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PREDICTIVE MODELING OF ABANDONED, LOST, OR DISCARDED FISHING GEAR IN BELIZE

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Introduction

This project aims to provide an initial baseline of information about probable locations of loss of fishing gear and locations where lost fishing gear is accumulating and potentially negatively affecting species and habitats in Belize. This is a recommended first step at evaluating the extent and impact of ALDFG in Belize (Jeffrey et al., 2016; Ocean Conservancy et al., 2020). Hotspot analyses have been shown to improve efficiency of ALDFG removal activities (Martens and Huntington, 2012). And the systematic identification of likely places to document ALDFG will assist in evaluating the scope of the problem and potential preventive action in Belize, including recommended specialized education programs for fishing industry stakeholders (UNEP CAR/RCU, 2014).

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 armful types of ALDFG due to their risk of loss and the negative impacts they cause after loss (Huntington, 2016).

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 (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 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 (Toller and Lundvall, 2008). 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 noted that there are up to 800,000 lobster casitas used in the Bahaman lobster fishery that are never retrieved (Ehrhardt et al., 2009).

Negative impacts to target species have been documented in simulation experiments of both lobster and fish traps in the Florida Keys, the Bahamas and the Virgin Islands (Butler et al., 2018; Butler and Matthews, 2015; Renchen et al., 2014). Significant reduction in production in lobster trap fisheries due to unretrieved 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).

Unfortunately, there is very little information about ALDFG in Belize. Even Belize's Marine Litter Action Plan, developed in 2018, makes only passing reference to ALDFG as a component of sea-based sources of marine litter. It includes no mention of ALDFG in its evaluation and assessment of sea-based sources of marine litter and includes no actions around preventing impacts from ALDFG (Commonwealth Litter Programme, 2019)

Fisheries in Belize

Belize manages offshore industrial fisheries (high seas) and inshore commercial and artisanal fisheries.

Belize is an 'open registry' state, meaning that some foreign owned vessels fly its flag (FAO, 2018a). Belize's domestic fishery management is the responsibility of the Belize Fisheries Department under the Ministry of Blue Economy and Civil Aviation. Fisheries management authority is codified in the Fisheries Resources Act No. 7 revised in 2020. The Fisheries Act and its amendments and regulations provides for local and foreign fishing operations, rules-making and enforcement, fisheries development and management plans and establishes a Fisheries Council. The Act establishes safeguards for marine protected areas fishers' managed access program. The Act specifically calls for the minimization or elimination of pollution and waste originating from fisheries operations including lost or abandoned gear. The Act requires all fishing gear that is not allowed to be used in the fishing area where the vessel is operating to be stowed securely as to not be readily accessible. But it does not prohibit the gear from being on the vessel (Belize, 2020a).

Belize is a net exporter of fish and fishery products, exporting 21.6 million USD in 2016. In 2017, the fisheries industry employed over 3,200 people (FAO, 2018a). There are approximately 2,500 licensed fishers in the domestic fisheries of Belize, operating out of over 600 small vessels 5 to 10 m in length with outboard engines 15 to 75 HP. The two primary species targeted by the domestic marine fisheries in Belize are the queen conch (*Strombus gigas*) and the spiny lobster (*Panulirus argus*), which make up 80% and 12% of total annual production respectively. Economically lobster is the primary, high-value product, with exports in 2018 valued at US$11.9M compared to conch exports the same year at US$6.5M (UNCTAD, 2020). The remainder of the catch is primarily finfishes such as snappers, groupers, hogfish, king mackerel, barracuda, and jacks; and primarily for local consumption are grunts, snooks, mullets, porgies, and triggerfish.

Most landings occur at established fisher cooperatives; there are two large cooperatives in Belize City, and two smaller ones in southern Belize (FAO, 2018a). The majority of fishing effort occurs in the shallow waters of the reef structure and the adjacent lagoons and seagrass beds. Some, but not many, fishers target deepwater silk snappers, Caribbean yellow eye snapper and other species in 200+ m of water off the outer reef (FAO, 2018a; Heyman & Graham, 2000), and a small amount of shark fisheries occur using longline gear. Most fishing vessels target multiple species throughout the year, especially during the lobster fishery closure from mid-February through mid-June.

Gear types primarily used in these fisheries include traps, casitas (lobster shades), trolling gear, hand lines, and free diving. Hand lines are the primary gear type used to target finfish, and conch are harvested by free diving. Bottom trawling has been banned since 2010. Recently updated fisheries regulations prohibit the use of gillnets in marine reserves, near river mouths, within 100 yards of reefs and other specific areas along the shoreline and prohibit the use of gillnets exceeding 100m in all internal waters (Belize, 2020a, 2020b; Belize Fisheries Department, 2020; FAO, 2018a). Prior to these prohibitions, gillnets were used to harvest fish such as sharks, jacks, snook and mackerel in relatively near shore areas, and baited gillnets were used to catch lobster in seagrass beds, primarily in southern Belize (Huitric 2005).

The lobster fishery is executed from two types of vessels: small wooden sailboats and skiffs. The sailboats have reefer capacity to preserve catch for six to ten days and can carry ten or more divers and a fleet of up to eight small canoes. Skiffs generally have less capacity and are used to take two to three day trips from local communities. Up to 90% of the lobster and conch landings are from the sailboats (Vivid Economics, 2014). The number of traps used per fisher varies; with some fishers deploying up to 1,200 traps, checking about 400 every two days (Huitric, 2005). To haul gear, a free diver descends to the deployed trap and hooks a line on it so that it can be retrieved by someone on the vessel. Lobster traps are not always marked due to fear of vandalism and poaching (Huitric, 2005), but most of the time there is a nearby stick or buoy in the vicinity of the trap to guide fishers to their gear (Ylitalo-Ward, 2016).

Lobster traps are mostly un-baited, but in some of the deeper waters where visibility is poor, bait will be used to attract lobster. Otherwise, lobsters are attracted to traps as shelter (Huitric, 2005). Most lobster traps are trapezoidal, made from strips of palmetto palm wood, with one or two funnel shaped tunnels on the end. In southern Belize some fishers use rectangular metal wire traps as opposed to the wood traps (Huitric 2004). There are no requirements for escape vents to allow for bycatch or undersized lobster to escape, nor are there biodegradable panels or other disabling mechanisms to reduce the amount of time lost gear would be ghost fishing. Fishers in Caye Caulker have said that lost lobster traps in Belize will continue to fish (Huitric 2005).

Lobster traps are set on the seafloor in shallow, clear water up to 30 m depth and typically soak for several days prior to harvest (Huitric, 2005). They are typically set on sand patches in seagrass beds in the lagoon areas around the main reef and at the Cayes and Atolls. Lobster traps are not allowed beyond the barrier reef, nor are they allowed within a distance of 300 m from any coral formation (FAO 2017).

