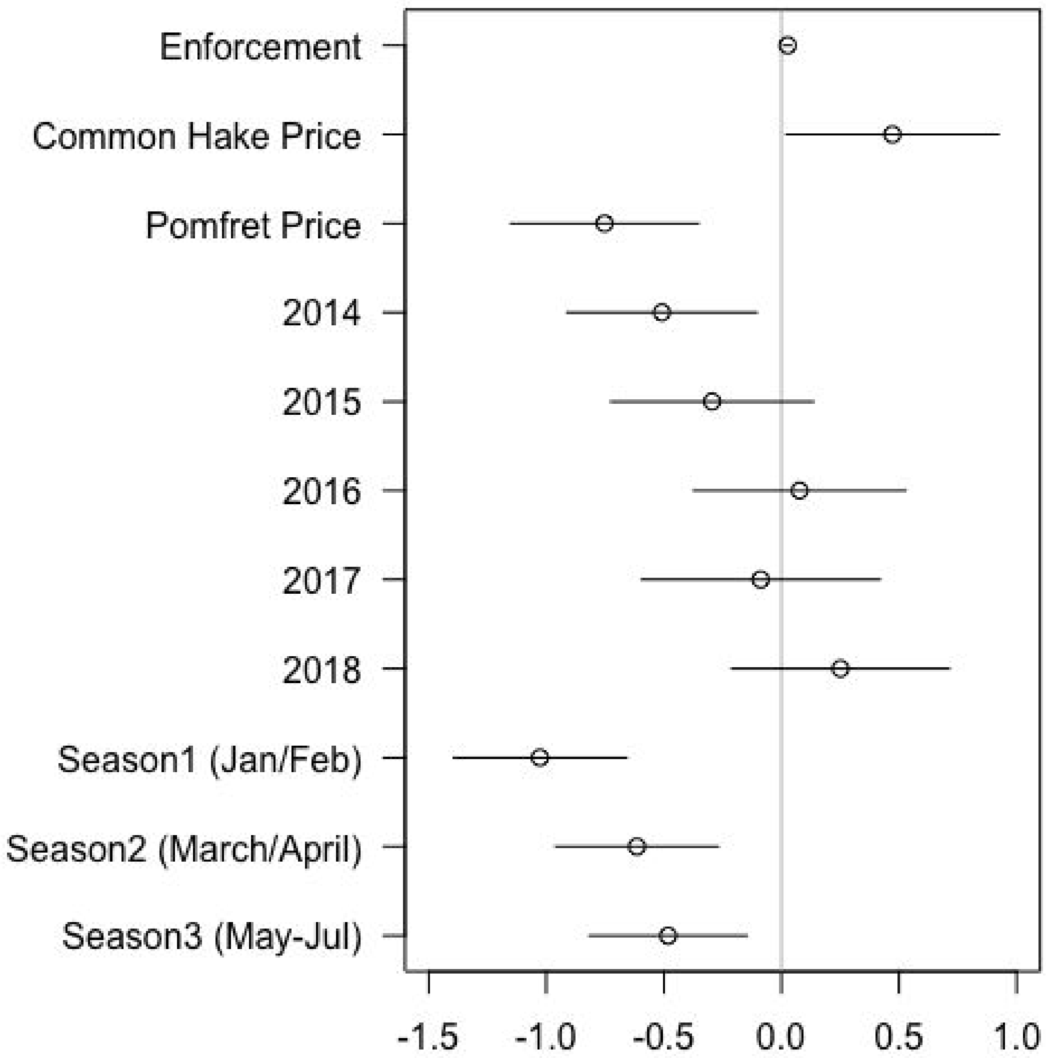


Figure 5.3.1. Output of the linear model. The response variable is common hake reported landings. Predictor variables are enforcement and prices of common hake and pomfret. The reference level for Year is 2019 and for season is Season 4. Circles represent estimate and lines represent 95% CI.

Supply-demand dynamic dimension

Key-informant interviewees indicated that fishers' operations were independent of price signals generated by the market. Respondents consistently pointed out that price, both at selling points and port level, depended on quantities landed. Moreover, respondents indicated that most fishers do not know the prices they will sell their catch for before going out fishing. This suggests that supply-driven processes dominate supply-demand dynamics in the case study. While demand-driven processes do have a role at specific times of the year (e.g. Easter), when suppliers (fishers) respond to price signals generated by the market, this is sporadic. There is uncertainty in this characterisation as supplier behaviour was the only attribute that we could assess for this element of the framework.

Legal/illegal interaction dimension

Responses from the key-informant surveys indicated that legal and illegal products are indistinguishable in the market. What differentiates a legal from an illegal product is the presence of permits, but the product itself is the same and it sells in the same markets. From the sensitive questioning surveys analysis, the linear model estimates of unreported catch were 0.73 (SE=0.046) tons per-trip for low quota boats, and 0.41 (SE=0.063) tons per-trip for high quota boat (Table 9.2.3 Supplementary Material). When extrapolated to the region, total unreported catch estimates were 24,204 tons for the high-effort scenario (based on 3 fishing trips per week, 11 months a year), and 6,658 tons for the low-effort scenario (based on the average number of trips reported to authorities a year). When compared to the quota allowed for the region, these estimates suggest that between 67 and 88% of the total catch for the region goes unreported.

5.3.5. Identifying interventions

Findings from actor, inter-actor and market level analyses are summarized in Table 5.3.2. Evidence at each level allows for an overall conceptualisation of the common hake market system. This market is dominated by an imbalance of access mechanisms between fishers and intermediaries. Fishers have limited control of the prices they receive for their catch and, because of their low quota levels, are highly depend on landing unreported catch for an income. Because unreported catches represent the vast majority of landings, only intermediaries that trade unreported (illegal) products can operate profitably in the market. This creates an oligopoly at the intermediary level which dominates the supply-chain and control prices.

This conceptualization enables the identification of a suite of interventions to improve sustainability of the common hake fishery. At the actor level, potentially-effective interventions depend on the component. For fishers, increasing the quota, creating price information platforms and better targeting of enforcement could reduce unreported catch, promoting more sustainable exploitation of common hake. For intermediaries, increasing enforcement, reducing entry barriers and preventing price-fixing could help to stop intermediaries over-accessing the benefits from the fishery, driving unsustainability. For vendors, increasing enforcement and creating alternative platforms and direct links to fishers could shorten the supply chain and improve communication and market access.

At the inter-actor level, interventions were similar to the actor-level ones, and had to do with incentivizing direct sale links from fishers to vendors and reducing entry barriers to the intermediary market component so as to improve competition. For the market analysis, evidence suggests that possible interventions are: improving access to alternative livelihoods such the pomfret fishery (if sustainable); reducing fishers' reliance on common hake; and providing mechanisms to differentiate legal and illegal products at the market (e.g. traceability through bar-coding (Thompson et al., 2005)).

Table 5.3.2. Summary of findings from the application of the framework to the common hake case study highlighting possibilities for intervention. The level of uncertainty in the assessment is indicated (Low, Med, High).

Level of Analysis	Dimension	Evidence from Common Hake Case Study	Methodology	Possible interventions	Uncertainty
Actor	Motivations	Fisher's motivations relate to their quota level (instrumental) and normative motivations (Oyanedel et al. 2020). Intermediaries motivations relate to instrumental factors such as the probability of detection by enforcers and market signals such as price. Vendors' motivations, similarly, were linked to instrumental factors such as the probability of detection	Key-informant interviews	- Increase quota to low-quota fishers through re-distribution programs - Targeted enforcement strategy	Med – Assessment of fishers' motivation in Oyanedel et al. 2020 allowed the disentangling of their motivational heterogeneity, but for intermediaries and vendors, key-informant interviews did not allow detailed characterisation
	Access	Fishers are price takers, and their only means of benefiting from the fishery has to do with their social identity, syndicate	Key-informant interviews	- Enforce against price fixing	Low – Responses from key-informant interviews were

		participation and their quota. Intermediaries are the greatest beneficiaries from the fishery through several access mechanisms (e.g. price-fixing, access to: market, capital, authority, knowledge). Vendors also have diverse access mechanisms (e.g. access to market, capital, organisation, knowledge) depending on where they operate (open-air markets or fishing terminal).		- Incentivise creation of an alternative fishing terminal platform - Incentivise direct supply links with fishers - Provide market information	consistent in identifying the different access mechanisms being used in each components of the fishery
Inter-actor	Supply chain structure	Key-informants indicated that the vast majority of product goes through a limited number of intermediaries. These are the ones who connect fishers with vendors. There are no significant alternative pathways for the market to operate through.	Key-informant interviews	- Incentivise direct sale links from fishers to vendors	Low –key-informant interviews consistently identified a short and aggregated market structure, restricted at the intermediary level

	Competition dynamics	Responses were consistent in indicating that the number of intermediaries in the region is fixed, with high barriers to new entries, making the intermediary component an oligopoly. We were not able to characterise the market structure for vendors. Fishers were characterised as competitive (but with some barriers to access).	Key-informant interviews	- Reduce entry barriers to the intermediaries' component	Low/Med – Responses from informants were consistent in identifying intermediaries as an oligopoly and fishers' as competitive. However, we could not characterise vendors
Market	Quantity and price determinants	Econometric analysis of factors affecting the legal supply of common hake indicates that own-price elasticity and pomfret (alternative product) price, as well as seasonality and enforcement, explain variability in reported supply.	- Econometric analysis	- Increase enforcement - Improve access to pomfret, if sustainable	High – Econometric analysis only considered legal supply, so there is high uncertainty about how the independent variables affect not only legal but also unreported supply

	Supply-demand dynamic	Respondents indicated that, generally, fishers (suppliers) operation is independent of price signals in the market, which characterises the overarching structure as supply-driven	- Key-informant interviews	- Reduce fisher's reliance on common hake - Provide alternative livelihood options	Med – Only some properties that allow characterisation of this market as supply-driven were easily identifiable from the key-informant interviews
	Legal/illegal interaction	Key-informants indicated that legal and illegal products are indistinguishable in the market and are sold in the same places. Total unreported catch estimates were 24,204 tons for the high-effort scenario and 6,658 tons for the low-effort scenario. Compared to the 2018 region's quota, these unreported catch estimates represent between 67 and 88% of the total catch for the region.	- Key-informant interviews - Sensitive questioning surveys	- Provide mechanisms to differentiate legal and illegal products (e.g. traceability through bar-coding)	Low/Med – The extrapolation method used produced large estimation ranges

Integrating the evidence compiled in Table 5.3.2 in order to identify interventions requires consideration of the uncertainty in the data and the interactions within and between analytical levels. Figure 5.3.2 lays out an intervention map considering these issues. For instance, while we found that own-price elasticity was significantly correlated with common hake supply in the price and quantity determinant dimension, this result clashes with findings from other dimensions of the market analysis. Respondents from key-informant interviews consistently indicated that fishers' activity did not depend on prices. While these results seem to contradict each other, evidence from the legal/illegal interaction dimension helps to clarify the situation. Because the vast majority of products traded are illegal, there is high uncertainty in the econometric analysis, which only considered legal supply. As such, econometric estimates only indicate how *legal* supply responds to price, while key-informant responses indicated how overall activity (legal/illegal) responds to price. This suggests that fishers respond to higher prices by reporting more, not by fishing more.

Based on the evidence collected at each analytical level, and their interactions, we lay out interventions that can be grouped into 3 main categories:

- Those that improve fishers' access mechanisms and reduce reliance on common hake, so that fishers can decrease their levels of unreported catch and better benefit from their legal catch. Interventions targeting fishers can have ripple effects via the competition dynamics and illegal/legal interaction dimensions, because increasing access mechanisms for fishers may change how intermediaries and vendors benefit from the fishery.
- Those that target the intermediary component, so as to break down the oligopoly and improve competition. This could improve sustainability through improving fishers’ negotiation power, resulting in better prices for their catch, and allowing for sustainability-led actors to come into the fishery as intermediaries to incentivize sustainable fishing practices. Moreover, this could disrupt

the current supply-chain structure, re-setting the way the different actors in each component access the benefits from the market and their motivations to participate.

- Those that aim to differentiate legal and illegal products, and improve enforcement across the supply chain so that illegal products don't dominate the market. This could improve sustainability by reducing the economic incentives for trading unreported catch, leading to decreases in fishers' underreporting and therefore a better basis for effective fishery management. This will affect intermediaries' motivations, which could result in them leaving the system if profits from operating legally are reduced too much. Moreover, it could affect vendors, reducing their supply and therefore their motivation to participate in the market

While some of the interventions that we propose have been proposed in the past (Plotnek et al., 2016; SUBPESCA, 2016), our approach allowed us to identify those interventions that respond to actual market dynamics of the fishery. For instance, the fishery's Management Committee proposed interventions that tackle both the demand and the supply side of the market (SUBPESCA, 2016). With our approach, we characterized the market as having an overarching supply-driven dynamic, which suggests that supply-side rather than demand-side interventions have a higher probability of success. Moreover, while the Management Committee does identify the low prices paid to fishers as an issue, by assessing the diversity of factors affecting the market dynamics we disentangle the mechanisms by which this occurs and what interventions can help to overcome it. As such, by applying this framework, we were able to use evidence to guide the analysis of which interventions, and why, might better target the unsustainability problem in this fishery.

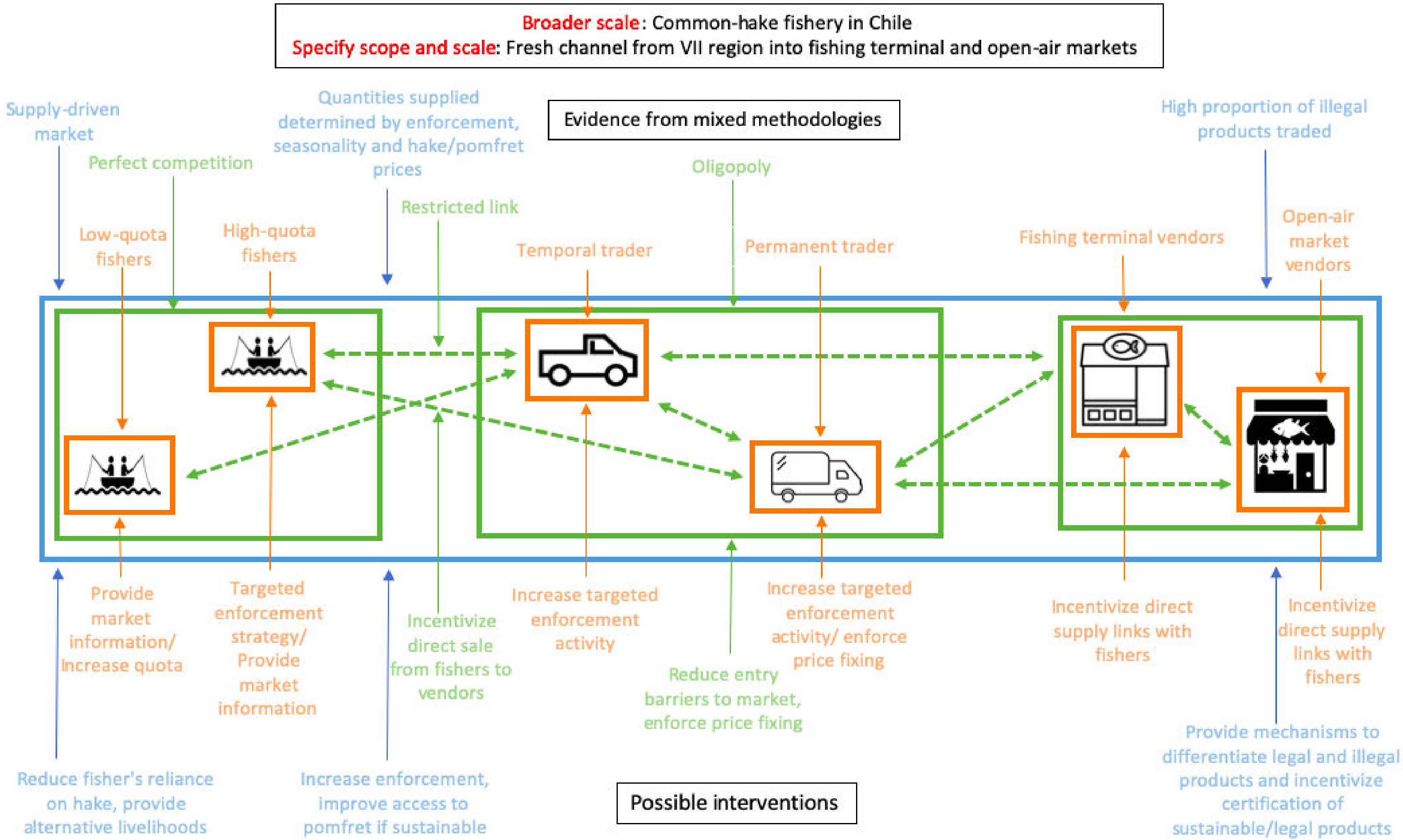


Figure 5.3.2. Evidence gathered from application of the framework and intervention map for reducing common hake unsustainable use

5.4. Conclusion

Unsustainable use of wildlife is old news. However, disentangling the role that markets play in driving unsustainable use, and how to intervene in them, still receives limited attention from those designing policies aimed at reducing this unsustainability. Our framework provides practical guidance on how to characterise a wildlife market system, identify research gaps and develop a suite of potential interventions to choose from, in cases where markets drive unsustainable wildlife use. The application of this framework to our case study allowed us to characterize the common hake fishery market using a suite of methodological and theoretical approaches. Despite limited data availability, we were able to combine mixed methods to dissect the different market characteristics that influence the main problem of the fishery; unreported catch. By doing so, we were able to identify interventions that would address the actual market dynamics of the fishery, and disentangle the mechanisms by which some of the key unsustainable issues of the fishery are maintained.

It is time to start tackling the question of how markets drive unsustainable wildlife use in a systematic way. Our framework allows for a more concerted approach to answering this question, by bringing together different theoretical perspectives and lines of evidence. Indeed, this can help managers to better identify those interventions that respond to actual market dynamics, rather than choosing interventions based on spurious assumptions (SUBPESCA, 2016). Moreover, this framework can help to prompt new ways of thinking about how to intervene in markets driving unsustainable wildlife use, by expanding the toolkit of available options and integrating diverse theoretical perspectives. Systematically tackling the role of markets in driving unsustainability requires approaches that can be used to compare and contrast between cases, learn from experiences and connect researchers working in diverse social-ecological systems under a common umbrella. We hope that this framework fuels a renewed interest in the perennial environmental issue of how markets drive unsustainable wildlife use.

Chapter 6: A dynamic simulation model to support reduction in illegal trade within legal wildlife markets

Abstract

Sustainable wildlife trade is critical for biodiversity conservation, livelihoods, and food security. Regulatory frameworks are needed to secure these diverse benefits of sustainable wildlife trade. However, regulations limiting trade can backfire, sparking illegal trade if demand is not met by legal trade alone. Assessing how regulations affect wildlife markets participants' incentives is key to controlling illegal trade. While much research has assessed how incentives at both the harvester and consumer ends of markets are affected by regulations, little has been done to understand the incentives of traders (i.e., middlemen or intermediaries). We built a dynamic simulation model to support reduction in illegal wildlife trade within legal markets by focusing on incentives traders face to trade legal or illegal products. We used an Approximate Bayesian Computation approach to infer illegal trading dynamics and parameters that might be unknown (e.g., price of illegal products). We applied the approach to a small-scale fishery in Chile, where we sought to disentangle within-year dynamics of legal and illegal trading and show that the majority (~77%) of traded fish is illegal. We utilized the model to assess the effect of policy interventions to improve the fishery's sustainability and explore the trade-offs between ecological, economic, and social goals. Scenario simulations showed that even significant increases (over 200%) in parameters proxying for policy interventions enabled only moderate improvements in ecological and social sustainability of the fishery at substantial economic cost. These results expose how unbalanced trader incentives are toward trading illegal over legal products in this fishery. Our

model provides a novel tool for promoting sustainable wildlife trade in data-limited settings, which explicitly considers traders as critical players in wildlife markets. Sustainable wildlife trade requires incentivizing legal over illegal wildlife trade and consideration of the social, ecological, and economic impacts of interventions.

6.1. Introduction

Sustainable management of wildlife use is critical for biodiversity conservation, livelihoods, and food security (Challender & MacMillan, 2014; Costello et al., 2020; Fukushima et al., 2020; Milner-Gulland et al., 2003). Accordingly, governments and multilateral organizations aim to promote legal and sustainable use of wildlife so that the broad range of benefits from the activity can be derived (t Sas-Rolfes et al., 2019). This requires regulations and policies at the local, national, and international levels to reduce unsustainable and illegal use (Andersson et al., 2021; Challender & MacMillan, 2014). However, regulatory interventions can have unintended consequences because restrictions on wildlife use can create illegal trade to meet demand that is not satisfied by legal trade alone. This is an important feature of many wildlife markets, especially when legal supply is limited or distinguishing legal and illegal products is challenging (e.g., Moyle 2017; Bennett et al., 2021).

