EMJMD: ISLANDS

Fishing for Answers:

METHODOLOGIES TO ASSESS DREDGING IMPACTS ON SMALL-SCALE FISHING LIVELIHOOD

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JULY, 2024

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Master Thesis
Research Master in Spatial Sciences
Track: Island & Sustainability

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University of Groningen
Groningen, July 2024

ABSTRACT

Small-scale fisheries are vital to their communities, providing livelihoods, subsistence, and sociocultural value. However, they face increasing pressures from climate change and coastal projects like dredging, which risk being labeled as ocean 'grabbing' if not carefully managed. These impacts can alter ecological compositions essential for fish stocks and restrict access to fishing grounds, potentially interfering with livelihoods. Understanding these impacts is critical for effective mitigation, yet detailed assessments have been limited.

This study addresses this gap by exploring methodologies to assess the impacts of dredging on small-scale fisheries. It identifies impact zones, focusing on extractive activities and equipment presence, and proposes a framework to assess components of small-scale fisheries across socioecological systems (resource systems, resource units, governance, and users). Using systematic literature reviews resulting in 22 case studies, document analysis of 4 main industry references, and 32 in-depth interviews, it specifies measurable components across ecological, operational, and spatial dimensions to establish baselines and monitor impacts over time. Quantifying impacts is feasible with sufficient data, but its data collection and analysis methodologies must also serve the needs of communities.

In summary, attributing changes in small-scale fisheries to dredging is complex due to the dynamic marine environment and climate change effects. While environmental and ecological impacts are hard to attribute, disruptions to fishing operations are more apparent. This research amalgamates resources and perspectives from both academic and industrial standpoints regarding dredging and small-scale fisheries, areas rarely explored in tandem. Moving forward, further studies should integrate more direct community involvement to gather more contextual insights in different locations globally.

Keywords: *small-scale fisheries, social impact, dredging, coastal projects, social-ecological systems*

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Acknowledgements

This thesis would not have been possible without the tremendous guidance of Philippe Hanna, who taught me to be critical and to challenge established assumptions. From you, I learned what it means to be a researcher and a lifelong learner. I would always be thankful for all the suggestions you made that helped me to shape this thesis and also the way I look at the world.

Words cannot express my gratitude towards my supervisors during my thesis internship, Iain Wood and Daniël Ouddeken, who have provided relentless support since my first day. When people said that a thesis can be a roller-coaster journey, I never imagined the process would be filled with so many opportunities, changes, and adaptations at the same time. Yet, throughout it all, you two have always been supportive and receptive to my questions and ideas.

I am incredibly grateful for everything that Benjamin Hennig has done as my faculty coordinator. Despite my numerous questions, you always found a middle ground for me to explore while still meeting program requirements. Thank you for being truly reliable and addressing all my concerns throughout the program.

To Dimitris Ballas and everyone involved in the ISLANDS consortium, especially my fellow first batch of students, thank you for being my comrades during this wild journey full of confusion and excitement. My encounters with all of you have enabled me to grow beyond what I expected when I began.

Lastly, to all those whose names I have not mentioned but who knew of my struggles throughout the program, thank you for all the love and support along the way.

1 INTRODUCTION

1.1 BACKGROUND

Albeit its minuscule attributes, small-scale fisheries play a major role for coastal communities. Compared to its industrial counterpart that is more structured and equipped with larger operations that seize higher catch, small-scale fisheries are often characterized to be labor-intensive with small vessels operating short and frequent fishing trips, and generating relatively low catch (IPIECA, 2023). Still, small-scale fisheries dominate the marine working field, with them composing up to 90% of global fish workers (FAO, 2015) and generating an estimated annual revenue of USD 77 billion globally (FAO et al., 2023). For generations, this has enabled the sector to be a source of livelihood, nutrition and food security, poverty eradication, equitable development, and even sociocultural significance that helps to sustain the communities (Allison & Horemans, 2006; Frawley et al., 2019).

Still, small-scale fisheries are facing mounting challenges. To start, they have typically struggled in accessing basic services and sustaining their operations due to barriers in securing financial assistance, diseconomies of scale, and competition in the market from sectors with stronger sociopolitical influences (Béné & Friend, 2011; Bennett et al., 2014; FAO, 2015; Rashid, 2020; Silva et al., 2019). Simultaneously, alike other communities that rely on marine ecosystem services (Andréfouët & Bionaz, 2021), anthropogenic pressures have strained the relationship between ocean and humans (Worm et al., 2006). This is driven by the rise of the blue economy, which entails large-scale development projects (Bennett et al., 2019; Silver et al., 2015), particularly with the emerging risk of ocean grabbing which refers to the 'dispossession or appropriation of use, control, or access to ocean space or resources from prior resource users, right holders or inhabitants' (Bennett et al., 2015).

One example of interventions that are integrated into a broader large-scale development project operating in the coastal and marine space is dredging. As an operation that involves the excavation and relocation of sediments from a body of water (Wenger et al., 2017), dredging is often associated with changes not only to the natural environment but also people relying on its resources (Barbier et al., 2011). Over time, efforts have been made to understand how dredging alters the environment (see Erftemeijer & Lewis, 2006; Jones et al., 2016; Kjelland et al., 2015; Wenger et al., 2018), as well as the organisms and consumers of aquatic life such as small-scale fisheries (Bridges et al., 2010). However, beyond the likely alteration of fish stocks and access to fishing areas, the full extent of dredging impacts on small-scale fishing communities remains unexplored, particularly in assessing these possible impacts before any operation commences.

This is important because the growth in blue economy often use potential economic benefits such as new job opportunities, increase in local and national economy, and to advance regional development as the rationale (World Bank & United Nations Department of Economic and Social Affairs, 2017). When done right, these projects indeed hold the potential to create shared prosperity (Keen et al., 2018; Patil et al., 2016). As also pointed out by IFC (2015), ocean-based projects such as dredging may also create benefits such as establishment of facilities to support long-term services and expanded transportation networks. Yet, in practice, the distribution of economic benefits from marine resource and ocean-based development is frequently inequitable (Österblom et al., 2020). Despite good intentions, many projects may still have impacts on prior resource users, such as small-scale fisheries, by excluding them or disrupting their livelihoods albeit temporarily (Pinkerton & Davis, 2015), which is even more concerning in developing countries and small island developing states (Bennett et al., 2015).

1.2 PROBLEM STATEMENT

The question that often follows the discussion on blue economy is of winners and losers—yet it should in fact be about ensuring that ocean-based development activities such as dredging can coexist with activities of local communities such as small-scale fisheries. It is, thus, crucial to avoid creating negative impacts to small-scale fisheries, and instead, create benefits for them alongside the progress of the projects. If we refer to the International Finance Corporation (IFC) Performance Standards as an acknowledged benchmark for projects, even when they are not funded by IFC, and further detailed in the IFC's (2015) Handbook 'Addressing Project Impacts on Fishing-based Livelihoods', projects such as dredging must identify and measure the impacts on fishing-based livelihoods through a comprehensive baseline across social, ecological, and technical dimensions. In order to do that, it requires proper identification, assessment, and mitigation of the impacts resulting from both the physical alterations caused by dredging. Without such information, dredging runs the risk of inadequately assessing impacts, leading to ineffective management and mitigation.

Nonetheless, operationalizing standards has been challenging. To begin, limited data on small-scale fisheries across the world has only complicated efforts for establishing baseline and creating sustainable management measures (FAO, 2002). Despite works by different stakeholders from academia and industries, the inadequate data persist mainly due to the diverse and intricate nature of small-scale fisheries across the globe (Berkes, 2001; Chuenpagdee et al., 2019). Simultaneously, the common focus of fisheries studies has been on ecological aspects aimed at assessing fishing pressure or estimating productivity and capacity of the environment supporting fisheries (see McClanahan et al., 2009) and often linked with high cost and effort of technical research requiring advanced expertise.

On the other hand, although there have been exploration to assess the value of small-scale fisheries (see Battaglia et al., 2010, 2017; Teh et al., 2011), socioeconomic studies have been limited. Even more so, interdisciplinary studies where the ecological and socioeconomic perspectives are combined have been rare. This is surprising given that small-scale fisheries operate in social-ecological systems where both environmental and human subsystems interact and shape each other (Berkes et al., 1998; Folke et al., 2005). However, attempting to do such interdisciplinary assessment is difficult. While ecological studies often employ specific indicators, standardized or transferrable metrics for assessing the sustainability of small-scale fisheries as livelihoods have remained elusive, hence magnifying the disconnect between the dimensions. This becomes particularly pronounced within dredging operations which intersect with small-scale fisheries in which both environmental and social impacts typically occur.

To sum up, while dredging can impact small-scale fisheries, the extent of these impacts has not been adequately measured. Despite the vital role of small-scale fishing for many communities, current literature lacks comprehensive methodologies for assessing the vulnerability and sustainability of these livelihoods in the face of coastal projects like dredging. Moreover, although standards and frameworks for impact assessment exist, real-life challenges in data access, availability, and other aspects necessary for collecting baseline information persist. These challenges are often overlooked in the literature, despite being recurring issues across projects even beyond dredging. Therefore, there is an urgent need to bridge this gap by developing robust methodologies and indicators to assess the impacts of dredging on small-scale fisherfolk livelihoods, which would enhance our understanding and management of these impacts and create opportunities to benefit small-scale fishing communities.

1.3 RESEARCH OBJECTIVES

The core of this study is to understand how dredging impacts small-scale fishing livelihoods. It aims to explore the methodologies that can capture the full extent of those impacts. The focus on livelihood, often associated with the financial dimension even though it extends beyond it, is grounded on the assumption that it is the most direct and measurable proxy for impact. This approach facilitates universal understanding and discussion across stakeholders, serving as an optimal entry point to comprehend the intricacies of other sociocultural dimensions. Beginning with identifying the possible dredging impacts, this study will then seek to determine the feasibility of quantifying impacts and to identify methodologies to establish baseline. Moreover, in the case it is not feasible, the study will examine the alternative approach so that impacts can still be identified and managed. Ultimately, this study will conclude by providing recommendations for improving the accuracy and effectiveness of those methodologies, particularly for future applicability in dredging projects.

1.4 RESEARCH QUESTIONS

To fulfill those objectives, the following question serves as the framework for this research:

How can we assess the impacts of dredging on small-scale fishing livelihood?

To delve into the matter, the following sub-questions that are targeted to gauge insights of the specific research objectives will be used to guide the research accordingly.

Table 1 Research subquestions

SUBQUESTION
What are the measures to monitor dredging impacts on small-scale fisheries over time?
What small-scale fisheries baseline data is needed to monitor dredging impacts?
What are the possible dredging impacts and to what extent can we attribute them to a dredging project?
Is quantification of impacts feasible? If so, when and how should it be conducted?
If quantification is unfeasible, what alternative measures to assess impacts can we use?

1.5 STUDY STRUCTURE

The structure of this research is outlined as follows. Chapter 2 covers the theoretical and conceptual framework, discussing relevant issues and questions related to the impacts of dredging on small-scale fisheries. Chapter 3 details the methodological approaches used in this research, from their rationale to their operationalization. Chapter 4 presents the main findings, including the identification of dredging impact zones, the assessment of these impacts from various perspectives, and considerations for operationalizing the assessments. Chapter 5 discusses how the findings address the research questions, their implications, and the next steps for both dredging project practices and academic research. Finally, Chapter 6 provides the conclusion and highlights key takeaways from the previous chapters.

2 THEORETICAL FRAMEWORK

2.1 COASTAL AND MARINE SOCIAL-ECOLOGICAL SYSTEMS

By nature, human beings are social creatures, wired to interact with one another to thrive. Throughout history, humans have forged connections to advance the world that we are currently living in. This inclination towards interaction reflects the dynamics observed in nature, where interactions among ecosystem components and their services are essential for supporting life on Earth. Nevertheless, these systems—human and natural systems—do not exist in isolation; rather, they are intertwined within complex systems where interactions, influences, and adaptations continuously shape and reshape each other. In literature, these have been explored and referred to as 'social-ecological systems' (Berkes, 2011; Ommer et al., 2011).

Grounded on the premise on complexity that influence their governance (Berkes et al., 1998), social-ecological systems can be defined as interdependent and complex adaptive systems comprised by social and ecological dimensions that interact constantly with each other at multiple levels (Ostrom, 2009). Delving deeper, the general mechanism entails resource systems (nature-based structure from which resources are obtained, e.g. forest), resource unit (smallest component of resource system that is subject to governance, e.g. plants), governance systems (the rules and institutions that regulate resource use, e.g. organizations managing the protected area), and users (individuals, groups, or organization that interact with and depend on the resource system for their livelihoods or other purposes, e.g. park rangers) (Ostrom, 2009), as shown in **Figure 1**.

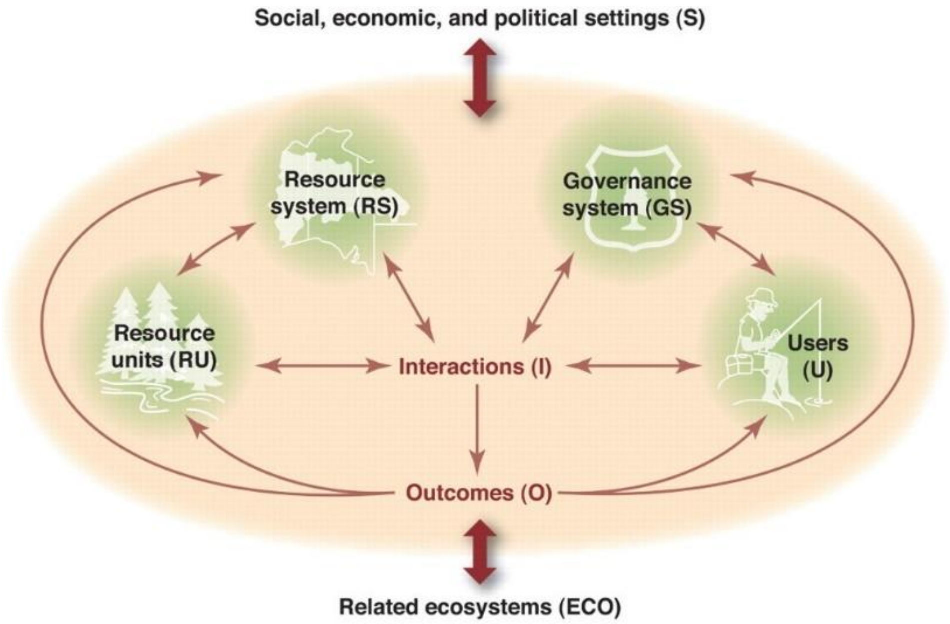


Figure 1 The core subsystems in social-ecological systems ***(Ostrom, 2009)***

These are the first-level core subsystems that are made up of multiple second-level variables, such as mobility of resource unit, knowledge of resource systems, and others. From here, they are also composed of deeper-level variables that get more specified based on context. An example of how this tiered system of variables emerged from the four first-level core subsystems is shown in **Figure 2** (Ostrom, 2009).

Social, economic, and political settings (S)

S1 Economic development. S2 Demographic trends. S3 Political stability.
S4 Government resource policies. S5 Market incentives. S6 Media organization.

Resource systems (RS)	*Governance systems (GS)*
RS1 Sector (e.g., water, forests, pasture, fish)	GS1 Government organizations
RS2 Clarity of system boundaries	GS2 Nongovernment organizations
RS3 Size of resource system*	GS3 Network structure
RS4 Human-constructed facilities	GS4 Property-rights systems
RS5 Productivity of system*	GS5 Operational rules
RS6 Equilibrium properties	GS6 Collective-choice rules*
RS7 Predictability of system dynamics*	GS7 Constitutional rules
RS8 Storage characteristics	GS8 Monitoring and sanctioning processes
RS9 Location	
Resource units (RU)	*Users (U)*
RU1 Resource unit mobility*	U1 Number of users*
RU2 Growth or replacement rate	U2 Socioeconomic attributes of users
RU3 Interaction among resource units	U3 History of use
RU4 Economic value	U4 Location
RU5 Number of units	U5 Leadership/entrepreneurship*
RU6 Distinctive markings	U6 Norms/social capital*
RU7 Spatial and temporal distribution	U7 Knowledge of SES/mental models*
	U8 Importance of resource*
	U9 Technology used

Interactions (I) → outcomes (O)

I1 Harvesting levels of diverse users	O1 Social performance measures (e.g., efficiency, equity, accountability, sustainability)
I2 Information sharing among users	
I3 Deliberation processes	
I4 Conflicts among users	O2 Ecological performance measures (e.g., overharvested, resilience, bio-diversity, sustainability)
I5 Investment activities	
I6 Lobbying activities	
I7 Self-organizing activities	O3 Externalities to other SESs
I8 Networking activities	

Related ecosystems (ECO)

ECO1 Climate patterns. ECO2 Pollution patterns. ECO3 Flows into and out of focal SES.

*Subset of variables found to be associated with self-organization.

Figure 2 Lower-level variables of social-ecological systems *(Ostrom, 2009)*

Through the above figure, we can see how complex social-ecological systems can be. As elaborated by Ostrom (2007, 2009), this concept challenges the assumption that disruptions within subsystems can be traced back to a single cause within its own system. Instead, causes are often multiple, non-linear, cross-scale, and tend to be cumulative from other processes if not evolutionary. Therefore, understanding the impacts of those disruptions cannot simply be seen as a result of a single factor, but rather multiple subsystems and their interactions.

An obvious example of such systems can be found in the coastal and marine context. Over the course of history, civilizations have nurtured an intricate bond with the ocean, where processes within the biophysical environment and human activities are intertwined (Partelow, 2018). Yet, this is now threatened by human actions (Worm et al., 2006). Until recently, there has been a global rise in coastal interventions (Wenger et al., 2018) in support of blue economy (Bennett et al., 2019) shown with modifications of coastlines through projects such as port development, seabed mining, beach nourishment, and land reclamation (Dafforn et al., 2015).

This trend shows no sign of stopping, particularly as coastal population is projected to grow (Neumann et al., 2015). The concern with this has been in the environmental stress magnified by climate change that has only influences local communities in varying intensities (Hobday et al., 2016). However, an equally pressing concern is that despite the focus on development, these interventions seem to frequently overlook the interplay between environmental and human dynamics in coastal and marine environments. As a result, despite the pursuit of development, they often fall short of ensuring that the intended benefits ultimately reach the local communities (Voyer et al., 2018).

What sets apart coastal and marine environments than their terrestrial counterparts is the heightened level of risks and uncertainties associated with resource use, dynamic nature of both human and aquatic resources, as well as the often obscure tenure arrangements (Ferrol-Schulte et al., 2013). This lack of clarity has only complicated management measures and putting livelihoods of coastal communities to be more vulnerable (Agardy et al., 2005). This, along with the high mobility of resources and users (Dietz et al., 2003) even more so than in terrestrial settings, makes delineating boundaries between ecological and social domains to be difficult.

Examining any interacting component within these subsystems requires integrated thinking between different fields (Andrews et al., 2021). Therefore, there is an urgency to thoroughly evaluate the relationship between the social and ecological dimensions of human vulnerability, especially in the context of improving governance over resources (Cinner et al., 2013). However, understanding the processes underlying these systems remains challenging to measure quantitatively (Comte et al., 2019). Efforts to translate resilience of these subsystems into practice have been on-going for the past three decades, nevertheless they have faced obstacles due to a lack of standardized measurement tools (Quinlan et al., 2016).