Belize employs a ‘managed access’ approach in its domestic fishery, establishing tenured fishing rights, or Territorial Use Right for Fishing (TURFS). Licenses to fish are issued for specified zones or managed access fishing areas. There are eight fishing areas in the territorial sea (Figure 1); individual fishers can be licensed in a maximum of two areas per year (M. Gongora, pers. comm). Fisher organizations and fishing cooperatives are an active force in Belize and the Fisheries Council includes four representatives from these organizations, two from cooperatives and two from fisheries organizations. More than 85% of licensed fishers are members of a fisher cooperative (FAO, 2018a). Regulations require registration of fishers and fishing vessels. Vessel registration must be displayed

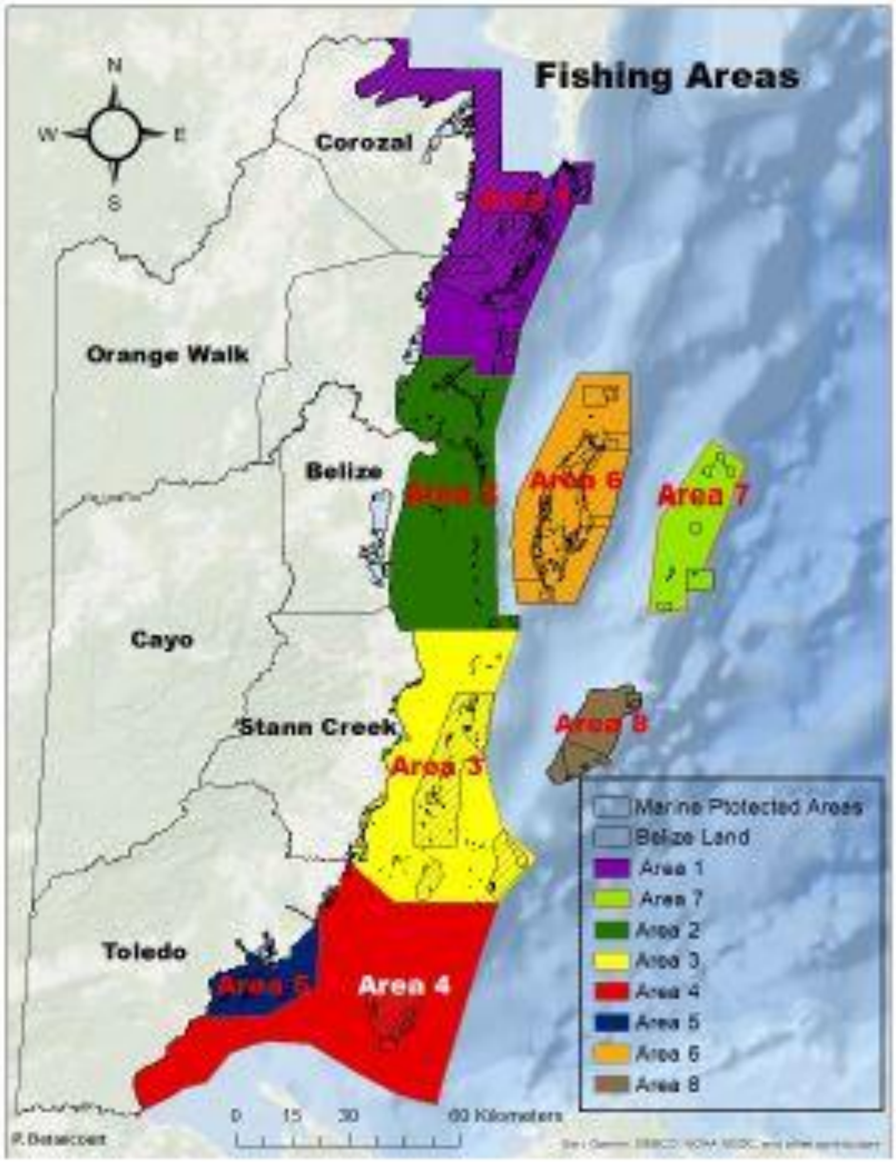

Figure 1. Fishing areas of Belize. Source BFD

on each vessel. There are no requirements to register or mark fishing gear of any kind (Belize, 2020a).

Belize belongs to the Caribbean Regional Fisheries Mechanism (CRFM), the Central America fisheries and Aquaculture Organization (OSPESCA), the Indian Ocean tuna Commission (IOTC), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the International Whaling Commission (IWC), the Latin American Organization for the Fisheries Development (OLDEPESCA), and the Western Central Atlantic Fishery Commission (WECAFC) (FAO, 2018a).

ALDFG Fisher surveys

The primary reasons for fishing gear loss around the globe have been well summarized, often including poor weather events, strong tidal currents, conflict with other gears, obstructions on the seafloor, and others (Macfadyen et al. 2009; Richardson et al. 2018; Antonelis 2012, 2013). However, how much these reasons contribute to gear loss is highly dependent on location, timing of fisheries, gear types, and other variables. Having known datapoints where ALDFG has been identified can assist in identifying relationships and correlations between the physical environment, fishing effort, other human activities and lost fishing gear (i.e., Antonelis 2013; NRC 2018).

Fishers are an invaluable source of information about ALDFG and many studies have shown the value of engaging fishers to estimate rates of gear loss, and to identify areas of frequent loss and reasons for loss (Antonelis, 2012; Carlson, 2015; Richardson et al., 2018). In March 2021, focused surveys of fishers were conducted in Belize to gather information on fishing and gear use and causes and extent of gear loss as well as to obtain insights from fishers on how best to prevent impacts from ALDFG. Surveys were conducted by Belize Fishery Department contractors and were focused on the commercial Spiny lobster trap fishery. The results of these surveys informed the predictive model and are reported below.

Methodology

Development of Derelict Fishing Gear Probability Areas

For the Belize lobster trap fishery, a dataset of ALDFG locations was not available. Therefore, we relied on summarizing reasons for gear loss in the fisher surveys conducted in March 2021 to gain an understanding of why traps are lost in the waters of Belize, and to identify corresponding spatial datasets that could be used as proxies to gear loss locations.

Completed scanned hard copies of completed fisher surveys were received March 22, 2021. NRC transcribed all data into an Excel spreadsheet for ease of analysis. Any numerical answers that were noted as ranges were averaged during input.