Understanding the effect of restrictions on wildlife trade is necessary in order to move towards regulations that effectively reduce the level of illegal trade and promote sustainability. There have been important advances in understanding how restrictions affect wildlife harvesters' incentives at one end of the commodity chain and end-markets and consumers' incentives at the other (Bulte & Van Kooten, 1999; Burton, 1999; Milner-Gulland, 1993). For instance, small-scale fishers who are overly restricted by quota regulations might turn to illegal fishing to complement their income (Oyanedel et al., 2020b). At the other end, sellers in end-markets may use diverse laundering techniques to sell illegal products as legal products where trade is poorly regulated (Moyle, 2017). However, research on how restrictions affect traders' incentives (sometimes also referred as middlemen or intermediaries) is limited (Jones et al., 2019; Phelps et al., 2016; Purcell et al., 2017). Traders connect end-markets and consumers with wildlife harvesters, ultimately influencing how wildlife is used (Crona et al., 2010; González-Mon et al., 2019). Therefore, understanding how restrictions affect traders' incentives and the dynamics of legal and illegal wildlife markets is critical to promoting sustainable use.

Assessing how restrictions affect traders' incentives requires understanding the overarching dynamics of the market in which they operate. Wildlife markets can be broadly categorized into two types. In supply-driven markets, suppliers participate in the market independently of price signals; therefore, in these markets supply is constrained. As such, overall quantities entering the commodity chain are determined by natural variability and harvester effort, so traders can only access a fixed supply. In demand-driven markets, suppliers' participation responds to price signals, so demand is filled at the available price (McNamara et al., 2016). Most classic models of illegal wildlife trade are based on the assumption that markets are demand driven (Bowen-Jones & Pendry, 1999; Brashares et al., 2004; Hall et al., 2008; Holden & Lockyer, 2021; McNamara et al., 2016; Milner-Gulland & Clayton, 2002; Milner-Gulland & Leader-Williams, 1992). However, if restrictions on the quantity that can be legally traded exist (e.g. as a result of a quota), decisions by the trader are made under a fixed supply (e.g., supply-driven market). As such, traders can play a crucial role in determining the proportion of legal and illegal product traded (Oyanedel et al., 2021). This proportion depends on traders' economic incentives, such as the difference in prices between legal and illegal products and the probability of illegal trade being detected by enforcement authorities. Ultimately, linking demand-driven and the less explored supply-driven market theories will provide a clearer picture of how markets in which illegality is present operate and the role of traders in them.

Understanding trading dynamics is complicated when illegal trade is present because, usually, only legal data are available (Gavin et al., 2009; Oyanedel et al., 2018). Assessing illegal behaviors is challenging because those involved are generally reluctant to participate in research elucidating the extent and characteristics of their activities (Hinsley et al., 2019). Understanding trading dynamics is further complicated in data-limited settings, where even legal data might be challenging to obtain. In these settings, simulation models can be powerful tools for assessing the economic incentives to trade legal or illegal products (or a mix of both), helping to elucidate overall legal and illegal trading dynamics. As such, simulation models can provide quantitative insights to assist managers in deciding on approaches to reduce the level of illegal trade in legal markets.

We devised a generic dynamic simulation model to assess the economic incentives that affect traders' decisions to trade in wildlife legally or illegally, thereby shedding light on the potential effectiveness of approaches to reducing illegal trade in legal markets. The model can be adapted to a broad range of wildlife use contexts where supply-driven dynamics dominate. It can be used to estimate the amounts of legal and illegal wildlife traded, explore the sensitivity of trade dynamics to market characteristics, and predict the effects of policy interventions, including the synergies and trade-offs between ecological, economic and social sustainability goals. To show the model's utility, we applied it to a small-scale fishery. With our model, we sought to provide management-relevant insights into the legal and illegal trading dynamics of this fishery. Reducing the unsustainable use of wildlife requires a better understanding of trade dynamics and novel tools to support management decisions. By assessing illegal wildlife use dynamics through a focus on traders' incentives, we aimed to provide a novel approach to understanding the hidden illegal dynamics of wildlife use, thereby advancing the theory and practice of conservation research.

6.2. Methods

6.2.1. Stationary general form of the model

The model's general, stationary form solved a profit maximization problem by calculating the optimal quantity of legal and illegal units to trade in one period (Fig 6.2.1). Units are generic and adaptable to any wildlife product. We considered supply at the harvest level, and trading occurred in one step in which the trader (focal agent in our model) links harvesters and end-markets. We defined costs (for the trader) at the harvest level and prices (for the trader) at end-market. Enforcement was targeted at the trader rather than the harvester or the end market.

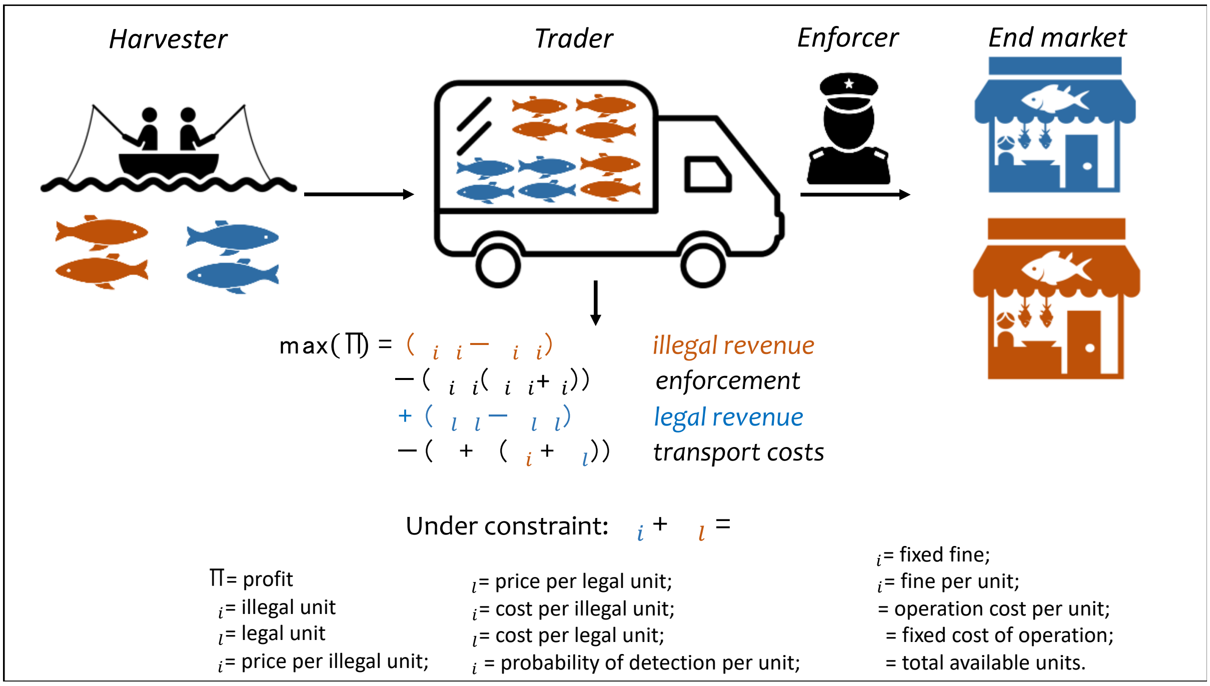


Figure 6.2.1. Schematic representation of the general, stationary form of the model built to support reduction in illegal wildlife trade within legal markets (brown, elements associated with illegal trade; blue, elements of legal trade).

In the model, traders faced a profit maximization problem in which they chose the quantities of legal and illegal units to trade. This is a generic profit function that considers the costs and benefits associated with legal and illegal units(Milner-Gulland & Leader-Williams, 1992):

$$\Pi = f(x_i, x_l) \quad , \tag{1}$$

where x_i is the number of illegal units and x_l is the number of legal units. Legal and illegal revenue was calculated simply by the number of legal or illegal units and their cost and price:

$$\Pi_{i=}(P_i x_i - C_i x_i) \qquad \text{and} \tag{2}$$

$$\Pi_{l=}(P_l x_l - C_l x_l) \quad , \tag{3}$$

where P_i and P_l are the price paid to the trader at the market per illegal (*i*) and legal (*l*) unit respectively and C_i and C_l are cost for the trader to purchase, from the harvester, an illegal and legal unit, respectively. When there was trading of illegal units, there was a cost to the trader associated with the probability of being enforced and the fine level, which was a linear function of the number of illegal units and the probability of detection per illegal unit. Moreover, we assumed all illegal units were discovered once the trader was caught. The enforcement cost function was composed of a variable component, for which we calculated the fine by multiplying the number of illegal units by a per-unit fine constant and adding a fixed fine component. Thus, the costs associated with enforcement were:

$$c_e = [\theta_i x_i (c_i x_i + f_i)] \quad , \tag{4}$$

where θ_i is the probability of detection per unit; c_i is the fine per illegal unit constant, and f_i is the fixed fine if detected. Finally, the trader's profit function included a cost associated with the operation, calculated with a fixed and a variable component (we assumed the operational costs of illegal and legal units were the same.):

$$c_o = [\sigma + \tau(x_i + x_l)] \quad , \tag{5}$$

where τ is the operation cost per unit and σ is the fixed cost of operation. Then, the profit maximization function was as follows:

$$\begin{aligned} \max_{x_i}(\Pi) &= (P_i x_i - C_i x_i) - [\theta_i x_i (c_i x_i + f_i)] + (P_l x_l - C_l x_l) - [\sigma + \tau(x_i + x_l)] \\ &= (P_i x_i - C_i x_i) - c_e + (P_l x_l - C_l x_l) - c_o \end{aligned} \tag{6}$$

under the constraints that $x_i > 0$, $x_l > 0$, and $(x_i + x_l) = T_a$, where T_a is the total available units from the harvester (or supplier further down the supply chain). The Karush–Kuhn–Tucker (KKT) conditions were necessary and sufficient for this constrained optimization problem, and the solution was unique due to the strong concavity of the objective function. It is given by $x_i = \max_{x_i}$ {0, min$[T_a$, arg$\max_{x_i}(\Pi)]$}.

This profit-maximization function can be solved analytically, given the condition (Eq. 7):

$$x_l = T_a - x_i \tag{7}$$

$$0 = P_i - C_i - 2\theta_i c_i x_i - f_i\theta_i - P_l + C_l\ , \tag{8}$$

which rearranges to

$$x_i = \frac{(P_i - C_i - f_i\theta_i - P_l + C_l)}{2\theta_i c_i} \tag{9}$$

6.2.2. Dynamic general form of the model

For the time-dynamic model, cost and price parameters changed each time step (*t*), depending on the amount of product supplied (product availability). Other parameters can also change over time (e.g., enforcement activity) to represent management, cultural, or market variability within a year. Product availability at each time step was taken from random draws from a prior distribution, so supply was exogenously determined. We assumed that the quantity of traded wildlife is determined by harvest effort and natural fluctuations, a feature of supply-driven markets, where harvesters participate in the market independently of price signals (McNamara et al., 2016; Oyanedel et al., 2021). As such, traders were recipients of supply and could not determine the total quantities being traded (only the proportion of legal and illegal units):

$$n_t = \mathrm{rand}(\delta)/T\ , \tag{10}$$

where n_t is units of wildlife products at time t, δ is prior distribution of total units traded, and T is time horizon.

Next we calculated C_i ,C_l , P_i, and P_l. Price and costs for illegal and legal units had separate elasticity terms that represented the change in prices and costs depending on product availability at time *t* compared to a reference quantity, cost and price. We introduced this elasticity term to account for how market dynamics at the consumer end, and harvester and trader bargaining power dynamics, determine prices and costs depending on availability. Moreover, different elasticity values for legal and illegal products reflected cases in which different processes determined the price and cost of legal and illegal units. This elasticity of price and costs is a feature observed, for instance, in fisheries (Loannides & Whitmarsh, 1987; Oyanedel et al., 2021) and bushmeat hunting contexts (McNamara et al., 2016, 2019). We also differentiated the price and cost of legal and illegal units by including a fixed permit fee paid by traders to harvesters (V_l) and a per unit price premium received by traders on the end market for legal products (β_l):

$$C_{i,t} = C_R\left(1 + \frac{\epsilon_{c,i}(n_R - n_t)}{n_R}\right) \quad \text{and} \tag{11}$$

$$C_{l,t} = C_R\left(1 + \frac{\epsilon_{c,l}(n_R - n_t)}{n_R}\right) + V_l \quad , \tag{12}$$

where C_R is the cost reference, n_R is the reference quantity, $\epsilon_{c,i}$ is the cost elasticity for illegal units, and $\epsilon_{c,l}$ is the cost elasticity for legal units. Similarly, $P_{i,t}$ and $P_{l,t}$ are calculated as

$$P_{i,t} = P_R\left(1 + \frac{\epsilon_{p,i}(n_R - n_t)}{n_R}\right) \quad \text{and} \tag{13}$$

$$P_{l,t} = P_R\left(1 + \frac{\epsilon_{p,l}(n_R - n_t)}{n_R}\right) + \beta_l \quad , \tag{14}$$

where P_R is the price reference, $\epsilon_{p,i}$ is the price elasticity for illegal units, and $\epsilon_{p,l}$ is the price elasticity for legal units.

Then, in each time step, these cost and price values were used to calculate $x_{i,t}$ and $x_{l,t}$, following the analytical solution in Eq. 9. Finally, total quantities of illegal and legal product traded over the whole period (x_i and x_l) were calculated:

$$x_i = \sum_{t=1}^{T} x_{i,t} \quad \text{and} \tag{15}$$

$$x_l = \sum_{t=1}^{T} x_{l,t} \tag{16}$$

6.2.3. Approximate Bayesian Computation for parameter estimation and model results

We used an approximate Bayesian computation (ABC) rejection algorithm for estimating unknown parameter distributions and calculating legal and illegal units traded (Beaumont, 2010; Fig 6.2.2). This approach helps when only some of the data that generates a process are available. The ABC approach models how the available data are generated from some partially unobserved (latent) variables. It then helps find the latent variable values, or their distributions in a probabilistic setting, that would approximately generate the observed data.

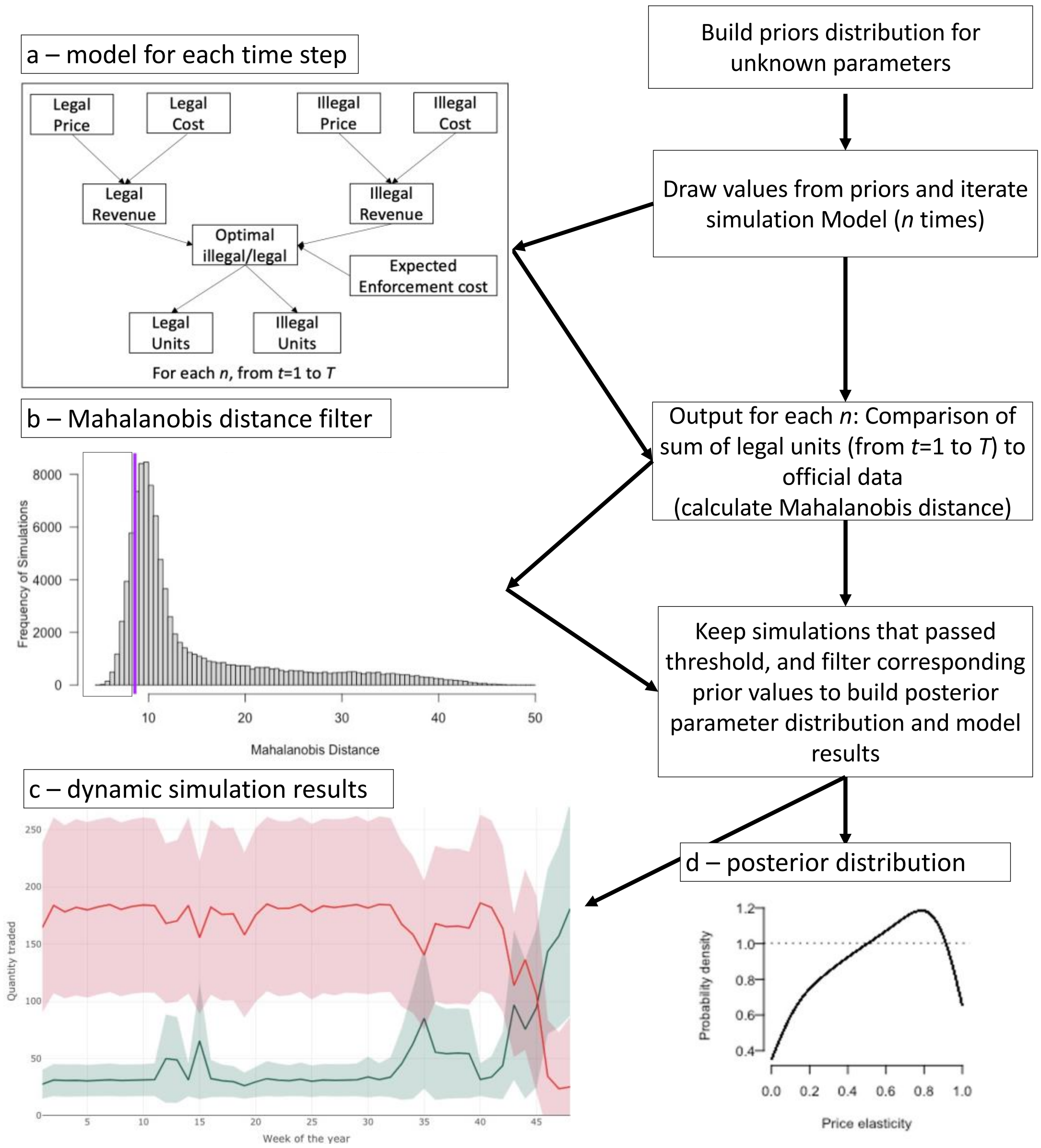


Figure 6.2.2. Schematic representation of the simulation model showing the approximate Bayesian computation (ABC) approach and the model steps: (a) known and unknown input and output variables (which ones are unknown depends on context), (b) Mahalanobis distance histogram with the distribution of simulations generated in an ABC run (purple vertical line, threshold computed from the mean and covariance computed from empirical data distribution; shaded area accepted simulations), (c) mean (SD) of simulations of legal (green) and illegal (red) units traded over time and (d) example of a posterior parameter distribution (price elasticity) constructed for each of the previously unknown parameters.

For the ABC approach, we constructed priors for unknown parameters (which might vary depending on the context, but are usually those associated with illegal trade). Ranges for priors can be obtained from previous knowledge, surveys, or key-informant interviews. Then, we ran several thousand simulations (~10,000-100,000) in which random values were drawn from the priors and combined with known parameters in the dynamic model presented above to calculate legal and illegal units traded. We compared model results for legal units (x_l) with available data and rejected simulation runs that did not match predefined criteria. Samples from the unknown parameter priors associated with simulations which were not rejected then composed the posterior distribution. The criterion we used for selection or rejection of simulations was that the Mahalanobis distance between the calculation of total number of legal units traded (x_l) and the official legal data was not higher than a pre-specified threshold. The Mahalanobis distance is a measure of the distance between a vector and a distribution summarized by its mean and covariance. We computed the pre-specified threshold so that the simulation was accepted if it could have been generated with probability 0.95 by a Gaussian distribution with mean and covariance computed from that empirical data distribution. The 0.95 threshold can be updated depending on the context. The R code for the model is provided in Appendix S6.

6.2.4. Common-hake fishery case study

The common hake (*Merluccious gayi gayi*) small-scale fishery in Chile employs more than 3,000 fishers directly, making it one of Chile's most important fisheries (SUBPESCA, 2016). The fishery comprises vessels usually less than 12 m in length (Arancibia & Neira, 2008). It is subject to extensive trade in illegal fish that infiltrates the legal market (Oyanedel et al., 2021). This sustainability challenge is especially severe in the country's VII region, where most of the fish traded does not comply with official regulations. The market for this fishery is primarily domestic. The trade goes from different ports along the coast of Chile to a central fishing terminal in Santiago (Chile's capital) (Oyanedel et al., 2020b). This is a single-species fishery, so fishers only target common hake when fishing this species. However, traders may occasionally engage in trading other fish species when trading hake, following the same route.

We used mixed methods to obtain the input data for the model. First, we used open-ended key-informant interviews to understand the fishery's operation and market. We focused on the most critical factors affecting trade dynamics and the decision to trade legal or illegal units (interview methodology in Supplementary Material). The interview methodology complied with Oxford University's ethical requirements (approval number R68516/RE001). We gathered primary data from government sources, including legal units sold from fishers to traders per day from 2015 to 2019 in the VII region; stage-specific and overall quota available for 2014-2019 (the government gives the quota to the fishery in 3 stages within the year) in the VII region; the number of enforcement activities per week for 2015-2019 in the VII region; and size of fines for the same period. Because we had valuable data on enforcement activities in the region, we adapted the probability of detection θ_i to be a function of enforcement effort (number of activities, θ_a) and efficiency of enforcement (θ_e, unknown parameter, prior) so that $\theta_i = \theta_e\theta_a$. Using these enforcement data (number of enforcement activities in the region) improved the model's predictive capacity substantially. An evaluation of model simulations with and without incorporating these data is in Supplementary Material 9.3.2, and Supplementary Material 9.3.2 contains the data sets used.

