Commercial fishing gear loss in Canada's Pacific Ocean: answering the why, where, and how with a mixed methods, transdisciplinary approach

by

Caitlin M. Frenkel
B.Sc, University of Victoria, 2016

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In the School of Environmental Studies

We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land, and sea, continue to this day.

Supervisory Committee

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Abstract

Derelict fishing gear comprises a large portion of the world's marine plastic pollution, causing damage to marine habitats, wildlife, and fishing industries globally. To mitigate these issues, managers and marine stakeholders must understand the reasons for, and areas of, fishing gear loss specific to their region. Additionally, regional case studies are important to add to the global literature on derelict gear research. I conducted a global review of reasons for commercial gear loss, and used the findings to design a commercial fisher questionnaire in Canada's Pacific region as a case study. I carried out these dockside and on-line questionnaires to record commercial fishers' experiences with lost gear. Additionally, I used a species distribution model approach to identify variables associated with presence of derelict gear. Lost gear presence data for the model came from both the questionnaire and existing data for the region, and results from the previous literature review and questionnaire informed which environmental and fishing variables to include. I then used results from the model to predict areas with high probability of derelict gear occurrence. The global review highlighted that the most common reasons for gear loss were interactions with other fishing vessels and their gear, marine weather, and snagging on submerged features. Questionnaire results with 29 fishers indicated that snagging gear on rough substrate was the most important reason for loss across all gear categories, and that Hecate Strait, Clayoquot Sound, and the Strait of Georgia were prevalent areas of gear loss. Through the questionnaire, fishers indicated various ways to reduce gear loss including: using high quality gear that is well maintained, knowledge sharing amongst the fleet, preventing overcrowding in fishing areas, and keeping static and active gear types away from each other. The species distribution model approach indicated that bathymetry, fishing effort, and wind were the most important variables in derelict gear occurrence and predicted the highest probability of gear loss in similar areas as the survey. These results can support removal efforts and management decisions to mitigate issues caused by derelict gear by increasing the scientific understanding of the topic in Canada's Pacific region.

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Acknowledgements

This thesis would not have been possible without the support of so many wonderful people. First, I would like to thank my supervisory committee, Dr. Natalie Ban and Dr. Josephine Iacarella for their unwavering support and guidance throughout this process. Natalie, thank you for taking me into the MER lab. With your endless encouragement I have fallen in love with the social sciences and have become a confident early-career scientist. Josie, thank you for sharing your statistical knowledge and your limitless patience as I bumbled my way through my first model. I would also like to thank Elly and the Ecostats group for answering my incessant and increasingly frantic questions about coding and statistics in R. I am so grateful for all of the time they spent with me trouble-shooting problems from basic coding syntax to creating my first predictive map. Additionally, I am grateful for the lovely folks in the MER lab. Beginning a graduate degree during the pandemic was isolating, so I am truly appreciative for all of the laughs and support shared over good food and caffeinated beverages with my lab mates.

Next, I would like to thank the T Buck Suzuki Environmental Foundation for collaborating with me on many parts of this research including survey design, field work, writing, and connecting me with fishers. Thank you to all of the fishers who took my survey and answering my many questions about lost gear and other fishing-related topics. I am honoured to continue my work with the TBSEF as their Sustainability Director where I will continue to learn about, and advocate for, sustainable fisheries in British Columbia.

Finally, thank you to my family and friends for their unconditional love and support during this process. Thank you for listening to me babble on about my research as I tried to make sense of it myself. Thank you for all of the phone calls and text messages checking in on me even though my status was the same (i.e. stressed, busy, anxious etc.). Thank you for thinking of me and passing along every news article about ghost gear, fishing, and cool ocean facts (even though I have not read them all yet!). Last but certainly not least, a huge thank you to my partner Jordy. Thank you for being my biggest fan and cheerleader, a faithful sounding board, and always believing in me even when I could not believe in myself.

Chapter 1 : Introduction

Introduction

Abandoned, lost, and otherwise discarded fishing gear (ALDFG; referred to as 'lost' or 'derelict' gear throughout this thesis) accounts for a significant portion of marine plastic pollution globally, having a detrimental effect on marine wildlife, habitats, and fisheries (Antonelis, 2013; Gilman, 2015; Global Ghost Gear Initiative, 2021; Good et al., 2010). Ghost fishing is one of the most severe consequences, whereby derelict gear continues to trap and ensnare marine life long after its initial loss (Antonelis et al., 2018a; Dameron et al., 2007; Donohue and Foley, 2007; Erzini et al., 1997). Additionally, lost gear can cause habitat degradation via scraping or smothering the seafloor and habitat-forming species (Du Preez et al., 2020; NOAA, 2015). These impacts of lost gear can accumulate to reduce fish biomass, therefore reducing commercial fish stocks and revenues globally (Bilkovic, 2016; Erzini et al., 1997; Gilman, 2015). This is especially problematic as most fishing gear is made of plastic materials to increase durability and longevity, causing lost gear to persist in the ocean and indefinitely damaging species and habitats (Du Preez et al., 2020). As many countries are striving to reduce their marine plastic pollution, preventing gear from becoming lost and mitigating its negative effects is one potential solution.

In collaboration with the T Buck Suzuki Environmental Foundation (TBSEF), my thesis explores reasons for and areas of commercial fishing gear loss in Canada's Pacific Ocean using mixed methods (i.e. qualitative and quantitative) within a transdisciplinary approach. I accomplish this by drawing on the global literature, surveying commercial fishers, and using a novel approach to model and predict lost gear occurrences in the study area. This introductory chapter outlines relevant background information about Canada's Pacific fisheries and what work on lost gear has been conducted thus far in Canada. Additionally, this chapter outlines my research questions, objectives, and thesis chapters. Finally, I will summarize my research methodology, including a description of my positionality within this work.

The global problem of derelict fishing gear

Derelict fishing gear is a global environmental and socioeconomic problem (Global Ghost Gear Initiative, 2021; NOAA, 2015). Based on a recent literature review on research between 1975 to 2017, Richardson et al. estimated that 5.7% of all fishing nets, 8.6% of all traps, and 29% of all lines are annually lost around the world (2019). Interviews with commercial fishers from seven different countries resulted in a global estimate of 2% of all commercial fishing gear becoming lost annually (Richardson, 2022). This derelict gear is detrimental to the environment and fisheries (Global Ghost Gear Initiative, 2021). Globally, 79% of all marine animals ensnared in lost fishing gear are harmed or killed (World Animal Protection, 2018).

Additionally, it is estimated that over 90% of the species caught by derelict gear are commercially valuable (Al-Masroori et al., 2004). This ghost fishing can cause considerable economic impacts for commercial harvesters. For example, studies in the USA for the Washington State Dungeness crab and Virginia blue crab fisheries have estimated revenue losses of $744,000 and $300,000 respectively per year due to derelict traps (Antonelis et al., 2011; Bilkovic et al., 2014). Researchers are also aware of broad reasons for gear loss on a global scale. A recent study interviewed over 400 fishers in seven different countries around the world and found that bad weather and interactions with marine wildlife were the most common reasons for gear loss (Richardson et al., 2021), and fishers using gear types that contact the seafloor often become lost due to snagging on bottom obstructions and conflicts with other fishers (Richardson et al., 2021).

Impacts of derelict gear and reasons for gear loss can vary regionally. Therefore, case studies are imperative to building our knowledge of gear loss on regional and global scales. However, most of the current research on regional reasons for, and areas of, fishing gear loss have primarily taken place in Europe, the USA, and Asia (Antonelis, 2013, 2012; Ayaz et al., 2010; Bilkovic, 2016; Gunarathna et al., 2019; MacMullen et al., 2002; Richardson et al., 2021, 2018; Santos et al., 2003). In order to understand derelict gear in a global sense, and to inform mitigation efforts regionally, it is important to conduct research in lesser studied countries, including Canada.

An overview of Canada's Pacific fisheries

Commercial fisheries and associated businesses have been historically important to Canada's economy. As of 2021, Canada's commercial fisheries and seafood processing industries were valued at approximately $8.5 billion CAD and provided over 64,000 jobs (Fisheries and Oceans Canada, 2022). Canada's Pacific Ocean, on the west coast of the country in the province of British Columbia (BC), is home to a prevalent commercial fishing industry. There are many commercial fishing hubs along BC's coast, providing ports in which commercial fishers can dock their vessels, offload their catch, and purchase necessary supplies (Figure 1). Fisheries and Oceans Canada (DFO) has issued over 6,000 commercial fishing licenses to over 2,000 registered vessels (Government of Canada, 2016). Pacific fisheries target many species including Pacific salmon, herring, crab, shrimp, and a variety of groundfish and shellfish. Generally, each major fishery in Canada's Pacific is managed via Integrated Fisheries Management Plans (IFMPs) that are updated yearly and outline which areas fishers may or may not harvest, the types of gear they may use, updates on the status of bycatch species, amongst other things.

Gear types for Canada's Pacific fisheries generally fall under the three main categories of lines, nets, and traps but vary widely within those categories. For example, the line gear category includes passive gear that may be set on the seafloor for a period of time, such as hook and line gear, as well as more active gear types such as troll and rod and reel gear. Similarly, the net

category also includes passive (e.g. gillnets) and active (e.g. seine nets, bottom trawl and midwater trawl nets) gear types with various interactions on the seafloor. While different fisheries may use the trap gear category for different target species (e.g. crab, prawn), traps are all generally passive gear types that are set on the seafloor. Additionally, some commercial fisheries are dive fisheries, where divers collect target species (e.g. geoduck, horseclam, sea cucumber) directly off the seafloor or use equipment to dig them out of the sand.

Lost fishing gear has become more of a concern in Canada's Pacific Ocean due to more recent public and government awareness. Marine stakeholders and First Nations are concerned about potential environmental and economic impacts of lost gear including: ghost fishing, habitat degradation, the cost of replacing the lost gear, the cost of repairing damaged gear, and the ability of derelict gear to cause more future gear loss. Removal and research efforts have been primarily initiated by environmental non-profit organizations (e.g. the T Buck Suzuki Environmental Foundation), commercial fishing associations (e.g. Area A Crab Association), and environmental consultants (e.g. Natural Resources Consultants). Despite this interest amongst these groups, very little academic and peer-reviewed research has been conducted on the topic in Canada's Pacific Ocean.

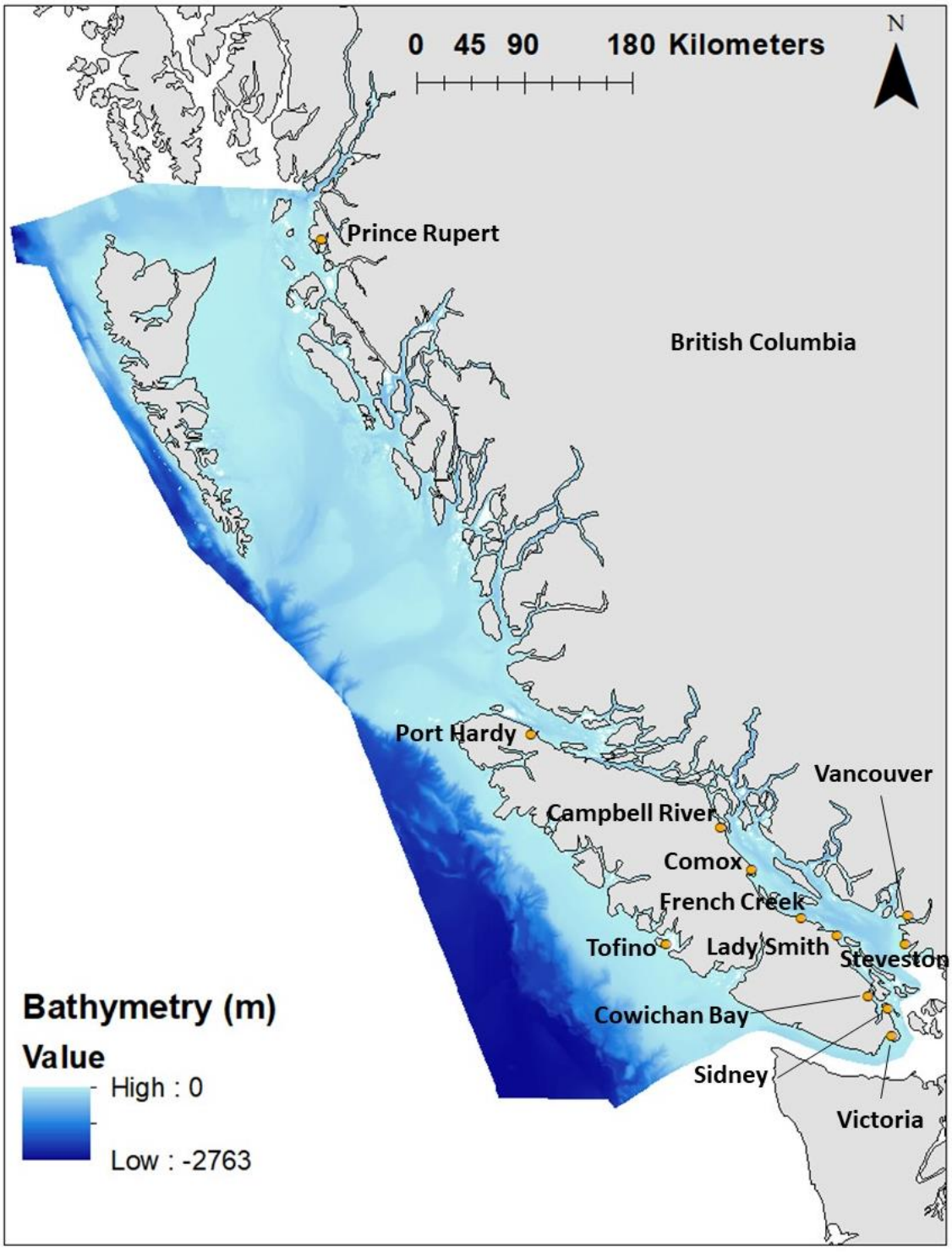

Figure 1. Canada's Pacific Ocean and some main fishing ports in BC Bathymetry data was obtained from the Government of Canada, and it does not include all of Canada's EEZ. Fishing ports include only those that were visited during the survey in Chapter 2.

Research on lost gear in Canada's oceans

In 2018, Canada's federal government joined the Global Ghost Gear Initiative (GGGI) – a multi-stakeholder alliance combatting the issues of lost gear worldwide – and has since encouraged lost gear related work through various funding initiatives. To date, there has been little peer-reviewed research in Canada's Pacific and Atlantic oceans, and no work in Canada's Arctic Ocean. This limited research has focused on: Dungeness crab mortality in derelict traps in the Pacific region (Breen, 1987), impact assessments of fishing gear on biological structures in Canada's Pacific seamount ecosystems (Du Preez et al., 2020), marine megafauna entanglement in Canada's Atlantic Ocean (Benjamins et al., 2012; Brown et al., 2009; Hamelin et al., 2017), and marine debris assessment surveys in the Atlantic region (Goodman et al., 2020). Comparatively, there is more lost gear related work in the grey literature conducted by ENGOs, environmental consultants, government, and fishing associations in both Pacific and Atlantic oceans. This work includes: conducting lost gear retrieval programs in Canada's Pacific ocean (Antonelis et al., 2018b; Paton, 2021; Eadie, 2022; Eadie, 2022a; Eadie, 2022b), predictive spatial mapping of derelict gear with limited data in the Pacific (Antonelis et al., 2013; Antonelis and Drinkwin, 2021), marine stakeholder workshops in both Pacific and Atlantic regions (Drinkwin et al., 2019; Eadie and Bright, 2021.; Fisheries and Oceans Canada, 2020), and an assessment of the environmental and economic impacts of lost gear in Canada's Atlantic Ocean (Goodman et al., 2021). All work to date has focused on commercial fisheries, with recreational gear loss posing a large knowledge gap in Canada.

Many smaller organizations (ENGOs, fishing associations, consultants etc.) in Canada's Pacific had been working separately to address derelict fishing gear issues on a local scale, including conducting targeted gear retrievals (Antonelis et al., 2018b; Paton, 2021) as academia had done little to address the topic. The first regional lost gear workshop was hosted by World Animal Protection in 2019, including various participants from BC's marine sector such as commercial fishers and their associations, fisheries management, harbour authorities, ENGOs, environmental consultants, and First Nations (Drinkwin et al., 2019). By bringing these various groups together, this regional workshop began a collective conversation about lost gear related issues and solutions in Canada's Pacific, urging fisheries management to take a more regionally and fishery-based approach to gear retrieval (Drinkwin et al., 2019). After the federal government of Canada hosted the national Gear Innovation Summit in 2020, they provided a major funding opportunity to these smaller organizations through their Ghost Gear Fund (Fisheries and Oceans Canada, 2020). The Ghost Gear Fund illustrated Canada's commitment to reducing lost fishing gear, mitigating its harmful effects, and supporting sustainable fishing practices (Fisheries and Oceans Canada, 2020). This opportunity provided organizations in Canada's the ability to obtain a larger sum of funding to conduct more thorough work on lost gear and provide the baseline information that inspired this thesis. Upon obtaining this funding, the T Buck Suzuki Environmental Foundation was able to conduct a series of workshops in fishing ports along BC's coast to record local knowledge from fishers regarding lost gear (Eadie and Bright, 2021). Through these workshops, common gear loss areas in the Pacific region were identified as well as strategies fishers use to avoid gear loss (Eadie and Bright, 2021). Due to the

timing of the TBSEF's workshops, the participants were mostly from the salmon and prawn fisheries (Eadie and Bright, 2021), which may have missed important perspectives from other fisheries (e.g. crab, halibut etc). Building on this grey literature, my thesis set out to fill current knowledge gaps in the peer-reviewed literature pertaining to regionally specific reasons and areas of gear loss, commercial fishers' gear loss prevention and mitigation methods and perspectives on how industry and management can help, and novel predictive models for lost gear in Canada's Pacific Ocean that use a larger amount of lost gear presence data.

Research questions and thesis structure

My thesis addresses the previously mentioned knowledge gaps regarding lost gear in Canada's Pacific Ocean with a transdisciplinary, mixed methods approach to answer the following questions for Canada's Pacific Ocean:

1. Why does commercial fishing gear become lost?
2. Where does commercial fishing gear become lost?
3. How can we prevent commercial fishing gear loss?

As this thesis uses two different methodological approaches to answer each of the above questions, Chapters 2 and 3 have been written as stand-alone manuscripts for peer-reviewed publication. Therefore, there is some repetition between chapters.

Chapter 1 serves as an introduction to my thesis. It provides necessary context of the effects of lost commercial fishing gear, Canada's Pacific fisheries, and a summary of lost gear research in Canada to-date. This chapter also outlines my research objectives, questions, thesis structure, and methodological approach to answer these questions. Additionally, I provide a positionality statement to situate myself in the context of this work.

Chapter 2 is the qualitative research chapter co-authored with my committee, Dr. Natalie Ban and Dr. Josephine Iacarella, and former T Buck Suzuki Evironmental Foundation staff Megan Eadie and Adrienne Murphy. While I led the project in terms of conception, data collection, analysis, and writing, my co-authors' expertise were integral to all aspects of the research. In this chapter, I describe how I conducted a global literature review of reasons why commercial fishing gear is lost. I used this literature review to inform the design of a survey of commercial fishers in Canada's Pacific. In this survey, I ask questions along the following themes: 1) why fishers lose their gear, 2) where fishers lost their gear, 3) methods fishers use to prevent and mitigate their gear loss, 4) fishers' perspectives on what the industry and management can do to prevent and mitigate gear loss. Through this work, I acknowledge that commercial fishers working in Canada's Pacific Ocean have a local expertise on the topic of lost gear. My goal with this chapter is to inform fisheries management, industries, marine stakeholders, and First Nations of this baseline information to further prevent and mitigate the harms of lost gear.

Chapter 3 is the quantitative research chapter where I apply a species distribution modelling (SDM) method to predict lost gear occurrence probabilities in Canada's Pacific Ocean. Again, this chapter was co-authored with my supervisory committee, Dr. Natalie Ban and Dr. Josephine Iacarella, who offered valuable insight and guidance throughout the process based on their expertise. While other spatial predictive mapping methods have been used to predict lost gear, I am taking a novel approach by using an SDM. In this chapter, I use lost gear occurrence data from Canada's Pacific Ocean, including data from Chapter 2, and relevant environmental variables to predict areas with high probabilities of lost gear occurrences. These results may be used to help inform and direct future gear retrieval efforts in order to efficiently use limited resources and funding.

Chapter 4 summarizes the results from Chapters 2 and 3 and compares how each method answered my research questions. This chapter discusses the practical applications and academic importance of my thesis work, as my research has the potential to inform fisheries management and add to the peer-reviewed literature on under-studied topics. Additionally, I provide recommendations for future research and practical contributions regarding lost gear in Canada's Pacific Ocean.

