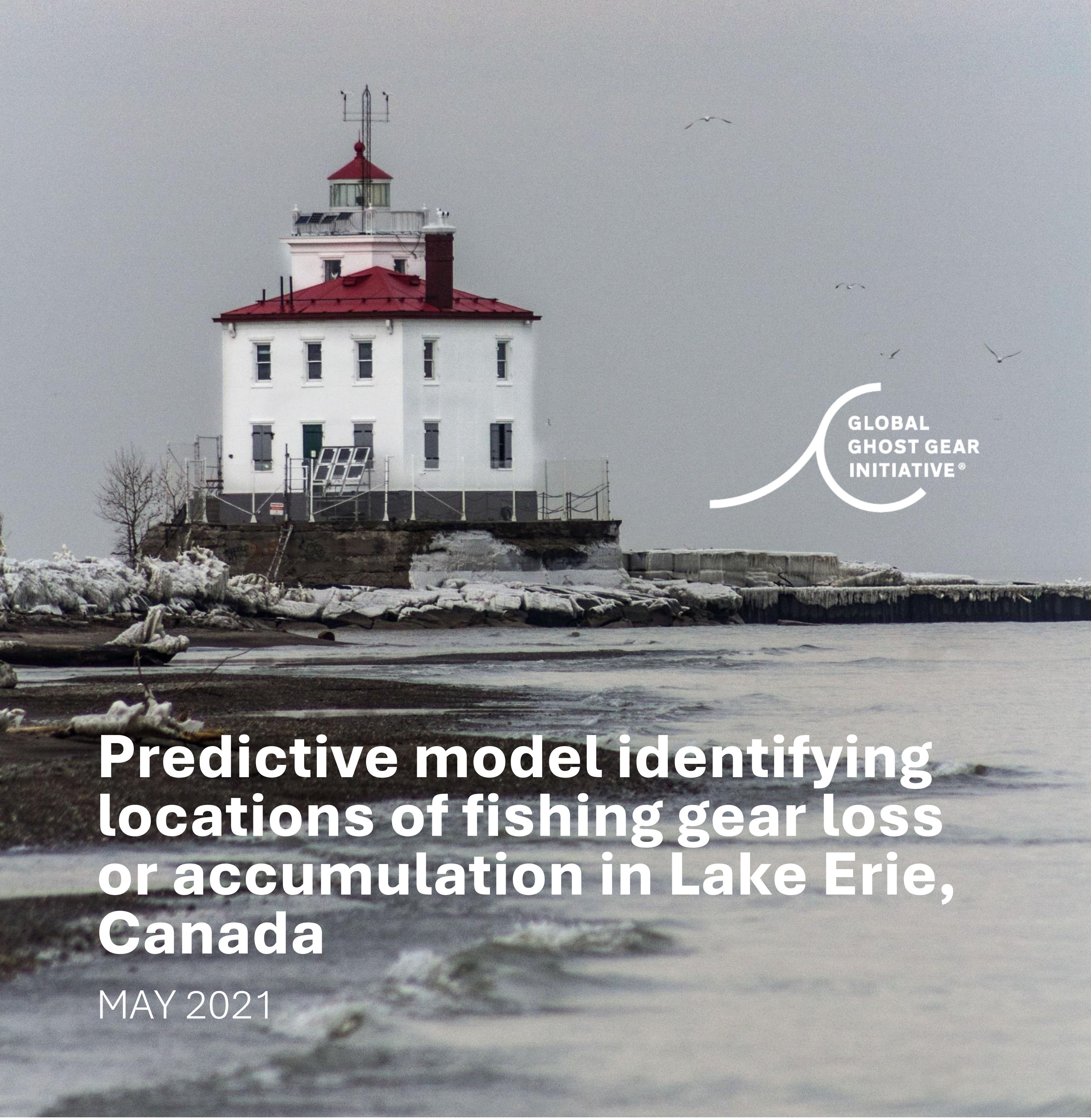

Predictive model identifying locations of fishing gear loss or accumulation in Lake Erie, Canada

MAY 2021

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Ocean Conservancy

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May 29, 2021

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Executive Summary

This project supports Canada's commitment to identify and reduce sources of plastic including abandoned, lost, and discarded fishing gear (ALDFG) and documents existing understanding of the extent of the issue and relative impacts from ALDFG in Canadian Lake Erie. This information, combined with geographic data and fisheries effort data, is used to identify locations where ALDFG may occur most. Potential reasons for fishing gear loss, best practices to prevent gear loss and negative impacts from gear loss are discussed. Recommended next steps are provided to address ALDFG in Lake Erie are consistent with Canada's commitments under the *Canada-Wide Action Plan on Zero Plastic Waste* to:

- improve consumer, business and institutional awareness to prevent and manage plastic waste responsibly
- reduce plastic waste and pollution generated by aquatic activities
- advance plastics science to inform decision-making and measure performance over time
- address plastics in the environment through capture and clean-up
- contribute to global action on plastic pollution reduction.