Survey questions of interest used a Likert Scale to determine likelihood of frequency (*Very frequently, Sometimes, Rarely, Never).* These options were used for questions around gear loss by component, Fishing Zone, month of the year, and depth. We applied a numeric value 3, 2, 1, 0, respectively to these answer options, with *Very frequently* assigned a value of 3 and *Never* assigned a value of 0. To indicate causes of gear loss, respondents were asked to indicate which common cause of gear loss was responsible for gear loss in their fishery. Answer options were *Always, Sometimes, Never* and *Don't know*. A numeric value 2, 1, 0, 0 respectively to these answer options with *Always* assigned a value of 2 and *Don't Know* and *Never* assigned values of 0. Respondents were asked to indicate how often each of 16 presented common causes of gear loss were observed. Causes presented as options and survey results are presented in Table 1.

We combined all response values for each identified cause of gear loss and determined which causes were most common based on total score of coded values. We combined the numbers for *Strong Currents* and *Drifted out of area that cannot be accessed by the vessel* because the latter indicates the presence of Strong Currents. Data analysis showed

Table 1. Frequency of identified gear loss causes

Causes for gear loss	Sum of Response Values	% of Total Response Values
Net snagged on an obstruction, such as reef or rocky area	3	1%
Poor weather conditions	58	21%
Damage or towed away by large animals	9	3%
Drifted out of area that cannot be accessed by the vessel	15	6%
Faulty, old or damaged gear	31	11%
Operator error	12	4%
Strong currents	38	14%
Deep water (like too short of line to buoy)	5	2%
Gear not properly stored on-board	3	1%
Conflict with other gear, e.g., trawls towing away other gear	5	2%
Vandalism (stolen or destroyed)	49	18%
The surface marking is lost, sunk, or malfunctioned	14	5%
Gear intentionally discarded overboard	2	1%
Equipment failure (i.e., hauler or location equipment)	2	1%
High traffic of other vessels	5	2%
Lack of communications between fishing vessels	20	7%

the three most common causes for lobster trap gear loss in Belize are, in order: *Poor weather conditions* (21%), *Strong currents* (combined with *Drifted out of area that cannot be accessed by the vessel*) (20%), and *Vandalism (stolen or destroyed)* (18%). We identified environmental and fishery data for use as proxies for these identified causes of gear loss.

Additionally, we related survey response data to information regarding water depths and habitat types where the fishery is executed, and a coarse summary of spatial distribution of fishing effort, in the form of number of licensed fishers per fishing area provided by Belize Fishery Department.

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, primarily lobster traps, occurrence in marine waters of Belize. Analysis of chosen datasets included ranking values between 0 and 3 to represent low to high probability of gear loss to occur at that location based on values estimated to influence gear loss. Analysis began with a series of base layers that included:

- Belize National Waters – shapefile map of Belize's EEZ (Maritime Areas, Territorial Sea) (Meerman 2004)
- Belize Basemap – shapefile map of Belize's land area, including Districts, Cayes, Islands, and Coastline. (Meerman et al., 2013)
- Belize Ecosystems – shapefile map of Ecosystems of Belize version 2017; vector shapefiles of terrestrial and marine ecosystems, including seagrass, lagoons, reef, mangrove, etc. (Meerman, 2017)

To properly analyze multiple layers together, we confirmed all datasets were set to the same geographic coordinate system. The datum chosen for this model was World Geodetic System (WGS) 1984, due to this being the original datum of the majority of the layers. Additionally, to ensure data analysis focused on the marine environment, rasters were masked by and vectors were clipped by the Belize National Waters shapefile.

We used wind speed to represent the *Poor weather conditions* variable identified in fisher surveys. Raster data coverage of wind speed data at 10 m elevation covering all of Belize land and waters was downloaded from Global Wind Atlas[1], which is available by country. This dataset provides mean annual wind speed values (m/s) per 250m grid cells. Wind direction was not analyzed, only mean wind velocity. Assuming there is a direct correlation between higher wind speeds and what fishers would consider poor weather conditions, the mean annual wind speeds were binned in three quantiles with an equal number of cells per bin, and then classified by rank order 1 – 3, with 3 being the highest wind speeds and 1 being the lowest (Table 2). Due to heavier winds in the outer Belize EEZ, beyond the lobster fishing ground, the rankings were calculated inside the Fishing Areas and Territorial Waters, then highest ranking was extended to those wind speed values extending to the outer EEZ boundary (Figure 2).

To represent *Strong currents* variable identified in fisher surveys, the monthly mean current speed (m/s) data for the Caribbean region was extracted from the Global Sea Physical Analysis and Forecasting Product, obtained from Copernicus Marine Environmental Monitoring Service (CMEMS 2020). Monthly mean current speed values (m/s) were summarized by 0.083° x 0.083° grids for the years 2019-2020. For a simple analysis of this parameter as a reason for gear loss, we chose to eliminate current direction and focus only on current speed. Therefore, each cell was represented by the mean absolute value of current speeds per month over the two year period. As it pertains to loss of fishing gear, we treat current speed similar to wind speed, in that the stronger the current, the more potential for gear loss. Therefore, the ranking values are simply binned by three bins of values that each have the same quantity of cells (Table 2; Figure 2).

Table 2. Classification ranking values for wind speed and ocean current speed predictive model. Higher class value reflects higher probability of ALDFG.

<table>
<tr><th>Wind Speed (m/s)</th><th>Class Rank</th><th>Ocean Current Speed (m/s)</th></tr>
<tr><td>1.23984 - 4.58681</td><td>1</td><td>0.0 - 0.05420</td></tr>
<tr><td>4.58682 - 4.98058</td><td>2</td><td>0.05421 - 0.09405</td></tr>
<tr><td>4.98059 - 5.42356</td><td rowspan="2">3</td><td rowspan="2">0.09406 - 0.45620</td></tr>
<tr><td>5.42357 - 5.65359 (outer EEZ)</td></tr>
</table>

[1] *Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information:* https://globalwindatlas.info

