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Food for Thought

Opportunities and challenges for improving fisheries management through greater transparency in vessel tracking

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When fisheries managers cannot see who is fishing or where fishing occurs, their scope for management interventions is limited. This lack of transparency in spatial fishing activity is considered a key enabler of illegal fishing and overfishing and hinders managers and consumers who aim to achieve sustainable fisheries. Increasing transparency in vessel location tracking is gaining momentum as a promising way to improve management of global fisheries. However, the mechanisms through which transparency in vessel activity can improve management have not been carefully studied. This paper provides a conceptual overview of the potential for greater transparency, both in quantity of vessels tracked and availability of data, from vessel tracking to help achieve sustainable fisheries goals. We identify four pathways through which these data can improve fisheries management and the conditions that enable transparency to be an effective governance tool. We qualitatively examine the costs and benefits of alternative models of transparency, including a hypothetical, fully transparent system. We highlight how potential costs and benefits of greater transparency depend on both governance context and management goals, and identify opportunities for future research to address key information gaps.

Keywords: accountability, AIS, fisheries, governance, transparency, VMS.

Introduction

While improvements have been made in fishery management, many fisheries across the world continue to face challenges to sustainability, including overcapacity, corruption, poor management, and illegal, unreported, and unregulated (IUU) fishing. In 2010, the UN Food and Agriculture Organization (FAO) cited a lack of basic transparency in fishing vessel activities and registries as an underlying facilitator of many of these persistent challenges (Food and Agriculture Organization, 2010). This observation spawned a burgeoning industry focused on fishery transparency to address governance issues and reduce IUU fishing (Environmental Justice Foundation, 2018; The Pew Charitable Trusts, 2019; Fisheries Transparency Initiative, 2020; Widjaja *et al.*, 2020). Despite this intense interest, little work has been done to disentangle the costs, benefits, and mechanisms through which transparency could affect fishery management.

The term "transparency" is often used synonymously with "openness" and broadly addresses the extent to which an entity reveals relevant information to external actors, enabling them to monitor its inner workings, have an informed voice in decisions, assess decisions, and/or evaluate performance (Florini, 2007; Grimmelikhuijsen *et al.*, 2013). Transparency is then about more than just the availability of information; it is also fundamentally about what is disclosed, to whom, and for what purpose (Seto *et al.*, 2020). Transparency policies can take many forms and may seek to improve information flows between governments, from governments to the public, between corporations, from corporations to governments, or from corporations to the public (Gupta and Mason, 2014). The call for greater transparency in fisheries centres on increasing information flows between fishers, fishing companies, management bodies, and the public. There are numerous perceived benefits to increasing transparency in fisheries, including facilitating accountability, reducing corruption, curbing IUU fishing, increasing compliance with regulations, and building trust and legitimacy in management systems (Environmental Justice Foundation, 2018; Fisheries Transparency Initiative, 2020; Widjaja *et al.*, 2020).

Yet, there is a growing body of research illustrating numerous cases across natural resource management contexts where transparency fails to meet its intended goals, underscoring the need to examine the assumption that greater transparency in the context of fisheries will necessarily lead to improved management outcomes (Weil *et al.*, 2006; Fox, 2007; Gupta, 2008; Dingwerth and Eichinger, 2010; Gupta, 2010a; Kosack and Fung, 2014; Vijge, 2018; Lujala *et al.*, 2020). Further, because data alone are insufficient to create meaningful transparency, understanding the relationship between transparency and management outcomes will require attention to the type, quality, and accessibility of fisheries data (Davis and Hanich, 2020). Evaluating the potential impact of greater transparency on fisheries management requires a conceptual theory around how different actors, interests, and institutions shape the

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potential for transparency in the fisheries sector and the pathways through which information can improve governance, management, and sustainability.

Here, we develop a conceptual theory of the potential for increased vessel tracking transparency to improve fisheries management. For tractability, we focus on satellite-based vessel position tracking. Vessel tracking provides information on vessel location and is an important way to increase transparency in fishing activity. Specifically, we consider two key components of vessel tracking transparency: (1) the increased visibility of vessel locations and inferred fishing activity from satellite-based tracking technologies (i.e. what data are collected); and (2) the availability of these data (i.e. to whom those data are disclosed, how often, and in what format).

The focus of this manuscript is on technologies for which vessel position monitoring is the primary goal. However, we acknowledge that there are numerous other fisheries monitoring approaches for which increased transparency could also affect fisheries management. For example, catch data obtained via port sampling, logbook programmes, observer programmes, and remote electronic monitoring systems (REM) such as closed-circuit television (CCTV) can provide complementary information to paint a fuller picture of fishery happenings. The potential environmental and economic benefits from improved fisheries governance are also outside the scope of this paper but have been discussed by others (e.g. Costello *et al.*, 2016; Hilborn *et al.*, 2020). Thus, we focus on the theoretical underpinnings of how vessel tracking transparency could improve fishery management. The first half of the manuscript introduces three existing primary forms of vessel tracking technologies and lays a conceptual foundation for the role of transparency in fisheries management. At a high-level, we synthesize existing literature to identify four main pathways through which vessel tracking data could improve fisheries management and broadly examine the conditions that enable transparency to be an effective governance tool. However, how these potential transparency benefits are actually realized in real-world fisheries management is highly context-dependent. In the second half of the manuscript, we therefore focus on two elements that influence transparency outcomes: (1) the degree of transparency (i.e. who is monitored, what data are collected, and to whom data are made available) and (2) the fishery context (i.e. intensity of management and fishery sector). We first discuss how differences in the design and implementation of vessel tracking schemes create varying degrees of transparency, which we organize into three distinct degrees of transparency: partial, incomplete, and full. We conclude with an evidence-based examination of the transparency pathways under each degree of transparency, qualitatively assessing the costs and benefits in different fishery contexts, and highlighting key challenges and opportunities for moving toward greater transparency in vessel tracking.

Vessel tracking technology

The opacity of where off-shore fishing occurs creates a critical information gap in fisheries management. Access to timely information on who fish where is fundamental to designing effective regulations across a broad range of management systems (Beddington *et al.*, 2007). Almost all fishery management systems try to regulate catch, gear, location, time, and/or fishing effort. To do so, managers require some level of information on who, when, where, and how much fishing is occurring. Vessel tracking technologies are one way to supply this information. These technologies provide near real-time vessel location data and basic vessel identity information, which can improve the ability of governments to monitor, enforce, and design regulations.

On a global scale, there are currently two dominant technologies used in vessel tracking for industrial fisheries: vessel monitoring systems (VMS) and the automatic identification system (AIS). A third type of technology, GPS vessel tracking, is used in some small-scale fisheries. VMS is the most common technology used by management agencies to monitor, control, and surveil fisheries. This technology has been used since the 1990s to monitor vessel activity from national fleets and foreign vessels within national waters, as well as to track national distant water fleets. VMS transmits information on the vessel's location and identification at intervals ranging from every 10 min to once daily, depending on local regulations (Food and Agriculture Organization, 1998). Although VMS data are collected intermittently at low temporal frequencies (e.g. European vessels have a one- to two-hour transmission rate; Shepperson *et al.*, 2018), these records can be interpolated to obtain continuous vessel tracks (e.g. Hintzen *et al.*, 2010). Fishing activity is commonly inferred from vessel speed information, which may be reported directly by VMS or estimated using the time and distance between VMS records (e.g. Witt and Godley, 2007; Lee *et al.*, 2010). The cost of VMS hardware ranges from $3000 to 5000 per vessel, including installation, and there are monthly transmission fees that start ~$50 but increase with the frequency of transmission (Lowman *et al.*, 2013). The use of VMS may be mandated at the national or regional level, and requirements vary based on vessel size, tonnage, gear type, or fishery.