To understand the effect on sustainability of intervening in the fishery, we selected 4 of the possible policy levers presented in Oyanedel et al. (2021) and performed a sensitivity analysis. These policy levers were: increase the legal quota, certify legal products in the end market, improve or increase enforcement, and incentivize consumption of alternative products. The increase in legal quota was included in the model as an increase in the overall quota (Q) parameter. The rationale was that higher quotas are associated with more legal fishing (Oyanedel et al., 2020b). We included certify legal product in the end market in the model as an increase in the price premium parameter (β_l, Eq. 14) because by certifying legal units there could be product differentiation and increased demand for legal products and a higher price premium. Improve or increase enforcement was included as an increase in enforcement efficiency (θ_e, Eq. 9), which shifts trader's incentives towards trading more legal products. Incentivize consumption of alternative products was included as an increase in the price elasticity parameter (ϵ_p, Eqs. 13 and 14). The rationale was that if consumers have alternative products, prices will respond faster to increases in supply.

For the sensitivity analysis, each selected parameter was assessed at a time by increasing it up to 300% while using random draws from the posterior distribution of the parameters not being assessed. Then, we selected those parameters that led to a reduction in the total number of units traded (i.e. that improved ecological sustainability). Next, we iterated the simulation model with randomly generated increases in all the selected parameters simultaneously in order to construct intervention scenarios. Finally, we explored options for improving the ecological sustainability of the trade, while limiting economic costs. We evaluated the parameter range that would produce 3 levels of improvement in ecological sustainability (measured as a decrease in overall units traded) while limiting the associated economic cost (measured as catch value lost) below a threshold. The thresholds were a minimum 10%, 30%, and 50% improvement in ecological sustainability, accompanied respectively by a maximum 20%, 40%, and 60% increase in economic cost. These thresholds were chosen arbitrarily, with the aim to show different sections of the simulated results space.

6.3. Results

6.3.1. Operation of the fishery and market and model adaptation

Key-informant interviews confirmed the presence of an active and extensive market for illegal hake, consistently indicating that the vast majority of trade was illegal. Moreover, interviews allowed us to understand the operation of the market (Supplementary Material). Legal and illegal units of product were traded in the same trucks and sold in the same end-market; the unit was a 27-30 kg box of hake. Fishers were the quota holders. By reporting their catch on a given day, they provided the trader with a legal permit for the quantity reported, which was discounted against their quota. There was product and price differentiation: traders paid a permit fee for legal units to fishers and received a price premium on the end-market for those units. This permit fee was set at a fixed value (CLP 3,000 [~US$4.3]) for most of the year, except towards the end of the year when this value decreased because fishers who still had quota rushed to sell it, lowering the permit value. We could not identify, from the interviews, a value for the price premium. Key informants indicated that traders operated with a minimum legal fraction of units per truck load to justify their operation for tax and registration purposes. However, this fraction varies depending on perceived enforcement activity levels and on the end-market price. For instance, enforcement effort and end-market price stepped up at Easter when demand for hake and the perceived likelihood of higher levels of illegal trade increase.

We adapted the model's general form to accommodate the peculiarities of this fishery's market. To do so, we added a parameter representing a minimum fraction of legal products traded per week, a constraint that no trading occurs when there is no quota left, and a permit fee elasticity parameter to account for the devaluation of the permit fee at the end of the year. The time step unit was defined as a week because a week was the finest scale time granularity of the available datasets (enforcement). We ran the model with 48 weeks because we removed September from the analysis given that there was a fishing ban during that month, so no trading occurred. For a summary of the unknown parameters for which we built priors, see Supplementary Material.

6.3.1. Parameter posteriors and trading dynamics results

The filtering process using Mahalanobis distance accepted around 15% of simulations (Supplementary Material), which enabled us to obtain posterior distributions for unknown parameters (Fig 6.3.1). Our estimate of the total traded units over the year and its probability distribution enabled us to estimate the ratio of legal and illegal units in trade. This confirmed the information from the key informant interviews that illegal units dominated the trade because the mean ratio was around 0.77. Our estimate of the overall mean number of legal units traded was close to the mean number of legal units recorded in official data (Fig 6.3.1).

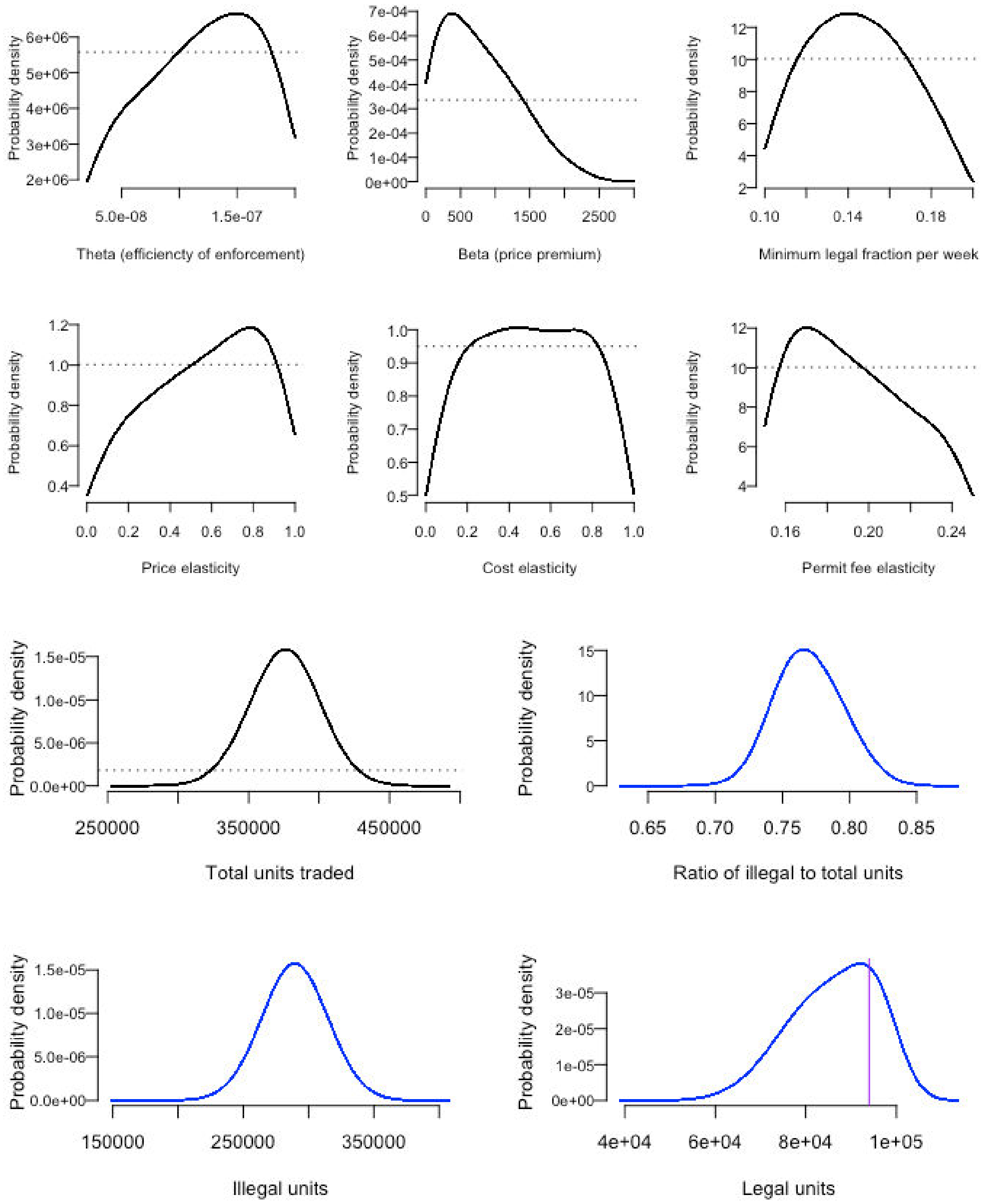


Figure 6.3.1. Prior (dotted lines, uniform distribution) and posterior distribution (black lines) for unknown parameters and model-aggregated results (blue) for the case study application of the model (purple line in the legal units plot is overall legal landings mean from the data).

The trade was dominated by illegal units year-round, except towards the end of the year (Fig 6.3.2). Our simulations gave temporally dynamic results that captured the fishery's dynamics relatively closely (Fig 6.3.2). The similarity of our simulation results on legal landings to the official data showed the model's ability to predict the data.

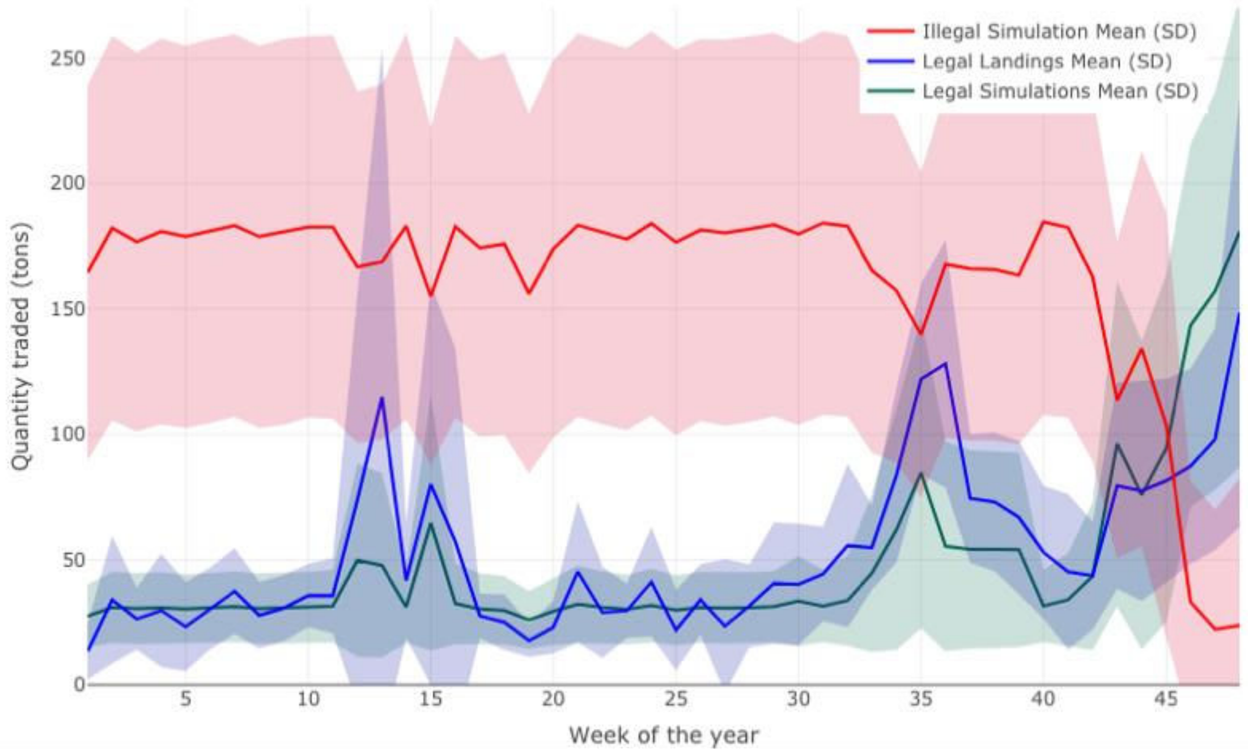
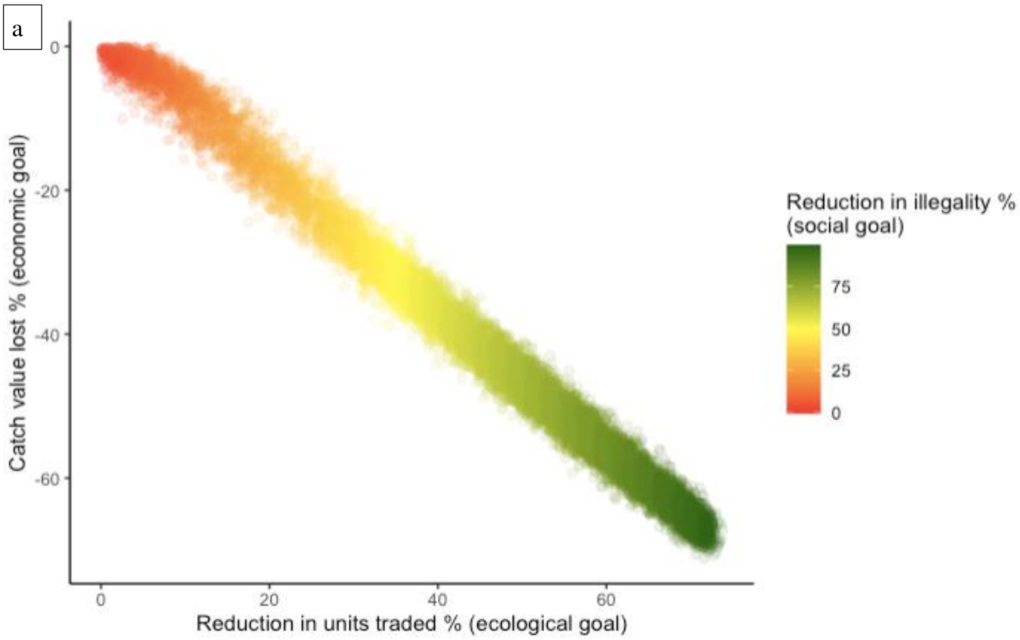


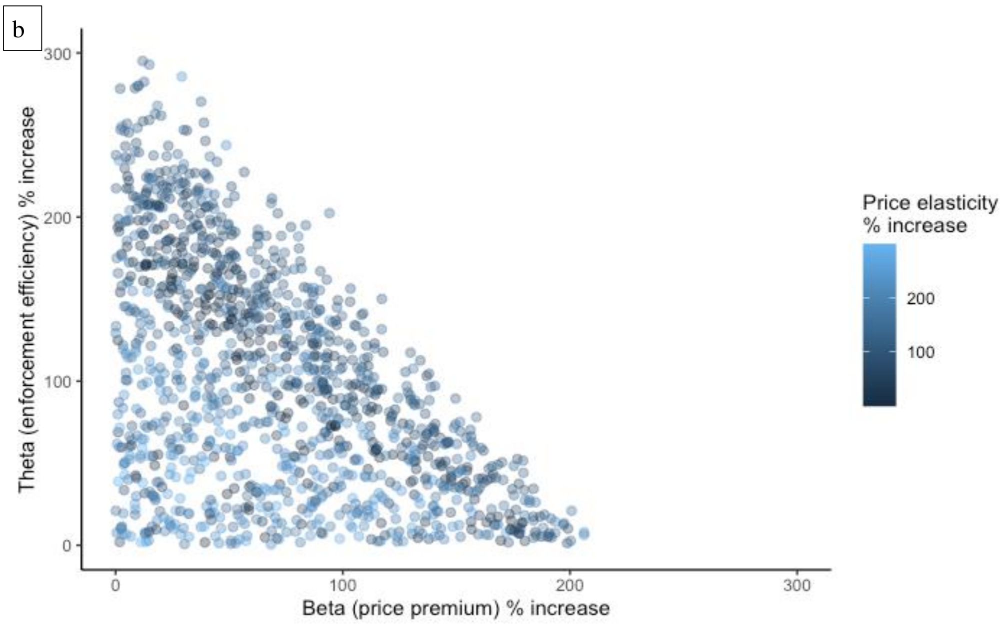
Figure 6.3.2. Mean (SD) from simulations of legal (green) and illegal (red) units traded compared with legal landings data from official records (blue, mean [SD] from 2014 to 2019).

6.3.2. Intervening for improving sustainability

Our sensitivity analysis showed that reductions in the total number of units traded were obtained when we increased beta (the price premium) by 100-300% (Supplementary Material 9.3.3). Reductions in units traded were obtained for all levels of increase in theta (efficiency of enforcement). Reductions in units traded were obtained with an increase in price elasticity of at least 150%. We observed no change in units traded when quota was increased alone. Therefore the sensitivity analysis suggested that only theta, beta, and price elasticity were effective at reducing the number of units traded (therefore holding promise as levers for improving ecological sustainability).

Our scenario assessment showed a negative linear relationship between the fishery's economic and ecological goals (Fig 6.3.3a). The highest reductions in illegality (social goal) were obtained at higher values of the ecological goal (i.e. more catch reduction) but lower values of the economic goal (i.e. less value derived from catch). To meet our minimum level of ecological sustainability improvement (10%) and economic cost (20%), the increases required in beta and theta were <200%, whereas price elasticity varied across its whole range (Fig 6.3.3b). To reach a 30% improvement in ecological sustainability for up to a 40% increase in economic cost, there was an expansion of the parameter space, concentrating on increases in beta and theta values >200% and 0-300% increases in price elasticity (Fig 6.3.3c). In the most extreme scenario (>50% reduction in overall catch, up to 60% increase in cost), the parameter space moved further towards higher levels of increase in beta and theta values, concentrating above 250% (Fig 6.3.3d).


a
Catch value lost % (economic goal)
Reduction in units traded % (ecological goal)
Reduction in illegality %
(social goal)
75
50
25
0
0
-20
-40
-60
0
20
40
60


b
Theta (enforcement efficiency) % increase
Beta (price premium) % increase
Price elasticity
% increase
200
100
300
200
100
0
0
100
200
300

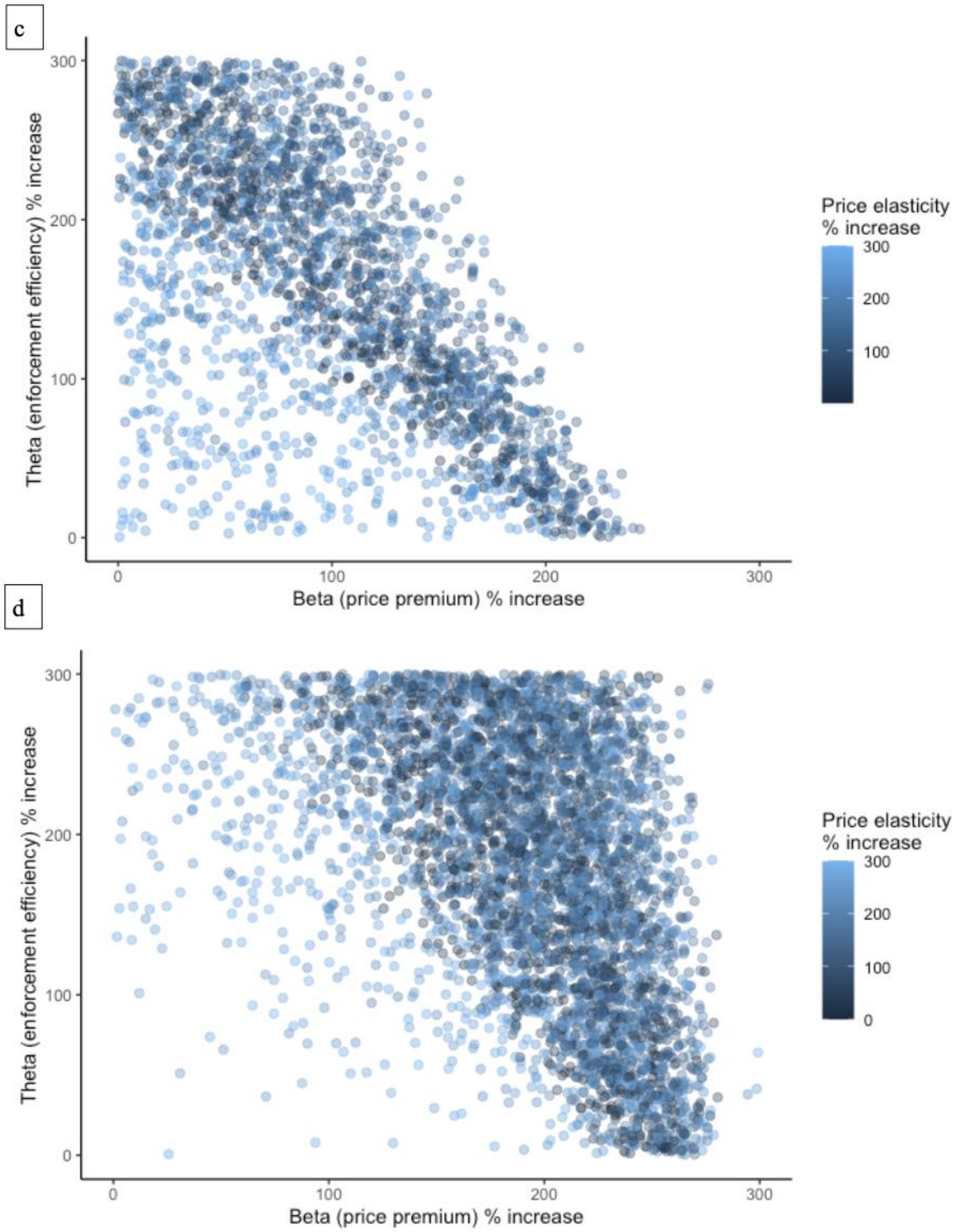


Figure 6.3.3. Intervening for sustainability. For 15,000 simulation runs of the case study model (a) scenario results in terms of social, ecological, and economic sustainability goals and (b), (c), and (d) values of parameters (policy levers) needed to accomplish ecological sustainability (measured as a decrease in overall units traded) of at least 10%, 30%, and 50%, respectively, and an economic sustainability (measured as catch value lost) of no more than -20%, -40% and -60%, respectively (the brighter the circle the more extreme levels of change in price elasticity; top right quadrant, extreme levels of change in beta [price premium] and theta [enforcement efficiency]).