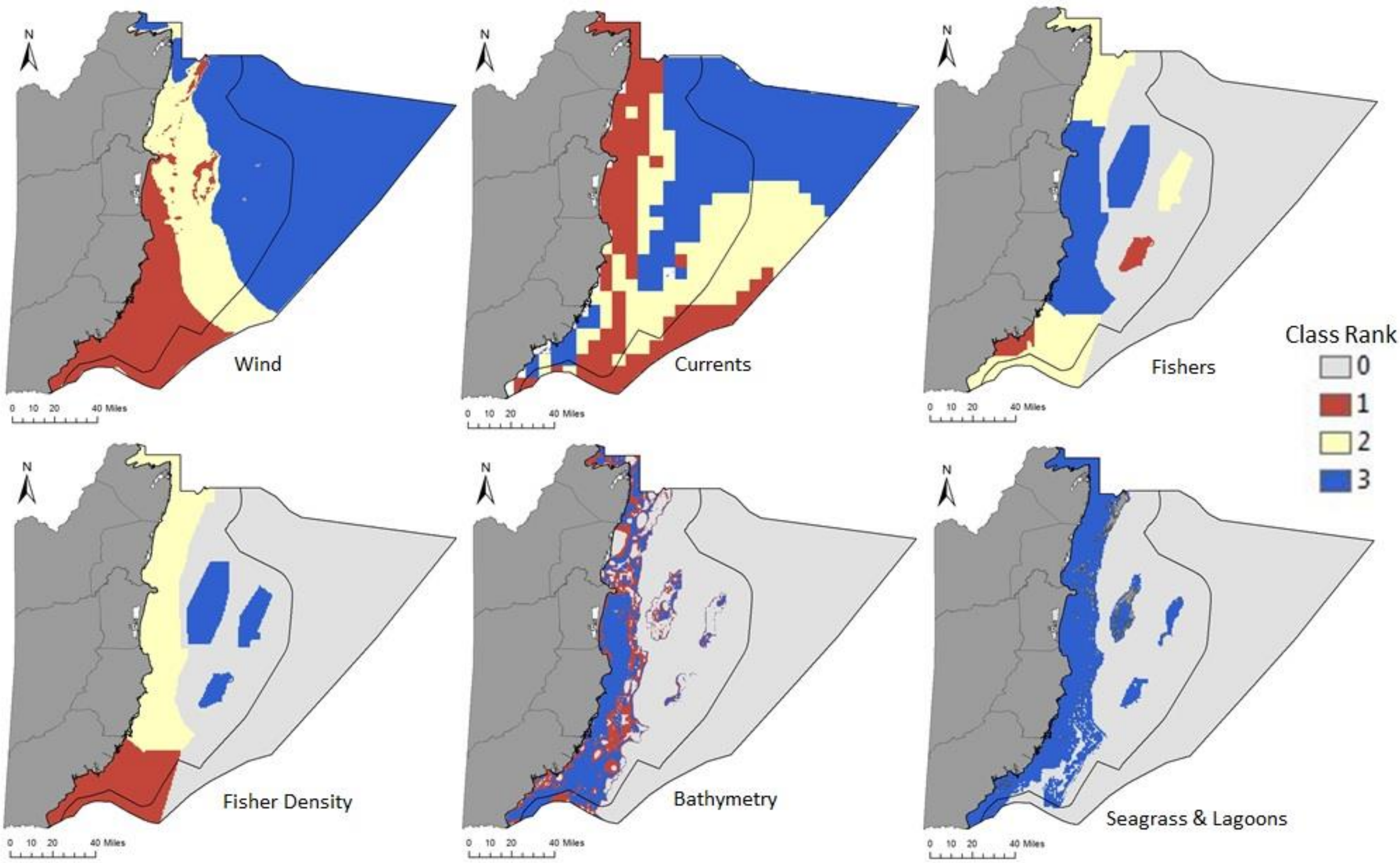

Figure 2. Six input variables re-classed to represent probability of ALDFG occurrence based on fisher survey responses. 0 = Low Probability – 3 = High Probability.

To represent the *vandalism* variable identified in fisher surveys as a variable for potential gear loss, we assume that most vandalism of commercial fishing gear is carried out by competitors and/or adversaries within the fishing sector. Fishers per square kilometer was calculated per fishing area and used to reflect the potential for vandalism per area. The number of fishing licenses per fishing zone was also used as a coarse metric for fishing effort, with the general assumption that gear loss will occur more frequently where more gear in the system is being used. Therefore, the number of licensed fishers per fishing zone is not only used as a metric for fishing effort but is also used as to represent the density of potential competitors on the fishing grounds. To represent this spatially, the Belize Fishing Area Map jpeg was imported into ArcGIS and georeferenced with ground control points at prominent landmarks and map grids. Heads-up digitizing was then used to create a Fishing Area vector map layer. Ranking of both the fishing density and the total number of fishers per fishing area were binned by natural breaks in the data, where relatively large gaps occurred between the values (Table 3; Figure 2). It should also be noted that all waters within the Belize EEZ that are not include in Fishing Areas 1-8 were given the 0 class value.

Table 3. Classification ranking values for wind speed and ocean current speed predictive model. Higher class value reflects higher probability of ALDFG occurrence.

Number of Licensed Fishers	Class Rank		Fishing Zone		Class Rank	Density (Licensed Fishers per km^2)
655	2		1		2	0.34422
958	3		2		2	0.503667
1071	3		3		2	0.471834
535	2		4		1	0.196847
79	1		5		1	0.210321
955	3		6		3	0.702575
566	2		7		3	0.915898
226	1		8		3	0.655052

Bathymetric raster data for water depth on a 15 arc-second grid for the marine waters of Belize was downloaded from GEBCO (2020). Bathymetric depth values were classified for the predictive model using available data from reports and survey information of the most common fishing areas. On the coarse level, all 45 respondents from the FAO surveys said that their fishing effort occurred between 0 and 50 m and literature review of the Belize lobster fishery provided information suggesting that most all lobster trap fishing occurs from 5 to 15 m water depth (Gongora, 2010), with some effort occurring out to 30 m (Huitric, 2005). To capture the primary fishing grounds without in the model we binned the bathymetry values in three bins; 0, 1, and 3. The 0 class value represents all water depths beyond 50 m, while the 1 value represents depths from 0 to 5 m and 30 to 50 m. Class value 3 was assigned to all water depths from 5 to 30 m (Figure 2).

Using the Reclassify tool in ArcGIS Spatial Analyst, the values for wind speed, ocean current speed, and bathymetry were reclassified to their new ranked values from 0 to 3. The rank values for each fishing area polygon were added in an attribute field and then the shapefile was converted to a raster with grid values equal to the rank classes. This was done twice; once for total number of fishers, and again for fishers per km^2. To account for fishing grounds as described in several reports as occurring in the lagoons and on seagrass beds, we extracted all polygons delineating seagrass beds and lagoons from the Ecosystems of Belize (2017) shapefile; prescribed both a class rank value of 3 and converted just the coverage of those features into a raster dataset. All re-classed raster sets were then input into the ArcGIS Cell Statistics Tool, and each grid cell represented the sum of all class values at that location. This produced a continuous raster covering the Belize marine waters, with grid values ranging from 0 to 18, with 0 representing the lowest probability of trap loss occurrence and 18 being the highest probability (Figure 2).

To ensure the lobster trap loss probability map is exclusively in the marine waters and not on land, the raster was converted into a vector-based shapefile and then the probability map was erased by all land areas, primarily islands, from the Belize Basemap. Finally, due to references explaining that trap fisheries do not occur on the reef and is prohibited within 300 m of any reef structure (FAO, 2017), we made a 300 m buffer around all reef polygons in the Ecosystems of Belize (2017) shapefile and used that data to erase values in the probability map; removing potential for high value probability to occur where fishing is reported not to occur. The probability map was then reviewed spatially to determine binned values that translate to Low, Moderate, and High probability of trap loss.

