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# Predicting factors of fishing gear loss and distribution across Canada's Pacific Ocean

Caitlin M. Frenkel [c], Josephine Iacarella [a,b], Natalie C. Ban [c,*]

[a] School of Environmental Studies, University of Victoria, Canada
[b] Marine Spatial Ecology and Analysis, Fisheries and Oceans Canada, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, BC V8L 4B2, Canada
[c] School of Environmental Studies, University of Victoria, School of Environmental Studies, David Turpin Building, B-Wing, B250, 3800 Finnerty Road, Victoria, BC V8P 5C2, Canada

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ABSTRACT

Abandoned, lost, and otherwise discarded fishing gear (ALDFG) comprises a large portion of the world's marine plastic pollution, damaging marine habitats, wildlife, and fishing industries globally. Lost gear retrieval can be an effective short-term mitigation strategy, and spatial modelling has been helpful tool determine where to target efforts. Using Canada's Pacific Ocean as a case study, we examined how environmental, and fishing attributes contribute to gear loss. We predicted areas of potentially high ALDFG occurrence based on key variables using a Species Distribution Modeling approach. We determined that important variables for predicting gear loss included bathymetry, fishing effort, and wind speed. Our projections of ALDFG occurrence indicated that the coastal areas of Canada's Pacific Ocean had the highest probability of gear loss. Our research has the potential to increase the efficiency of future gear retrieval and provide insight to fisheries management to effectively mitigate the negative effects of lost fishing gear in Canada's Pacific Ocean.

## 1. Introduction

Abandoned, lost, or otherwise discarded fishing gear (ALDFG) comprises a large part of marine plastic pollution and is detrimental globally to marine wildlife, habitats, and fishing industries [2,32,31,34]. Ghost fishing, where fishing gear continues to catch marine animals long after its initial loss, is one of the most adverse impacts of ALDFG [5,16,18,24]. One study in Oman estimated that up to 90 % of species that fall victim to ghost fishing are commercially valuable [1], which could cause negative effects to commercial fishing stocks and revenues globally [31,24,12]. 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 [4]. Additionally, ALDFG 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 [55,20,50,45]. As these biogenic habitats are vital in supporting diverse marine communities, damage caused by ALDFG could potentially reduce biodiversity in these areas, further harming commercial fish stocks [31,24,12]. Despite an understanding of the harms caused by ALDFG, little is known about where it accumulates in the oceans, making it a difficult problem to mitigate.

ALDFG 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 [32,72]. Canada is illustrative of the recent focus on ALDFG related issues given concern about impacts to economically important fisheries [26]. In 2018, Canada joined the Global Ghost Gear Initiative (GGGI), a multi-stakeholder alliance tackling ALDFG issues worldwide, prioritizing ALDFG related research and removal projects through several funding initiatives (. While it is critical to identify prevention methods for gear loss relevant to regional fishing practices across Canada, removal of existing ALDFG is required to mitigate ongoing impacts [12,30,68,64,45]. Generally, marine and coastal habitats have benefited from targeted gear removal programs [8]. Habitat forming species such as eelgrass, kelp, seaweeds, hydroids, and cordgrass can show 30–100 % recovery within a year after ALDFG is removed [68,45]. Additionally, ALDFG removal can be more cost effective than the incurring monetary losses experienced by commercial fisheries due to ghost fishing [4,30,65]. For example, a study in Puget Sound estimated that within the lifetime of one derelict gillnet, $19,656 USD worth of Dungeness crab would be lost to the commercial fishery whereas it only cost $1358 USD to remove the net [30]. This equated to a 1:14.5 cost:benefit ratio, where the cost to remove the

* Corresponding author.
*E-mail address:* nban@uvic.ca (N.C. Ban).