6.4. Discussion

Assessing how to reduce illegality in legal markets is necessary to promote sustainable use and derive the diversity of benefits from wildlife trade (t Sas-Rolfes et al., 2019). Our model presents a novel tool for understanding trade dynamics in cases where legal and illegal products are traded in the same market, but only partial information on the dynamics of that trade is available; this is a relatively common situation for wildlife markets. Understanding these dynamics is especially important in small-scale resource use settings, where even data on legal trade might be limited. By combining data from different sources and using an Approximate Bayesian Computation (ABC) approach, our model allowed us to uncover hidden illegal trade dynamics. Moreover, it helped disclose previously unknown information about the market through the estimation of posterior distributions. As such, our approach can help elucidate the operation of hard-to-assess markets and how legal and illegal trade dynamics interact within them.

Our approach is innovative because it focuses on the trader's economic incentives to trade legal or illegal products, which allowed us to explore an untapped facet of wildlife markets (González-Mon et al., 2019; Jones et al., 2019). By modeling the determinants of trader decision-making, we were able to reconstruct legal and illegal wildlife harvest rates over time (Figure 6.3.2), suggesting that these traders might play an essential role in defining the overall dynamics of legal and illegal wildlife markets, at least when they are supply-driven (Oyanedel et al., 2021). As such, focusing on better understanding traders' incentives could catalyze a richer understanding of how to disincentivize illegal wildlife trade in legal markets. Research is slowly starting to include traders in assessments of wildlife use (Crona et al., 2010; González-Mon et al., 2019; O'Neill et al., 2018;

Purcell et al., 2017). However, more research is needed to understand whether traders influence legal and illegal wildlife trade dynamics in other contexts, such as in demand-driven markets.

The capacity of uptake of our model and approach by researchers and practitioners will vary depending on the type of market and supply chain being assessed. This, in turn, needs to be accounted for in decision-making so that lessons learned from the application of the model consider the uncertainties and limitations of both the model and the data used. We have provided the code of our model to encourage uptake, but on-the-ground adoption might require adaptations, especially in cases when different products are derived from the same species, when trading involves multiple species, or when there is transformation along the supply chain(M. Arias et al., 2020; Rosales et al., 2017). Similarly, researchers and practitioners might struggle to acquire or obtain the necessary data to run the model as presented here. To account for this, we offer several options depending on data availability in the model code included in Appendix S6. For instance, we provide an alternative code option for contexts lacking enforcement-effort data, where researchers will need to use the model with a fixed probability of detection parameter over time.

With regard to our fishery case study, key informants indicated that illegality dominated the market. Interviews allowed us to build priors for unknown parameters by informing the ranges within which these parameters might vary. Posterior distributions and model results confirmed that the vast majority of the market was illegal, except towards the end of the year (Figure 6.3.2). Moreover, our model allowed us to better understand and explain the within-year temporal variability of trade in the small-scale common hake fishery. For instance, we elucidated a somewhat counterintuitive dynamic of the fishery by including the permit fee elasticity parameter. That is, in this fishery legal landings increased dramatically at the end of the year but decreased as soon as the new year started. This dynamic is not a result of market or environmental factors but rather of how the fishery is managed. As fishers who still have quota permits at the end of the year rush to sell them, they lower the permit price and shift the traders' incentives towards more legal trading. This phenomenon dissipates when the new year starts, and fishers get new quota permits. In sum, by combining a qualitative initial interview stage to familiarize ourselves with the market and a quantitative approach with the ABC model, we were able to shed light on the legal and illegal trading dynamics of the small-scale common hake fishery in Chile.

Our results suggest that improving the sustainability of the fishery by disincentivizing traders to trade illegal units requires significant increases in the policy levers we assessed (Supplementary Material and Figure 6.3.3). To reduce the total units traded by at least 30%, the policy levers generally needed to increase by >200%. While the government could potentially directly increase the efficiency of enforcement, the other policy levers (increasing the price premium in the end-market for legally sourced fish and increasing the price elasticity of demand via consumers shifting more readily between hake and alternatives as the price changes) are more complex to increase and uncertain in their outcomes because they involve the market responding to policy changes. These results show how unbalanced the market's current incentives are towards trading illegal over legal products and the scale of the interventions that would be required to improve the fishery's sustainability. Indeed, our results suggest that solving the illegality problem in this fishery is challenging and would require a combination of different interventions to start shifting traders' incentives towards trading more legal products.

While ecological and economic goals are usually discussed in conservation, social goals are also key to sustainability (Newing, 2010a). Improving compliance is a crucial social goal because it can help improve legitimacy of regulations and cohesion within the community and reduce tension and mistrust caused by noncompliance (Faasen & Watts, 2007; Oyanedel et al., 2020a). Moreover, considering impacts with respect to the three pillars of sustainability (social, ecological, and economic) when intervening in wildlife markets can help avoid unintended consequences (Larrosa et al., 2016). This can help shed light on where to direct efforts and which interventions to avoid. For instance, while increasing the quota has been proposed as a solution for this specific fishery (Oyanedel et al., 2021), our results indicate that increasing the quota alone would have no effect on the ecological sustainability of the fishery, but would only legalize the illegal catch (Supplementary Material). Moreover, taking a broader perspective when planning interventions can help managers and policy makers evaluate the trade-offs between goals and enact policies with a clear understanding of their potential effects on the ground. Indeed, our results (Fig 6.3.3a) lay out the tradeoffs between the social, economic, and ecological goals for the case study. Visualizing these tradeoffs serves to predict where interventions might help and where they might bring negative or unintended consequences.

Trading wildlife brings unavoidable risks (Bennett et al., 2021; Booth et al., 2020). Managing these risks can help sustain wildlife use and trade over time, delivering the broad suite of benefits this activity can bring (Andersson et al., 2021; Challender & MacMillan, 2014; Milner-Gulland et al., 2003; t Sas-Rolfes et al., 2019). The risk of illegal products entering legal markets is present in many contexts (Bennett et al., 2021). Thus, tools that help assess the effects of interventions that reduce this risk are of great importance for sustainability. Our approach shows that understanding the risk of illegality requires a more profound recognition of traders' role in determining wildlife use dynamics. Indeed, traders are an understudied stakeholder in wildlife use contexts but can be of significant importance in determining how wildlife is used (Crona et al., 2010; Oyanedel et al., 2021). As such, advancing the understanding of the role of traders in diverse wildlife use contexts is critical. Our approach contributes to this task by delivering a versatile tool to quantify illegal wildlife trade in legal markets and assess the tradeoffs between potential interventions that specifically target trader's incentives. Sustainable wildlife trade requires better assessment of how to incentivize legal over illegal wildlife trade, considering the potential social, ecological, and economic impacts of interventions.

Chapter 7: Discussion

7.1 Research summary

The overall aim of my thesis was "to contribute to the scientific understanding of how non-compliance in small-scale wildlife use contexts can be studied and ultimately managed, through innovative and interdisciplinary approaches, using a small-scale fishery in Chile as a case study." This aim was two-fold: on the one hand, it included a case-study-based approach in which I dived into the small-scale common hake fishery in Chile, trying to understand its non-compliance problem and ways to solve them. On the other hand, it involved a broader view in which I tried to understand and explore different avenues by which non-compliance in the context of wildlife use can be studied. These aims are intertwined, but it is also important to note the tension between providing a detailed case study assessment and the generalizations that can come out of it. I expand on this tension later in this Chapter.

To achieve this aim, I had four objectives. The first objective of my thesis was to "Assess and review diverse literature and approaches that can be applied to study and reduce non-compliance in fisheries and beyond." This objective was achieved through, mainly, Chapter 3. Here, I explored diverse kinds of literature, ranging from economics to criminology. From this, I was able to categorize approaches to study non-compliance into two types: actor-based approaches, which address the underlying motivations for people to comply or not with regulations; and opportunity-based approaches, which assume that non-compliance is not distributed randomly across space and time and focus on the role that the immediate environment plays in the performance of non-compliant behaviours. Generating this categorization permitted a clear identification of the shortcomings and benefits of each approach. Indeed, in that Chapter, I explored barriers and opportunities for actor- and opportunity-based approaches to complement each other and improve non-compliance research and practice. This first objective, however, permeated Chapter 5 as well. In Chapter 5, I reviewed the diverse literature on understanding wildlife product supply chains and markets in order to create my framework. Chapter 5 was therefore beneficial in expanding the reach of the first objective as it included diverse literature that did not fit in Chapter 3, which was mainly focused on harvesters.

The second objective of my thesis was to "estimate rates of non-compliance with different rules and regulations, amounts of illegal extraction, and disentangle what underlies the heterogeneity of observed non-compliance behaviour of small-scale fishers." This objective was fulfilled in Chapters 4, 5, and 6. In Chapter 4, I estimated rates of non-compliance with different regulations in the small-scale common hake fishery in Chile. I found that non-compliance rates were heterogeneous, with 92–100% fishers complying with temporal or gear rules, but only 3% complying with the quota limit. Moreover, I found that legitimacy-based motivations (i.e., acceptance of decision-making and its outcomes by citizens) were more important in explaining why fishers comply with temporal/gear rules than they are for compliance with the quota. I also found that normative motivations (i.e., prescriptions commonly accepted in a group, supporting desirable behaviors and forbidding undesirable ones) were significantly related to the degree of non-compliance with the quota. Disentangling these motivations was key to unpacking compliance responses, guiding policy, and moving toward a better compliance theory.

The second part of this second objective, estimating amounts of illegal extraction, was achieved with Chapters 5 and 6. In Chapter 5, and using responses from the same survey used in Chapter 4, I estimated the amount of catch that goes unreported (and is therefore illegal). The range estimate was that the total unreported catch was 6,658 tons for the low-effort scenario (based on the average number of trips reported to authorities a year), and 24,204 tons for a high-effort scenario (based on three fishing trips per week, eleven months a year). Compared to the quota allowed for the region, these estimates suggest that between 67 and 88% of the total catch in the region goes unreported. The upper estimate was then used to construct the prior range for the model in Chapter 6 (the lower estimate was no unreported catch). Using this model, I estimated that around 77% of the catch is unreported.

By fulfilling this objective, I was able to derive meaningful conclusions about the case study. First, that non-compliance with the quota limit is extensive and involves most of the catch. The reasons for these high levels of non-compliance are complex, involving low quota levels given to fishers and low levels of legitimacy of the quota rule itself. This is mainly because fishers thought that the distribution of rights was very unfair; while 40% of the quota goes to more than 3,000 fishers, 60% is given to the industrial fleet, which operates with only 1-2 vessels. As such, the quota-based management system for this fishery is deeply flawed, as rights are distributed so unfairly that fishers felt entitled to not comply with the quota, ultimately creating a local social norm that non-complying with the quota was permitted.

The third objective of my thesis was to “develop a framework that can help guide ways to better understand wildlife markets when there are unsustainable and/or illegal practices and identify potential interventions to reduce them." I worked towards this objective in Chapter 5. Here, I developed a novel framework to study wildlife markets and the supply chain and explore how to intervene to reduce unsustainable and/or illegal practice. I focused on three analytical levels: The first level, "actor", assesses the underlying motivations and mechanisms that allow or constrain how actors benefit from wildlife markets. The second level, "inter-actor", considers the configuration of wildlife product supply chains and the type of competition between actors participating in wildlife markets. The third level, "market", evaluates supply-demand dynamics, quantity and price determinants, and the presence and effect of illegal products flowing into markets. I applied this framework to my case-study in Chile, which permitted the identification of interventions to reduce illegal trade based on empirical analyses. By applying this framework, I concluded that an important part of the problem of non-compliance in this fishery is due to the highly imbalanced power that actors in the supply chain have compared to harvesters. Because of this, they can control and fix prices artificially low, incentivizing fishers to overfish. As such, fishers not only perceive that the quota system is illegitimate, but they also suffer from unfair prices received for their products, further incentivizing the local norm accepting non-compliance as a valid response to the situation. This insight sheds light on the importance of moving the focus of analysis from harvesters (fishers) to all actors involved in the supply chain - both for this specific case study, and for wildlife products more generally.

The fourth and final objective of my thesis was to "develop a simulation approach to understand what drives traders to trade legal or illegal wildlife products and identify which policy levers might change those incentives towards more legal trading." This was dealt with in Chapter 6. In this Chapter, I devised a dynamic simulation model that focused on incentives traders face to trade legal or illegal products. By doing this, I moved the target of analysis from harvesters to traders. The model used a Bayesian Approximate Computation Approach to deal with uncertainty in unknown parameters (e.g., those related to illegal activity). This model could be adapted to different species and contexts, where data availability might differ. Moreover, this model allows assessment of the effect of policy interventions to improve the sustainability of wildlife trade, considering the trade-offs between ecological, economic, and social goals. Applying it to the small-scale common hake fishery shows that most of the products flowing into the market are illegal. We also found that even significant increases (over 200%) in parameters proxying for potentially implementable policy interventions would enable only moderate improvements in ecological and social sustainability of the fishery, at a substantial economic cost to the fishers. These results expose how unbalanced trader incentives are toward trading illegal over legal products in this fishery and how important traders can be in determining how wildlife markets operate. It also suggests that, in this system, intervening for sustainability would require long-term and holistic approaches, as isolated and short-term potential policy interventions would do little to change current incentives.

7.2. Intervening for sustainability

Throughout my DPhil, I have gathered different pieces of data that can inform interventions in the common hake fishery to improve sustainability. In this section, I discuss a series of potential interventions and ways forward, combining the evidence gathered in the different chapters of my thesis (which go beyond those interventions proposed in Chapter 5).

Moreover, I discuss these interventions considering a broader perspective in which I draw parallels with what has been found in other contexts.

7.2.1. Improve participatory processes

Participatory processes for decision-making in wildlife use contexts can improve legitimacy and shift social norms towards compliance, making management more effective (Jentoft & McCay, 1995; Oyanedel et al., 2016; Viteri & Chávez, 2007). This is because if wildlife users feel embedded in the decisions that govern their operations, they have higher incentives for complying (Birnbaum, 2016; Kuperan & Sutinen, 1998b). Moreover, participatory processes for decision-making can incentivize peer or community-based enforcement, as actors who participate in a management system engage in surveillance of the rules they define, as they have a higher stake because of the time invested in decision-making processes (Ostrom, 1990). Participation is one of the necessary conditions for sustainable and long-term management of common-pool resources, such as wildlife (Ostrom, 2018).

Results from the small-scale fishery in Chile case study show that one of the main reasons for non-compliance with the quota is the low level of legitimacy of this regulation (Chapter 4). Interestingly, there is a well-established participatory governance system for this fishery, the Management Committees, in which small-scale and industrial fishers and government officials participate (Gelcich, 2014). However, this Management Committee can only decide the yearly quota within a range proposed by a Scientific Committee, which is obliged to be completely independent of the Management Committee. Moreover, the Management Committee cannot decide how the quota is distributed between small-scale and industrial fleets (set by the general fisheries law). As such, the Management Committee has little influence on how the quota level is decided and distributed. This has led to disappointment and frustration amongst fishers, who feel that the quota levels are too low and unfairly distributed (as 60% goes to industrial fishers and 40% to small-scale). Moreover, fishers state that because their participation in management doesn't involve the quota, which is the central regulation of the fishery, their participation is futile. This is in line with Ostrom's principles for managing the commons, which indicate that participation is necessary but not sufficient – especially when participation doesn't involve power (Ostrom, 1990).

Indeed, problems of unfair quota distribution are common where industrial and small-scale fishers share a fishing stock, as they might have different capacities to lobby for their interests (Sumaila, 2018). A way to overcome this is through interventions that set up transparent and participatory quota distribution and determination processes. First, to include a more participatory and fair approach to determine quota distribution, governments could aid in this task by mapping out the number of beneficiaries from the fishery. This should consider not only those who directly harvest the stock but also those participating in the supply chain and market (Kelleher et al., 2012). Having better data on those who benefit from the stock could be an input for discussing how to distribute the quota between the industrial and small-scale fleets. In the case of the common hake, the same governance structure of the Management Committee could be used to discuss the issue. Still, the general fisheries law would need to be amended to allow re-distribution of quota to be decided within the Management Committee.

Another way to increase legitimacy in the quota regulation would be through participatory stock assessment for determining yearly quota levels. Even though there is abundant evidence of long-term and extended fishing over the quota (underreporting), the common hake stock shows some signs of recovery (SUBPESCA, 2016). This goes against what would be expected from a fisheries population dynamics perspective, as the quota determined by the Scientific Committee is set to reach Maximum Sustainable Yield (MSY); if the quota is dramatically surpassed, the expectation would be depletion of the stock rather than recovery (Costello et al., 2008). There is an alternative explanation, however. In cases with consistent underreporting over time, models that use catch data will misleadingly estimate population size and MSY levels, but the stock status estimation will be unbiased (Rudd & Branch, 2017). Put another way, the stock might be larger than predicted by models in cases where there is consistent underreporting (such as the common hake). This is in line with what fishers report on the ground; that the stock is much larger than estimated by the Scientific Committee (Personal. communications).

Given this potential misinterpretation of the stock size and MSY levels, a participatory stock assessment as a way forward could include direct communication channels between those scientists who participate in stock assessment and fishers who target the species. Since fishers are constantly finding wherever the demersal common hake stock is, as it moves along the ocean bottom, they have a much better perspective on where to find it than scientists might have. Survey vessels, by contrast, visit the same sites year after year. Collaboration between scientists and fishers could indeed be of great use for improving the estimation of the stock and, with it, quota legitimacy. Moreover, it could incentivize fishers to anonymously reveal underreporting to improve stock assessment models. In Namibia, for instance, the collaboration between hake fishers and scientists has led to a better understanding of stock behaviour and higher confidence in the assessment on the part of fishers (Paterson & Kainge, 2014).

7.2.2. Include all those involved in wildlife trade in management

Wildlife trade research has focused extensively on those who harvest or consume wildlife products (Arias & Sutton, 2013; Biggs et al., 2017; Boonstra & Hentati-Sundberg, 2015; Thomas-Walters et al., 2020). However, the results from Chapters 5 and 6 show that traders play an essential part in how non-compliance operates, which has also been observed in other cases (Crona et al., 2010; Phelps et al., 2016). There has been growing interest in the wildlife trade literature to include and understand the operations of those involved in trading wildlife, how products and resources flow through supply chains, and how that ends up affecting compliance and sustainability (Challender et al., 2021; McNamara et al., 2016; Moyle, 2017). For instance, by exploring how benefits are shared among those involved in fisheries supply chains, (Purcell et al., 2017) found that the share that fishers received of the end-market price is negatively related to the products' value. They highlight the need to improve supply chain governance so that fishers' share of the product is increased and thus their income, providing an incentive to reduce exploitation rates and improving sustainability (Purcell et al., 2017).

Given the importance of traders and other supply chain actors in affecting how wildlife is used, as exemplified in the common hake fishery, a potential intervention would be to include them in registers managed by wildlife authorities. Having a broader perspective to include traders and participants of supply chains in wildlife governance could provide several benefits. First, it would allow more transparency to understand who participates in the supply chain and market, their diverse roles, and the relationships between actors (Kelleher et al., 2012; Purcell et al., 2017). For instance, informal patron-client relationships between fishers and fish-buyers in Mexico led to a well-established system in which fish buyers extensively influenced fisher decisions (González-Mon et al., 2019). Fish buyers in these systems play diverse roles, such as permit providers or sourcing financial assistance or equipment for fishers (Lindkvist et al., 2017). Acknowledging and understanding these diverse roles could provide a clearer picture of the operation of wildlife markets and expand wildlife authorities' scope of action to improve compliance and therefore the sustainability of wildlife trade.

Moreover, including supply-chain participants in management can help to better understand who benefits from wildlife trade. Because management (and research) is often focused on harvesters, other participants in wildlife markets might be invisible to assessments that predict the effect of regulations on wildlife users. Indeed, recent efforts to map and account for the diversity of people working in processing and transporting seafood show that almost half of the beneficiaries in this sector are women who might be invisible to policy-making as their activity is not reported (Kelleher et al., 2012). This assessment shows that fish processing activities provide essential livelihoods in fishing communities (Kelleher et al., 2012). Policies designed to improve compliance cannot overlook these diverse and vital roles in wildlife trade because of the risk of negatively affecting the wellbeing of those who might generally be invisible to management (Britton & Coulthard, 2013).

7.2.3. Focus enforcement where it is more effective

Enforcement is crucial for incentivizing compliance (Keane et al., 2008). While much of my thesis has been based on the idea of moving beyond an instrumental approach of only considering cost-benefit analyses, some sort of coercive incentive is needed in most wildlife trade contexts (Hilborn et al., 2006; Keane et al., 2008; Sutinen & Andersen, 1985). Because resources are often limited for enforcement, especially in small-scale wildlife use contexts, improving enforcement efficiency is critical. One approach to improve enforcement is by reconsidering the target to include all those who participate in the supply chain. However, re-considering the enforcement target is no easy task because, depending on the sector of the supply chain, actors will use diverse avoidance strategies as a reaction to enforcement (Arias et al., 2021). Future work could look at the diversity of avoidance strategies actors use along the supply chain and the difference in resources invested in avoidance in response to enforcement.

