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# Predictive model identifying locations of fishing gear loss or accumulation in Montserrat

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## Introduction

The negative impacts of abandoned, lost, and discarded fishing gear (ALDFG) are a growing concern in the Caribbean region. Whether intentionally discarded or accidentally lost, ALDFG is one of the deadliest forms of marine litter. It catches and wastes target and non-target marine species, damages marine and nearshore habitats, poses navigation risks, and is expensive and hazardous for fishermen and marine communities to deal with (Macfadyen et al., 2009; National Oceanic and Atmospheric Administration Marine Debris Program, 2016; NOAA, 2015). Of the fishing gears used in the Caribbean, nets, traps and fish aggregation devices (FADs) are identified as the most harmful types of ALDFG due to their risk of loss and the negative impacts they cause after loss (Gilman et al., 2021; Global Ghost Gear Initiative, 2021).

Surveys of fishers and other stakeholders have indicated that ALDFG is widespread in the Caribbean region, with traps and nets making up the bulk of the problem (Antonelis and Drinkwin, 2021; Matthews and Glazer, 2009). Limited published sources have documented incidences, impacts, and rates of loss of fishing gears in the region. The International Coastal Cleanup documented more than 42,000 fishing nets found on coastal beaches in the region from 1989-2012 (UNEP CAR/RCU, 2014). Toller and Lundvall, (2008) documented that 5.5% of fishing trips at Saba Bank result in lost gear. They further estimated an annual loss rate from 13% to 49.4% for both lobster and fish traps at Saba Bank. Large numbers of lost lobster pots have been documented impacting reefs of the Florida Keys National Marine Sanctuary (Uhrin et al., 2014). Ehrhardt et al. (2009) noted that up to 800,000 lobster casitas used in the Bahaman lobster fishery are never retrieved.

Negative impacts from ALDFG to target species have been documented in simulation experiments of both lobster and fish traps in Dominica, the Florida Keys, the Bahamas and the Virgin Islands (Butler et al., 2018; Butler and Matthews, 2015; Norris et al., 2010; Renchen et al., 2014). Significant reduction in production in lobster trap fisheries due to un-retrieved traps has also been documented in Nicaragua (Ehrhardt, 2006). Anchored Fish Aggregation Devices (aFADs), are being increasingly deployed in Caribbean fisheries (CRFM, 2019; Wilson et al., 2020). Lost FADs are known to damage sensitive nearshore habitats (Balderson and Martin, 2015) and at least one lost FAD has been found beached on the north side of Grenada (Baske and Adam, 2019).

Recognizing that lost fishing gear can harm marine habitats and impact fishers' livelihood, Montserrat joined the Global Ghost Gear Initiative in March 2018 and has since been active engaging on the issue of ALDFG. This project builds on efforts of the Montserrat Fisheries and Governance Unit to address problems associated with ALDFG by providing an initial baseline model of probable locations of fishing gear loss and accumulations. This is a recommended early step at evaluating the extent and impact of ALDFG in Montserrat (Jeffrey et al., 2016; Ocean Conservancy et al., 2020) and will assist in evaluating the scope of the problem and potential preventive action in Montserrat (UNEP CAR/RCU, 2014).

## Fisheries in Montserrat

The Fisheries and Ocean Governance unit manages all fishing in Montserrat. The exclusive economic zone around Montserrat is approximately 7,586 $km^2$, with 146-168 $km^2$ of shelf area, where inshore fishing activities occur (Masters, 2014; Tsui et al., 2020). Commercial and subsistence fishing is managed in Montserrat, with the commercial fleet entirely made up of artisanal vessels with open access to fisheries. Fisheries in Montserrat are small-scale, targeting multiple species, with various gear types including bag nets, traps and pots, beach seines, gillnets, hand lines, and longlines (Ponteen, 2021; Tsui et al., 2020) in the commercial sector, and more varied gear for subsistence fishing. In 2021 there were 24 registered, artisanal fishing vessels in Montserrat ranging from 3 to 10 meters in length (Dosell et al., 2021). Most fishing products go towards human consumption. The Montserrat Fisherman's Cooperative was established in 1968 to provide a collective voice for fishers. The Cooperative has approximately 20 members in 2020 (CANARI, 2020).

Targeted species vary by fishing location, categorized by reef, coastal pelagic, and pelagic environments (Ponteen, 2021) (Table X1). Catches include the following major commercial groups: tuna and billfishes, sharks and rays, perch-like fishes, herring-like fishes, crustaceans, and other fish and invertebrates. Most fishing targets perch-like fish and other fishes in invertebrate categories in Montserrat. In recent years, the catch has been composed primarily of large (>90cm) pelagic, medium (30-89cm) demersal, and medium reef fishes (Tsui et al., 2020) (Figure X1).

**Table 1. Commonly targeted species**

| Reef Fish | Coastal Pelagic | Pelagic |
|---|---|---|
| Red hind (*Epinephelus guttatus*) | Needlefish/Gar (family *Belonidae*) | Wahoo (*Acanthocybium solandri*) |
| Queen triggerfish (*Balistes vetula)* | Ballyhoo (*Hemiramphus brasiliensis*) | Mahi-Mahi (*Coryphaena hippurus*) |
| Doctorfish (*Acanthurus chirurgus*) | Crevalle Jack (*Caranx hippos*) | Tuna (family *Scombridae*) |
| Blue tang (*Paracanthurus hepatus*) | Bigeye Scad (*Selar crumenophthalmus*) | Kingfish (*Seriola lalandi)* |
| Snappers (various) | Bar Jack (*Caranx ruber*) | |
| Longjaw squirrelfish (*Neoniphon marianus*) | | |
| Honeycomb cowfish (*Acanthostracion polygonius*) | | |
| Coney (*Cephalopholis fulva)* | | |

Approximately 45.3 tonnes of fish and crustaceans were caught in the Montserrat artisanal sector in 2018, with most of the catch coming from lines, gillnets, and pots or traps (19, 14, and 10 tonnes, respectively) (Tsui et al., 2020) (Table 2, Figure 2). An estimated 23 open pirogues, canoes carved from a single log, ranging in size from 3-10 meters, landed approximately 31 metric tonnes of artisanal catches in 2018 (Ponteen

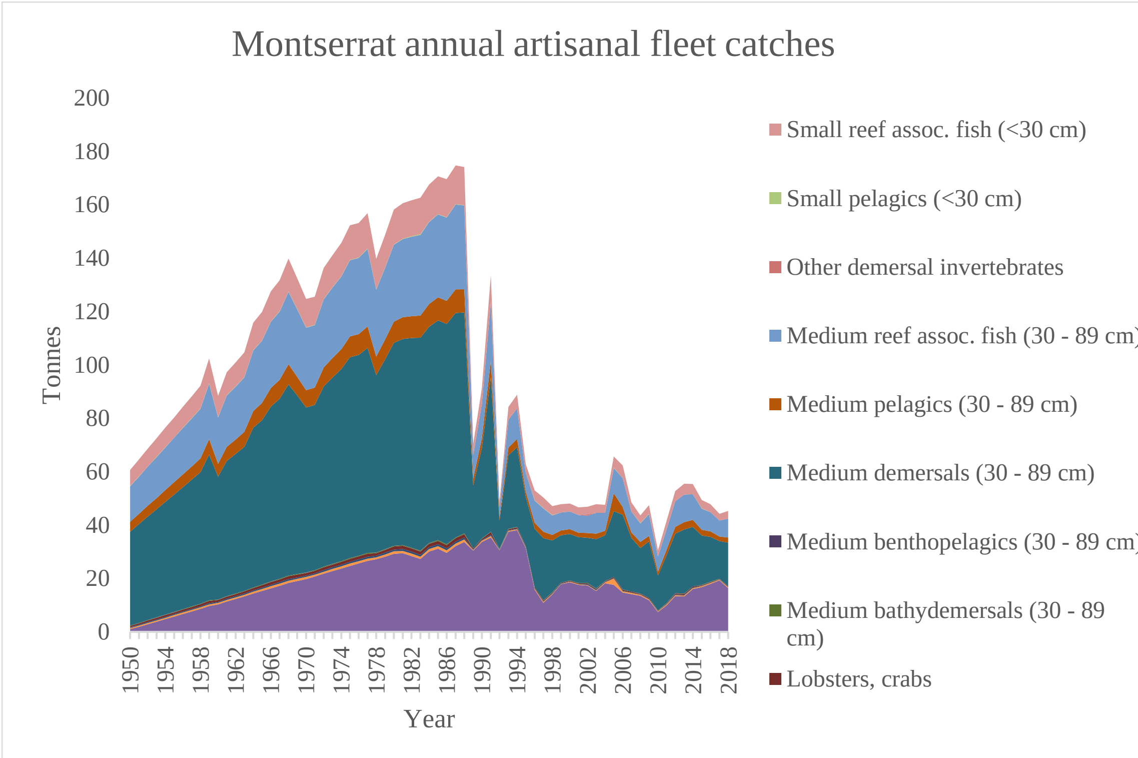


Figure 1: Annual catches categorized by fish functional groups (Tsui et al., 2020).