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derelict gillnet was 14.5x lower than the profits lost to the commercial Dungeness crab fishery [30]. In Chesapeake Bay, Virginia, another study found that removing over 34,000 derelict crab pots 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 [64]. 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 [64]. In other words, the potential monetary gain from ALDFG removal could offset the costs of the removal programs themselves. 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, ALDFG removal programs must have a good understanding of which marine areas to target to be as efficient as possible.

There is limited information regarding ALDFG 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 [33]. 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 [2,18,53]. 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 [2]. 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 [53]. 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 ALDFG requires information regarding reasons why the gear was originally lost. According to the literature [29], the most common reasons for

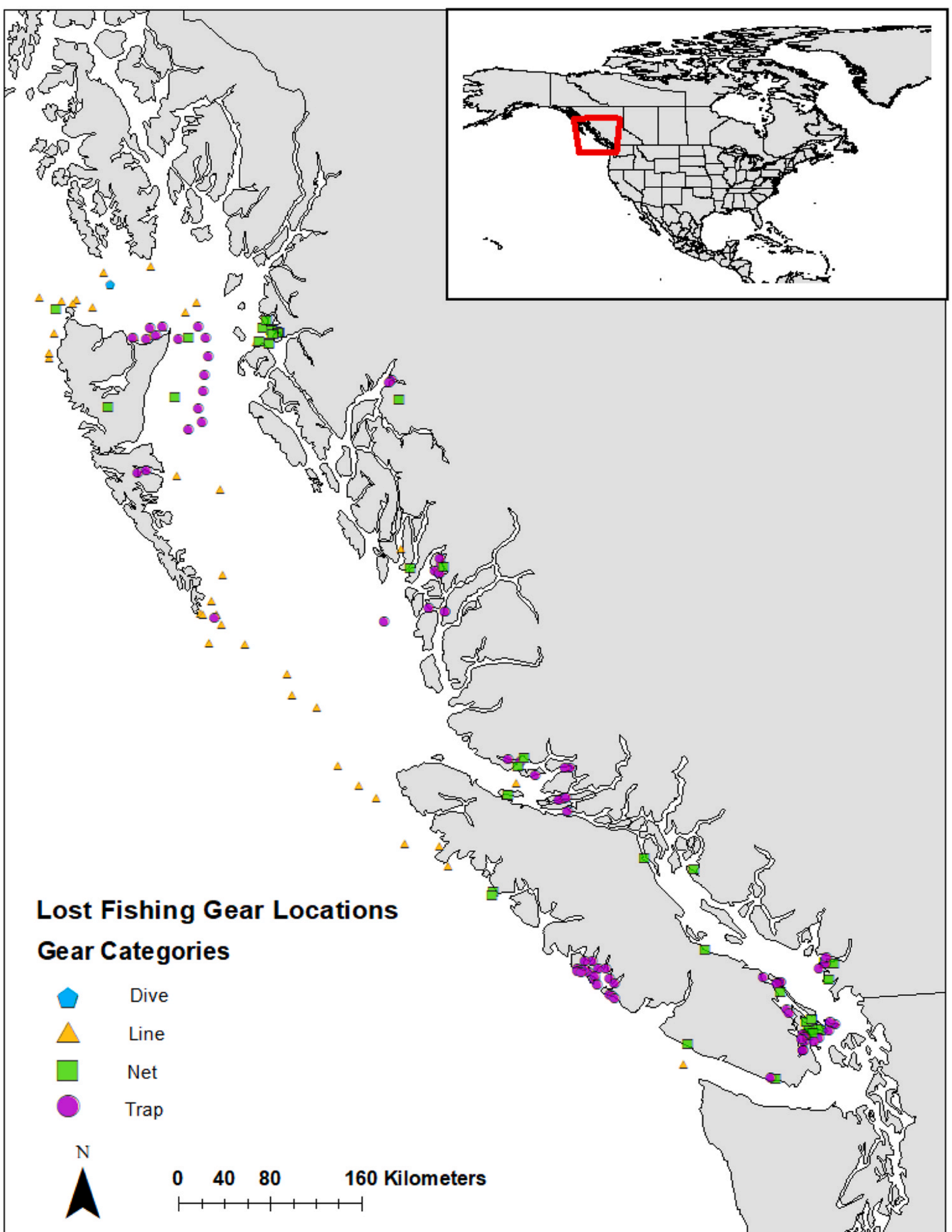


**Fig. 1.** Map of the study area depicting locations of lost gear by gear categories.

**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. | [51] [39] [2] [55] [35] | m | [46] |
| 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 the amount of time spent fishing in an area could increase the chances of commercial fishers experiencing other variables (e.g. bathymetric features, different substrate types, wind, tides etc.) that could lead to gear loss. | [67] [51] [63] [39] [9] [6] [2] [55] [58] [19] [59] [22] [35] [60] [32] | Total hours actively fishing between 2012 – 2019 | [43] |
| Rocky Substrate | Rocky substrate was the second most common substrate type that fishers reported causing gear loss in Lost Gear Survey.<br>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) | [15] [51] [63] [9,39] [6] [2] [55,58] [35] [22] [60] [32,59] | Ratio of cell coverage from 0 to 1 | [25] |
| 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).<br>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) | [15] [51] [63] [9,39] [6] [2] [55,58] [35] [22] [60] [32,59] | Ratio of cell coverage from 0 to 1 | [25] |
| 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 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. | [67] [51] [63] [39] [9] [55,12] [58] [19] [38] [59] [22] [35] [60] [32] | Measured in m/s 10 m above sea level | [17] |
| 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). | [51,12] [55,54] | m/s | [27] |
| 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 | [29] | - | - |

(*continued on next page*)

**Table 1** (*continued*)

| Variable or Interaction | Reasoning | References | Unit | Data Source |
|---|---|---|---|---|