Results

Probability Mapping Analysis

Using spatial representation of known variables that influence the probability of gear loss including, wind speeds, current speeds, concentration of fishing effort, water depth, and habitat type, the probability model reported here provides integer values from 0 to 18 representing low to high probability of ALD lobster traps within the marine waters of Belize. The final product of the probability mapping includes grouped areas of Low, Moderate, and High Probability Areas. In total the predictive model covers 33,482 km^2. The Areas of low probability (value: 0 – 9) cover the majority, 77% (25,761 km^2) of the total area, primarily in the expansive outer waters of the EEZ (Figure 3). Moderate probability areas (value: 10 – 13) make up a total of 18% (6,067 km^2) of the EEZ, and occurs primarily inside the territorial waters, in common fishing areas. The high probability areas only account for 5% (1,654 km^2) of the total area, and patches of high probability occur in all fishing areas except areas 4 and 5 (Figure 3).

The probability map suggests that the areas with most potential for gear loss to occur are in Fishing Areas 2 and 4; but the densest concentrations per km^2 of high probability areas

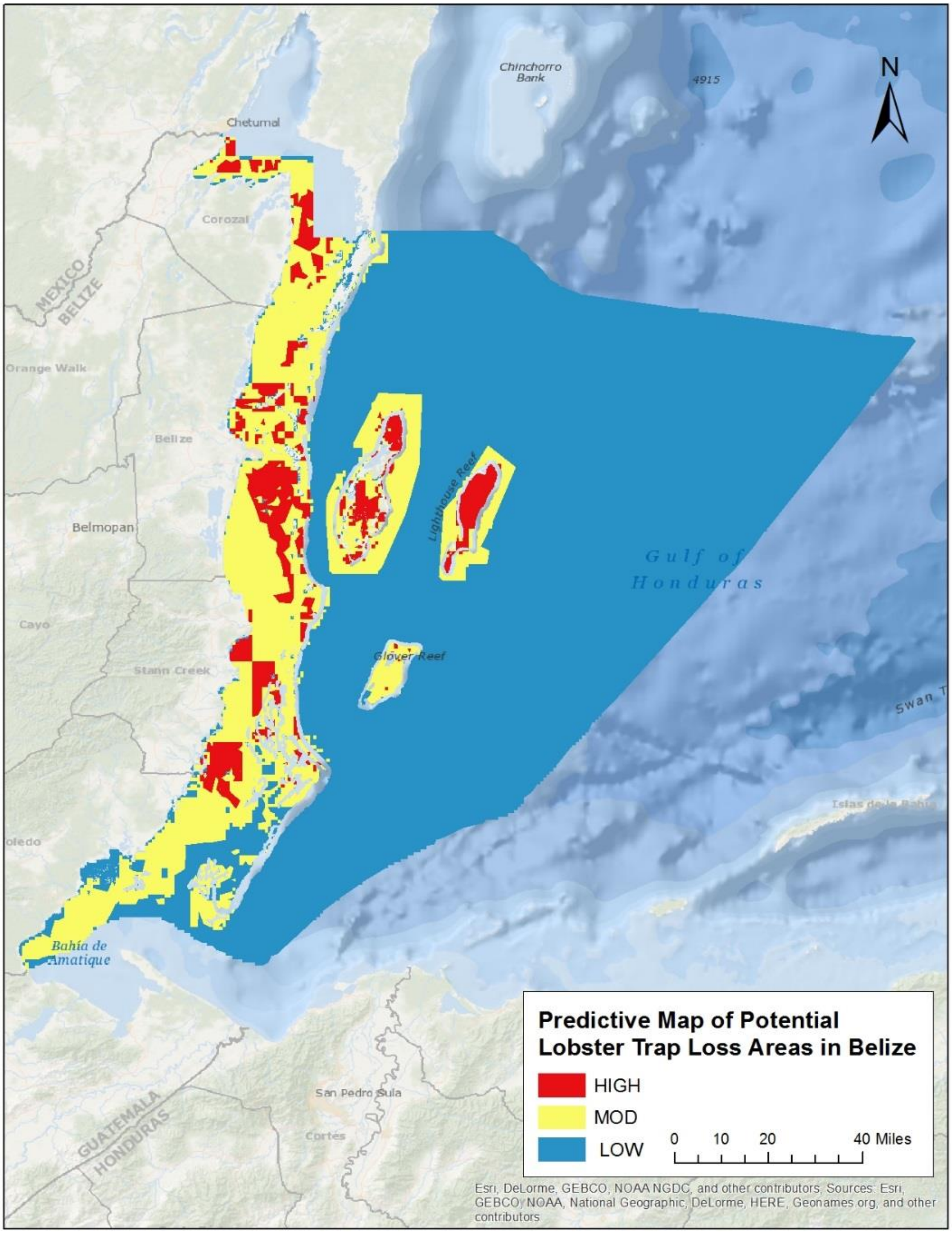

Figure 3. Predictive model result; areas of low, moderate, and high potential for lobster trap loss based on fisher surveys and spatial analsysis of multiple data layers.

are Area 7 and 2 (Table 4). While this is an unweighted, linear model, all variables were considered equally, and it is clear that the gradually higher wind speeds eastward, and the higher current speeds north and east (Figure 2).

Table 4. Total area in km^2 of ALDFG probability areas that cover Belize Fishing Areas and percentage each probability category per Fishing Area

Fishing Area	Combined Low, Mod, High Areas- km^2	LOW	MOD	HIGH
1	1,629	10%	74%	16%
2	1,738	5%	63%	32%
3	1,853	12%	65%	23%
4	2,494	57%	43%	0%
5	341	40%	60%	0%
6	1,076	6%	74%	20%
7	500	4%	60%	37%
8	245	37%	61%	2%
Grand Total	9,877	22%	61%	17%

Fisher Surveys

Fisher surveys were conducted in three main fishing areas where lobster traps are traditionally used: the northern and central fishing areas and Turneffe Atoll. The surveys targeted fishers and vessel owners at 49 fishing camps in Fishing Areas 1, 2, 3, and 6. Fishing Areas 2 and 6 are the primary fishing grounds for Spiny lobster trap fishing (Carcamo, 2021).

Forty-five fishers/owners of fishing camps and vessels were interviewed during March 2021. 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

We focus our results reporting on the sections of the surveys relating to fisher information, fishing gear use, operations, and ALDFG.