AIS was created as a safety feature to help vessels avoid collisions and enable authorities to monitor vessel traffic. Since the year 2000, vessels exceeding 300 gross tonnes engaged in international voyages are required to broadcast their position via AIS as a collision avoidance measure, except where under threat from piracy. States can also exempt their registered fishing vessels from this mandate (International Maritime Organization, 2019). However, sovereign states may have stricter mandates. For example, all vessels over 15 m that are flagged to a European Union country are required to carry AIS [Council Regulation (EC) 2371/2002]. Given that its primary purpose is safety, vessels not mandated to use AIS may opt to use it. There are two types of AIS transponders: class A and class B. Class A transponders have longer ranges and higher power and cost around $5000, while Class B responders have smaller ranges and cost around $500 (Selbe, 2014). AIS messages provide information on the vessel's position, speed, and heading with a considerably higher frequency than VMS. Since AIS was designed as a collision avoidance technology, the transmission rate depends on vessel speed, with lower transmission rates at slower speeds (e.g. every 30 s–3 min) and higher transmission rates at higher speeds (e.g. every 2–10 s) (MarineTraffic, 2021). Importantly, this higher rate of transmission makes possible the development of accurate machine learning models that use spatio-temporal movement patterns to infer fishing activity and differentiate between gear types (de Souza *et al.*, 2016; Kroodsma *et al.*, 2018). Basic vessel identity information such as vessel name, Maritime Mobile Service Identity number, International Maritime Organization number, and call sign are broadcast separately from vessel positions at less frequent intervals (e.g. every 5 min). This identity

information can be linked to vessel registration and fishing authorization lists to provide detailed data on the identity of the vessels (Kroodsma, 2018). Unlike VMS, AIS devices are not always required to be turned on, even when their use is mandated (The International Convention for the Safety of Life at Sea, Chapter V, Regulation 19). An analysis of AIS disabling events estimated that up to 6% of activity from AIS broadcasting vessels in 2017–2019 was obscured by intentional disabling of AIS hardware (Welch *et al.*, 2022). In addition, the quality of reception coverage varies across the globe due to congestion of AIS signals, gaps in satellite coverage, and incomplete or non-transparent land-based receiver data.

The use of VMS and AIS among small vessels and across small-scale fisheries is currently limited. Traditional VMS and AIS hardware is relatively large, heavy, costly, and requires external power sources (Tassetti *et al.*, 2022), so these technologies are thought to be less suitable for many small vessels. However, a variety of GPS tracking devices have been designed for use by small-scale fishing vessels (for a list of existing technologies, see Fujita *et al.*, 2018). GPS tracking systems come in a variety of forms, and the information they provide depends on the design of the system. The simplest GPS trackers transmit vessel locations only, while others may also include speed, heading, and vessel identity information. Handheld GPS devices have been used to gather spatial data on small-scale fishing activity (e.g. Navarrete Forero *et al.*, 2017; Metcalfe *et al.*, 2017; Cardiec *et al.*,2020) and can cost anywhere from $70 to 400. Many of these devices are solar- or battery-powered and use cellular networks or a hybrid of cellular networks and satellites to transmit data. For example, the Pelagic Data System (PDS) is a solar-powered vessel tracking device that records vessel positions every few seconds and uploads them via cellular network to a secure cloud server (PDS, 2022). PDS devices cost around $150 plus $20/month for data services (Fujita *et al.*, 2018). Mobile devices equipped with GPS are also being used as a low-cost method for tracking small-scale fishing vessels (e.g. Tassetti *et al.*, 2022). Fishing activity can then be inferred using similar methods applied to location information from AIS or VMS.

Transparency pathways for better governance

The broad embrace of transparency as a governance tool is driven by widespread belief in its transformative potential (Gupta *et al.*, 2020), though the mechanisms for delivering improved outcomes are more opaque. Even when information is made available, institutions and actors shape the uptake and use of information, driving changes to governance through a variety of mechanisms. Here, we examine four pathways through which vessel tracking data can improve governance: (1) scientific research, (2) decision-making, (3) monitoring and enforcement, and (4) markets (Figure 1). We first describe these pathways at a high level, that is, agnostic to the degree of transparency (e.g. partial, incomplete, or full transparency) or type of fishery.

Scientific research

Scientific research that employs vessel tracking data in empirical analyses can shape the design of fisheries policy by providing credible information to decision-makers. Fisheries management is fraught with uncertainty and limitations, particularly related to fishing effort data, that are often required for policy design and reform. Transparency in vessel tracking provides a rich dataset on vessel locations and inferred fishing activity that can be used to evaluate the effectiveness of fisheries policies, fill knowledge gaps, and determine the feasibility of different management measures (Kritzer, 2020). The expansion of AIS and VMS is part of a larger trend in increasing ocean data collection through technology platforms like satellites, autonomous underwater vehicles, remote electronic monitoring, social media, and smartphones (Brett *et al.*, 2020). The dramatic increase in the volume and diversity of information presents unprecedented opportunities for scientific research. Indeed, increased availability of AIS and VMS data has fundamentally altered opportunities for scientific research, which is reflected in the rapid increase of publications leveraging AIS or VMS data in recent years. A Google Scholar search for "fishery" and "AIS or VMS" revealed >2.5 times as many articles published in the decade 2010–2020 compared to the preceding decade. These publications demonstrate the breadth of research that is now possible with access to vessel tracking data and include findings that could directly inform management improvements via spatially refined fishing effort estimation (e.g. Witt and Godley, 2007; Lee *et al.*, 2010; de Souza *et al.*, 2016; Kroodsma *et al.*, 2018); the quantification of environmental impacts of fishing activities (e.g. Lambert *et al.*, 2011; Coello *et al.*, 2015); and the inclusion of vessel tracking data into marine spatial planning efforts (e.g. Campbell *et al.*, 2014; James *et al.*, 2018), among others. Vessel tracking data has also been used to quantify global carbon emissions associated with bottom trawling (Sala *et al.*, 2021), analyse the redistribution of fishing effort in response to area closures (Murawski *et al.*, 2005), and identify industrial fishing vessels with suspected forced labour (McDonald *et al.*, 2021).

Decision-making

Access to accurate and high-quality data is often presumed to be fundamental to establishing effective management policies (Pauly *et al.*, 2005; Bradley *et al.*, 2019a). Well-managed fisheries guided by formal stock assessments are in better condition than poorly managed fisheries lacking comprehensive assessments (Mora *et al.*, 2009; Costello *et al.*, 2012; Hilborn *et al.*, 2020). Transparency is generally presumed to improve the quality of decision-making by providing relevant and reliable information to decision-makers. Near-real time vessel tracking provides management agencies with accurate information on fishing activity that may be used in several ways, including estimating fishing effort, assessing spatial and/or temporal changes in fishing activity, improving fishery-dependent stock assessment indices, and supporting more effective regulatory design (James *et al.*, 2018; Watson *et al.*, 2018).

