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

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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 overarching 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, <i>Merluccius gayi gayi</i> 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.
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Dear Co-Editors-in-Chief Dr Barceló and Dr Gan,

Attached please find our manuscript entitled “*A framework for assessing and intervening in markets driving unsustainable wildlife use*”. The unsustainable use of wildlife is a pervasive problem, and the role that markets play in driving unsustainability is still unclear. Formalising a framework that integrates different research fields and makes use of data obtained using mixed methods can help researchers to improve understanding of the role of markets in driving unsustainable use, inform policy and shape interventions towards long-term solutions.

This paper fits the Aim and Scope of the journal as it provides an interdisciplinary approach to a critical environmental problem; the unsustainable use of wildlife. Moreover, we offer a generalisable approach to showcase the utility of the framework. We consider that this work significantly progresses the fundamental understanding of how different aspects of wildlife markets interrelate. We believe it will be of interest of a broad readership dealing with issues related to how markets drive unsustainable wildlife use. Practitioners, scientists and policy-makers from different biomes will benefit from the lessons drawn in our work, since unsustainable wildlife use is a threat to marine, terrestrial and freshwater ecosystems alike.

This manuscript is original work and has not been published elsewhere. All co-authors agree with the manuscript content and submission. We acknowledge all funding sources that supported this work.

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Thank you for the opportunity to submit this manuscript for review. Please feel free to contact us via email with any questions.

Sincerely,
Rodrigo Oyanedel, Stefan Gelcich and EJ Milner-Gulland.

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

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Figure 1. A framework for assessing and intervening in markets driving unsustainable wildlife use

Highlights

- We propose a novel framework to assess and intervene in markets driving unsustainable wildlife use
- This framework integrates different analytical levels to account appropriately for the complexity of wildlife markets
- We applied the framework in a data-limited small-scale fishery case study, highlighting the framework’s utility for identifying interventions to improve sustainability
- Tackling markets driving unsustainable wildlife use requires approaches that integrate the different aspects that define wildlife market dynamics

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

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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 overarching 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.

Keywords: theory of access; econometrics; supply-chains; sustainable use; biodiversity conservation; natural resources.

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., 2020; 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 and Milner-Gulland, 2006; Lunstrum and 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 (e.g. Damania et al., 2005; Ling and Milner-Gulland, 2006; McNamara et al., 2016; Milner-Gulland and 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 and Ribot, 2020; Ribot and 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 and 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 overarching 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).

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92 Previous work has looked at motivations for the use and consumption of wildlife
93 products (Thomas-Walters et al., 2020), provided frameworks for analysing illegal wildlife
94 trade (Phelps et al., 2016) and theorized on how wildlife supply and demand might change
95 under different scenarios (Bulte and Van Kooten, 1999; Chen and 't Sas-Rolfes, 2021;
96 Crookes, 2017; Crookes and Blignaut, 2015; Damania et al., 2005). To progress beyond
97 sectoral analyses, we here propose a framework for assessing and intervening in markets
98 driving unsustainable wildlife use which integrates the actor, inter-actor and market levels.
99 This will assist in the identification of interventions that can help reduce unsustainable
100 wildlife use, especially in incomplete or data-limited setting. We first describe the structure
101 of the framework, specifying each of the components and how to integrate their
102 interactions across different scales. We then apply the framework to a data-limited small-
103 scale fishery case study, to showcase the utility of the approach. Insights from the
104 application of the framework provided relevant, tailored management recommendations
105 for improving sustainability in the fishery. We finish by offering recommendations on how to
106 use the framework and discussing its relevance and limitations.

2) The Framework

2.1 Wildlife Markets

In the framework, wildlife markets are structured into three components (Figure 1).

Harvesters refer to those who directly interact with wildlife and extract it from nature through fishing, hunting, snaring, logging, mushroom picking, etc. Intermediaries refer 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.