Today, the primary commercial fisheries in Lake Erie target yellow perch, walleye, rainbow smelt, white bass, and white perch. The gear types used in these fisheries are bottom set gillnets, trap nets, and midwater trawls. There are approximately 190 commercial fishing licenses that share the Ontario quotas in the Canadian portion of Lake Erie. In recent years, there are about 60 active vessels in the western basin, and 30 vessels in the central and eastern basin of the lake. Gillnet panels generally measure 30m and multiple panels are strung together in straps up to 6.4km in length. From 2010 to 2019, an average of 35,000km of gillnets were in use in Lake Erie annually.

To characterize the existing understanding of ALDFG in Lake Erie, a literature review was undertaken, augmented with information gleaned from an online survey, targeted interviews with industry stakeholders, and beach cleanup data obtained from the International Coastal Cleanup. To prepare the predictive model of ALDFG locations, a series of physical and fisheries datasets, along with data representing human activity, were overlain in ArcGIS with two datasets including known locations of ALDFG. Each dataset represented a potential cause for gear loss, and values were extracted at ALDFG locations to identify association or correlation between these variables and where ALDFG is found. Based on results from initial investigations, a linear additive model was developed using fishing effort, Relative Exposure Index (REI; fetch and wind speed), concentration of man-made snags, commercial waterways, and substrate formations to identify varying levels of probability for ALDFG occurrence within Canadian Lake Erie. The strongest associations within the data were concentration of commercial waterways, and REI; which in ALDFG terms represent heavy vessel traffic and poor/inclement weather, respectively.

The literature review and other data collection pertaining to locations of and impacts from ALDFG in Lake Erie revealed no peer-reviewed publications addressing ALDFG in Lake Erie and only scant information about ALDFG in the other Great Lakes. Likewise, there are no published studies identifying ALDFG as a source of microplastics in the lake. However, considering that most fishing gear used in the lake has plastic components, it is likely that as these plastic components degrade and fragment they contribute to the impacts of plastics and microplastics in the lake. Interviews with stakeholders identified possible causes of gear loss in the lake, including bad weather and ice, snagging on bottom obstructions, vessel conflicts (both commercial and recreational), conflicts with recreational fishing gear, and intentional discard.

The results of the modeling exercise include three separate probability maps predicting levels of likelihood (low, moderate, high) of where different types of ALDFG may occur: one, for gillnets in Lake Erie, another for trawl gear, and finally one for various ALDFG that washes up and becomes deposited on the shoreline. The most notable locations for potential high probability of gear loss are the Pelee Island – Pelee Point region, where heavy gillnet effort overlaps with relatively dynamic substrate, numerous shipwrecks, and concentrated vessel traffic. The other area of significance is the eastern basin, where nearly all the trawl effort occurs; the area also includes condensed commercial waterways and several obstructions on the substrate, both anthropogenic (well heads) and natural (ridges and high relief). Based on these models, the highest potential for ALDFG to wash up on shores occurs along the shores of the central basin and the eastern side of Pelee Island.

Of the fishing gears used in Lake Erie, gillnets are widely documented to pose the greatest risk of ghost fishing (continuing to catch target and non-target species after gear is lost). Trawl nets pose a lower risk of ghost fishing but may damage sensitive habitats. Sources agree that a low-level of gillnet (and sometimes trawl) loss occurs regularly in Canadian Lake Erie. Sources suggest that lost gillnets are quickly covered with dreissenids *(Dreissenid sp.)*growth, thereby minimizing any direct species impacts from ghost fishing (SAI Global, 2021; pers. com. Allan K. Feb. 25, 2021). While collapse of netting due to biofouling does eliminate potential animal entanglement and reduces navigation hazards, it presents potential problems related to plastic degradation which is linked to multiple harmful impacts to benthic biota, water quality, and human health.

Some current fisheries management strategies in the Lake Erie gillnet fishery are consistent with identified best practices to prevent gear loss and mitigate its harm after loss. The practice of “daylighting” gillnets is consistent with consensus recommendations that reducing soak times and/or actively tending a net is an effective method to avoid gear loss. The requirement to report lost nets and to retrieve nets within eight days during winter fishing is also consistent with best practices to minimize negative impacts from ALDFG after loss.