2.2 SMALL-SCALE FISHING COMMUNITIES

The term 'small-scale fisheries' may conjure images of traditional fishing vessels equipped with low-tech gears that requires labor-intensive practices with the fishers working as the individual vessel operator or in small crews (Smith & Basurto, 2019). Throughout places, different attributes such as traditional, artisanal, and small-scale are often used interchangeably. Nevertheless, they all denote the same communities that, despite their locations and diversity, exhibit similar characteristics. In literature, small-scale fisheries are often defined in comparison to their industrial counterpart. As Johnson (2006) has elaborated, the main characteristics are as follows:

Table 2 Classification of fisheries and their characteristics *(Johnson, 2006)*

Fisheries-related characteristics	Categories		
	Small-scale		Large-scale
	Subsistence	Domestic commodity production	Industrial
Social organisation			
Socio-economic			
Nature of fishing unit	Individuals and community based groups usually linked by ties of social reciprocity	Small groups, with some specialisation and some division of labour; importance of household and community	Small and larger groups; higher specialisation and division of labour
Nature of work	Part-time, multi-occupational; catch shared	⟵⟶	Usually full time, professional; greater prevalence of wage-labour or salaries
Disposal of catch and market integration	Primarily household consumption but some local barter and sale	Household consumption and sale to local, national, and international markets	Sale primarily to mass markets
Processing of catch	Mostly direct consumption	⟵⟶	Mostly processed, including large quantities of fishmeal for non-human consumption
Ownership	Individual or group ownership and operation; occasional absentee ownership	Usually owned by senior operator, or operators jointly; some absentee ownership	Concentration of ownership, often by non-operators; often ownership is corporate
Investment	Capital investment low, although often high investment of labour time	Low to medium capital investment, large proportion borne by other than operator	Capital investment high, large proportion borne by other than operator
Operator/Owner's income level	N/A or minimal	Low or medium	Often high
Knowledge and technology	Premium on skill and local knowledge	Highest diversity of target species and techniques; and thus high skill and knowledge needs	Skill and experience important, but supported by high technology
Craft	None or small and non-motorised	Small with low power engines	High power engines
Gear	Often hand made and operator-assembled; mainly non-mechanised	Many machine-made components, often operator-assembled, high diversity of gear types; manual and mechanised gear	Machine-made components, assembled by others, low diversity of gear types; electronics and automation
Catch capacity	Very low to low	Low to medium	Large to vast
Management			
Fisheries authority	Local community or kin-based	Regional, community, or kin-based, with few scientists/managers	Comprehensive in scope, science driven; many scientists/managers
Management units	A great many small units	Usually many small units	One or few large units
Rules	Customary	Customary and state	Usually state regulated
Fisheries data collection	Often none due to difficulty of collection	Difficult due to features of fisheries and authorities	Relatively straightforward but does depend on authority's capacity
Space and time			
Fishing bases	Highly dispersed	Dispersed	Concentrated
Fishing location	On or adjacent to shore	Relatively near to shore	Exploits all marine areas
Fishing duration	Few hours	Few hours to few days	Few days to months
Seasonality	Seasonal	Extended seasons due to more robust craft and gear	Ability to withstand rough weather and to go to the fish; all but eliminates climate related seasons

On aggregate, the long-term trend has been for global fisheries to shift in this direction, but this trend is neither inevitable nor irreversible.

Primarily, many differences could be linked to financial investment. For small-scale fisheries, investment mainly comes from individuals, families, or small organizations (Smith & Basurto, 2019). This small pool of resources then determines the operational scale in terms of vessels and gears that the fisherfolks can utilize. However, the role that small-scale fishing plays as a source of livelihood is immense as it generates approximately USD 77 billion annually (FAO et al., 2023). Serving as the largest employer of any marine sector (World Bank, 2012), more than 90% of the 4.36 million active fishing vessels worldwide are classified as small-scale (FAO, 2014). For many, small-scale fishing has been a last resort of employment that save many households from extreme poverty (Sumaila et al., 2012) especially for those considered as 'the poorest of the poor' (Pauly, 1997).

Hence, the delineation of small-scale and industrial transcends mere technical classification. Small-scale fisheries encompass more than operations; they carry significant social and political implications. While industrial fishing is mainly driven by profit, the significance of small-scale fisheries also extends to poverty alleviation, provision of jobs, and contribution to seafood markets and consumption (Jentoft et al., 2017). Their role in food security and nutrition, especially for those living in poverty, cannot be overstated with evidence indicating that small-scale fisheries supply nearly half of the world's seafood (FAO, 2020).

Nonetheless, as has been largely known, small-scale fisheries face various challenges. Although small-scale fisheries vary across contexts and are deeply intertwined with local communities, they often encounter similar problems. These include low economic performance, obstacles in sustaining benefits from fishing, high levels of poverty, and globalization pressures (Chuenpagdee et al., 2006; Zeller et al., 2006). To make matters worse, they also must deal with poor governance of the fisheries management (Sumaila et al., 2012), ineffective management and under-representation in decision making (Allison & Ellis, 2001; Béné, 2003; Béné & Friend, 2011). At the same time, climate change has been linked to provoke significant alteration to the marine primary production (Steinacher et al., 2010) thus possibly affecting the food webs underpinning fisheries production (Borgne et al., 2011). Due to this, fisheries stocks around the world have been overfished, collapsed, and even disappeared (Jackson et al., 2001) which will only render implications for the livelihoods these fisheries provide (Hobday et al., 2016).

2.3 SMALL-SCALE FISHERIES AS SOCIAL-ECOLOGICAL SYSTEM

Provided that small-scale fisheries operate within both ecological and human subsystems (Berkes et al., 1998; Folke et al., 2005), using social-ecological systems to examine small-scale fisheries can then help to conceptualize the dynamics of small-scale fisheries and how fitting measures should be provided if there are changes to those subsystems. Again, within this context, it is impossible to isolate one subsystem, as each is intricately intertwined. For example, marine policies that restrict certain catch due to overfishing pressures can alter the composition of fish stocks and subsequent catch, ultimately affecting the value derived from each fishing trip and consequently, the income of fisherfolks. Comprehending these interconnections necessitates a multidisciplinary framework, such as social-ecological systems.

If we refer to core subsystems by Ostrom (2009), small-scale fishing operations can be classified as the resource system, with catch as the resource unit, fisherfolks as users, and the governance system to entail local government and regulation. Villasante et al. (2022) further explored the dynamics of small-scale fisheries within social-ecological systems, particularly regarding the possible pathways that these communities could take if changes were invoked. As depicted in **Figure 3**, these communities could either navigate through changes and shift accordingly, getting trapped in a situation where they can continue their operation yet not sustainably, or they could entirely collapse. What determines which pathway they can take is their adaptive capacity of both the social and environmental systems (Bennett et al., 2016).

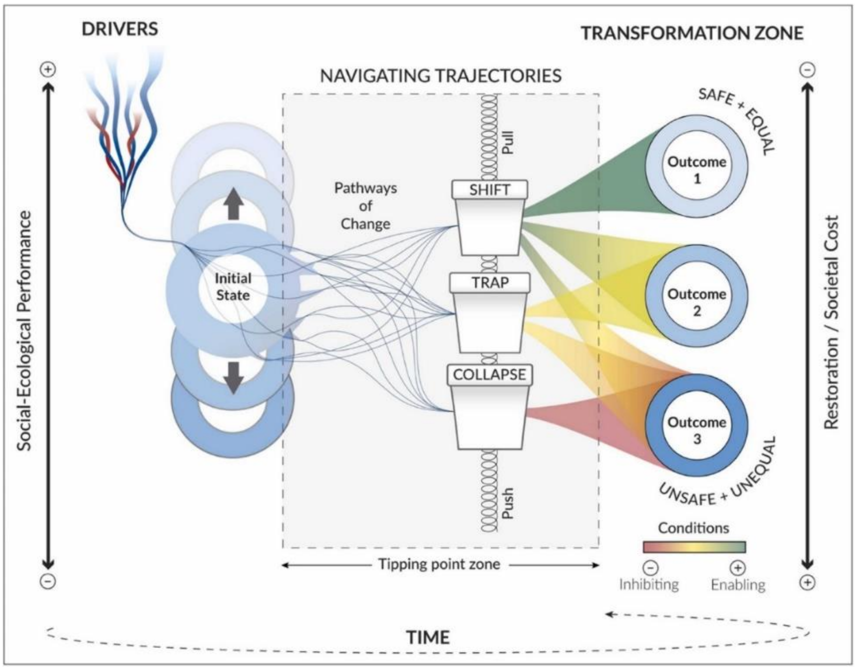


Figure 3 Holistic view of social ecological changes in small-scale fisheries (Villasante et al., 2022)

Taking this into the context of projects, it is critical to understand what components are being impacted and how communities can adapt. To do this, it will demand the comprehensive knowledge of all ecosystem components and perspectives of all people involved (McClanahan et al., 2009). However, challenges arise due to the costs and efforts to attain such information. Small-scale fisheries have already been at the disadvantage of being data-poor. Historically, small-scale fisheries have been unaccounted, underestimated, or excluded from fisheries statistics (Smith & Basurto, 2019). Measurement of small-scale fisheries has been impeded by their diversity, compounded by a lack of institutional capacity and political commitment to comprehend the nuances and address the challenges associated with collecting data (Kittinger et al., 2013). This has only exacerbated the issue that small-scale fishing communities are frequently sidelined from decision-making.

The absence of data becomes more apparent through gender perspective. In contrast to the perception that fishing is male-dominated (Harding, 1991), women actually make up half of those involved in small-scale fisheries (World Bank, 2012). Yet, in some locations, cultural norms and gender stereotypes hinder women's participation, leading to them being undervalued in decision-making (Chambon et al., 2024) thus only perpetuating their marginalized status (Bennett, 2005). Women’s participation can indeed be found along the entire value chain (Kleiber et al., 2015), but as it is predominantly not in harvesting activities which becomes the basis for data collection in fisheries studies, their role is often left hidden. This gender myopia is not only discriminating—it is also dangerous to let on as underestimation of fishers may lead to an incomplete understanding (Kleiber et al., 2014). This will exacerbate the ongoing data scarcity worldwide. Until these challenges are addressed, the ability to understand and implement appropriate measures to ensure the sustainability of small-scale fisheries will continue to be hindered.

2.4 DREDGING IMPACTS TO SMALL-SCALE FISHERIES

Dredging, by its nature, involves altering the environment and is thus expected to have impacts (Bray, 2008). Serving as a fundamental operation for many infrastructure projects, dredging can be defined as the ‘excavation and relocation of sediment from lakes, rivers, estuaries, or seabeds’ (Wenger et al., 2017). The choice of dredging mechanisms, which includes vessel options such as cutter suction and trailing suction hopper dredgers, is influenced by project specifications and operational demands. Each of these decisions comes with its array of factors, spanning aspects such as precision to safety. These accumulated decisions then lead to a specific operation of dredging which can yield varied impacts on the environment (Bray, 2008).

Over time, there has been a number of research uncovering these impacts, which include increases in turbidity, organic matter, and metal compounds in both water and dredged sediment (Ljung et al., 2010; Wu et al., 2007). Turbidity has emerged as a prominent concern (Aarninkhof, 2008), although its incline is typically temporary (Manap & Voulvoulis, 2016). Then again, the resuspension of fine sediments, whether through natural events or human activities can yield similar impacts to those observed in dredging (Hamburger, 2003). This has only enabled better understanding that environmental impacts associated with dredging cannot be generalized, but rather should be evaluated case-by-case. Nonetheless, as dredging may also remove considerable volume of material from the seafloor, it would carry the risk of disturbance to bottom habitat and alter seabed morphology and might also lead to shoreline erosion, which has happened in Dukjeok Island, South Korea (Cho, 2006).

For small-scale fisheries, these changes from dredging, albeit temporary, may cause long-term impacts to their livelihoods. This includes potential shifts in catch composition (de Jonge et al., 1993), loss of particular species that are unable to adapt to new conditions (Appleby & Scarratt, 1989), accumulation of contaminants leading to species deformities (Thibodeaux & Duckworth, 2001), increased risk for diseases (Landos, 2012), and declined catch per unit effort, particularly in disposal areas (Hatin et al., 2007). Dredging may also lead to the burial and mortality of fish eggs and larvae, while also disrupting migration (Soinski et al., 2022). Moreover, Ward-Campbell and Valere (2018) suggest that it may disturb benthic communities crucial for fish production. This arises from the resuspension of sediments as well as the removal of benthic habitat, and while ecosystems have the capacity to recover, their rate varies. Estuarine muds, for instance, may take 6-8 months to recover, while sand and gravels may require 2-3 years, and reef structures up to 5-10 years (Newell et al., 1998).

Apart from ecological disruptions affecting fish stock and catch for small-scale fisheries, dredging operations can also impact these communities at an operational level. The presence of dredging vessels and project areas may disrupt access to primary fishing grounds, leading to increased travel costs to reach alternatives. Furthermore, fisherfolks may need to invest in modifying their practices and gear. Additionally, change in the catch composition, potentially resulting in less valuable or more labor-intensive species being caught, can further impact the economic viability of small-scale fishing operations (Heenan et al., 2015).

From the viewpoint of projects, implementing specific modifications can mitigate these, including careful site selection and the use of appropriate equipment and practices (Soinski et al., 2022). Also, maintaining suspended sediment concentrations below certain thresholds and implementing access restrictions during critical life stages, as proposed by Wenger et al. (2018), can further alleviate the impacts. However, the quantification of dredging impacts where these potential impacts are linked to changes in small-scale fishing livelihoods remains unexplored, especially before dredging projects commence. This has only limited the understanding of the modifications necessary to avoid those impacts before the project takes place.

2.5 ASSESSING IMPACTS

Bennett et al. (2015) argued that while ocean grabbing is a real threat, it is crucial to avoid uncritically applying it to all initiatives involving changes in the allocation of marine resources or spaces, such as dredging. In the context of blue justice, three considerations can help determine whether an initiative constitutes ocean grabbing: the quality of governance, actions that undermine human security and livelihoods, and impacts that negatively affect social-ecological well-being (Bennett et al., 2015).

While there are main aspects to be examined—environmental, technical, and social—the attention given to each has been asymmetrical. Aside from the focus of dredging companies to the technical aspect, assessments of impacts have followed the predominant focus in fisheries studies, which emphasize environmental evaluations and modeling of stock and ecosystem. This is mostly based on the premise that these components are the more direct recipients of dredging impacts with more methodologies that can be used to assess environmental change. However, conventional research for ecological assessments are typically characterized by high costs, time-intensive, and technocratic (Pomeroy, 2016).

Simultaneously, without discounting environmental impacts, especially considering that small-scale fisheries are a social-ecological systems, impacts entail more than species composition and habitat recovery time—it also includes the change of the societal fabrics which is often unaccounted. Consequently, there have been calls for in-depth exploration into social impacts. An initial step involves examining changes in the catch and value gained in each fishing trip. While financial capital is indeed merely one aspect, it serves as a starting point. After all, it often acts as an enabler that facilitates access to other livelihood capitals and it is its absence that compels reliance to alternative capitals (DFID, 2001). Thus, financial capital offers a direct measure of vulnerability, especially in quantifying the changes incurred due to projects such as dredging. Nevertheless, while changes in catch and value are a crucial starting point, other factors influencing income—such as engine power, boat capacity, and trip frequency—must also be considered as they are often overlooked (Al Jabri et al., 2013).

At the same time, there has also been exploration in behavioral dynamics of fishers, with mobility to be identified as a key determinant of adaptive capacity (Béné, 2003). A prominent example is that dredging may disrupt fishing routes and restrict access to fishing grounds, hence altering the capacity for fishing trips. Recently, there has been interest in integrating the spatiotemporal data to enhance the analysis (Pinto et al., 2019), yet this is still not a common practice. Nonetheless, in the case where complete and regular data collection may not be possible, fishing behavior may represent the sum descriptive total of the fishery dynamics driven by both ecologically and economically (Castellanos-Galindo et al., 2018).

In support of enriching the knowledge within small-scale fisheries, FAO has issued various technical guidelines with the emphasis on measuring the state and sustainability of small-scale fisheries (e.g., FAO, 2015, 2017, 2022). In their latest work on 'Monitoring, Evaluation, and Learning Framework' (FAO, 2023) which was established to support the 'Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication' (FAO, 2015), they have identified 295 indicators that can be used to monitor small-scale fisheries across six thematic objectives. Although they are categorized into different themes, this is still a big number of indicators to investigate. Also, in its implementation to gather information, the challenge in collecting data has also been traced to the general lack of bureaucratic capacity at various administrative levels, the scale of these fisheries that is deemed too small to be regulated, and the lack of appropriate infrastructure and resources to undertake local research (Bennett, 2005). This lack of data across governance levels has only complicated projects to gather necessary baseline information prior to their operations.

Given this consistent lack of data and the challenges associated with methodologies that are too technocratic and costly, there has been more increasing experiments to collect data in which allow broader and direct engagement of the fishers (Thorpe et al., 2016). This also opens a new avenue for local communities to produce information to address problems through their perspectives that they think are key, which may not always be the same problems identified by scientists (Ahtuangaruak, 2015). Along with this, there is a trend towards recalling memories of past events such as specific species encounters or best catch during their fishing career, which provides valuable historical information where no prior data exist (Castello, 2023).

2.6 IFC PERFORMANCE STANDARDS

From the project's perspective, International Finance Corporation (IFC) has established a set of Performance Standards (see IFC, 2012) which provides guidance in identifying and managing project-related risks and impacts. This set typically applies to projects that are funded by either the IFC or banks affiliated with the Equator Principles. Nonetheless, even in the case of projects without such funding or obligation to comply, these Performance Standards remain a benchmark for a good practice of environmental and social risk assessment. As shown in **Figure 4**, there are eight standards that projects must adhere to, with the first one to emphasize the importance of conducting integrated assessment to identify risks, impacts, and opportunities of projects across environmental and social dimensions. It also highlights the necessity for effective engagement and consultation with the communities as well as the management of identified impacts.

Figure 4 IFC Performance Standards

Small-scale fisheries fall within the purview of Performance Standard 5 (Land Acquisition and Involuntary Resettlement), which recognizes that project-related land acquisition and restrictions on land use may adversely affect the communities residing and/or using the land. These impacts may result in economic displacement, such as loss of assets or access to them leading to loss of livelihoods, as well as physical displacement, which involves relocation or loss of shelter. As quoted directly from IFC Performance Standards Guidance Note (IFC, 2012), the objectives encompass:

a. To avoid, and when avoidance is not possible, minimize displacement by exploring alternative project designs.
b. To avoid forced eviction.

c. To anticipate and avoid, or when avoidance is not possible, minimize adverse social and economic impacts from land acquisition or restrictions on land use[1] by providing compensation for loss of assets at replacement cost;
d. ensuring that resettlement activities are implemented with appropriate disclosure of information, consultation, and the informed participation of those affected.
e. To improve, or restore, the livelihoods and standards of living displaced persons.
f. To improve living conditions among physically displaced persons through the provision of adequate housing with security of tenure at resettlement sites.

The classification of impacts as either physical or economic displacement dictates the type of mitigation plan to be developed. In instances of physical displacement, the project is required to draft a Resettlement Action Plan whereas in the case of economic displacement, they will need to develop a Livelihood Restoration Plan. In the case where the nature or magnitude of impacts are unclear to cause physical and/or economic displacement, projects should initially develop a Resettlement and/or Livelihood Restoration Framework. Subsequently, as more information becomes available, these can be expanded into either a Resettlement Action Plan (RAP) or a Livelihood Restoration Plan (LRP). While the details in compensation for the two displacements differ, the emphasis is to provide compensation of equal or better value than the asset or property being lost. This classification along with the type of affected persons are elaborated in **Table 3** below.