Methodological approach

I took a transdisciplinary, mixed methods approach to answer my research questions. Mixed methods are common in fisheries research (Magee et al., 2018; Bennett et al., 2021), as they combine the strengths of both qualitative and quantitative methods. Problems faced by small-scale commercial fisheries are complex, often involving economic, social, and ecological aspects (Said et al., 2018). Therefore, it is important to draw from the benefits of both qualitative and quantitative approaches in order to find practical solutions that transcend the boundaries of these individual disciplines within academia.

In Chapter 2, I conducted a global literature review, including both peer-reviewed and grey literature, of reasons why commercial fishers around the world lose their gear, including work that exists in Canada. This literature review informed the design of my commercial fisher survey. Expert knowledge of local fishers is common in fisheries research (Bennett et al., 2020; Harper et al., 2022). Commercial fishers have extensive knowledge and a thorough understanding of their chosen fisheries, providing researchers with important regional context to various issues. Local fisher knowledge is becoming more common in lost fishing gear related work (Eadie and Bright, 2021; Goodman et al., 2019; Gunarathna et al., 2019; Richardson et al., 2021, 2018). Therefore, directly surveying Pacific region commercial fishers was of utmost importance to answer my research questions.

In Chapter 3, I applied SDM methods as a novel approach to predictive spatial mapping of lost gear. These models are frequently employed in ecological research to anticipate possible areas of species presence based on their environmental needs, such as temperature and precipitation (Franklin, 1995; Guisan et al., 2017; Lecours, 2019). SDMs are especially

beneficial when observational data are low, as in the case with lost gear presence data. Additionally, SDM methods can offer insight into which environmental variables are the most important to species occurrences, therefore leading to more accurate predictions of where species should occur (Wenger, 2012). While the insights of commercial fishers may be on a more localized scale, an SDM can assess which environmental variables (as proxies for gear loss reasons) play a role in lost gear occurrence at a larger, regional scale throughout Canada's Pacific Ocean. Additionally, using a quantitative modelling approach can identify statistical patterns and significance in potential reasons for gear loss on a broad scale.

My collaboration with T Buck Suzuki Environmental Foundation was imperative to this thesis, and enabled me to take a transdisciplinary approach. The TBSEF is a charity based in BC, Canada that promotes sustainable fisheries and coastal community well-being, advocating for the needs of local fishers. They work closely with local small-scale fishers in Canada's Pacific Ocean on a variety of fisheries sustainability projects and issues, including lost gear. The TBSEF has been a member of the GGGI since 2017 and has since been a leader on lost gear related work in Canada's Pacific, conducting fisher workshops (Eadie and Bright, 2021) and coordinating gear retrievals with commercial fishers (Eadie, 2022; Eadie, 2022a; Eadie, 2022b). For my research, the TBSEF provided guidance on research questions and approaches that would be useful for their work with commercial fishers. Additionally, they were able to circulate the survey amongst their commercial fisher contacts to help test the survey, and accompanied me on field work. Additionally, they were able to offer insights on the different environmental variables I used in the lost gear predictive model. This collaboration came about through Dr. Natalie Ban's previous relationship with the TBSEF.

Positionality statement

As research is conducted by humans it is inherently influenced by the researcher's previous experiences. I am a woman of European descent who grew up in Prince George, BC on the unceded traditional territory of the Lheidli T'enneh First Nation. This land is part of the Dakelh (Carrier) peoples' territory. I currently live and work in Victoria, BC on the unceded territories of the Lekwungen and W̱SÁNEC peoples. My love for marine life led me to pursue a BSc Biology (concentration: marine biology) from the University of Victoria (UVic). My education and work have taken me to many places around Vancouver Island, including Nanaimo (traditional territory of the Snuneymuxw, Snaw-naw-as, and Stzuminus peoples), Bamfield (traditional territory of the Huu-ay-aht First Nations), and Port Hardy (traditional territory of the Kwakiutl First Nations). These adventures inspired my passion for Canada's Pacific Ocean and fisheries. I first become interested in the topic of lost fishing gear through previous work at Archipelago, where I worked in their Fisheries Monitoring Program. I worked directly with commercial fishers and others associated with the fishing industry, learning about fish identification, commercial fishing operations, and most importantly the deep connections between small-scale fishers and the ocean. I first learned about lost fishing gear and its impacts when Archipelago became a member of the GGGI, and I worked on a committee that organized

workshops and projects regarding lost fishing gear in Canada's Pacific. I realized that massive knowledge gaps regarding lost gear still exist in Canada's Pacific, which inspired me to return to UVic and conduct my thesis research. As most of my fisheries experience is directly tied to the commercial sector, conducting research with practical applications is of utmost importance to me. During the later part of my MSc, I began working part-time with the TBSEF as their Sustainability Director. I collaborate with folks in BC's fishing community on all aspects of fisheries sustainability, and plan on continuing my work on lost fishing gear after completing my MSc.

Chapter 2 : Why, and where, is commercial fishing gear lost? A global review and case study of Pacific Canada

Introduction

Abandoned, lost, or otherwise discarded fishing gear is a known yet under-studied problem in the marine environment, despite having detrimental effects on oceans and fishing industries worldwide (Antonelis, 2013; Gilman, 2015; Global Ghost Gear Initiative, 2021; Good et al., 2010). Ghost fishing is one of the most adverse effects of lost gear, due to its ability to trap marine animals long after its initial loss (Antonelis et al., 2018a; Dameron et al., 2007; Donohue and Foley, 2007; Erzini et al., 1997). For example, 79% of marine animals entangled in lost fishing rope and netting are harmed or killed around the world (World Animal Protection, 2018). Lost gear causes marine habitat degradation by being dragged over and entangling or breaking habitat-forming species, such as corals and sponges (Du Preez et al., 2020; NOAA, 2015), or by disrupting the benthos through scouring and smothering, damaging seagrass beds and reefs while reducing access to local species (June and Antonelis, 2009; Macfadyen et al., 2009; NOAA, 2015). Ghost fishing and habitat degradation caused by lost gear can combine to reduce marine biomass and negatively impact commercial fishing stocks and revenues worldwide (D.M. Bilkovic, 2016; Erzini et al., 1997; Gilman, 2015). Some studies have estimated that over 90% of species caught by lost gear are commercially valuable (Al-Masroori et al., 2004). For example, a study in Washington state estimated that ghost fishing caused a 4.5% loss of Dungeness crab stocks annually, equating to revenue loss of $744,000 to the fishery (Antonelis et al., 2011). Ghost fishing mortality is often unaccounted for in many commercial stock assessments (Gilman, 2015; Uhlmann and Broadhurst, 2015). Unaccounted for mortality is especially problematic as most modern fishing gear is made out of plastic to increase its durability and longevity, such that lost gear can persist in the ocean and cause damage for decades (Du Preez et al., 2020).

The issue of lost gear has recently been garnering more attention from scientists worldwide as countries aim to reduce marine plastic pollution. Research to date has focused primarily on the following issues related to lost gear: its effects on marine wildlife and sensitive habitats (Arthur et al., 2014; Du Preez et al., 2020), predictive spatial analysis and hotspot mapping (Antonelis and Drinkwin, 2021; Donohue and Foley, 2007; Martens and Huntington, 2012), the economic costs of gear loss (Scheld et al., 2021, 2016), and reasons for fishing gear loss globally (Gilman et al., 2022; Richardson et al., 2021) and in specific regions (Gunarathna et al., 2019; Richardson et al., 2018; Santos et al., 2003). However, the current research on regional reasons for, and areas of, gear loss are scattered across a few countries, primarily in Europe, the United States, and Asia (Antonelis, 2013, 2012; Ayaz et al., 2010; Bilkovic, 2016; Gunarathna et al., 2019; MacMullen et al., 2002; Richardson et al., 2021, 2018; Santos et al., 2003). Reasons for gear loss can be specific to regional fisheries and geographies, so it is important to determine which reasons from the global literature are relevant at local scales to best manage the problem.

Areas of gear loss are also linked to gear loss factors specific to regional fisheries and geographies. A lack of information in many countries prevents fisheries management and marine stakeholders from having a thorough understanding of gear loss in their area, making them ill-equipped to mitigate this issue.

Canada is illustrative of the newfound focus on lost gear, and recognition of its relevance given the economic importance of the fishing industry (Fisheries and Oceans Canada, 2022). For example, in 2021 outputs from Canada's commercial fisheries and seafood processing industries were valued around $8.5 billion CAD and provided over 64,000 jobs (Fisheries and Oceans Canada, 2022). Some peer-reviewed research was previously conducted regarding marine megafauna entanglement in Eastern Canada (Benjamins et al., 2012; Brown et al., 2009; Hamelin et al., 2017) and Dungeness crab mortality caused by derelict traps in British Columbia (BC) (Breen, 1987). After Canada joined the Global Ghost Gear Initiative (GGGI) – a multi-stakeholder alliance tackling derelict gear issues worldwide – in 2018, the federal government made lost gear a larger priority through several funding initiatives. More recent work on lost gear in Canada includes predictive spatial mapping projects (Antonelis et al., 2013; Antonelis and Drinkwin, 2021), marine stakeholder workshops (Drinkwin et al., 2019; Eadie and Bright, 2021.; Fisheries and Oceans Canada Library et al., 2020), marine debris assessment surveys (Goodman et al., 2020), impact assessments on Canada's Pacific seamount ecosystems (Du Preez et al., 2020), and assessment of the environmental and economic impacts of lost gear in Canada's Atlantic region (Goodman et al., 2021). Despite this recent work, Canada is lacking peer-reviewed research regarding regionally specific reasons for why and where commercial fishing gear becomes lost and how that compares to global findings. Additionally, little information exists on commercial fishers' prevention methods and perspectives regarding lost gear in Canada. Understanding reasons for commercial fishing gear loss, areas where gear is commonly lost, and fishers' perspectives on lost gear could offer valuable insight into how and where future management actions should be targeted in the region.

Expert knowledge from fishers is commonly used in fisheries research (Bennett et al., 2020; Harper et al., 2022), and studies are increasingly working with fishers to understand gear loss as well (Eadie and Bright, 2021; Goodman et al., 2019; Gunarathna et al., 2019; Richardson et al., 2021, 2018). Fishers have extensive knowledge and experiences regarding their chosen fisheries, providing researchers with regional context to different fisheries problems, including lost gear. In 2019, World Animal Protection and the GGGI hosted a workshop with participants across BC's marine sector, including commercial fishers and their associations and fisheries management staff, to discuss various aspects of lost gear in Canada's Pacific (Drinkwin et al., 2019). This was followed by a series of workshops in 2020 conducted in several of BC's coastal communities to begin recording lost gear knowledge from local fishers, primarily from the salmon and prawn fisheries (Eadie and Bright, 2021). These workshops identified some prevalent areas for gear loss in the Pacific region, some actions that fishers can take to prevent gear loss, encouraged fisheries management to update their regulations to include lost gear prevention and mitigation methods and allow fishers more flexibility in returning others' lost gear (Drinkwin et al., 2019; Eadie and Bright, 2021). Generally, fishing gear was lost in areas that experienced rough ocean conditions, such as Hecate Strait, and high levels of vessel traffic,

such as Boundary Bay (Drinkwin et al., 2019; Eadie and Bright, 2021). These workshops also concluded that interactions with previously lost gear on the seafloor or actively fishing gear can also cause loss and that management policies should be updated to allow fishers to retrieve others' lost gear to reduce environmental impacts (Drinkwin et al., 2019; Eadie and Bright, 2021). While these workshops provide helpful insight on lost gear in BC, more work is needed to get a broader overview of fishers' perspectives across a larger variety of fisheries and gear types.

In this study, I first conducted a literature review to identify global reasons for gear loss across all fisheries and gear types. I then fill the knowledge gap on lost gear in Canada's Pacific by learning why and where commercial fishing gear becomes lost. I surveyed commercial fishers across BC, with survey design informed by the global literature review, to identify the following: which reasons for gear loss were most relevant to their gear category of choice (lines, nets, or traps), where they lose their gear, identify their gear loss prevention and mitigation methods, and record their perspectives on how industry and management can prevent and mitigate the ill-effects of gear loss.

Materials and Methods

Study Area

I focused this study on the Pacific coast of Canada, where Fisheries and Oceans Canada (DFO) has issued over 6,000 commercial fishing licenses to over 2,000 registered vessels in 2020 (Government of Canada, 2016). Fisheries currently target many species including Pacific salmon, herring, crab, shrimp, and a variety of groundfish and shellfish, with an array of commercial gear types falling under the three broader categories of lines (e.g. longlines, troll, rod and reel), nets (e.g. bottom and mid-water trawl, seine, gillnet), and traps (e.g crab, prawn).

There are a variety of commercial fishing hubs along BC's coastline, providing ports for fishers to dock their boats and offload their catch. The locations we visited for in-person surveys were selected based on their connections to the commercial fishing industry (Figure 1), and we also had the survey available online. These locations act as hubs for commercial fishing activity, as they have the infrastructure to house vessels and offload commercial catch (e.g. government docks, fish plants, fishing supply stores, close proximity to fisheries observing services). Additionally, fishers using all three main gear categories (lines, nets, and traps) landed in each of these locations.

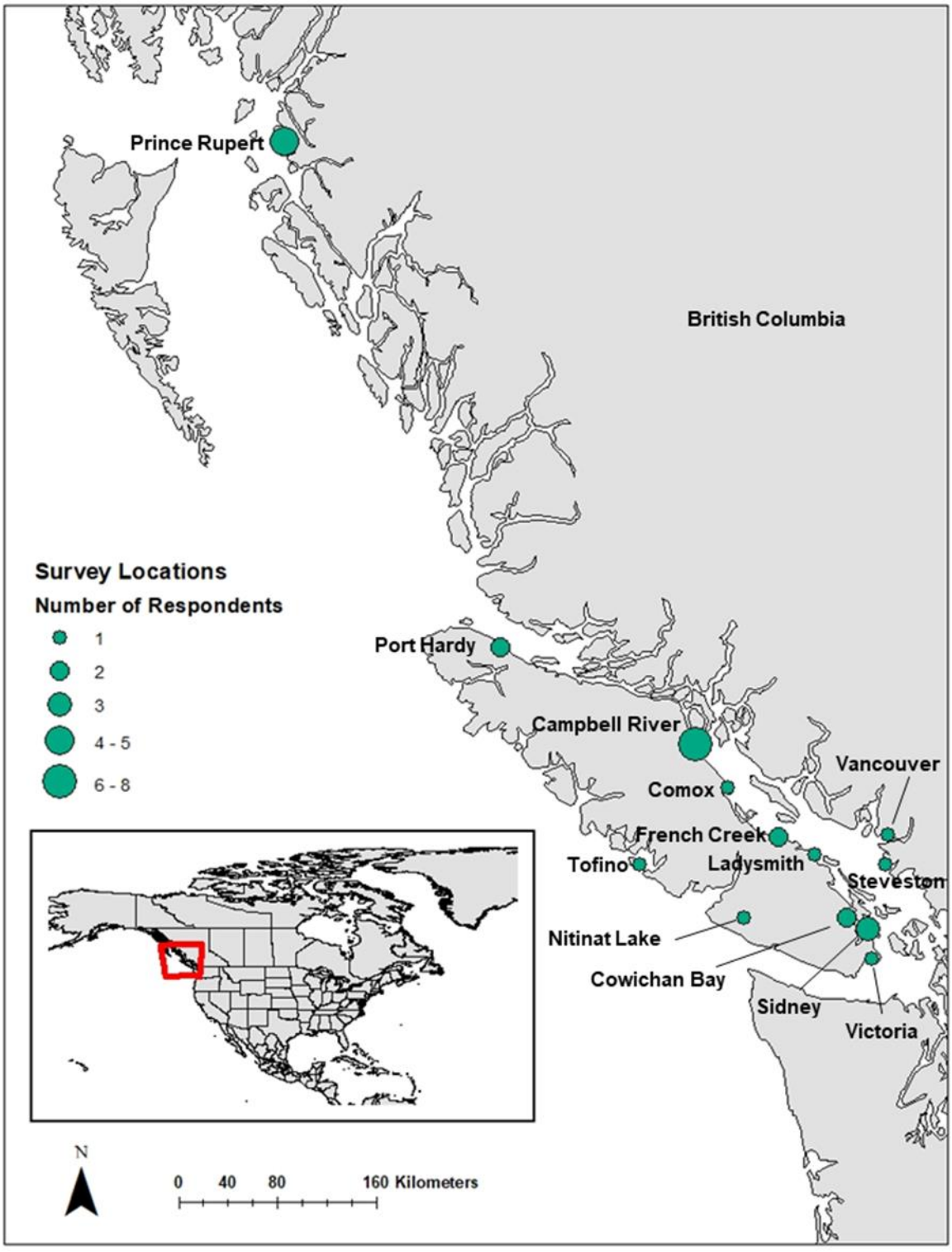

Figure 1. Locations of the questionnaire 29 respondents along BC's coastline for both dockside and on-line surveys. The size of the green circles indicates the total number of respondents from that area.

Literature Review, Survey Design, and Data Collection

I first conducted a literature review to determine prevalent reasons for gear loss worldwide to inform our survey questions. I included articles and reports in both the academic and grey literature, using Google, Google Scholar, ScienceDirect, W&M Scholar Works, Wiley Online Library, Inter-Research Science Publishers, Proquest, Biodiversity Heritage Library, and Directory of Open Access Journals databases. I used the following search terms: "reasons for fishing gear loss", "derelict fishing gear", and "ghost gear". I reviewed sources that specifically mentioned commercial fishing gear loss in the title or abstract, only including those that had information on factors leading to the gear loss. I concluded the literature review when we could no longer find new, relevant sources after five pages on the databases, ending the review in April 2021. The results are summarized in Table 1.

I designed the survey questions iteratively along the following themes: (1) participants' experience in the commercial fishery; (2) main reasons for gear loss, using the list from the literature as a starting point; (3) frequency of gear loss; (4) what can be done to prevent gear loss; and (5) locations where gear was lost, or lost gear encountered. Finally, (6) I also asked demographic questions to provide context of the respondents' background, such as their homeport and age. I tested the survey with several fishers who have an interest in gear loss, and revised it based on their feedback. Approval was given by UVic's Human Research Ethics Board (approval #21-0144), and the survey was launched in late September 2021.

I used two convenience sampling approaches to solicit responses to the survey. Convenience sampling is a non-probability sampling method common to qualitative research whereby survey participants are chosen based on both meeting the inclusion criteria and their ease of access to the researcher (Acharya et al., 2013; Stratton, 2021). First, I created an online version of the survey for research partners at the T. Buck Suzuki Environmental Foundation to circulate to their contacts in the commercial fishing industry via social media, phone, and email. Online surveys generally took 10 to 15 minutes to complete, and were hosted on the Trailmark™ Web online software as it allowed multiple-choice, open-ended, and mapping questions. The on-line survey was available until the last day of data collection in March 2022. Second, I conducted dockside surveys between late September and early November, 2021; I began the surveys when it was deemed safe to do so during the COVID 19 pandemic, and completed when most fisheries had finished for the season and few fishers were at the docks. I travelled to the various fishing ports and approached fishers at the dock to conduct the survey (Figure 1). In-person surveys took 30 to 45 minutes to complete as fishers relayed their stories and experiences, and some surveys took up to one hour to share more detailed information. Fishers answered the survey in the context of their most economically important fishery, with the option to complete it for up to three different fisheries. I continued to use social media advertisements to encourage commercial fishers to take the on-line survey on the T. Buck Suzuki Foundation's website. Data collection ended in early March 2022, when no new surveys were completed online after several reminders.

Data Analysis

I analyzed survey data by the three broader gear type categories of lines, nets, and traps. I used descriptive statistics to illustrate the quantitative survey questions: reasons for gear loss, the seafloor types fishers have lost their gear on, the types of vessels their gear comes into contact with, and the types of actively fishing and lost gear that their gear comes into contact with, and other reasons for gear loss. I qualitatively coded the open-ended survey questions regarding ways to prevent and reduce gear loss, to identify themes and visualize how they linked to categories of gears (Table S1). Descriptive statistics and qualitative coding were conducted in R (V 2.0.4; R Studio Team 2022) and NVivo 12 (NVivo 12 Plus; QSR International Pty Ltd, 2020), respectively.

I mapped lost fishing gear (both full and partial losses) locations indicated in the survey to visualize their locations along BC's coast (ArcMap V 10.8.1; ESRI, 2020). Data points included gear that the respondents had lost as well as lost gear that they had found.