2018). Subsistence fishing harvested 7.5 tonnes, bringing the estimated total harvest to 52.7 tonnes in 2018 (Tsui et al., 2020).

Volcanic eruptions in the last decades have affected the location of fishing in Montserrat. Volcanic flows in the southern island smothered fishing grounds and continued volcanic hazards has closed two-thirds of the southern coast to fishing, pushing more fishers into the northern island reefs (Flower et al., 2020). Increased shipping resulting from increasingly important sand and aggregate mining (another byproduct of the volcanic eruptions) has also impacted fishing area on the southwest coast of the island (Dosell et al., 2021; Flower et al., 2021; Granderson et al., 2018).

The Fisheries and Ocean Governance unit plans to deploy more anchored fish aggregation devices (aFADs) to expand their high-value commercial fishing efforts (Ponteen, 2021). Along with increasing access to pelagic species, a goal of an aFAD program is to reduce the use of fish traps and pots in the inshore reef systems (Granderson et al., 2018). These gear types are frequently lost, leading to unobserved mortality through ghost fishing. There are currently four aFADs in place. The unit is also developing a management plan to increase commercial and subsistence aquaculture (Ponteen, 2021).

**Table 2. Tonnes of harvest in 2018 by commercial species category and fishery sector (artisanal or subsistence)**

| Commercial category | Artisanal | Subsistence | Total |
|---|---|---|---|
| Crustaceans | 0.25 | 0.07 | 0.31 |
| Herring-likes | 0.03 | 0.01 | 0.04 |
| Other Fishes & Invertebrates | 19.81 | 5.28 | 25.09 |
| Perch-likes | 20.92 | 2.08 | 23.00 |
| Sharks & Rays | 0.14 | 0.04 | 0.18 |
| Tuna & Billfishes | 4.11 | 0.03 | 4.14 |
| Grand Total | **45.26** | **7.50** | **52.76** |

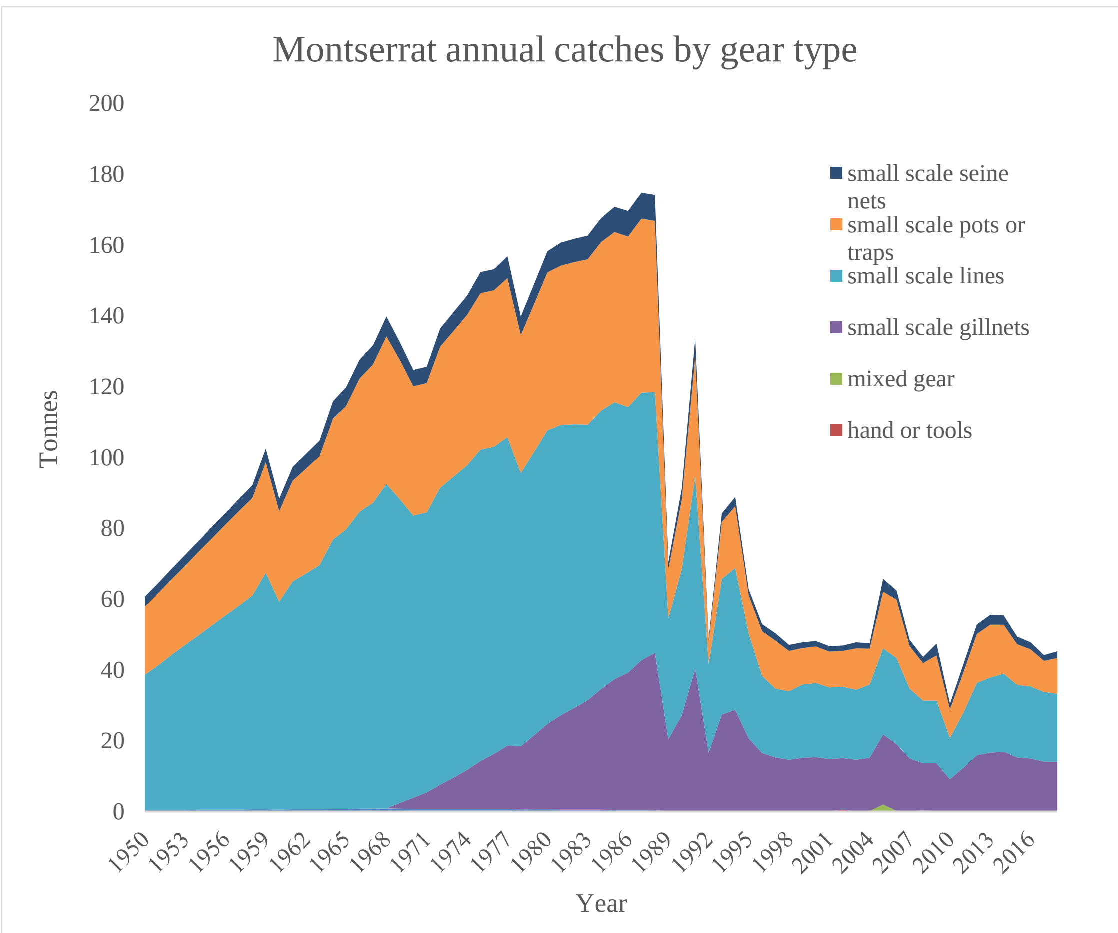


Figure 2: Annual catches categorized by gear type (Tsui et al., 2020).

## Abandoned, lost, and discarded fishing gear in Montserrat

Vessel conflict is a prominent cause of fishing gear loss in Montserrat. On the west side of the island, increases in shipping related to sand and aggregate mining, have caused conflicts between fishing and vessel traffic (Dosell et al., 2021). Fishers also report that increasing storms and changing weather patterns due to climate change are causing gear loss in inshore fisheries (Granderson et al., 2018). Beach cleanups in Montserrat have also collected ALDFG suspected of drifting onto Montserrat's shores from foreign fishing vessels (Department of Environment, 2020).

Fishers have been active in finding solutions to the problem of ALDFG. Dosell et al. (2021) document a 2019-2020 process that resulted in the creation of restricted zones in the pot fishing areas along the west side of Montserrat where cargo and tug vessels are prohibited. These zones were developed specifically to reduce pot loss from vessel conflicts and resulted from fisher data collection and collaborative meetings with fishers and vessel traffic interests.

The Montserrat Fishing and Boaters Association Inc. (MFBA) obtained funding for the Climate Change Adaptation in the Fisheries of Anguilla and Montserrat project to improve the design of aFADs to allow fishers to locate the units remotely and to test the use of biodegradable escape cord on fish traps to allow escape of trapped animals if traps are lost during fishing. The project was carried out from 2017-2020 cooperatively with the Montserrat Fisherman's Cooperative (CANARI, 2020).

### Lost Fishing Gear Surveys

Fisher surveys were conducted in Little Bay, Montserrat. Fishers were asked a series of questions designed to elicit information about:

- Basic information about the fisher
- Fishing gear use and location
- Fishing operations, cost, and catches
- Gear loss and reporting
- End-of-life fishing gear and other waste management
- Fishing gear marking regulations
- ALDFG perceptions and management insights

The surveys were designed by FAO and will be used for local purposes but also to feed into a global study of fishing gear loss. Each survey was specific to gear type: seine nets, gillnets, traps and pots, and hook and line. Fishers were asked, among other things, to identify the main causes of gear loss from a list of common reasons for loss. Fishers also reported the prevalence of good fishing practices that help to avoid fishing gear loss.

## Fisher survey results

*Results*

We focus our results reporting on the sections of the surveys relating to fisher perceptions of ALDFG causes, and fisher suggestions to prevent gear loss. Surveys were conducted by officers of the Montserrat Fisheries Department. In Little Bay, 39 fishers were interviewed. Of those fishers, 3 were interviewed more than once as they use multiple gear types. A total of 42 surveys were completed by gear types: 5 for seine nets, 5 for gillnets, 15 for traps and pots, and 17 for hook and line. With one exception, vessel size for fishing operations was consistently less than 12 m in length.