Table 3 Displacement as possible project's impacts (IFC, 2022)

Type	Economic	Physical
Landowner – formal title or legally-recognized customary right	• Replacement cost – market price & transaction costs. • Land-for-land compensation preferred.	• Replacement cost – market price & transaction costs for ALL impacted assets. • Choice of housing (resettlement site/self relocation).
Land user – no title or recognizable legal rights (e.g., informal settlers/users)	• No compensation for land. • Replacement cost for standing assets. • Moving allowance ++	• Standing assets – house, crops, and so on at replacement cost. • Adequate housing with security of tenure.
Livelihood restoration	• Equal or better transitional support.	• If livelihood affected, equal or better, transitional support.
Documentation required	• Livelihood Restoration Plan.	• Resettlement Action Plan.

In the case of small-scale fisheries, most impacts have been associated with economic displacement. Dredging operations can temporarily limit small-scale fishers' access to resources and marine spaces, which, if not effectively managed, can have significant long-term socioeconomic consequences. Specifically in regards of small-scale fisheries, IFC has also published a separate guideline, 'Addressing Project Impacts on Fishing-Based Livelihoods' (IFC, 2015). Within this, impacts are assessed across fish resources and habitats, fisheries systems, fishing-based livelihoods, transportation, safety, health, security, and environment. To do that, baseline data is needed particularly in terms of access and use, identification of fishermen and labor, catch analysis, and income.

Being able to assess impacts and establish baseline plays an important role for projects in not only fulfilling obligations under Performance Number 5, but also serves as a basis for mitigation measures and/or livelihood alternatives to be designed that suit the significance, time period, and extent of those impacts. Yet, this has been difficult to translate in practice.

[1] This also applies to marine context with land to refer to the area.

Even with the guidelines on how to assess different aspects of small-scale fisheries, it has been proven challenging to obtain reliable data that accurately represent their conditions (FAO, 2004), especially through which metrics those changes can be attributed back to dredging.

Simultaneously, while it is logical to base small-scale fisheries within these Performance Standards given that these livelihoods are nature-based, the complications in fisheries have led to implications. Although also covering the marine context, Performance Standard 5 is primarily prepared for land-based assets which are more measurable and easier to quantify. For instance, for a plot of land, projects can calculate what is grown on it, determine its market value, and calculate the income that might be temporarily or permanently lost during a project. In contrast, small-scale fisheries are much more mobile, complex, and diverse by nature of operations and behaviors.

To conclude, social impacts of dredging projects to small-scale fisheries are indeed challenging to measure, yet it should not serve as a rationale for inadequate measurement or negligence. Instead, this challenge should motivate efforts to identify indicators that can effectively capture the extent of these impacts (Burdge, 2003). To do this, there is a need to explore how those indicators work in challenging situations that portray the reality for most projects where no ideal situation exists, hence needing adaptability of which approaches serves best both the requirements for projects to proceed while still considering small-scale fisheries accordingly. The importance of choosing the right measure extends to the notion that the approach in examining a problem influences the methodologies being used which then determine the nature of data being collected, and the generated data will 'color the perspective and tenor of the analysis' that then follows (Natarajan et al., 2022). Thus, unless metrics to measure impacts of dredging to be properly chosen, any assessment of impacts will never get to the root of the problem and risk of mitigating them inappropriately.

2.7 CONCEPTUAL FRAMEWORK

Given the discussions of relevant concepts and issues so far about small-scale fisheries and dredging, the following **Figure 5** serves as the basis of analysis throughout this research.

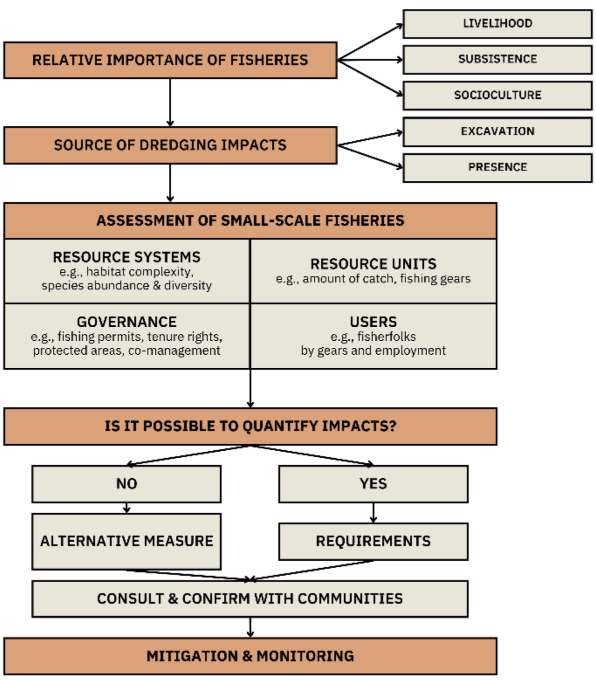


Figure 5 Conceptual framework

This conceptual framework, structured as a decision tree, visualizes the process governing the impact assessment of dredging projects on small-scale fisheries. It begins by examining the significance of fishing operations to the related communities (livelihood, subsistence, and/or sociocultural) and identifying the predicted sources of dredging impacts (excavation processes and/or the presence of dredging vessels or other project facilities). Guided by the underlying research questions, the framework emphasizes exploring the different components of the social-ecological systems that small-scale fisheries are part of. This central analysis focuses on identifying key components to be examined. Therefore, the initial assumptions provided are preliminary and will be refined through the research process.

The framework then explores the feasibility of different assessment methods. If quantification through those methods is not feasible, it seeks the best alternative for estimating impacts and establishing a baseline to inform appropriate mitigation measures. Additionally, it emphasizes the importance of community engagement throughout the process. Although not explicitly depicted in the figure, the research aims to determine when and how community participation should be integrated into impact assessments and how dredging projects can accommodate such participation to improve impact assessments. Ultimately, this approach will lead to equitable mitigation and monitoring processes, aligning with the principles of blue justice, and preventing the risk of dredging projects being perceived as ocean grabbing as campaigned by (Bennett et al., 2015).

3 RESEARCH DESIGN

3.1 OVERVIEW

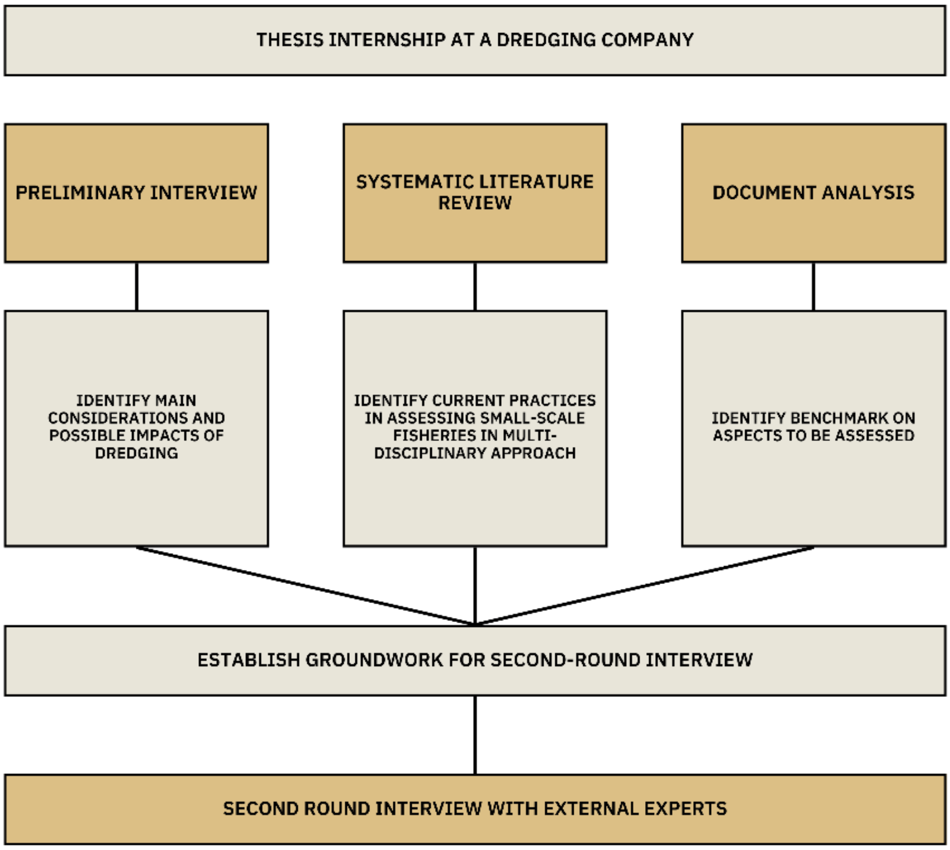


Figure 6 Multi-layered methodologies within this research

This study employs a multi-layered approach. As a groundwork, a preliminary interview round was done with practitioners in dredging industries and experts in small-scale fisheries, encompassing various roles and perspectives. This was aimed to establish a robust foundation, particularly identifying practical issues that have received limited coverage in literature. Subsequently, a systematic literature review was performed to evaluate the current understanding and utilization of indicators for assessing small-scale fishing livelihoods, especially in cases where specific stressors like dredging are prominent. This helps to describe existing knowledge, pinpoint effective research methodologies, identify experts, and uncover unpublished insights (Fink, 2019). Given the scarcity of studies focusing on dredging project impacts on small-scale fisheries, the systematic literature review encompasses a broader scope by including all case studies where small-scale fisheries are a primary focus, regardless of the stressors, as long as they are identified and explicitly elaborated.

The next stage entails evaluating common guidelines utilized in practice. This assessment is carried out through document analysis which can help to corroborate findings across diverse data sets (Bowen, 2009). Building upon the methodologies employed thus far, another series of in-depth interviews was conducted with selected experts. These interviews were specifically focused on exploring methodologies to assess and, if possible, quantify the impacts of dredging on small-scale fishing livelihoods. Adopting a semi-structured format, the interviews aimed to directly gather the perspectives of experts on various metrics and methodologies for assessing small-scale fishing livelihoods. Additionally, experts were asked about their approaches to addressing challenges encountered in projects.

This thesis is carried out under an internship with a dredging company operating on global scale which provided the researcher the access to internal expertise and knowledge on various projects and across disciplines. With this to enhance research process, the multi-layered approach aims to provide a comprehensive understanding of the methodologies suitable for quantifying dredging impacts on small-scale fishing livelihoods. Below, each of them is elaborated in detail.

3.2 SYSTEMATIC LITERATURE REVIEW

The systematic literature review adheres to the advised stages outlined by Moher et al. (2009) and follows the structure of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). To start, systematic searches were conducted on Web of Science using the combination of keywords: monitoring AND small-scale AND fisheries; assessing AND small-scale AND fisheries; quantifying AND small-scale SND fisheries; small-scale AND fisheries AND indicators. The term 'small-scale fisheries' was exclusively used as after preliminary searches, the other term such as 'artisanal fisheries' or 'traditional fisheries' yielded too low number (<10 in some keywords). Searches were limited to papers that were peer-reviewed and published in scientific journals, in English, between 1990-2024. This timeframe was chosen based on the earliest to latest available data in the Web of Science. However, it is important to note that the search was conducted in March 2024, excluding any publications released after this date. These searches yielded the following results:

Table 4 Yielded result per search keyword

SEARCH KEYWORDS	RESULTS	SCREENED
monitoring small-scale fisheries	768	138
assessing small-scale fisheries	1132	91
quantifying small-scale fisheries	284	27
small-scale fisheries indicators	466	24
	TOTAL	280
	REMOVAL OF DUPLICATES	-39
	TOTAL	**241**

The selection of papers was conducted in two stages, using predefined inclusion and exclusion criteria. Due to the vague nature of some titles, the first stage involved reading both the titles and abstracts. For each search result, the following inclusion criteria were applied during the first stage: the study must explicitly 1) examine small-scale fisheries, 2) focus on a specific location, and 3) use quantitative approaches. Studies meeting at least two of these criteria were included in the second stage. In the second stage, all selected articles were marked using the Marked List Manager from Web of Science, which automatically removed any duplicates. Approximately 10% of each paper was then read, with a focus on the methodology section, to apply the final inclusion and exclusion criteria.

Table 5 Inclusion and exclusion criteria for second screening stage of SLR

INCLUSION CRITERIA	EXCLUSION CRITERIA
Has a specified region, country, or delineated administrative spatial area.	Has general small-scale fisheries focus.
Specifies the type of fishery (by target catch and/or gears)	Only mentions small-scale fisheries but did not specify what kind.
States explicitly the stressors impacting small-scale fisheries (e.g., climate change, fishing restrictions, project).	Does not have focused stressors identified aside from that fishing-based livelihoods are vulnerable.
Elaborates the methodologies in detail, from study design, data collection, and analysis.	Does not provide enough details to replicate the study in other contexts.
Collects primary data. Secondary data sources are only permissible if they are of public access and the analysis is conducted by the researchers directly.	Strictly only use secondary data or from another study but did not specify or provide source for those data nor that those data are of public access.
Has a quantified result or range.	Does not provide a quantified result or range.

The next phase involved thoroughly reading all articles that met the inclusion criteria. The final selection of studies for the review was based on the same criteria used in the second screening stage, with a greater emphasis on the replicability of the studies. This emphasis was informed by consultations with experts at a dredging company affiliated with this thesis internship, particularly regarding the feasibility of conducting the studies at the project's outset before any dredging operations commenced. Studies not included in the final selection were still read in full and proved valuable for designing fisheries studies and developing potential monitoring methodologies when more time and resources could be allocated. Data from the selected articles were then extracted and organized into a table in Microsoft Excel (see **Appendix**). **Figure 7** illustrates the overall structure of the systematic literature review process.

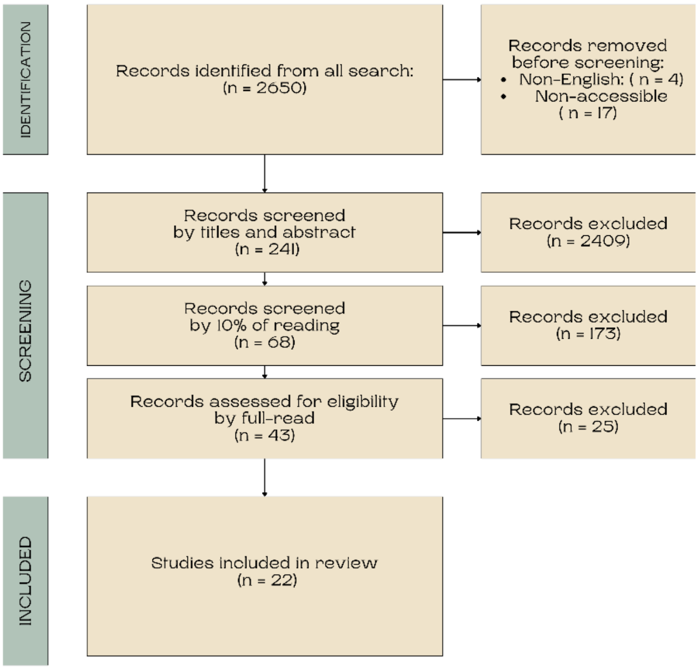


Figure 7 Overview of systematic literature review within this research

3.3 DOCUMENT ANALYSIS

Document analysis was employed to evaluate current industrial practices and assess whether explored approaches meet the requirements of dredging projects. To identify relevant documents, suggestions were sourced from internal experts from the dredging company and fisheries experts involved in the preliminary interviews. While there have been many references identified and later used during theoretical framework and discussion, these included below have been the general references that capture holistically the issue at hand.

Table 6 Resources used in document analysis

REFERENCE	KEY INFORMATION
Addressing Project Impacts on Fishing-Based Livelihoods (IFC, 2015)	Produced by IFC themselves whose Performance Standards have been the basis as benchmark for projects, this guideline is central to refer to especially in terms of specific contexts as to how various factors of projects need to be considered when they interact with small-scale fisheries by exploring even into the different types of fisheries by habitat, location, and gears being used. Although not specifically related to dredging, the listed considerations are highly relevant.
Social Impact Assessment: Guidance for Assessing and Managing the Social Impacts of Projects (Vanclay et al., 2015)	This document has been the core reference for assessing all sorts of social impacts that might arise when a project occurs through different capitals that communities need to ensure their prosperity. The document was mainly a reference in terms of how stakeholders such as local communities should be involved throughout the process and what considerations should be taken into account in these engagement efforts.
Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO, 2015)	FAO has published various guidelines specifically made for small-scale fisheries, yet most of them were developed in support of this main reference of how to ensure sustainability of small-scale fisheries. While it is important to examine other documents as well as they put more details, having this as a reference is better as all details were already mapped out anyway.
Monitoring, Evaluation, and Learning Framework: A Handbook (FAO, 2024)	This is one of the supporting documents that are most important to be considered separately than other documents as this specifies in the indicators and methodologies to use in monitoring small-scale fishing management efforts. Although this is not in the context of projects, many indicators are developed to monitor changes in fisheries which is what this study is concerned about in relation to dredging impacts being associated to it.

Also, during analysis stage, these documents became the basis for comparing of what can be done in the field according to various experts with what these institutions expect, hence going back and forth between findings and checking again with these documents to ensure expectations are met and when they are not, why. It is necessary to mention that none of these guidelines were made directly for dredging, and the closest one to fit the context to be the (IFC, 2015)'s Addressing Project Impacts on Fishing Livelihoods.

3.4 IN-DEPTH INTERVIEW

Given interview is a methodology to explore perspectives from experts about complex issues (Barriball & While, 1994), they were deemed the most appropriate approach for this research. Consulting with experts allowed for the acquisition of empirical knowledge, offering insights into specific contexts, and enabling discussions of existing studies. Moreover, experts provided the opportunity to explore new methodologies that could be applied in the context of dredging which are often not captured or documented within research of this nature. Semi-structured format is chosen so that there can be easy movement between questions (Åstedt-Kurki & Heikkinen, 1994) and even the opportunity to change questions depending on the discussion (Dearnley, 2005). Two types of interviews with a total of 32 experts were conducted: preliminary interviews and in-depth interviews.

For preliminary interviews, 16 experts were interviewed with seven to be internal experts within a dredging company, representing different departments and roles. Four experts were academic researchers with expertise in impact assessments, while the remaining experts were fisheries experts holding various roles, ranging from leader of fishers' associations to fisheries biologist. Follow-up sessions were conducted with some of these experts to discuss new findings from other interviews that were particularly relevant to their backgrounds, as discovered in the initial interviews. Each interview lasted between 35 to 70 minutes, with an average duration of about 60 minutes.

The preliminary interviews served a dual purpose: investigating the impact of dredging on small-scale fisheries and understanding the perspectives of different stakeholders involved in dredging that intersect with small-scale fisheries. The key questions in the interviews included asking stakeholders to walk through the process of dredging or coastal and marine projects to identify potential interactions with small-scale fisheries. For fisheries experts, the focus was on exploring how the stages in general dredging operations might impact small-scale fisheries.