Results

Literature Review

Multiple reasons for gear loss from around the world were reported in each of the 19 articles found in the literature review (Table 1). The most common reasons for gear loss were interactions with other fishing vessels and their gear, and marine weather (n = 15 articles each). The second most common reason for gear loss was snagging gear on submerged features (n = 14). Equipment malfunction and poor gear condition were found to be the third most common reasons for gear loss (n = 9).

Out of the 19 articles, 4 contained information on reasons for gear loss in Canada's oceans (Table 1). The most common reasons for gear loss in Canada were snagging on submerged features (3 articles), interactions with other fishing vessels and their gear (3 articles) and marine weather (3 articles). Other reasons for gear loss in Canada included interactions with non-fishing vessels (1 article), lack of fisher experience (1 article), depth (1 article), and equipment malfunction and poor gear condition (1 article).

Table 1. Literature review results for reasons for gear loss from around the world.

Reason for Gear Loss	Description	Total Studies (out of 19)	References	Location
Interactions with other fishing vessels and their gear	When fishing vessels and/or their gear come into contact with another vessel's gear, causing it to become dislodged or damaged, resulting in its loss. This could be due to poor communication about the location of set gear, theft, or overcrowding on the fishing grounds. A common conflict is when active gear types (e.g. bottom trawl) come into contact with static gear types (e.g. traps, bottom longlines).	15	Swarbrick & Arkley, 2002	Southwest & Northwest England, West Coast of Scotland
			MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Santos et al., 2003	Southern Portugal
			Hareide et al., 2005	West & North Great Britain, Ireland
			Ayaz et al., 2010	Turkey (eastern Mediterranean)
			Antonelis, 2012	The United States (Puget Sound)
			Antonelis, 2013	The United States (Puget Sound)
			NOAA, 2015	Global
			Richardson et al., 2018	Australia (Gulf of Carpentaria), Indonesia (Arafrua Sea)
			Drinkwin et al., 2019	Canada (Eastern Pacific Ocean)
			Richardson et al., 2019	Global
			Eadie & Bright, 2021	Canada (Eastern Pacific Ocean)
			Goodman, 2020	Canada (Bay of Fundy)
			Richardson et al., 2021	Belize, Iceland, Indonesia, Morocco, New Zealand, Peru, US
			Global Ghost Gear Initiative, 2021	Global
Marine Weather	When rough weather events cause fishing gear loss by knocking it off of the vessel's	15	Swarbrick & Arkley, 2002	Southwest & Northwest England, West Coast of Scotland

	deck, making it difficult to set or haul, or moving it from its original location.		Macmullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Santos et al., 2003	Southern Portugal
			Hareide et al., 2005	West & North Great Britain, Ireland
			Ayaz et al., 2010	Turkey (eastern Mediterranean)
			NOAA, 2015	Global
			Bilkovic et al., 2016	The United States (Chesapeake Bay)
			Richardson et al., 2018	Global
			Drinkwin et al., 2019	Canada (Eastern Pacific Ocean)
			Gunarathna et al., 2019	South Coast Sri Lanka
			Richardson et al., 2019	Global review
			Eadie & Bright, 2021	Canada (Eastern Pacific Ocean)
			Goodman, 2020	Canada (Bay of Fundy)
			Richardson et al., 2021	Belize, Iceland, Indonesia, Morocco, New Zealand, Peru, US
			Global Ghost Gear Initiative, 2021	Global
Snagging gear on submerged features	When fishing gear becomes caught on features under the ocean's surface. This could include: rocky pinnacles, shipwrecks, boulders, old aquaculture equipment, logs etc. This is most common in gear types that come into contact with the seafloor while fishing (e.g. bottom trawl nets, bottom longlines, traps etc).	14	Breen, 1990	Global
			Macmullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Santos et al., 2003	Southern Portugal
			Hareide et al., 2005	West & North Great Britain, Ireland
			Ayaz at al., 2010	Turkey (eastern Mediterranean)
			Antonelis, 2012	The United States (Puget Sound)
			Antonelis, 2013	The United States (Puget Sound)
			NOAA, 2015	Global

			Richardson, 2018	Australia (Gulf of Carpentaria), Indonesia (Arafrua Sea)
			Richardson, 2019	Global review
			Goodman, 2020	Canada (Bay of Fundy)
			Eadie & Bright, 2021	Canada (Eastern Pacific Ocean)
			Richardson, et al. 2021	Belize, Iceland, Indonesia, Morocco, New Zealand, Peru, US
			Global Ghost Gear Initiative, 2021	Global
Equipment malfunction and poor gear condition	Fishing vessels and gear may occasionally malfunction, resulting in loss. Additionally, gear that is in poor condition is more likely to break under environmental stress due to general wear and tear and other existing damage.	9	Hareide et al., 2005	West & North Great Britain, Ireland
			Antonelis, 2012	The United States (Puget Sound)
			Antonelis, 2013	The United States (Puget Sound)
			NOAA, 2015	Global
			Bilkovic et al., 2016	The United States (Chesapeake Bay)
			Gilman, 2015	Global
			Richardson et al., 2018	Australia (Gulf of Carpentaria), Indonesia (Arafrua Sea)
			Goodman, 2020	Canada (Bay of Fundy)
			Global Ghost Gear Initiative, 2021	Global
Interactions with non-fishing vessels	When non-fishing vessels come into contact with fishing gear and dislodge or damage it, resulting in gear loss. Some examples include tankers, shipping vessels, ferries, and recreational vessels.	6	MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Ayaz et al., 2010	Turkey (eastern Mediterranean)
			Antonelis, 2012	The United States (Puget Sound)
			Bilkovic et al., 2016	The United States (Chesapeake Bay)
			Gunarathna et al., 2019	South Coast Sri Lanka
			Drinkwin et al., 2019	Canada (Eastern Pacific Ocean)

			Goodman, 2020	Canada (Bay of Fundy)
Deliberate disposal at sea	Fishers may intentionally dispose of their gear at sea. Common reasons include: bad weather making retrieval dangerous, discard of unwanted parts is more practical/economical than disposal at shore, insufficient room on board to store gear	5	MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Santos et al., 2003	Southern Portugal
			Hareide et al., 2005	West & North Great Britain, Ireland
			NOAA, 2015	Global
			Global Ghost Gear Initiative, 2021	Global
Abandonment at sea	Fishers may abandon their gear at sea due to adverse weather conditions making recovery dangerous, gear retrieval being too difficult or taking too long, or illegal operations.	3	MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			NOAA, 2015	Global
			Global Ghost Gear Initiative, 2021	Global
Depth	Loss due to depth depends on the fishery and gear type. Some fishers lose their gear due to deep water environmental conditions, while others lose their gear due to a mismatch between gear size and water depth. This can be prevalent with gillnets due to their large size and long soak times causing gear stress and snags. Additionally, deeper water also makes gear more difficult to retrieve.	6	MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Hareide et al., 2005	West & North Great Britain, Ireland
			Antonelis, 2013	The United States (Puget Sound)
			NOAA, 2015	Global
			Richardson et al., 2019	Global review
			Goodman, 2020	Canada (Bay of Fundy)
Large gear size	Fishers may use gear that is too large for the area or depth they are fishing in.	4	MacMullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Antonelis, 2012	The United States (Puget Sound)
			Antonelis, 2013	The United States (Puget Sound)
Large amounts of gear	Fishers may set more gear than they are able to retrieve in a timely manner.	1	Hareide et al., 2005	West & North Great Britain, Ireland
Interactions with wildlife	Marine wildlife can come into contact with fishing gear,	4	Ayaz et al., 2010	Turkey (eastern Mediterranean)

	causing it to become dislodged from the fishing vessel.		Gunarathna et al., 2019	South Coast Sri Lanka
			Global Ghost Gear Initiative, 2021	Global
			Richardson et al., 2021	Belize, Iceland, Indonesia, Morocco, New Zealand, Peru, US
Vandalism & theft	Third parties can intentionally cause damage to or steal fishers' gear, causing loss.	4	Swarbrick and Arkley, 2002	Southwest & Northwest England, West Coast of Scotland
			Macmullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Ayaz et al., 2010	Turkey (eastern Mediterranean)
			Global Ghost Gear Initiative, 2021	Global
Strong Ocean Currents	Strong currents can increase the difficulty of setting and hauling gear, in addition to moving gear from its original location, both of which can result in gear loss.	4	Macmullen et al., 2002	Norway, Sweden, UK, Spain, Portugal, France
			Natural Resources Consultants, 2012	The United States (Puget Sound)
			NOAA, 2015	Global
			Bilkovic et al., 2016	The United States (Chesapeake Bay)
Lack of fisher experience or training	In-experienced fishers are less familiar with the geography they work in and lack knowledge on the best practices to prevent and mitigate gear loss.	3	Antonelis, 2013	The United States (Puget Sound)
			Richardson et al., 2018	Australia (Gulf of Carpentaria), Indonesia (Arafrua Sea)
			Goodman, 2020	Canada (Bay of Fundy)
Operator error	Sometimes fishers make mistakes while setting or hauling their gear while (e.g. accidentally dropping a trap while hauling). This may be due to lack of fisher experience and/or training.	2	Antonelis, 2012	The United States (Puget Sound)
			Antonelis, 2013	The United States (Puget Sound)

Demographics

Overall, 29 fishers responded to the survey for their most economically important fishery. Four of the respondents also answered questions for their second most economically important fishery, thus resulting in a total of 33 survey responses (Supplementary Table S1). Ten of the responses were for trap fisheries, 9 for net fisheries, and 14 for line fisheries (Supplementary Table S1). More specifically, most fishers surveyed were from the halibut longline and prawn trap fisheries. The majority of respondents had more than 10 years of fishing experience, were older than 50, and 90% identified as male (Supplementary Table S2).

Why does gear get lost?

Important reasons for gear loss were fairly consistent across gear category. Snagging on rough ground beneath the surface was the most important reason for gear loss for lines (64% ranked as important to extremely important), nets (89%), and traps (100%) (Figure 2). Additionally, seafloor type was the second most important gear loss factor across all three gear categories likely due to the ability of rougher types to snag gear. Forty-five percent of line fishers answered 'N/A' to the question regarding which seafloor types their gear interacts with (Table 2), indicating that seafloor type is not relevant for their gear loss. Otherwise, the most common seafloor types causing gear loss for lines were corals, mixed, and rocky substrate. Net fishers indicated that their gear interacted the most with marine debris (43%). Trap fishers indicated that mixed seafloor types most commonly caused gear loss (Table 2).

Other important reasons for gear loss varied by gear category. Most line fishers ranked interactions with previously lost fishing gear as important, very important or extremely important in terms of their gear loss (Figure 2), with 45% of line fishers responding that their gear comes into contact with lost longline gear (Table 2). Lost fishing gear was identified as lower importance for net and trap fishers (Figure 2). However, net fishers commonly lost their gear due to encountering lost gillnets, prawn and shrimp traps, and crab traps, while trap fishers were more likely to have issues with crab traps and prawn traps (Table 2). Trap fishers were more likely to lose their gear due to other reasons not stated in the survey (Figure 2), with the most common reasons being operator error (33%), crowding on the fishing grounds (17%), and marine debris (17%) (Table 2). More than half (57%) of line fishers indicated that other reasons for gear loss not stated on the survey were very important or extremely important (Figure 2), such as large marine mammals (13%), worn gear (13%), low experience (7%), poor maintenance (7%), and weather (7%) (Table 2). Additionally, 70% of trap fishers ranked currents as important to extremely important in terms of their gear loss (Figure 2). Weather as a reason for gear loss had mixed results amongst the gear categories, but appeared to be more important for line fishers (64%) and least important for trap fishers (70%) (Figure 2).

Similar to important reasons for gear loss, the reasons of lesser importance were also consistent across gear types. These reasons included interactions with actively fishing gear (64-80% of all fishers ranked least to slightly important) and interactions with other vessels (55- 71% ranked least to slightly important) (Figure 2).

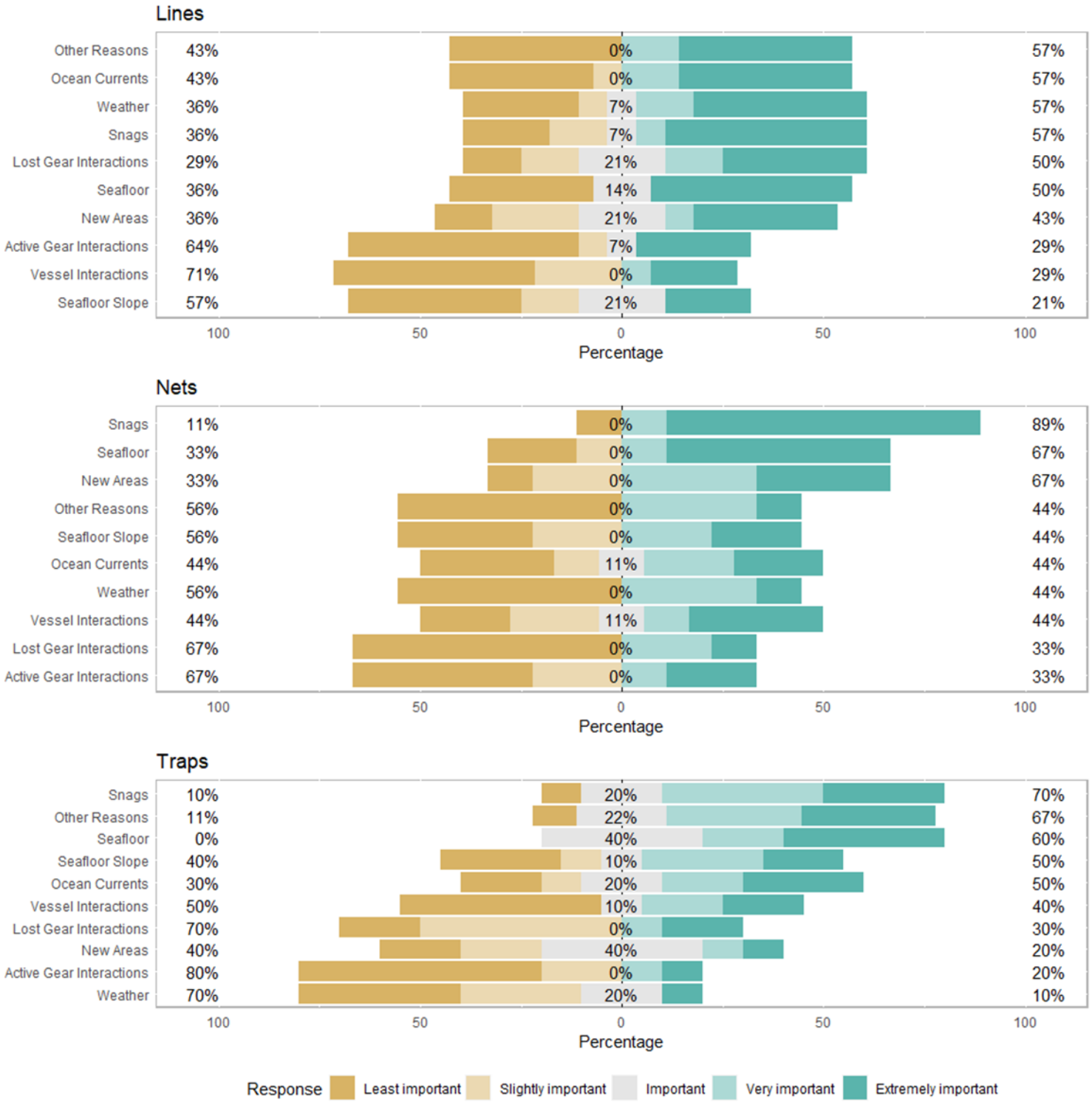

Figure 1. Survey responses (n = 33) for ranking questions, where fishers were asked to rank different reasons for gear loss from least to most important. Results are organized by the gear category of line (n = 14), net (n = 9), and trap (n = 10) fisheries. Percentages of response for least to slightly important (yellow), important (grey), and very to extremely important (teal) are indicated on the left, middle, and right of the plots respectively.

Table 2. Reasons for gear loss, summarized by gear category (lines, nets, traps) as percentage of responses. 'N/A' indicates that a factor was not relevant to the respondent's gear loss experience. Seafloor types are consistent with the categories the Department of Fisheries and Oceans Canada uses in their research.

Reasons for gear loss	**Description**	**Lines (%)**	**Nets (%)**	**Traps (%)**
Seafloor Type (Lines n=20, Nets n=14, Traps n=12)	Corals	20	7	17
	Kelp forest	5	7	0
	Marine debris	5	43	17
	Mixed	10	21	50
	Rocky	10	7	8
	Sponge/glass sponge reefs	5	0	0
	Sandy/muddy	0	7	8
	N/A	45	7	0
Vessel Interactions (Lines n=15, Nets n=11, Traps n=18)	Other fishing vessels	47	55	33
	Shipping vessels	13	0	11
	Tug boats	7	0	17
	Recreational vessels	7	18	22
	Lost crab pots	0	9	0
	Log towing vessels	0	0	6
	Ferries	0	0	6
	N/A	27	18	6
Actively Fishing Gear (Lines n=22, Net n=13, Traps n=15)	Bottom Trawl Nets	23	15	13
	Crab Traps	18	0	20
	Longlines	27	8	0
	Mid-Water Trawl Nets	9	0	0
	Sablefish Traps	5	8	0
	Troll Lines	5	0	7
	Gillnets	0	8	0
	Prawn/Shrimp Traps	0	23	33
	Recreational Traps	0	8	7
	N/A	14	31	20

Lost Fishing Gear (Lines n=22, Nets n=15, Traps n=16)	Bottom Trawl Nets	18	0	6
	Crab Traps	18	20	25
	Longline	45	7	0
	Sablefish Traps	9	0	0
	Gillnets	0	27	0
	Prawn/Shrimp Traps	0	20	50
	Recreational Gear	0	7	13
	Aquaculture Gear	0	0	6
	N/A	9	20	0
Other Reasons (Lines n=15, Nets n=10, Traps n=12)	Large Marine Animals	13	10	0
	Low Experience	7	0	0
	Poor Maintenance	7	10	0
	Storms	7	0	0
	Worn Gear	13	10	8
	Marine Debris	0	10	17
	Crowding	0	0	17
	Illegal Fishing	0	0	8
	Operator Error	0	0	33
	Theft	0	0	8
	Log Booms	0	0	8
	N/A	53	60	0

How can we prevent and reduce gear loss?

Fisher actions

Many fishers (56%) did not have any specific modifications to prevent gear loss or make it easier to retrieve, but those that did indicated that they altered their equipment (48%). Line and trap fishers mentioned the importance of using appropriate gear, such as “heavier gear for deeper water” (anonymous respondent 11). Additionally, net and line fishers indicated the importance of keeping up with gear maintenance, as poorly maintained gear is more likely to break off and become lost while in use. Line and trap fishers reported the importance of ensuring gear quality such as using “strong buoy-lines and proper floats/scotchmen for all weather, tides, and other

vessel traffic" (anonymous respondent 29). A trap fisher also recommended that vessels should keep gear retrieval equipment on board (anonymous respondent 29) so that they are prepared to retrieve their gear after loss. Line and trap fishers also cited some more gear specific modifications, including those that would wear down their gear more slowly and reduce snag frequency with seafloor obstructions. One example from a tuna troll fisher included de-burring the inside of the jigs to reduce wear on the lines.

Most fishers have made changes to how they fish to actively prevent gear loss (61%). Fishers across all categories reported changing their fishing areas to avoid crowding and other vessel traffic, areas with many lost crab traps, areas with a rocky bottom, stormy areas, high tides, fish farm anchors, and log boom and towing operations. Additionally, fishers mentioned relying on bottom mapping technology and their own experience to help them prevent gear loss. One example of a fishing method modification was from a prawn trap fisher (anonymous respondent 1) who suggested using a "breaking strands" method when fishing in high traffic areas. In this method, fishers attach their line to a buoy in such a way that it breaks when another vessel runs over it, preventing the entire line with all of their traps from being dragged to a different location (anonymous respondent 1). The buoys indicate the location of the lines and traps, allowing fishers to find them and then haul the broken halves of the line and retrieve their traps (anonymous respondent 1). Fishers also recommended not setting gear in "high snag areas" (anonymous respondent 1), or areas with many rocky outcroppings or bottom obstructions. Trap fishers reported that their fisheries were encouraging the use of bigger and heavier gear (anonymous respondent 17) that was more difficult to move from its original location to prevent loss. Additionally, one trap fisher suggested that fishing via the "American style" where large traps are set individually would help mitigate gear loss as only one trap would get lost at a time rather than a whole set of traps attached to one long line (anonymous respondent 18). Some fishers changed their fishing methods to adapt to poor winter weather conditions by setting their traps in more protected areas and using less traps over all (anonymous respondent 19).