For seine nets, the minimum days fished per season was 12 and the maximum was 240. The average days fished per season was 115. For gillnets, the minimum days fished per season was 25 and the maximum was 60. The average days fished per season was 41. For traps and pots, the minimum days fished per season was 24 and the maximum was 120. The average days fished per season was 53. For hook and line, the minimum days fished per season was 20 and the maximum was 180. The average days fished per season was 67. (Table 3).

**Table 3. Vessel and fishing effort information by gear type in Little Bay**

| Gear Type | Average vessel size (m) | Min days fished per season | Max days fished per season | Average days fished per season |
|---|---|---|---|---|
| Seine nets | < 12 | 12 | 240 | 115 |
| Gill nets | < 12 | 25 | 60 | 41 |
| Traps and pots | < 12 | 24 | 120 | 53 |
| Hook and line | < 12 | 20 | 180 | 67 |

*Seine nets*

For seine net fishers, the leading causes of gear loss were reported to be nets getting snagged on obstructions, faulty gear, and damage due to interaction with large animals. (Figure 3). Other causes of gear loss, noted as sometimes resulting in gear loss, were poor weather conditions, operator error, strong currents, interference from other gear, and vandalism. Fishers also reported on good fishing practices that help to avoid fishing gear loss (Figure 4). In most cases, they reported that they generally always avoid setting gear in areas known for snagging, avoid fishing in poor weather conditions, avoid fishing in areas with strong currents or high vessel traffic, and avoid fishing in areas where animals were likely to damage their gear. Most fishers also reported always repairing or replacing worn fishing gear, securely stowing fishing gear to withstand bad weather, and making sure to properly maintain all their fishing equipment. All fishers surveyed reported that other occasional good practices include avoiding areas where animals were likely to damage their gear, properly training their crew how to use and properly dispose of fishing gear, openly communicating with nearby fishing vessels, and maintaining all fishing gear in good condition.

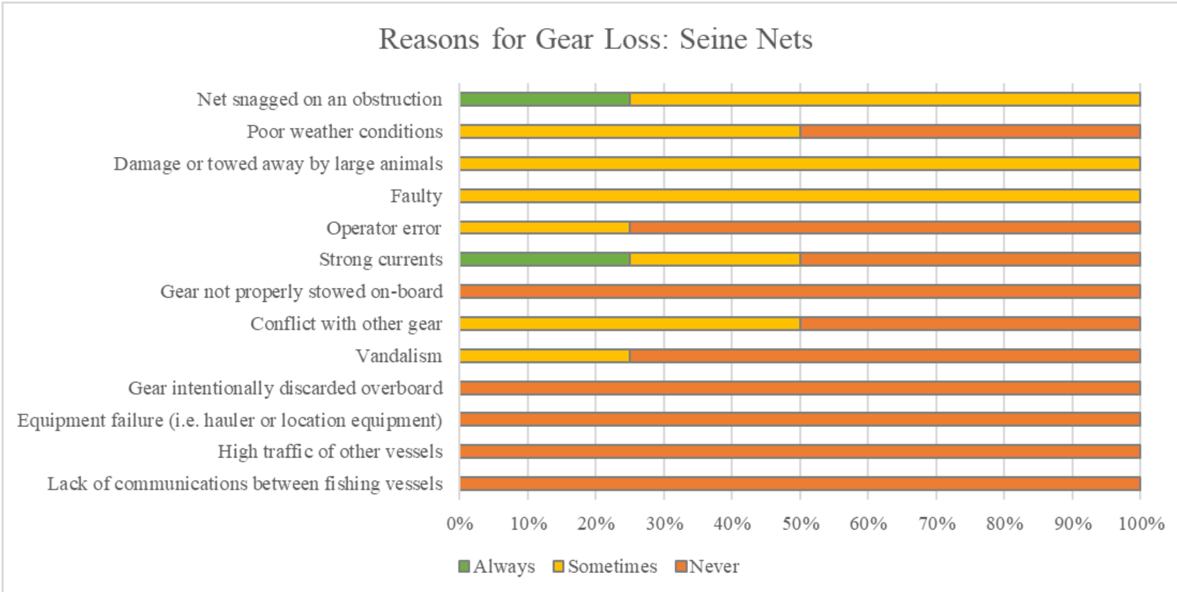


Figure 3: Results from the Little Bay fisher survey on the primary cause of gear loss for seine net fishing.

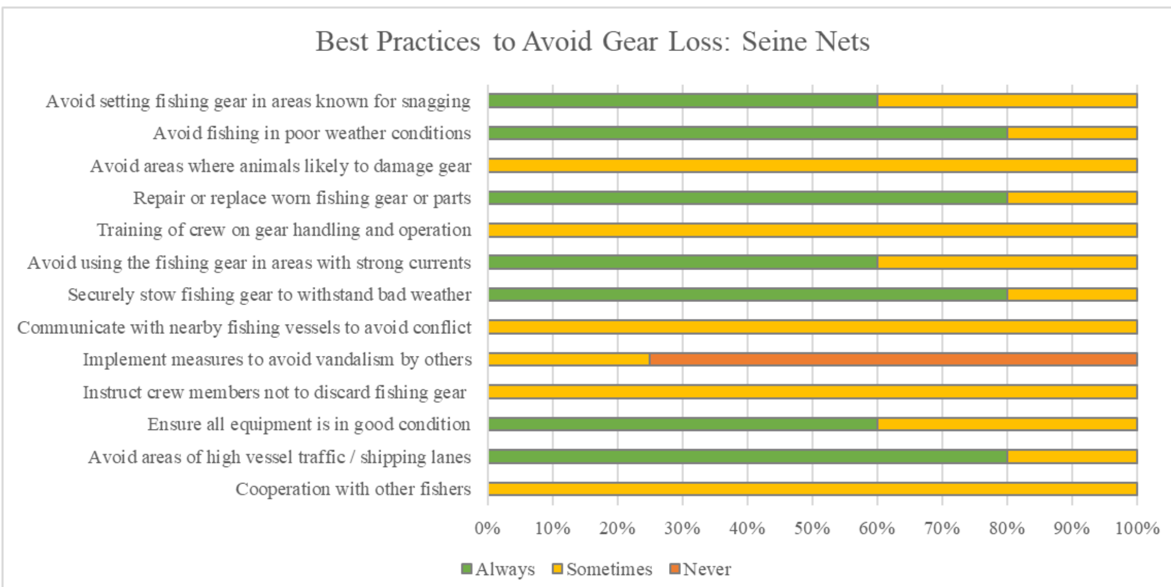


Figure 4: Results from the Little Bay fisher survey on the fisher suggestions for seine net loss prevention.

*Gillnets*

For gillnet fishers, the leading causes of gear loss reported by fishers were nets snagging on an obstruction, poor weather conditions, damage from interaction with large animals, and generally faulty gear. (Figure 5). Other causes of gear loss, noted as sometimes resulting in gear loss, were operator error, conflict with other gear or vessels, theft,

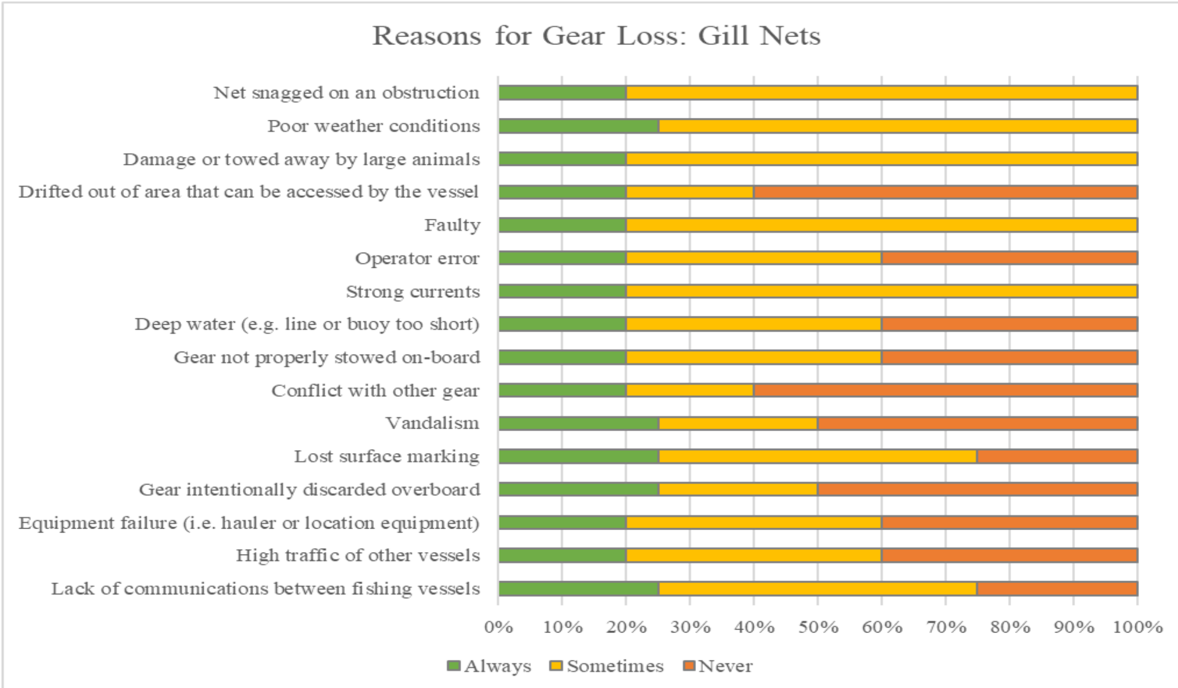


Figure 5: Results from the Little Bay fisher survey on the primary cause of gear loss for gill net fishing.