Insights from these interviews, combined with findings from the systematic literature review on metrics for measuring small-scale fishing livelihoods and international guideline standards, provided a comprehensive understanding of how dredging projects unfold and the challenges in assessing impacts. A total of 16 interviews were consulted with four to have background in ecology, two in impact assessment, four in marine policy and management, four in stakeholder engagement and community management, and three in fisheries or environmental economics. Among these, four experts have prior involvement in dredging projects, while the rest have varied exposure or knowledge to dredging operation or industry. In contrast with the preliminary interviews, all experts interviewed for the second round were entirely external. The duration of these interviews ranged from 70-110 minutes, with average to be of 90 minutes. The second round of interviews focused on gathering insights from dredging practitioners and small-scale fisheries experts on the baseline information that should and could be collected from small-scale fisheries potentially affected by dredging. Additionally, it explored the best methodologies for quantifying these impacts.

All experts were sampled initially using purposive sampling targeting mainly fisheries experts, dredging practitioners, and experts in social impact assessments. However, while both initial samples have been done upon the consultation with supervisors of this research, many experts being interviewed in the second round were sourced through their contact details provided in their published studies. From there, snowballing method were conducted. After the interview, some experts remain in discussion through e-mail conversation to corroborate the analysis. In conjunction with all on-going methodologies during this research, the internal experts across departments of the dredging company continue to provide insights and assist in the analysis.

3.5 ANALYSIS & STORAGE

Analysis was mainly carried out with the help of Microsoft Excel and Atlas.ti. While there are three methodologies being lined out and done subsequently after one another, there is a back-and-forth research process across the methodologies once the second round of interviews started especially as the experts provided guidance also in documents or projects to investigate.

All interviews were done with consent that their insights will be used in this research. All personal data or affiliations beyond their nature of expertise were anonymized to reduce the risk of identifiability. Nonetheless, respondents have the right to access, rectify, and erase their data that has been gathered through interviews by directly contacting the researcher. This is provided even though before and after each interview, a confirmation of consent was done and how data would be managed in the research had been elaborated. Participation for the interview was entirely voluntary and all respondents could withdraw from this research at any time.

In terms of storage, OneDrive was the main point and a backup on Unishare with only the researcher to have access. No raw data will be shared to any respondents or external parties other than the outputs elaborated in this study, nor that any data will be shared in future research without permissions from the interviewees. Nonetheless, as the aim of this research is also to build network with experts to consult upon projects, the supervisors have knowledge of the experts being interviewed and can also inquire which insights is whose to consult deeper on future projects. This is however upon request and has been made clear with all the interviewees.

3.6 POSITIONALITY

This thesis was conducted as an internship at a dredging and maritime engineering company, specifically within an in-house engineering department. From the outset, there seems to be a concern of positionality, as the thesis might provide recommendations that primarily benefit the company and overlook considerations for small-scale fisheries, given the department's engineering-dominated background. The researcher acknowledges the potential for bias and the concern that the thesis might favor the company's interests. While this is a valid concern, it was indeed one of the drivers to pursue the thesis at the company. The goal was to understand the perspectives of individuals, primarily engineers, and engage in direct discussions about the issues identified in this thesis, as well as insights from fisheries experts. This back-and-forth dialogue aimed to find solutions that satisfy multiple interests and would not have been possible without the access provided by the company to these experts willing to engage in extensive conversations. The researcher also remains committed to the primary objective to understand the full extent of dredging impacts on small-scale fisheries so that the communities can sustain their livelihoods. It is, however, also a limitation due to time and resources restrictions that this research did not have more direct involvement with various parts of small-scale fishing communities in a specific context. Hence, this serves as an avenue for future research to enhance the depth and applicability of findings.

4 FINDINGS

4.1 ZONE OF IMPACTS

Preliminary interviews with internal experts from the dredging company focused on discussing the main activities of dredging and listing possible components of these activities that might impact small-scale fisheries. Interviews with fisheries and social impact experts further explored these interactions in the context of changes that might affect small-scale fisheries. From these, potential impacts are categorized by the main components of dredging: extractive activities that alter the environment upon which fisheries depend, and the presence of dredging vessels and facilities that directly interact with fishing activities. These predefined zones of impact represent potential ways that dredging could affect fisheries, rather than definitive impacts. It is important to note that in many occurrences of these impacts, they are typically temporary, which can reduce catch capacity and income rather than result in a total loss of livelihood.

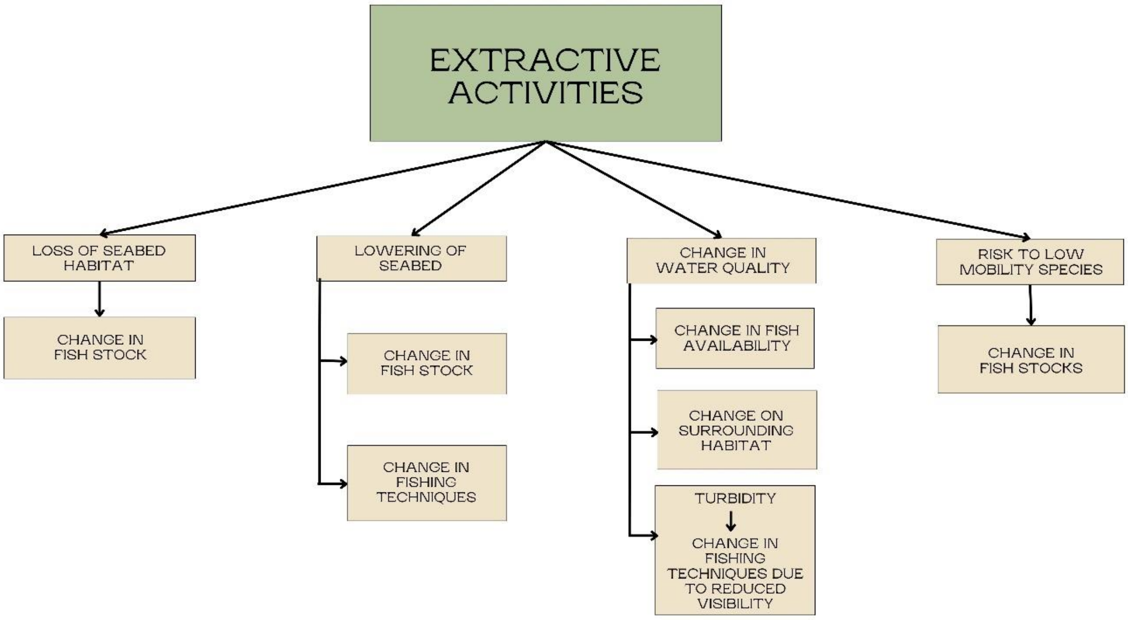


Figure 8 Possible zone of impacts from extractive activities of dredging

Examining each component, it is best to start with the environmental changes associated with dredging. The general concerns of dredging gathered from the preliminary interviews align with existing literature, especially in regards of disturbance to turbidity (see Aarninkhof, 2008; Bray, 2008). First and foremost, changes in turbidity may influence fish community composition and species growth in long-term (Ryan, 1991; Sigler et al., 1984), although such severe changes may also be caused by chronic case of turbidity. In dredging, turbidity is expected to be temporary as proclaimed by Manap & Voulvoulis (2016), which then may revert to pre-dredging levels once the dredging concludes or if appropriate mitigation measures are implemented to facilitate environmental recovery. Nonetheless, turbidity is not the only factor contributing to changes in marine dynamics. There are many factors influencing primary production that thus affect the availability of fish stock, which is often related to the condition of the habitats. Dredging may also alter habitats which have varying recovery rate once it is disrupted (Newell et al., 1998). However, recovery is not only about habitat, but also about the fish itself.

The critical consideration here is that each species has different recovery rate given their life history, with long-lived species may take decades to recover (Lotze et al., 2011). It is difficult to quantify and then generalize the recovery rate of all species in each habitat, hence in the case of dredging, it is best to identify the important species and whether these species can recover given the disruptions. Another consideration is the species mobility as it determines the species capacity to navigate through changing processes, such as excessive light or noise, within the ecosystems (Booth et al., 2013) which eventually influences the ability for the species to survive (Dill, 1983). Expanding on prior discussions, these environmental changes resulting from dredging could then be linked to the change in the catch capacity of small-scale fisheries, with abundance being the most immediate indicator. Then, beyond altering catch quantity, these may also shift the overall catch composition. It is crucial to assess whether the new composition is comparable in value to the previous, as this will directly impact the income of fisherfolk.

Furthermore, another concern is the alteration of seabed depth (see Cho, 2006), which can directly impact fishing. Many practices and target species are tied to specific depths, and any changes may lead to shifts in catch composition as they respond to the new conditions. Moreover, such alterations could demand adjustments to established practices or even require complete change of gear. While this may seem straightforward, the implications are more profound—fishers may require financial support, which can be challenging given the existing struggle to secure funding for their operations (Béné & Friend, 2011; Bennett et al., 2014; FAO, 2015; Rashid, 2020; Silva et al., 2019). Yet, as pointed out in interviews, the issue extends beyond the financial capacity to switch gears. This is because unlike industrial fisheries that are financially driven, fishing for these communities is ‘a way of life’ that is deeply ingrained in the identity of fishers and their communities, and as quoted from the interview (**R10**), the loss is beyond financial, it can also be cultural:

‘To have fisheries as livelihood taken away or replaced,
[it is] a loss of the generation.’

Therefore, changes in fishing practices can provoke shifts in identity, posing significant challenges beyond economic, and not only difficult to measure but also challenging to address.

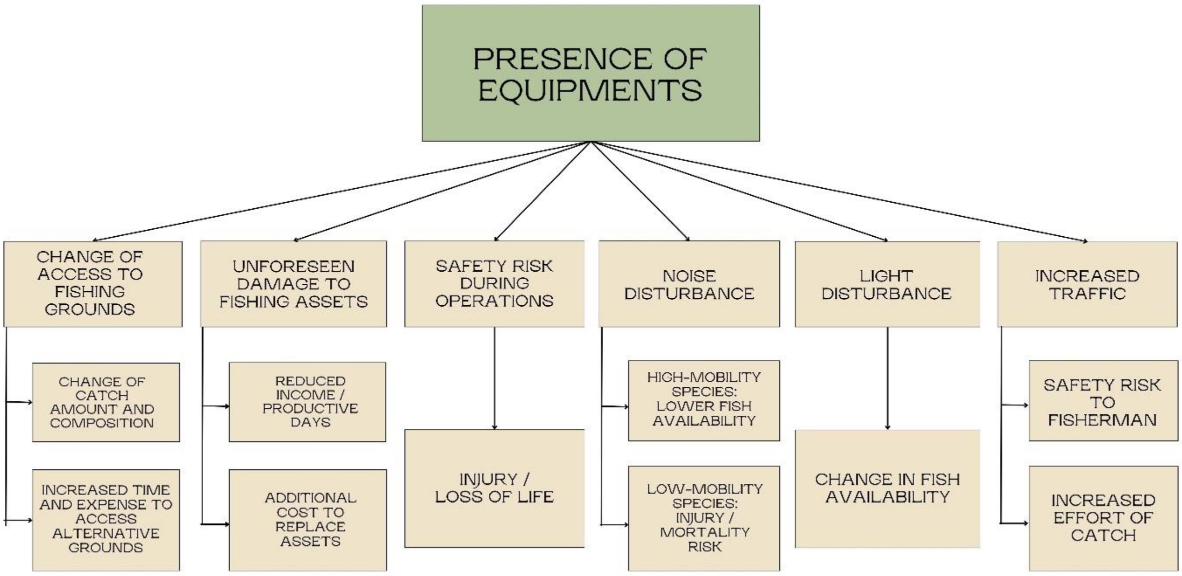


Figure 9 Possible zone of impacts from presence of equipment of dredging

Another cause of impacts is the presence of dredging vessels and facilities within or near primary fishing grounds, especially during important fishing periods. This can disrupt fishing and subsequently affect the fishers' income. This stems not only from the physical presence of dredging vessels but also from the routes these vessels traverse along, which may also pose safety hazards for fishing vessels. Additionally, projects often entail the closure of specific areas. Unfortunately, these closures tend to restrict fishers' movement and reduce their opportunities for fishing.

On the surface, addressing these challenges may seem feasible by either: schedule dredging operations accordingly to fishing activities and/or redirect small-scale fisheries to alternative fishing grounds. However, dredging is a costly endeavor, and idling dredging vessels when they are not in use would incur substantial costs. From the technical perspective of dredging, the question then shifts to determining which is more preferable: a condensed dredging schedule that impacts fisheries over a shorter window of time, such as four months, or a longer dredging period lasting up to nine months to allow for co-use of space with fisheries, and which option has the least impacts.

Moreover, dredging covers large-scale operations using vessels which mechanisms cannot be easily turned on and off, it entails long process and technical specificities that are more complicated to adjust to fishing operations, which is dynamic by nature (Finkbeiner, 2015) hence it is truly hard to know their movements given the lack of spatial data (Behivoke et al., 2021; Gill et al., 2019; Léopold et al., 2014). Therefore, if fishers need to be redirected to alternative fishing grounds, they are likely to face increased cost per fishing trip (e.g., fuel) required to reach these areas. Additionally, one fisheries expert specializing in stock assessment also pointed out that alternative fishing grounds also may not provide the same catch composition as primary grounds.

An added concern related to dredging operations is the potential damage they can incur to fishing gear, particularly the fixed structures such as nets and traps. Repairing or replacing these structures will not only impose an additional cost, but also render certain days for fishing unproductive. Nevertheless, compared to other concerns, there are commonly already mechanisms in place to assist such disruption or loss in this regard. For instance, fishers whose gear have been damaged can file complaints to the project team who then commence investigations leading to potential compensation. This, however, also depends on the governance of fisheries as well as the arrangements made by the dredging project and the client and may vary by project.

Another concern associated with the movements of dredging is linked to increased traffic, which poses safety risks for fishers, particularly if strict exclusion zones are not established. Nonetheless, this is dilemmatic—without these zones, there is a concern that fishers may inadvertently venture too close to dredging vessels which may have a risk in damaging their gear and boats as well as posing a potential harm to their safety, yet with it, it might reduce the fishing opportunities. This traffic increase may disrupt the capacity for fishers to conduct their fishing trips as per usual, hence impacting their ability to sustain income at the normal level.

Now, identifying impacts is critical for understanding how they occur, allowing us to mitigate them. When assessing impacts, it is imperative to trace them back to their root causes. This is echoed by Schönwandt et al. (2014) who emphasized that defining a problem and understanding its causes are essential toward finding solutions. Without this, any attempt at a solution is likely to fail. This becomes crucial when we regard small-scale fisheries, which as FAO (2002) stated, 'without reliable information, no supportable decisions can be reached, no diagnoses on the state of fisheries can be performed, and no prognoses on the effects of management control can be made'. After all, for an effect to be considered an impact, it must be causally linked, not merely coincidental (Schönwandt et al., 2014).

However, due to the complicated nature of social-ecological systems in which small-scale fisheries and dredging are part of, attributing impacts to a specific dredging operation can be difficult. Indeed, the difficulty mainly resides in the impacts associated with ecological consequences resulting which becomes complicated by climate change. A note from one expert (**R26**) demonstrated this complication:

> *'If you really want to trace it separately, you really have to cover everything, [yet] there is no way to separate everything.'*

These zones of impact represent the areas where dredging intersect with small-scale fisheries. From the elaboration provided, we can identify two primary zones of impact: ecological alteration and operational interactions. Each of these zones exhibits distinct temporal dynamics but shares similar consequences, such as disruptions or loss of livelihood. Nevertheless, the critical question arises: how can we measure these impacts and their significance?

4.2 THE SEASCAPE OF METHODOLOGIES

'How do you measure the impact of the dredging if you don't know what was going on before? Or what was happening all around?'

R24

Following the keyword search, before any screening was conducted, the results were dominated by case studies from developed countries such as the United States. Even though 'small-scale fisheries' was included in the keywords, the search results often still included studies mixed with industrial fishing. However, the results shifted once the inclusion criteria were applied. Almost all studies that made it into the final selection were conducted in developing countries in which they have all shared a common issue: the lack of reliable data on small-scale fisheries and the absence of mechanisms to collect data. In developing countries, bureaucratic limitations and insufficient integration of data across administrative levels have resulted in incomplete and fragmented datasets (Silvano & Hallwass, 2020; Teh et al., 2011). While this is a persistent issue across regions, experts also argue that it may also stem from the lack of integration of local knowledge which involves different metrics than those commonly used, thus not considered 'scientific enough' to be in official reports or statistics. Nevertheless, this data limitation, especially to conduct time series or historical analysis of fisheries, has been the challenge to conduct many assessments.

The first stage of systematic literature review confirmed that the focus of fisheries studies has been on ecological issues such as climate-related pressures (e.g., Macusi et al., 2020) and overfishing (e.g., Gill et al., 2019). This stage also revealed an increasing number of studies assessing indicators to best portray the full picture of small-scale fisheries, such as van Zwieten et al. (2011). Although none of these studies were included in the final review due to their different focus, they provided insights for exploring ideas on indicators to discuss with experts.

In the review, there were two studies which were done under similar research project in which the scope is 17 Pacific Island countries and territories (PICTs) (see Kronen et al., 2010, 2012). Aside from these and a study along the Southern Gulf of Mexico by Torres-Irineo et al. (2021), there were other 13 countries being represented in the review: Turkey (1), New Caledonia (1), Brazil (5), Taiwan (1), Philippines (1), Madagascar (2), Tonga (1), Barbados (1), Thailand (1), Malaysia (1), Colombia (2), Indonesia (1), Myanmar (1). The full overview of all case studies is provided in **the Appendix**.

Across the reviewed fisheries study, only Silvano & Hallwass (2020) explicitly mentioned infrastructure projects as major stressors to small-scale fisheries. Most studies focused on climate change and fisheries-related pressures, such as overfishing, as the main concern while stressors like dredging projects were rarely a focus. So far, despite the growing literature on affected fisheries, no studies have established and estimated a baseline before a dredging project started to then monitor the actual impact and assess the accuracy of that baseline in the end of the project. Currently, research typically takes one of two approaches: projecting scenarios to assess possible impacts or evaluating the significance of already occurring impacts by comparing them to historical data. This highlights the recurring norm in broader impact assessment, where the process is often treated as a 'one-shot' effort, concentrating primarily on the initial stages while considerably less in the end of the project (Arts, 1998; Arts & Morrison-Saunders, 2004; Runhaar & Arts, 2015) nor the assessment whether the estimation or assumption of impacts made in the beginning were accurate. Given the limited number of academically published project-related fisheries studies, this research aimed to encompass general fisheries studies to provide a broader context. The real-life occurrences and replicability of these studies were central to discussions during interviews with all experts.

A notable pattern in the geographical context is that many island regions face significant fishing challenges, necessitating sustainable solutions for their small-scale fisheries, as these are often the sole livelihoods available. However, governance and management efforts have been insufficient to ensure the sustainability of these fisheries (Jul-Larsen et al., 2003; Orensanz et al., 2005). Given the extreme climatic pressures that jeopardize the sustainability of these islands and their natural-resource-dependent livelihoods (Betzold, 2015; Hay, 2013; Nunn & Kumar, 2017), these regions face pronounced challenges due to the data-poor conditions of their fisheries. In designing fisheries studies, however, it was found that small-scale fisheries exhibit similar characteristics regardless of their geographic locations, and the differences would be placed on the significance fishing holds for the communities themselves. However, a significant difference is that compared to when project is conducted on the coastal area of mainlands, island regions often suffer from heightened dependency when disruptions related to ocean-based developments occur in their fishing livelihoods. This dependency and vulnerability of islands are often overlooked in literature, policy, and project considerations.