Industry and management actions

Most fishers did not think there was anything that industry could do to prevent gear loss for any fishery (55%). For example, one fisher expressed: "I don't feel much could be done in Canada. We fish really clean. Gear loss is going to happen. You can't avoid it 100%." (anonymous respondent 29). Conversely, some line and trap fishers believed there were actions industry could take to reduce gear loss (44%), including gear maintenance, and knowledge sharing amongst fishers.

Most fishers (62%), especially those who fished with lines, did not think that there was anything that fisheries management could do to prevent gear loss. However, others (37%) disagreed, indicating that crowding and competition in the fishing grounds could be addressed by management. Line and net fishers suggested that flexible management could help, especially for smaller areas, to reduce crowding (e.g. salmon and herring) and allow fisheries to handle their

own gear loss (e.g. Area A crab). Another fisher recommended that fisheries management reduce crowding and competition by "buy[ing] back the same percentage of fleet as the percentage of [fishing] area taken away for parks" (anonymous respondent 17). Fishers also mentioned the importance of keeping conflicting gear types away from each other in a fishing area (e.g. bottom trawl nets and crab traps) and reducing how much gear each fisher may set (e.g. line and trap gear). Additionally, line and trap fishers thought that reporting lost gear to fisheries management was important. However, one fisher suggested making lost gear reporting more approachable, as many are worried about punishment and older individuals can struggle with online reporting processes. Additionally, some fishers may require more education, especially if it is not yet mandatory in their particular fishery.

During dockside surveys, fishers were eager to share their thoughts on how fisheries management could help prevent lost gear and appreciated being included in the survey, indicating a desire for more participatory approaches to research and management. One fisher advised that "having a group of fishermen together to discuss [what fisheries management/policy could do to prevent gear loss] would get the best answers" (anonymous respondent 23). Additionally, another mentioned that fisheries management may need more education on gear loss. A more collaborative approach between industry and fisheries management could help provide solutions to gear loss in BC.

Where does gear get lost?

During dockside and on-line surveys, fishers indicated various locations of gear loss both verbally or in writing, in addition to the data points they placed on a map of BC's marine environment. These lost gear locations included both full and partial losses of line, net, and trap gear. Trap gear was the most common gear category reported (70 points), followed by lines (36 points), and nets (12 points). One instance of dive gear was reported. The locations generally fell within commercial fishing grounds.

Clusters of lost gear were identified along BC's coastline, particularly at the north and south ends of the Hecate Strait near Haida Gwaii, Clayoquot Sound, and the Strait of Georgia along the east coast of southern Vancouver Island (Fig. 3). Additionally, there were some smaller clusters in the Queen Charlotte and Johnstone Straits along the east coast of northern Vancouver Island. In a few cases, some of the clustering occurred near areas with a higher number of respondents including Prince Rupert (Hecate Strait, Queen Charlotte Sound), Campbell River (Queen Charlotte Strait, Johnstone Strait, Queen Charlotte Sound), and Cowichan Bay and Sidney (Strait of Georgia). Lost trap gear was mostly concentrated around the north east side of Haida Gwaii, in the Charlotte and Johnstone Straits, in Clayoquot Sound, and the Strait of Georgia (Figure 3). Lost line gear was dispersed between the north end of Haida Gwaii, into the Queen Charlotte Sound, and the north end of Vancouver Island. Net gear loss was more sporadic without a discernable pattern (Figure 3).

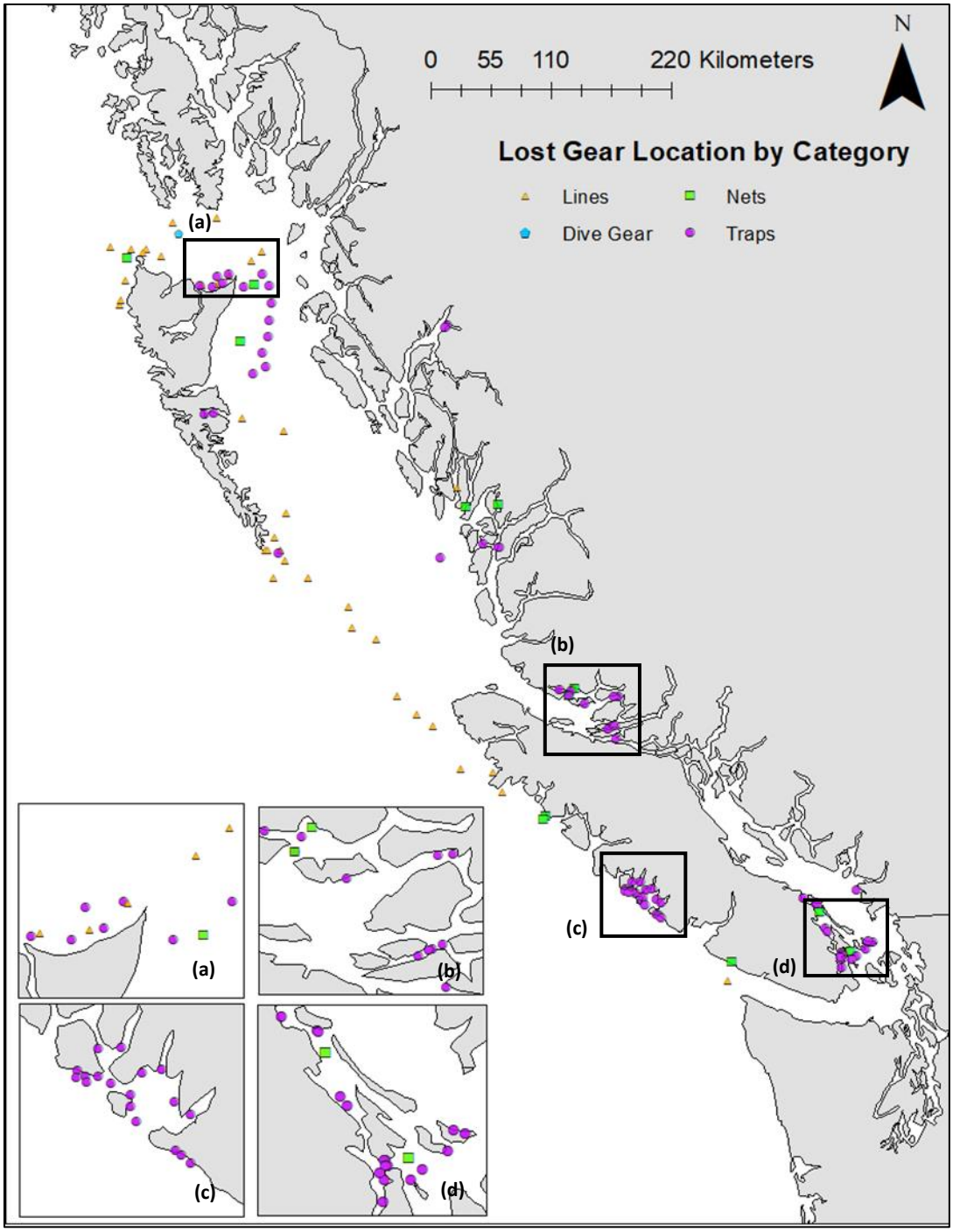

Figure 2. Map of lost commercial fishing gear data points indicated by survey respondents along BC's coast. These points include both locations where respondents have lost their own gear and found others' lost gear. Data points are separated by gear category, indicated by different shapes and colors.

Discussion

Gear loss is attracting attention globally, and regional nuances are important to consider. My global review indicated that the main reasons for gear loss were interactions with other fishing vessels and their gear, marine weather, snagging gear on submerged features were most common (Antonelis, 2012; Richardson et al., 2019, 2018). Reasons for gear loss were similar in my case study in BC, with snagging gear on rough substrate as the main reason, followed by seafloor type. This may indicate that rougher seafloor types (e.g. mixed, rocky, corals etc) are more likely to cause gear loss in Canada's Pacific than other types. Importantly, I found that reasons for gear loss in BC varied by gear type, which was also reflected in the global review (Eadie and Bright, 2021; Natural Resources Consultants, 2012; Richardson et al., 2018). My research corroborated findings reported in the grey literature that summarized fishers' suggestions for minimizing gear loss in BC (Drinkwin et al., 2019; Eadie and Bright, 2021), and on Canada's East Coast (Goodman et al., 2020) , and that pointed to specific areas in BC as hotspots of gear loss (Antonelis and Drinkwin, 2021; Drinkwin et al., 2019; Eadie and Bright, 2021; Paton, 2021).

My findings highlight that reasons for gear loss were specific to the gear category was also reflected in the literature. In particular, for line and net gear, both the literature and my survey indicated that worn out gear and large marine animals were prevalent reasons for gear loss (Antonelis, 2013; Gunarathna et al., 2019; Nitta and Henderson, 1993; NOAA, 2015; Richardson et al., 2021, 2019, 2018). Poorly maintained gear may break more easily if it encounters difficult environmental conditions, such as bottom obstructions, and is therefore more likely to become lost (NOAA, 2015; Richardson et al., 2018). In a recent global fisher survey, 65% of all respondents mentioned that wildlife interactions were the second most common reason for gear loss (Richardson et al., 2021). This is especially concerning in BC, as various marine animals have been observed interacting with actively fishing gear (e.g whales, pinnipeds), which could lead to their entanglement and fishers' subsequent gear loss (NOAA, 2015; Williams et al., 2011). Additionally, some whale (e.g. humpback, grey) and pinniped populations have increased in recent years, leading to increased risk of their entanglement on commercial fishing grounds. Additionally, my survey indicates that fishers who used line gear experienced gear loss due to entanglement with previously lost gear, which has also been reported in previous fisher engagement in BC (Eadie and Bright, 2021; personal communication with Megan Eadie). Trap fishers surveyed indicated that they lost their gear due to operator error, crowding on the fishing grounds, and ocean currents, which has also been well documented in the global literature (Antonelis, 2013; Bilkovic, 2016; Macfadyen et al., 2009; Natural Resources Consultants, 2012; Richardson et al., 2019, 2018). Overcrowding can create conflicts between fishing vessels and gear, encourage fishers to take more risks, and push fishers into different areas that they typically would not fish in, further resulting in gear loss (Macfadyen et al., 2009; Richardson et al., 2018).

Some reasons for gear loss reported by other studies were found to be unimportant in BC, indicating the value of researching regional gear loss factors. For example, interactions with

other actively fishing gear and non-fishing vessels did not appear to be important gear loss factors for survey participants despite evidence from other fisheries around the world (Antonelis, 2013; Erzini et al., 1997; Global Ghost Gear Initiative, 2021) and in Canada (Drinkwin et al., 2019; Eadie and Bright, 2021; Goodman, 2020). In BC, fisheries management has separated some industries with active (e.g. bottom trawl) and passive (e.g. trap, longline etc) gear spatially and temporally to prevent conflict. Additionally, some fishers with conflicting gear types, for example traps that fish passively and bottom trawls that fish actively on the seafloor, try to communicate well to ensure awareness of where and how much gear is being set and hauled, especially in difficult environments. There have also been instances of BC fishers collaborating with other marine industries to prevent other vessels from disrupting or damaging their gear. For example, crab fishers from Area A along BC's north coast collaborated with BC ferries to create a specific ferry lane that fishers are prohibited from working in to prevent trap loss caused by the ferries (Paton, 2021). However, that these gear loss factors did not appear in our results may be due to our small sample size. Most fishers surveyed were from the halibut longline and prawn trap fisheries, and it is possible that we did not survey those who worked in areas affected by gear conflict and non-fishing vessels.

The small sample size was a limitation of this study, encountered due to extensive fishing closures and the COVID-19 pandemic. The 2021 season was closed for almost 60% of the commercial salmon fishery. Thus, when I arrived in Port Alberni for instance (a major salmon fishing port), there were no fishers on the docks despite many vessels being tied up there. The pandemic delayed the start of the survey as I waited for the university to provide permission to conduct in-person research. I began data collection in the fall, and might have missed some fisheries that are active during the summer (e.g. groundfish trawl, crab trap). Furthermore, some fishers we approached at the dock did not wish to participate in the survey for a variety of reasons, including that their gear types did not get lost very easily. This was a common response for salmon fishers.

This study further emphasizes the need for more participatory approaches to resolve lost fishing gear issues in BC, and more education. The fishers who participated in our survey were eager to share their knowledge and experiences around lost gear, expressing a desire to collaborate with each other and fisheries management to find solutions. Involving fishers, management, and other marine stakeholders in lost fishing gear projects has been successful in both Canada and the US, leading to the removal of thousands of pounds of derelict gear while employing fishers during seasonal closures (Armstrong et al., 2016; Eadie, 2022a, 2022b; Eadie, 2022; Havens et al., 2011; Paton, 2021). BC fishers have a wealth of knowledge and experience, and encouraging their involvement in lost gear projects will allow for effective research on prevention and mitigation strategies. Furthermore, fishers in this and other surveys continually emphasized the importance of proper gear maintenance as a way to prevent gear loss (Richardson et al., 2021). As more experienced fishers age out of BC's industry, it is important to ensure new and less experienced fishers are trained in the appropriate tools, technologies, and gear management practices for local fishing conditions (Richardson et al., 2018). Fishers, management, and NGOs could collaborate on gear management education initiatives to ensure all members of BC's commercial fleet are working with the current best practices.

Fishers expressed a desire for more education around gear reporting, and for management to make it more approachable. Gear reporting and management materials should be translated into other languages common amongst BC's commercial fleet, such as Vietnamese, to ensure full compliance. Currently, DFO's lost gear reporting system relies on email, which may not be accessible to all commercial fishers due to poor internet access and the fact that older fishers, who make up most of the fleet, are generally uncomfortable using technology (Goodman, 2020). Recent work in Canada's East Coast fisheries recommended adding an automated phone line to DFO's reporting system, where fishers can leave voicemails or text messages, as a possible solution (Goodman, 2020). For younger fishers who are more technology savvy, adding gear loss reporting to electronic fishing log book (e-logs) systems would also increase usability (Goodman, 2020). Sections for gear loss reporting were added to e-logs and paper logs for BC's commercial groundfish hook and line fisheries in early 2020; it is important to add these sections to log books for other Pacific Region fisheries if they have not already been implemented. It is also important for DFO to be clear on whether or not any punitive action will be taken. Many BC fishers are concerned about punishment for losing their gear or having retrieved others' derelict gear. It is important for DFO to emphasize the importance of reporting this information and be transparent on how it will be used.

Gear loss is an important global issue with regional variations. My study highlighted the importance of working with fishers to not only identify drivers of gear loss, but also to develop solutions for minimizing and tracking gear loss. Combatting lost fishing gear is solution to reduce marine plastic pollution and ensure fisheries sustainability. Therefore, it is important for regions to understand why and where commercial fishing gear becomes lost in order to prevent and mitigate further marine environmental harm.

Chapter 3 : Predicting factors of fishing gear loss and distribution across Canada's Pacific Ocean

Introduction

Abandoned, lost, or otherwise discarded fishing gear comprises a large part of marine plastic pollution and is detrimental globally to marine wildlife, habitats, and fishing industries (Antonelis, 2013; Gilman, 2015; Global Ghost Gear Initiative, 2021; Good et al., 2010). One of the most adverse impacts of derelict gear is ghost fishing, where gear continues to ensnare marine animals long after its initial loss (Antonelis et al., 2018a; Dameron et al., 2007; Donohue and Foley, 2007; Erzini et al., 1997). In fact, up to 79% of marine animals caught in derelict gear are harmed or killed globally (World Animal Protection, 2018). One study in Oman estimated that up to 90% of species that fall victim to ghost fishing are commercially valuable (Al-Masroori et al., 2004), which cause negative effects to commercial fishing stocks and revenues globally (Bilkovic, 2016; Erzini et al., 1997; Gilman, 2015). For example, ghost fishing in Washington state (USA) was estimated to cause a 4.5% loss of Dungeness crab stocks annually, leading to revenue losses of $744,000 per year (Antonelis et al., 2011). Additionally, derelict gear can severely damage marine habitats by breaking, entangling, and smothering habitat forming species (e.g. corals, sponges, eelgrass), or by scouring and disrupting the benthos (Du Preez et al., 2020; June and Antonelis, 2009; Macfadyen et al., 2009; NOAA, 2015). As these biogenic habitats are vital in supporting diverse marine communities, damage caused by derelict gear could potentially reduce biodiversity in these areas, further harming commercial fish stocks (Bilkovic, 2016; Erzini et al., 1997; Gilman, 2015). Despite an understanding of the harms caused by derelict gear, little is known about where it accumulates in the oceans, making it a difficult problem to mitigate.

Derelict gear has become a globally recognized marine issue, garnering more attention from scientists and resources managers as countries aim to reduce sources of marine plastic pollution (Global Ghost Gear Initiative, 2021; World Animal Protection, 2018). Canada is illustrative of the recent focus on derelict gear related issues given concern about impacts to economically important fisheries (Fisheries and Oceans Canada, 2022a). In 2018, Canada joined the Global Ghost Gear Initiative (GGGI), a multi-stakeholder alliance tackling derelict gear issues worldwide, prioritizing derelict gear related research and removal projects through several funding initiatives (Government of Canada, 2020). While it is critical to identify prevention methods for gear loss relevant to regional fishing practices across Canada, removal of existing derelict gear is required to mitigate ongoing impacts (Bilkovic and Slacum, 2016; Gilardi et al., 2010; June and Antonelis, 2009; Scheld et al., 2021, 2016; Uhrin and Schellinger, 2011). Generally, marine and coastal habitats have benefited from targeted gear removal programs (Arthur et al., 2014). Habitat forming species such as eelgrass, kelp, seaweeds, hydroids, and cordgrass can show 30% to 100% recovery within a year after derelict gear is removed (June and Antonelis, 2009; Uhrin and Schellinger, 2011). Additionally, derelict gear removal can be more cost effective than the incurring monetary losses experienced by commercial fisheries due to

ghost fishing (Antonelis et al., 2011; Gilardi et al., 2010; Scheld et al., 2016). For example, removing over 34,000 derelict crab pots in Chesapeake Bay, Virginia (USA) increased commercial blue crab harvest by 27% while employing fishers during their off-season, allowing fishers to increase their revenue in both fishing and non-fishing seasons (Scheld et al., 2016). This result was applied to make a global estimate that fishing industries worldwide could gain up to $831 million USD in landings by removing less than 10% of derelict traps from large shellfish fisheries (Scheld et al., 2016). Despite the benefits of gear removal, it is notoriously difficult and expensive work that requires specialized training and equipment, large vessels, and fuel. Considering the expense of this work, derelict gear removal programs must have a good understanding of which marine areas to target in order to be as efficient as possible.

There is limited information regarding derelict gear locations, and spatial models can be effective tools to fill knowledge gaps. Many countries, including Canada, have only recently begun recording locations of gear loss (e.g., see "GGGI Data Portal," n.d.; Government of Canada, 2019). Such presence-only data – which is typically what is available for derelict gear – can be used to predict marine areas with high probabilities of derelict gear occurrence (Antonelis, 2013; Donohue and Foley, 2007; Martens and Huntington, 2012). For example, a simple linear additive model was created for Puget Sound in Washington State (USA) using gear removal data, variance in seafloor depth, bathymetry, and fishing effort to predict areas with various probabilities of salmon gillnet loss to target future removal efforts (Antonelis, 2013). In Biscayne National Park, Florida (USA), a GIS approach was used on benthic habitat and bathymetric attributes of derelict lobster trap removal locations to create hot spot maps indicating target sites for future removal efforts (Martens and Huntington, 2012). These outputs can help direct removal efforts to focus on areas with high probabilities or densities of derelict gear occurrence and therefore a higher likelihood of finding it.

Developing accurate models to identify likely locations of derelict gear requires information regarding reasons why the gear was originally lost. According to the literature (see Chapter 2), the most common reasons for gear loss globally include: interactions with other vessels and fishing gear (Antonelis, 2012; Swarbrick and Arkley, 2002), snagging gear on submerged features (Antonelis, 2013; Richardson et al., 2021; Santos et al., 2003), poor marine weather (Bilkovic, 2016; MacMullen et al., 2002; Richardson et al., 2018), fishing equipment malfunction and poor gear condition (Gilman, 2015; Goodman, 2020; Hareide et al., 2005), interactions with non-fishing vessels (Ayaz et al., 2010; Drinkwin et al., 2019), strong ocean currents (Natural Resources Consultants, 2012; NOAA, 2015), deliberate disposal at-sea (Global Ghost Gear Initiative, 2021; Santos et al., 2003), depth (Antonelis, 2013; MacMullen et al., 2002), large gear or large amounts of gear (Antonelis, 2013; Hareide et al., 2005), interactions with marine wildlife (Gunarathna et al., 2019; Richardson et al., 2021), vandalism and theft (Ayaz et al., 2010; Swarbrick and Arkley, 2002), lack of fisher experience or training (Goodman, 2020; Richardson et al., 2018), and operator error (Antonelis, 2013, 2012). These reasons for gear loss can vary regionally based on different fisheries and the local geographies where they take place. While not all of the aforementioned gear loss reasons can be quantified and analyzed spatially, those that can could help predict where lost gear is present, therefore reducing the potential search areas for removal efforts.