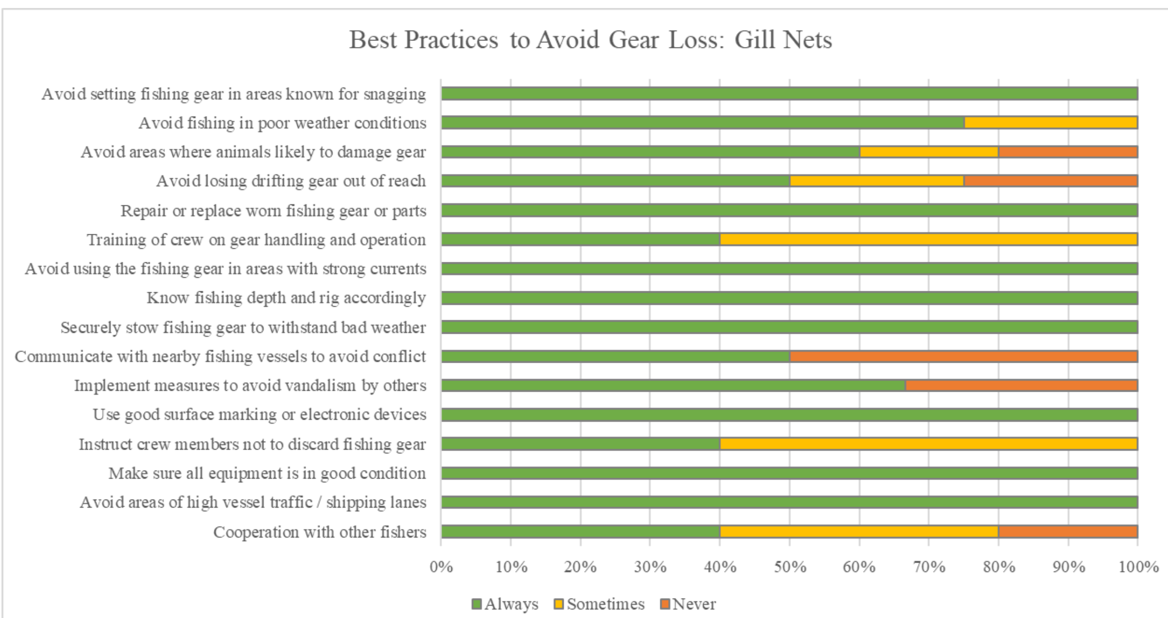


Figure 6: Results from the Little Bay fisher survey on the fisher suggestions for gill net loss prevention.

vandalism, or equipment failure. Fishers also reported the prevalence of good fishing practices that help to avoid fishing gear loss (Figure 6). They reported that they always avoid setting gear in areas known for snagging; maintain or replace worn fishing gear;

avoid fishing in strong currents; rig their gear according to the appropriate depth; securely stow fishing gear when not in use; use good surface indicators; perform proper gear maintenance; and avoid fishing in areas with high vessel traffic. Some fishers reported that avoiding fishing in poor weather conditions, avoiding areas where animals would likely damage gear, and losing drifting gear were all practices aiding in preventing gear loss. Additionally, some fishers claimed that good communication with nearby vessels, preventative measures against vandalism, and cooperation with other fishers were also good practices.

*Traps and pots*

For trap and pot fishers, the leading causes of gear loss reported by fishers were poor weather conditions, misjudgment of the water depth, faulty gear, other vessels interfering with their pots (Figure 7). Other causes of gear loss, noted as sometimes resulting in gear loss, were gear drifting from the set location, vandalism, strong currents, and a lack of communication between fishing vessels. Fishers also emphasized the importance of good fishing practices that help to avoid fishing gear loss (Figure 8). The most common methods fishers reported practicing were stow fishing gear to withstand harsh weather, properly maintaining equipment over time, and avoiding areas with high vessel traffic.

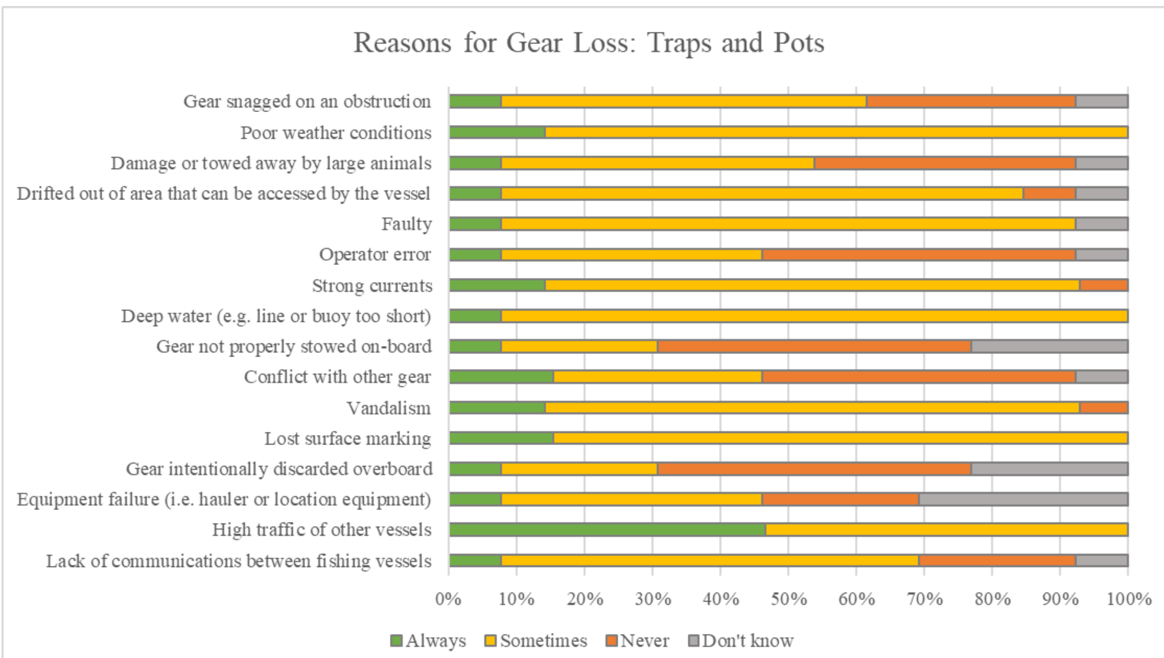


Figure 7: Results from the Little Bay fisher survey on the primary cause of gear loss for trap and pot fishing.