In organizing the type of indicators, five classifications were inductively created: sociodemographic, catch, operation, economic, and environmental. Sociodemographic covers the information in regards of the communities with household as unit of focus. Catch includes species composition, capacity, and period of fishing. Operation entails the technical details during fishing operations such as type of gear, location of fishing, route to reach fishing grounds, time, and others. Economic then entails all the indicators in regards of value attributed to catch as well as financial investment put forth into fishing operations. Finally, environmental covers all the indicators of environmental component that are believed to be linked to small-scale fisheries.

In terms of frequency, catch and operation indicators predominate, appearing in 15 and 14 out of 22 studies, respectively, while sociodemographic, economic, and environmental indicators feature in about half of the studies. Classifying these indicators has been challenging due to overlap, especially among the catch, operation, and economic categories as they are often compiled together under an indicator of catch per unit effort (CPUE – further discussed in section **4.2.1**). Therefore, these indicators and the assessments involving them were categorized into: *operational* in which catch, activities, and resources are examined; *ecological* in which aspects related to the productivity and capacity of the environment to support fisheries; and *spatial* in which location and movement of components are explored to provide proxy of limited or missing data.

4.2.1 OPERATIONAL ASPECT

Many studies (e.g., Macusi et al., 2020; Pennino et al., 2016; Selvaraj et al., 2023; Silvano & Hallwass, 2020; Torres-Irineo et al., 2021) and experts involved in this research have told us to follow the fish to understand the extent of dredging impacts. However, when we discuss about catch in fisheries, it is not simply the weight that fisherfolks gain. In fisheries studies, it is included in a parameter called catch per unit effort ($CPUE$ / C/f) which has long been used as a measure (Petrere et al., 2010). There have been many criticism in using CPUE (Beverton & Holt, 2012; Hilborn & Walters, 2013; Walters, 2003) as raw or nominal CPUE cannot be considered directly or proportional to abundance as many factors contribute. Nevertheless, it remains the most common indicator to assess fisheries productivity by measuring stock biomass, with its reliability is influenced by the selected unit of effort. Referring to Hubert & Fabrizio (2007), CPUE or a C/f index is defined mathematically as:

$$C/f = qN \tag{1}$$

in which C represents the catch (commonly measured in weight, e.g., kilogram), f denotes the unit of effort at expense (e.g., fishing hours per week, traps used), and q stands for the catchability coefficient or probability of catching an individual fish in one unit of effort and N is the absolute abundance of fish in the stock. Taking it further, f is defined depending on the gear, area of habitat, or duration (Hubert & Fabrizio, 2007). Standardizing CPUE, however, requires the decisions of which components will be used as measures of catch and effort. These can be influenced by biology of the species, fisheries structure, data availability, and the aim of the analysis (Hoyle et al., 2024). The challenge with measuring catch in weight also lies in the units of measurement commonly used by fisherfolk. Experts have acknowledged that fisherfolk often do not use or report their catch in standardized units. For example, they might use proxy measures such as the number of buckets of fish, which then need to be converted to kilograms by the researchers.

According to the insights from several experts, besides ensuring that catch is calculated by each species, it is crucial to consider the most appropriate unit of effort. This has resulted in variations, which the most common in fisheries studies of small-scale fisheries to be:

$$CPUE = \frac{total\ weight\ (kg)}{number\ of\ fishers \times number\ of\ fishing\ days} \tag{2}$$

One elaboration from this general conceptualization is done in the study by Barnes-Mauthe et al. (2013), where the variations of catch during normal, bad, and good weather is accounted:

$$CPUE = [K_{gd} * \lambda_{gd}] + [K_{bd} * \lambda_{bd}] + [K_n * \lambda_n] \tag{3}$$

where K is the catch weight (kg) per fish per day and λ is the normalized chance or probability of the catch being good. In their study of Madagascar, segregating this has clear benefits not only to increase accuracy of the total economic value of small-scale fisheries to be $ 6.9 million, but also specify that number by different types of targets catch and their associated revenue.

Table 7 Estimated value of Madagascar's small-scale fisheries by species group (Barnes-Mauthe et al., 2013)

Species group	Landings (t)	% sold	Fishing revenue (in thousands)	Total value (in thousands)
Cheap finfish	2615	0.78	$1667	$2029
Sea cucumber	189	1.00	$1562	$1562
Octopus	1009	1.00	$889	$891
Avg. priced finfish	974	0.80	$786	$964
Mad. R. herring	433	0.94	$753	$776
Crab	84	1.00	$78	$78
Squid	40	0.72	$107	$148
Lobster	4	1.00	$31	$31
Exp. finfish	23	0.86	$28	$32
Shrimp	22	0.88	$25	$27
Shark	21	0.89	$12	$13
Bivalve	33	0.08	$4	$46
Shellfish	11	0.13	$6	$50
Urchin	51	0.11	$4	$37
Cowrie shell	43	0.02	$4	$187
Ray	16	0.32	$2	$7
Turtle	0	0.31	$0	$0
Total:	5524	0.83	$5958	$6880

One note when we attach landed value of that catch is to know whether the data on price that we have is ex-vessel price. This is important because ex-vessel price is the per unit fish price that fishers receive when they land their catch (Teh et al., 2011) which can be calculated from reported landed values and landings (Sumaila et al., 2007) instead of the aggregate market value that consumers pay but not always reflective of fishers' earning. An alternative to estimate total valuation was conducted by Teh et al. (2011) in which they measured the contribution of small-scale fisheries in Sabah, Malaysia in proportion to the state economic by multiplying the landed value of catch (V) with a weighted multiplier (α) which was developed by Dyck & Sumaila (2010). This has in fact shown that Sabah's small-scale fisheries from the early 1990s has been undervalued by up to 225%.

Furthermore, unit of effort is not solely determined by the time spent in fishing; it can also be influenced by the type of gear used, such as the number of traps. This aspect was emphasized during an interview (**R24**).

'…the catch per unit effort needs to be directed to the type of fisheries, the type of fishing gear not just the number of folks.'

In fact, another expert (**R29**) also suggested knowing the effort as a start by:

'…doing some kind of inventory research of diversity in fishing. So, trying to understand, because small-scale fisheries is such a broad category, which with lots of it contains lots of different styles of fishing.'

Similar to the approach for defining catch by each species, it is as essential to calculate unit of effort and overall catch per unit effort (CPUE) separately for each type of gear. Different gear operates in distinct ways, and aggregating into one measure could oversimplify the operations.

There are many methods to gather information of catch, namely logbooks, sightings, and market studies, export data and others (Teh et al., 2011). Most of them will require direct consultation with the fisherfolks, especially if the historical data of the fisheries has been limited. Aside from the identification of important species, information that could be as useful for calculating CPUE is the seasonal variability of fishing operations which could be gathered through seasonal calendar where fisherfolks are asked not only the composition of important species across seasons, but also their catchability. However, gathering reliable catch and effort information requires access and trust with local communities and demand a large sample to accurately represent the fishery (Hutchings & Ferguson, 2000; Rocha et al., 2004).

4.2.2 ECOLOGICAL ASPECTS

The predominant focus of ecological aspect in fisheries literature is logical given that fisheries rely in the dynamics of social-ecological systems. When disturbances occur, different fish species will react based on their species' sensitivity and capacity, even if there is interpopulation variation (Schulte, 2014). Given that fish serve as the resource unit in social-ecological systems (see section **2.3**), their responses can be a starting point. As noted by Torres-Irineo et al. (2021), environmental conditions play a role in shaping the spatial distribution of species, specifically net primary production and sea surface temperature. Kronen et al. (2012) demonstrated in their study across Pacific Islands that it is feasible to model the fishing pressure in relation to the productivity rate of the habitat, and then further showed that even low fishing intensity may provoke unpredictable and severe cascading effects.

Then, it is crucial to establish a baseline by identifying species that are important for small-scale fisheries across ecological, commercial, and subsistence dimensions. In fact, before delving into detailed data on fisheries, identifying the key species is of foremost importance. For ecologically important species, knowing their life history stages, particularly spawning times and other life stages, is crucial. Knowing this helps to identify which components of dredging may affect their life stages and when to best schedule dredging operation around these periods. Then, in the case of commercially and subsistence-important species, which form the core catch composition, it is vital to understand not only their life history stages but also the seasonality of fishing operations. It is, however, important to limit the definition of 'important' species within only 5-10 species as this will help to specify the focus and provide more fitting measures according to the capacity of the project.

Mapping the relative importance of various fish species has been conducted by Silvano & Hallwass (2020) who surveyed fishers along Tapajos River in Brazil. Participants were asked to rank the five most important fish species based on their catch, providing insights into the perceived importance of each species. Below is the aggregated and visualized result.

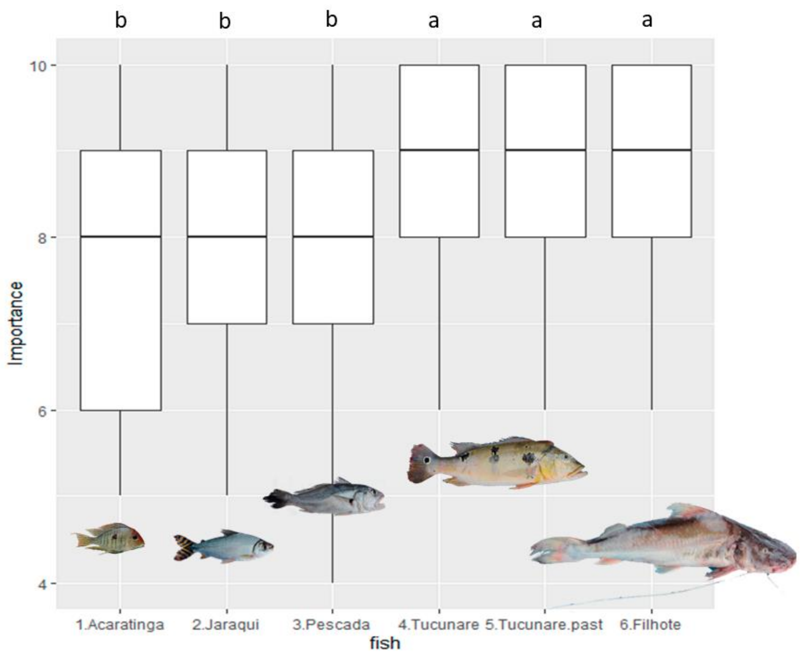


Figure 10 Median values of importance attributed to specified fish species (Silvano & Hallwass, 2020)

In fisheries studies, assessing gonadal or reproductive organs maturity has traditionally been a focal point for understanding the life history of species. This provides biological data for analyzing fish stocks and their long-term reproductive cycles (Marriott et al., 2010). However, it requires specialized expertise and can be challenging within limited time. Fortunately, there has been a proliferation of data-limited methodologies being developed and applied (Chrysafi & Kuparinen, 2016; Dowling et al., 2015) where length-frequency assessment emerges as an option due to its cost effectiveness and relative ease of collection (Hordyk et al., 2015; Mildenberger et al., 2017; Pilling et al., 2008).

Length-frequency assessment can be measured as L_m (length at maturity) or L_c (length at capture) and commonly in centimeter (cm). By measuring the length of the species over a specific period, this method can be used to monitor if dredging impacts the species by directly comparing the changes in length over time. During an interview with the same expert, it was determined that approximately 200 samples per species would be a reasonable starting point for the sample size. Following the data collection, there are various subsequent analytical approaches and packages that can be explored (see Chong et al., 2020; Pons et al., 2020). Nevertheless, without a substantial amount of datasets over longer time series, this assessment still fall short to prove an indication of impact upfront, in the same way that a recovery period of habitat can only be assumed, but difficult to accurately state.

The potential if ecological data is available at extensive scale and detail is demonstrated by Kim et al. (2008) who estimated the damages from entrainment and temporary loss of seafloor habitat productivity because of marine sand mining to commercial fisheries in Ongjin, South Korea. In this study, an estimate was possible to be quantified as losses were limited to two environmental stresses: direct lost catch from entrainment of species in the sand-water slurry; and the indirect reductions in catch which results from loss of forage species and food webs effects from the temporary loss of productive bottom habitat. By approximating a single dredging operation to be of 4 km^2 mining site, mined to 2 m depth with seven months of habitat recovery time, which is illustrative to common mining practices in South Korea (Korean

Aggregates Association, 2002) and running the scenario of both single mining site and cumulative impact of recurring mining over multi-year periods, this study used fisheries abundance data (kg wet weight per km^2) throughout seasons for a full fishing year and specified species (annual data from another study by Han & Park (2002) to assess the environmental impacts of sand mining), life history data by each identified important species (mortality, length, weight, t_R (time of recruitment to the fishery), life span) sourced from national databases, and area-specific and weighted average ex-vessel price (2004 $/kg) sourced from the national statistics and local fisheries cooperative. Using a Beverton-Holt year-class model (see Ricker, 1975), the estimate of mining impacts was calculated in three different ways: short-term, long-term, and indirect effects through the food webs. The results are presented as follows:

Table 8 Loss of catch in 2004 $ (Kim et al., 2008)

Area	Blue crab	Other crab	Shrimp	Trump shell	Jacopever	Others	Total
One site	$23,690	$3,284	$88	$606	$1,660	$4,383	$33,710
20 sites	$473,791	$65,688	$1764	$12,114	$33,198	$87,655	$674,209

Table 9 Estimated damage from aggregate mining in 2004 $ (Kim et al., 2008)

Area	Short-term	Long-term	Food web effect	Total
One mining site	$10,282	$15,405	$8,024	$33,710
20 mining sites	$205,637	$308,098	$160,473	$674,209

Table 10 Estimated cumulative losses due to aggregate mining in 2004 $ (Kim et al., 2008)

Area	Short-term	Long-term	Food web effect	Total
5-year mining	$2,891,552	$1,397,658	$1,707,320	$5,996,531
10-year mining	$9,871,973	$2,486,720	$5,401,327	$17,760,020

If we refer to Freeman (2003), the quantification of possible loss of services, as illustrated in the above case, can be viewed as a reference for the minimum amount of compensation required for projects to provide for the communities. Compensation here does not necessarily mean direct monetary payment, nor does it imply that the value of quantification is solely financial. Rather, it provides an estimate of the significance of impacts experienced by the affected communities. This allows dredging projects to allocate sufficient and appropriate resources to address different impacts based on their relative significance, considering the project's time and resource constraints. Additionally, knowing the extent to which dredging may incur loss of services can also allow the project to reconsider operational methodologies or working schedules to minimize or avoid the impacts altogether.

4.2.3 SPATIAL ASPECT

Small-scale fisheries also encompass the individuals behind the gear who are just as mobile and dynamic as the fish they pursue. This aspect—the movements of the fishers—has been overlooked (Torres-Irineo et al., 2014). As Salas & Gaertner (2004) argued, despite the complex dynamics of fishing operations, fisheries management has frequently treated fishers as 'fixed elements', failing to account for individual attitudes influenced by their operating scales—geographical, ecological, social, and economic—and personal goals. Analyzing how fishers respond to changes in varying conditions as well as which drivers are involved in effort allocation and species targeted can provide a basis for the development of viable management strategies (Katsanevakis et al., 2010). One account from **R28**:

'But where do you start? You figure out, I guess, what the current situation is in terms of usage. ... I would look at establishing how long the fishery has been there, what their practices are, where they fish, how often they fish, what the different types of fishes are in that community.'

Therefore, we need to also follow the fishers. Understanding fishers' behavior is about knowing the important sites for fishing and movement in-between. Aside from the primary fishing grounds and landing sites, mapping the spatial distribution of fishing vessels and the factors that influence this can facilitate identification of alternative fishing grounds when necessary (McCluskey & Lewison, 2008). Nevertheless, compared to the environmental and economic assessment, spatial understanding of small-scale fisheries has been comparatively restricted and rarely integrated into marine spatial plans in which conservation policies are designed (Janßen et al., 2018).

Large-scale, industrial fisheries are typically equipped with advanced navigation and tracking systems, such as a complete set of global positioning system (GPS) technologies that include vessel monitoring systems (VMS) and automatic identification systems (AIS). The primary purpose of these is to monitor the dynamics of fishing activities and provide critical data for managing these operations efficiently (Jennings & Lee, 2012). In contrast, small-scale fisheries often lack the capacity and resources to have such systems (Johnson et al., 2017) and they instead use their experiential knowledge for navigation. This has resulted in a lack of spatial data availability of small-scale fisheries (Behivoke et al., 2021). This is concerning as understanding their spatial representation is critical as they mostly operate in coastal areas where they have to compete for space and resources with multiple users such as aquaculture, coastal projects, maritime transport, and others (Jentoft et al., 2017). If this is not managed well, this situation may lead to 'ocean grabbing' (see section **1.2**) – in analogy to land grabbing (Smyth & Vanclay, 2024) – where small-scale fishers may risk losing their rights to access or use ocean space or resources (Bennett et al., 2015).

Tools of geographic information systems (GIS) have been explored for fisheries, particularly in illustrating the value of importance of fishing areas (see Aswani & Lauer, 2006; Scholz et al., 2004; Wheeler et al., 2008) and the spatial patterns of fishing effort (see Hall et al., 2009; Hall & Close, 2007). While georeferencing technologies have mainly been associated with tracking vessel movements thus gathering the latitude, longitude, timestamp and sailing speed, recent advancements have enabled the incorporation of other datasets such as environmental variability into models for stock assessment and fishing dynamics. Yet, this is not the only use for small-scale fisheries. Being able to present such knowledge that was scattered and incomplete, it allows sharing of information and enhancing the dialogue between stakeholders thus strengthen the participation and knowledge of the communities in the decision-making process (Jankowski, 2009). In fact, many models for quantifying loss in fisheries, which can be replicated in dredging projects, are often hindered by a lack of catch data. These models can initially use spatial data as a proxy and in the later stages, they can be supplemented with more specific catch information to improve and verify the estimates.

A notable example of moving forward from tracing the movements to integrating environmental and spatial data to enhance fisheries management comes from a study by Torres-Irineo et al. (2021), which focused on the Southern Gulf of Mexico. In this study, researchers combined various environmental factors—such as net primary production ($mgC.m^{-2}.day^{-1}$), sea surface temperature (°C), and bathymetry (m)—with spatial data that included the locations of existing fishing grounds and vessel movements, as shown in **Figure 11**. Aside from being useful in mapping alternative fishing grounds for small-scale fisheries, it can also be used if the sand borrow areas for projects have not been identified hence can minimize the risk of loss of productivity or value of small-scale fisheries by placing it with least impact to these fisheries.