| Fishing Effort: Bathymetry | 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. 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. | [2] | - | - |

commercial fishing gear loss globally include: interactions with other vessels and fishing gear [6,67], snagging gear on submerged features [2, 60,63], poor marine weather [51,58,12], fishing equipment malfunction and poor gear condition [35,39,31], interactions with non-fishing vessels [9,19], strong ocean currents [55,54], deliberate disposal at-sea [32, 63], depth [2,51], large gear or large amounts of gear [2,39], interactions with marine wildlife [38,60], vandalism and theft [67,9], lack of fisher experience or training [35,58], and operator error [2,6]. These reasons for gear loss can vary regionally based on different fisheries and the local geographies where they take place. While not all gear loss reasons can be quantified and analyzed spatially, those that can could help predict where ALDFG is present, therefore reducing the potential search areas for removal efforts.

In this research, we explore a novel method of predicting marine areas with high probabilities of ALDFG occurrence using a species distribution model (SDM) approach, in Canada's Pacific Ocean as a case study. Fisheries and Oceans Canada (DFO) has issued over 6000 commercial fishing licenses to over 2000 registered vessels in the study area [36]; Fig. 1). 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. ALDFG is a great concern in this region, and efforts are underway by organizations such as the T.Buck Suzuki Foundation, Emerald Sea Protection Society, and Area A Crab Association to retrieve gear.

SDMs are typically used in ecology and conservation to predict areas of potential species occurrence based on their environmental requirements [28,37,48]. SDMs are especially useful when observation data are limited, which is why we believe the method could lend itself well to predicting areas of derelict gear occurrence in an ocean environment with poor visibility. As derelict gear presence data is becoming increasingly available via the GGGI's data portal [33] and local gear retrieval organizations, SDM methods may offer more detailed insights on important reasons for gear loss and predictions of derelict gear locations. One grey literature predictive modeling exercise exists in the region based on limited data: Antonelis and Drinkwin [3] created linear additive models for salmon and herring fisheries based on a small number of derelict fishing net data points (n = 20), and a geographically weighted regression models for the shellfish and groundfish fisheries based on summarized derelict gear polygons drawn by fishers at workshops. However, we propose a novel approach by applying the SDM concept to identify important variables in ALDFG occurrence and create spatial predictions across the Pacific Region of Canada.