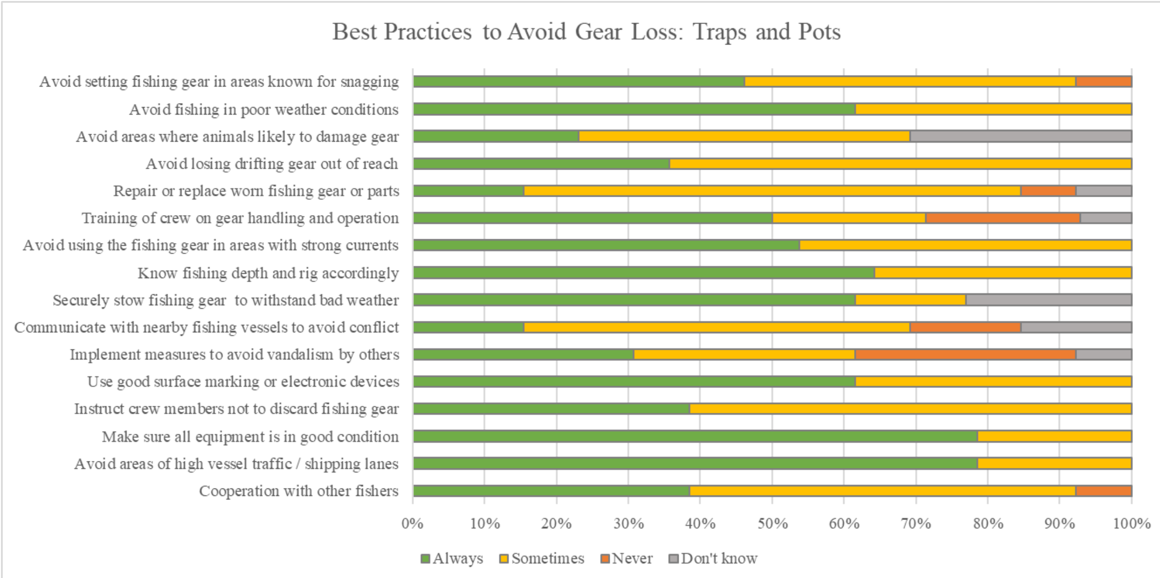


Figure 8: Results from the Little Bay fisher survey on the fisher suggestions for trap and pot loss prevention.

Some fishers reported that avoiding areas where animals could interfere with their gear, properly training their crew to operate their fishing gear, preventing vandalism, practicing frequent communication between vessels, and cooperating with other fishers were occasional good practices for avoiding gear loss.

*Hooks and lines*

For line fishers, the notable causes of gear loss reported by fishers were gear from damage due to getting snagged on obstructions and interactions with large animals (Figure 9). Most fishers also indicated that occasional reasons for gear loss included using faulty gear, fishing in strong currents, and operator error. Additionally, nearly all fishers interviewed reported that they sometimes or never lost fishing gear due to poor weather conditions, gear drifting out of their fishing area, losing gear in deep water, improperly stowing gear, conflicts with other fishing gear, vandalism, losing their surface marking, intentionally discarding gear overboard, or fishing in areas with high marine traffic. The majority of fishers reported that good practices for avoiding gear loss always included properly maintaining their fishing gear, avoiding setting gear where it was likely to snag, securely stowing gear during bad weather, avoiding fishing in poor weather conditions or areas with high vessel traffic, using good surface marking devices, instructing crew not to dispose of gear overboard, and properly maintaining fishing gear (Figure 10).

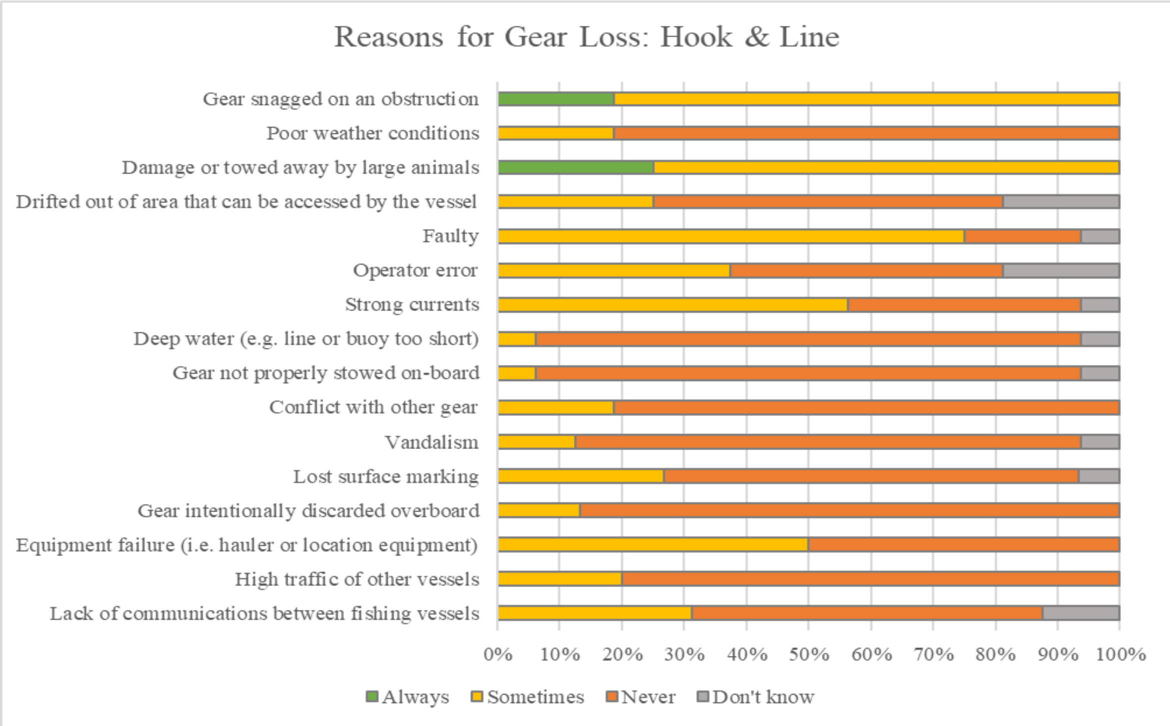


Figure 9: Results from the Little Bay fisher survey on the primary cause of gear loss for hook and line fishing.

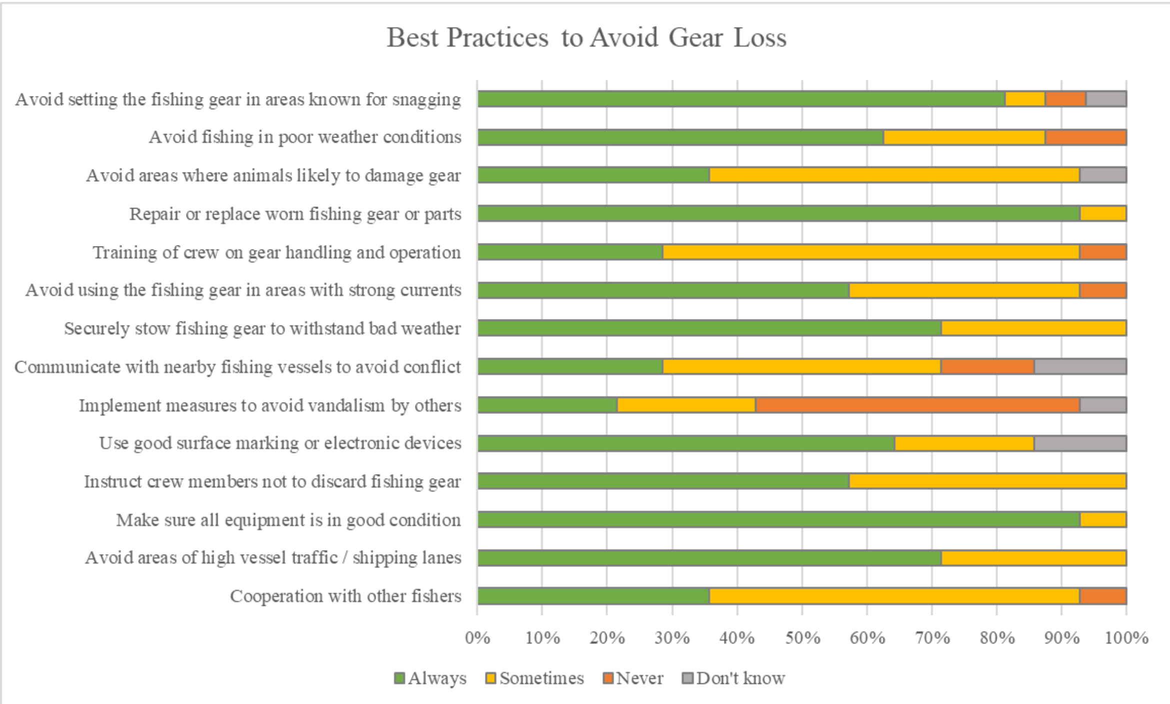


Figure 10: Results from the Little Bay fisher survey on the fisher suggestion for hook and line loss prevention.