Recommendation for future efforts to address ALDFG in Lake Erie align with Canada’s commitments under its Action Plan on Zero Waste: Phase 2. An appropriate next step could be to determine baseline of loss rate for gillnets and trawls and direct ecological and economic impacts of ALDFG by working closely with industry and utilizing structured interviews. Documenting a defensible rate of loss of fishing gear in Lake Erie will also lead to more informed prevention strategies. To understand how much fishing gear is lost, abandoned, or discarded into the lake, a mass budget for fishing gear could be calculated. The legacy lost gillnets documented in this report could be retrieved in a targeted retrieval effort using trained divers. Retrieving these nets could serve to eliminate future indirect impacts from this ALDFG and provide helpful data related to the ALDFG itself, including potentially when and from which fishery it was lost. Further coordination of lost gear reports should include a documented response and retrieval protocol. Recruiting fishers to participate in all future efforts will build awareness of the issue of ALDFG and help to develop solutions that are both feasible and palatable to the fishing industry.

Introduction

The negative impacts of abandoned, lost, and discarded fishing gear (ALDFG) are a growing concern globally. Whether intentionally discarded or accidentally lost, ALDFG is one of the deadliest forms of marine litter. Lost gear can catch and waste target and non-target species (ghost fishing), damage habitats, and pose navigation risks (Gilardi et al., 2020; Macfadyen et al., 2009; National Oceanic and Atmospheric Administration Marine Debris Program, 2016; NOAA, 2015). The waste of target species can significantly impact the economics of a fishery, with 4%-30% loss of harvest from ghost fishing documented in some fisheries (Antonelis et al., 2011; DelBene et al., 2019; Gilardi et al., 2010; Humborstad et al., 2003; Tschernij and Larsson, 2003).

Because most fishing gear has significant plastic components, the negative impacts from ALDFG also include less direct but longer term impacts associated with other plastic pollution and microplastics including negative effects on biota, water quality and even human health (Cera et al., 2020; GESAMP, 2016, 2015). Plastic debris, including fishing gear, can fragment into smaller debris, some with diameters less than 5mm (microplastics). Microplastics are of growing concern but most research has focused on their impacts in the marine environment. A global review of research on microplastics in freshwater found the main contaminating polymers are polypropylene (PP) and polyethylene (PE) for sediment and water, and PP, PE, and polyethylene terephthalate (PET) for biota. In America, PE is more prevalent, accounting for 48% of polymers found in American studies of freshwater microplastics (Li et al., 2019). Microplastics are more easily taken up by freshwater organisms. Impacts from microplastics on freshwater biota include negative effects on growth, reproduction, and predatory performance (Cera et al., 2020).

While most information around ALDFG addresses negative impacts in marine waters, ALDFG has similar direct and indirect negative impacts in freshwater environments (Cera et al., 2020; Natural Resources Consultants, 1990; Nelms et al., 2021; Spirkovski et al., 2019).

Solving this problem on a global scale has gained momentum with the efforts of the Food and Agriculture Organization (FAO), the United Nations Environmental Program, and the International Maritime Organization; the creation of the Global Ghost Gear Initiative (GGGI); and the establishment of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Pollution (GESAMP) Working Group 43. FAO recently published Voluntary Guidelines for the Marking of Fishing Gear to help prevent negative impacts from ALDFG in the world's fisheries (FAO, 2018). The GGGI is a multi-stakeholder alliance of over 100 organizations, business and governments that brings seafood stakeholders together to address ALDFG at all points along the seafood supply chain. GGGI has published a Best Practices Framework for the Management of Fishing Gear (BPF) that provides management strategies to prevent harm from ALDFG directed at 10 different seafood supply stakeholders, including fisheries managers (Huntington, 2017). The GESAMP Working Group 43 was established to develop a report of sea-based sources of marine litter identifying extent, causes, impacts, and recommended solutions to the global problem of marine litter from sea-based sources, including ALDFG. Its second Interim Report was presented to FAO's Committee on Fisheries (COFI) in June 2020 (Gilardi et al., 2020).

Canada has recently taken steps to address problems of ALDFG in its fisheries. As president of The Group of Seven (G7) in 2018, Canada launched an *Ocean Plastics Charter* and published its *Strategy on Zero Plastic Waste* which includes a Result Area specific to ALDFG solutions (Canada, 2018; Canadian Council of Ministers of the Environment, 2018). Also during the G7 presidency, Canada demonstrated its commitment to the reduction of ALDFG by formally signing on to the GGGI. In 2019, Canada announced significant investment in reducing and preventing the harms caused by ALDFG through the introduction of the $8.3 million dollar Sustainable Fisheries Solutions and Retrieval Support Contribution Program. While the Canadian government has included ALDFG in its national strategy, little is known about this problem in the North American Great Lakes. The *Canada-Wide Action Plan on Zero Plastic Waste: Phase 2*, published in 2020, includes specific actions to reduce impacts from ALDFG (Canadian Council of Ministers of the Environment, 2020).