In this research I explore a new method of predicting marine areas with high probabilities of derelict gear using a species distribution model (SDM) approach, using Canada's Pacific Ocean as a case study. SDMs are typically used in ecology and conservation to predict areas of potential species occurrence based on their environmental requirements (Franklin, 1995; Guisan et al., 2017; Lecours, 2019). SDMs are especially useful when observation data are limited. As derelict gear presence data is becoming increasingly available via the GGGI's data portal and local gear retrieval organizations, SDM methods may offer more detailed insights on important reasons for gear loss and predictions of derelict gear locations. I applied the SDM concept to identify important variables in derelict gear occurrence and create spatial predictions across the Pacific Region of Canada.

Methods

I focused this study on Canada's Pacific Ocean (Figure 1), where Fisheries and Oceans Canada (DFO) has issued over 6,000 commercial fishing licenses to over 2,000 registered vessels (Government of Canada, 2016). Fisheries currently target many species including Pacific salmon, herring, crab, shrimp, and a variety of groundfish and shellfish, with an array of commercial gear types falling under the three broader categories of lines, nets, and traps. Derelict gear is a great concern in this region, and efforts are underway by organizations such as the T.Buck Suzuki Foundation to retrieve gear. One grey literature predictive modeling exercise exists in the region, but it was based on limited data: Antonelis and Drinkwin (2021) created linear additive models for salmon and herring fisheries based on a small number of derelict fishing net data points (n = 20). They used a geographically weighted regression models for the shellfish and groundfish fisheries based on summarized derelict gear polygons drawn by fishers at workshops. As these models are based on regionally relevant reasons for gear loss, outputs can inform removal efforts and assist marine stakeholders and management in addressing derelict gear related issues (Antonelis and Drinkwin, 2021). However, to ensure a more accurate depiction of gear loss Canada's Pacific Ocean, spatial models should be updated with as much derelict gear presence location data as possible.

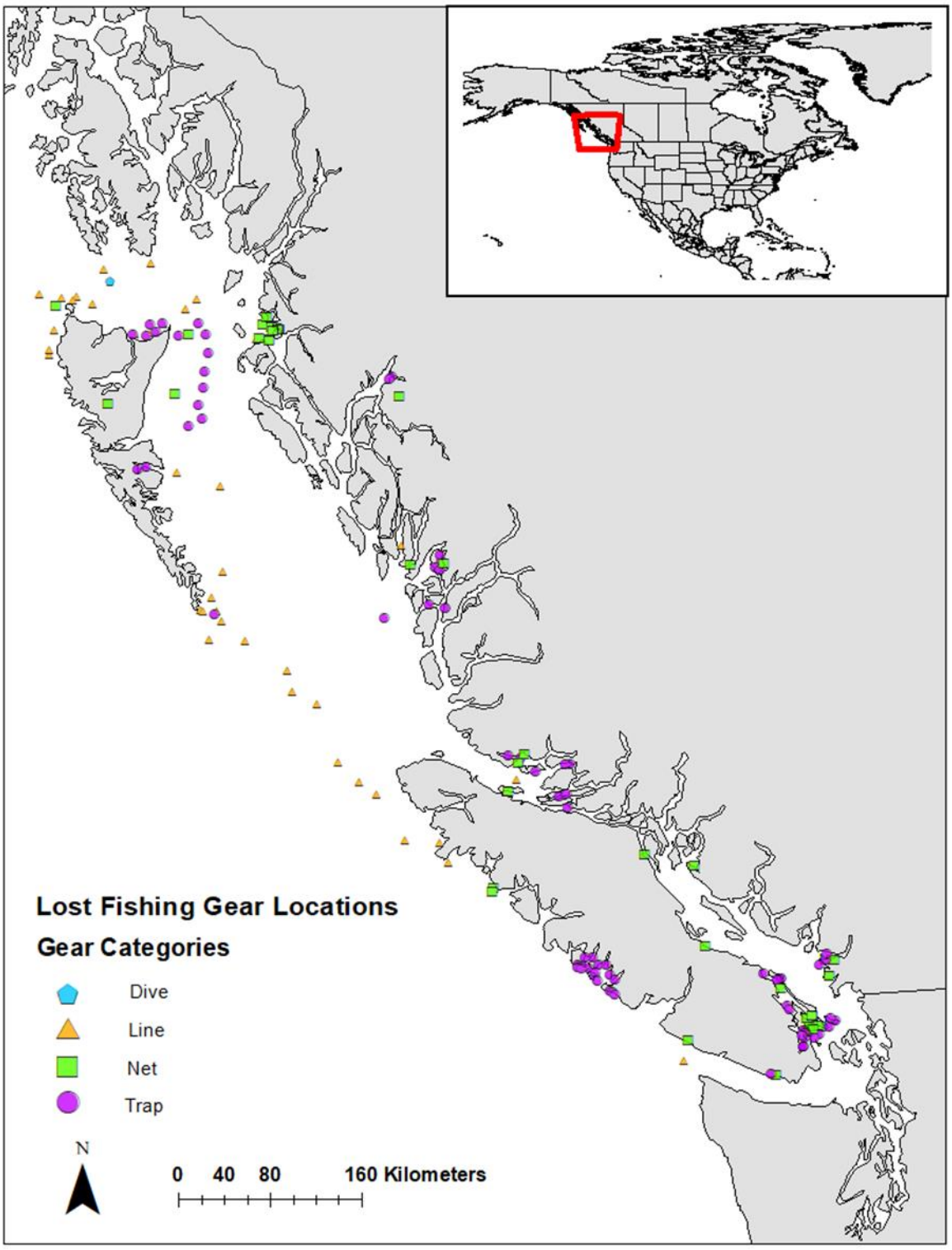

Figure 1. Map of the study area, the Pacific region of Canada, depicting locations of lost gear by gear categories. Lost gear data points are from the commercial fisher survey, Natural Resources Consultants, and the Global Ghost Gear Initiative.

I collated the best available data for gear loss reasons (and spatial data to depict those reasons) that were mentioned in the literature and by our previous survey of commercial fishers in Canada's Pacific Ocean (see Chapter 2). Specifically, I obtained spatial environmental layers for bathymetry (Kung, 2021), rocky substrate (Fields & Nephin, 2020), mixed substrate (Fields & Nephins, 2020), wind speed (Global Wind Atlas 3.2, 2022), tidal current speed (Foreman, 2010), and fishing effort (Iacarella et al., 2023) for the study area from a variety of sources (Table 1, Supplementary Fig. 1). All data layers were continuous. As rocky and mixed substrate are similar, and issues fishers encounter relate to snagging gear on rough substrate, we combined these two layers to create one layer for rough substrate. I amalgamated lost gear presence data for the study area from various sources including from our previous survey (Chapter 2), the Global Ghost Gear Initiative's Data Portal, and Natural Resources Consultants (personal communication), resulting in 242 total data points of lost gear locations (Fig. 1). These lost gear presence points consisted of mainly longline, prawn trap, gill and seine net gear types (Fig. 1). I used ESRI's ArcMap (Version 10.8.1; ESRI, 2020) to convert tidal current speed data to raster format via inverse distance weighted interpolation and used R (V 2.0.4; R Studio Team 2022) to convert all raster data into 1km-by-1km grid cell resolution (Hijmans, 2022).

I randomly selected 3900 pseudo-absence points because having 16x as many pseudo-absence points as presence points is recommended for optimal modelling (Liu et al., 2019). I removed outliers, determined as any lost gear occurrence points associated with an environmental variable with a value 4x higher than the average data point when plotted. I also removed any lost gear occurrence points that were on land. This resulted in a final total of 202 lost gear presences and 3691 pseudo-absences.

I used a Generalized Additive Model (GAM) with a binomial distribution to fit non-linear relationships, which is a common method for SDMs (Baquero et al., 2021; Valavi et al., 2022) with excellent variable selection ability (Wenger and Olden, 2012). I built a global model that included the following smoothed terms: bathymetry, fishing effort, rough substrate, wind speed, current speed, the interaction between fishing effort and rough substrate, and the interaction between fishing effort and bathymetry (mgcv package in R; Wood, 2017; Table 1). I used backwards stepwise elimination to find the most parsimonious model. I compared nested models using ANOVA chi-squared tests, model summaries, and the difference in AICc (bbmle package in R, Bolker, 2012; MuMIn in R Bartoń, 2022) to determine the top models (Table 2). I focused our results and projections using the simplest model with the lowest AICc score (Table 2).

I calculated the Area Under the Receiver Operator Curve (AUC) of the top model to assess how effective the GAM was at predicting lost gear presence in the study area (pROC package in R; Robin et al., 2011; Shabani et al., 2018). AUC is a metric that describes the diagnostic accuracy of a model, where a value of 0 indicates an entirely inaccurate prediction, 0.5 indicates the model performs no better than chance, and 1 suggests that the model predicts perfectly (Mandrekar, 2010). I created GAM partial plots to illustrate how each variable affected the presence of lost gear while holding other variables at their mean value ('mgcv' package in R; Wood, 2017). I used our final GAM to project across the study extent ('raster' package in R;

Hijmans, 2022), allowing us to visualize where lost commercial fishing gear may occur in Canada's Pacific Ocean.

Table 1. Reasoning for including variables and interactions in the GAM and data information for each variable.

Variable or Interaction	Reasoning	References	Unit	Data Source
Bathymetry	Fishing gear can become lost when the seafloor becomes shallow very suddenly, such as a rocky pinnacle; this has been observed in Puget Sound. Conversely, some fishers may lose their gear in deep water environments.	MacMullen et al., 2003 Hareide et al., 2005 Antonelis, 2013 NOAA, 2015 Goodman, 2020	m	Kung, 2021
Fishing Effort	Fishing effort is a measure of resources used to harvest in a fishery, and could be measured in the number of fishing vessels, number of fishing hours, amount of gear deployed etc. Increasing these factors in an area could lead to a fishing vessel's gear coming into contact with another's, causing it to become dislodged or damaged & therefore lost. This could look like overcrowding on fishing ground, poor communication about location of set gear, theft & other conflict.	Swarbrick & Arkley, 2002 MacMullen et al., 2003 Santos et al., 2003 Hareide et al., 2005 Ayaz et al., 2010 Antonelis, 2012 Antonelis, 2013 NOAA, 2015 Richardson et al., 2018 Drinkwin, 2019 Richardson et al., 2019 Eadie & Bright, 2020 Goodman, 2020 Richardson et al., 2021 Global Ghost Gear Initiative, 2021	Total hours actively fishing between 2012 – 2019	Iacarella et al., 2023
Rocky Substrate	Rocky substrate was the second most common substrate type that fishers reported causing gear loss in Lost Gear Survey. This will be combined with mixed substrate as a proxy	Breen, 1990 Macmullen et al., 2003 Santos et al., 2003 Hareide et al., 2005 Ayaz at al., 2010 Antonelis, 2012 Antonelis, 2013 NOAA, 2015 Richardson, 2018	Ratio of cell coverage from 0 - 1	Fields & Nephin, 2020

	for gear getting caught on rough surfaces on the seafloor. This is common in gear types that come into contact with the seafloor while fishing (e.g. bottom trawl nets, bottom long lines, traps)	Richardson, 2019 Goodman, 2020 Eadie & Bright, 2020 Richardson, et al. 2021 Global Ghost Gear Initiative, 2021		
Mixed Substrate	Mixed substrate was the most common bottom type that fishers reported causing gear loss in the Lost Gear Survey. Consists of a mixture of hard and soft substrate type (e.g. soft sediments with patchy distribution of cobbles and/or boulders, soft sediments distributed over bedrock patches) as classified by Greger et al. 2013. This will be combined with mixed substrate as a proxy for gear getting caught on rough surfaces on the seafloor. This is common in gear types that come into contact with the seafloor while fishing (e.g. bottom trawl nets, bottom long lines, traps)	Breen, 1990 Macmullen et al., 2003 Santos et al., 2003 Hareide et al., 2005 Ayaz at al., 2010 Antonelis, 2012 Antonelis, 2013 NOAA, 2015 Richardson, 2018 Richardson, 2019 Goodman, 2020 Eadie & Bright, 2020 Richardson, et al. 2021 Global Ghost Gear Initiative, 2021	Ratio of cell coverage from 0 - 1	Fields & Nephin, 2020
Wind Speed	This will be used as a proxy for rough marine weather, as poor weather conditions make fishing difficult. High winds could cause gear loss by blowing unsecured gear off of the vessel, increase the difficulty of properly setting or hauling gear, or blow the gear from its original set location. This is fishery dependent, but	Swarbrick & Arkley, 2002 Macmullen et al., 2003 Santos et al., 2003 Hareide et al., 2005 Ayaz et al., 2010 NOAA, 2015 Bilkovic et al., 2016 Richardson et al., 2018 Drinkwin et al., 2019 Gunarathna et al., 2019 Richardson et al., 2019 Eadie & Bright, 2020 Goodman, 2020	Measured in m/s 10m above sea level	Global Wind Atlas 3.2, 2022

	for example in BC wind speed above 13 m/s and 18 m/s are considered strong for the prawn trap and halibut/lingcod longline fisheries respectively.	Richardson et al., 2021 Global Ghost Gear Initiative, 2021		
Tidal Current Speed	Strong currents can increase the difficulty of setting and hauling gear, in addition to moving gear from its original location, both of which can result in gear loss. This has been shown to cause loss of traps in both Puget Sound & BC (Natural Resources Consultants & BC Lost Gear Survey). This is fishery dependent, but for example in BC anything above 3 knots is considered a strong current speed for the prawn trap and halibut/lingcod longline fisheries (personal communication).	Macmullen et al., 2003 Bilkovic et al., 2016 NOAA, 2015 Natural Resources Consultants, 2012	m/s	Foreman, 2010
Fishing Effort : Rough Substrate	Snagging on rough ground beneath the surface and rocky bottoms were one of the leading reasons for gear loss reported in the BC Lost Gear Survey. Fishers also reported concerns about overcrowding. The more time fishers spend in rocky areas could lead to increased risk of gear loss due to the combination of overcrowding and problematic seafloor conditions. This interaction is important to include separately in the model as it has not been modelled before.	Chapter 2	-	-

Fishing Effort : Bathymetry	Fishing gear may become lost in areas that become shallow very suddenly, as has been observed in Puget Sound. It is possible that gear loss due to depth could happen more frequently in areas that are more heavily fished. This interaction is important to include in the model to assess its effect in Canada's Pacific Ocean, as some areas have a similar geography to Puget Sound.	Antonelis, 2013	-	-

Results

My best fit model consisted of the following smoothed terms: bathymetry (p-value < 0.001, edf = 5.01), fishing effort (p-value < 0.001, edf = 6.45), and wind speed (p-value < 0.001, edf = 7.00). The second-best fit model also included the smoothed rough substrate term, but it was not significant (p-value = 0.14, edf = 1) (see Table 2, which shows the top models within 10 AICc of each other). All terms within the top model show non-linear relationships with lost gear presence (Fig. 2). Specifically, lost gear presence increased slightly as the seafloor became shallower, leveling off around 1400m below sea level (Fig. 2a). Lost gear presence generally increased with fishing effort until approximately 7.5 total hours between 2012 and 2019 before declining and increasing again at 11 hours (Fig. 2b). This relationship between lost gear location and fishing effort could indicate fisher behaviour as they may be moving to different fishing areas to try to avoid crowding. In terms of wind speed, lost gear presence increased steadily between 0 – 4 m/s (0 – 8 knots), before declining sharply and increasing slightly around 5.5 m/s (11 knots) (Fig. 2c). This relationship between lost gear location and wind speed may also indicate some aspects of fisher behaviour, where fishers are trying not to fish in very windy areas. Confidence intervals were wider for all modeled terms in areas where there were fewer lost gear data points, indicating less predictive power for higher depths, higher levels of fishing effort, and stronger winds (Fig. 2).

The adjusted r-squared was low (0.219) for our top model. Additionally, the deviance explained for our top model was low, indicating that it only explains 31.4% of the variability in our dataset.

Generally, my model predicted the highest probability of lost commercial fishing gear occurrence along the coastlines of mainland British Columbia (BC), Vancouver Island, and Haida Gwaii (Fig. 3). Areas with the highest probability of lost gear occurrence included: the Strait of Georgia near the south-east end of Vancouver Island and the Southern Gulf Islands, the west coast of Vancouver Island in Barkley and Clayoquot Sounds, Hecate Strait near the north-east tip of Haida Gwaii, and along the north-east coast of Vancouver Island in the Queen Charlotte Strait (Fig. 3). Generally, more open water areas further away from BC's coastline were predicted to have the lowest probability of lost commercial fishing gear occurrence (Fig. 3).

The AUC score fell within the higher end of the acceptable range of 0.7 – 0.8 (Mandrekar, 2010) with a value of 0.79. Generally, AUC values of 0.5 or less are considered no better than random change, while values closer to 1 increase in their predictive capacity (Mandrekar, 2010).

Table 2. Top models determined by backwards stepwise elimination and ranked by AICc. The presented models are all within 10 AICc of each other and the best fit model has the lowest AICc score. s indicates smoother used on a singular term, while ti indicates a smoother used on interacting terms.

Model	AICc	dAICc	df
1. status ~ s(bathymetry) + s(fishing effort) + s(wind speed)	351.47	0.0	11.9
2. status ~ s(bathymetry) + s(fishing effort) + s(rough substrate) + s(wind speed)	353.25	1.8	13.1
3. status ~ s(bathymetry) + s(wind speed)	354.96	3.5	10.6
4. status ~ s(bathymetry) + s(fishing effort) + s(rough substrate) + s(wind speed) + s(current speed)	355.28	3.8	14.7
5. status ~ s(bathymetry) + s(fishing effort) + s(rough substrate) + s(wind speed) + s(current speed) + ti(fishing effort, rough substrate) + ti(fishing effort, bathymetry)	355.30	3.8	19.2
6. status ~ s(bathymetry) + s(fishing effort) + s(rough substrate) + s(wind speed) + s(current speed) + ti(fishing effort, rough substrate)	355.86	4.4	18.3

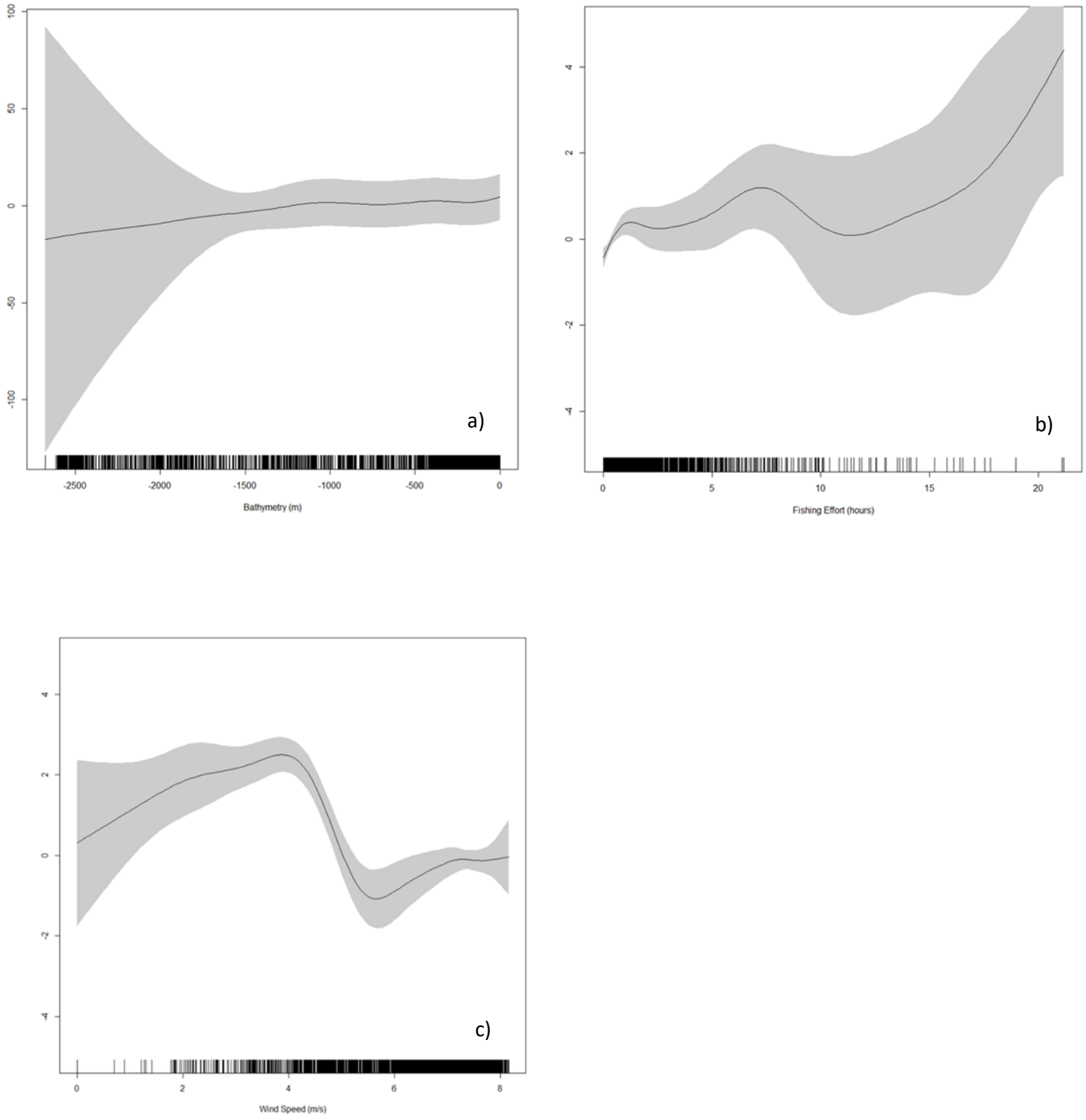

Figure 2. Smoothed fits of GAM covariates: a) bathymetry (m), b) fishing effort (hours), and c) wind speed (m/s). 95% confidence intervals are indicated by grey shading, and observed data points are indicates by rug marks along the x-axis.