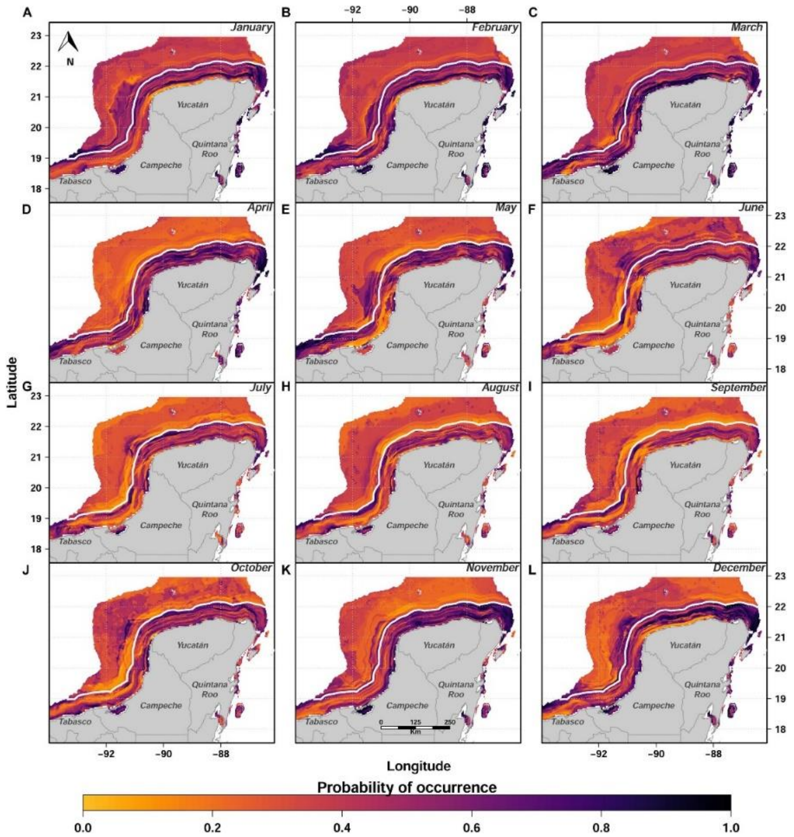


Figure 11 Modeling for potential fishing grounds (Torres-Irineo et al., 2021)

Another integration worth considering is also between spatial elements with CPUE, particularly for assessing the biological outcomes and sustainability of marine resources in response to environmental changes (Stelzenmüller et al., 2008). In the case of dredging, this is essential for assessing its spatiotemporal effects on small-scale fishing. If dredging lead to ecological alterations that create uncertain conditions for fisherfolks, analyzing suitable habitats to map alternative fishing grounds under changing environmental conditions becomes key (Marco et al., 2021). Moreover, small-scale fisheries often lack the specialized technology to locate their target species immediately once the stock in a particular area is disrupted or access to the area is compromised.

There has been a rising exploration in how GIS can be implemented and beneficial for fisheries studies, even for innovative uses such as mapping the nighttime fishing intensity using proxy data using Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band in the case of Myanmar (see Exeter et al., 2021). During a discussion with fisheries experts well-versed in GIS application in small-scale fisheries, another valuable application emerged. In addition to identifying alternative fishing grounds with optimal ecological capacity and catch composition similarity to primary grounds, there is potential in mapping least cost path for fisherfolks. This approach aims to minimize time and cost per fishing trip while avoiding dredging project areas and vessel movements. Surprisingly, this has rarely, if ever, been explored and warrants further investigation as it can integrate various critical components relevant to both dredging operations and small-scale fisheries.

Lastly, despite its potential, the implementation of GPS tracking as data collection of fishing operations faces varying supports. While there are experts, such as **R21**, who are not only in favor of but also developing tracking kits that are of low-effort and affordable to be provided to small-scale fisherfolks (see Tassetti et al., 2022), some other experts prefer other ways to collect such spatial data by engaging directly with the fisherfolks. These methods vary, such as self-reporting logbooks (Vincent et al., 2007), sightings (Breen et al., 2015), participatory mapping (Gill et al., 2019; Léopold et al., 2014), or combinations of various participatory methods. Many of these methods have been challenged with the concern that they can host certain degree of inaccuracies due to observer bias (Brown, 2012, 2017). As a matter of fact, one expert (**R26**) also noted that spatial modeling will only be beneficial if the analysis goes beyond merely tracking where vessels are:

'If it is mixed with other layers such as location of nurseries and other ecological layers, it could be really useful, but if it is only to look into where the fishing grounds by tracking, you can always just ask the fishers. It can potentially be a starting point of discussion when discussing alternatives, such as why they do not go to specific places.'

Additionally, as per discussions with some fisheries experts, spatial tracking of vessels faces the challenge of fisherfolk refusing to disclose their known fishing grounds, which is well resounded across many fisheries experts. They do this to maintain a competitive edge in a highly uncertain field influenced by many factors beyond just biology and technology. Aside from that, as quoted from **R29**:

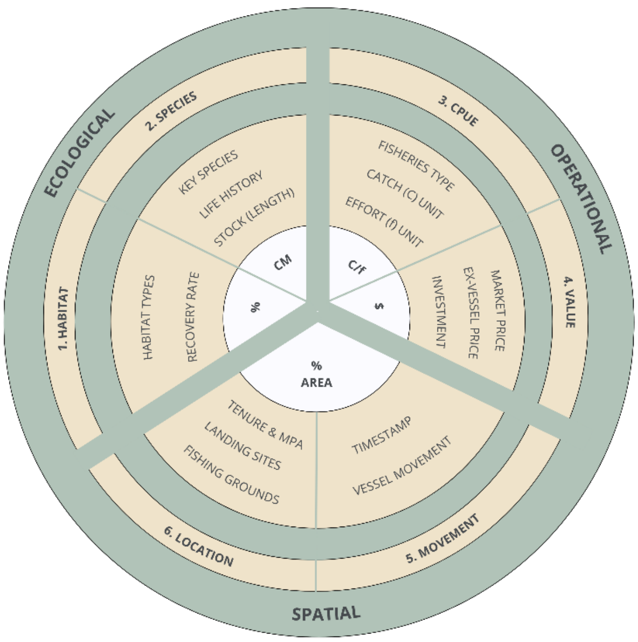
'Fishers in many cases also a little bit suspicious of people which they associate with, [be it] state intervention or government, because they might be afraid that there will come more rules, restrictions, etcetera.'

Another concern in participatory mapping is that the provided map may use a basemap unfamiliar to the fisherfolk, who might prefer to use their own spatial references when navigating the sea, such as coral reefs or sunk ships, instead of standard coordinates. This must be taken into account to avoid forcing the use of a printed map with a scientist-familiar basemap, and instead adopt the fisherfolk's perspective. Furthermore, conducting participatory mapping with a planned infrastructure project is tricky. There is ongoing debate on whether to fully disclose the potential project location upfront, which in some cases the communities have directly associated with severe impacts, or to provide a clean map where communities delineate their operating areas before disclosing the project details for further discussion. Even among experts, this remains a topic of discussion that should be tailored to specific contexts.

4.3 ASSESSMENT WITH PURPOSE

Reflecting on the findings so far, this study identified three starting points that are most relevant and applicable in the context of dredging: operational, ecological, and spatial. Referring them as starting points is intentional as it is expected that assessment begins with one aspect and may iteratively incorporate others. This is aligned with FAO (2015) which demands for integrated data collection encompassing 'bioecological, social, cultural and economic' which has low data requirements, at least to start the assessment and complement further data collection at later stages. This has also been in favor of the campaign for more multidisciplinary studies (e.g., Said et al., 2019) given that most still operate within their realm of knowledge, hence pushing the need for more holistic (Herrón et al., 2019) as well as simpler and more cost-effective methods (Herrón et al., 2018).

When assessing the socioeconomic aspects of small-scale fisheries, it is important to recognize that there is no universal approach that suits every context, as each study design must be tailored to meet specific objectives (Bennett et al., 2021). Building on this, the research introduces a framework to quantify impacts of dredging (**Figure 12**) which is designed to capture the multifaceted nature of small-scale fisheries as social-ecological systems. This was developed from the findings discussed in the previous sections.



Note:
1. Recovery rate = % of being able to revert back to before dredging)
2. Stock (length) = trend analysis of length in centimeters of each species
3. Catch Per Unit Effort (CPUE - C/f) = amount of catch (commonly kilogram) per exerted effort (time and/or gear)
4. Value = measured in monetarily value
5-6. % area = overlap of area with project operation
6. MPA = marine protected area

Figure 12 Assessment framework

Through each starting point, this framework points towards a quantifiable reference that can be established. These indicators were chosen not only because they have been the most recurring to be mentioned during interviews, but also due to the available models using these indicators that can be replicable to dredging as shown in the discussions in prior sections.

To start, the *ecological aspect* entails both habitat and species. Generally, the relationship between projects, habitat, and small-scale fisheries has been thoroughly explored within IFC (2015)'s handbook which should serve as the primary reference. An important factor to evaluate is the recovery rate of habitats following stressors (Kronen et al., 2012; Pennino et al., 2016), examining the timeframe and effectiveness with which ecosystems can rebound from disturbances—a key indicator of resilience and sustainability for the fisheries they support. Regarding species, a primary recommendation is to identify key species that are crucial for maintaining ecological balance and commercial interests, as well as understanding the life history stages of these species. Then again, as stated by an expert (**R17**), it is:

> *'not always just about the numbers, it is about really understanding the population you're looking at. Because [only then] you can see how well your management action will be on that population.'*

Operational-wise, it is important to understand the role that fishing plays in livelihood and subsistence to appropriately assess the impacts of projects. This is essential for selecting the right units of measurement for both catch and effort, which are key to calculating CPUE for the fishing practices identified. From here, value of those catch determined by each species and gear should be examined through both market and ex-vessel price. If available, information on investment in terms of source and allocation of resources towards fishing operations can help to better understand the role fisheries play for the communities. Expanding this analysis, there is an avenue to explore the broader economic impact of fishing on regional economies and to trace the full value chain of small-scale fisheries, from pre-harvest to post-harvest stages.

Finally, while *spatial data* might be as limited, having access to information on tenure rights, especially including customary rights for Indigenous communities, and allocated areas such as marine protected areas would be a good starting point. After all, small-scale fishing communities need to have secure tenure rights to the resources that form the basis for their social and cultural well-being, their livelihoods and their sustainable development (FAO, 2015). Then, aside from the georeferenced information of fishing activities at sea which is commonly of longitude and latitude and time which can be made up to vessel movement, important sites such as fishing grounds both primary and alternative, landing sites, and zones of fishing tenure and marine protected areas should be identified.

4.3.1 OPERATIONALIZATION OF ASSESSMENT

It is crucial to understand how this framework translates into practice and fits within the overall impact assessment process and project management. To visualize this, the initial conceptual framework of this study has been adjusted and expanded by including the findings (**Figure 13**).

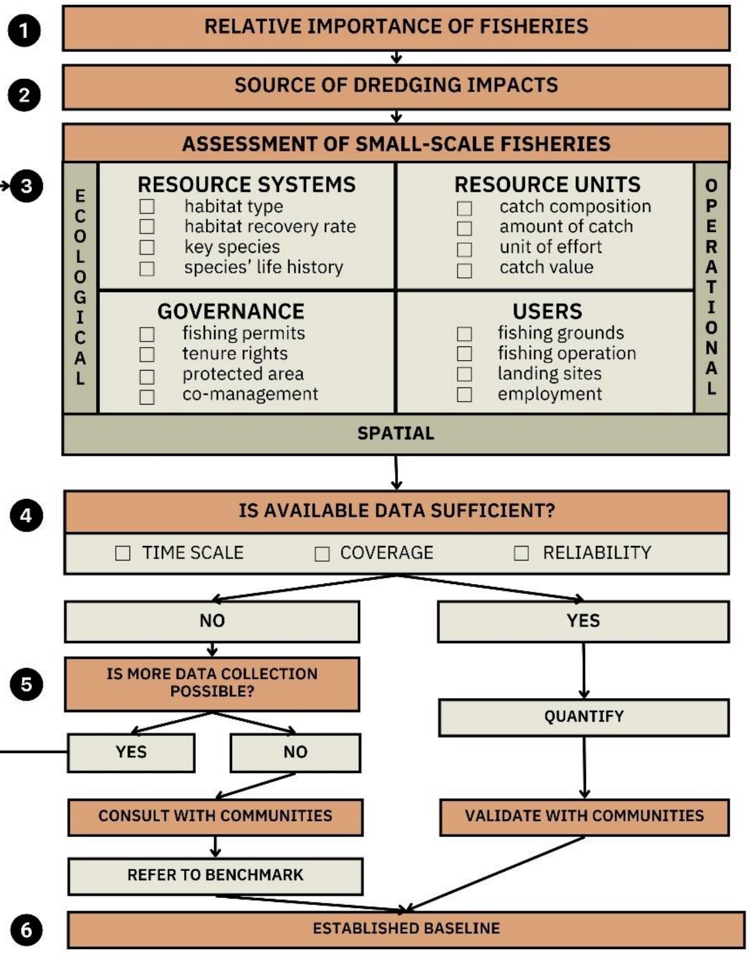


Figure 13 Stages to establish fisheries baseline data for dredging projects

Starting with identifying the relative importance of fisheries (livelihood, subsistence, and/or sociocultural) and the potential sources of dredging impact, the assessment of small-scale fisheries across operational, ecological, and spatial aspects begins. Moving forward, quantification of fisheries and impacts of dredging which provides reliable baseline data may only be feasible when the available data on fisheries meet the requirements in at least one of the outlined components (resource systems, governance, resource units, or users). Further, through these components, data of each is assessed in terms of availability over time to allow trend analysis, coverage of identified communities and different groups within those communities, and the reliability of the data and its sources. If the data does not meet these standards, further data collection is needed, guided by the missing information from the quantification framework to complement existing data.

When data collection is not possible due to time and resource limitations, it is best to consult directly with the communities, local experts, or experts who have worked with the communities before. This consultation should identify the contextual concerns and insights about small-scale fisheries. By establishing a baseline together, projects and communities can ensure that the measures used are accurate and reliable from both scientific and local perspectives. This practice is not limited to cases where quantification is unfeasible due to data limitations; it applies universally, even when quantification is feasible by validating this with the communities themselves.

Establishing a baseline is not just about a numerical reference for the project; it also involves an agreement with the communities on identifying problems, understanding initial conditions, determining the best monitoring methods, and deciding on appropriate measures to mitigate impacts from their perspectives. This process empowers the community to have a voice in decision-making, aligning with the campaigns of many studies and initiatives advocating for community involvement (e.g., FAO, 2017, 2023; FAO et al., 2023; Grati et al., 2022; Wiber et al., 2009). By involving the local communities, the project benefits from local insights and ensures that interventions are effective and respectful of community needs and priorities.

The assessment of small-scale fisheries considering the impacts of dredging projects should be conducted not only before any dredging operation commences but also before the project design becomes finalized. Establishing a baseline for small-scale fisheries early on enables the application of better mitigation measures and can even help avoid and reduce impacts by influencing changes in the design and operation of dredging projects to align with the needs and conditions of small-scale fisheries. **Figure 14** illustrates the mitigation process that should be considered upon establishing the baseline, taking into account the significance of impacts in terms of the number of affected people or groups in the communities, the duration of impacts (temporary or permanent), and whether the nature of impacts is direct or indirect.

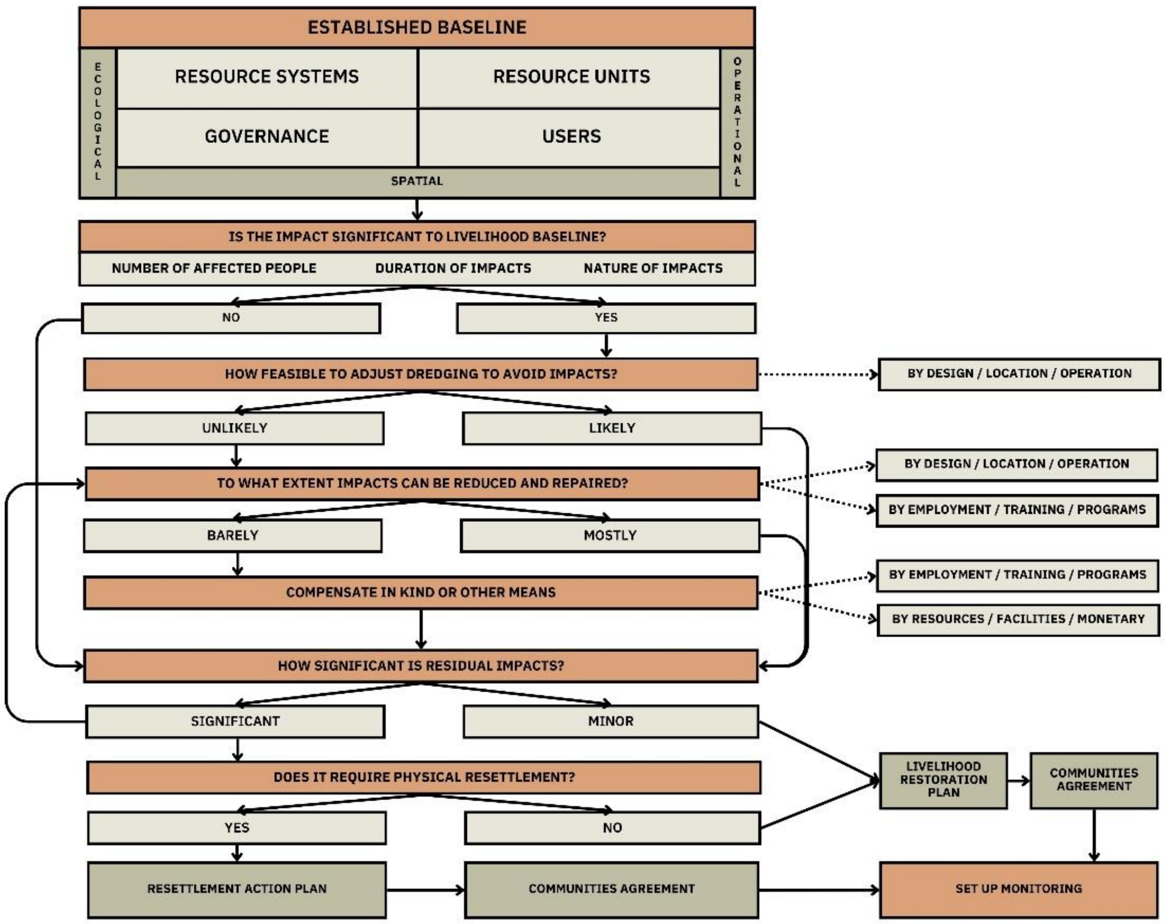


Figure 14 Mitigation hierarchy upon establishing baseline

Throughout the stages, projects are encouraged to adjust to the needs of small-scale fisheries rather than the other way around, consistently seeking ways to modify the project to accommodate small-scale fishing operations so that they can co-exist rather than disrupting each other's operation. Ultimately, this approach may lead to the development of either a Resettlement Action Plan (if impacts entail physical relocation) or a Livelihood Restoration Plan (if impacts cause socioeconomic disruption without physical relocation). This involves engaging with the community to confirm these arrangements and establishing monitoring schemes to track the impacts of the dredging project.

4.3.2 SUPPORTING TOOLS

The previous sections have explored different methodologies and models of analysis to assess impacts given that the required datasets are available in the selected spatial and temporal scale. Their applicability and replicability, however, depends on the context of the project, the availability of existing data, and capacity to carry out further data collection when necessary. These various models, including those carried out in the above case studies, have been mostly based on software or programs in which one must build their own model. This is aligned with the aim to build an iterative model in which different components of the proposed starting points can be integrated when the datasets are ready to be explored and integrated for analysis. Nonetheless, these tools are not specifically designed to assess ocean-based development and its impacts in a readily usable format. Considering this, this research also examined off-the-shelf tools that were developed specifically for managing marine resources and space. It evaluated whether these tools could also be useful, specifically addressing how these can be adapted to fit predefined inquiries.

There are various off-the-shelf or pre-packaged assessment or decision-making tools designed for the ocean context. Given the rapid advancement in this field, there will likely be increasing exploration into operationalizing different measurements. Using these tools can save time, energy, and resources; guide users through the challenging steps of decision-making processes, enabling them to efficiently move from data analysis to final decisions; allow for the repetition of analysis with ease; reduce redundancy by leveraging the work of others; minimize the need for extensive human expertise; document decisions about inputs and parameters; and enhance the understanding of planning requirements and limitations across multiple sectors involved in the planning process (Center for Ocean Solutions, 2011).