This project supports Canada's commitment to identify and reduce sources of plastic waste under Annex 2 of the draft 2020 *Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health* (Government of Canada and Province of Ontario, 2019). It also supports actions outlined in the *Canada-Wide Action Plan on Zero Plastic Waste: Phase 2* and Canada's contributions to NOAA's *Great Lakes Marine Debris Action Plan* (Canadian Council of Ministers of the Environment, 2020; National Oceanic and Atmospheric Administration Marine Debris Program, 2020).

This project compiles existing information about ALDFG in the Canadian portion of Lake Erie and develops a predictive model to identify probable locations of loss of fishing gear and locations where lost fishing gear is accumulating and potentially negatively affecting species and habitats. Lake Erie was selected for this project because it has the largest commercial fishing effort of any of the Great Lakes, and the fishery utilizes gillnets, a fishing gear rated as high risk for impacts from ALDFG (Gilman et al., 2021; Huntington, 2016). Predictive models are valuable to characterize largescale problems, such as ALDFG, where physical surveys are cost-prohibitive. Identifying likely locations of ALDFG will assist in evaluating the scope of the problem and potential preventive action in Lake Erie. However, as with any model, predicting ALDFG locations benefits from accurate data of known ALDFG and correlation between locations and causes of gear loss or accumulation (Jeffrey et al., 2016; Martens and Huntington, 2012; UNEP CAR/RCU, 2014).

A literature review, augmented by results from meetings, interviews, and online surveys, are used to document the existing understanding of the relative impacts from ALDFG in the Canadian portion of Lake Erie. this information, combined with geographic data and fisheries effort data, are used to identify locations where ALDFG may occur most.

Potential reasons for fishing gear loss, best practices to prevent gear loss and negative impacts from gear loss are discussed Recommended next steps to address ALDFG in Lake Erie consistent with Canada's commitments under the *Canada-Wide Action Plan on Zero Plastic Waste: Phase 2 are provided.*

Fisheries in Lake Erie

Lake Erie has historically hosted the most productive commercial fisheries among the Great Lakes, with annual harvests sometimes exceeding the production from all the other lakes combined. Targeted species are diverse. Fisheries in the 1800s targeted lake trout, lake whitefish, blue pike, walleye, and lake herring. The commercial lake trout and herring fisheries were substantial for several decades. By the 1970s their numbers declined so that they were no longer part of the commercial fisheries. These declines were a result of both intense fishing and eutrophication. As fishing effort shifted to other species such as whitefish and walleye, they too experienced downturns due to environmental factors and fishing pressures. While always important in the Lake Erie fisheries, the yellow perch became even more important as the lake whitefish and herring declined. Fishing intensity for the rainbow smelt, an invasive species, increased significantly in the 1960s.

In 1955, the Canadian/U.S. Convention on Great Lakes Fisheries established the Great Lakes Fishery Commission (GLFC) to conduct fisheries research, control invasive species, and facilitate cooperative fisheries management between state, provincial, tribal, and federal agencies. Under guidance of the GLFC, the Lake Erie Committee (LEC) was formed by resource agencies from Michigan, Ohio, Pennsylvania, New York, and Ontario to perform the coordinated management of major fisheries in Lake Erie through population assessment and setting of total allowable catch (TAC). Regulations such as gear restrictions, season closures, size limits, quotas, and refuges are set by agencies, and regulations are enforced by law enforcement personnel within state and provincial jurisdiction. Some federal enforcement agencies also participate. The Fisheries in Canadian Lake Erie are primarily managed by the Ontario Ministry of Natural Resources and Forestry (OMNRF) who issue licenses and set annual quotas. The Canadian commercial fisheries in Lake Erie are on species-specific individual transferable quota (ITQ) system, and many of the policy guidelines are defined in the *Strategic Policy for Ontario's Commercial Fisheries* (Government of Ontario, n.d.). License conditions typically stipulate the geographic area where fishing will occur (i.e., Management Unit or Quota Zone), species, gear type, and time frame for fisheries operations. The Ontario commercial fishing fleet in Lake Erie is represented by the Ontario Commercial Fisheries' Association (OCFA), in place to ensure resource sustainability, sound science, and long-term success for the commercial industry in Ontario.

Today, the primary fisheries in Lake Erie target yellow perch, walleye, rainbow smelt, white bass and white perch. There has not been effort targeting lake whitefish since 2013. The gear types used in these fisheries are bottom set gillnets, trap nets, and midwater trawls. In U.S. waters of Lake Erie, the recreational fisheries are an economic powerhouse in New York, Pennsylvania, Michigan, and Ohio; while in Ontario the commercial sector dominates the fisheries. The commercial fisheries that do occur in U.S. waters are primarily in Ohio, but also occur in Michigan, New York, and Pennsylvania and are limited to trap net fisheries for whitefish and yellow perch. Primarily due to the differences in gear types, and the scope of work for this project, we focus here on the commercial fisheries within Canadian waters of Lake Erie to gain an understanding of how they may contribute to ALDFG and plastic pollution in Lake Erie.