One potential intervention for improving the sustainability of my case study fishery, based on Chapters 5 and 6, is to increase the enforcement on other actors in the supply chain beyond fishers. The Chilean government is moving in this direction (Personal communication). One limitation of this approach is that targeting enforcement on actors other than fishers usually requires coordination with other government agencies such as the police, making it more costly.

This is because only fishers are under the fisheries enforcement agency's jurisdiction. Accounting for this, an interesting future line of work could be to use enforcement effort and sanctions data to understand the effect of different enforcement strategies (and their costs) on the probability of detecting a violation. This could, in turn, help improve enforcement efficiency adaptively, as new approaches are tested and analyzed constantly. Moving in this direction would require encounter data models that account for potential biases inherent to enforcement data (Burn et al., 2011; Keane et al., 2011). Recent work, fortunately, sheds light on new mathematical approaches that use enforcement data to derive bias-controlled estimates of violation rates (Critchlow et al., 2015; Dobson et al., 2020; Underwood et al., 2013).

Another potential intervention is to incentivize or enhance community-based or government-independent enforcement. In Chapter 3, I show that the regulation created by fishers (fish only three days a week) is highly complied with, with instrumental (community-based enforcement), and normative motivations partly explaining compliance. Providing fisher communities with tools and appropriate channels for locally enforced rules could be a cost-efficient way to improve compliance. Community-based enforcement approaches have been widely promoted, but unfortunately, most projects do not explicitly assess their effectiveness (Roe & Booker, 2019). Better understanding which type of strategies works best in which context could significantly improve compliance in wildlife trade systems.

7.3. From research to proposing interventions

Because sustainability research in many cases involves recommending interventions to reduce non-compliance, the research process very much influences the type of intervention proposed. This obvious implication is often overlooked, risking unintended consequences and misleading interventions. In this section, I look inwards at my journey as a sustainability researcher in order to explore how sustainability research could more fruitfully identify those interventions that might most effectively reduce non-compliance in wildlife use contexts.

7.3.1. Overcoming path dependency

The reasons why researchers might engage in studying wildlife use non-compliance, and the ways to reduce it, are varied. It could be because of previous evidence or pre-conceived ideas of the drivers of non-compliance in a system or much more personal experiences and affinity with a specific sector, for instance, small-scale fishers in my case. While conservation researchers come from different backgrounds, expertise, and have diverse goals (Pienkowski et al., 2021), they usually share an interest in a specific context or area where they might have personal connections or experiences. As such, no researcher starts from nowhere: everyone brings a suite of ideas, experiences, and biases to the system they study and the methodologies they use. This leads, unmistakably, to a path dependency issue. Path dependency is the process by which previous actions and decisions preclude (or increase) the likelihood of future actions, making new choices resemble past choices even if a different approach is potentially superior (Fulton, 2021). This can have significant consequences when studying non-compliance and conservation issues in general. Because of path dependency, researchers can get locked in studying a component or dynamic of a system that might not be the primary driver of the problem they are trying to understand and solve. This can lead to proposing interventions that won't necessarily have the largest possible impact on a system.

This potential issue was very apparent in my thesis and trajectory. Since I started my career, I have been very interested in small-scale fishers and their culture. This set my path as a researcher to focus on them as the main target of my studies. Unsurprisingly, I started to assess the non-compliance problem in the common hake fishery by understanding fishers and their motivations to comply or not. However, what I encountered when doing fieldwork for my first Chapter changed my ideas of the system I was studying. While fishers were important, as they were the ones harvesting legal and illegal fish, the most important driving force behind the non-compliance issue was the supply chain and the traders that participated in it (Chapter 5 and 6). This presented a challenge, as the techniques and methodologies I had used in the past weren't necessarily optimal to study this system component. Changing gears, I was able to overcome my path dependency and re-structure my thesis around this finding. This led to important insights into how the common hake market operated, which wouldn't have emerged if I had maintained my focus on fishers alone.

Looking inwards into my research process, I realized the risks of path dependency and the importance of researchers being aware of it. Researchers can suffer from individual-level path dependency based on their own interests and experiences. But also, because they are embedded in an academic environment and discipline, they can also suffer from collective path dependency, much like Kuhn's "normal science" phase (Kuhn, 1962). Understanding how the decisions we make as researchers on what to focus on next pertain to personal or intertwined discipline-level path dependency is challenging. These limitations make overcoming path dependency puzzling. However, opportunities might arise that trigger new options and paths. External shocks, for instance, such as COVID-19 or climate change, can help pivot researchers to think in new and innovative ways that would have been unlikely in the absence of the shock (like Kuhn's "revolutionary" phase) (Mahoney, 2000). But, overcoming path dependency can also happen through observation and encounters with new pieces of information that were not the direct purpose of the research process originally, as happened in my case. Attention is needed from researchers so that path dependency doesn't overly influence how research is done, and barriers that inhibit change are reduced, and shifting paths is easier so new alternative approaches can be implemented (Kirk et al., 2007).

7.3.2. Twist from evidence to proposing intervention

Studying non-compliance is no easy task, so evidence on this topic is scarce in most wildlife use contexts (Arias et al., 2020; Gavin et al., 2009; Hinsley et al., 2019). With this backdrop, cognitive biases may become apparent and lead to inaction. For instance, because of a lack of information, researchers and practitioners can become insensitive to the magnitude of a problem, misleadingly underestimating the need to design interventions to solve it (Fulton, 2021). Another way that scarce evidence can lead to inaction is through researchers and practitioners aiming to constantly seek more information before intervening, even if the available but scarce information is enough (Golman & Loewenstein, 2018; Milner-Gulland & Shea, 2017). Inaction can have two negative consequences: no new evidence is collected, which creates feedback of lack of information that leads to continuous inaction, and the problem of non-compliance can grow undetected.

Moreover, when moving from inaction to proposing interventions, cognitive biases (such as information, memory, and conformity biases) can make researchers overstate the likelihood of success of intervening based on cases in which there were more data or where interventions have already happened and proven successful (Fulton, 2021). This was apparent in my case study, where most of the interventions that have been tried in the past to reduce non-compliance were targeted on fishers (despite the lack of evidence that they are the most effective group to target). This is because most of the information about the fishery pertained to this group as it forms part of the fisheries agency's register, and previous research has focused on them (Plotnek et al., 2016; SUBPESCA, 2016). Much less attention has been given to other supply chain participants, and in particular no solid interventions targeting traders have been tried and evaluated.

On top of this, the shift from gathering evidence to proposing interventions is a sensitive one as researchers might be affected by other, and more profound, biases that impede adequate interpretation of the available information. Not only this can lead to inaction but also inappropriate interventions (Challender et al., 2021). One recent example is the work by Natusch et al. (2021), in which they flagged potential and harmful biases in Sosnowski & Petrossian (2020). The critique is methodological and identified anti-trade biases by Sosnowski & Petrossian (2020) that could help explain the authors' interpretation of the results and their proposed interventions to reduce or stop wildlife trade (Natusch et al., 2021). Being aware of these and other potential biases can help researchers better take the step from the evidence gathered during the research process to proposing interventions which might work (Challender et al., 2021). Looking inwards into our process as researchers can help correctly identify and predict where, when, and how to intervene based on the research outputs we produce (Travers et al., 2019). Failing to do so can lead to poor interventions that don't respond to the actual dynamics of the system, undermining trust in the scientific process, and failing to improve compliance in wildlife use contexts.

7.4. Cross-cutting themes and recommendations for further research

7.4.1. Adaptive compliance management

Throughout my empirical chapters, I found that non-compliance is an extensive problem, which is now well established in the operation of this fishery. In Chapter 4, I show that almost all fishers (~96%) do not comply with the quota limit. Moreover, when assessing the motivations for compliance I found that there is a social norm that sees non-compliance as an appropriate response given the low level of legitimacy of the quota regulation. Moreover, in Chapter 5, I show that the supply chain of the fishery is structured in a way that enables trade in non-compliant products because of the type of organizations traders have developed, and the well-established system of price differentiation between legal and illegal products. Similarly, in Chapter 6, I found that traders' incentives are highly imbalanced towards trading illegal over legal products. This is due to the efficiency with which traders can do so, and the possibility to develop avoidance strategies to evade enforcement. All these findings suggest that intervening in this system might require major changes at different levels and scales.

Building on these findings, further research could be directed towards developing approaches for adaptive compliance management. In the same way that adaptive management of fisheries assesses how fish resources responds to regulations, which then feeds back into decision making (Williams, 2011), compliance management could assess the compliance response of actors towards regulations to then feed into decision-making (Cinner et al., 2019). Adaptive management is based on the idea that the systems being managed are only partially understood, and that drawing lessons over time serves the purpose of improving the understanding of the system (Armitage et al., 2009). In the case of compliance, an adaptive management approach could help to find ways to reduce non-compliance at the same time as better understanding the non-compliance itself. Similarly, uncertainty about the outcomes of regulations can be systematically reduced with an adaptive management approach if efficient iterative learning processes are incorporated into management, and new evidence emerges as new rules and regulations are established (Williams, 2011).

Implementing an adaptive compliance management approach could help as a preventive tool, as measures could be taken before non-compliance settles, becomes a norm and a feature of supply-chains and markets, as happened with the common-hake fishery. Indeed, this could provide benefits in cases where non-compliance issues are emerging, due to new regulations, markets, technologies, or factors that might incentivize non-compliance (e.g. when non-compliance developed for the sea cucumber fishery in Mexico as new high-value markets were created (Gamboa-Álvarez et al., 2020)). Another example of this is when new Marine Protected Areas (MPAs) are established. MPAs suffer from extensive non-compliance, which may prevent their potential outcomes from being realized (Iacarella et al., 2021). Applying an adaptive compliance management approach could help identify which rules are being violated and when, providing an opportunity to adjust them before legitimacy is too low and a social norm develops in favour of non-compliance. Another example is with the supply chain of wildlife products. Adapting regulations that affect those participating in supply chains based on compliance factors can prevent actors developing specific supply chain channels or mechanisms that allow them to evade regulation (Phelps et al., 2016). This has the potential to control trade more effectively, by intervening early on rather than when well-established supply chain structures are set that might make it more challenging to intervene.

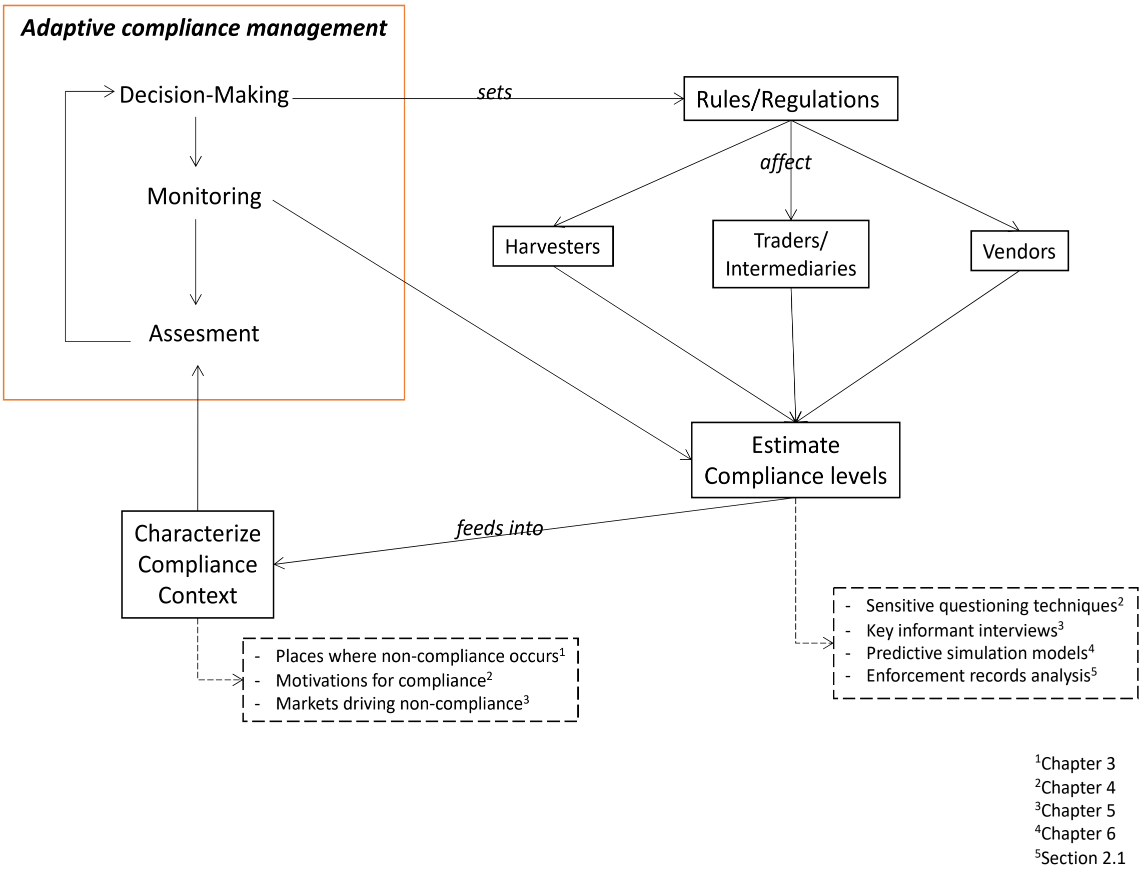


Figure 7.4.1. Adaptive compliance management, based on Williams 2011 (red square). Dashed boxes represent research opportunities.

7.4.2. Non-compliance is more than a conservation issue

Another cross-cutting theme I found is that non-compliance in wildlife trade is more than a conservation issue, involving other risks that transcend the impacts on the species being targeted. Results from Chapter 4 suggest that the high incidence of non-compliance could be causing a loss in social capital. This is because the presence of non-compliance activities has eroded relationships with the government and fuelled narratives in the press portraying fishers as criminals. Moreover, results from Chapter 5 indicate that the oligopoly formed within the intermediary component of the supply chain uses illegal means to benefit from the fishery such as price fixing, further eroding social capital in the system. Results from Chapter 5 also indicate how, by avoiding enforcement, non-compliant products being traded escape sanitary controls. By doing so, non-compliant products lack any certificates that ensure safety, quality or that basic cold chain processes have been maintained. This lack of quality assurance and transparency ultimately threatens consumer safety. Finally, in Chapter 5 I describe how much more illegal than legal product is being traded. This has huge repercussions in terms of lost tax revenues, as illegal products are not declared and therefore fail to pay taxes.

Considering that non-compliance is more than a conservation issue could be a way forward for more systematically dealing with non-compliance issues, by fostering coordination between institutions that might directly or indirectly deal with non-compliance. Conservationists tend to partner with institutions and multi-lateral organizations that regulate wildlife use with the explicit mission and scope of action to do so (e.g., CITES (Andersson et al., 2021)). But, wildlife trade can also fall under the jurisdiction of regulatory institutions that deal with other issues. These include those exposed above, but also invasive species and zoonotic disease control (Booth et al., 2020; García-Díaz et al., 2017). These controls are especially pertinent to non-compliance in fisheries and wildlife supply chains, as these products can therefore escape invasive species preventative inspections and zoonotic disease monitoring (Biggs et al., 2021). There is an untapped potential for combining the efforts, tools, and jurisdictions of various agencies and regulatory bodies to intervene in wildlife markets. This could unlock resources, attention, and expertise to catalyse wildlife use sustainability, via compliance with other rules.

One potential avenue for future research is to use social network analysis to map potential (theoretically or technically feasible) and actual (empirical) interactions between researchers and/or agencies that might directly or indirectly deal with wildlife trade issues. Mapping potential against actual networks could be an easy-to-represent manner to identify nodes and connections that require better understanding and targeting for non-compliance in wildlife use (Bodin et al., 2006). Similarly, social network analysis could be used to understand the flow of information between those studying or working in the management of wildlife trade-related issues in a specific context, the level of reciprocity of that communication and the density of connections (Oyanedel et al., 2016). Another potential future research direction is to estimate case study-based potential economic costs of the diverse negative impacts of non-compliance in wildlife trade (García-Díaz et al., 2017; t Sas-Rolfes et al., 2019). This could catalyze action by thoroughly assessing the diverse and sometimes understudied costs associated with non-compliance (Castello y Tickell 2016).

7.5. Final reflections

Reflecting on the process of immersing myself into the literature about non-compliance and applying new concepts and methodologies to my case study, I find myself in a very different position than when I started my DPhil. Illegal and/or non-compliant use of wildlife has gained increased academic attention since I began my studies because of the COVID-19 crisis and its links to wildlife trade (Booth et al., 2020; McNamara et al., 2020). This increase in attention from scientists has been paired with overwhelming media attention. With this backdrop, studying non-compliance in wildlife trade wasn't a process isolated in an academic silo, but a topic of broad societal interest. Having your research theme under the spotlight has clear advantages, such as potential funding and policy attention, but also drawbacks.

Even before the emergence of COVID-19, the widespread attention on wildlife trade has created a narrative around non-compliance in which harvesters are portrayed negatively, and their actions sometimes even assumed to be linked to criminal activities such as terrorism (Haenlein et al., 2016; Mackay et al., 2020). This has been fuelled by generalizations that combine a diversity of behaviours and context into a single term, which can do more harm than good. An example of this is the recent proposal of the term Illegal and Unsustainable Wildlife Trade (IUWT) (Cardoso et al., 2021; Fukushima et al., 2021). This term envisions bringing together the diversity of issues around illegal and unregulated wildlife trade. "Illegal" and "unsustainable", however, are different, with implications for how to study them. Putting everything into the same bag can risk making concepts meaningless, which is starting to happen with Illegal, Unsustainable, and Unregulated fishing (IUU), for instance. This is more than a semantic problem and can have significant consequences, undermining, for instance, small-scale fisheries by disregarding their diversity with the all-inclusive IUU concept and imposing burdens through trade-related agreements to counter IUU (Song et al., 2020).

Coming into the DPhil with extended fieldwork experience, I was doubtful of the negative and homogenous narrative around non-compliance in wildlife trade. Instead, I had witnessed that fishers failing to comply with regulations had very diverse motivations, and some of those motivations weren't classifiable into "right or wrong". Doing fieldwork is not only about collecting data but also a way to get close to what we study and, as such, a critical process for researchers to be constantly nurturing their ideas with "reality-checks". Losing this can risk falling into a spiral of biased interpretations about the world, making the scientific process futile in trying to represent and understand reality.

But going into the field brings other issues, such as the tension between case study research and theory building. Building theory from the bottom up, using case study research, is complex, as researchers try to provide exhaustive descriptions of a particular phenomenon. This can inhibit theory-building if there isn't constant refinement between interpreting data and theory revision (Dooley, 2002). Throughout my thesis, I have felt the tension of providing a solid interpretation of the non-compliance issue in the small-scale common hake fishery in the VII region of Chile and the need to generalize and build theory from that interpretation. I have tried to navigate this tension by providing tools with broad applications rooted and tested in the context I worked. This has been facilitated by being surrounded by wildlife trade researchers working on very different systems. The framework provided in Chapter 5 and the simulation model in Chapter

6 are contributions that, I believe, can be useful in many contexts and can help to advance the theory of non-compliance. This is just a starting point, and these tools will need to be constantly updated as new evidence and applications emerge.

Writing at the end of my DPhil, I can’t stress enough the importance of reflecting on what we do as researchers and our contribution to the narratives that describe what we study. There isn’t much time to reverse the environmental impacts humans are creating and move towards a more sustainable future. This urgency needs sustainability research to be as effective as possible. For that, reflecting on how we do it and evaluating what we do is critical for our research to be truly impactful. I leave my DPhil program with lots of questions and a few answers, but most importantly, with a genuine desire to move scientific inquiry forward. This, for me, means a more cautious approach to research; one that helps create narratives that are connected to the ground, is as unbiased as possible, and has a clear goal to better understand, in the long-term, how to make society more sustainable.