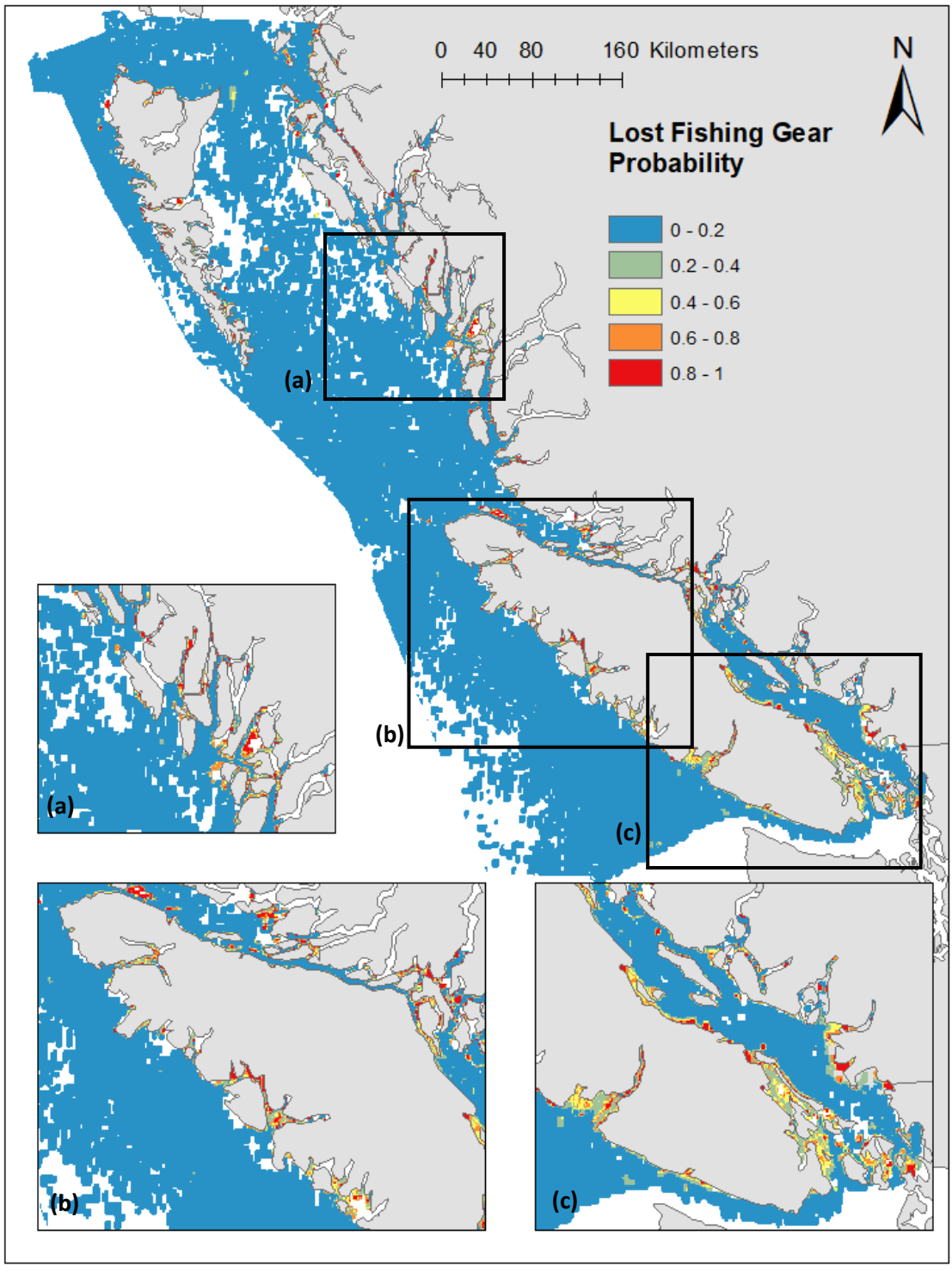

Figure 3. GAM probability predictions of lost gear occurrence in Canada's Pacific Ocean. Areas of dark red indicate high probability of lost gear occurrence, while areas of blue indicate low probability. White areas indicate no data.

Discussion

My study has shown that SDMs have potential to predict areas of lost commercial fishing gear presence in Canada's Pacific Ocean. SDMs are valuable tools in ecological and conservation fields, and researchers are finding novel ways to apply them to anthropogenic marine impacts. For example, SDMs have recently been used to predict commercial and recreational fisher distribution in response to newly added marine protected areas in California (Zellmer et al., 2018). All terms in our top model of Canada's Pacific Ocean (bathymetry, fishing effort, and wind speed) are well substantiated by the global literature as common reasons for gear loss (Antonelis, 2013; Gunarathna et al., 2019; MacMullen et al., 2002; Richardson et al., 2021, 2018). Additionally, the areas predicted to have the highest probability of lost gear occurrence are reflected in recent grey literature in the study area (Antonelis and Drinkwin, 2021). As the issue of lost fishing gear continues to gain the global attention of researchers, fisheries management, and governments more data will become available to further improve predictive modelling methods. This will help mitigate derelict gear issues by being able to efficiently direct gear removal efforts and help make decisions to prevent future gear loss.

Generally, the relationships between lost fishing gear location and the gear loss variables of bathymetry, fishing effort, and wind speed reflect the global literature (Antonelis, 2013; Gunarathna et al., 2019; MacMullen et al., 2002; Richardson et al., 2021, 2018). I found that lost fishing gear presence increases as ocean depth becomes shallower, similar to the relationship between derelict gillnets and depth in Puget Sound, Washington State (WA), USA (Antonelis, 2013). While my model indicates that there is an increase in lost gear presence with shallower depth, this relationship does level off around 1400m depth. However, most lost gear presence data was between 0 to 500m depth with very few between 1750 to 2500m depth. Research has shown that commercial nets fishing in depths over 500m are likely to become lost due to excessive length, long soak times, and cumulative gear stress (Antonelis, 2013; Hareide et al., 2005). Depending on the target species, commercial fishers may set their gear between 40 to 1000m depth. Unlike similar salmon fisheries in WA, DFO has smaller gillnet size restrictions in Canada, such that the depth (dimension from the top to the bottom of the net) ranges from 6.4 to 12.2m depending on the species in the Pacific Ocean (Fisheries and Oceans Canada, 2022a, 2022b, n.d.). These gear restrictions may reduce the likelihood of Canadian commercial fishers catching, and potentially losing, their gear on shallow areas (Antonelis, 2013). Additionally, the commercial crab trap fishery in Canada's Pacific Ocean has some fishing depth restrictions and gear modifications depending on the area to prevent conflict with other gear types (Fisheries and Oceans Canada, 2022d).

Fishing effort was the most common reason for gear loss in a recent literature review (see Chapter 2), as higher numbers of vessels and time spent in a fishing area could increase the risk for gear loss. Commercial fishers surveyed in British Columbia mentioned that overcrowding on the fishing grounds was a common reason for gear loss, especially for those who fish with traps (see Chapter 2). An increase in fishing effort in an area could lead to a higher likelihood of fishing vessels interacting with others' gear, causing subsequent loss (Richardson et al., 2018).

This is especially problematic in areas where multiple gear types are in use, such as sablefish traps and longlines interacting off the west coast of Haida Gwaii in BC (Eadie and Bright, 2021), and trawl gear coming in contact with gillnet and seine nets in Australia and Indonesia (Richardson et al., 2018). Additionally, even in fishing grounds with one primary gear type it is possible for fishers to accidentally set their gear too close to, or on top of, another's causing snarls and subsequent gear loss (Goodman, 2020). High levels of fishing effort in an area can lead to overcrowding, driving fishers to harvest in riskier areas that they would not work in otherwise (Richardson et al., 2018). When surveyed, many fishers in BC mentioned moving to different fishing areas to avoid overcrowding and suggested that Canadian fisheries management address this issue to reduce future gear loss (see Chapter 2). Addressing overcrowding, and therefore high levels of fishing effort, has also been suggested by a study with Australian and Indonesian fishers (Richardson et al., 2018).

Bad weather was identified as the second most common reason for commercial fishing gear loss in the global literature (see Chapter 2), and the most common reason in a global study (Richardson et al., 2021). Wind speed is an important aspect of bad weather events, as high winds can blow improperly secured fishing gear off of vessel decks and increase the difficulty of hauling or setting gear (Drinkwin et al., 2019; Eadie and Bright, 2021). My model indicated that gear loss generally increased with wind speed up to 4 m/s before decreasing (Fig. 3). A local BC fisher who harvests with trap and longline gear mentioned that fishing in winds over 13 m/s was very difficult (personal communication, anonymous). While this wind speed threshold is higher than indicated by the model, it is possible that fishers in the study area were opting out of harvesting in high wind conditions, which was further substantiated by the BC fisher survey (see Chapter 2). However, depending on the fishery type and area, fishers may still have to work in windy conditions. For example, Hecate Strait is known to experience high winds and rough weather more often compared to other areas of Canada's Pacific Ocean, so fishers who primarily work there may not be able to opt out of harvesting during bad weather. The fisher survey from Chapter 2 indicated many lost gear location points in Hecate Strait, however the model did not highlight this area has having a high probability of gear loss which may be due to differences in scale between the two methods.

Contrary to my predictions, rough substrate was not included in our top model, as snagging on rough seafloor consistently comes up in the literature as one of the most important reasons for gear loss (Antonelis, 2013, 2012; Eadie and Bright, 2021; Richardson et al., 2021, 2019, 2018). Additionally, this was the most common reason for BC commercial fishers' gear loss in a recent survey across all gear categories (see Chapter 2). The second-best model included rough substrate, though it did not have a significant effect on gear loss. It is possible that this variable does play a role in lost gear presence in the study area, but may be important for gear types that actively interact with the seafloor, such as bottom trawl nets. I modelled all gear types together, as we did not have enough data to separate out the presence points by gear type. Our lost gear data was primarily made up of longline, prawn trap, gillnets, and seine nets so it is possible that rough substrate would have been included if gear types such as bottom trawl nets and crab traps were included.

My model predicted the highest probability of lost commercial fishing gear occurrence along the coastline of BC, Vancouver Island, the Southern Gulf Islands, and Haida Gwaii (Fig. 3). These areas have been noted in previous modelling (Antonelis, 2013; Antonelis and Drinkwin, 2021), regional workshops (Eadie and Bright, 2021), and in the BC Lost Gear Survey (see Chapter 2). My results are consistent with the fact that much of the small-scale commercial fishing in Canada's Pacific Ocean takes place near the coast (Iacarella et al., 2023). However, it is possible that the predicted areas of loss may look different depending on the gear type and future follow-up studies could be useful to identify gear specific patterns.

While SDM studies are starting to explore multiple models to compare fits, I focused on GAMs as they are a well-established method to fit non-linear relationships and to determine variable importance (Guisan et al., 2017; Peterson, 2011; Sagarese et al., 2014). However, as my model only explains 31.4% of the variability in the dataset, there are clearly other factors affecting gear loss in Canada's Pacific Ocean. These potential factors effecting gear loss in the study area may not be able to be spatially modelled. For example, previous work indicated that equipment malfunction and poor gear condition resulting from improper maintenance can cause gear loss in WA, USA and in BC, Canada (Antonelis, 2013, 2012; Chapter 2). Lack of fisher experience and operator error were also reasons for gear loss that came up in studies done in the USA, Canada, and Australia (Antonelis, 2013; Goodman, 2020; Richardson et al., 2018; Chapter 2) as new fishers are more likely to make mistakes when using gear or selecting a place to fish. Using gear that is large in size or amount may also lead to gear loss, as fishers may have a difficult time controlling the gear (Antonelis, 2013, 2012; Hareide et al., 2005; MacMullen et al., 2002). In Canada's Pacific Ocean, deliberate disposal at sea and vandalism or theft are relatively rare reasons for gear loss. During a survey of commercial fishers in the region, many fishers mentioned that they do everything they can to retrieve lost gear immediately as gear can be very difficult to replace (see Chapter 2). Additionally, commercial fishing gear is well marked in Canada's Pacific Ocean, so other fishers are aware of who passively fishing gear belongs to in order to reduce accidental theft. However, in a recent survey, fishers who harvested in areas frequented by tourists occasionally had traps stolen, perhaps by recreational fishers (see Chapter 2). Additionally, gear loss factors may also be gear-specific, and the relationships between the factors and lost gear location do not appear when all gear types are modelled together.

While I used the best available AIS data for fishing effort in Canada's Pacific Ocean, there are some limitations. In Canada small fishing vessels are not required to have AIS, and if they do, they use it is voluntary (Iacarella et al., 2020). Many fishers do not wish to have AIS on-board their vessels as they often wish to keep their preferred fishing grounds private (Iacarella et al., 2020). In this case, up-to-date effort based on DFO fishing logs would have been more representative, as all vessels must fill out and submit their logbooks upon landing. However, that data is often unavailable to those outside of fisheries monitoring and management.

Future modelling efforts for Canada's Pacific Region should focus on predicting locations by gear and fishery type in order to provide more detailed insight on gear loss factors and locations. In Canada's Pacific Ocean, it is currently unknown whether lost gear stays in its original location of loss or moves. This may vary by gear type and weight (e.g. heavy traps tend

to get buried in the seafloor, a light gillnet may drift), but including factors such as current and wind direction may add insight to where lost gear accumulates in the study area.

Canada's Pacific Ocean needs a more centrally organized gear retrieval program to mitigate negative effects, such as ghost fishing and habitat degradation, before lost gear becomes derelict. Previously, DFO has funded short-term gear retrieval projects led by fishery associations (e.g. Area A Crab Association), NGOs (e.g., T Buck Suzuki Environmental Foundation, Emerald Sea Protection Society), and environmental consultants (e.g. Natural Resources Consultants). A more consistently funded and coordinated effort is needed in Canada's Pacific Ocean to ensure the continuity and efficiency of retrieval programs moving forward, which could be associated with current mandatory gear loss reporting programs. For example, the Northwest Straits Foundation in WA, USA, has been hosting a Reporting, Response, and Retrieval program since 2012 to retrieve newly lost nets before they cause environmental harm (Antonelis, 2013). Commercial fishers are experts on gear loss and retrieval, and the marine environment in which they work, making them excellent candidates to contribute to this work. There are many examples of fishers who have been successfully trained and employed in seasonal, short-term gear removal programs in Canada and the US (Armstrong et al., 2016; M Eadie, 2022a, 2022b; Megan Eadie, 2022; Havens et al., 2011). Therefore, it is imperative to provide longer term gear retrieval supports to local fishers, especially in the off-season or to those unable to fish, to facilitate their marine stewardship into the future.

Chapter 4 : Discussion

Introduction

Lost fishing gear can cause harm to marine wildlife, habitats, and fisheries globally (Antonelis, 2013; Gilman, 2015; Global Ghost Gear Initiative, 2021; Good et al., 2010). As countries around the world aim to address issues with marine plastic pollution and fisheries sustainability, more attention is being focused on research about lost gear. Considering the economic importance of Canada's commercial fisheries and associated businesses (Fisheries and Oceans Canada, 2022), and the social and cultural importance of its oceans (Bennett et al., 2018; Reid et al., 2022), it is of utmost importance for Canada to prevent and remove lost fishing gear. However, in order to understand how to mitigate harm from lost gear, it is important to understand reasons for, and areas of, commercial gear loss.

In this thesis, I use Canada's Pacific Ocean as a case study to address the following research questions: 1) why does commercial fishing gear become lost?, 2) where does commercial fishing gear become lost?, and 3) how can we prevent commercial fishing gear from becoming lost?. This chapter synthesizes how I answered these questions with a mixed methods approach within a transdisciplinary framing. Additionally, I reflect on the academic and practical contributions of this research, limitations, and recommendations for future research.

Why does commercial fishing gear become lost in Canada's Pacific Ocean?

In order to understand how to prevent commercial fishing gear loss in Canada and mitigate potential harm, it is important to know why fishers may lose their gear. Reasons for fishing gear loss can vary regionally, and also depend on fishery and gear type. By using a mixed methods approach, I was able to answer this question in two different ways: 1) via a survey of commercial fishers that I developed to ask about key reasons for gear loss as documented in the global literature, and 2) a statistical approach, using a species distribution modeling (SDM) method. By collaborating with the T Buck Suzuki Environmental Foundation, I used a transdisciplinary framing to answer these questions. Working with the TBSEF staff was vital to my research in order to create the survey and inform my decisions on which environmental and fishing variables were most important to include in the model. As TBSEF is well-regarded amongst fishers in the Pacific Region, this partnership gave my research more credibility, encouraging fishers to trust me enough to take the survey.

In Chapter 2, I conducted a review of global causes of commercial fishing gear loss, and I used the results to design a survey focused on fishers in Canada's Pacific Region. I conducted dockside and online surveys of 29 commercial fishers to document their experiences losing gear in the broader categories of nets, lines, and traps. According to the global review, the most common reasons for gear loss were interactions with other fishing vessels and their gear, marine

weather, and snagging on submerged features. The results of the survey with fishers in the Pacific region revealed that snagging gear on rough substrate was the primary cause of gear loss across all gear types, followed by seafloor type. Other reasons for gear loss varied depending on whether the fisher used net, line, or trap gear.

In Chapter 3, I examined how environmental and fishing attributes contribute to commercial gear loss in Canada's Pacific Ocean and chose the most relevant of those to include in a SDM, which was used to predict areas where lost gear may occur. From the variable selection process, I concluded that bathymetry, fishing effort, and wind speed were the most important for predicting gear loss in the study area.

My thesis is the first study that I am aware of to use both qualitative and quantitative approaches to identify reasons for, and locations of, gear loss. All reasons for gear loss from both research chapters aligned with the global literature (Antonelis, 2013; Bilkovic, 2016; Richardson, 2018) with some differences that may be due to scale. The commercial fishers who participated in the survey answered the questions in a smaller, more localized scale based on their own experiences and observations. In contrast, the statistical model was making predictions on a larger, more regional scale due to the resolution of available data.

An example helps to illustrate the different scales considered in the qualitative and quantitative approaches. Commercial fishers reported that snagging on rough substrate and substrate type were important reasons for gear loss (Chapter 2); however, rough substrate was not included in the top selected statistical model (Chapter 3). Conversely, the survey indicated that interactions with actively fishing vessels and bad weather were not important reasons for gear loss (Chapter 2), despite both fishing effort and wind speed being included in the top model (Chapter 3). These two reasons for gear loss (fishing effort and wind speed) may have nuances between the two methods (i.e. survey and model). As the survey results were based on the experiences of individual fishers, it is possible that on a more local level they are observing interactions with other vessels that lead directly to their own gear loss (e.g. another vessel setting on top of their gear, a bottom trawl being dragged over their trap etc.). The statistical model was likely to be making predictions based not only on the environmental and fishing variables themselves, but also based on fishers avoiding particular areas. An increase of lost gear presence with an increase in fishing effort on a larger scale may not necessarily be due to gear conflicts or interferences, but instead due to the fact that there is more fishing happening in the area. Additionally, the model indicated a decrease in lost gear presence at higher wind speed (Chapter 3), which could be explained by fishers avoiding areas with high winds due to a higher risk of gear loss and other dangers. While fishers indicated direct lost gear presences in the survey (Chapter 2), it is also possible that the other lost gear presences included in the model may not have been the original location of loss. In other words, it is possible that the other lost gear presences are due to the gear drifting from its original location of loss via ocean currents or winds at different ocean depths.