There are approximately 190 commercial fishing licenses that share the Ontario quotas in Canadian Lake Erie. Not all licenses are active, and some vessels may carry more than one license. In recent years there are about 60 active vessels in the western basin, and 30 vessels in the central and eastern basin of the lake. Figure 1 shows annual commercial harvest by species in Canadian waters of Lake Erie from 1970 through 2015. Most effort occurs from March through June, and September through November. Harvest in the summer months is limited to only daytime fishing and the amount of effort during those months tends to be much less. Even though the same amount of gear may be fished, it is over a shorter time frame. There is essentially no fishing during January and February.

The modern Lake Erie fisheries are highly regulated and monitored, and regulations are in place to address fishing gear loss should it occur. Limitations to soak times, up to eight days, and sometimes much shorter, depending on weather conditions allow fishers to time to track down and recovery gear should it move from position. Licensees are required to notify OMNRF if a net is lost or stolen, and all records of fishing activity are kept in a captain's daily logbook and catch reports. Additionally, in the winter when the weather is poor and ice is present all vessels are required to enable AIS or similar GPS transponders so fishing, and vessel activity can be monitored in case accidents occur; this assists with efforts to recover gear should it become lost.

Lake Erie is the shallowest of the Great Lakes with an average depth of 19 m and is naturally split into three distinct basins. The western basin is the shallowest, with depths averaging 7.4 m, and the eastern basin is the deepest, with average depths around 24.4 m. The central basin averages 18.5 m depth. There are two walleye stocks in Lake Erie, the western stock that occurs in the western and central basin, and the eastern stock which is in the eastern basin. There are four yellow perch stocks that geographically define four management units that are distributed from west to east (Figure 2).

Fishing in the shallow western basin primarily occurs during the cooler months of the year, while effort shifts east into deeper cooler water in the summer. Gillnet fisheries occur year around, with most effort occurring in the spring (April – June) and fall (September – November); little effort is expended during January and February (Figure 3a-c). In the summer months the amount of gillnet set (measured in km) is similar to other months of the year; however, the duration of soak time is significantly less, as seen in Figure 3a and 3b. Gillnet panels generally measure 30m and multiple panels are strung together in straps up to 6.4km in length. From 2010 to 2019, an average of 35,000km of gillnets were in use in Lake Erie annually (OMNRF 2021). The greatest fishing intensity occurs in the western basin (Figure 2).

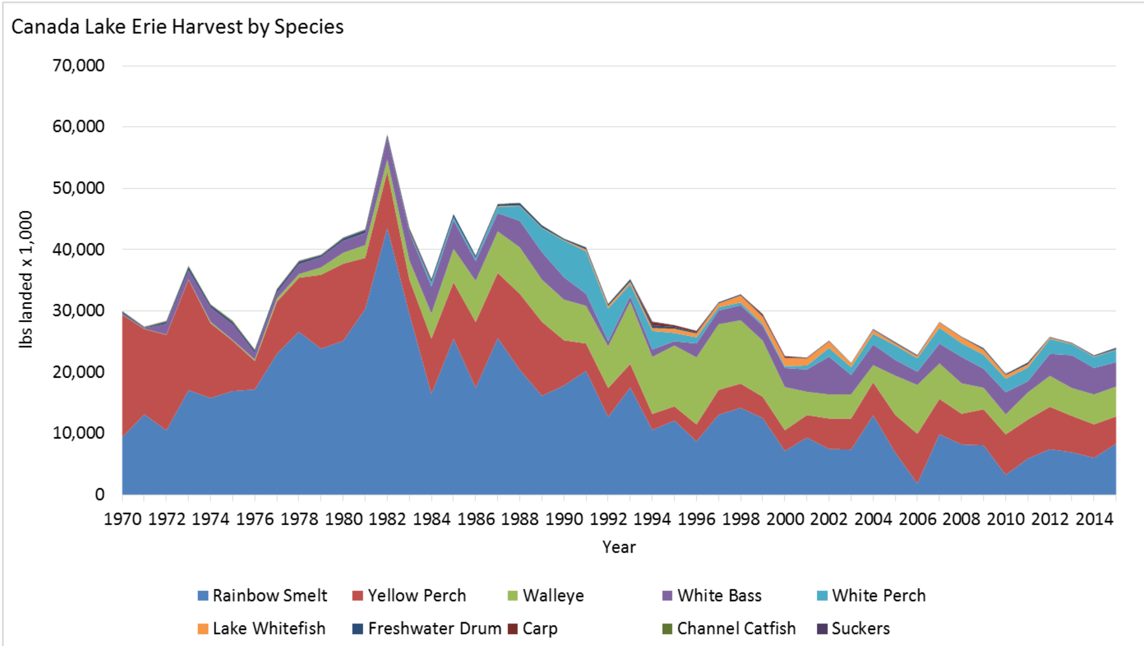

Figure 1. Harvest by species in Canadian Lake Erie Commercial Fisheries 1970 – 2015. Source: GLFC