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Supplementary Material

9.1. Supplementary Material Chapter 4

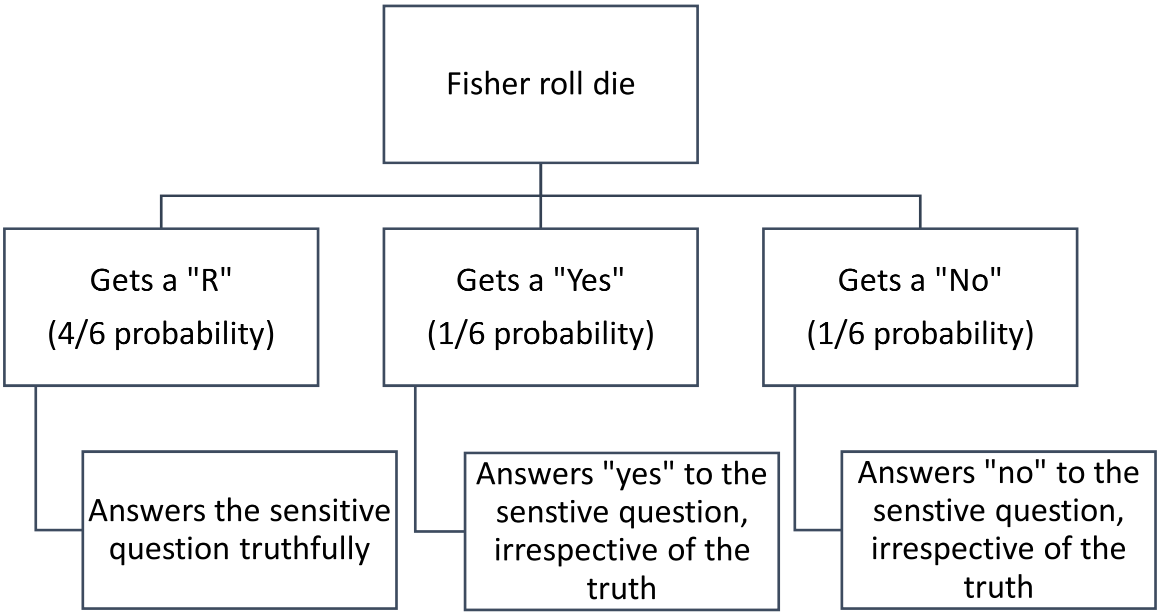
Table 9.1.1. Questions to assess compliance with 4 rule-types and estimate quantities of underreporting

Rule-type assessed	Question (same for RRT and direct questions)
Fishing Gear	When you go fishing, are your nets smaller in diameter than the ones authorized to fish common hake?
Reproductive Ban	Do you extract common hake during the closure in September?
3-day	Do you infringe the self-imposed measure in the VII fishing region to only fish 3 days a week?
Quota limit	Averaging over the year, do you report fewer boxes than you actually caught?
Quota limit (low price)	In the months of low price, do you report fewer boxes than you actually caught?
Quota limit (high price)	In the months of high price, do you report fewer boxes than you actually caught?
Quantities of underreporting	Doing a per fishing trip estimate, how many boxes (27 kg. per box) of common hake do you extract and not report?

Randomized Response Technique (after (Oyanedel et al., 2018).

For the RRT section, we adapted (Boruch, 1971) forced response model after. For this section, before each sensitive question, fishers had to roll a die in an opaque baker. We used a modified die that had one side with a “yes”, 1 side with a “no” and the 4 other sides with a letter R. If fishers rolled an R they had to answer the question truthfully (R meant response) (probability 4/6). If fishers rolled a “yes” or a “no” they had to answer a forced yes or no (1/6 of probability for each roll). As the results of the roll was only revealed to the interviewee, the privacy and anonymity of the fisher’s answer was protected. As we knew the probabilities to answer the sensitive question of give forced yes or no, the proportion of respondents who have undertaken the sensitive behaviour can be calculated (Figure S1).

(a)



(b)

$$\pi = (\lambda - \theta)/s$$

Where;

π= estimated proportion of the sample who have undertaken the behaviour

λ = proportion of all responses in the sample that are yes responses

θ = probability of the answer being a forced yes

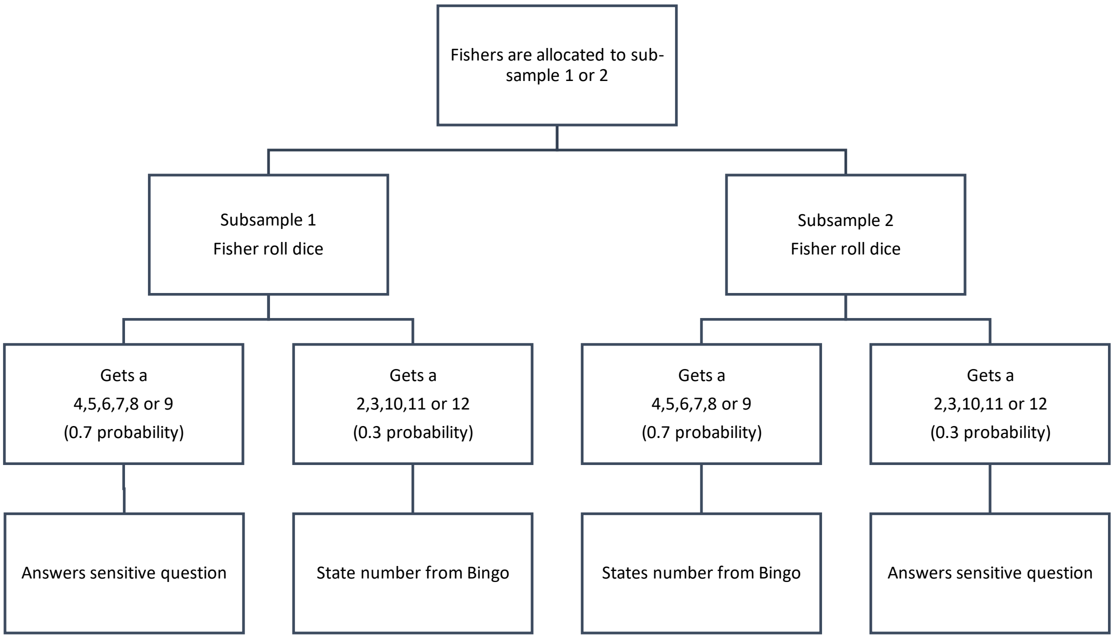
s = probability of having to answer the sensitive question truthfully

Figure 9.1.1. Decision tree to explain RRT process (a) and formula to calculate aggregate levels of sensitive behaviour (b), following (Fox & Tracy, 1986).

Quantitative Adaptation of Randomized Response Technique

To assess quantities of underreporting per fishing trip we used a quantitative adaptation of the RRT, following (Greenberg et al., 1971). Here, fishers had two regular dice, numbered 1-6 in an opaque beaker. The respondents roll the dice and depending on the sum of both dice, were instructed to answer the sensitive quantitative question, or state a number previously pulled from a “bingo” bag that had chips numbered 1-60 (Table S2). By pairing a sensitive question with a random device (bingo bag), and using 2 subsamples with different probabilities of rolling the sensitive ($p_{1,2}$) or the bingo ($1 - p_{1,2}$), we were able to draw a system of equations to determine the quantitative estimation sought (Figure S2).

(a)



(b)

$$\mu_A = \frac{(1-p_2)\bar{Z}_1 - (1-p_1)\bar{Z}_2}{p_1 - p_2}$$

and

$$\mu_Y = \frac{p_2 * \bar{Z}_1 - p_1 * \bar{Z}_2}{p_2 - p_1}$$

Where;

μ_A = quantitative average estimates for the sensitive question

μ_Y = quantitative average estimates for the “bingo” question

p_1 and p_2 = known probability to answer the sensitive question for each subsample p_1 and p_2

Z_1 and Z_2 = average of the raw data collected for each subsample.

Figure 9.1.2. Decision tree for quantitative RRT (a) and formula to calculate sensitive quantitative estimate (b), following (Greenberg, Kuebler, Abernathy, & Horvitz, 1971).

Table 9.1.2. A framework for determining which question an interviewee answered

Subsample 1			Subsample 2		
sum of dice	question	p[a]	sum of dice	question	p[a]
4, 5, 6, 7, 8, or 9	sensitive	0.7	2, 3, 10, 11, or 12	sensitive	0.3
2, 3, 10, 11 or 12	bingo	0.3	4, 5, 6, 7, 8, or 9	bingo	0.7

[a] Probability of obtaining each question.

Table 9.1.3. Questions to assess motivations for compliance. Each question was repeated for each of the 4 conservation rules. Responses were assessed (except perceived colleague non-compliance indicator) using a 5-point Likert scale that ranged from strongly disagree (1), disagree (2), neutral (3), moderately agree (4) and strongly agree (5).

Motivation Component (indicator assessed)	Question
Instrumental (Probability of enforcement)	It is likely that the authority will catch me if I violate this (conservation rule)
Instrumental (Probability of sanction)	It is likely that the authority will sanction me if I violate this (conservation rule)
Legitimacy-based (Legitimacy of authorities)	I believe that the authorities that dictate this (conservation rule) are competent and act honestly
Legitimacy-based (Equity of conservation rule)	I believe that this (conservation rule) is fair and equitable for the management of this fishery
Legitimacy-based (Appropriates of conservation rule)	I believe that this (conservation rule) is appropriate, valid and acceptable for the management of this fishery
Normative (Colleague disapproval)	My friends / family / colleagues would disapprove me if I violate this (conservation rule)
Normative (Feeling of guilt)	I would feel guilty if I violate this (conservation rule)
Normative (Perceived colleagues non-compliance)	Do you think your colleagues comply with this (conservation rule)? (answer yes/no)

9.2. Supplementary Material Chapter 5

Methodology

Key Informant Interviews

Key-informant open-ended semi-structured interviews started with an explanation of the project scope and objectives and followed with a list of reference questions (see below). Reference questions were divided into four categories, regarding: a) actors' motivations (focusing on why they trade legal or unreported products), b) how actors access the benefits of the fishery, the supply-chain structure and component interaction, c) the operation of the legal/illegal market, and d) the overarching market dynamic. Interviews were performed during March-April 2019. Due to COVID-19, all interviews were done over the phone or email. Before each interview, we informed participants that participation was voluntary and that participants could refuse to answer any particular question. We used snowballing sampling, starting with leaders of the main fishers' associations in the region and known contacts of the researchers. In total, we interviewed 23 informants, including fishers, government officials, intermediaries, vendors, NGOs staff, and enforcement agents. Depending on the key-informant's role, some questions were omitted, and others were explored in more depth. Interviews over the phone lasted between 30 and 90 minutes. The study complied with Oxford University's ethical requirements (approval number R68516/RE001).

Key-informant interview list of reference questions

a. Factors affecting actor’s decision to trade legal or unreported products

- What are the main factors that affect the decision to trade legal or unreported common hake?
- Do intermediaries always carry legal hake?
- What determines the legal/unreported purchase ratio?
- Does this ratio vary?
- What affects its variability?

b. How actors access the benefits of the fishery, the supply-chain structure and component interaction

- Are there groups of actors with excessive (or lack of) capacity to access the benefits of the market?
- Do fishers have power to negotiate prices with intermediaries?
- Do intermediaries set prices?
- How would you characterize the nature of the relationship between actors in the market?
- Do intermediaries finance the activity of fishers?
- Do actors enter and exit the fishery?
- What causes actors to enter or leave the fishery?
- Are there barriers to entry for new actors? Why?

c. Operation of the legal/unreported market

- Can legal and unreported products be distinguished at the market?
- How does fish enter the market without a permit?
- Is there a price premium for legal products?

d. Overarching market dynamic

- What are the most important factors that determine prices?
- Does fishing activity respond to prices? Or, alternatively, are prices driven by the quantities of fish landed

Typology Construction

For the actor level analysis, typologies were constructed to characterise participants in the market. Typologies refer to the systematic construction of types - which are unique combinations of dimension's attributes that influence the relevant outcome. We used motivations and access as dimensions for constructing the typologies for each of the four market components (harvesters, intermediaries, vendors and consumers). Following (Kluge, 2000) we divided the typology construction process into four steps:

a) Development of relevant analysis dimensions

Based on our framework's actor analytical level, we defined motivation and access as the analytical dimensions for constructing the typologies. We used three motivation attributes: instrumental motivations, mixed motivations and non-instrumental motivations. We used two access attributes: limited/low access and varied/high access

b) Grouping the cases and analysis of empirical regularities

From the results of the key-informant survey, we were able to group actors into empirical regularities (Supplementary Material). This process allowed to identify which combination of dimensions' attributes were present and absent in the actors of the case study. Moreover, this step confirmed that the dimensions and attributes selected contained sufficient heterogeneity, which is necessary for creating types.

Table 9.2.1. Analysis of empirical regularities (present/absent) to construct typologies at the actor-level analysis.

	Motivation			Type of Access
Sector	Only Instrumental	Mixed	Non-instrumental	
Harvester	Absent	Present	Absent	Limited/low Access
	Absent	Present	Absent	Varied/high access
Intermediaries	Present	Absent	Absent	Limited/low Access
	Present	Absent	Absent	Varied/high access
Vendors	Absent	Absent	Absent	Limited/low Access
	Present	Absent	Absent	Varied/high access

c) Analysis of meaningful relationships and type construction

After we grouped the cases based on the selected attributes, we eliminated the "non-instrumental" attribute from the motivation dimension, as there were no present cases for that attribute (Supplementary Material). From this we were able to identify the 6 different empirically founded groups that share combination of the selected attributes. We named each type according to the attribute that differentiated them. Each attribute space that was present was considered a type and two types were constructed for vendors with instrumental motivations and varied/high access.

Table 9.2.2. Type construction process. Non-instrumental motivations were eliminated from the final matrix and each type was named according to its differentiating attributes.

	Motivation		Type of Access
Sector	Only Instrumental	Mixed	
Harvester	x	Type I "Low quota fishers"	Limited/low Access
	x	Type II "High quota fishers"	Varied/high access
Intermediaries	Type III "Temporal intermediary"	x	Limited/low access
	Type IV "Permanent intermediary"	x	Varied/high access
Vendors	x	x	Limited/low access
	Type V "Fishing terminal vendor" Type VI "Open-air market vendor"	x	Varied/high access

d) Characterization of the constructed types

For the results of the characterization of the constructed type please refer to the main text.

Sensitive Questioning Surveys Analysis

Per-trip quantitative estimates of unreported catch from Oyanedel et al. 2020 were used to calculate regional yearly quantities of unreported catch, to assess the legal/illegal interaction dimension (market analysis). Oyanedel et al. 2020, using sensitive questioning methods (the Randomised Response Technique) and direct questions, estimated under-reporting per trip to be 548.37 [SE = 66.42], and 594.54 [SE = 33.75] kg for RRT and direct questions, respectively. To extrapolate the per boat/per trip unreported catch rates from (Oyanedel et al., 2020b) to an overall yearly estimate, we first fitted a linear model with unreported catch rates as the response variable and a binomial predictor of whether boats had high or low quota. We were able to categorise boats into low or high quota based on their port of operation. From this, we obtained unreported catch rates estimates for low and high quota boats. Then, from the records of SERNAPESCA, we obtained the total number of high and low quota boats in the region to calculate a region-wide per-trip estimate. Since these estimates were per trip, the second step was to calculate yearly rates of unreported catch. For this, we built two scenarios of the number of trips per boat in a year. The "high" scenario considered a 3-day local rule (high scenario), and therefore that fishers fish three days a week for 11 months (because of a reproductive ban in September) (Oyanedel et al. 2020). For the "low" scenario, we obtained data from SERNAPESCA on the number of registered trips for the region in 2015-2018. From this, we calculated an average per boat number of trips a year. Estimates from these two scenarios were compared to the annual quota limit for the VII region.

Table 9.2.3. Quantitative estimates of unreported catch and comparison to assigned quota in 2018 (in tons), data from Oyanedel et al. 2020a.

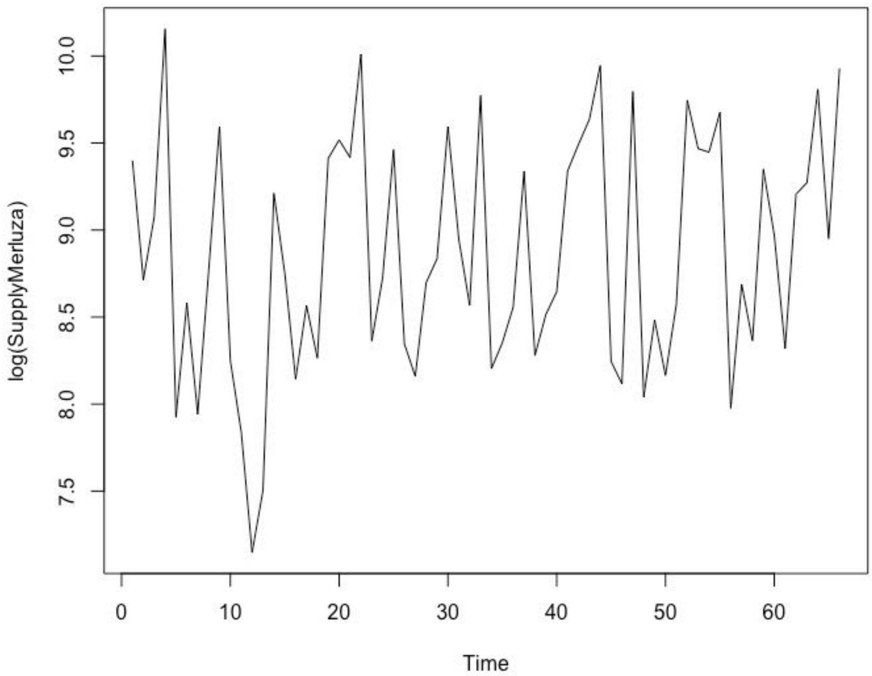
	High Scenario		Low Scenario
Low Quota Boats/trip (Std. Error)	0.73 (0.046)		
High Quota Boats/trip (Std. Error)	0.41 (0.063)		
Per year Region	24204		6658
Quota		3267	
Total Catch	27471		9925
Unreported Catch (%)	88		67

Econometric Model

We used an econometric model to assess the quantity and price determinant dimension of the market analysis level. We used three different datasets from the Chilean government. First, legal landings data which included anonymised legal transactions (reporting) from fishers to intermediaries per day for the 2014-2019 period in the VII region. We collapsed this daily data into monthly data for analysis. Second, we used data on enforcement effort by government authorities. This dataset included all enforcement activities done per day for the 2014-2019 period. We counted the number of enforcement activities per month in the VII region to obtain monthly enforcement indexes. Lastly, we explored average monthly ex-vessel price in the 2014-2019 period for common hake, as well as Pacific pomfret (*Brama australis*) at the country level. Pacific pomfret is an important fishery in the VII region of the country, in which common hake fishers actively participate. A log-log linear model was fitted using reported landings as a response variable and prices of common hake, pacific pomfret and enforcement indexes as predictor variables. Year and four seasons (Jan-Feb, March-April (representing Easter when consumer demand for hake is high), May-Jul, Aug-Dec) were used as dummy variables to account for temporal variation in reported landings. September was removed from the analysis because of a fishing ban that prevents reporting of common hake.

We specified several candidate econometric models. First, we tested for correlation between pairs of predictors with Pearson's product-moment correlation test and found no significant correlations. Then we tried various model specifications, starting with just season as a predictor, then adding year, enforcement, hake price and pomfret price. We also tested enforcement, hake price and pomfret price alone and log transformed. Moreover, we tested model structures where the response variable (common hake landings) was log-transformed. After several iterations, the best fit model (with the lowest AIC) included the log-transformed response variable and all predictors (enforcement, hake price, pomfret price and season and year as dummy variables) with both price predictors log-transformed. This model specification made sense based on economic theory and empirical evidence.

We took several steps to validate the econometric model. First, we tested whether the response variable (supply of common hake) was stationary using a Dickey-Fuller test. We found that it was non-stationary (Dickey-Fuller = -3.2423, p-value = 0.089, Ho = non-stationary). The non-stationarity was a result of two clear outliers (January and February 2015; Supplementary Material). There was no obvious reason for the abrupt decrease in recorded landings in those months. Therefore we replaced these points with an average of the values of the corresponding months in other years (Supplementary Figure). We decided not to remove these values as our data set wasn't big enough and removing two months would have unbalanced the dataset with respect to analysis of seasons within years. After replacing these values, the landings data were stationary (Dickey-Fuller = -3.6729, p-value = 0.034, Ho = non-stationary). Consequently, we proceeded with the analysis using the dataset with the replaced values



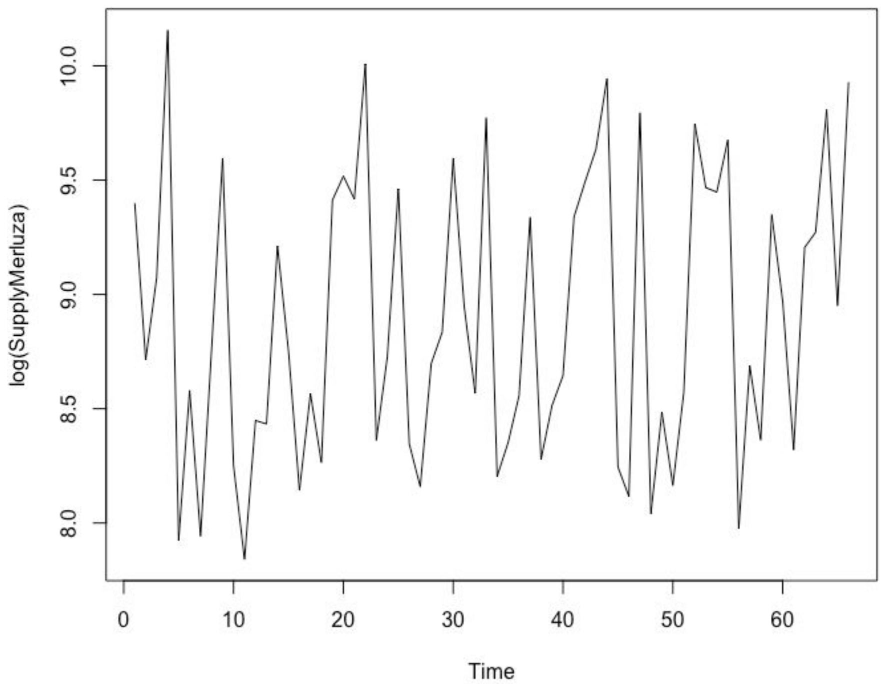


Table 9.2.4. Log of landings monthly averages (2014-2019) for the data before (upper panel) and after replacement (lower panel).