Of the 45 fishers interviewed, 43 indicated their age. All were between 30 and 70 years of age with most older than 40. Twenty (47%) fishers reported they had 5-20 years of experience and 23 (53%) reported over 21 years fishing experience (Figure 4). All

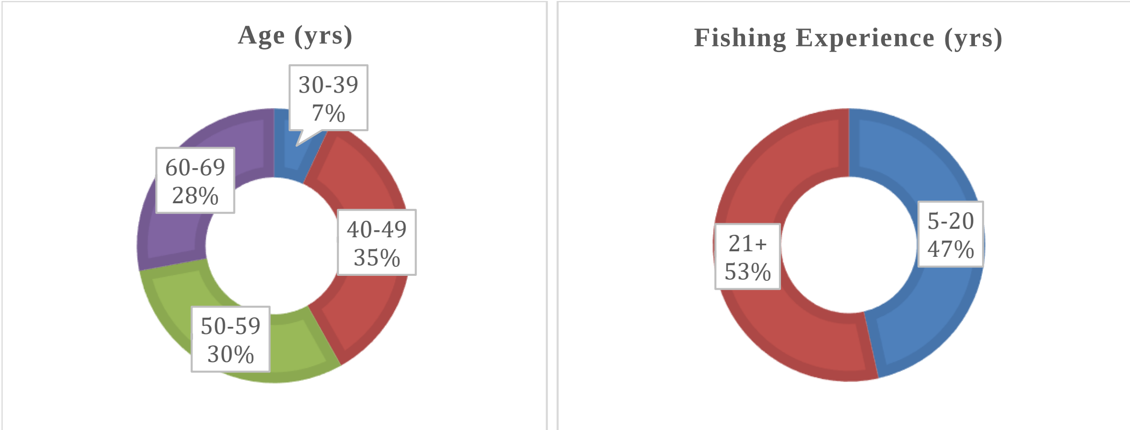

Figure 4. Age and years of fishing experience of interviewed fishers

respondents indicated they fished from vessels measuring less than 12m. All were spiny lobster trap fishers.

Most (36%) of the fishers interviewed fished in Fishing Area 6, followed by 34% fishing in Fishing Area 2 (Table 5.). Several respondents indicated they fish in more than one area. But 36 indicated they fish exclusively in one area with 19 respondents indicating they spend 100% of their effort in Areas 6 (Table 6).

Table 5. Number of fishers using select Fishing Areas

Area 1	Area 2	Area 3	Area 6
6	18	10	19

Table 6. fisher reported % fishing effort per Fishing Area

	Area 1	Area 2	Area 3	Area 6
25%	1	2	1	1
50%	0	4	4	0
75%	1	2	2	0
100%	5	9	3	19

The number of days fishers reported fishing ranged from 18 to 160 days with an average of 41.4 fishing trips annually. Trips lasted from 1 to 10 days with an average of 3.2 days. Fishers reported using from 35 – 2,800 traps/year. The median number of traps/year reported was 100. Fishers reported the average cost of each trap was 52 BZD (approximately 26 USD). Fishers reported an average soak time of 9.1 days.

Fishers were asked how often fishing gear was lost. Fishers indicated an average of 21 traps/year lost. The median reported annual trap loss per fisher was 4. This represents a 4%-8% loss rate (Table 7).

Table 7. Annual Spiny lobster trap loss rate

	Total (N=45)	Average/ fisher	Median/ fisher
# Reported traps used annually	12,895	286.56	100.00
# Reported traps lost annually	976	21.69	4.00
Calculated loss rate	8%	8%	4%

Fishers were asked to identify the main causes of gear loss from a list of common reasons for loss. Poor weather conditions were the leading cause of loss identified, followed by vandalism, high currents, and faulty, old or damaged gear (Figure 5). Fishers also reported the prevalence of good fishing practices that help to avoid fishing gear loss. They reported that they generally always avoid poor weather conditions and high currents. They stow their gear securely and ensure their crew is properly trained, including instructing them to not discard waste fishing gear overboard Figure 6).

Fishers were asked to indicate the importance of management practices to the prevention of gear loss or damage. Fishers indicated that access to accurate weather forecasting was most important as was quality fishing gear. They also noted the importance of the awareness of negative impacts of ALDFG. Fishers also corroborated the importance of fisher knowledge and experience (Figure 7).