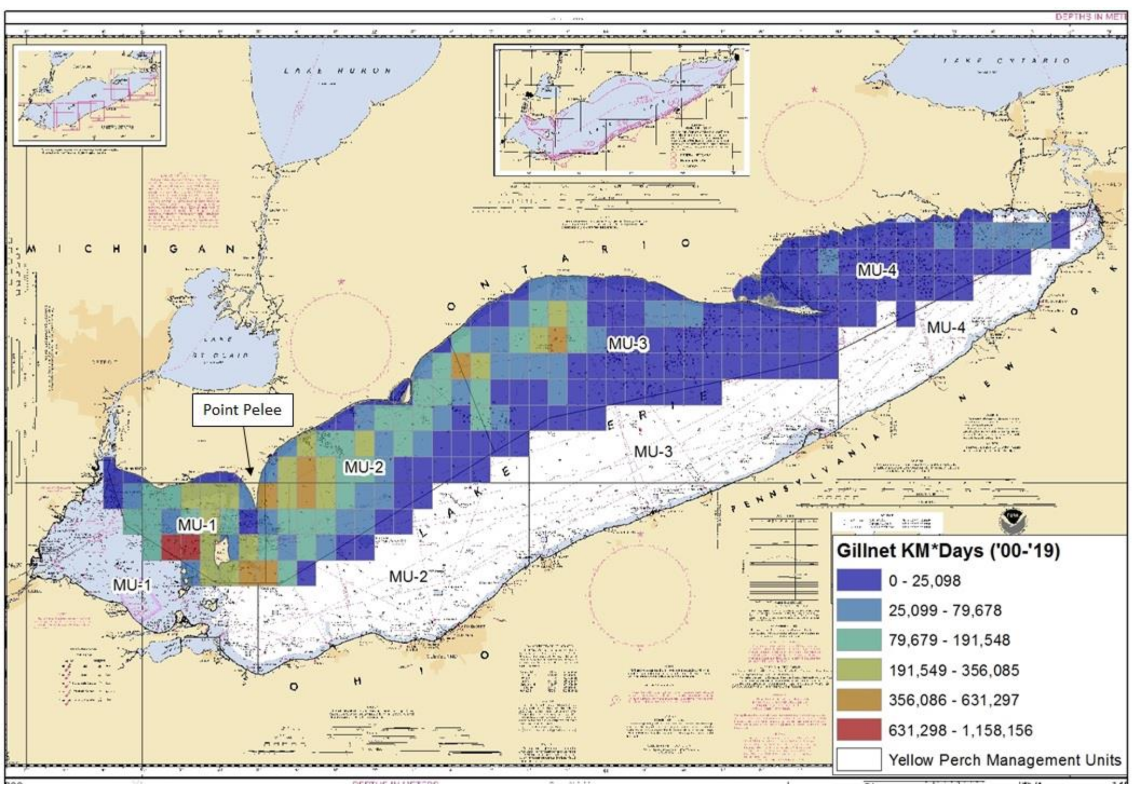

Figure 2. Yellow Perch Management Units and Lake Erie Canadian commercial gillnet effort per 5min grid combined for years 2000-2019. Effort portrayed in kilometer*days. Source: OMNRF