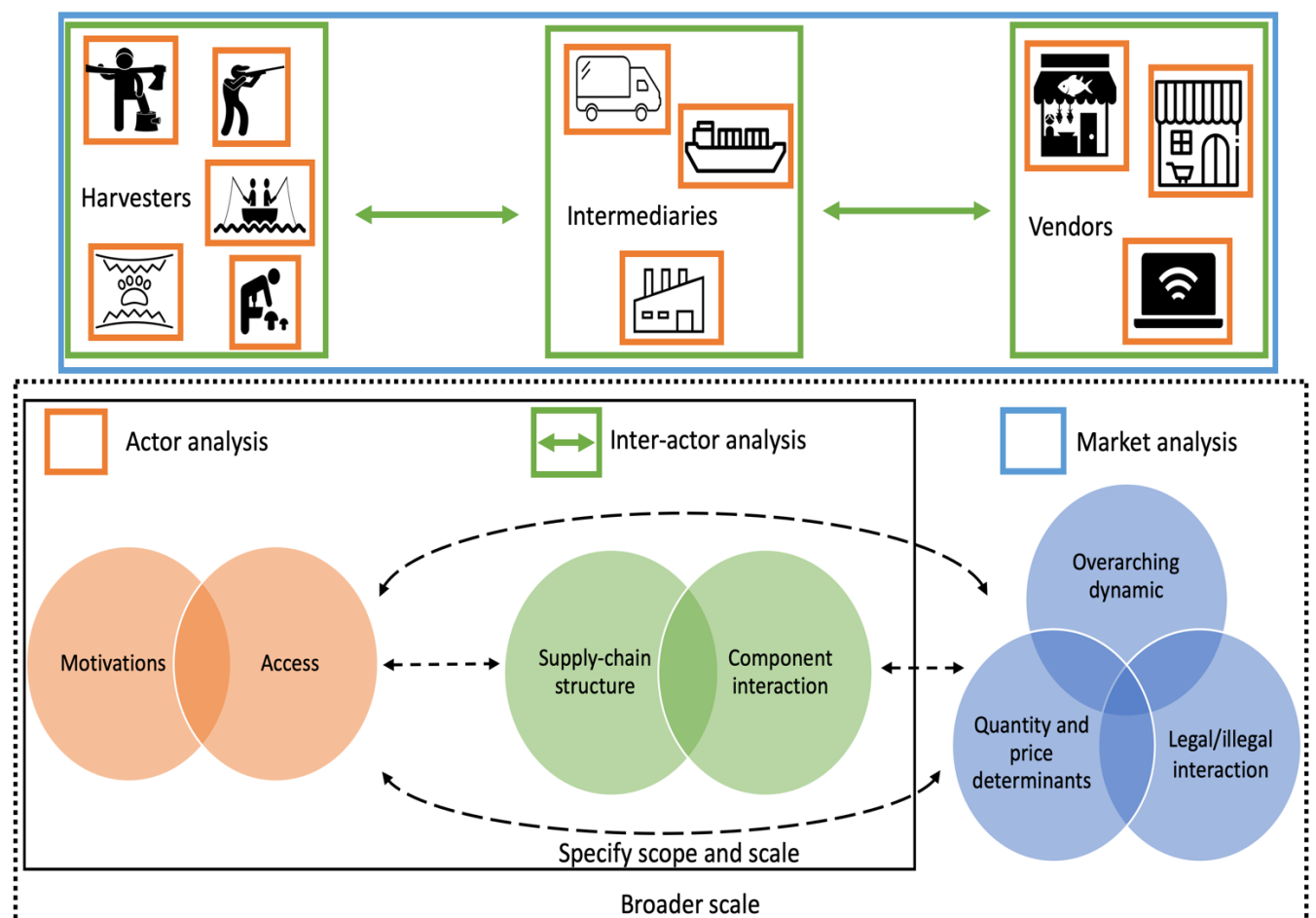


Figure 1. A framework for assessing and intervening in markets driving unsustainable wildlife use (print color).

2.2 Actor Analysis

The first level of analysis, actor, assesses the characteristics of actors that participate in the market (Table 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), the theory of planned behaviour, instrumental and/or normative approaches can be used to frame evaluations of behavioural drivers (Fairbrass et al., 2016; Oyanedel et al., 2020a). Methodologies to assess these motivations include surveys, key-informant interviews and behavioural economic methodologies such as contingent valuation and choice experiments (Bova et al., 2018; 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 and 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 and 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).

2.3 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). 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 *component interaction 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).

2.4 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 and 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 *overarching dynamic 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).

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.

2.5 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. For instance, when new buyers emerge for a certain species or product, overall demand can increase, leading to unsustainable exploitation. In other cases, unsustainable use might be caused by external factors changing the dynamics of the system, for example when legal supply is reduced through legislation, leading to increases in prices which can drive higher illegal exploitation levels. 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.