Monitoring and enforcement

Fisheries monitoring programmes often have multiple goals, including monitoring for compliance with catch and effort regulations, size limits, gear restrictions, spatial and temporal closures, and/or transshipment regulations. Increasing transparency through vessel tracking provides management bodies with a way to address some, but not all, of these objectives. Because vessel tracking enables managers to observe historical and real-time vessel positions at sea, they can use these data to design and enforce spatial and temporal restrictions (Bradley *et al.*, 2019a) and identify patterns of transshipment (Miller *et al.*, 2018). Effective enforcement is one of the most

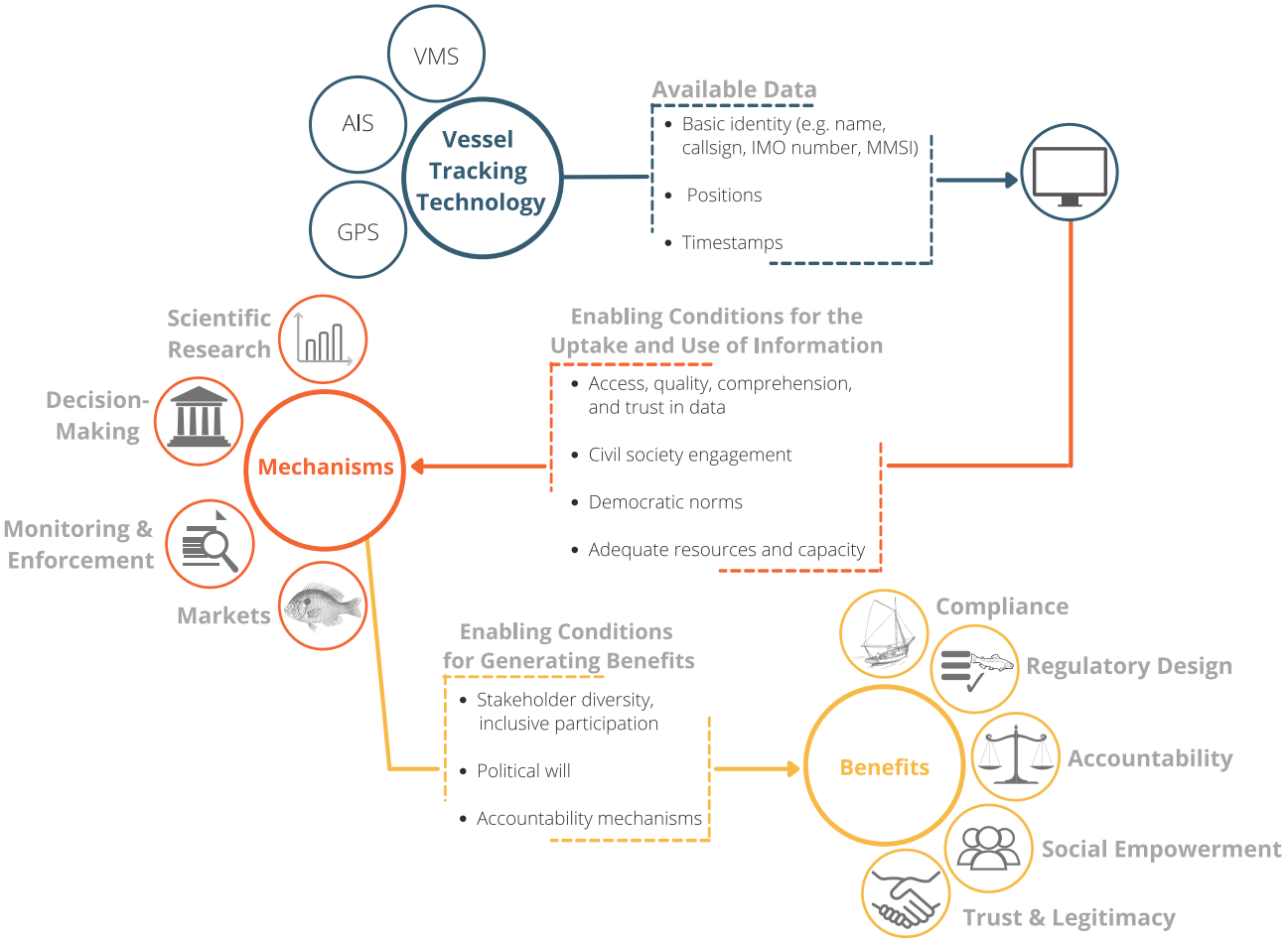

Figure 1. A conceptual diagram of pathways and enabling conditions through which vessel tracking data can improve governance and management of fisheries.

important factors for building legitimacy in management systems (Hatcher and Gordon, 2005; Ali and Abdullah, 2010; Kritzer, 2020). The ability to detect and prosecute noncompliance shows well-intentioned actors that activities are being prosecuted and managed fairly, building confidence in the validity of the system (Branch *et al.*, 2006; Kritzer, 2020). Detection of noncompliance is a necessary first step to enforcement, and the ability to effectively monitor offshore fishing activity has long been a key challenge in fisheries management. The availability of better information on vessel positions can reduce uncertainty around where vessels are and improve the models used to infer where fishing activity occurs. In turn, improvements in the spatial and temporal estimates of fishing activity may lower the costs of monitoring and enforcement relative to standard approaches such as surveillance planes and patrol vessels. With better information, agencies can improve the allocation of limited enforcement resources and prioritize inspection of high-risk vessels, areas, and seasons, thereby improving their ability to enforce the rules. Stricter enforcement of regulations raises the probability that violators will be detected, increasing the expected cost of illegal behaviour and incentivizing compliance with regulations (Branch *et al.*, 2006). Though vessel tracking may support other goals like catch monitoring if paired with additional data streams, alone these technologies do not provide data on which species are being caught or how much.

Markets

Better information on fishing activities can play an important role in the creation, expansion, and functioning of markets, in particular by improving traceability. Food traceability supports food safety and risk management, product control and verification, supply chain management, quality assurance, and consumer communication (Coff *et al.*, 2008). The global seafood industry is complex and opaque. Often, retailers and consumers do not know where their fish were caught, how they were caught, how the fish moved through the supply chain from boat to market, or what the environmental or social impacts might have been. Thus, the ability to access, manage, and share information on seafood production is increasingly important for mitigating ecological, social, economic, and political risks for actors along the seafood supply chain (Bailey *et al.*, 2016). Vessel tracking data can support both regulatory and consumer-facing transparency initiatives. Many regulatory traceability efforts seek to reduce the amount of IUU catch in the market by improving boat-to-market traceability. For example, regulations in the European Union emphasize detailed catch documentation and traceability covering all stages of the supply chain from catch to landing at port, transport, processing, and sale [Council Regulation (EC) No 1005/2008 and Council Regulation (EC) No 1224/2009]. These regulations rely on catch certification, which requires a record of catch location and date as well as a declaration

of any transshipment activities. In the absence of vessel tracking, these reports can be falsified, but vessel tracking and electronic reporting help verify the legitimacy of catch dates, locations, and at-sea transshipment (Martinsohn, 2011; Bailey *et al*., 2016).

Consumer-facing transparency focuses on communicating the quality, origin, and sustainability of seafood to consumers (Bailey *et al*., 2016). Eco-labels like the Marine Stewardship Council (MSC) and Fair Trade provide a way for consumers and retailers to identify sustainably sourced seafood. Vessel tracking can help fulfill eco-label data collection requirements such as the MSC at-sea data collection standard (Marine Stewardship Council, 2021) or the Fair Trade seafood traceability system standard (Fair Trade USA, 2021). However, vessel tracking alone does not provide catch monitoring, which is often a requirement for eco-labels, suggesting that vessel tracking data may need to be paired with observer programmes or electronic monitoring to fully comply with standards. Other organizations, such as Sustainable Fisheries Partnerships and Seafood Business for Ocean Stewardship, bring key industry players together to improve supply chain transparency and seafood traceability. Vessel tracking can provide these organizations with credible data to inform best practices and support the achievement of key commitments to improve transparency and traceability in operations and reduce the presence of IUU products in supply chains (Seafood Business for Ocean Stewardship, 2021). Holding vessels, companies, and supply chains to account through information on production practices can limit market access for bad actors, incentivizing a shift toward more sustainable practices that improve environmental performance (Widjaja *et al*., 2020).