Across various tools, this study has discovered that they all follow either of two primary directions: ecosystem-services-based estimation or valuation, and marine spatial planning or modeling. For the former, the aim of accounting for the benefits of services has been highlighted in numerous studies (e.g., Costanza et al., 1997, 2014) and is seen as a prerequisite for understanding the dynamics across benefits. In dredging, the functionality of valuation is crucial for estimating the damage incurred by dredging on fisheries, taking into account the resources and derived services. On the other hand, the goal of marine spatial planning tools is to create and establish a more rational use of marine space and the interactions among its uses. This approach balances demands for development with the need to protect the environment and deliver social and economic outcomes in an open and planned way (Queffelec et al., 2021). For example, such tools can identify the most suitable site for marine reserves (e.g., Barbosa et al., 2019). In dredging, this can be used to conduct suitable site selection, for instance burrow area with the least impact on fisheries.

There have also been many studies assessing and comparing the uses of these tools such as Stanford's Center for Ocean Solutions (2011) in which the nine tools were compared: Artificial Intelligence for Ecosystem Services (ARIES), Atlantis, Coastal Resilience, Cumulative Impacts, InVEST, MarineMap, Marxan with Zones, Multi-Scale Integrated Models of Ecosystem Services (MIMES), Multipurpose Marine Cadastre (MMC). Across these, four were chosen on the basis of: open-access, readily available models to run (whether built-in features or with supports) and case studies in literature in which each tool have been used in the case of dredging or aggregates mining in relation to fisheries. In the following table, a brief profile of each has been provided and further assessment of features have been explored further.

Table 11 Comparison between ARIES, InVEST, Atlantis, & Marxan

CRITERIA	ARIES	INVEST	ATLANTIS	MARXAN
Developer	Basque Center for Climate Change (BC3), University of Vermont—Gund Institute for Ecological Economics, Conservation International, and Earth Economics	The Natural Capital Project—Stanford University, World Wildlife Fund, The Nature Conservancy, and the University of Minnesota	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research	University of Queensland
Website	www.ariesonline.org	www.naturalproject .org /InVEST.html	atlantis.smar.csiro.au	www.uq.edu.au /marxan
Aim	Ecosystem services valuation	Ecosystem services valuation	Marine spatial planning/modeling	Marine spatial planning/modelin g
Key features	Ecosystem service mapping; Biophysical and socioeconomic data integration	Ecosystem services valuation; scenario analysis	Ecosystem modeling; social-ecological systems interaction; scenario analysis	Site selection; zoning; spatial optimization
Data requirements	Spatial data (e.g., land cover maps); socioeconomic data	Spatial data (e.g., habitats, species distribution); socioeconomic data	Comprehensive ecological, physical, and human activity data	Datasets are integrated
Support & documentation	Good documentation and community support; model customization may require expert help	Extensive documentation, tutorials, and user support forum	Detailed documentation and scientific publications, but lack user-friendly support	Comprehensive manuals, case studies, and active user community
Access	Web-based	Web-based	Desktop	Desktop
Run-time / processing	Real-time	Real-time	Delayed result	Delayed result
Allow single, dual, and multiple objectives (scenario)	✓	✓	✓	✓
Has integrated data sources	✓	✓		
Allow external datasets		✓	✓	✓
Allow models beyond built-in analytical models		✓	✓	✓
Run analytical model independently developed			✓	✓
User collaboration	✓	✓	✓	
Participatory interface	✓	✓		

In the case of quick assessment, tools with readily-built models to estimate ecosystem services value and loss, such as InVEST and ARIES, can be particularly useful—especially ARIES, given its integrated database and AI support. However, the availability and quality of these tools' outputs depend on the local context and may diminish at lower spatiotemporal scales. Nonetheless, they can serve as a starting point to identify data, determine what additional information is needed, and provide direction for further investigation. Tools like Marxan with Zones offer siting and zoning functions to plan project locations in a way that minimizes impacts or conflicts. For comprehensive, end-to-end modeling of holistic socio-ecological systems, tools like Atlantis are more suited. They facilitate the integration of different data layers from other tools, making them ideal for monitoring and assessing impacts throughout the project lifecycle.

One example of integrating different models of varying dimensions into a single tool is demonstrated by Bossier et al. (2018) in the context of the Baltic Sea using Atlantis. They combined the HBM-ERGOM model, which processes biogeochemical and hydrodynamic information for holistic ecosystem analysis, with the FISHRENT model, which analyzes the economics of commercial fish biomass outputs. The study aimed to understand and quantify the spatial and temporal intensity of human pressures, such as coastal and ocean-based developments, including dredging, and the resulting responses of marine ecosystems. To run this analysis, the following scenarios were created, with *Scenario #1* to be the baseline for all others to be compared against.

	Scenario #1	**Scenario #2**	**Scenario #3**	**Scenario #4**	**Scenario #5**
	'Status quo'	Nutrient load reduction	Nutrient load reduction	Nutrient load reduction matching BSAP2*	Nutrient load reduction
Area		Denmark	Denmark, Sweden & Germany	Selected coastal zones	pan-Baltic
Polygon # and amount of decrease for each polygon		12 %, 33%, 24% for polygon 1, 2, 4	33% for polygon 1, 2, 3, 4	9%, 20%, 15%, 32% for polygon 1, 2, 3, 4, 21.4%, 23% for #5 & #9, 19% for #12 & #13, 35%, 33% for #14 & #17	33%
	Scenario #6	**Scenario #7**	**Scenario #8**	**Scenario #9**	**Scenario #10**
	50% reduction of fishing pressure on cod	50% reduction of fishing pressure on sprat	50% increase of fishing pressure on cod	50% increase of fishing pressure on sprat	The maximum 2005–2012 observed fishing pressure on cod and sprat
Area	pan-Baltic	pan-Baltic	pan-Baltic	pan-Baltic	pan-Baltic
Fishing mortality for adult fish**	0.16	0.035	0.64	0.14	1.2 for cod, 0.6 for sprat

Figure 15 Scenario on the basis of nutrient load reduction or fishing pressure (Bossier et al., 2018)

Their analysis led to critical findings such as the time series of total biomass per group, diet composition per functional group, population structure and spatial distribution, sensitivity per functional group, and nutrient load reduction scenarios. More importantly, they linked ecological findings to fisheries economic evaluations through the FISHRENT model. This connection allowed them to assess economic value over time, measured by net present value (NPV) in million EUR, under Scenario #1 (baseline) and three different nutrient scenarios believed to influence fishing mortality (F) and total stock biomass (TSB), as shown in **Figure 16**. By doing this, the analysis demonstrated the decrease in nutrient load in the ecosystem and the subsequent change in associated economic value (in million EUR).

		Original F & TSB		Atlantis F & TSB	
Scenario	Sea	NPV (mill EUR)	Relative change (%)	NPV (mill EUR)	Relative change (%)
Scenario #1	Total	154.8		182,1	
	Kattegat	44.8		0,1	
	Western Baltic	36.4		37,9	
Scenario #2	Total	154.4	-0.26	182,1	0
	Kattegat	44.7	-0.22	0,1	0
	Western Baltic	36.3	-0.27	37,9	0
Scenario #3	Total	153.4	-0.90	174,7	-4.1
	Kattegat	44.4	-0.89	0,1	0
	Western Baltic	36.2	-0.55	37,7	0.5
Scenario #4	Total	153.3	-0.97	179.0	-1.7
	Kattegat	44.3	-1.12	0,1	0
	Western Baltic	36.1	-0.82	37,3	-1.6

Total NPV over all waters shown, together with NPV in Kattegat and NPV in Western Baltic.

Figure 16 Total net present value (NPV) over all waters shown (Bossier et al., 2018)

In conclusion, the reviewed tools offer significant potential for dredging projects for assessing impacts, optimizing spatial planning, and valuing ecosystem services. These tools enable effective decision-making and impact mitigation through features like ecosystem service valuation, scenario analysis, spatial optimization, and detailed ecosystem modeling. Moreover, these tools are not standalone; they can be integrated with each other to leverage their complementary strengths.

5 DISCUSSION

5.1 DATA: LIMITATION AND OPPORTUNITY

In assessing dredging impacts on small-scale fisheries, the starting point and depth of analysis hinge on the availability and quality of data, as expressed by one expert (**R24**):

> *'The first thing is to collect data. Because when you have data and you collect that in the right way, you can use it to your own requirements.'*

This proposed framework offers both flexibility and limitations. Its adaptability allows it to be tailored to fit the available data, making it a suitable starting point depending on the project's time and resource constraints. However, this also means that it is dependent on the quality and comprehensiveness of the data. In fact, many opportunities to use various types of models in the tools and case studies reviewed in prior sections have also hindered by the disconnect between the data collectors and modelers as they often do not collaborate thus not all collected data are able to be effectively utilized (Goethel et al., 2023).

This is, however, not to imply that the scope should vary depending on the availability of data, but rather, the framework will help in highlighting which information is still lacking given the scope of the impacts. Therefore, it is crucial to identify which data are essential for supporting the methodologies proposed by the framework. Discussing which datasets are critical—and recognizing which ones may limit the ability to quantify impacts before dredging occurs—helps in operationalizing the framework.

For the ecological starting point, the demand of data is substantial, particularly in terms of duration needed for accurate trend analysis and the information required on habitat and species (Kindong et al., 2023). A recurring issue for small-scale fisheries is the unavailability of such comprehensive data, which makes performing robust stock assessments challenging (Ramírez et al., 2017). Even the length-based approach, which is less data-intensive, often proves unfeasible due to restrictions on conducting direct assessments. Such restrictions limit the ability to gather adequate data for temporal analysis, rendering ecological assessments unreliable for establishing baselines. In this case, it has much better potential to monitor impacts over time and compare it between pre- and post-dredging and conclude that there are indeed impacts to the ecological side of small-scale fisheries. Nevertheless, it is still important to know the composition of key species. However, as discussed in section **4.2.2**, there should be a practical limit to the number of identified species, as remarked by an expert (**R24**):

> *'You have to look at the main species and you have to know that you can't do it for every species and for every type of fisheries and everything….[What] you have to do to [is] to really find out who is fishing in that area of the project and what they are fishing' … and what gets to the market.'*

Looking into operational side, knowing fisheries type and the unit of effort through which we can quantify it is important (Hoyle et al., 2024), but unless we have catch data segregated by gear and species for a full fishing year, it is challenging to accurately assess the extent of the dredging impact. A fisheries expert (**R24**) provided a suggestion that in this case, conducting market studies can be beneficial to understand the catch and value composition of fishing operations especially in terms of what usually the market receives.

From there, a prior analysis could be conducted by identifying which fishing grounds are likely to be disrupted by dredging. This would involve calculating the CPUE from those grounds, assessing the composition of catch, and considering the demographics of fisherfolk. This is not without limitations, as the catch from a specific fishing ground may be linked to multiple landing sites and sold in various locations (Ouréns et al., 2022), complicating the traceability. Hence, while this provides a starting point, it should be seen as a baseline to refine and build upon. Nonetheless, as argued by many experts, unless the size of catch for specific species and gear over seasons is known, CPUE falls short to provide initial baseline of how much dredging impacts small-scale fisheries.

The spatial dimension of assessing the impacts of dredging on small-scale fisheries remains unexplored, yet it potentially offers a valuable starting point for modeling changes in small-scale fisheries (see Gill et al., 2019; Grati et al., 2022; Torres-Irineo et al., 2014). Although there is a lack of spatial data concerning the movements of small-scale fishing operations (Johnson et al., 2017), spatial data available from dredging vessels in regards of where they traverse and operate can serve as a base. From there, aside from identification of primary fishing location by recognized tenure arrangements from local government or fishing associations, data could then be improved by participatory mapping of fisherfolks on confirming and specifying even more the fishing grounds as well as gear and target species.

Reflecting on the methodology conducted by Kim et al. (2008) (see section **4.2.1**), establishing a zone of operation, dividing this zone into specified grids in which each cell of $4km^2$ containing its weighted calculation of catch and associated value, and running it through different scenarios, can help contextualize the possible loss incurred in different project designs. This model of analysis, though it involves many assumptions and generalizations, helps to illustrate the potential loss based on the area occupied by the dredging operation in a multi-user sea and to interpolate acquired information in locations in which information is still limited based on similarity of feature or activities. Also, even without complete spatial information on small-scale fisheries, this framework can provide a foundation for making initial assumptions and building more reliable and holistic information over time. These assumptions can then be validated by implementing low-cost, low-burden tracking kits for vessel movement, as explored by Tassetti et al. (2022) which can be used to monitor potential losses or reduced access to fishing grounds. Concurrently, other components of small-scale fisheries, including ecological and operational aspects, can be integrated as layers in such GIS-based analysis. Therefore, spatial modeling for small-scale fisheries is an avenue worth exploring, especially given the growing interest in various approaches. This includes not only determining which indicators should be included but also integrating participatory approaches into the modeling process, from data collection to data verification (Grati et al., 2022).

Many existing methodologies fall short due to their intensive data and analysis requirements. However, if there are time constraints and data collection is not feasible, it is possible to retroactively reconstruct data (see Gill et al., 2019; Moreno-Baez, 2010). By understanding how dredging vessel disruptions affect fishing activities and monitoring the value and catch per fishing trip or day during the disrupted period, researchers can estimate what conditions might have looked like in the absence of dredging. This reconstructed baseline can help quantify the proportional impacts of dredging on fisheries before it occurred, offering insights that guide both current management and future mitigation strategies. This shows that out of all the three starting points, the spatial approach may serve as the most fitting proxy to quantifying the fishing area occupied by dredging and its vessels movements, enhance the data for monitoring to see whether provided compensation based on that is appropriate, and even reconstruct fisheries data pre-dredging.

5.1.1 PARTICIPATORY DATA COLLECTION

In addressing data gaps, an increasing number of studies have turned to participatory approaches as the alternative means to enhance data quality and accessibility (McCluskey & Lewison, 2008; Ramírez et al., 2017). These approaches have also becoming more common given the rising awareness to include ethnography into impact assessment, which can not only improve the understanding of local context and quality of impact assessment but also the insights gathered through these approaches can lead to better outcomes for communities and the overall performance of the project (Hanna et al., 2024). Aside from self-sampling, logbooks, in-depth interviews, and observations (Lokrantz et al., 2009), spatial-focused studies (e.g., Grati et al., 2022; Reis et al., 2023) have demonstrated that participatory approaches can provide reliable data which can be used on its own or in combination with other datasets. Mapping the activities of small-scale fishing communities, whether on physical, printed paper or through assisting technology and researchers, has been a useful approach to reveal nursery, migratory, and reproduction sites, to investigate distribution and habitat preferences of fish, to establish sampling designs, or to assess temporal changes of fishing sites of marine and estuarine fish (Aswani & Lauer, 2006; Lavides et al., 2016; Le Fur et al., 2011; Yochum et al., 2011). Participatory mapping of the small-scale fishing effort could also help track changes in fishing grounds, and indirectly, follow the distribution of target species over time and space, besides detecting changes in species abundance or the arrival of alien species (Ennouri et al., 2021). However, such changes can be detected only if collecting more detailed information on catches (e.g. species distribution and quantities). Indeed, in data-poor fisheries this method could also be used to collect information on catches, as well as on the amount and technical features (e.g. mesh size) of gears, which are useful to estimate ecological, economic, and community-based performance of the fishery (Anderson et al., 2015).

Aside from active fishers, the knowledge from retired fishers could be of high prevalence. Seminara et al. (2024) explored their potential as Fish Identification Experts to enhance the insights being gathered on historical data. Furthermore, participatory approaches have been deemed to improve capacity building through training of community members, raise awareness among local communities on the need to manage resources, and empower them to participate in decision-making (Obura et al., 2019; Schemmel et al., 2016; Wiber et al., 2009). A clear example in which it has been useful for a project is the case study examined in (IFC, 2015)'s handbook, community-based participatory monitoring program (Proyecto Escolta) was designed to monitor impacts of offshore seismic activities after a series of dead dolphins found on the beach of Lambayeque, Peru and was perceived to be linked to the project, where later their participation also helped to change the perception of communities towards the project and found that the impacts were indeed not caused by project.

A major drawback of the participatory approach is however the 'recall bias' (Gill et al., 2019) where fishers may underestimate or overestimate catch or provide imprecise location of fishing operations, especially those with no established demarcations. This has been confirmed and discussed during the interviews. To avoid or at least minimize such bias, a validation process should be conducted with cross-checks in the field to investigate the reliability of the data. In addition, an expert (**R24**) mentioned:

'Recall bias depends on the question that you pose. If you ask for fishing period, the seasonality, and the fishing grounds, you should not have a big bias because they will not exaggerate. But, if you want to collect information on catch, probably you should prepare some categories of potential CPUE [by gear].'

Bias can also be minimized by employing larger sample sizes and conducting multi-layered data collection methods instead of relying solely on a single methodology (see Silvano & Hallwass, 2020). By doing this, they found that participatory monitoring in Tapajos River provided about three times more data for analysis compared to monitoring conducted by researchers in Tocantins River. However, two main limitations were still identified: the turnover of voluntary participants, leading to difficulty in standardizing data and introducing variability, and the need for additional time to train data collectors, resulting in variations in data quality even among participants.

In regards of integration of local (ecological) knowledge systems to scientific methods, this study would like to bring forth that in 2000, Johannes et al. explored five cases where marine scientists and resource managers dismissed fishers' ecological knowledge. This oversight not only was later proven to be a mistake but also potentially jeopardized fishery resources and unnecessarily compromised the welfare of resource users. Johannes et al. (2000) argued that the prevailing mindset among marine scientists, particularly biologists, was that research must yield statistically analyzable data to be considered worthwhile. To change this, marine scientists must challenge the way they think of different knowledge systems which demands humility on their side to acknowledge these systems alongside scientific methods and knowledge that they are familiar with. Nonetheless, to this day, little has changed in this regard.

Therefore, despite these criticisms regarding reliability, fishers' local knowledge can aid in reconstructing long-term fisheries data, which is often unavailable through conventional scientific research (Ainsworth et al., 2008; Johannes et al., 2000). Discussion with experts confirmed this, especially when there is limited time and historical data to conduct trend analysis, this can be a starting base for projects. Aside from this, engaging with communities would also help to reveal key concerns that might not be expected from scientific or project assessment without their direct engagement (Ahtuangaruak, 2015). Simultaneously, much research often falls into the trap of being conducted 'on' communities rather than 'with' them. This approach overlooks the potential for communities to be not only sources of information but also active collaborators in the research process.

For effective collaboration, it is crucial to build trust within the communities. According to one expert (**R30**), trust can only be genuinely gained if the community holds '*the opportunity to change the outcome'*. This means involving community members in the decision-making process, ensuring their voices are heard, and their insights are valued and acted upon. By fostering a collaborative environment where community contributions can influence outcomes, researchers can build more meaningful and impactful partnerships. In practice, however, it can be challenging for projects to engage communities upfront, especially when there are major concerns about planned infrastructure projects and fears of being co-opted or misled. To overcome this, it is important to start the engagement early, build trust, ensure communities are fully informed about the project and its expected impacts, and explain the process for establishing a baseline, assessing impacts, and working with the communities to minimize and/or compensate for those impacts. This demands considerable time and effort from project's side and would often begin by establishing focal points or community liaisons within the community to bridge and facilitate communication. These liaisons can also become part of data collection and monitoring teams, further integrating the community into the project's processes and ensuring that their concerns and needs are continuously addressed.