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.

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

251

252 Applying the framework allows the user to transparently conceptualise a wildlife
253 market system. This can then act as a guide for identifying interventions that address the
254 specific characteristics of the market that might be driving unsustainable wildlife use.
255 Identifying interventions involves integrating the results of the different analytical levels,
256 considering the interactions within and between analytical levels. Selecting and predicting
257 which of the set of feasible interventions will best assist in reducing the selected
258 unsustainability problem is beyond the scope of the framework. However, we provide some
259 insights into how to select interventions. For instance, participatory processes can be used
260 to choose amongst the interventions selected using the framework, involving communities
261 and resource-users in finding the most appropriate intervention (Travers et al., 2016).
262 Alternatively, cost-benefit analysis can be used to predict which interventions will provide
263 the best value for money. Moreover, before-after-control-intervention analyses can help to
264 assess the effect of specific interventions or changes in the system (Ferraro et al., 2019).

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Table 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	<ul style="list-style-type: none"> - Key informant interviews and surveys - Economic methods (e.g. choice experiments, contingent valuation) - Cost-benefit analysis - Risk profiles - Typology construction 	<ul style="list-style-type: none"> - 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 and Trost, 1998; Ferrier, 2008; Jouffray et al., 2019; Milner-Gulland and Clayton, 2002; 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	<ul style="list-style-type: none"> - Key-informant interviews - Literature review - Social network analysis - Access mapping - Typology construction 	<ul style="list-style-type: none"> - 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 	(Peluso and Ribot, 2020; Purcell et al., 2017; Ribot, 1998; Ribot and 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 products from the wild to consumers	<ul style="list-style-type: none"> - System mapping - Key-informant interviews - Literature review - Social network analysis 	<ul style="list-style-type: none"> - 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 and Viswanadham, 2007; González-Mon et al., 2019; Jena et al., 2017)

	Component interactions	The way that actors participating in each market component compete: oligopoly, perfect competition, monopoly or monopsony	<ul style="list-style-type: none"> - Key-informant interviews - Literature review - Econometric analysis 	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Key-informant interviews - Econometric analysis 	<ul style="list-style-type: none"> - 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 and Whitmarsh, 1987; McNamara et al., 2019; Pitt, 1981)
	Overarching dynamic	The interplay between different attributes that together suggest if the overarching dynamic is dominated by supply or demand-driven processes	<ul style="list-style-type: none"> - Key-informant interviews - Econometric analysis 	<p>If demand-driven:</p> <ul style="list-style-type: none"> - Increase the availability of alternative products - Change consumer preferences - Introduce market regulations <p>If supply-driven:</p> <ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Key informant interviews - Sensitive questioning surveys - Econometric analysis 	<ul style="list-style-type: none"> - 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 and 't Sas-Rolfes, 2021; Oyanedel et al., 2018; Zeller et al., 2015)

3) Common hake fishery case study as an application of the framework

3.1 Select sustainability problem and define scope and scale

Common hake (*Merluccius 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 and 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. 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 overarching 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.

3.2 Actor-level analysis

3.2.1 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)).

3.2.2 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.

3.2.3 Typology construction

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 2).

Table 2. 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
	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
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.
	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.
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.
	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.

3.3 Inter-actor level analysis

3.3.1 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.

3.3.2 Component interactions 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.

3.4 Market level analysis

3.4.1 Overarching 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 the overarching 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.

3.4.2 Quantity and price determinants dimension

The econometric analysis indicates that own-price elasticity was positively and significantly related to common hake reported landings ($\beta=0.472$ SE=0.23; Table 3, 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 ($\beta=-0.752$ 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 ($\beta=0.025$ SE=0.008). Only year 2014 was significantly (negatively) related to supply compared to the baseline of 2019 ($\beta=-0.508$ SE=0.205). All seasons were negatively and significantly related to supply compared to the baseline of Aug-Dec (Season 1 ($\beta=-1.026$ SE=0.187), Season 2 ($\beta=-0.614$ SE=0.176) and Season 3 ($\beta=-0.482$ 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.

Table 3. Output of linear model. Response variable is common hake reported landings. Predictor variables are enforcement and prices of common hake and pomfret. Dummy variable 2019 and Season 4 are not estimated to prevent co-linearity between variables.