Transparency enabling conditions

Each of the pathways discussed above represents a possible mechanism to improve governance and contribute to the various benefits associated with greater transparency. However, increased access to information has not always improved governance, casting doubt on the effectiveness of transparency reforms (Weil *et al*., 2006; Gupta, 2008, 2010b; Dingwerth and Eichinger, 2010; Gupta and van Asselt, 2019). It is therefore critical to understand what conditions enable these pathways for transparency to be an effective governance tool. There is a need to examine the conditions under which transparency is likely to produce positive impacts on fisheries management (Guggisberg *et al*., 2021). Below, we review several enabling conditions identified in transparency literature as being critical drivers of successful transparency schemes and group them as either: (1) those enabling the uptake and use of information or (2) those necessary for information to generate benefits (Figure 1).

Enabling conditions for the uptake and use of information

For transparency to be effective, recipients of the data must want the information and be able to use it. Attributes of information, the level of demand for transparency, and adequate resources and capacity can all influence how information is perceived, valued, and ultimately used to drive change (Figure 1).

Literature on information disclosure has defined characteristics of information that make it more likely to be used by the intended recipients. Information must be timely, relevant, representative, and accessible. Further, it must be presented in a format that is disaggregated, comparable, and comprehensible (Fung *et al*., 2004, 2007; Heald, 2006; Weil *et al*., 2006). Disaggregated data enable meaningful analysis of groups, while comparable formats allow users to compare across groups, and comprehensible data provide the information at a level of technicality that is appropriate for the audience (Weil *et al*., 2006; Fung *et al*., 2007). If the likely end-users cannot understand, make use of, or trust the information, there is little demand for greater transparency (Standing, 2011; Lujala *et al*., 2020). Credibility, legitimacy, relevance, and timeliness are key attributes necessary for scientific information to be incorporated into fishery policy decisions (Soomai, 2017), which could make increased vessel tracking transparency a stronger pathway towards achieving more robust fisheries management.

Traditionally, demand for transparency has been largely driven by civil society organizations and other interested stakeholders who are engaged and aware of resource governance issues (Boldbaatar *et al*., 2019). While some transparency initiatives may be government-led, outcomes are likely to vary between high- and low-governance countries or regions. In low-governance contexts, government-led transparency is often weak in addressing corruption or exposing governance failures, as authorities have little incentive to disclose information exposing wrongdoing and may instead publish selective or dishonest information (Standing, 2011). In the absence of government-led initiatives, successful disclosure policies may be enabled by vigorous, independent, and engaged civil society actors and media (Mol, 2008, 2010; Gaventa and McGee, 2013; Gupta and Mason, 2014; Barclay, 2015; Walton *et al*., 2020). Non-governmental organizations (NGOs) have been active advocates for greater transparency in the fisheries sector. While VMS data are often not shared publicly, Belize, Chile, Peru, Panama, Ecuador, Brazil, and Costa Rica now publish public VMS data through Global Fishing Watch (Global Fishing Watch, 2022). The presence of democratic norms also contributes to the ability of civil society to demand transparency. The level of democratization shapes how transparency mechanisms emerge, how far they succeed, and how people perceive and appreciate transparency (Goetz and Jenkins, 2004; Grimmelikhuijsen *et al*., 2013). The feasibility and likelihood of success may depend on the extent to which basic political and civil rights are guaranteed, including access to information and freedoms of expression, association, and assembly (Malena *et al*., 2004). For example, in Africa, many NGOs working on fisheries issues depend on donors and rely on the good will of government agencies to function, which may undermine their independence and increase the risk of self-censorship (Standing, 2011). A meta-analysis of transparency and accountability initiatives found little evidence of impact in non-democratic settings, which complements other theories that transparency must follow from advances in democratic accountability (Gupta, 2010a; Gaventa and McGee, 2013).

Finally, meaningful transparency requires adequate capacity and resources to integrate and act on information both in government and civil society (Gaventa and McGee, 2013; Boldbaatar *et al*., 2019). Data requiring high levels of processing or analytic capacity may be out of reach for many potential users, especially those in marginalized groups (Gupta, 2010a; Mitchell, 2011; Walton *et al*., 2020). Satellite data on

vessel locations requires computing resources and analytic capabilities to render the information usable. Raw VMS and AIS data include vessel positions but do not indicate whether a vessel is fishing or not in a given location. Increases in the volume of data also pose practical challenges for data management, putting strain on existing data management infrastructures and requiring additional human and technical resources to transmit, store, and review data (ICES, 2019). Further, when data are managed through individual disparate infrastructure it creates additional barriers for effective use including duplicate data, missing data, or poor documentation, which can limit accessibility and usability of data (Tanhua *et al*., 2019). In many cases, civil society organizations can fill this gap by acting as an intermediary to translate, manage, and validate information for the broader public. For example, Global Fishing Watch uses machine learning to estimate fishing activity from raw AIS data and publishes it online for free (Kroodsma *et al*., 2018). In fisheries, the importance of capacity and resources is further complicated by the management of transboundary fish stocks, which requires adequate capacity to process, use, and share information across all jurisdictions involved in managing a particular stock (Walton *et al*., 2020). Transparency can be hindered if large amounts of coordination are required or when there is a lack of consensus around what information should be shared across jurisdictions (Zürn and Faude, 2013; Clark *et al*., 2015; Walton *et al*., 2020).

Enabling conditions for generating benefits

While the uptake and use of information generate the pathways through which information improves governance, the formation of these pathways alone does not guarantee positive outcomes. Inclusive participation of diverse stakeholders, political will, and strong accountability mechanisms are important enabling conditions for generating governance benefits from increased transparency (Figure 1).

Participation of fishers and stakeholders can improve the design of regulations and is recognized as an important aspect for building legitimacy of management systems (Cochrane *et al*., 2011). When participants view systems as legitimate, they are more willing to comply with rules and regulations (Jentoft and McCay, 1995). Systems that promote inclusive participation in the design and implementation of regulations also have stronger effects on compliance (Ali and Abdullah, 2010; Finkbeiner and Basurto, 2015; Kritzer, 2020). Vessel tracking data can support meaningful participation by providing fishers with the data necessary to better represent their interests in decision-making processes, increasing collective bargaining power, or enhancing the ability to influence the design and implementation of regulations. In addition to the participation of fishermen, including the input of scientific experts is essential for improving regulatory design. A global evaluation of fisheries management regimes indicates a higher likelihood of sustainable fisheries in places where national fishing authorities sought scientific advice and effectively incorporated those findings into policies (Mora *et al*., 2009). However, instances where scientific advice is ignored are relatively common due to corruption, political pressure, or high socioeconomic costs (Mora *et al*., 2009). Corruption in the fisheries sector can also lead to poor enforcement of rules and regulations, lax monitoring and inspection of catch and supply chains, unfair policy making, or failure to punish illegal activity (Yan and Graycar, 2020). Generating political will or support from powerful industries can alleviate some of the barriers to incorporating vessel tracking data into policy making [Stanford Center for Ocean Solutions (COS) and the Stanford Law School, 2020]. However, where political will or industry support are low, strong accountability mechanisms play an important role in making transparency effective.