## Predictive Model Methodology

For the development of a predictive model for where ALDFG is likely to occur in the marine territorial waters of Montserrat, focus was placed on pot gear and gillnets, as they are often considered to be the most common and harmful types of ALDFG (Huntington 2016). Seine nets and hook-and-lines were not specifically included in this model; however, most of the environmental variables included in the models represent reasons for fishing gear loss of any type, and therefore should have some value in predicting where loss of these gears are likely to occur. Summaries from the fisher surveys (described in previous section) were used identify the primary reasons for gear loss in Montserrat fisheries, which were used to inform the development of a suite of spatially explicit datasets, each representing a reason for gear loss. To quantify and rank the reasons for gear loss by gear type, we applied numeric values 0 – 2 to each of the fisher survey responses *Never* (0), *Sometimes* (1), and *Always* (2). The frequency of each response type was multiplied by the applied values to determine a score for each reason for gear loss; the scores were ranked from highest to lowest based on their percent of the total scored values. Similarly, survey responses to questions about depth of fishing effort and depth of gear loss were reviewed to identify differences in gear loss potential by depth profile.

Based on the ranking scheme, the five most common reasons for pot gear loss in Montserrat are: *High traffic of other vessels* (12.2% of total), *Poor weather conditions* (8.8% of total), and *Strong currents*, *Vandalism*, and *Lost surface marking* (each with 8.3% of total). For gillnets, the top five reasons for gear loss were: *Net snagged on obstruction*, *Strong currents*, *Damage or towed away by large animals*, and *Faulty* (each with 8.7% of total), and *Poor weather conditions* (7.2% of total).

Spatial analysis using ESRI ArcGIS 10.5 with the Spatial Analyst Tools extension was conducted to design a linear additive model to predict varying levels of likelihood of ALDFG occurrence in the territorial waters of Montserrat. Analysis began with individual analysis of series of base layers, each used to represent a specific reason for gear loss (Table 4). Datasets were not available for some of the primary reasons for gear loss, such as *Damage from large animals* and *Faulty [equipment/gear]*. For consistency and processing requirements across layers, datasets were set to the World Geodetic System (WGS) 1984 geographic coordinate system. Following data review and pre-modeling processing, the modeling analysis for each individual layer included clipping the layer extent to include only the waters around Montserrat, then ranking values between 0 and 6 to represent low to high probability of gear loss to occur at that location based on values estimated to influence gear loss.

**Table 4. List and description of spatial datasets used to represent primary causes for fishing gear loss, used to develop predictive model for ALDFG in Montserrat marine waters.**

| Cause of Gear Loss | Representative Dataset | Description & Source |
|---|---|---|
| Delineation of Study Area | Montserrat Coastline | Shapefile map of Montserrat administrative boundaries and detailed coastline (UN OCHA 2019) |
| Fishing Effort/Intensity | Fishing Effort | Raw VTS data (2018-2021) of Montserrat fleet filtered and aggregated by occurrence per 0.005° grid cell. Data provided by Montserrat Government (under confidentiality agreement). |
| Bathymetric profile | Bathymetry | Raster data for water depth (m) at 15 arc-second grids for waters surrounding Montserrat, obtained from GEBCO (2021) |
| Poor Weather | Wind Speeds | Mean annual values (m/s) per 250 m grid cells within Montserrat territorial waters (Global Wind Atlas 2021) |
| Strong Currents | Ocean Current Speeds | Monthly mean northward and eastward current speeds (m/s) per 0.083° grid cell in Montserrat waters extracted from the Copernicus-Globcurrent model, obtained from E.U. Copernicus Marine Service Information (CMEMS 2021) |
| Conflict with Vessel Traffic | Vessel Traffic Density | Observed ship movement from 2015 – 2020 within 500 m grid cells around Montserrat. Obtained from World Bank Catalog Data (Cerdeiro et al. 2020) |
| Seafloor Obstructions | Vector Ruggedness Measure (VRM) | Processed GEBCO bathymetry raster to depict variation in three dimensional orientation of grid cells within 3-cell neighborhood (GEBCO 2021; this study) |
| Seafloor Obstructions | Reef Locations | Polygon data at locations of coral reef structures around Montserrat, obtained from Flower et al. (2019). |

To spatially represent fishing effort and intensity by gear type, the Montserrat and UK governments provided raw vessel tracking systems data (VMS) from the Montserrat fishing fleet from 2017 through 2021. Data included GPS point locations collected multiple times per minute for each vessel during all fishing activities. Raw data included: *timestamp*, *boat number*, *trip ID*, *latitude*, *longitude*, *speed (m/s)*, *range (m)*, *boat name*, and *community*; the original dataset approximately 30 million entries. Due to incomplete coverage of the fleet in 2017 (A. Ponteen, pers. comm), only data from 2018 – 2021 were used for this model. Data was not distinguished by gear type. To distinguish data collected during pot and gillnet fishing activity from vessel transit or other fishing activity, the data was filtered for speeds from 0 to 2.0 knots (0 – 1.03 m/s) based on analysis from Dosell et al. (2021) of vessel speeds during different fishing related activities, and other studies showing that gillnet fishing activity is also executed within the same range of speeds (≤ 2 knots) (Guan et al., 2021) We did not filter for fishing activity from other gear types such as seines and hook-and-lines,  however future iterations of these models could include such data if warranted. All filtered data points were transferred to ArcGIS summed within 0.005° grid cells covering the study area. This provided a high resolution estimate of spatial distribution and intensity of pot and gillnet fishing activity in Montserrat waters. Fishing effort was binned in eight categories (0 – 7), representing low to high probability of gear loss simply based on the frequency of presumed fishing activity occurring within each cell (Table 5). Additionally, a review of the data shows that 99.5% of filtered data points fall within 0 – 550 m water depth, according to the GEBCO 2021 bathymetric data. To eliminate spatial outliers, and keep the analysis within Montserrat territorial waters, the 550 m contour was used to define the outer bounds of the study area for the predictive model. This differs from the 3 nautical mile territorial waters, as it covers the large shelf north of Montserrat, but a relatively narrow area in the southern waters where water depths increase abruptly.

**Table 5. Probability ranking for fishing effort/intensity as a cause for gear loss based on aggregated VTS data per 0.005° grid cells from 2018-2021.**

| Fishing Effort | Rank | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|
| | Value Bins (points/cell) | >500 | 201 - 500 | 101 - 200 | 51 - 100 | 26 - 50 | 11 - 25 | 1 - 10 | 0 |

Fisher survey responses about depth at which gear is lost suggests that pot gear loss is most frequent in water depths between 50 – 200 m, closely followed by 0 – 50 m, and may sometimes occur in depths >200 m. For gillnets, survey responses suggest that gear is lost almost exclusively in 0 – 50 m water depths; however, some gillnet fishing effort occurs at depths 50 – 200 m. Bathymetric depth profiles were ranked in four categories (0 – 3) according to these responses, to reflect likelihood of gear loss by water depth (Table 6).

**Table 6. Probability ranking for bathymetry as a cause of gear loss based on fisher survey responses.**

| Bathymetric Profiles | Gear | Value Bins (m) | >1,000 m | 201 – 1,000 | 51 - 200 | 0 - 50 |
|---|---|---|---|---|---|---|
| | Pots | Rank | 0 | 1 | 3 | 2 |
| | Gillnets | Rank | 0 | 0 | 1 | 3 |

The Global Wind Atlas dataset provided mean annual wind speed (m/s); wind direction was not analyzed. Assuming there is a direct correlation between higher wind speeds and what would be considered *poor weather conditions* at sea, the mean wind speeds were split by quantile into four bins, and then classified by rank order 1 – 4, with 4 being the highest wind speeds and most likely to cause gear loss, and 1 being the lowest (Table 6). Poor weather was one of the top three reasons for gear loss in fisher surveys for both pot and gillnet gears, therefore the same ranking system for wind speeds was used for modeling pot and gillnet loss potential.

**Table 7. Probability ranking for wind speed as a reason for gear loss based on association with poor weather conditions within velocity bands.**

| Wind Speeds | Rank | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| | Value Bins (m/s) | 9.3 - 8.27 | 8.27 - 7.24 | 7.24 - 6.21 | 6.21 - 5.18 |

Vessel traffic density as a variable representing potential gear loss due to conflicts with vessel traffic was represented by the dataset showing all observed ship movement from 2015 through 2020 within 500 m cells. Vessel traffic was as a reason for gear loss was ranked differently for pots and gillnets; for pots is was ranked highest, whereas for gillnets it was ranked fourth, along with other reasons. To emphasize the influence of vessel traffic on pot gear loss, values were split by quantile in to six bins with six ranked values for probability (1 – 6). For gillnet loss, these same the vessel traffic density was split into three bins with corresponding ranks (1 – 3). The bins ranking from 0 – 3 for gillnets, and 0 – 6 for pots represent low to high probability of gear loss occurring due to conflict with passing vessels (Table 8).