## 2. Methods

We 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 [29]. Specifically, we obtained spatial environmental layers for bathymetry (Kung, 2021), rocky substrate [25], mixed substrate [25], wind speed (Global Wind Atlas 3.2, 2022), tidal current speed [27], and fishing effort [43] for the study area from a variety of sources (Table 1, Supplementary Figure 1). All data layers were continuous and not correlated ($r < 0.6$). 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. We amalgamated lost gear presence data for the study area from various sources including from our previous survey [29], the Global Ghost Gear Initiative's Data Portal [33], 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). We used ESRI's ArcMap (Version 10.8.1;[23] to convert tidal current speed data to raster format via inverse distance weighted interpolation and used R (V 2.0.4; [57]) to convert all raster data into 1 km grid cell resolution [41].

We randomly selected 3900 pseudo-absence points to obtain 16x as many pseudo-absence points as presence points for optimal modelling [49]. We 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. We 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.

We used a Generalized Additive Model (GAM) with a binomial distribution to fit non-linear relationships, which is a common method for SDMs [69,10] and enables determination of important mediating variables [70]. We 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; [71]; Supplementary Table 1). We used backwards stepwise elimination to find the most parsimonious model. We compared models using ANOVAs and the difference in AICc (bbmle package in R, [13]; MuMIn in R [11]) to determine the top models (Table 2). We focused our results and projections using the simplest model with the lowest AICc score (Table 2). We calculated the unique, averaged shared, and individual $R^2$ values for each of the retained variables using the *gam.hp* package in R [47]. This allowed us to evaluate the amount of variance explained and their relative importance in ALDFG locations in our top model [47].

We calculated the Area Under the Receiver Operator Curve (AUC) of the top model to assess how effective the GAM was at predicting ALDFG presence in the study area (pROC package in R; [66,62]. We 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; [71]). We used our final GAM to project across the study extent ('raster' package in R; [41]), allowing us to visualize where lost commercial fishing gear may occur in Canada's Pacific Ocean.

## 3. Results

Our best fit model consisted of the following additive 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 rough substrate, but it was not significant (p-

**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. Smoothers used on singular terms are indicated by ‘s’, while smoothers used on interacting terms are indicated by ‘ti’.

| 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 |

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, ALDFG presence increased slightly as the seafloor became shallower, leveling off around 1400 m below sea level (Fig. 2). ALDFG presence generally increased with fishing effort until approximately 7.5 total hours between 2012 and 2019 before declining and increasing again at 11 h (Fig. 2). 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. 2). Confidence intervals were wider for all modeled terms in areas where there were fewer lost gear data points, indicating less predictive power for deeper depths, higher levels of fishing effort, and stronger winds (Fig. 2).

The adjusted $R^2$ was 0.219 for our top model. Additionally, the deviance explained for our top model indicates that it explains 31.4 % of the variability in our dataset. The unique, average, and individual $R^2$ for each term in our best fit model provided insight on how each term effected ALDFG location in the study area. Wind speed explained the most unique ($R^2 = 0.1151$), shared (0.0513), and individual variance (0.1664) than the other terms in our best fit model. Bathymetry explained the second most unique (0.0722), average (0.0463), and individual variance (0.1185), and fishing effort explained the least unique (0.0067), average (0.0026), and individual variance (0.0093). Of the variance explained in the top model, wind speed explained 56.56 %, bathymetry explained 40.28 %, and fishing effort explained 3.16 %.

Generally, our model predicted the highest probability of commercial ALDFG occurrence along the coastlines of mainland British Columbia (BC), Vancouver Island, and Haida Gwaii (Fig. 3). Areas with the highest probability of ALDFG 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 commercial ALDFG occurrence (Fig. 3).

The AUC score fell within the higher end of the acceptable range of 0.7 – 0.8 [52] 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 [52].