Differences in findings between the qualitative and quantitative approaches may also be due to the fishing gear categories encompassed in Chapter 2 and 3. The survey mostly consisted of responses from fishers who used line or trap gear categories (primarily halibut long line and

prawn trap), whereas the lost gear presence data used in the model came from a wider variety of gear types spanning all three gear categories (lines, nets, and traps). I was able to separate the survey responses by gear category (line, net, or trap); however, due to the small dataset used in the model I was not able to conduct separate analyses based on gear category.

Where does commercial fishing gear become lost in Canada's Pacific Ocean?

Understanding where prevalent gear loss areas exist in Canada's Pacific Ocean can help direct gear retrieval efforts, ensuring that resources are being used efficiently and effectively. These gear retrieval efforts offer a short-term solution to mitigating the potential harms of lost and derelict fishing gear, so ultimately understanding why commercial gear becomes lost is imperative to preventing initial loss. Typically, areas of gear loss may vary depending on the fishery and gear type. I used a mixed methods approach via a commercial fisher survey based on a global literature review, and a modeling approach (SDM) to answer this question. Again, my collaboration with the TBSEF was vital to my transdisciplinary research as fishers trusted me enough to take the survey and help provide insight into my model.

As part of the survey from Chapter 2, I asked commercial fishers from Canada's Pacific region where they have lost their own gear and where they have come across others' lost gear. Participants indicated those point locations on a map of the study area. Survey participants indicated that traps were the most common gear category that they lost or came across, followed by lines and then nets. Most of the lost fishing gear points clustered around the north and south ends of Hecate Strait, Clayoquot Sound, along the west side of the Strait of Georgia, and in the Queen Charlotte and Johnstone Straits.

In Chapter 3, I used the relevant environmental and fishing attributes (bathymetry, fishing effort, wind speed) from the variable selection process to create an SDM. This SDM predicted probable areas of lost gear occurrence in Canada's Pacific Ocean. Generally, the model predicted that the areas with the highest probability of lost gear occurrence were along the coasts of BC in similar areas as seen in Chapter 2.

According to the results from both the survey and predictive model, commercial fishing gear appears to be lost along the coastal regions of BC, within about 15 to 20km from shore. These areas are similar to outputs from other predictive models in the grey literature (Antonelis, 2013; Antonelis and Drinkwin, 2021). The fisher survey and statistical model indicate different reasons for gear loss across local and regional scales. However, the similarity in gear loss areas shows general alignment between the survey participants' observations and the predictive capacity of the model.

How can we prevent commercial fishing gear from becoming lost in Canada's Pacific Ocean?

Gear loss prevention measures can also vary regionally and by fishery and gear type. Understanding commercial fishers' perspectives on how they themselves, industry, and management can prevent gear loss can help inform future decisions. I answered this question via the survey conducted in Chapter 2. Collaboration with TBSEF was also key to answering this question as it helped garner trust amongst the surveyed fishers.

Fishers using all gear categories (lines, nets, and traps) in Canada's Pacific Ocean emphasized the importance of using high quality gear, keeping up with gear maintenance, and knowledge sharing amongst the fleet as ways to reduce their own gear loss. Generally, they relied upon bottom mapping technology in addition to their own local experience to determine when they needed to move onto new fishing grounds to reduce the risk of gear loss. Fishers continually stressed the importance of management reducing overcrowding on the fishing grounds, keeping static and active gear types away from each other, providing more clarity on all aspects of the lost gear reporting process (e.g. why lost gear must be reported, who will have access to the data, if punishment will be involved etc.), and more accessible methods of gear reporting. Most fishers were keen to share their insights and perspectives with me, and expressed a need to be included in lost gear management decisions.

These findings are similar to those in both academic and grey literature on lost gear in other parts of the world. Survey results of Indonesian and Australian fishers also supported the importance of reducing crowding in fishing areas, gear maintenance, and education and capacity building amongst crew members regarding lost gear prevention and mitigation methods (Richardson et al., 2018). Additionally, a report prepared for the Fishing Gear Coalition of Atlantic Canada stressed the importance of making gear reporting to federal managing bodies more accessible for fishers via automated phone lines that can receive phone or text messages and updating electronic logbooks to include lost gear reporting (Goodman, 2020). In order for fishers in Canada's Pacific to feel confident in honestly reporting their lost gear to DFO, it is important for DFO to be entirely transparent regarding how this reported information will be used and whether or not punitive action will take place.

Academic contributions

My thesis adds to the global academic literature on reasons for, and areas of, commercial fishing gear loss (Richardson et al., 2021; Swarbrick and Arkley, 2002; Bilkovic, 2016). This work is especially important as Canada's Pacific Ocean is an understudied region with no peer-reviewed research on this particular topic, and case studies build the basis of regional and global understanding of gear loss. Additionally, no other lost gear research has compared the results of qualitative and quantitative methods at different scales, making my study novel to the field. By conducting a literature review that includes both academic and grey sources, I was able to

provide a comprehensive overview of prevalent reasons for gear loss globally. This review will be able to support future work, and the results from my survey and model will be able to add to it further. My commercial fisher survey shows that local fisher knowledge and expertise can effectively inform research about local lost fishing gear related issues, further supporting the current literature on including fishers in research (Bennett et al., 2020; Harper et al., 2022; Richardson et al., 2021) and highlighting the need for more participatory methods to address lost gear issues in Canada's Pacific. Additionally, by using a new approach, I show that SDMs can be effectively used to predict lost fishing gear locations on a regional scale. Using both qualitative and quantitative approaches to derelict gear work allows researchers to draw on the strengths of both methods and answer questions at different scales.

Practical applications

My thesis research has practical value to people working in commercial fisheries, fisheries management, and conservation and sustainability initiatives. Understanding why commercial fishers lose their gear offers insight on what actions can be taken to prevent future loss so that fishers and managers can work together on solutions. While the survey and model highlight different gear loss reasons, these differences offer insight of the importance of including as many fishers and gear types in this work as possible and taking scale into account. Fishers' local knowledge of their particular fishing grounds could be combined with broader scale trends produced by a model to obtain a more comprehensive view of gear loss in a particular area. While the resolution of the prediction map from Chapter 3 may be too coarse to target specific retrieval efforts, it can highlight likely problem areas in Canada's Pacific Ocean. Highlighting these areas can show fishers, managers, and others where to explore for potential gear retrieval operations and decide on how to operate in these areas to reduce gear loss risk. Understanding how fishers are actively working to prevent gear loss, and their perspectives on what management and industry can do to support their efforts, can inform fisheries management on how to prevent future gear loss and target retrieval efforts.

This work also emphasizes the need for increased participatory methods regarding lost fishing gear management. Commercial fishers who participated in my survey were keen to share their thoughts on why and where fishing gear becomes lost, in addition to ways that fisheries management and industry can prevent and ameliorate the effects of derelict gear. They also expressed a strong desire to collaborate with each other and fisheries management on lost gear solutions. As stated in Chapter 2, partnership between commercial fishers, ENGOs, and government organizations have been shown to be effective at combatting derelict gear in Canada and the USA (Havens et al., 2011; Armstrong et al., 2016; Paton, 2021; Eadie, 2022). These partnerships can lead to effective research design, implementation, and outputs as well as improved management strategies. Additionally, commercial fishers can be employed during their off seasons, or when they are otherwise unable to fish (Havens et al., 2011; Eadie, 2022). This employment can provide economic stability (Havens et al., 2011; Eadie, 2022), technical skills

training (Havens et al., 2011), and encourage fishers' sense of marine stewardship which may have benefits towards their overall sense of well-being.

Study limitations

There are several limitations to my thesis research. First, the sample size of my commercial fisher survey is relatively small. This was due to several reasons. There were severe closures to the salmon fishery in Canada's Pacific, and the COVID-19 pandemic also caused changes. Most of the commercial salmon fishery was closed, leading to less potential fishers to take the dockside survey. Due to the pandemic, the survey start time was delayed as I had to wait for UVic to grant permission to resume in-person research. Additionally, some fishers did not wish to participate in the survey, mostly because their gear types did not become readily lost. This was particularly common for fishers who used large nets (e.g. seines, gillnets), as the high economic cost of their gear encouraged fishers to minimize losses. Additionally, it was more common for them to only lose small pieces of their large nets. Also, fishers with very high levels of experience in a particular area and with a particular gear type did not wish to participate in the survey as their gear loss was negligible.

In addition to survey sample size and timing, there are also some limits with the data for both Chapters 2 and 3. First, some of the lost gear location data points used in the model were placed on land rather than in marine areas of Canada's Pacific. This could be due to human error on the part of survey participants or those conducting data entry into the GGGI Data Portal or Natural Resources Consultant's spreadsheet. I subsequently had to remove 40 of these data points before conducting the model in Chapter 3, which may have reduced fine scale accuracy of these data. Going forward, if a similar study were to be conducted, instructing fishers to zoom in on the survey software as needed would lead to more effective lost gear location placement. Reviewing that all latitude and longitudinal data is correct when submitting to a data portal or spreadsheet is also important. Another issue was the scale of the spatial data needed for the model. Some datasets were available at a fine scale, while others were only available at a coarser scale requiring me to resample all datasets to a 1km resolution, losing some of the nuance of the original datasets. Additionally, I was limited by the accessible datasets available to me at the time, some of which were in the process of being updated (e.g. GGGI data portal), outdated (e.g. BCMCA tidal current data), or unable to be accessed (e.g. DFO's lost gear data). I used AIS fishing effort data from 2012 to 2019 in my model (Iacarella et al., 2023), and while this is the best available data for Canada's Pacific it is not representative of the total commercial fishing effort in the region. Small vessels and fishing vessels are not required to have AIS devices (Iacarella et al., 2020). As such, this AIS fishing effort is an under-estimation of the total fishing effort in Canada's Pacific Ocean (Iacarella et al., 2023).

Future research directions

This thesis highlights the need for future research to be conducted on this topic in Canada's Pacific Ocean, most notably along the topics of: participatory research with fishers, modelling specific to gear and fishery type, and recreational gear loss. In terms of participatory research, it is imperative to include commercial fishers in all lost gear related work so that they may direct research efforts that are important to them. Other research in both academic and grey literature have also emphasized the importance of including fishers and their knowledge in future research (Richardson et al., 2017; Richardson et al., 2018; Goodman, 2020; Antonelis and Drinkwin, 2021). In Chapter 2, fishers mentioned that knowledge and experience are key to reducing gear loss, and as individuals age out of the Pacific region's fleet this knowledge and experience are leaving with them. This exodus of experienced fishers reduces the number of potential mentors for newer members of the fleet, causing a critical knowledge gap in the industry. Education initiatives between more experienced and newer fishers would help pass along this local fishing knowledge, and researchers could be helpful in documenting and analyzing key takeaways. It would also be important to discover if there are different reasons for and areas of gear loss on a finer scale for different fisheries and gear types, as I only looked at the broader gear categories of lines, nets, and traps. This information would provide insight into future modelling endeavours and improve fisheries management as there is much variation amongst gears within the same category (e.g. the category of nets includes bottom trawl, seine, mid-water trawl, and gill- nets). I recommend prioritizing trap and longline gear types, due to their high risk of ghost fishing, prevalence of loss, and ability to cause future gear loss.

As we learn more about lost commercial fishing gear in Canada's Pacific Ocean, more detailed modelling efforts would help improve our predictive capacity lost gear locations to improve retrieval operations. While this recommendation has not appeared in the literature, I believe that creating models for different fisheries, gear types, and areas will identify specific gear loss trends in Canada's Pacific. Other data that could be included in future models, if available, could include current and wind direction as lighter gear types could potentially move to areas away from their original loss (Donohue and Foley, 2007).

Studying why and where recreational gear becomes lost would help provide a more detailed view of gear loss in Canada's Pacific. This has been noted by my survey participants (Chapter 2), academic literature (Bilkovic et al., 2014), and ENGOs and environmental consultants (Natural Resources Consultants, 2012; Eadie & Bright, 2020). Currently, recreational fishers are not part of lost gear initiatives in Canada. Recreational fishing is widely popular amongst locals and tourists in Canada's Pacific, with a wider demographic of people who can obtain recreational fishing licenses. As such, there is likely a range of skill sets and abilities amongst recreational fishers from those who are highly experienced and knowledgeable to those who are trying it for the first time. It is possible that less frequent recreational fishers are more likely to lose their gear, compared to those who are highly experienced, and since there is a larger number of people who may fish recreationally in Canada's Pacific there is the opportunity for more gear to become lost. Therefore, it is important to understand why and where

recreational fishers lose their gear to ensure effective management across all fisheries. This topic is especially timely, as the GGGI will be turning their focus on recreational fisheries globally and creating a Best Practices Framework for recreational fisheries within the next few years (personal communication, Joel Baziuk, GGGI).

Future practical applications

In order to be effective, there must be more consistent gear retrieval support in Pacific Canada (and nationally) to help mitigate harmful effects of lost gear (Antonelis, 2013; Goodman, 2020). This may take the shape of a more centralized response, such as the Reporting, Response, and Retrieval program in WA, USA covered in Chapter 3 (Antonelis, 2013). Alternatively, this may look like supporting individual fisheries managing their own gear loss, such as the decades-long program run by the Area A Crab Association in BC's north coast (Paton, 2021). Providing consistent funding and support can ensure effective gear removal by providing specialized training to interested parties and allowing for gear retrieval knowledge to stay consistent within organizations. Regardless of what gear retrieval looks like in Canada's Pacific, it is of utmost importance to employ as many commercial fishers in these efforts as possible moving forward. Commercial fishers are experts on this topic and the marine environments in which they work, and it is important to encourage their stewardship efforts into the future.

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Appendix A

Table S1. Survey responses by fishery types and gear categories (traps, nets, and lines).

Gear Category	Fishery Types Included	Response Count
Traps	Crab Trap	1
	Prawn & Shrimp Trap	9
		Total: 10
Nets	Groundfish – Trawl	1
	Herring Roe – Gillnet	2
	Salmon – Gillnet	3
	Shrimp – Trawl	3
		Total: 9
Lines	Halibut – Longline	8
	Sablefish – Longline	2
	Salmon – Troll	2
	Tuna – Troll	2
		Total: 14
Total # Responses		33

Table S2. Demographic information of fishers who responded to the survey.

Demographic Information	Description	# of Respondents	% of Respondents
Experience	0 – 4 years	6	21
	5 – 9 years	6	21
	Over 10 years	17	59
Regions Fished	Haida Gwaii & North Coast	33	31
	Central Coast & Northern Vancouver Island	33	31
	West Coast Vancouver Island	18	17
	South Vancouver Island (Strait of Georgia & Juan de Fuca Strait)	18	17
	Offshore	3	3

	International	1	1
	US Waters	1	1
	Fraser Canyon	1	1
Age Range	18 – 29 years	1	3
	30 – 39	7	24
	40 – 49	3	10
	50 – 59	7	24
	60+	11	38
Gender	Male	26	90
	Female	3	10

Appendix B

Lost Fishing Gear in British Columbia: Survey for Commercial Fishers

Background

This survey will explore commercial fishing gear loss in British Columbia (BC), Canada, to understand why commercial fishing gear is lost and to identify high-risk areas for loss.

Lost fishing gear is a global problem causing the entanglement of marine wildlife, degradation of marine habitats, reduction of commercial fishing stocks from 'ghost fishing', and vessel navigational hazards. Very little information is known about lost fishing gear in BC, particularly why and where commercial gear becomes lost. This knowledge is important to help resource managers understand how to mitigate lost gear and where to target removal efforts. This survey will gather information from commercial fishers in BC to determine the primary reasons for gear loss for each major commercial gear type and industry, the areas where gear is most likely to be lost, and potential solutions to commercial gear loss. This project is a partnership between the T Buck Suzuki Foundation and the University of Victoria. Results from this survey will be used to help determine gear retrieval sites in BC and fulfill the requirements of a Master's thesis.

Lost commercial fishing gear is defined for this survey as any commercial fishing gear that is lost, abandoned, or otherwise discarded in the marine environment. This includes small pieces of gear (e.g. a small section of a net, a couple of skates off a longline, etc.) or the entirety of gear (e.g. a whole trap, a string of traps, an entire net, etc.).

Consent:

This questionnaire will take about 10 - 15 minutes of your time. This survey has received ethics clearance from the Human Research Ethics Board of the University of Victoria (ethics # 21-0144). For information about this protect, contact Caitie Frenkel (MSc student, UVic) at frenkelc@uvic.ca, or Megan Eadie (Director of Innovation, T Buck) at megan@bucksuzuki.org. For questions relating to the ethical process of this research you may contact the Human Research Ethics office at 250-472-4545 or via email at ethics@uvic.ca.

By completing and submitting this survey, your free and informed consent is implied, and you are also agreeing for the project to use the information you have provided for this and potential future projects. Responses to this survey will be analyzed to prepare a report of the findings, one or more academic manuscripts and a Master's thesis. All information provided will be confidential. If you begin the survey, but decide to withdraw, you are free to do so. However, the survey will be anonymous and the results will be aggregated, if you choose to withdraw after completing the survey, we will not be able to remove your data as the survey will not be identifiable.

1. Which of the following fisheries are you involved with? Please check all that apply.
   - ☐ Clam
   - ☐ Crab
   - ☐ Dogfish – Hook & Line
   - ☐ Euphausiid – Trawl
   - ☐ Geoduck and Horseclam
   - ☐ Green Sea Urchin – Dive
   - ☐ Groundfish – Trawl
   - ☐ Hake – Midwater Trawl
   - ☐ Halibut – Hook & Line
   - ☐ Herring Roe – Gill Net
   - ☐ Herring Roe – Seine
   - ☐ Herring Spawn on Kelp
   - ☐ Lingcod – Hook & Line
   - ☐ Prawn and Shrimp – Trap
   - ☐ Red Sea Urchin
   - ☐ Rockfish
   - ☐ Sablefish – Hook & Line
   - ☐ Sablefish – Trap
   - ☐ Salmon – Gillnet
   - ☐ Salmon – Seine
   - ☐ Salmon – Troll
   - ☐ Sardine
   - ☐ Sea Cucumber
   - ☐ Shrimp – Trawl
   - ☐ Tuna – Troll
   - ☐ Tuna – International Waters (SEC68)
   - ☐ Tuna – US Waters (USA68)
   - ☐ Other: _____

2. Of the fisheries you just selected, which is the most economically important to you?
   - ☐ Clam
   - ☐ Crab
   - ☐ Dogfish – Hook & Line
   - ☐ Euphausiid – Trawl
   - ☐ Geoduck and Horseclam
   - ☐ Green Sea Urchin – Dive
   - ☐ Groundfish – Trawl
   - ☐ Hake – Midwater Trawl
   - ☐ Halibut – Hook and Line
   - ☐ Herring Roe – Gill Net
   - ☐ Herring Roe – Seine
   - ☐ Herring Spawn on Kelp
   - ☐ Lingcod – Hook and Line
   - ☐ Prawn and Shrimp – Trap
   - ☐ Red Sea Urchin
   - ☐ Rockfish
   - ☐ Sablefish – Hook and Line
   - ☐ Sablefish – Trap
   - ☐ Salmon – Gillnet
   - ☐ Salmon – Seine
   - ☐ Salmon – Troll
   - ☐ Sardine
   - ☐ Sea Cucumber
   - ☐ Shrimp – Trawl
   - ☐ Tuna – Troll
   - ☐ Tuna – International Waters (SEC68)
   - ☐ Tuna – US Waters (USA68)

   Other: _____

3. In the last 10 years, how many years did you work in your most important fishery?

   Answer: _____

4. The next questions are also about different factors that influence gear loss. On a scale of 1 - 5, how important is snagging on rough ground beneath the surface to gear loss for your most important fishery?