**Table 8. Probability ranking for vessel traffic density as a reason for gear loss within density bands for pot gear loss and gillnet gear loss.**

| Vessel Traffic Density | Gear | Values (v/cell x 1 million) | 14.56 – 17.10 | 2.34 – 14.56 | 2.12 – 2.34 | 0.47 – 2.12 | 0 – 0.47 | 0 |
|---|---|---|---|---|---|---|---|---|
| | Pots | Rank | 6 | 5 | 4 | 3 | 2 | 1 |
| | Gillnets | Rank | 3 | | 2 | | 1 | |

Seafloor features were analyzed through bathymetric variance, as abrupt changes in water depth and the ruggedness of benthic terrain can cause gear loss. This is used to represent gear loss associated with *Net snagged on an obstruction*. As this was identified as the primary reason for gillnet loss, but not a significant reason for gear loss in the pot fishery, this dataset was used for the gillnet predictive model only, and not for the pot gear predictive model. To identify areas of high bathymetric variance, the bathymetry data was processed to determine the Vector Ruggedness Measure (VRM) within a 3-cell radius neighborhood, which is one of several ways to identify changes in terrain by capturing variability in slope and aspect of terrain in a single measure (Sappington et al. 2007). High VRM values represent greater complexity in the benthic terrain, and therefore areas we assume to have greater chances of causing fishing gear loss and/or accumulation by presenting an obstruction or snag. Values ranged from 0.002 – 0.946, and were split into four bins, 1 - 4, representing low to high probability of gillnet presence (Table 9).

**Table 9. Probability ranking for VRM representing bathymetric variance and potential seafloor obstructions as a reason for gillnet gear loss.**

| | Rank | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| Bathymetric Variance | Value Bins (VRM) | 0.946 – 0.538 | 0.538 – 0.279 | 0.279 - 0.089 | 0.089 – 0.002 |

It should be noted that the differences in number and values of bin rankings per dataset were the result of determining the best fit for the model after analysis of each individual dataset. In some cases, a standard number of bins per variable can often cause models to be overwhelmed by vast spans of high probability areas or understated with a paucity of high probability areas. The reliability of the data and the importance of each reason for gear loss is considered during analysis and contribute to the decision process. These considerations can be narrowed when known locations of ALDFG are available to analyze as part of the modeling process. Additionally, some datasets may be omitted from the modeled due to homogeneous distribution of values and/or coarse resolution. This was the case for the ocean currents data obtained from CMEMS. The monthly mean current speed (m/s) were summarized by month per 0.083° cell within the study area over the two year period 2020 – 2021. Analysis of data included summarizing monthly mean values and interpolating those values, using the kriging technique, to cover the entire study area. However, due to the coarse resolution of this dataset within the relatively small study area of the Montserrat fishing grounds, and the small variations of summarized and interpolated current speeds, we determined to omit this data from the predictive modeling process.

Using ArcGIS Spatial Analyst, all datasets that were not in raster format were converted to raster, and the values of each of the variables were reclassified by their value bins for each gear type (pots and gillnets). For each of the models, all re-classed raster sets were input into the ArcGIS Cell Statistics Tool and summed. They were each masked to cover only the study area, from the shoreline to 550 m water depth. The output result for the pot gear model was a full coverage raster with cell values ranging from 3 to 19, with 3 representing the lowest probability of gear loss occurrence and 19 representing the highest probability. For the gillnet model, the full coverage raster included cell values ranging from 4 to 19. Both models were converted to feature shapefiles for area summary purposes. To identify other potential areas for ALDFG that may not be highlighted within the predictive models, all known locations of coral reef structures were overlaid with the predictive models to highlight potential areas where ALDFG may likely occur, regardless of the predictive model values.

## Predictive Model Results and Discussion

Using spatial representation of variables known to influence the probability of fishing gear loss including concentration of fishing effort, bathymetric depths, wind speed, vessel traffic, and benthic terrains, the probability models reported here provide integer values from 3 to 19 representing low to high probability, respectively, of pots and gillnets within the fishing grounds around Montserrat. For visual analysis, the final products of the probability mapping includes binned groups of these values for final ALDFG probability ranking in six categories; *Remote*, *Low*, *Low-Moderate*, *Moderate*, *Moderate-High*, and *High* (Figures 11 & 12).

Both the pot gear and gillnet predictive models cover 208.53 $km^2$, with the lower half of the probability rankings (*Remote*, *Low*, & *Low-Moderate*) covering 55% and 62% of the total study area, respectively. In the pot gear model, 30% of the study area was considered *Moderate* probability for gear loss, with the remaining 16% covered by *Moderate-High* (14%) and *High* (2%) probability values. Within the gillnet model, *Moderate* values also covered 30% of the study area, while *Moderate-High* values covered 8%, and *High* values covered 1% (Table 10). The distribution of probability rankings for the pot gear model generally highlight the western portion of the study area, with higher value concentrations around the major fishing communities near the northwest and southwest sides of Montserrat, and offshore of these areas towards the outer bounds of the study area (Figure 11). These are likely the result of the high density vessel traffic that occurs along the west side of Montserrat. Some higher values also appear in the northeast portion of the study area, where strong winds and vessel transit routes overlap. In general, the gillnet model shows similar distribution of higher levels of probability, but with a greater emphasis on the northeast portion of the study area along the outer half of the large shelf (Figure 12). This is a result of the variance in benthic terrain in the area, along with the concentrations of heavy winds, vessel traffic, and fishing effort.

The coral reef areas cover 8.69 $km^2$, which equates to 4% of the total modeled area. Probability rankings for the pot gear model within the coral reef areas are fairly consistent, with 49% in the *Remote*, *Low*, and *Low-Moderate* categories, and 51% in the *Moderate*, *Moderate-High*, and *High* categories. For the gillnet predictive model, this split skews toward the higher probability categories, with 32% in the *Remote*, *Low*, and *Low-Moderate* categories, and 68% in the *Moderate*, *Moderate-High*, and *High* categories (Table 10). This suggests that, there is a greater likelihood of ALDF gillnets than pot gear to occur on the reef structures in the study area. Coral reef coverage in higher probability areas occurs primarily at the coral reefs along the northwestern coast of Montserrat (pots and gillnets), and in the northeastern portion of the study (gillnets) on the expansive shelf (Figure 11 & 12).

It should be emphasized that these are not “hot spot” maps, as they do not contain known data points of where ALDFG has been identified; yet we believe that they can provide guidance when determining where to apply resources to address ALDFG and can be used to identify potential ALDFG survey locations. The high probability areas shown here were developed through a predictive model based on input data from publicly available datasets and data collected by fishers (surveys) and resource managers (fishing effort). The purpose of this is to assist interested parties in identifying where the potential for ALDFG presence is more likely and help guide assessments in survey investigations. These models can be refined as more data on specific ALDFG locations in Montserrat waters become available.