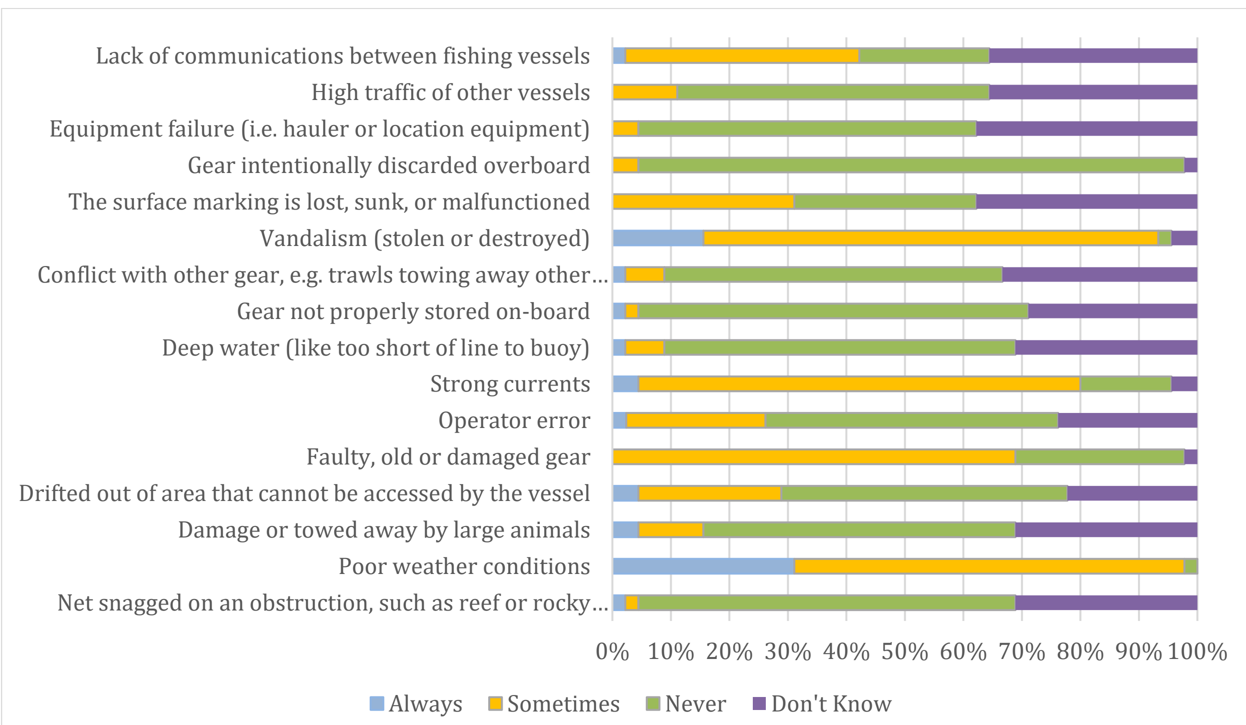

Figure 5. Causes of gear loss identified by fishers

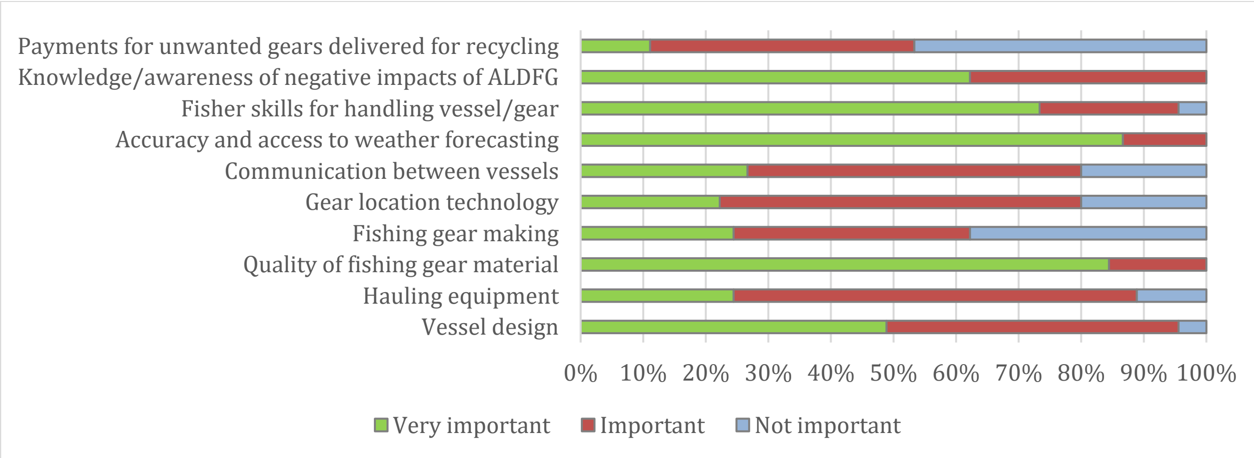

Figure 6. Best management practices to prevent ALDFG

Discussion

It should be emphasized that this not a “hot spot” map. The high probability areas shown here were developed through a predictive model based on input data primarily from fisher surveys and publicly available datasets. The one input feature that did not exist in this model were known locations of ALDFG. The purpose of this model is to assist in identifying where the potential for ALDFG presence is more likely and help guide assessments in survey investigations. As the first iteration of this model in the Belize lobster fishery, this is a working model that can be updated as more information becomes

available. If records of lost gear locations are collected, or if follow-up survey interviews were conducted with the fishing fleet members, the model can be adjusted to reflect new information.

The predictive model developed to identify varying levels of lost lobster pot probability was possible due to the gear data made available by the fisher interviews. Seafloor ruggedness or bathymetric variance was not used as one of the variables in the model as it did not appear high in the ranking of causes for gear loss with the lobster fishers. This is likely because trap fishing is exclusively conducted in the lagoon and seagrass, and therefore a rough or obstructed seafloor is likely not encountered often.
Of the fishing gears used in Belize, pots and traps are widely documented to pose the risk of ghost fishing (continuing to catch target and non-target species after gear is lost) (Antonelis et al., 2011; Breen, 1990; Butler et al., 2018; Butler and Matthews, 2015; Ehrhardt, 2006; Gilardi et al., 2020; Uhrin et al., 2014). Pots and traps are identified by the Global Ghost Gear Initiative (GGGI) as one of the most harmful types of ALDFG due to their risk of loss and the negative impacts they cause after loss (Huntington, 2016).

Whereas the prohibition on gillnets effectively eliminates impacts from this high-risk fishing gear, there is reported presence of Illegal, Unregulated, and Unreported (IUU)