Accountability is widely recognized to contain two dimensions: answerability and enforcement (Schedler, 1999). Answerability refers to the right to be informed of decisions and to receive justifications for decisions by those in power, while enforcement involves consequences or sanctions (Mason, 2020). Greater transparency has been shown to directly improve answerability by reducing information asymmetries and lowering information costs (Mason, 2020). Access to public vessel tracking data reduces information asymmetries between powerful actors (i.e. governments and corporations) and fishers, stakeholders, and civil society. These data can foster answerability both from fishers and from management authorities. Vessel tracking can provide management agencies and industry with a means to verify vessel activity and hold vessels accountable for following regulations. For example, vessel tracking data has enabled better monitoring of spatial regulations like area closures (e.g. Chang, 2011) and temporal regulations such as night-setting requirements in longline tuna fisheries (e.g. Winnard *et al*., 2018). Publicly available vessel tracking data can further allow NGOs and civil society groups to hold management agencies accountable for effective conservation and management of fish stocks. Vessel tracking information can lend credibility to accountability claims and incentivize behavioural changes by increasing the likelihood that rule violators will be held accountable.

Enforcement, i.e. the ability to impose sanctions or punish violators, is critical to generating accountability. Vessel tracking may reveal instances where vessels are violating fisheries regulations, but if there are no consequences, vessels have little incentive to comply. In many cases, institutional frameworks provide methods for sanctioning vessels that fail to comply with regulations. However, proving vessels are operating illegally is challenging, and in some cases, vessel tracking data may not be sufficient as sole evidentiary proof in a court of law (Stop Illegal Fishing, 2018; Guggisberg, 2019).

Degrees of transparency within vessel tracking

Thus far, we have provided an overview of how greater transparency might improve governance through scientific research, decision-making, monitoring and enforcement, and markets, as well as the conditions that enable transparency to be effective. In reality, governance benefits derived from greater transparency are highly contextual, and one critical consideration is the degree of transparency with regards to: (1) the fraction of fleets equipped with hardware; (2) the entity owning and controlling data access; and (3) the level at which the information is publicly available. Differences in these key characteristics across vessel tracking technologies create varying degrees of transparency. We conceptualize different degrees of transparency as a spectrum, from partial transparency to full transparency.

Partial transparency

On one end of the spectrum is partial transparency from private vessel tracking data, like VMS and most GPS trackers.

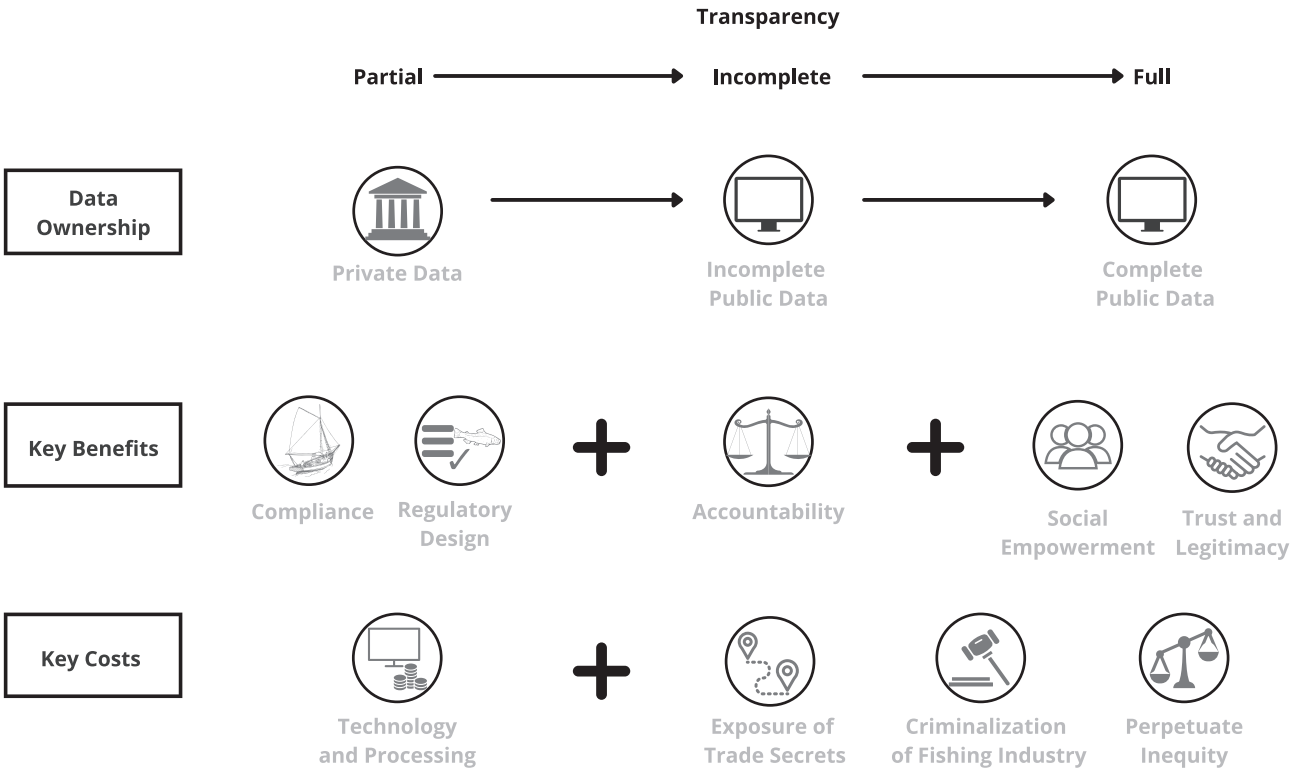

Figure 2. A conceptual diagram illustrating the key governance benefits and costs associated with different degrees of transparency in vessel tracking.

These technologies increase transparency in vessel activity at sea by providing data on vessel identity and position, which can be used to infer vessel activity. VMS data are usually transmitted solely to monitoring agencies, thereby increasing the information flow between fishing vessels and governments. Often, VMS is mandated fleet-wide and provides comprehensive coverage of vessels within a fishery. Access to VMS data is controlled by national governments and generally considered confidential, which limits public access. In some cases, VMS may be shared with other governments, management entities, or for research purposes, but often in a highly aggregated form to preserve confidentiality (Hinz *et al.*, 2013). In rare instances, like in Chile, there may be legal mandates to make VMS data available to the public (Ministerio de Economía, Fomento y Turismo, 2019).

Incomplete transparency

In the middle of the spectrum is transparency from public vessel tracking data, like AIS. Similar to VMS, AIS increases the transparency of vessel activity at sea by providing data on vessel identity and position that can be used to infer fishing activity. AIS data are broadcast differently than VMS and may be picked up by satellite receivers, land receivers, or other vessels, thereby increasing information flows between fishing vessels, governments, and the public through external data platforms. However, transparency created from AIS data is still incomplete because AIS lacks consistent coverage and may have uneven adoption within a fishery. Additionally, AIS data compiled by third-party entities are public but not necessarily free or easy to use. Some platforms, like Shipview, Skylight, and Marine Traffic, publish AIS data but charge a fee for access, while others, like Global Fishing Watch, provide free, downloadable AIS data. While AIS may provide a greater degree of transparency than VMS, gaps in coverage and the ability to turn devices off create practical challenges that can further limit the use and interpretation of these data.