- 1 (not at all important)
- 2
- 3
- 4
- 5 (extremely important)

Please add any comments here: _____

5. On a scale of 1 - 5, how important is seafloor type to gear loss for your most important fishery?
   - 1 (not at all important)
   - 2
   - 3
   - 4
   - 5 (extremely important)

   Please add any comments here: _____

6. For your most important fishery, which types of seafloor does your gear get caught on? Check all that apply.

   - Rocky
   - Sandy/muddy
   - Mixed
   - Sponge/glass sponge reefs
   - Coral reefs
   - Seagrass beds
   - Kelp forests
   - Other (please specify): _____
   - N/A

7. On a scale of 1-5, how important are interactions with other vessels to gear loss for your most important fishery?
   - 1 (not at all important)
   - 2
   - 3
   - 4
   - 5 (extremely important)

   Please add any comments here: _____

8. Indicate which types of vessels your gear from your most important fishery is coming into contact with by checking all that apply:
   - □ Shipping vessels
   - □ Ferries
   - □ Recreational vessels
   - □ Other fishing vessels
   - □ Coast Guard/government vessels
   - □ Other (please specify): _____
   - □ N/A

9. On a scale of 1 - 5, how important are interactions with other fishing gear types to gear loss for your most important fishery?
   - □ 1 (not at all important)
   - □ 2
   - □ 3
   - □ 4
   - □ 5 (extremely important)

   Please add any comments here: _____

10. Indicate what other gear types your gear from your most important fishery is coming into contact with by checking all that apply:
    - □ Longline
    - □ Mid-water trawl nets
    - □ Bottom trawl nets
    - □ Seine nets
    - □ Troll lines
    - □ Crab Traps
    - □ Prawn Traps
    - □ Sablefish Traps
    - □ Gillnets
    - □ Other (please specify below): _____
    - □ N/A

11. On a scale of 1 - 5, how important are rough weather events to gear loss for your most important fishery?
    - □ 1 (not at all important)
    - □ 2
    - □ 3
    - □ 4
    - □ 5 (extremely important)

    Please add any comments here: _____

12. On a scale of 1 - 5, how important are strong ocean currents to gear loss for your most important fishery?

- 1 (not at all important)
- 2
- 3
- 4
- 5 (extremely important)

Please add any comments here: _____

13. On a scale of 1 - 5, how important is fishing in a new area you haven't fished in before to gear loss for your most important fishery?

    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

14. On a scale of 1 - 5, how important is seafloor slope to gear loss for your most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

15. On a scale of 1-5, how important is other lost fishing gear on the seafloor to gear loss for your most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

16. Indicate what gear types the gear from your most important fishery comes into contact with by checking all that apply:

- ☐ Longline
- ☐ Mid-water trawl nets
- ☐ Bottom trawl nets
- ☐ Seine nets
- ☐ Troll lines
- ☐ Crab Traps
- ☐ Prawn Traps
- ☐ Sablefish Traps
- ☐ Gillnets
- ☐ Other (please specify below): _____
- ☐ N/A

17. On a scale of 1 - 5, how important are other reasons not listed to gear loss for your most important fishery? Please specify the reason below.

Other reason: _____

- ☐ 1 (not at all important)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (extremely important)
- ☐ N/A

18. In the past 10 years, how often (# of instances) have you lost gear (both full and partial gear loss)?

Answer: _____

19. For how many years have you been a fish harvester in any and all fisheries?

- ☐ Less than 5 years
- ☐ 5 – 9 years
- ☐ 10 – 19 years
- ☐ 20 – 29 years
- ☐ 30+ years

20. Where have you lost any type of gear? Indicate by placing a marker in the map and selecting a gear type from the drop down menu. Place as many markers on the map as needed. There are full or partial loss options for each gear type.

A basic map of BC's coast line pops up here where fishers can select from the following gear types for each marker they place on the map:

- Bottom Trawl Net - Full Loss
- Midwater Trawl Net – Full Loss
- Gill Net – Full Loss
- Seine Net – Full Loss
- Hand Line – Full Loss
- Long Line – Full Loss
- Troll Line – Full Loss
- Crab Trap – Full Loss
- Prawn & Shrimp Trap – Full Loss
- Sablefish Trap – Full Loss
- Dive Gear – Full Loss
- Bottom Trawl Net – Partial Loss
- Midwater Trawl Net – Partial Loss
- Gill Net – Partial Loss
- Seine Net – Partial Loss
- Hand Line – Partial Loss
- Long Line – Partial Loss
- Troll Line – Partial Loss
- Crab Trap – Partial Loss
- Prawn & Shrimp Trap – Partial Loss
- Sablefish Trap – Partial Loss
- Dive Gear – Partial Loss
- N/A – no gear loss

21. In which regions of the coast do you fish or harvest seafood for any fishery? Please check all that apply.

- Haida Gwaii
- North Coast
- Central Coast
- Northern Vancouver Island
- West Coast Vancouver Island
- Strait of Georgia
- Juan de Fuca Strait
- Offshore
- US Waters
- International Waters
- Other: _____
- Prefer not to say

22. Do you think lost fishing gear stays on the seafloor where it was lost, or do you think it drifts? Please elaborate.
    - Stays where it was lost
    - Drifts

- Please elaborate: _____
- N/A

23. Has the amount of fishing gear, from any fishery, you lose per season has changed over the last 10 years?
    - Increased a lot
    - Increased somewhat
    - Unchanged, with some amount of loss
    - Unchanged, with no loss
    - Decreased somewhat
    - Decreased a lot
    - I have never lost fishing gear

24. If you have experienced a change in gear loss for any fishery, why do you think the amount of fishing gear you lose per season has changed over time?

    Answer: _____

25. What types of lost fishing gear do you encounter most often?

    - Longline
    - Mid-water trawl nets
    - Bottom trawl nets
    - Seine nets
    - Troll lines
    - Crab Traps
    - Prawn Traps
    - Sablefish Traps
    - Gillnets
    - Other (please specify below): _____
    - N/A

26. Where have you encountered any type of lost gear? Indicate by placing a marker in the map and selecting a gear type from the drop down menu. Place as many markers on the map as needed.

    A basic map of BC's coast line pops up here where fishers can select from the following gear types for each marker they place on the map:

    - Bottom Trawl Net
    - Midwater Trawl Net
    - Gill Net
    - Seine Net
    - Hand Line
    - Long Line
    - Troll Line
    - Crab Trap
    - Prawn & Shrimp Trap
    - Sablefish Trap
    - Dive Gear
    - N/A

27. On average for each instance of gear loss for any fishery, how much time does your vessel spend on retrieving its lost gear?

    - ☐ No time
    - ☐ A few hours
    - ☐ An entire day
    - ☐ Several days
    - ☐ N/A

28. What do you think would have prevented your own gear from being lost (from your most important fishery)? Please check all that apply:

    - ☐ More secure on-board storage
    - ☐ Shorter soak times
    - ☐ Better/more clear gear marking
    - ☐ Less overlap with other fishing industries in an area
    - ☐ Less vessel traffic
    - ☐ Better knowledge of the area being fished in
    - ☐ Industry regulations
    - ☐ Government policies
    - ☐ Other (please specify): _____
    - ☐ Nothing

29. What could industry do to help prevent gear loss for any fishery?

    Answer: _____

30. What could fisheries management/policy do to help prevent gear loss for any fishery?

    Answer: _____

31. Have you made any changes to how you fish to actively prevent gear loss?

    - ☐ Yes
    - ☐ Answer: _____
    - ☐ No

32. Do you have suggestions on how to modify the gear to prevent loss and/or make it easier to retrieve?

    Answer: _____

33. What is your age group?

    - ☐ 18 – 29 years old

- 30 – 39 years old
- 40 – 49 years old
- 50 – 59 years old
- 60+ years old
- Prefer not to say

34. What is your gender?
    - Male
    - Female
    - Other
    - Prefer not to say

35. Where is your home port?
    - Prince Rupert
    - Port Hardy
    - Port McNeil
    - Campbell River
    - Ucluelet
    - Nanaimo
    - Parksville
    - Victoria
    - Vancouver
    - Steveston
    - Pender Harbour
    - Other (please specify): _____
    - Prefer not to say

36. Do you have any notes about gear loss that you're willing to share (such as GPS coordinates, fishing logs, computer screen shots, drawings, verbal reports etc.)?
    - Yes
    - No

37. Would you be willing to answer the survey questions again for your next most important fishery?
    - Yes
    - No

If respondent answer's 'yes', they answer the following questions for their second most economically important fishery:

38. Of the fisheries you participate in, which is the second most economically important to you?
    - Clam
    - Crab
    - Dogfish – Hook & Line
    - Euphausiid – Trawl
    - Geoduck and Horseclam
    - Green Sea Urchin – Dive
    - Groundfish – Trawl
    - Hake – Midwater Trawl
    - Halibut – Hook and Line
    - Herring Roe – Gill Net

- ☐ Herring Roe – Seine
- ☐ Herring Spawn on Kelp
- ☐ Lingcod – Hook and Line
- ☐ Prawn and Shrimp – Trap
- ☐ Red Sea Urchin
- ☐ Rockfish
- ☐ Sablefish – Hook and Line
- ☐ Sablefish – Trap
- ☐ Salmon – Gillnet
- ☐ Salmon – Seine
- ☐ Salmon – Troll
- ☐ Sardine
- ☐ Sea Cucumber
- ☐ Shrimp – Trawl
- ☐ Tuna – Troll
- ☐ Tuna – International Waters (SEC68)
- ☐ Tuna – US Waters (USA68)

Other: _____

39. The next questions are also about different factors that influence gear loss. On a scale of 1 - 5, how important is snagging on rough ground beneath the surface to gear loss for your second most important fishery?

- ☐ 1 (not at all important)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (extremely important)

Please add any comments here: _____

40. On a scale of 1 - 5, how important is seafloor type to gear loss for your second most important fishery?

- ☐ 1 (not at all important)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (extremely important)

Please add any comments here: _____

41. For your second most important fishery, which types of seafloor does your gear get caught on? Check all that apply.

- ☐ Rocky
- ☐ Sandy/muddy
- ☐ Mixed
- ☐ Sponge/glass sponge reefs
- ☐ Coral reefs
- ☐ Seagrass beds

- Kelp forests
- Other (please specify): _____
- N/A

42. On a scale of 1-5, how important are interactions with other vessels to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

43. Indicate which types of vessels your gear from your second most important fishery is coming into contact with by checking all that apply:
    - Shipping vessels
    - Ferries
    - Recreational vessels
    - Other fishing vessels
    - Coast Guard/government vessels
    - Other (please specify): _____
    - N/A

44. On a scale of 1 - 5, how important are interactions with other fishing gear types to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

45. Indicate what other gear types your gear from your second most important fishery is coming into contact with by checking all that apply:
    - Longline
    - Mid-water trawl nets
    - Bottom trawl nets
    - Seine nets
    - Troll lines
    - Crab Traps
    - Prawn Traps
    - Sablefish Traps
    - Gillnets

- Other (please specify below): _____
- N/A

46. On a scale of 1 - 5, how important are rough weather events to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

47. On a scale of 1 - 5, how important are strong ocean currents to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

48. On a scale of 1 - 5, how important is fishing in a new area you haven't fished in before to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

49. On a scale of 1 - 5, how important is seafloor slope to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3

- 4
- 5 (extremely important)

Please add any comments here: _____

50. On a scale of 1-5, how important is other lost fishing gear on the seafloor to gear loss for your second most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

51. Indicate what gear types the gear from your second most important fishery comes into contact with by checking all that apply:

    - Longline
    - Mid-water trawl nets
    - Bottom trawl nets
    - Seine nets
    - Troll lines
    - Crab Traps
    - Prawn Traps
    - Sablefish Traps
    - Gillnets
    - Other (please specify below): _____
    - N/A

52. On a scale of 1 - 5, how important are other reasons not listed to gear loss for your second most important fishery? Please specify the reason below.

    Other reason: _____
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)
    - N/A

53. In the past 10 years, how many years did you work in your second most important fishery?

Answer: _____

54. What do you think would have prevented your own gear from being lost (from your second most important fishery)? Please check all that apply:
    - ☐ More secure on-board storage
    - ☐ Shorter soak times
    - ☐ Better/more clear gear marking
    - ☐ Less overlap with other fishing industries in an area
    - ☐ Less vessel traffic
    - ☐ Better knowledge of the area being fished in
    - ☐ Industry regulations
    - ☐ Government policies
    - ☐ Other (please specify): _____
    - ☐ Nothing

55. Have you made any changes to how you fish in your second most important fishery to actively prevent gear loss? If yes, what changes have you made? Please specify gear type.
    - ☐ Yes
    - ☐ Answer: _____
    - ☐ No

56. Do you have suggestions on how to modify the gear for your second most important fishery to prevent loss and/or make it easier to retrieve?

    Answer: _____

If respondent answer's 'yes', they answer the following questions for their second most economically important fishery:

57. Of the fisheries you participate in, which is the third most economically important to you?

- Clam
- Crab
- Dogfish – Hook & Line
- Euphausiid – Trawl
- Geoduck and Horseclam
- Green Sea Urchin – Dive
- Groundfish – Trawl
- Hake – Midwater Trawl
- Halibut – Hook and Line
- Herring Roe – Gill Net
- Herring Roe – Seine
- Herring Spawn on Kelp
- Lingcod – Hook and Line
- Prawn and Shrimp – Trap
- Red Sea Urchin
- Rockfish
- Sablefish – Hook and Line
- Sablefish – Trap
- Salmon – Gillnet
- Salmon – Seine
- Salmon – Troll
- Sardine
- Sea Cucumber
- Shrimp – Trawl
- Tuna – Troll
- Tuna – International Waters (SEC68)
- Tuna – US Waters (USA68)

Other: _____

58. The next questions are also about different factors that influence gear loss. On a scale of 1 - 5, how important is snagging on rough ground beneath the surface to gear loss for your third most important fishery?

    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

59. On a scale of 1 - 5, how important is seafloor type to gear loss for your third most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

60. For your third most important fishery, which types of seafloor does your gear get caught on? Check all that apply.

- ☐ Rocky
- ☐ Sandy/muddy
- ☐ Mixed
- ☐ Sponge/glass sponge reefs
- ☐ Coral reefs
- ☐ Seagrass beds
- ☐ Kelp forests
- ☐ Other (please specify): _____
- ☐ N/A

61. On a scale of 1-5, how important are interactions with other vessels to gear loss for your third most important fishery?

- ☐ 1 (not at all important)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (extremely important)

Please add any comments here: _____

62. Indicate which types of vessels your gear from your third most important fishery is coming into contact with by checking all that apply:

- ☐ Shipping vessels
- ☐ Ferries
- ☐ Recreational vessels
- ☐ Other fishing vessels
- ☐ Coast Guard/government vessels
- ☐ Other (please specify): _____
- ☐ N/A

63. On a scale of 1 - 5, how important are interactions with other fishing gear types to gear loss for your third most important fishery?

- ☐ 1 (not at all important)
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 (extremely important)

Please add any comments here: _____

64. Indicate what other gear types your gear from your third most important fishery is coming into contact with by checking all that apply:

- ☐ Longline

- Mid-water trawl nets
- Bottom trawl nets
- Seine nets
- Troll lines
- Crab Traps
- Prawn Traps
- Sablefish Traps
- Gillnets
- Other (please specify below): _____
- N/A

65. On a scale of 1 - 5, how important are rough weather events to gear loss for your third most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

66. On a scale of 1 - 5, how important are strong ocean currents to gear loss for your third most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

67. On a scale of 1 - 5, how important is fishing in a new area you haven't fished in before to gear loss for your third most important fishery?

    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

68. On a scale of 1 - 5, how important is seafloor slope to gear loss for your third most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

69. On a scale of 1-5, how important is other lost fishing gear on the seafloor to gear loss for your third most important fishery?
    - 1 (not at all important)
    - 2
    - 3
    - 4
    - 5 (extremely important)

    Please add any comments here: _____

70. Indicate what gear types the gear from your third most important fishery comes into contact with by checking all that apply:

    - Longline
    - Mid-water trawl nets
    - Bottom trawl nets
    - Seine nets
    - Troll lines
    - Crab Traps
    - Prawn Traps
    - Sablefish Traps
    - Gillnets
    - Other (please specify below): _____
    - N/A

71. On a scale of 1 - 5, how important are other reasons not listed to gear loss for your third most important fishery? Please specify the reason below.

    Other reason: _____
    - 1 (not at all important)
    - 2
    - 3

- 4
- 5 (extremely important)
- N/A

72. In the past 10 years, how many years did you work in your third most important fishery?

    Answer: _____

73. What do you think would have prevented your own gear from being lost (from your third most important fishery)? Please check all that apply:
    - More secure on-board storage
    - Shorter soak times
    - Better/more clear gear marking
    - Less overlap with other fishing industries in an area
    - Less vessel traffic
    - Better knowledge of the area being fished in
    - Industry regulations
    - Government policies
    - Other (please specify): _____
    - Nothing

74. Have you made any changes to how you fish in your third most important fishery to actively prevent gear loss? If yes, what changes have you made? Please specify gear type.
    - ☐ Yes
    - ☐ Answer: _____
    - ☐ No

75. Do you have suggestions on how to modify the gear for your third most important fishery to prevent loss and/or make it easier to retrieve?

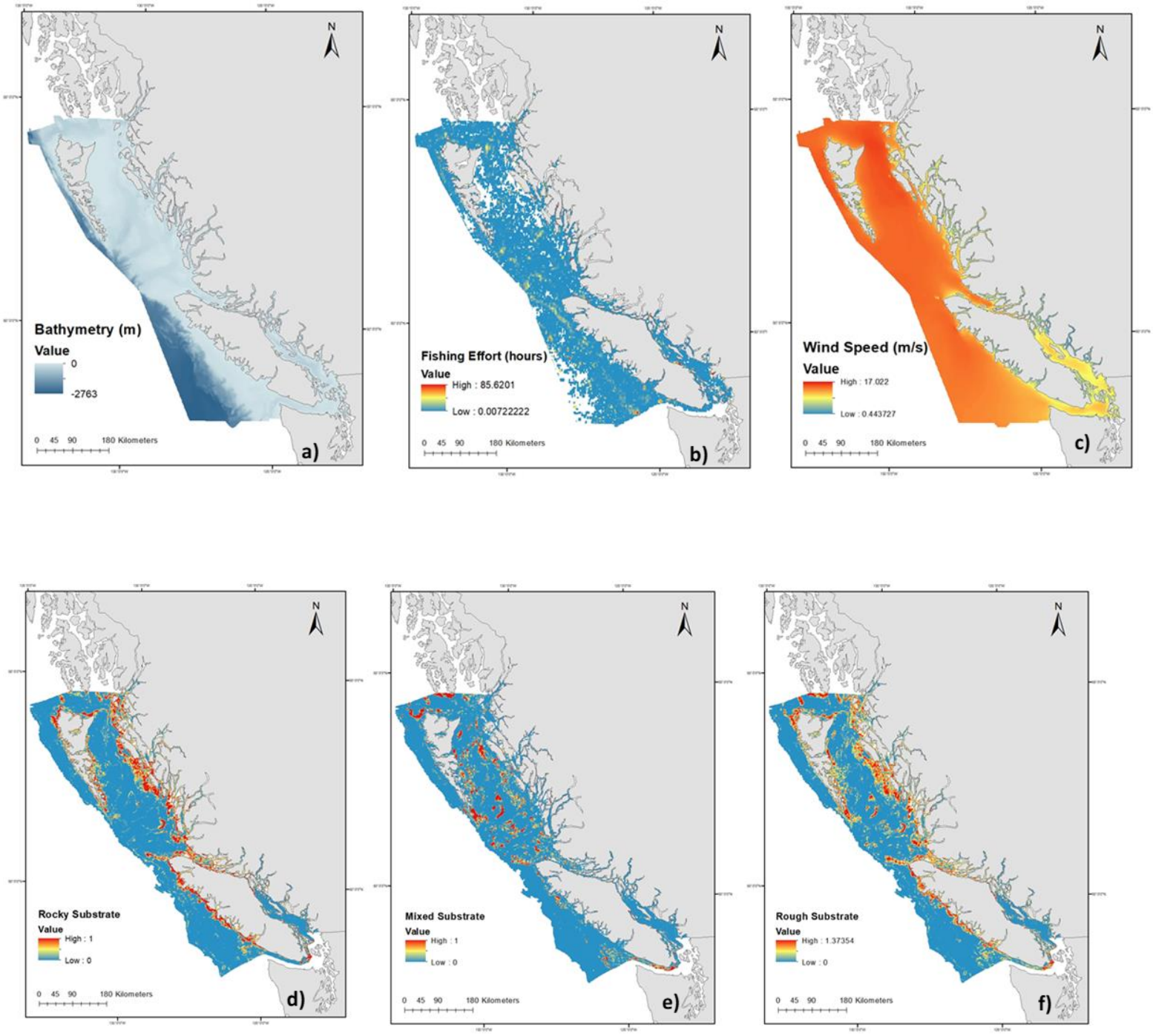
    Answer: _____

If respondent answers ‘no’ after the first or second round of questions, or they finish the third round of questions, they are brought to this final question:

76. Do you have any last comments?

    Answer: _____

Appendix C



Supplementary Figure 1. Spatial distribution of gear loss variables: a) bathymetry (m), b) fishing effort (hours), c) wind speed (m/s), d) rocky substrate (ratio of 0 -1 cell coverage), e) mixed substrate (ratio of 0 – 1 cell coverage), f) rough substrate (sum of rocky and mixed substrate).