	Estimate	St. Error	Statistic	p-value
(Intercept)	11.0877612	1.7653754	6.28068183	6.03E-08 *
Enforcement	0.02599822	0.00805792	3.22641701	0.00213144 *
Common Hake Price	0.47207359	0.23038132	2.04909659	0.04532455 *
Pomfret Price	-0.7525714	0.2035584	-3.6970786	0.00051126 *
2014	-0.5085382	0.2057347	-2.4718156	0.01662631 *
2015	-0.295213	0.2195385	-1.3446982	0.1843439
2016	0.07697101	0.23012826	0.33447004	0.73932053
2017	-0.0880686	0.25832677	-0.3409194	0.7344872
2018	0.25099405	0.23576964	1.06457327	0.29180629
Season1 (Jan/Feb)	-1.0266626	0.18763171	-5.4716901	1.18E-06 *
Season2 (March/April)	-0.614522	0.17652943	-3.4811306	0.00099661 *
Season3 (May-Jul)	-0.4821952	0.17060726	-2.826346	0.00658798 *

3.4.3 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 (Supplementary Table 3). 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.

3.5 Identifying interventions

Findings from actor, inter-actor and market level analyses are summarized in Table

5. 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,

434 evidence suggests that possible interventions are: improving access to alternative
435 livelihoods such the pomfret fishery (if sustainable); reducing fishers' reliance on common
436 hake; and providing mechanisms to differentiate legal and illegal products at the market
437 (e.g. traceability through bar-coding (Thompson et al., 2005)).

438 **Table 5.** Summary of findings from the application of the framework to the common hake case study highlighting possibilities for intervention.
 439 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	<ul style="list-style-type: none"> - 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 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).	Key-informant interviews	<ul style="list-style-type: none"> - Enforce against price fixing - Incentivise creation of an alternative fishing terminal platform - Incentivise direct supply links with fishers - Provide market information 	Low – Responses from key-informant interviews were 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	<ul style="list-style-type: none"> - 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

	Component interactions	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
	Overarching 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 in order to identify interventions requires consideration of the uncertainty in the data and the interactions within and between analytical levels. Figure 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.

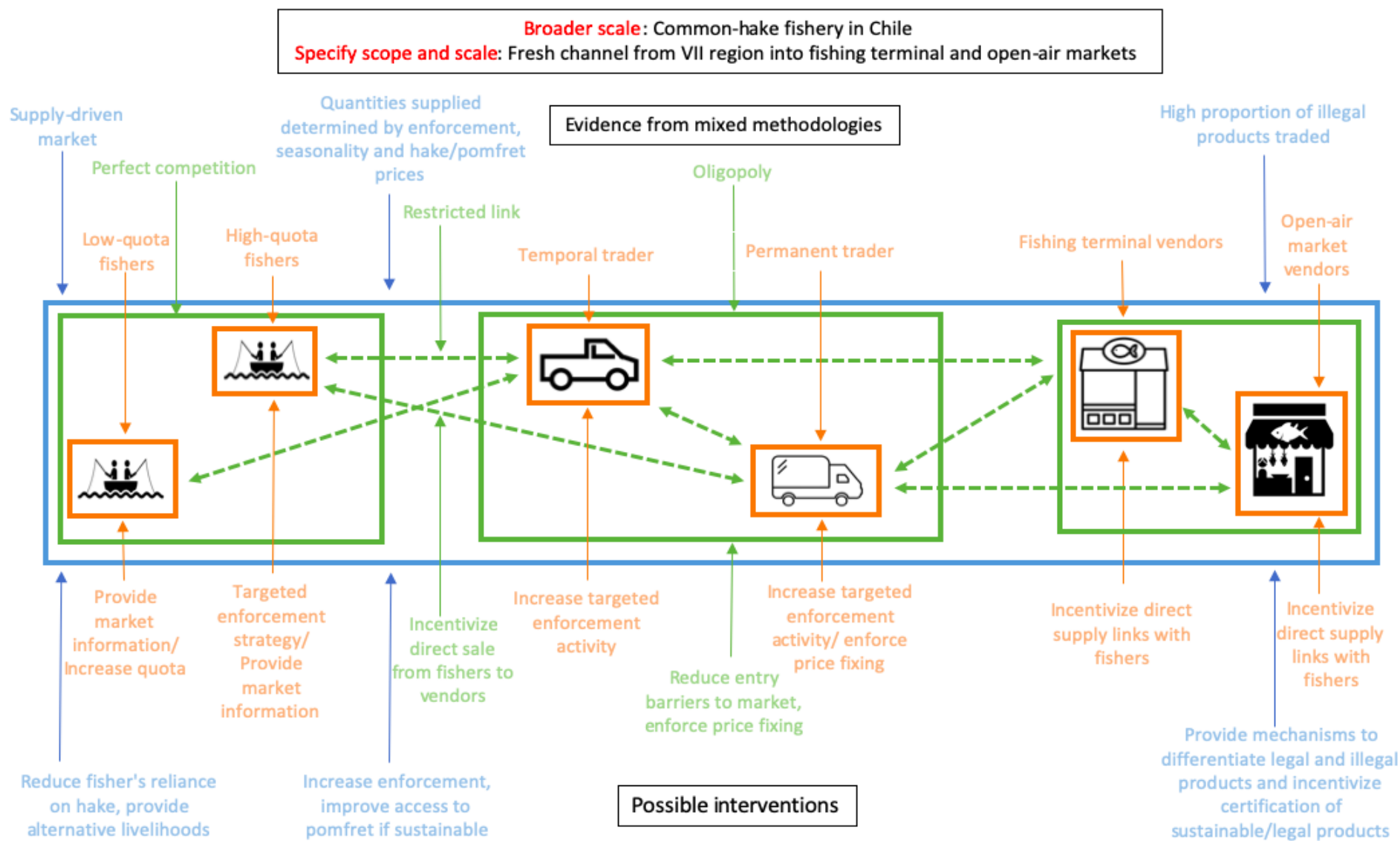
Based on the evidence collected at each analytical level, and their interactions, we lay out interventions that can be grouped in 3 main categories:

- 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;
- Those that target the intermediary component, so as to break down the oligopoly and improve competition. This can improve sustainability through; improving fishers' negotiation power which can results in better prices received for their catch, and

allowing for sustainability-led actors to come into the fishery as intermediaries and incentivize sustainable fishing practices.

- Those that aim to differentiate legal and illegal products, and improve enforcement across the supply chain so that illegal products don't enter and dominate the market. This can 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.

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.



487

488 **Figure 2.** Evidence gathered from application of the framework and intervention map for reducing common hake unsustainable use (print color)

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 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.

Our framework takes a step forward in integrating different analytical levels to consider the complexity of wildlife markets. However, this framework will not be useful in all settings. For many wildlife unsustainability issues, markets are not a significant driver. For those cases in which markets are important, applying this framework requires special attention to the scope and scale delimitation of the market. Defining the market for a wildlife product and its associated supply-chain can be challenging. This is especially so in cases when different products are derived from the same species, when different species are used for the same product or when there is transformation along the supply chain (Arias

et al., 2020; Rosales et al., 2017). Because it was straightforward to delineate the scope and scale for our case study, how to best tackle the scope and scale definition in other circumstances remains open. Lessons from the application of this framework to other settings will be fundamental to advancing our understanding of how to define the analytical scope and scale of wildlife markets and products. This will be helpful not only for applying this framework but also to advance research on wildlife markets more broadly.

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.

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544 **Declaration of interests**

545 The authors declare that they have no known competing financial interests or personal
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547

548 **Author contribution statement**

549 **Rodrigo Oyanedel:** Conceptualization, Methodology, Formal analysis, Investigation, Data
550 curation; Writing – Original Draft, Writing – Review & Editing; Visualization; Funding
551 Acquisition. **Stefan Gelcich:** Conceptualization, Methodology; Writing – Original Draft,
552 Writing – Review & Editing; Funding Acquisition; Supervision. **EJ Milner-Gulland:**
553 Conceptualization, Methodology; Writing – Original Draft, Writing – Review & Editing;
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Author contribution statement

Rodrigo Oyanedel: Conceptualization, Methodology, Formal analysis, Investigation, Data curation; Writing – Original Draft, Writing – Review & Editing; Visualization; Funding Acquisition. **Stefan Gelcich:** Conceptualization, Methodology; Writing – Original Draft, Writing – Review & Editing; Funding Acquisition; Supervision. **EJ Milner-Gulland:** Conceptualization, Methodology; Writing – Original Draft, Writing – Review & Editing; Funding Acquisition; Supervision

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.