Full transparency

At the far end of the spectrum, we consider a hypothetical scenario of full transparency. Full transparency would provide public vessel tracking data on all fishing vessels and could make use of a number of different vessel tracking technologies and data access portals. For example, it could include publishing existing VMS and/or GPS tracking data, establishing new VMS programmes, mandating AIS on all vessels, or a combination of approaches that ultimately lead to full access to all vessel activity by any interested party.

Towards greater transparency in vessel monitoring

The design and implementation of existing vessel tracking schemes around the world provide a unique opportunity to examine the qualitative costs and benefits associated with different degrees of transparency. In positioning these degrees of transparency along a spectrum, we can assess the challenges and opportunities for moving toward full transparency in vessel tracking. Figure 2 depicts some of the salient costs and governance benefits for each degree of vessel tracking transparency. At the low end, partial transparency from private VMS or GPS data provides vessel activity information to governments and management agencies with high coverage rates but lower temporal frequencies. In the middle of the transparency spectrum lies incomplete transparency from AIS data. While AIS allows for public access to vessel tracking data at high temporal frequencies, there is uneven adoption across

global fleets and potential problems with data quality. At the far end of the spectrum is a hypothetical scenario of full transparency, which would enable public tracking of all fishing vessels and could make use of a variety of tracking technologies (e.g. VMS, AIS, other GPS trackers). In the following section, we summarize the consequences of these three alternatives and discuss how the benefits, costs, and challenges arising from different vessel tracking schemes could differ across fishery contexts. Specifically, we consider differences in costs and benefits between weakly, intensely, and RFMO-managed fisheries as well as between industrial-scale and small-scale fisheries. We consider intensely managed fisheries as those that could use vessel tracking data if available, and weakly managed fisheries as those that could not due to limited capacity, poor governance, and/or a lack of technical infrastructure.

Partial transparency

Perhaps the most obvious benefit of vessel tracking is to improve compliance through better monitoring and enforcement of regulations. While compliance benefits can arise across many fishery types, they may be most likely to arise in intensely managed fisheries with established monitoring, control, and surveillance (MCS) programmes and adequate resources and capacity to process and use data to directly inform MCS activities. VMS can support effective spatial and temporal monitoring, which may deter illegal activity, lower the cost of investigations for violations, and enable efficient inspections (Food and Agriculture Organization, 1998). Fishery enforcement agencies can use VMS to monitor and enforce regulations at the national scale. For example, Chang (2011) illustrates how VMS was used in Taiwan to enable effective monitoring of regional tuna fishing zones by integrating spatial boundaries into VMS software that alerted authorities of possible violations if boundaries were crossed. Typically, though, fishery management agencies can monitor only their own fleet via VMS. Without data-sharing agreements or legal mandates, they are unable to monitor foreign-flagged vessels operating within their waters. This can be of particular concern for countries with high levels of foreign fishing. To better facilitate the exchange of VMS data, governments are increasingly engaging in multilateral data sharing agreements. For example, the Pacific Islands Forum Fisheries Agency (FFA) hosts a Regional Fisheries Surveillance Centre that collects data to support MCS and provides real-time information on vessels operating in the region to all 17 Member States. The FFA's regional MCS efforts resulted in issuing 83 infractions to vessels operating in the region from 2015 to 2018 and earned them the top prize in the 2019 Stop Illegal, Unreported, and Unregulated Fishing Competition (Pacific Islands Forum Fisheries Agency, 2018).

Much fishing activity that occurs outside areas of national jurisdiction (i.e. the high seas) is regulated by Regional Fisheries Management Organizations (RFMOs). RFMOs lack their own MCS systems and instead rely on coordinated efforts from Member States (Widjaja *et al.*, 2020). While many RFMOs require the use of VMS by large vessels fishing within the convention area (e.g. Western Central Pacific Fisheries Commission Conservation Management Measure 2014–02, Indian Ocean Tuna Commission Resolution 15/03, Northwest Atlantic Fisheries Organization Conservation and Enforcement Measures Article 26), Member States are responsible for mandating the installation and operation of VMS as well as enforcing reporting obligations (Widjaja *et al.*, 2020). VMS data are not necessarily shared with all other members of the RFMO, which can hinder efforts to improve compliance through vessel tracking. Even if information were shared more readily across jurisdictions, there are technical costs associated with the ability to access and assess large amounts of data, and low capacity may prevent meaningful analysis of shared data (Blasiak *et al.*, 2019; Walton *et al.*, 2020). For example, VMS requires software to receive the satellite information, computing equipment to process, analyse, and store data, and the technical capacity to process the data into a readily usable format.

Although VMS data are generally considered confidential, they are sometimes shared for scientific research. Published studies using VMS data illustrate additional benefits of VMS data, including the ability to estimate fishing effort (Witt and Godley, 2007; Lee *et al.*, 2010; Chang, 2011) and validate catch (O'Shea and Thompson, 2006; Palmer and Wigley, 2009; Chang, 2011). In US northeast fisheries, VMS-derived stock area landings showed appreciable gains in accuracy relative to logbook reporting when fishing activities occurred over multiple regions (Palmer and Wigley, 2009). The ability to accurately estimate spatial and temporal fishing effort can have important policy implications for marine protected area design and spatial planning (e.g. Murawski *et al.*, 2005; Campbell *et al.*, 2014; Birchenough *et al.*, 2021) and support regulatory impact evaluation (Palmer and Wigley, 2009; Watson *et al.*, 2018). For example, a pilot study on VMS for nearshore small vessels (<12 m) in the UK found that accurate time-series data on inshore fishing activities could support the development of more targeted sustainable fisheries management policies to improve industry outcomes relative to the current precautionary approach (Birchenough *et al.*, 2021). Such studies illustrate how VMS in intensely managed fisheries can reduce uncertainty in fishing activity and improve the design of regulations, to the benefit of fish stocks and fishers alike. However, the utility of VMS for scientific research and subsequent feedback between research and scientifically informed fisheries management depends on the willingness of governments and fishers to share data and the level of resolution provided. VMS data are commonly collected at lower temporal resolutions and are often aggregated over larger spatial scales (e.g. three nautical miles) prior to being released to preserve confidentiality. This hampers the ability of external researchers to provide accurate estimates of fishing activity impacts on management outcomes and may lead to an overestimation of fishing activity (Hinz *et al.*, 2013; Shepperson *et al.*, 2018). Increasing the polling frequency of VMS could be a viable way to provide the high-resolution data required to generate accurate estimates of fishing activity that would ultimately benefit fishers and scientists (Shepperson *et al.*, 2018).

Incomplete transparency

The public nature of AIS data strengthens compliance and regulatory design through expanded scientific research and analysis. For RFMO-managed fisheries, public data can help overcome barriers associated with data sharing and improve MCS efforts. For example, public AIS data have been used to determine vessel-level compliance with night-setting regulations in longline tuna fisheries, demonstrating a method that can be used for monitoring and enforcement across tuna RFMOs and Member States (Winnard *et al.*, 2018). Similar to VMS

data, AIS data require a level of processing to be usable by a general audience, and early studies on AIS focused on creating methods to estimate fishing effort and the extent of fishing activity (e.g. de Souza *et al*., 2016; Jiang *et al*., 2016; Kroodsma *et al*., 2018). Models built from AIS data have been able to identify fishing activity with >90% accuracy (Kroodsma *et al*., 2018). These efforts have allowed the scientific community to leverage AIS data in a wide range of studies that impact fisheries policy in many dimensions, including protected area design and enforcement (e.g. James *et al*., 2018; Bradley *et al*., 2019b; McDermott *et al*., 2019; Lynham *et al*., 2020; Villaseñor-Derbez *et al*., 2020; Visalli *et al*., 2020); subsidy reform (Costello *et al*., 2021); and transshipment (e.g. Miller *et al*., 2018; Seto *et al*., 2020), among others.