We then used a Ramsey's RESET test for functional form to validate the choice of using a log-log model. Results supported the hypothesis that the model was correctly specified (RESET = 2.89, p-value = 0.064, Ho = model is correctly specified). We tested for multicollinearity between predictive variables using Variance Inflation Factors (VIF) and found that all predictor variables had VIF values <3.3, showing no multicollinearity. We used a studentized Breusch-Pagan test for residual heteroskedasticity, and found no heteroskedastic residuals (BP = 16.496, p-value = 0.123, Ho = variance of the residuals is constant). We tested serial residual autocorrelation with a Durbin-Watson test and found no autocorrelation of residuals (Autocorrelation=0.0401, p-value = 0.188, Ho = no autocorrelation). Finally, we tested residual stationarity with a Dickey-Fuller test and found residuals were stationary (Dickey-Fuller = -4.2384, p-value = 0.01, Ho = residuals are non-stationary).

9.3. Supplementary Material Chapter 6

Appendix S1. Open- ended Key Informant Interviews

Key-informant open-ended semi-structured interviews started with an explanation of the project scope and objectives and followed with a list of reference questions (see below). Interviews were performed during March-April 2019. Due to COVID-19, all interviews were done over the phone or email. Before each interview, we informed participants that participation was voluntary and that participants could refuse to answer any particular question. We used snowballing sampling, starting with leaders of the main fishers' associations in the region and known contacts of the researchers. In total, we interviewed 23 informants, including fishers, government officials, intermediaries, vendors, NGOs staff, and enforcement agents. Depending on the key-informant's role, some questions were omitted, and others were explored in more depth. Interviews over the phone lasted between 30 and 90 minutes. The study complied with Oxford University's ethical requirements (approval number R68516/RE001). These methods represent a subsample of those reported in Oyanedel et al. 2021.

Key-informant interview list of reference questions

e. Factors affecting actor’s decision to trade legal or unreported products

- What are the main factors that affect the decision to trade legal or unreported/illegal common hake?
- Do intermediaries always carry legal hake? How much?
- What determines the legal/illegal purchase ratio?
- Does this ratio vary?

- What affects its variability?

f. Operation of the legal/unreported market

- Can legal and unreported products be distinguished at the market?
- How does fish enter the market without a permit?
- Is there a price premium for legal products? How much is it?

g. Overarching market dynamic

- What are the most important factors that determine prices?
- Does fishing activity respond to prices? Or, alternatively, are prices driven by the quantities of fish landed

h. Prior ranges

- What is the price of a legal and an illegal unit, at the port and at the market?

Appendix S2. Model runs without and with enforcement data

To test the appropriateness of including weekly enforcement effort data into the model, we first run the model with a randomly generated weekly vector of enforcement effort (with minimum and maximum similar to data). We then run the model again, included the weekly enforcement effort data (average of 2014-2019). We found that including the enforcement data helped better predict the legal landings data dynamics (Figure SM 1). This was especially so for the peaks in legal landings around week 11-16 and 33-37.

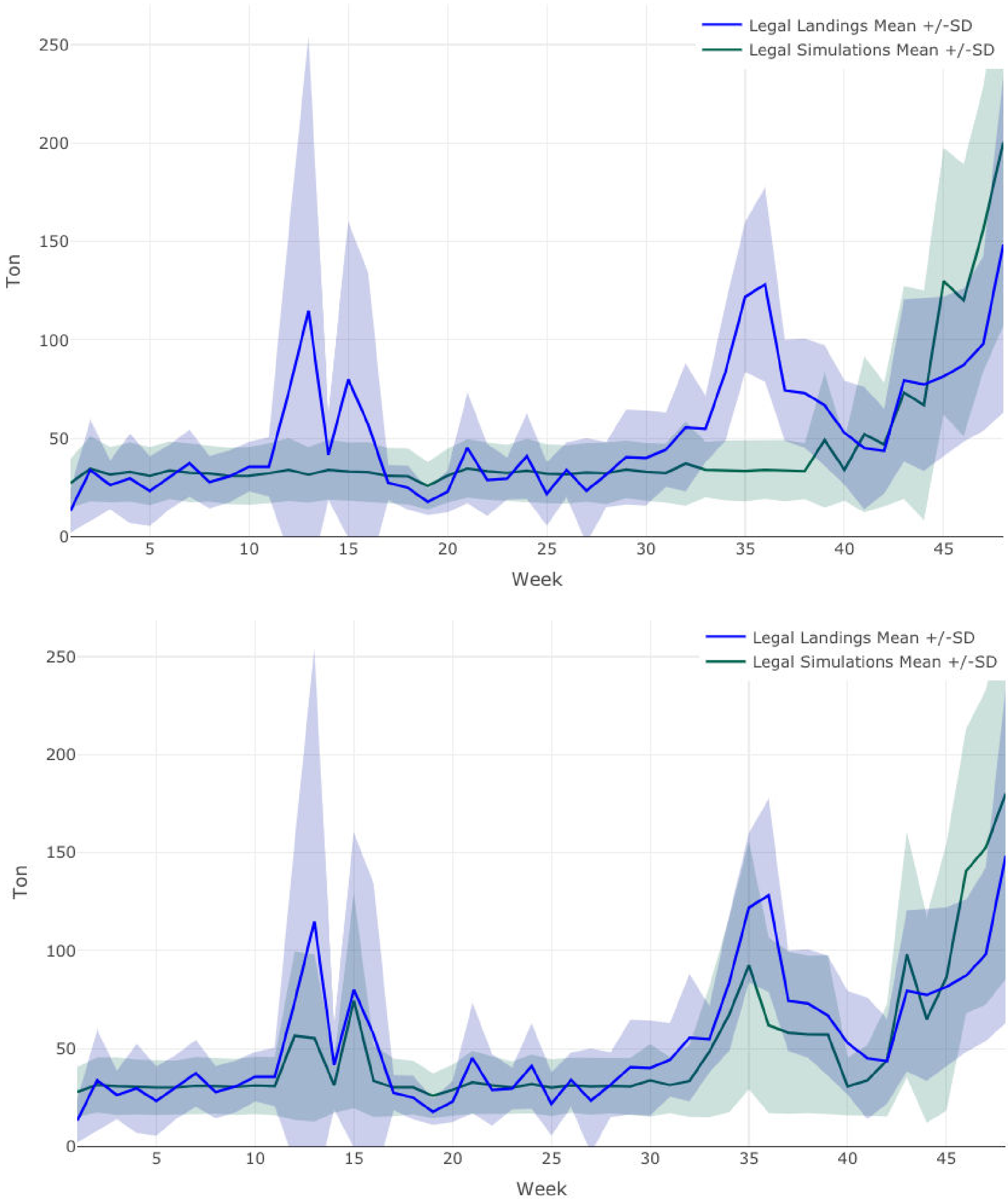


Table 9.3.1. Model run without (upper panel) and with (lower panel) weekly enforcement effort data

Appendix S3. Prior range construction and data sources

Table 9.3.2. Parameters used in the simulation model case study application and their source.

Parameter	Description	Type	Value	Source
Theta: Efficiency of enforcement (θ_e)	Fraction of illegal units that each enforcement action detects. We fixed this parameter for each simulation, so the same value is used across weeks	Prior – Uniform distribution	Range: 2e-7 - 2e-8 units/enforcement action	Number of activities from enforcement records and overall illegal units traded estimates from Oyanedel et al. 2021. See below for detail
Beta: Price premium (β_l)	Price paid to traders for legal units at the end-market. Unit is Chilean pesos. We fixed this parameter for each simulation	Prior – Uniform distribution	Range: CLP 0-3,000 (4,3 USD)	Range obtained from key informant interviews
Minimum legal fraction per week ($x_{l,m}$)	Percentage set minimum of legal units that traders take each week. We fixed this parameter for each simulation	Prior – Uniform distribution	Range: 10-20% of a truckload	Range obtained from key informant interviews
Price elasticity (ϵ_p)	Elasticity of the price of units at the end-market, depending on units available. We fixed this parameter for each simulation and used the same value for legal and illegal units	Prior – Uniform distribution	Range: proportion from 0 to 1	Broad range used because we obtained no information from key informant interviews
Cost elasticity (ϵ_c)	Elasticity of the cost of units at the port, depending on units available. We fixed this parameter for each simulation and used the same value for legal and illegal units	Prior – Uniform distribution	Range: proportion from 0 to 1	Broad range used because we obtained no information from key informant interviews

Permit fee (V_l)	Value charged to traders for legal units at the ports. Unit is Chilean pesos. We fixed this parameter for each simulation	Data	CLP$ 3,000 (4,3 USD) except towards end of the year	Value obtained from key informant interviews
Permit fee elasticity (ϵ_v)	The rate at which permit fee value decreases towards the end of the year. We fixed this parameter for each simulation	Prior – Uniform distribution with range	Proportion from 0.15 to 0.25	We obtained the range for this parameter through iterations of the model and fit of data, see below for formula
Total units traded (δ)	Sum of legal and illegal units. This parameter changes each week, when we draw random values from the prior	Prior – Uniform distribution	Range: 2000 – 13333 units/week	Upper limit obtained from illegal estimates from Oyanedel et al. 2021. The lower limit is no illegal landings
Legal units traded ($x_{l,d}$)	Data on legal units traded each week	Data – Weekly mean value and SD for 2014-2019 period	See Table S2	From government landings data
Enforcement actions (θ_a)	Data on the number of enforcement actions (officers doing enforcement in the region) each week	Data – Weekly mean value and SD for 2014-2019 period	See Table S2	From government enforcement data
Price reference (P_R)	We used a reference price to calculate price considering elasticity. We used a reference quantity, which we set at the mean of the total landing's prior. We fixed this parameter across weeks and simulations	Data	CLP$ 30,000 (43 USD)	Value obtained from key informant interviews

Cost reference (C_R)	We used a reference cost to calculate price considering elasticity. We also used a reference quantity, which we set at the mean of the total landing's distribution. We fixed this value across weeks and simulations	Data	CLP$ 15,000 (21,5 USD)	Value obtained from key informant interviews
Fixed fine if detected (f_i)	Monetary fixed fine if detected trading illegal units, which we fixed across weeks and simulations	Data	CLP 9,200,00 (13,090 USD)	From government legislation
Fine per illegal unit constant (c_i)	Monetary fine if detected trading illegal units, per unit, fixed across weeks and simulations	Data	$4P_l$	From government legislation
Overall and stage-specific quota (Q)	Total quota for legal trading in a year, which we fixed across simulations. The government gives this quota in 3 periods within the year	Data – Mean value for 2014-2019	98,000 units. See below for periods	From government registers

a. Efficiency of enforcement (θ_e)

For the efficiency of enforcement (θ_e) parameter, the lower range of the prior was calculated as:

$$\theta_e = x_c/(\theta_E n_T i_r)$$

Where: x_c= total amount of units confiscated by the enforcement authority during the 2014-2019 period (10,230); θ_E= sum of the effort in terms of number of enforcement visits during the 2014-2019 period (1,538); n_T= total units traded (3,788,373) considering legal catch, and using

i_r from Oyanedel et al. 2021 that illegal rate maximum is 88%. For the upper range of the prior, we multiplied this lower range value by ten, to account for a broad dispersion of how much the real value of θ_e could be.

b. Permit fee (V_l) equation

Based on the permit fee elasticity ($\in_v$), we calculated V_l in the model as follow:

$V_l = max(0, V_r(1 - \in_v(max\ (0, R - R_0)\ /R_0)))$

Where: V_r= permit fee reference value (CLP 3,000); $R = ql_t/(T$-t+1); $R_0 = Q/$(T+1); $ql_t =$ quota left in time t; $Q =$ overall quota; T= time horizon.

c. Overall and staged quota (Q)

The overall quota for the 2014-2019 period mean was 98,000 units, given in stages, according to government data as:

- January= 8,613
- February to June=49,000
- July to December=98,000

Data sets used

Table 9.3.3. Data sets used: landings mean (+/- SD) per week and enforcement (mean) count of visits per week in the region.

Week	Landings			Enforcement
	Mean	Mean + SD	Mean - SD	Mean
1	493	902.49	3.51	1.33
2	1258	2203.79	312.21	4.00
3	977	1434.60	519.40	6.00
4	1101	1942.55	259.45	4.50
5	862	1518.96	205.04	2.33
6	1134	1739.31	528.69	4.17
7	1388	2019.79	756.21	5.00
8	1031	1521.88	540.12	5.50
9	1137	1627.28	646.72	4.83
10	1323	1791.84	854.16	4.83
11	1320	1874.06	765.94	5.67
12	2731	5767.54	-305.54	9.67
13	4254	9402.74	-894.74	9.33
14	1544	2389.20	698.80	4.17
15	2964	5935.31	-7.31	11.83
16	2117	4973.98	-739.98	6.17
17	1022	1353.31	690.69	6.33
18	927	1340.03	513.97	3.17
19	657	900.70	413.30	3.17
20	851	1241.07	460.93	4.33
21	1675	2715.87	634.13	6.00
22	1072	1749.47	394.53	5.67
23	1098	1496.17	699.83	4.33
24	1522	2329.96	714.04	5.67
25	812	1409.37	214.63	2.67

26	1264	1780.41	747.59	4.33
27	870	1859.05	-119.05	2.17
28	1173	1785.84	560.16	3.33
29	1504	2398.33	609.67	3.83
30	1486	2384.21	587.79	5.33
31	1639	2336.42	941.58	3.67
32	2060	3264.83	855.17	4.83
33	2030	2656.30	1403.70	7.17
34	3099	4386.78	1811.22	8.50
35	4517	5926.72	3107.28	10.83
36	2091	4705.74	-523.74	7.50
37	4314	6070.10	2557.90	7.50
38	2647	3659.65	1634.35	7.33
39	2590	3331.04	1848.96	7.17
40	2316	3352.96	1279.04	3.00
41	1760	2829.25	690.75	4.00
42	1549	2439.28	658.72	4.83
43	2336	4086.18	585.82	7.33
44	3071	4191.20	1950.80	4.33
45	2896	4470.63	1321.37	3.50
46	2868	4262.47	1473.53	5.83
47	3532	5136.05	1927.95	5.50
48	5350	8660.61	2039.39	3.50

Appendix S4. Mahalanobis distance distribution

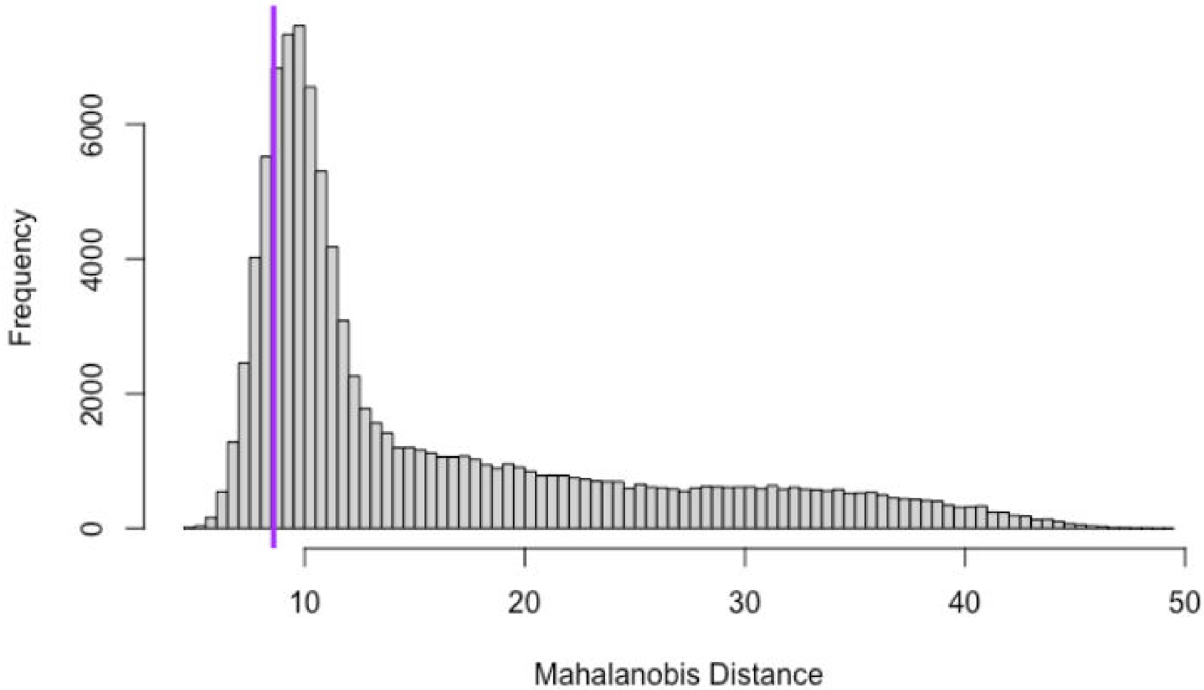
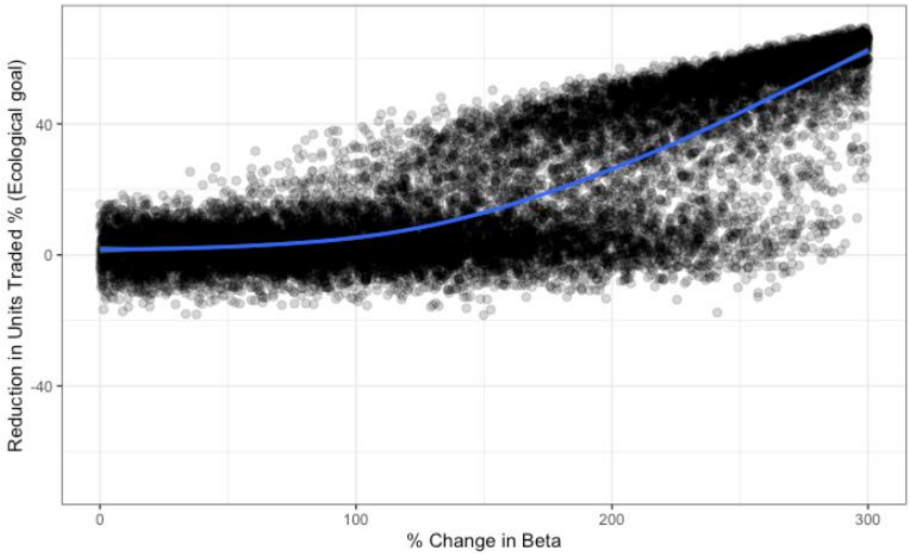
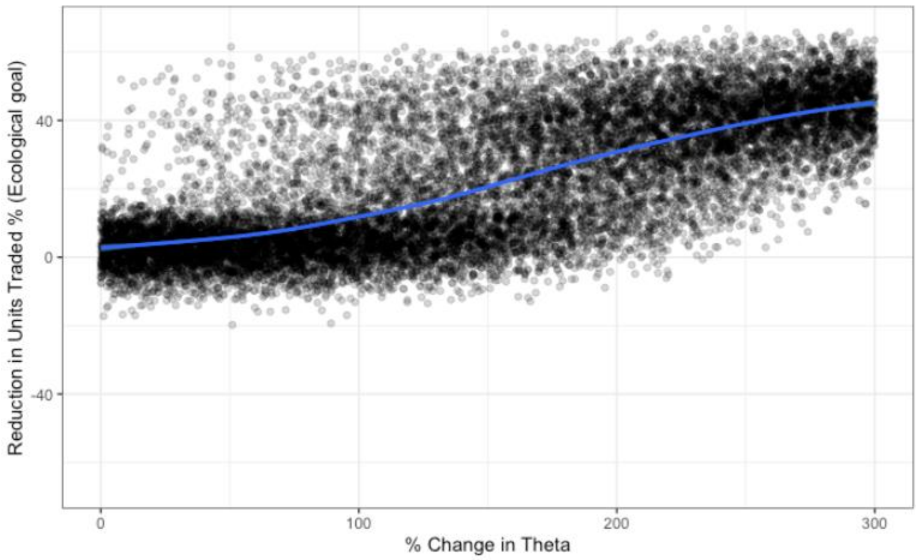


Table 9.3.4. Mahalanobis distance distribution of model results. Purple line indicates threshold, so simulations to the left are accepted (~15%).