## 4. Discussion

Recent public and government awareness about the impacts of ALDFG have caused concern amongst fisheries, management, and other marine stakeholders in Canada’s Pacific Ocean [21,56,19]. Examples of these regional economic and environmental concerns include 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 [21,22,29,19]. Despite these concerns, there has been

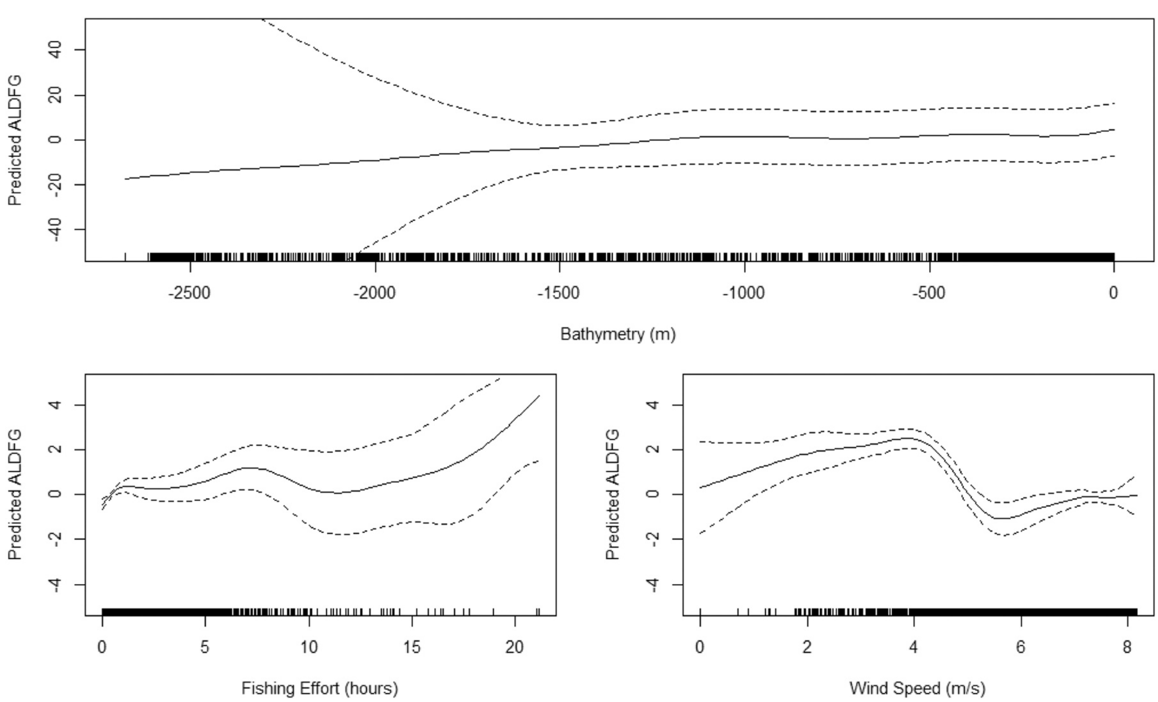


**Fig. 2.** Smoothed fits of GAM covariates bathymetry (m), fishing effort (hours), and wind speed (m/s). 95 % confidence intervals are indicated by the dashed lines and observed data points are indicated by rug marks along the x-axis.