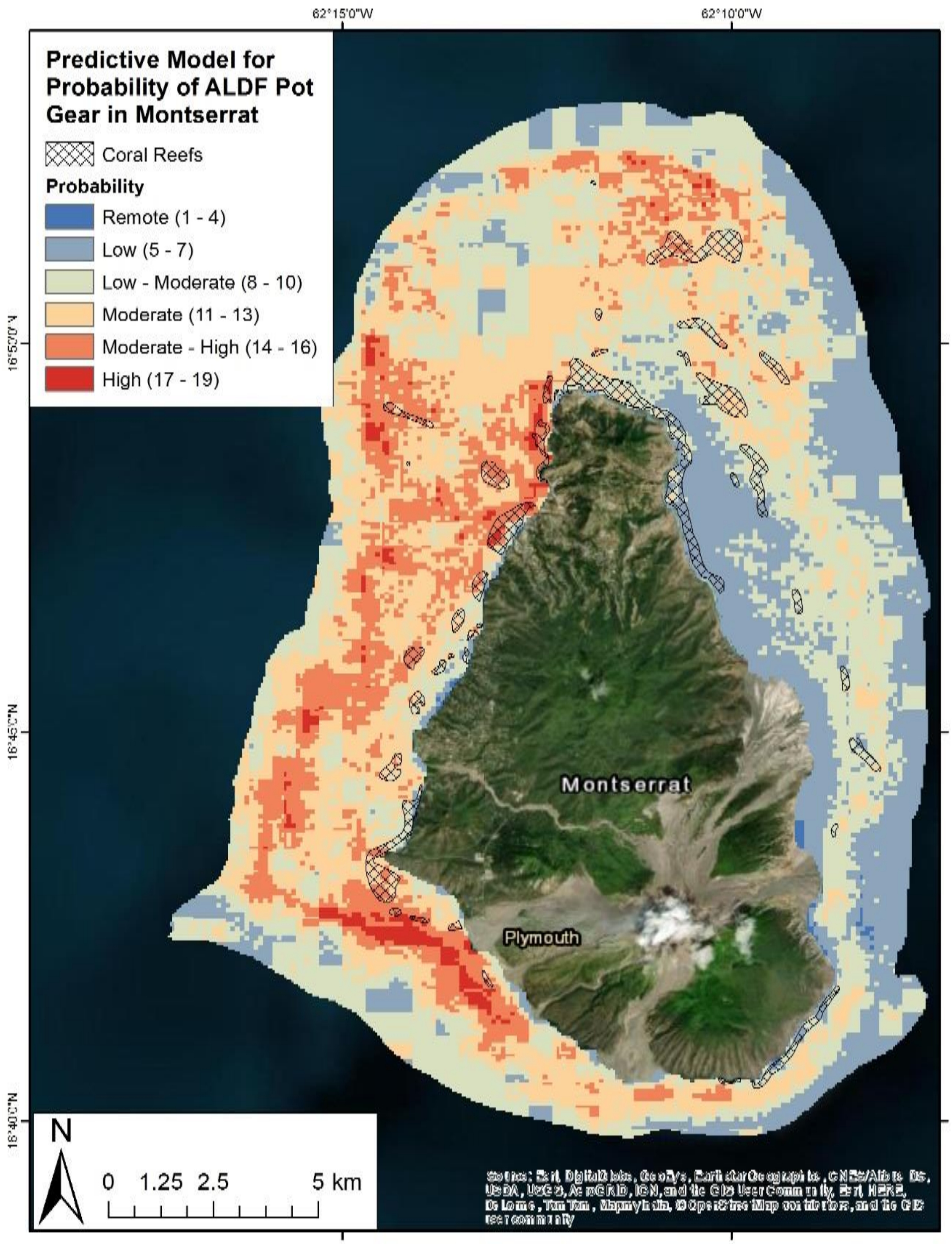


Figure 11: Predictive model result for ALDF pot gear; areas of low to high potential for occurrence based on spatial analysis of multiple layers in the Montserrat study area.

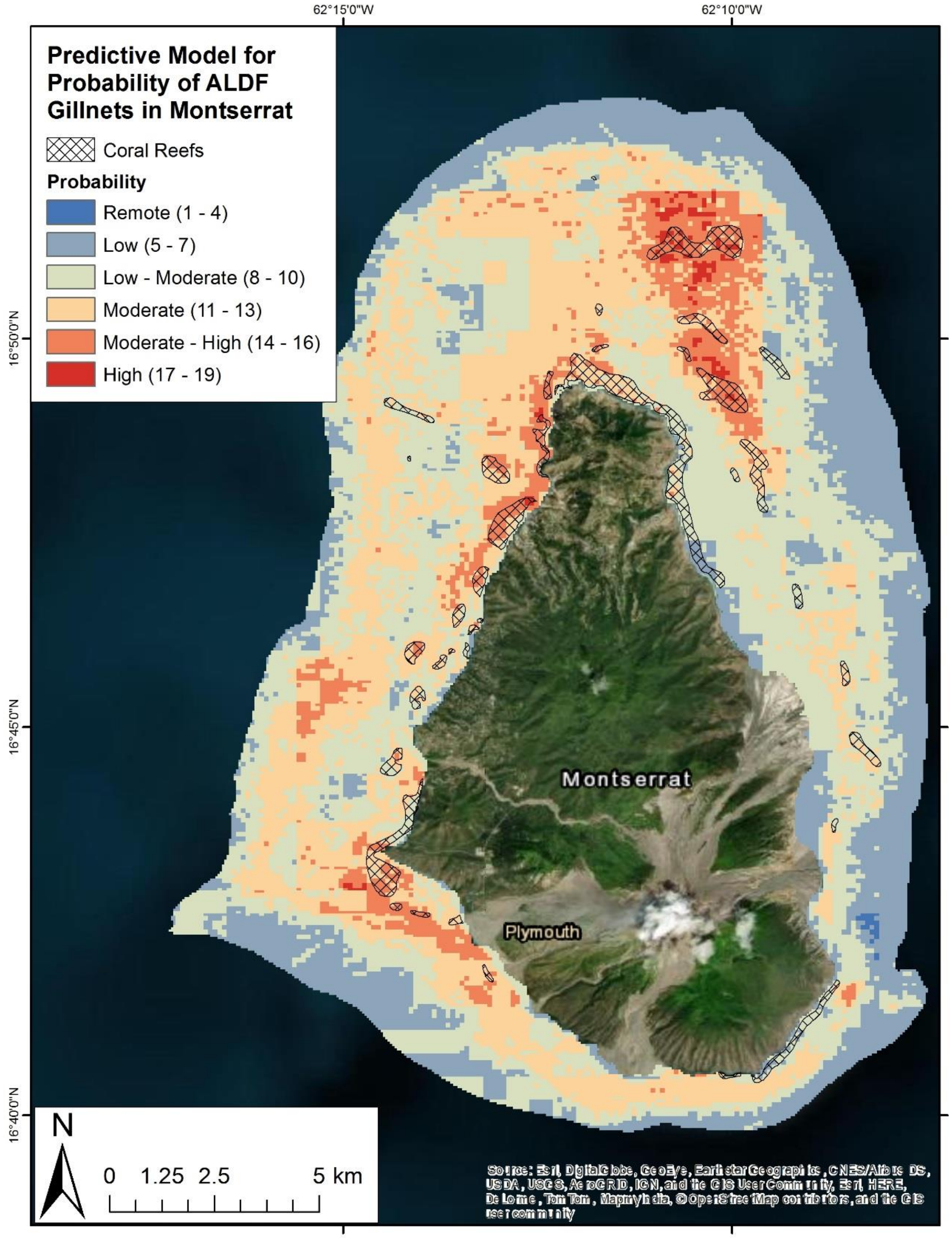


Figure 12: Predictive model result for ALDF gillnet gear; areas of low to high potential for occurrence based on spatial analysis of multiple layers in the Montserrat study area.

**Table 10. Percent of total Area of ALDF pot gear and gillnet probability model values and rankings in the Montserrat study area, and specifically within coral reef delineations inside the study area.**

| Model Value | Probability Rank | % of Pot Model Area | % of Gillnet Model Area | % of Pot Model Area in Coral Reefs | % of Gillnet Model Area in Coral Reefs |
|---|---|---|---|---|---|
| ≤ 4 | Remote | 0.2% | 0.1% | 0.2% | 0.0% |
| 5 - 7 | Low | 21.1% | 23.7% | 15.0% | 4.3% |
| 8 - 10 | Low-Mod | 33.2% | 37.9% | 33.6% | 27.7% |
| 11 - 13 | Moderate | 30.1% | 29.7% | 30.8% | 32.7% |
| 14 - 16 | Mod-High | 13.7% | 7.9% | 17.9% | 32.3% |
| 17 - 19 | High | 1.6% | 0.7% | 2.4% | 3.0% |

Accompanying this report are seven datasets for use in ArcGIS. They include:

- mont_pot_pm – raster file of the final pot gear data map with values depicting Probability Rankings (3 – 19).
- mont_GN_pm – raster file of the final gillnet gear data map with values depicting Probability Rankings (4 – 19).
- Montserrat_PotGear_PredMod.shp – vector shapefile with 17 features, each representing coverage of the modeled values 3 – 19, with attributes describing their area, and corresponding probability rankings.
- Montserrat_PotGear_PredMod_CoralReefs.shp – vector shapefile with 15 features, each representing coverage of the modeled values 4 – 18, that fall within coral reef delineations; with attributes describing their area, and corresponding probability rankings.
- Montserrat_Gillnet_PredMod.shp – vector shapefile with 16 features, each representing coverage of the modeled values 4 – 19, with attributes describing their area, and corresponding probability rankings.
- Montserrat_Gillnet_PredMod_CoralReefs.shp – vector shapefile with 14 features, each representing coverage of the modeled values 5 – 18, that fall within coral reef delineations; with attributes describing their area, and corresponding probability rankings.
- MontserratStudyArea550m.shp – vector shapefile delineating the study area from the Montserrat coastline extending to 550 m bathymetric contour line.

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