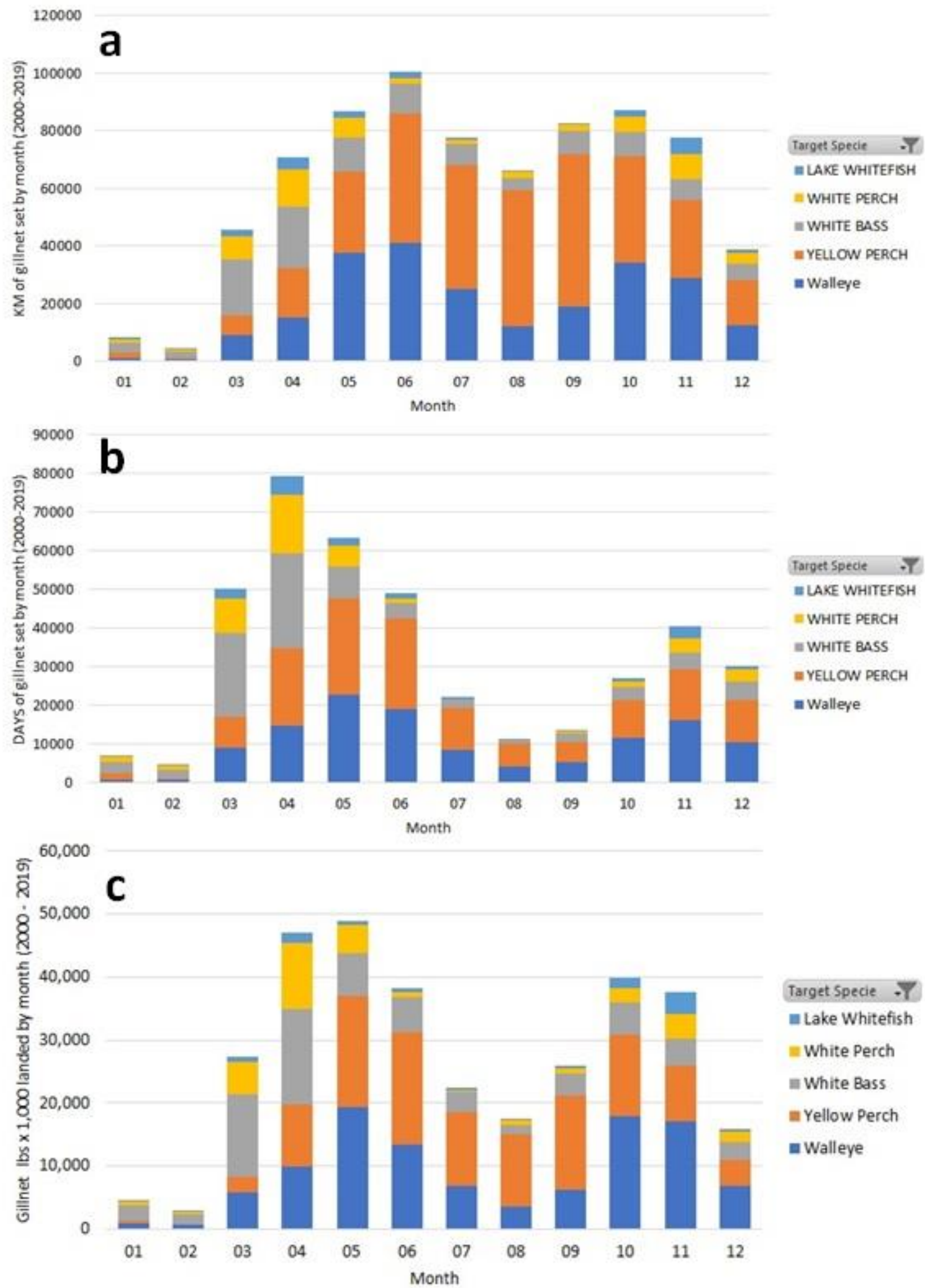

Figure 3. (a) Kilometres of gillnet, (b) days of gillnet soak time, and (c) total harvest per month by target species in Canadian Lake Erie commercial gillnet fisheries; 2000 – 2019 combined. Source: OMNRF

Methods

Literature Review

A literature search was undertaken using Google Scholar to identify published works related to ALDFG in the Great Lakes. Search terms included common terminology used to report on ALDFG, including "ghost gear", "ghost fishing", "lost fishing gear" combined with "Great Lakes." Finding little in the way of published literature on ALDFG, we expanded our search to include "microplastics," "marine debris" and "plastic debris" combined with "Great Lakes." Grey literature, including fisheries management reports and Marine Stewardship Council (MSC) assessments were obtained through searches and through partner contacts.

Information was obtained through informal interviews with regulatory and fisheries management personnel, fishers, and recreational and salvage divers.

NRC developed and disseminated an online survey, using the SurveyMonkey platform, to elicit sightings, locations, type of ALDFG (https://www.surveymonkey.com/r/8STSJGN). The online survey was disseminated in February 2021 to dive clubs and to the head of Lake Erie Charter Boats Association. The survey asked for locations and type of sited ALDFG. See Appendix 1 for survey questions.

Additional data was obtained from the 2019 International Coastal Cleanup, an annual community beach clean-up event sponsored by the Ocean Conservancy. Cleanup activities are conducted along both Canadian and U.S. Lake Erie shorelines, where debris is collected and sorted for disposal or recycling. During sorting, types of debris are noted using an established data collection protocol, including the individual counts for fishing gear related items:

- Fishing buoys, pots, and traps
- Fishing net and pieces
- Fishing line
- Rope
- Fishing gear (general category in online Clean Swell app)

In general, the first two categories (Fishing buoys, pots, and traps and Fishing net and pieces) are related to commercial fishing. Fishing line will generally represent debris from recreational fishing. Rope and 'fishing gear' could be from either commercial or recreational fishing. We analyzed and mapped data points from each of these five categories to obtain some general locations of where ALDFG might be accumulating on shore.