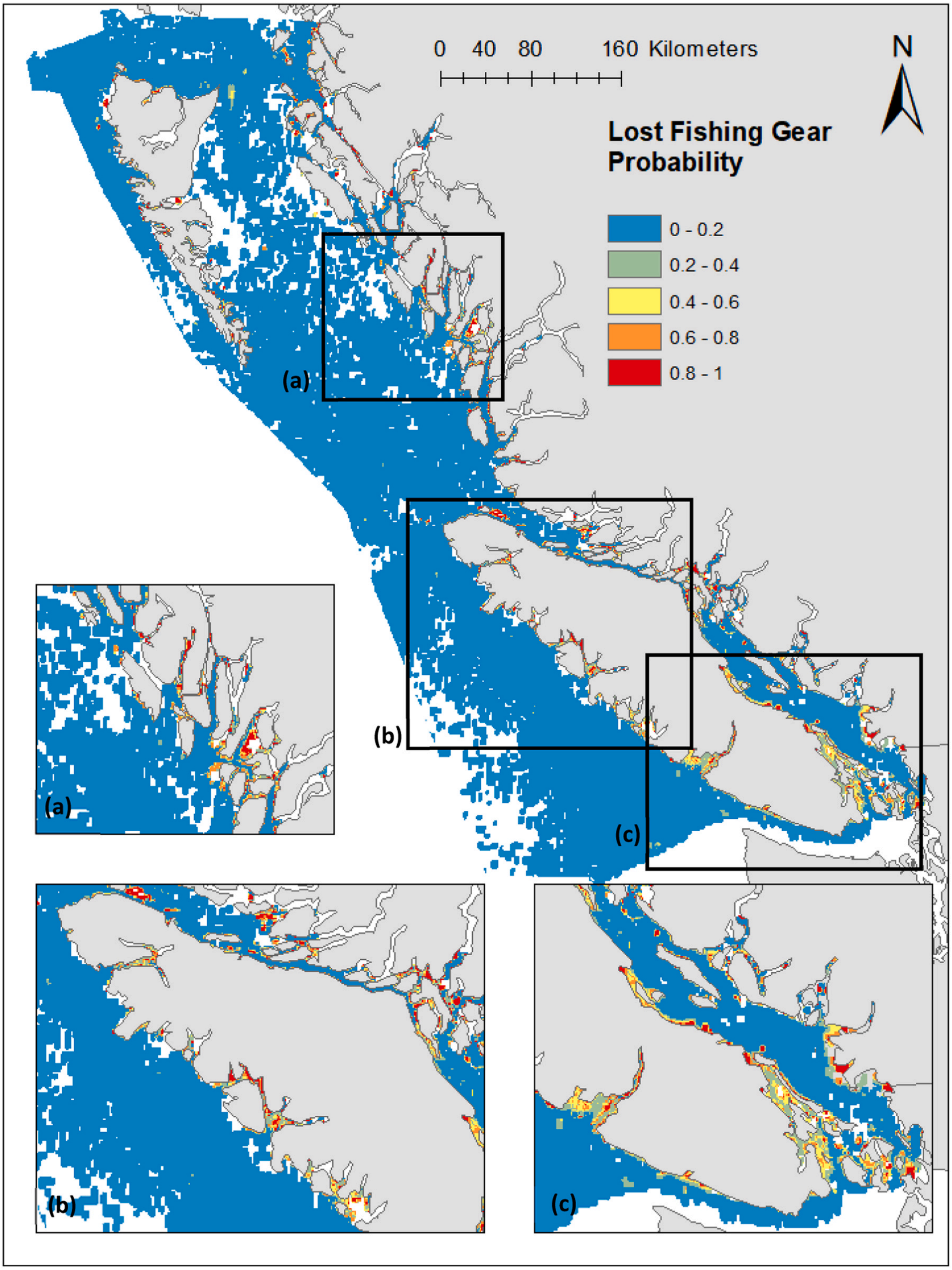


**Fig. 3.** GAM probability prediction of ALDFG occurrence in Canada's Pacific Ocean. Areas of dark red indicate high probability of lost gear occurrence, while areas of blue indicate low probability. White areas indicate no data.

minimal academic and peer-reviewed research conducted on ALDFG in Canada's Pacific Ocean. To date, peer-reviewed research on ALDFG in the region includes Dungeness crab mortality in derelict traps [14], impact assessments of fishing gear on Canada's Pacific seamount ecosystems [20], and a literature review and fisher survey assessing common reasons for gear loss amongst local fishers [29]. To help fill knowledge gaps in Canada's Pacific Ocean, environmental non-profit organizations (e.g. T Buck Suzuki Environmental Foundation, Emerald Sea Protection Society), commercial fishing associations (e.g. Area A Crab Association), and environmental consultants (e.g. Natural Resources Consultants) have been documenting their work in project reports and other grey literature sources. Some of this work includes lost gear retrieval programs [21,56,5], predictive spatial mapping of derelict gear with limited data in the Pacific [2,3], and marine stakeholder workshops [22,19]. To date, all this work has been focused on commercial fisheries.