Appendix S5. Sensitivity Analysis





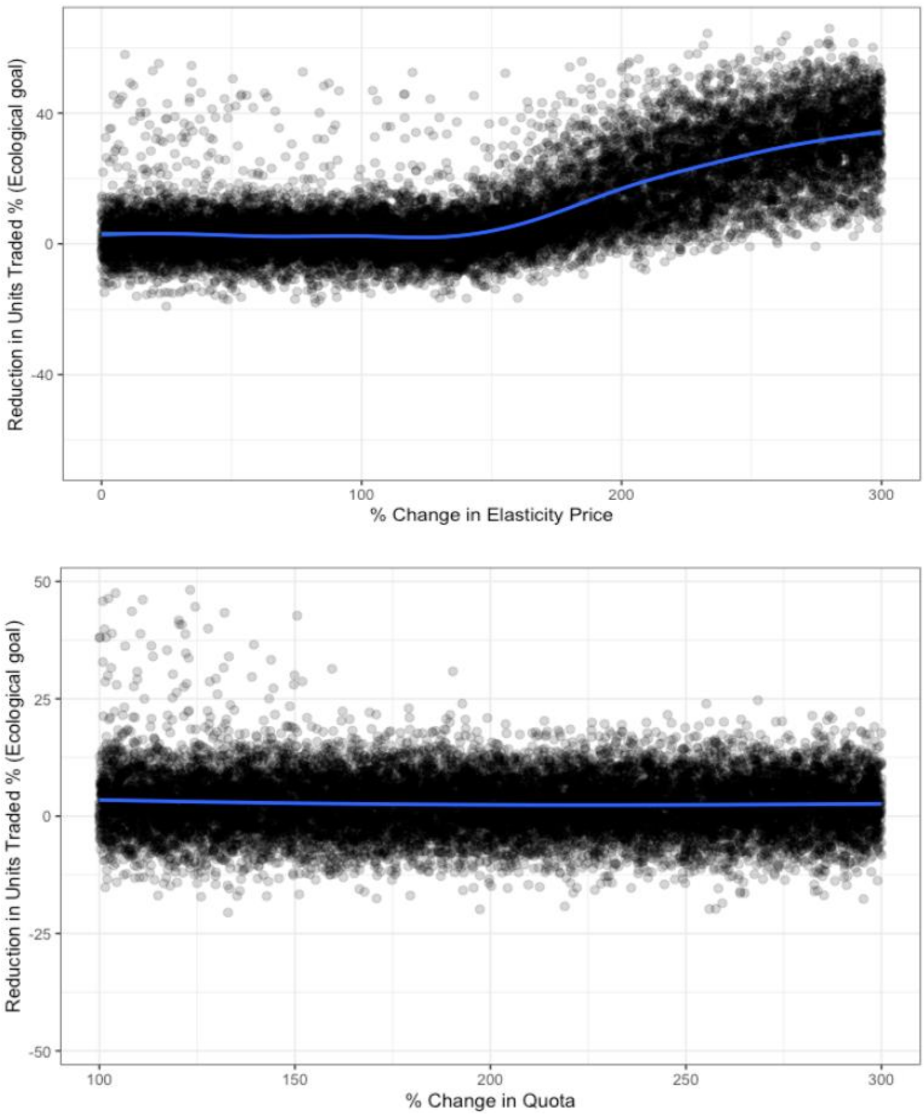


Figure 9.3.1. Evaluation of ecological sustainability of the fishery improvements (as measured by decreases in units traded) when changing the value of parameters that are proxies for possible policy levers: a) theta (efficiency of enforcement); b) beta (price premium); c) price elasticity, and d) quota. Black dots represent simulation results, and the blue line is the smoothed conditional mean.

R Code

Load required packages

```
```{r, cache=FALSE}

library(ggplot2)

library(plotly)

```
```

Load data

```
```{r, cache=FALSE}

legal_units_data   <-  #Here load a vector of data for legal units traded (mean). For instanc
e, use per week value. If no data available can use the following to try the model read.csv('https://r
aw.githubusercontent.com/emilemathieu/illegal_fishing/master/data/unitsYear.csv')

enforcement_data <-   #Same than units, could use this dataset for demonstration: read.csv ('https
://raw.githubusercontent.com/emilemathieu/illegal_fishing/master/data/enfcomnocom.csv')

```
```

Setting variable

```
```{r, cache=FALSE}
```
```

```
###Setting variables for the model. All monetary values are in Chilean pesos

iterations= 10000    ###  Number of times the model is ran

weeks= 48          ###  Weeks in a normal year, for demonstration purposes we use 48 which excludes September when there is no fishing in our case study

legal_units_data  = legal_units_data[1:weeks,]

cost = 500         ###  Approximate per unit traded

fine = 9.2e+05      ###  Fine expected if detected trading illegal products

permit_fee = 3000    ###  Use if there is a cost difference between legal and illegal products at the harvest level

c_ref= 15000       ###  Reference cost per unit

p_ref= 30000       ###  Reference price per unit

mean_land=mean(legal_units_data$mean)*weeks


#### Creates a vector of quota available in each week. Can be the same value across weeks, or can be given in stages (see Supplementary Material)

quota_overall= 98000 ###  Yearly overall quota for the species

quota_available        = (1:weeks)

quota_available[1:weeks] = quota_overall


#### Create a data frame of enforcement activities mean per week

enforcement=as.data.frame((enforcement_data[,3]))

```
```
```

Create priors for Approximate Bayesian Approach

```
```{r, cache=FALSE}

###First, create ranges

####Prior range for beta (price premium)

beta_min=0    ### price premium lower limit

beta_max=3000 ###price premium higher limit


####Prior range for overall units trade

###First define overall range of units traded and how much are illegal units traded ratio

MaxIllegalrate=0.85    #85% Illegal, higher limit (this can be changed if there is an estimate of % of i

llegal units traded in the market)

MinIllegalrate=0.0     #0% Illegal, lower limit


###Then calculate Prior range

T_min=(quota_overall/weeks) * (1/(1-MinIllegalrate))  ## Min overall units traded

T_max=(quota_overall/weeks) * (1/(1-MaxIllegalrate))  ## Max overall units traded

qr=(T_min+T_max)/2                              ## Reference quantity for elasticities


####Prior range for Theta (probability of detection per unit for each enforcement action)

theta_max= 2e-7    ### See supporting information

theta_min= 2e-8


###Prior range for cost elasticity
```
```

```
E_minC=0

E_maxC=1


###Prior range for price elasticity

E_minP=0

E_maxP=1


###Prior range for end of year permit_fee elasticity

permit_feeend_min=0.15   ### See supporting information, but this might not be necessary outsid
e of the case study. If there is no need for this parameter, then use 0

permit_feeend_max=0.25


###rior range for minimum legal per week

minlegal_min=0.1   ### See supporting information

minlegal_max=0.2


####This creates the priors based on the ranges above

beta_P           = runif(n=iterations, min = beta_min, max = beta_max)

theta_P          = runif(n=iterations, min=theta_min,  max=theta_max)

T_I             = runif(n=iterations, min=T_min,  max=T_max)

permit_fee_elasticity_P  = runif(n=iterations, min=permit_feeend_min,  max=permit_feeend_max)

Price_elasticity_P = runif(n=iterations, min=E_minP,  max=E_maxP)
```

```
Cost_elasticity_P  = runif(n=iterations, min=E_minC,  max=E_maxC)

min_legal_P       = runif(n=iterations, min=minlegal_min,  max=minlegal_max)

          ```
```

Run Simulation model

```
          ```{r, cache=FALSE}

          ###Tracks time it takes to run

start_time <- Sys.time()

start_time

          ##Create matrix for results

results         = matrix(0,iterations,14)     ### Keeps track of simulation results

legal_units      = matrix(0,weeks,iterations)  ### Keeps track of legal units in each simulation

illegal_units    = matrix(0,weeks,iterations)  ### Keeps track of illegal units in each simulation

permit_fee_value = matrix(0,weeks,iterations)  ### Keeps track of permit_fee value in each simulat
ion

Quota_left       = matrix(0,weeks,iterations)  ### Keeps track of quota left in each simulation

ratio           = matrix(0,weeks,iterations)  ### Keeps track of quota left in each simulation


### Start loop of iterations

for (simulation in 1:iterations) ### Start iterations

{
```

```
###Sample each parameter from the prior


beta                = sample(beta_P,1)

theta               = sample(theta_P,1)

price_elasticity      = -(sample(Price_elasticity_P,1))

cost_elasticity       = -(sample(Cost_elasticity_P,1))

permit_fee_elasticity  = (sample(permit_fee_elasticity_P,1))

min_legal           = (sample(min_legal_P,1))


##Start loop of weekly simulations

weekly_simulation  =  matrix(0,weeks,11)


for (t in 1:weeks)

{

prob_detection = theta*enforcement[t,1] # uses the enforcement data per week, otherwise enfor
cement could be a vector of 1s of length weeks

x_T          = sample(T_I,1)        # Sample units for that week


###Calculates quota left for end of year and value of permit_fee in t

quota       = quota_available[t]

quota_left  = (quota-sum(weekly_simulation[,1]))

rate_r      = quota_overall/(weeks+1)

rate        = quota_left/(weeks-t+1)
```

```
permit_fee_t= max(0, permit_fee * (1 - permit_fee_elasticity * (max(0, rate - rate_r) / rate_r)))


#Calculates prices and costs
C_L=  (c_ref *  (1-((cost_elasticity*((qr-x_T)/qr)))))  + permit_fee_t #Elasticity of cost for legal box
es, wrt units + permit_fee
C_I=  (c_ref *  (1-((cost_elasticity*((qr-x_T)/qr)))))            #Elasticity of cost  for illegal boxes, wrt
units
P_L=  (p_ref  * (1-((price_elasticity*((qr-x_T)/qr))))) + beta        #Elasticity of price legal boxes, wrt
units + beta
P_I=  (p_ref  * (1-((price_elasticity*((qr-x_T)/qr)))))            #Elasticity of price illegal boxes, wrt u
nits


###Calculates x_l (legal units), x_i (illegal units) with constraint that x_l cannot be higher than x_T,
or lower than 0 and there is no trading if there is no quota left
x_l      = x_T-((((P_I-C_I-P_L+C_L-(fine*  prob_detection))/(8*  prob_detection*(P_L))))) ##legal uni
ts (here we use 8 insted of 2 as indicated in the manuscript, because fines in Chile the variable fine
is 4P_L (Supplementary Material)
min_bound  = if(quota_left>0) {min_legal * x_T} else 0
max_bound  = min(x_T, quota_left)
x_l      = if(x_l <= max_bound) {x_l} else {max_bound}
x_l      = if(x_l <= min_bound) {min_bound} else {x_l}
x_i      = if(quota_left>0) {x_T-x_l} else 0
```

```
weekly_simulation[t,1] = x_l

weekly_simulation[t,2] = x_i

weekly_simulation[t,3] = C_L

weekly_simulation[t,4] = C_I

weekly_simulation[t,5] = P_L

weekly_simulation[t,6] = P_I

weekly_simulation[t,8] = permit_fee_t

weekly_simulation[t,9] = quota_left

weekly_simulation[48,9] = quota_left - x_l

weekly_simulation[t,10] = (x_i/(x_i+x_l))

weekly_simulation[t,11] = (x_l*C_L) + (x_i*C_I)


}




### Fill matrices for posterior analysis

legal_units[,simulation]      = weekly_simulation[,1]

illegal_units[,simulation]    = weekly_simulation[,2]

permit_fee_value[,simulation] = weekly_simulation[,8]

Quota_left[,simulation]       = weekly_simulation[,9]

ratio[,simulation]            = weekly_simulation[,10]
```

```
## Fill results of each simulation, by summing across weeks and capture prior values
results[simulation,1] = sum(weekly_simulation[,1])
results[simulation,2] = sum(weekly_simulation[,2])
results[simulation,3] = sum(weekly_simulation[,1])+sum(weekly_simulation[,2])
results[simulation,4] = beta
results[simulation,5] = theta
results[simulation,6] = price_elasticity
results[simulation,7] = cost_elasticity
results[simulation,8] = permit_fee_elasticity
results[simulation,9] = sum(weekly_simulation[,2])/(sum(weekly_simulation[,1])+sum(weekly_simulation[,2])) ## Ratio
results[simulation,10]= simulation
results[simulation,12]= min_legal

}

end_time <- Sys.time()
end_time - start_time
```

Mahalanobis distance rejection criteria calculation

```
```{r, cache=FALSE}

#Create matrices and units values needed to calculate Mahalanobis distance

SimResults       = data.frame(results)

mahalanobis_dist  = matrix(0,iterations,2)

true_mean        = apply(legal_units_data, 1, mean, na.rm=TRUE)

true_std         = apply(legal_units_data, 1, sd, na.rm=TRUE)

true_cov         = diag(true_std ** 2)




#Calculate the Mahalanobis distance for each simulation result

for (m in 1:iterations)

{

mahalanobis_dist[m,1]= sqrt(mahalanobis(legal_units[,m], true_mean, true_cov))

mahalanobis_dist[m,2]=m

}


##Reject those simulations above the threshold

p=0.95              ## Rejection criteria

threshold           = sqrt(qchisq(p=p, df=weeks))

mahalanobis_dist_filter= subset(mahalanobis_dist,mahalanobis_dist[,1]<threshold)


## Plot distances and threshold (line)

hist      (mahalanobis_dist[,1], breaks=100, xlab="Mahalanobis Distance", ylab="Frequency of Simul
```
```

```
ations")
abline    (v=threshold, col="purple",  lwd=3)
```

```
          ## Select those simulations that were accepted
Accepted_Legs       = legal_units[,c(mahalanobis_dist_filter[,2])]     ##Select those legal vectors tha
t passed the filter
Accepted_Ills       = illegal_units[,c(mahalanobis_dist_filter[,2])]    ##Select those illegal vectors that
passed the filter


filter        = mahalanobis_dist_filter[,2]
SimResults     = subset(SimResults,SimResults$X10 %in% filter)    ##Select parameter values of those
simulations that passed the filter


#Create posteriors variables for graphs
Legalboxes     = SimResults$X1
Illegalboxes   = SimResults$X2
unitsboxes     = SimResults$X3
Beta           = SimResults$X4
Theta          = SimResults$X5
ElasticityPrice= SimResults$X6
ElasticityCost = SimResults$X7
permit_feeEndofyear  = SimResults$X8
```

```
Minlegal      = SimResults$X12

Ratio         = SimResults$X9

          ```
```

Parameter Posterior Graphs

```
          ```{r, cache=FALSE}

          ###This code creates the graphs for the posterior distributions, figure 3


####Theta

options(scipen=999)

old.par <- par(mfrow=c(2, 3))

DDetIn   = density(Theta, n=iterations, adjust=3,from=theta_min, to=theta_max) #

yDetecIN = DDetIn$y

xDetecIN = DDetIn$x

plot(xDetecIN,yDetecIN, type="l",xlab="Theta (efficiencty of enforcement)",ylab="Probability densit
y", col="black", bty="n")


###Beta

DDetIn   = density(Beta, n=iterations, adjust=3, from=beta_min, to=beta_max)#

yDetecIN = DDetIn$y

xDetecIN = DDetIn$x
```

```
plot(xDetecIN,yDetecIN, type="l",xlab="Beta (price premium)",ylab="Probability density", col="black
", bty="n")



###Min Legal
DDetIn   = density(Minlegal, n=iterations, adjust=3, from=minlegal_min, to=minlegal_max)#
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
plot(xDetecIN,yDetecIN, type="l",xlab="Minimum legal fraction per week",ylab="Probability density
", col="black", bty="n")




###Price Elasticity
DDetIn   = density(-ElasticityPrice, n=iterations, adjust=3, from=0, to=1)#from=E_minP, to=E_maxP)
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
plot(xDetecIN,yDetecIN, type="l",xlab="Price elasticity",ylab="Probability density", col="black", bty=
"n")




###Cost Elasticity
```

```
DDetIn   = density(-ElasticityCost,   n=iterations, adjust=3, from=0, to=1) #from=E_minC, to=E_max
C
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
plot(xDetecIN,yDetecIN, type="l",xlab="Cost elasticity",ylab="Probability density", col="black", bty="
n")



##permit_fee Elasticity
DDetIn   = density(permit_feeEndofyear, n=iterations, adjust=3,  from=permit_feeend_min, to=per
mit_feeend_max)
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
plot(xDetecIN,yDetecIN, type="l",xlab="Permit fee elasticity",ylab="Probability density", col="black",
bty="n")

        ##Total units
old.par <- par(mfrow=c(2, 2))
DDetIn   = density(unitsboxes, n=iterations, adjust=3)
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
plot(xDetecIN,yDetecIN, type="l",xlab="Total units traded",ylab="Probability density", col="black", b
ty="n")
```

```
##Ratio
DDetIn   = density(Ratio, n=iterations, adjust=3)
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
p7      = plot(xDetecIN,yDetecIN, type="l",xlab="Ratio of illegal to total units",ylab="Probability dens
ity", col="black", bty="n")


##Illegalboxes
DDetIn=density(Illegalboxes, n=iterations, adjust=4)
SimY=DDetIn$y
SimX=DDetIn$x
plot(SimX,SimY, type="l",xlab="Illegal units",ylab="Probability density", col="black", bty="n")



## Legal Boxes
DDetIn   = density(Legalboxes, n=iterations, adjust=4)
yDetecIN = DDetIn$y
xDetecIN = DDetIn$x
p8      = plot(xDetecIN,yDetecIN, type="l",xlab="Legal units",ylab="Probability density", col="black",
bty="n")
```

Graph units over time and comparison to data

```
```{r, cache=FALSE}

#This code creates figure 4


##Calculate weekly means
unitsMean    = transform(Accepted_Legs, MEAN=apply(Accepted_Legs,1, mean, na.rm = TRUE))
IllegalMean  = transform(Accepted_Ills, MEAN=apply(Accepted_Ills,1, mean, na.rm = TRUE))
unitsSD      = transform(Accepted_Legs, SD  =apply(Accepted_Legs,1, sd, na.rm = TRUE))
IllegalSD    = transform(Accepted_Ills, SD  =apply(Accepted_Ills,1, sd, na.rm = TRUE))


###Create data frame with units data, mean and SD
units_plot        = matrix(0,weeks,9)
units_plot[,1]    = legal_units_data$mean
units_plot[,2]    = legal_units_data$mean_p_std
units_plot[,3]    = legal_units_data$mean_m_std


###Calculate means and SD for simulations legal
units_plot[,4]    = unitsMean$MEAN
units_plot[,5]    = unitsMean$MEAN+unitsSD$SD
units_plot[,6]    = unitsMean$MEAN-unitsSD$SD


###Calculate means and SD for simulations illegal
units_plot[,7]    = IllegalMean$MEAN
```
```

```
units_plot[,8]     = IllegalMean$MEAN+IllegalSD$SD

units_plot[,9]     = IllegalMean$MEAN-IllegalSD$SD

units_plot        = as.data.frame(units_plot)

boxtoton          = 27/1000


###Creates Graph

##Legal units simulations

units_Figure <- plot_ly(units_plot, x = ~seq(1:weeks), y = ~units_plot$V4*boxtoton, type = 'scatter',
mode = 'lines',
            line = list(color='rgb(0,100,80)'),
            name = 'Legal Simulations Mean +/-SD')
units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V5*boxtoton, type = 'scatter', mode = '
lines',
                   line = list(color = 'transparent'), name = 'High units',showlegend = FALSE)


units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V6*boxtoton, type = 'scatter', mode = '
lines',
                   fill = 'tonexty', fillcolor='rgba(0,100,80,0.2)', line = list(color = 'transparent'),
                   showlegend = FALSE, name = 'Low units')


##Data

units_Figure <- units_Figure%>% add_trace(units_plot, x = ~seq(1:weeks), y = ~units_plot$V2*boxt
oton, type = 'scatter', mode = 'lines',
```

```
            line = list(color = 'transparent'),
             showlegend = FALSE, name = 'High units')
units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V3*boxtoton, type = 'scatter', mode = '
lines',
             fill = 'tonexty', fillcolor='rgba(0,17,157,0.2)', line = list(color = 'transparent'),
             showlegend = FALSE, name = 'Low units')
units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V1*boxtoton, type = 'scatter', mode = '
lines',
             line = list(color='blue'),
             name = 'Legal units Mean +/-SD')



##Illegal units simulations
units_Figure <- units_Figure%>% add_trace(units_plot, x = ~seq(1:weeks), y = ~units_plot$V8*boxt
oton, type = 'scatter', mode = 'lines',line = list(color = 'transparent'),showlegend = FALSE, name = 'Hi
gh units')
units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V9*boxtoton, type = 'scatter', mode = '
lines',fill = 'tonexty', fillcolor='rgba(220,20,60,0.2)', line = list(color = 'transparent'),showlegend = FA
LSE, name = 'Low units')
units_Figure <- units_Figure %>% add_trace(y = ~units_plot$V7*boxtoton, type = 'scatter', mode = '
lines',line = list(color='red'),name = 'Illegal Simulation Mean +/-SD')
```

```
units_Figure <- units_Figure %>% layout(yaxis = list(range = c(0,270)))

units_Figure <- units_Figure %>% layout(showlegend = TRUE)

units_Figure <- units_Figure %>% layout(xaxis = list(title = "Week of the year"))

units_Figure <- units_Figure %>% layout(legend = list(x =0.67, y = 1))

units_Figure <- units_Figure %>% layout(yaxis = list(title = "Quantity traded (tons)"))

units_Figure

        ```
```
```