5.1.2 INTANGIBILITY IN SMALL-SCALE FISHERIES

Assessing dredging impacts on small-scale fisheries, even by using the proposed framework, depends on the availability of data and the specific characteristics of the fisheries. When data are insufficient for analyzing temporal changes and the affected fisheries and fisherfolk are highly diverse, making accurate assessments becomes exceedingly complex to preemptively calculate the extent to which dredging impacts fisheries.

In the discussion of social impacts, there is one recurring question that is well-proposed during one of the interviews (**R26**):

'…if we can quantify impacts, but whether we should quantify [them].'

In another account from **R30**:

'People who come up with modelling exercise [and] that kind of tools, … most of them are, you know, modelers, scientists, and they come from a more quantitative side of things. So there's a tendency to try and quantify and [it's] less subjective about what's happening. … But it's very different from what we do when we talk about fisher's knowledge.'

This constant struggle between the need to quantify impacts for data-driven mitigation and the overemphasis on quantification, which often neglects intangible aspects of fisheries such as their sociocultural significance and non-monetary value, remains a recurring debate. According to the same expert, '*what is more important is not to calculate things and then tell them, 'This is how much you're [going to be] compensated if you ever lose it.''*. Instead, it is *'how much of this decision making…actually consider small-scale fishers as a part [of it]?'*

Yet, again, the concern from the perspectives of environmental justice, especially when we reflect to the risk of ocean grabbing (Bennett et al., 2015), also revolves around whether the communities have the opportunity to argue against the baseline data and the capacity to substantiate it. It is important to also note that when discussing the intangibility of fisheries, livelihoods are oftentimes a part of it. While fishing is a central for fisherfolks to gain an income,

'When we talk about fishing is a way of life, [it] means they feel safe fishing, because they know what they are doing. You can't take that away.'

R24

It is important to also note that while quantification is critical for establishing a baseline for dredging projects, it typically accounts for only certain measurable aspects. If not approached carefully, quantification can be used to justify compensation rather than to alter the project design to avoid impacts altogether. Yet, there is often a misguided assumption that projects only aim to quantify impacts to provide monetary compensation. However, even according to IFC (2015), monetary compensation is not considered good practice in mitigating impacts and instead, compensation in-kind is preferred. When discussing livelihood restoration or alternative livelihoods that communities may want to explore, it is essential first to understand what is being lost to develop appropriate programs. For example, this could include short-term measures such as fuel assistance. Accurately quantifying the impacts helps in designing and implementing these programs effectively, ensuring they address the actual needs and losses experienced by the communities.

The danger of this misguided assumption is not only on the side of the project, but also on the social consequences of how the communities may react upon project, as noted during an interview (**R25**):

'They didn't learn to work together to see how it could have less impact. They just learned how to ask for money, you are here, then you have to pay.'

As a middle ground for reluctance to early quantification, it then can first be done through multi-criteria analysis or classification through scale of importance, vulnerability, or adaptive capacity of the communities. It allows for the quantification of impacts for project reference while incorporating local knowledge in decision-making. This is too what is advised by multiple experts, as quoted from **R28**:

'You can quantify, you can get information that's quantitative by doing rating, or one of the other methods to basically put things into categories. I think at the moment, that's the only thing we have if we really want to look at trade-offs that are all quantitative.'

An example of this approach can be seen in the study of Selvaraj et al. (2023), where the vulnerability and adaptive capacity of small-scale fisheries were mapped by incorporating the communities' own perspectives within that scale. This type of information can be easily integrated with spatial modeling and can also be an initial dataset which can be improved upon once more information becomes available, and when communities put higher trust to the project to collaborate.

Furthermore, in the case where it gets too big for comprehensive assessments in which baseline data could be established, interviews with experts have revealed that developing collective benefits may offer more value than attempting for overly detailed individual assessments. Involving the fisherfolks early on in co-developing benefits, particularly beyond monetary, can also be beneficial in making sure that the plans prepared and proposed by the projects stem out of the concerns actually experienced by the communities, reflecting their true livelihood capitals, and providing a projection of how they foresee their livelihoods in the case of disruptions.

In such cases, complications arise once again. Another concern is that when the assessment is confined to relative classifications such as minor or major impacts, it does not explicitly state the extent of the impacts on the communities. This makes it even more difficult to determine how to compensate for damages in a way that sustains their livelihoods in the long run. Projects indeed should aim to create a lasting legacy (Esteves et al., 2012), but it is also crucial to critically assess whether the support provided by the projects aligns with the long-term objectives and sustainability of the communities. For instance, even when projects comply to communities' requests to build certain facilities or provide services not offered by the government, they must carefully consider if these contributions support the communities' long-term goals and do not become sunk cost. Projects should focus not only on building initiatives but also establishing a clear exit strategy and ownership transfer to the communities to avoid creating dependency on projects.

5.2 GOVERNANCE IN BLUE ECONOMY

'You have to find a way to work and live together in the water.'

R19

Globally, the value of key ocean resources has been estimated at USD 24 trillion and the value of derived services to be approximately USD 1.5-6 trillion annually (Lillebø et al., 2017; World Wildlife Fund, 2015). As coastal populations rise and coastal and ocean-based development grows, the sea is indeed becoming increasingly crowded, setting the stage for this research. Initially, this started as an endeavor to explore methodologies, yet in doing so, it encountered much more beyond the tools: the emerging discussion of blue economy and how justice should be considered in marine planning.

Throughout this research, we have explored the concern of ocean grabbing which could emerge as a result of inappropriate governance process as all forms of development or environmental management in the marine or coastal environments necessarily involve the allocation or re-allocation of rights to control, access, or use ocean space or resources (Bennett et al., 2015). Ideally, a sustainable blue economy entails recognition, equal access to resources, and fair distribution of benefits and insulation for the most vulnerable from risks of harm, and when harm is done, assign liability and responsibility for remedy (Klain et al., 2014; Klein et al., 2015). Yet, in the current scene, the power dynamics operating in ocean space may mirror those on land in which powerful actors and interests benefit from existing arrangements. In fact, distribution of benefits from ocean use flows disproportionately (Klain et al. 2014; Wynberg and Hauck 2014). While legal frameworks to support equity exist, they have not been sufficiently developed nor implemented as in practice, ocean policies are still considerably 'equity-blind' (Österblom et al., 2020). Thus, instead of the promise of more opportunities and improved economies, blue economy might instead bring negative effects on the environment and human health, loss of livelihoods, limited financial opportunities for vulnerable groups and challenges to nutritional and food security (Österblom et al., 2020).

The drivers for ocean grabbing are 'as diverse as the means through which it occurs' (Bennett et al., 2015), but one should be careful of mislabeling specific initiatives without fully understanding the context within which they occur. However, one of the strongest and most obvious case in which ocean grabbing occurs is when livelihoods and security of affected communities are undermined as they are vulnerable to bear the cost of these developments while stronger parties benefit from the current arrangements. As quoted from Cipriani (2022):

'Inequality is a consequence not by accident but by design.'

After all, marine spatial planning should be a 'process of designing and redesigning the tules of the game at sea with the purpose of coordinating sea-uses within specific sea-area' (Spijkerboer et al., 2020). Challenging inequality directly threatens powerful interests that benefit from existing arrangements (Österblom et al., 2020). However, unless these inequalities are addressed, the aim of the blue economy to promote shared prosperity will be difficult to achieve. It is important to note that projects operating in ocean spaces may not have the capacity to solve the systemic problem of inequity, as this issue extends beyond the scope and capacity of individual projects. Addressing these entrenched issues requires more than individual project efforts. It necessitates comprehensive policy reforms and robust frameworks to ensure genuine community involvement and equitable treatment in decision-making processes.

Nonetheless, projects can set an example of how communities should be treated, involved, and empowered. By demonstrating inclusive practices and ensuring community involvement in decision-making, projects can shift perceptions and show how communities could be better positioned within a project. This incremental approach can contribute to broader changes over time. Projects can provide a model for equitable treatment and engagement, highlighting the importance of fair resource distribution and community empowerment. Through these efforts, projects can play a role in fostering a more just and inclusive blue economy, helping to address systemic inequities bit by bit.

Beyond the awareness and actions of individual projects, there should be strengthened institutional requirements for Environmental Impact Assessments (EIA) to ensure robust fisheries studies that involve direct consultation and participation of affected fisherfolk. Clear procedures and guidelines for performing these studies are essential. Then, fisherfolk must be specifically consulted regarding the outcomes of the impact assessment, with an absolute requirement for their agreement on identified impacts and possible mitigation measures before projects proceed. Additionally, a Memorandum of Agreement should be enforced upon approval to establish a legal enforcement mechanism for the agreed-upon measures, ensuring accountability and commitment to these practices.

5.2.1 ATTRIBUTING IMPACTS TO DREDGING

The core of this research revolves around the extent dredging impacts small-scale fisheries. Through extensive discussions with experts, it has become evident that attributing changes experienced by small-scale fisheries, particularly those associated with ecological changes, to dredging projects is inherently challenging. This difficulty arises due to the presence of multiple stressors in marine ecosystems, coupled with limited data availability and the complexity of proper analysis to run holistic modeling of ecosystems.

Situated within coastal and marine social-ecological systems, dredging projects do not occur in isolation. Such ecosystems are intricate systems characterized by non-linear dynamics, making it difficult to predict changes accurately (Hsieh et al., 2005). Across studies being reviewed, it has been established that climate change magnified and complicates the traceability of human interventions to nature. After all, *'[t]he ocean is so fluid that once things goes wrong, it goes everywhere.'* When posed with the question whether it is possible to trace directly the impacts back to dredging operations, all experts agree with this difficulty caused by climate change. One interviewee (**R26**) noted the complication:

> *'You just simply cannot identify, . . . but you can definitely not to say this has nothing to do with you. That's the pain of the climate change.'*

Another expert (**R24**) agrees in a way that:

> *'Natural variances to catch composition itself it difficult to trace. That's why it's very difficult to predict [the extent of impacts] preemptively.'*

Throughout this research, several models have been presented to understand the significance of dredging impacts on fisheries through three possible perspectives: ecological, operational, and spatial. These perspectives were analyzed across various tools. Nonetheless, given the established notion that the ocean is fluid, resulting in non-linear and often multi-causal impacts, understanding the true significance of these impacts requires detailed assessments at high spatiotemporal scales. While there have been tremendous developments since then, understanding the impacts of operations such as dredging remains complex. This complexity is exacerbated when there are multiple or recurring operations at the same locations or in proximity to each other, or when dredging is part of a larger megaproject with consecutive processes. These factors make impacts even more challenging to analyze and model. To effectively understand and manage these impacts, it is crucial to employ a combination of advanced modeling tools, high-resolution data collection, and continuous monitoring, leading to cumulative impact/effect assessment, which is now increasingly being explored. This approach allows for a more comprehensive and nuanced understanding of the ecological, operational, and spatial dimensions of dredging impacts. Simultaneously, cumulative impact assessment still struggles with delineating the scope of what should be examined to understand the impacts fully. In 2006, Maunder et al. stated that 'science has not reached the stage where reasonable whole ecosystem management can be applied', and this still applies, especially in the context of the ocean, which is further complicated by climate change pressures.

However, this demands a higher degree of cost, effort, and collaboration across different stakeholders, which falls beyond the scope of a single project and would most likely need to be managed at a regulatory level. In a discussion with an expert that has experience in building cooperative between many companies and stakeholders in seafood industries (**R31**), it is indeed an idea to pursue to *'make [dredging] companies talk to each other and ideally at the higher level'* by proposing an avenue to discuss *'what can you do together that you cannot do alone in your company'* given that dredging industry is dominated by only few companies dominating the industry compared to the seafood industry which demanded more stakeholders to collaborate to make a change in its governance.

Additionally, as Vanclay et al. (2015) pointed out, social impacts are just as complex and also rarely caused by singular cause. Therefore, as one interviewee accounted, *'there can never be knowing fully the manifestations of impacts until it truly happens'*. Yet, the rights of communities are often vulnerable due to this complexity, not only because of the existing arrangements of projects but also due to the regulatory environmental licensing process (Hanna et al., 2014), especially when there is rapid development occurring in the area (Vanclay & Hanna, 2019). This highlights the necessity of collecting baseline data that fits our specific context and continuously monitoring to confirm or adjust our understanding of those impacts as more data becomes available. Indeed, when it comes to attributing impacts resulting from dredging projects, certain effects, such as reduced access to fishing grounds or frequency of fishing trips, leading to lower catch and income, can be comparatively easier to identify. Having said this, it is not to disregard the other impacts that have been previously identified. This complexity should not dissuade efforts to quantify these impacts; rather, it emphasizes the necessity of sufficient data to inform accurate assessments. The responsibility of dredging projects, is then, not only about monitoring these impacts and simply compensate for such disruption, but rather:

'…to 'empower the communities instead of providing resources they can be reliant upon and get vulnerable when the operation closes.'

R25

In order to do so, there should be more participatory approaches explored between the project and small-scale fishing communities. Ultimately, *'if you want to get involved, you cannot remain on the outside'* (**R19**).

For the longest time, the reluctance to quantitatively measure small-scale fisheries has been based on the premise that there are too many variables to be examined concurrently, encompassing social, ecological, and economic dimensions. Moreover, the dynamic and complex nature of these variables complicates the assessment of fisheries viability using quantitative method (Schuhbauer & Sumaila, 2016). Compounded by the challenges stemming from costs and efforts required to gather such information, it becomes evident that the full extent of changes in small-scale fisheries may never be fully known (Partelow, 2018). Yet, this is exactly why this study emerged: to know where to begin and up to what point we can trace our human impacts and sustain both the developments we want to actualize through our projects as well as sustaining small-scale fisheries as livelihoods. After all, assessment of impacts is indeed an 'iterative learning' in which it would be almost impossible to determine at the outset of the comprehensive matters that should be considered.

To wrap up, a noteworthy note from the interviews is that discussions about dredging impacts often focus predominantly on the negative aspects, overlooking the potential for positive outcomes. IFC (2015) also acknowledges that projects can bring about development and improvements to the area, including better access to basic services like water and transportation, as well as enhanced fishery-related facilities such as docking facilities. This is echoed by Vanclay et al. (2015), who argue that projects cannot be simply classified as universally 'good or bad', and that it is overly simplistic to view them in terms of 'winners and losers'. Instead, the aim should be to maximize project benefits while minimizing negative impacts which should also be another focus taken in future studies of dredging.

6 CONCLUSION

Undertaking research on fisheries is challenging, but evaluating impacts from ocean-based developments that possibly impact small-scale fisheries is even more complex yet understudied. Despite guidelines from relevant institutions, dredging projects often face unique challenges that these guidelines do not fully address. One of the primary difficulties is the scarcity of data on small-scale fisheries. Combined with the lack of engagement and involvement of the community in decision-making, this makes it even harder for dredging projects to establish baselines, monitor impacts, and mitigate them throughout the project's lifecycle. This challenge was the core question that initiated this research.

Composed of 32 interviews with experts, 22 reviewed studies, and 4 main references for document analysis, this research began by identifying the zones of impact from dredging on small-scale fisheries, tracing these impacts to either extractive activities or the presence of operations. By exploring the consequences of these impacts on small-scale fishing livelihoods, and combining findings from case studies and interviews, the research specified components of small-scale fisheries that can be measured through ecological, operational, and spatial dimensions. Serving as starting points, these three dimensions—ecological, operational, and spatial—are expected to assist in establishing baselines and indicators for monitoring the impacts of dredging on small-scale fisheries over time. While the goal is a holistic assessment of these impacts, these dimensions have been identified as foundational for further studies. Throughout each dimension, different case studies have been presented, which can be replicated for future dredging projects.

Additionally, across these dimensions, spatial assessments leading to spatial modeling, which integrate spatial, ecological, and operational data, offer a promising avenue for implementing the proposed framework in this research and guiding future research in small-scale fisheries studies. To assist in this process, there has been a growth of readily available tools that can help establish impact estimates or optimize the spatial planning of marine areas. In this study, four tools were assessed: ARIES, InVEST, Atlantis, and Marxan. Among these, Atlantis stands out as the most holistic, offering comprehensive ecosystem modeling. ARIES is considered the most user-friendly, as it comes with integrated data sources and still allows for modifications according to specific needs. These tools collectively provide valuable resources for developing effective strategies to assess and mitigate the impacts of dredging on small-scale fisheries.

Thus, being able to establish a baseline and assessing impacts especially in quantified manner can be feasible under certain circumstances, such as when data availability and reliability are sufficient. However, it is essential to consider whether this quantification genuinely serves the needs and interests of small-scale fishing communities or merely benefits projects without genuinely involving the community in decision-making. When impact assessments are conducted and validated with input from the communities themselves, they can be highly valuable as this helps determine the extent of impacts, allowing projects to avoid 'ocean grabbing', ensuring adherence to best practices for proper assessment and mitigation of environmental and social impacts, and identify potential benefits for the communities.

Attributing changes in small-scale fisheries to dredging activities is challenging due to the dynamic nature of marine environments. Unlike terrestrial settings, oceans absorb and accumulate impacts from various sources, including dredging, and these effects are further complicated by climate change, which amplifies and renders them unpredictable. Environmental and ecological changes caused by dredging are particularly difficult to attribute directly to the activity, making it essential for dredging companies to take responsibility for mitigating any impacts they can. This is then the reason as to why establishing a baseline is crucial in this context. Conversely, impacts from dredging that directly disrupt fishing operations and reduce catch capacity are more apparent and easier to measure. However, the data-limited nature of small-scale fisheries still hampers the ability to attribute these impacts accurately, especially without ongoing monitoring extending to post-project.

To address these issues, future research should explore direct, on-the-field exploration of participatory approaches within dredging projects, involving both project teams and the affected communities. Nevertheless, alongside the issue of the blue economy and ocean grabbing arises the concept of blue justice. This notion asserts that ocean spaces should not be subject to competition but used collaboratively and in harmony with nature, ensuring equitable treatment for all. This is particularly crucial for vulnerable and marginalized groups, such as small-scale fishing communities, which are at greater risk. The justice implications in the ocean context are an emerging issue, and while inequality often suffered by the small-scale fisheries is of systemic nature, projects such as dredging can contribute by set forth an example or standard of community participation and empowerment. This approach also ensures that even after the project's completion, there is a lasting legacy that benefits the communities.

To sum up, this research addresses the critical gap in understanding and assessing the impacts of dredging on small-scale fisheries. By identifying indicators and methodologies, the study aims to assist projects to establish baselines, monitor impacts, and implement strategies to minimize harm while creating benefits for small-scale fisheries. The research connects academic and technical resources across dredging, impact assessment, and fisheries. Discussions with experts from diverse backgrounds and geographical contexts have provided valuable insights, helping to advance this research and foster collaborations for future studies. These collective efforts highlight the importance of integrating both quantitative and qualitative data, ensuring that the needs and interests of small-scale fishing communities are accurately represented and addressed.

The strength of this research lies in its ability to amalgamate resources and perspectives from both academic and industrial standpoints regarding dredging and small-scale fisheries, areas that have been rarely explored in tandem. However, a notable limitation is the reliance on consulting strictly with experts. While their backgrounds and experiences are invaluable, this research would benefit even more from direct involvement with the marginalized and vulnerable communities of small-scale fisheries directly affected by dredging projects. Unfortunately, due to time and resource constraints, this was not possible for this thesis. Moving forward, it is essential to engage these communities more actively in research and impact assessments, incorporating their perspectives, including those related to gender, which may have been insufficiently addressed in this study. Despite this limitation, it is hoped that this research will still bridge knowledge gaps concerning the impacts of dredging on small-scale fisheries, as well as to stimulate new questions and encourage additional research and practical approaches in this field.

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