Our study shows that SDMs can predict areas of commercial ALDFG presence in Canada's Pacific Ocean, which is a novel approach in the field of ALDFG research. Additionally, our work is the first peer-reviewed model of the region, not only growing the small body of peer-reviewed research on the topic, but also supporting the grey literature produced by regional ENGOs, fishing associations, and environmental consultants. 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 [73]. 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 [2,38,51,58,60]. Additionally, the areas predicted to have the highest probability of ALDFG occurrence are reflected in recent grey literature in the study area [22,3,19]. As the issue of ALDFG 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 ALDFG location and the gear loss variables of bathymetry, fishing effort, and wind speed reflect the global literature [2,38,51,58,60]. The amount each variable influences commercial fishing gear loss is context dependent, and differs based on the fishery type, management, and geography, amongst other factors [32]. Our results indicate that wind speed predicted ALDFG location the most (56.56 % of total variance explained), followed by bathymetry (40.28 %), and fishing effort (3.16 %). However, it is possible that the loss of different gear types (nets, traps, lines) are affected by each of these factors (and potentially others) differently. While we did not have enough data to assess each gear type separately, it would be helpful for future research to do so to gain a deeper understanding of ALDFG in the region.

Bad weather was identified as the most common reason for commercial fishing gear loss globally [60], and the second most common reason locally [29], and the most common reason in a global study [60]. 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 [22,19]. Our model indicated that gear loss generally increased with wind speed up to 4 m/s before decreasing (Fig. 3). A local BC fisher who uses 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 [29]. 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 Frenkel et al. [29] 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 and data coverage between the two methods.

We found that ALDFG presence increases as ocean depth becomes shallower (Fig. 2a). This relationship is similar to that between derelict gillnets and depth in Puget Sound, Washington State (WA), USA [2], various net fisheries in Australia and Indonesia [58], and the results of a review on causes and drivers of ALDFG globally [61]. Most ALDFG presence data occurred between 0 – 500 m depth in our case study (Fig. 2a), which falls within the 40 – 1000 m depth at which fishers set their gear in Canada's Pacific Ocean (depending on the target species). Setting fishing gear in shallow waters can increase the risk of snags on bottom obstructions including rocky outcroppings, including but not limited to rocky outcroppings, boulders, shipwrecks, logs, derelict aquaculture equipment, or other fishing gear [2,32,6,39,51,55,58,60,59,63,9,15]. DFO has introduced measures around commercial fishing gear to reduce its loss due to shallow depths. For example, DFO requires commercial gillnets in Canada's Pacific Ocean to be much shallower than their American counterparts in Puget Sound to reduce the likelihood of fishers potentially catching and losing their gear on rocky pinnacles in deeper areas [2]. 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 [26]. However, fishing gear loss still occurs despite the existing preventative measures.

Fishing effort is a key reason for ALDFG, as fishing will result in losing gear accidentally as the gear is exposed to various levels of environmental and other factors while in use (Table 1). In order words, the more time commercial harvesters spend fishing, the more likely they are to experience environmental challenges that could cause them to lose their gear. However, the level of effort may not be the primary factor that influences gear loss as indicated by fishing effort explaining the least amount of variance in our model. For example, high effort in optimal conditions may not result in gear loss, whereas lower effort in poor weather conditions (or other suboptimal conditions) could lead to a substantial amount of gear loss. Additionally, fishing effort is relatively continuous along the coastline of BC and therefore other factors (e.g. wind speed, bathymetry) are necessary to understand why gear loss happens more often in particular areas. As better data becomes available, it would be interesting to assess if the density of fishing vessels impacts commercial fishing gear loss in the region as it is possible for these factors to be correlated.