Public AIS data also allow for other non-state actors to play a greater role in monitoring and surveillance. Partnerships between non-state actors and management agencies can be an important avenue for addressing capacity gaps in weakly managed or RFMO-managed fisheries. In particular, NGOs are actively working to identify instances of potential non-compliance and share relevant information with states and/or RFMOs. This has led to the successful interdiction of vessels found to be in violation of regulations (e.g. Bladen, 2019a; Gray, 2020). The US Coast Guard (USCG) supports enforcement of conservation management measures in the North Pacific for the region's two RFMOs: the North Pacific Fisheries Commission and the Western and Central Pacific Fisheries Commission. In 2019, the USCG collaborated with Global Fishing Watch using AIS data to conduct in-depth research on potential IUU fishing activities to help inform which vessels to target during the annual patrol. The patrol boarded 45 fishing vessels and assessed 68 violations, a 344 and 867% increase, respectively, compared to 2018 (Bladen, 2019b). While data sharing between non-governmental actors and governments can occur through formal partnerships, it often relies on informal processes such as participation by non-governmental observers in RFMO meetings. The reliance on informal processes of information exchange can limit the potential for NGOs to perform accountability functions, as their role in and contributions to compliance mechanisms are often not explicitly acknowledged. Further, governments have no legal requirement to act on information provided by NGOs or report back on findings in instances when investigations are undertaken (Guggisberg, 2019). For example, an Oceana report on illegal fishing in the Mediterranean was presented and discussed at two meetings of the General Fisheries Commission for the Mediterranean, but no information was provided on whether vessels had been fined or punished as a result of the report (Madina, 2018). Without open and transparent decision-making processes, it can be difficult for NGOs to obtain follow-up information and validate the credibility of their role in enhancing accountability (Guggisberg, 2019).

Despite the higher temporal frequency of data collection and public access, transparency from current AIS usage is still incomplete. Filling the remaining gaps in adoption and coverage would improve the quality and usability of AIS data. Currently, AIS data are biased toward large vessels over 24 m in length, upper- and middle-income countries, and distant water fleets (Taconet *et al*., 2019), leaving substantial gaps in the ability to assess activity from small-scale vessels and coastal fisheries. For example, the Western Indian Ocean (FAO Area 51) has a high proportion of fishing activity from artisanal and semi-industrial fleets with low levels of AIS use, making it difficult to accurately monitor fishing activity using AIS technology (Murua *et al*., 2019). Even large industrial vessels operating in FAO Area 51 have low AIS usage, creating challenges for interpreting observed and inferred fishing and vessel activity (particularly for trawlers and purse seines; Murua *et al*., 2019). Studies using AIS to evaluate management effectiveness also confirm these biases and suggest that the current level of AIS adoption may prohibit meaningful analysis in many countries and fisheries. In an examination of Pacific tunas, one of the most intensely managed and monitored transboundary fisheries in the world, Seto *et al*. (2020) found the level of publicly available data did not allow them to verify the legality of 68% of observed encounters between vessels in the study area. Studies comparing fishing effort estimates from AIS and VMS also find considerable gaps in AIS data compared with VMS, which may lead to underestimates of fishing activity when only using AIS (e.g. Russo *et al*., 2016; Shepperson *et al*., 2018). Even where usage is sufficient, poor satellite reception quality, especially nearshore, large amounts of "noisy" data, and the ability to turn an AIS system off or broadcast a false location can obscure vessel activity in some parts of the world and make AIS data challenging to work with. For example, while AIS use is high for vessels in the Northeast Atlantic (FAO Area 21), reception quality differs between class-A and class-B AIS devices, and more than three-quarters of the vessels operating in the region use class-B devices, which have weaker reception (Iriondo *et al*., 2019). Since different gear types in this region often use different class devices and have differing levels of usage, AIS data in this case show realistic patterns of fishing activity for trawlers and longliners, but poorly represent other regionally important fishing gears such as dredgers and purse seines (Iriondo *et al*., 2019). Increasing the coverage of AIS use and mandating AIS devices with higher quality reception (e.g. Class A) could address some data quality issues and further improve the utility of AIS data. Additionally, while models employed to estimate fishing activity from AIS data (e.g. de Souza *et al*., 2016; Jiang *et al*., 2016; Kroodsma *et al*., 2018) can estimate if a vessel is likely fishing or not fishing at a given position with relatively high accuracy, they are unable to group positions of fishing activity into other common effort metrics, such as a longline set or trawling tow, which can make it challenging to relate AIS data to other sources of catch or effort. This is an important area for future research that would bridge the gap between inferred fishing activity from vessel tracking and catch documentation from logbooks, observers, or electronic monitoring.

AIS data share many of the technical costs of VMS including requiring computing resources for processing and storage and technical capabilities to analyse data. AIS data are also not free; however, NGOs and private companies (such as AstraPaging, Navama, Global Fishing Watch, and OceanMind) are taking on important roles as data intermediaries, working to provide more readily accessible and comprehensible data and, in some cases, making these data free for public consumption.

Full transparency

The potential benefits of a hypothetical future with full transparency would likely vary across fishery contexts. Intensely managed, RFMO-managed, and industrial-scale fisheries already using VMS and/or AIS for MCS may gain some additional benefits from a fully transparent system of vessel tracking. However, as VMS only allows for monitoring of a coun-

try's national fleet, full transparency in vessel tracking could allow for better monitoring of distant water fleets and enforcement against vessels not authorized to fish in a particular country's or RFMO's waters. Meanwhile, weakly managed fisheries and small-scale fisheries typically have less capacity and technical infrastructure to make use of vessel tracking data in their management decisions. These fisheries may experience smaller direct management benefits because providing vessel tracking data alone does not mean it will be used to improve compliance, enforcement, or accountability. Effective enforcement requires further investigating possible violations identified through satellite monitoring, which can have high human resource and technology costs and may be beyond the institutional capacity of many governments (Rowlands *et al*., 2019). However, the public and scientific communities could use fully transparent vessel tracking data to highlight challenges these fisheries may be experiencing and propose innovative solutions that could otherwise go unnoticed. In small-scale fisheries, more transparent vessel tracking may enhance social empowerment by democratizing data access and ownership and providing fishers and other often marginalized groups with access to and control over information. Access to accurate data on fishing effort and location can be critical in helping fishers advocate for access rights (CLS Fisheries, 2021), participate meaningfully in the development of management systems (Metcalfe *et al*., 2017), and represent their interests in spatial planning efforts (Jentoft and Knol, 2014). Inclusive and meaningful participation are also recognized as important aspects for building the legitimacy of management systems (Cochrane *et al*., 2011). In evaluating two Danish fisheries, Nielsen and Vedsmand (1999) found direct participation by fishers in rule-making encouraged individual members to comply with the rules, and multi-user group participation increased the legitimacy of decision-making.