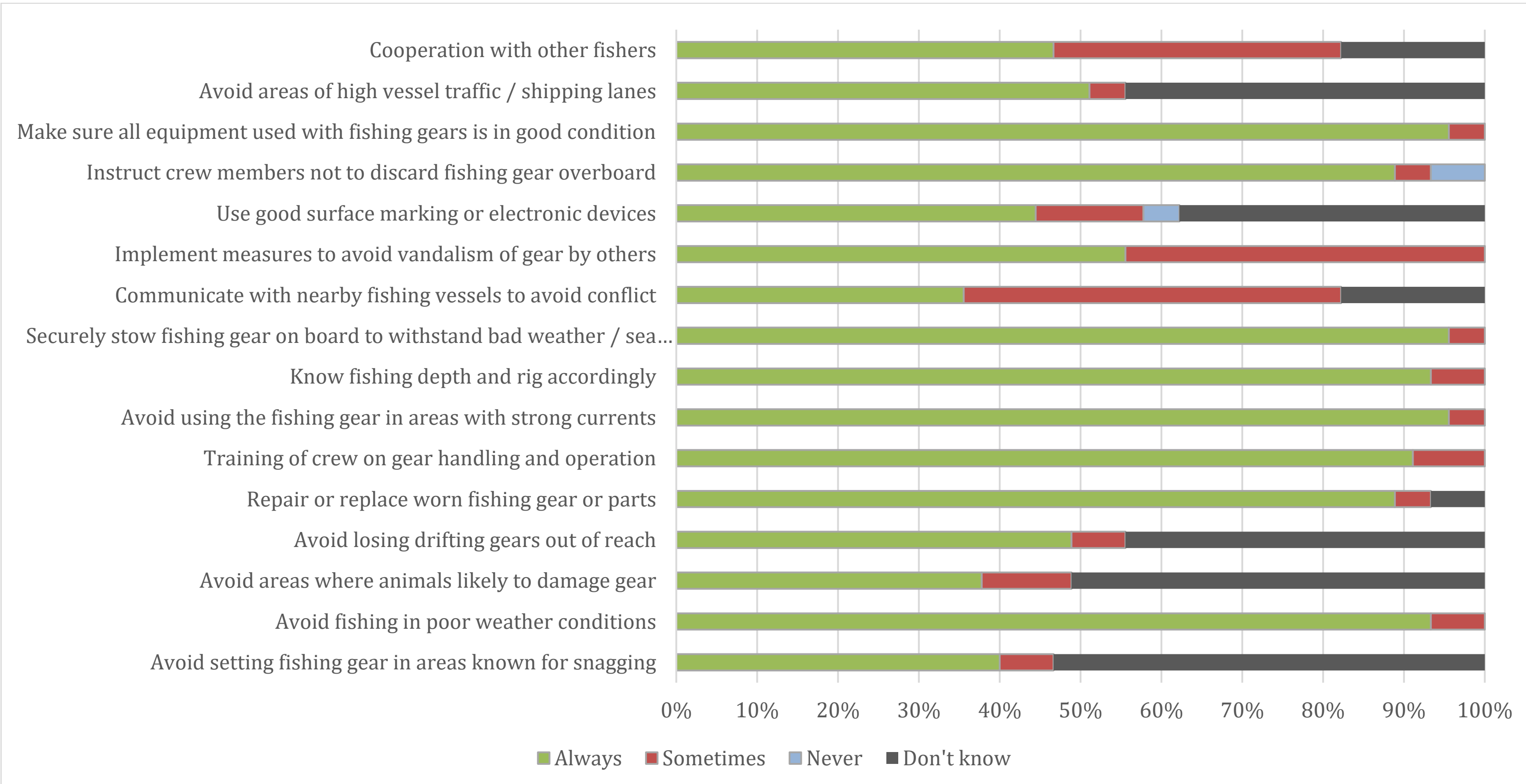

Figure 7. Good practices used to avoid fishing gear loss

fishing, particularly with gillnets, by fishers from neighboring countries in the southern Belize EEZ (Oceana 2020). This is certainly a challenge to all aspects of fisheries management, regulation, and sustainability. IUU fishing is known to propagate gear loss, and potentially at higher than usual rates for a variety of reasons (Macfadyen et al., 2009; Gilman 2015; Richardson et al., 2018).

Sources agree that a low-level of trap loss occurs in the Belize Spiny lobster trap fishery. The loss is generally whole traps that are lost and cannot be located by the fisher who deployed them.

We estimated a 4%-8% loss rate for Spiny lobster traps from fisher survey data. A recent study of global rates of fishing gear loss developed from mostly Northern hemisphere sources, estimated that 8.6% of all pots and traps used globally are abandoned, lost or discarded into the environment (Richardson et al., 2019). And Lively and Good (2018) estimate that 7% - 50% of pots and traps are lost with 41% - 66% of lost traps actively ghost fishing at any given time.

The GGGI launched the Best Practice Framework (BPF) for the Management of Fishing gear, a comprehensive guidance document detailing best practices for stakeholder throughout the seafood supply chain (from fishers to seafood companies and fisheries managers) to reduce impacts from ALDFG (Huntington, 2016, 2017). The BPF aligns closely with best practice recommendations included in other literature and key international instruments issued by the Food and Agricultural Organisation of the United Nations (e.g. Guidelines for the Marking of Fishing Gear) IMO (e.g. MARPOL Index V), OSPAR (e.g. Regional Action Plan for the Management and Prevention of Marine Litter) and provides a reference point for interventions throughout the supply chain (FAO, 2018b; Gilman, 2015; Macfadyen et al., 2009; OSPAR Commission, 2014).

The BPF include categories of management options specific to each stakeholder group including fisheries managers and control officers. Fisheries management practices included in the BPF common fisheries management strategies to help prevent and mitigate gear loss including spatio/temporal separation of fishing fleets, registration, seasonal restrictions, and gear marking to help prevent and mitigate gear loss.

Some of these recommended fisheries management practices are implemented in the Spiny lobster fishery in Belize, serving to minimize both loss of gear and negative impacts from lost gear. The use of wooden lobster traps is consistent with recommendations in the BPF to use biodegradable gear parts to limit the amount of time gear with ghostfish (Gilman, 2016; Huntington, 2017). However, in simulated lost lobster pots, Mathews and Thomas (2015) observed wooden slat pots in Florida ghost fishing for 509 days. Therefore, while it is good these are not persistent plastics, they can capture lobsters and other non-target species while abandoned. Without degradable escape panel, ghost fishing could occur a much longer time than should be acceptable. The spatial and length restrictions on gillnets are consistent with some of the best management practices outlined in the BPF and reduce the most damaging impacts to species and habitats from gillnets lost at sea (Gilman, E., Chopin, F., Suuronen, P. & Kuemlangan, 2016; Gilman et al., 2021; Huntington, 2016, 2017).

The Belize Marine Litter Action Plan recommends including information about best practices to prevent introduction of marine litter into the ocean (Commonwealth Litter Programme, 2019). This could include information about the BPF and the VGMFG.

Recommendations

To appropriately address negative impacts of ALDFG in Belize, developing a predictive model of where gear is lost is an appropriate first step. But to develop effective management strategies that are appropriate to the scope and scale of the issue, a clearer picture of the issue is needed. Effective management of ALDFG generally follows a logical path as outlined by the Global Ghost Gear Initiative:

- Document the scope and scale of ALDFG with baseline ecological and economic studies, predictive models, fisher surveys and gear loss reporting.
- Identify underlying causes of gear loss.
- Identify solutions specific to the causes (often management actions).
- Advocate for adoption of the solutions (through education, policy, or regulatory changes).
- Execute the solutions and monitor their effectiveness.

(Ocean Conservancy et al., 2020).

A similar approach was taken in the Chesapeake Bay to address lost crab pots and in Puget Sound to address lost crab pots and lost gillnets (Drinkwin, 2016; Jeffrey et al., 2016; NWSF, 2007). The Food and Agriculture Organization (FAO) also recommends that an ALDFG risk assessment be undertaken to ensure recommended marking and other prevention schemes are feasible and appropriately address identified risks (FAO, 2018b). By characterizing the issue, managers can better understand the overall risk of ALDFG to species, habitats, the fishery, and navigation. With that understanding, the level of effort to devote to preventing further impacts from ALDFG can be determined weighed against other demands on resources.

The surveys of fishers performed for this project was an appropriate step to get a picture of the degree of the problem in the Spiny lobster trap fishery. Further surveys with high seas fishers could help provide a baseline understanding of loss rate for gear types other than traps. We recommend working closely with the fishing industry to develop a more robust estimate of loss rates in conjunction with research to determine the ecological and economic impacts of lost lobster traps.

Continued reliance on wooden Spiny lobster traps will help prevent further negative impacts that are associated with plastic and/or metal traps. However, we recommend language be added to lawful gear requirements to include an escape panel that becomes available after the failure of biodegradable twine or other material, so that lobsters and other animals entrapped in lost gear can escape. We also recommend requiring the use of wooden traps in fisheries regulations to prevent any future transition to plastic or metal traps.

We recommend that gillnets lost during IUU fishing activities are considered in further efforts to understand and address ALDFG in Belize.

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