Our 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 [2,3], regional workshops [22], and in the BC Lost Gear Survey [29]. In addition to supporting previous grey literature in the study area, our results are also consistent with the fact that much of the small-scale commercial fishing in Canada's Pacific Ocean takes place near the coast [42]. While we 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 voluntarily [44]. Many fishers do not wish to have AIS on-board their vessels as they often want to keep their preferred fishing grounds private [44]. For example, flyover estimates of fishing effort in Canada's Pacific Ocean found that 89 % of commercial fishing vessels did not have AIS during the survey [42]. It is therefore likely that fishing effort is much higher in the study region, though this would not change the model's spatial predictions of lost gear if the distribution of fishing effort is adequately represented by the subset of tracked vessels. Fishing effort based on DFO fishing logs would provide more comprehensive data as all vessels must fill out and submit their logbooks upon landing. However, those data are currently unavailable to those outside of fisheries monitoring and management. It is also possible that the predicted areas of ALDFG occurrence may be different depending on the gear type, and future follow-up studies could be useful to identify gear-specific patterns. Despite some limitations of our model, we believe that the output is a useful starting point for fisheries, management, and other stakeholders to consider when developing best practices to reduce fishing gear loss and retrieval programs in the study area.

There are clearly other factors affecting gear loss in Canada's Pacific Ocean as our model explains 31.4 % of the variability in the dataset. 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 Puget Sound and in British Columbia, Canada [2,29,6]. 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 as new fishers are more likely to make mistakes when using gear or selecting a place to fish [2,29,35,58]. 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 [2,6,39,51]. In Canada's Pacific Ocean, deliberate disposal at sea is a relatively rare reason 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 because gear can be very difficult and expensive to replace [29]. Additionally, commercial fishing gear is well marked in Canada's Pacific Ocean, so other fishers are aware of who passively fishing gear belongs to if it becomes dislodged from its original locationt. Additionally, gear loss factors may be gear-specific, and only general or dominant relationships between the factors and lost gear location will be apparent when all gear types are modelled together. Finally, ALDFG from recreational fisheries poses a large knowledge gap, which would be a great direction for future research considering the popularity of recreational fishing in the region.

We have shown that a SDM approach can be used to predict ALDFG locations, however, future efforts for Canada's Pacific Region could improve on our current model. First, predicting ALDFG locations by fishery and gear types would provide more detailed insight on gear loss factors and locations in the region. Second, including current and wind direction could highlight if those factors (or their interactions with others) influence lost gear accumulation by potentially moving gear from its original location. For example, it is possible that heavy traps could get buried in soft bottom environments and lighter gillnets might drift. Implementing these considerations into future modelling efforts for Canada's Pacific Region will provide more detailed insight of commercial fishing gear loss factors in the region, therefore allowing fishers and management to develop fishery specific strategies to reduce future gear loss.

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. DFO has funded short-term commercial fishing 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 Puget Sound has been hosting a Reporting, Response, and Retrieval program since 2012 to retrieve newly lost nets before they cause environmental harm [2]. 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 [21,40,7]. Therefore, it is imperative to provide long term gear retrieval support to local fishers, especially in the off-season or to those unable to fish, to facilitate their marine stewardship into the future.

## CRediT authorship contribution statement

**Natalie C. Ban:** Supervision, Conceptualization, Writing – review & editing, Methodology. **Josephine Iacarella:** Supervision, Conceptualization, Writing – review & editing, Data curation, Methodology. **Caitlin M. Frenkel:** Methodology, Conceptualization, Writing – review & editing, Project administration, Formal analysis, Writing – original draft, Investigation, Data curation.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2025.106861.

## Data availability

The data that has been used is confidential.

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