Moving toward full transparency would require expanding vessel tracking to all fishing vessels, which could be achieved using a variety of complementary available technologies and policy mandates. One step toward full coverage would be to require that VMS data be publicly available (e.g. Global Fishing Watch, 2021). This option would only expand the transparent coverage of those vessels currently equipped with VMS, which are typically vessels that are already in intensely managed fisheries. Since VMS data have historically been considered confidential, there may be some opposition from the fishing industry to making those data public. In addition to feeling like vessel tracking is an intrusion and violation of privacy (Mangi *et al*., 2015; Michelin *et al*., 2018; Berleant, 2022), public vessel tracking can reveal industry "trade-secrets", namely fishing locations. In a recent workshop on fisheries data confidentiality, industry participants argued fishing location data were proprietary and provided a competitive advantage, though perceptions of the level of sensitivity varied by gear type and over time (Azmi *et al*., 2022). There is also a concern that data may be misused or misinterpreted to criminalize the fishing industry or make unfounded claims against fishing vessels (Azmi *et al*., 2022). Many of these privacy concerns are also highlighted in research on the adoption of electronic monitoring technologies (Michelin *et al*., 2018; van Helmond *et al*., 2020). A second possibility is to scale up the requirements to use existing AIS technologies (e.g. McCauley *et al*., 2016; Dunn *et al*., 2018). Current regulations on AIS use vary widely, which can reduce the usefulness of these data as many vessels may not be required to carry AIS hardware. Adopting a single AIS mandate across international, regional, and national scales would provide a streamlined way to improve transparency in vessel tracking. However, AIS is costly, and currently there is no policy mechanism in place to mandate global adoption. Additionally, there are still issues with satellite coverage and reception that present challenges to data quality and usability. As both VMS and AIS have unique limitations, making both data sources fully public may provide a more accurate picture of vessel activity than either source alone (e.g. Cabral *et al*., 2018; Thoya *et al*., 2021). However, this would likely still require many fisheries to install either AIS or VMS hardware, which may be prohibitively expensive or unsuitable for many small-scale fisheries. Therefore, expanding vessel tracking to all vessels will likely require a third option, which is the use of alternative, lower-cost GPS tracking technologies. In small-scale fisheries in the Republic of the Congo, low-cost GPS trackers have been used in combination with community engagement to provide fine-scale information on fleet dynamics and fishing locations (Metcalfe *et al*., 2017). However, like VMS, there are privacy concerns associated with publicizing vessel tracking data from GPS trackers. In examining incentives for voluntary adoption of vessel tracking in small-scale fisheries, Silva *et al*. (2022) found fishers would prefer vessel tracking systems where fishers or governments have ownership of the data rather than industry or public ownership. While increasing transparency through multiple mandates or technology options may be the most cost-effective, it will also require some effort to streamline data collection, processing, and sharing requirements to centralize vessel tracking in a way that makes it relevant, timely, and accessible to users. Data that requires piecing together vessel tracks from several sources could be inaccessible to many potential users, especially those who already lack the resources to implement vessel tracking programmes.

Reaching full transparency would require a massive increase in tracking small-scale vessels, which raises important ethical considerations. Transparency for these vessels could inadvertently exacerbate inequalities by further empowering the already powerful (Mason, 2008, 2020; Mol, 2014; Gardner *et al*., 2019). For example, while the European Union's IUU regulations—which restrict or block imports if exporting countries fail to show significant efforts to reduce IUU fishing activity in their waters and by vessels under their control—have proven successes, they can also have inadvertent impacts on small-scale fisheries (Song *et al*., 2020). The data collection and reporting requirements of these trade restrictions can have significant costs for small-scale fishers, and export bans may have persistent and long-lasting negative impacts on fisher income that are not easily recuperated (Houssa and Verpoorten, 2015; Song *et al*., 2020). In some regions, particularly rural areas, the cost of developing infrastructure may be infeasible, and limited electricity and internet challenges can preclude fisheries from developing the technology-based traceability systems required to gain access to higher-end markets (Duggan and Kochen, 2016).

These examples illustrate potential social challenges and costs that could arise when demand for transparency is defined and driven by wealthy countries or fisheries, which could burden lower-income small-scale fisheries, largely in the global South. Inclusive participation and bottom-up design have shown promise in gaining support for vessel tracking and demonstrated the value of these data in developing more equitable management systems and improving social outcomes

(Metcalfe *et al*., 2017). However, for transparency to be empowering, it may need to be paired with new fisheries institutions [such as territorial use rights in fisheries (TURFs)] or other types of initiatives (e.g. poverty alleviation, healthcare development, and access to education) that support the priorities of small-scale fishers (Fisheries Transparency Initiative, 2021).

Conclusion

"Transparency" in natural resource exploitation is often colloquially understood as a public benefit, where the thinking is: more transparency is better, and it will surely enhance sustainability. While such claims are ubiquitous, reasonable counterarguments exist that transparency infringes on personal liberties, reveals trade secrets, and exacerbates inequality. We must think critically about the design, implementation, and evaluation of transparency initiatives in global fisheries. Partial transparency is achieved through private vessel tracking technologies, which provide important data on vessel locations and inferred activities to governments or management bodies but often at lower temporal resolutions. Increasing transparency through more widely adopted VMS or GPS trackers can improve monitoring and enforcement, in particular for national fleets, but in the absence of streamlined data sharing agreements and expanded capacity across relevant jurisdictions, it is unlikely to have a strong impact on regional compliance. If VMS data remain confidential, accountability is unlikely to improve, and inequalities may be perpetuated, especially where resource use by small-scale fisheries conflicts with larger commercial fisheries. However, making VMS or GPS data public is likely to be met with continued opposition from the fishing industry, partially because it reveals long-held secret fishing locations. Incomplete transparency is achieved through AIS, which provides higher-resolution information to governments and the public but has uneven adoption and issues with data quality. Cohesive AIS mandates may be an efficient way to improve transparency through greater coverage of vessels, but they would be costly and financially untenable for many small-scale vessels. The potential to manipulate data and the low coverage nearshore leaves concerns over the quality and reliability of AIS data. Further, simply making data available is not sufficient to support scientific research, build trust, or generate accountability. Vessel tracking data may carry little value without first being processed, and the usefulness of these data will require data sharing across national and regional scales, the willingness and ability to use the available information, adequate enforcement for violations, and sufficient accountability mechanisms for decision-makers.

All this is to say that scaling up transparency must be done with great care. It will require explicitly identifying the goals of transparency and weighing the costs and benefits of the various approaches for achieving them. While we have outlined many of the possible qualitative benefits and costs of vessel tracking transparency to fisheries management outcomes, there is insufficient empirical evidence to evaluate their magnitude. Accurately quantifying the costs and benefits of expanding transparency in vessel tracking requires moving beyond information availability towards understanding the likelihood that vessel tracking data will be integrated into decision-making and ultimately influence fisher and manager behaviour and fisheries outcomes. To this end, we suggest two future research themes to deepen our understanding of the influence of vessel tracking information on fisheries management: fisher behaviour effects and decision-making. Specific research questions could include: (1) do fishers alter their fishing behaviour (a) as a result of being tracked? (b) by knowing what other fishermen are doing? or (c) preemptively given the potential for increased transparency? And (2) to what extent is public vessel tracking data integrated into the decision-making processes of various user groups (e.g. management agencies, eco-certification bodies, NGOs)? Answers to these questions will help reveal the circumstances under which greater transparency in vessel tracking improves fisheries management and at what cost.

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Author contributions

S. O.: conceptualization, writing-original draft preparation, visualization. J. M. and C. C.: conceptualization, writing-reviewing, and editing. G. M. and D. B.: conceptualization, writing-reviewing and editing, and supervision.

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