Development of Derelict Fishing Gear Probability Areas

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 derelict fishing gear occurrence in Lake Erie. Initial investigations included a large variety of physical datasets from the Great Lakes region, and specifically Lake Erie. Input included the physical structures of the fishing grounds, biological behaviour of the target species, and human activities within and outside the fisheries. Those datasets included:

- Bathymetry: depth of water; 30 m spatial grid raster (GLAHF 2014; NOAA/NGDC 1999). Other files related to bathymetry data included substrate relief and slope.
- Hydrogeoforms: bathymetry and relief classifications combined to form 24 unique substrate formations, standardized to GLAHG 30m framework grid (Gallant et al., 2005; GLAHF 2014).
- Lake Erie circulation: magnitude and direction of water flow for 2006 through 2012, each year represented by separate datasets (Chu et al., 2011; GLAHF 2014)
- Wind fetch: unobstructed distance wind can travel in a constant direction. Average values of wind speed over years 2005, 2006, 2009, 2010, and 2014 (GLAHF 2014).
    - Data provided in separate sets per year were combined into one raster depicting the mean fetch values per 30 m grid cell.
- Relative Exposure Index (REI): effective fetch scaled by mean wind speed for 2005, 2006, 2009, 2010, and 2014 (Mason et al. 2018)
    - Data provided in separate sets per year were combined into one raster depicting the mean REI values per 30 m grid cell.
- Potential man-made underwater obstructions & snags
    - Well Head Locations: point data for over 2,200 well head locations from the petroleum industry in Ontario, most of which are in Lake Erie (Oil, Gas and Salt Resources Library 2019).
    - Shipwrecks Database and ALDFG Locations for Lake Erie: coordinates and names of 322 shipwrecks in Lake Erie (U.S and Canada), 69 of which are recorded to host ALD fishing nets (Wachter and Wachter, 2017)
- Commercial Waterways: polyline data representing commercial waterways throughout the Great Lakes and Lake Erie, extracted from United States Army Corps of Engineers National Waterway Network for the Great Lakes Basin (USACE 2017)
    - For analysis, data was buffered by 2.5 km to capture general area on either side of official lane that is used by vessels. Area of commercial waterways were then summarized per 5 minute grid.
- ALDFG Locations
    - ICC data from coastal cleanup projects in 2019

- Nets found snagged on 69 of the 322 shipwrecks recorded in the shipwrecks database. Locations, photos, and description provided by Erie Wrecks (Wachter and Wachter, 2021)

- Fishing Effort – per month, per target species, per year, per 5 minute grid, for years 2000 through 2019; provided by OMNRF (2021)
  - Gillnet harvest by pounds landed, and effort by length of gillnet (yards and km), and soak time (minutes, hours, days)
  - Midwater trawl harvest (lbs. landed) and effort (trawl set time)
- Fisheries Management Units, provided by OMNRF
  - Walleye management units 1-4 and yellow perch management units 1-4, each split by U.S. and Canada waters.
  - 5 minute grid cells – 269 grids covering Canadian Lake Erie within which fishing effort and harvest data are recorded.

To ensure all effort metrics for gillnet fishing effort were consistent, all soak times were converted to days. A summary of fishing effort by months in Lake Erie shows that depicting effort independently by gear length or soak time, would not accurately capture effort in terms of gear exposure that occurs in the system (Figure 3). Therefore kilometer*days were used as the unit of effort to ensure that both length of gear and time fishing were captured. Kilometer*days were summarized for each month, and year over all years (2000 – 2019) for each 5 minute grid cell (0 – 269), then joined spatially with the Lake Erie 5 minute grid vector shapefile. This produced a heat map showing spatial distribution of gillnet fishing effort in Canadian waters of Lake Erie (Figure 2). Similarly, trawl effort was summarized as set hours per month per 5 minute grid cells over all years (2000 – 2019); producing a heat map of trawl effort shown in Figure 4.

The two datasets of ALDFG from ICC and Erie Wrecks were analyzed separately, due to the differences in how and where the gear items were found (i.e., beach cleanup vs. SCUBA diving). In general, we assume that gear used offshore, that are found during beach cleanups, are typically deposited where they are found after being transported by wind, waves, and current forces. Where these debris are found, is not necessarily the location of loss. While this could also be said for ALDFG found on shipwrecks, it is likely more common that gear found on shipwrecks were accidentally entangled or snagged on the shipwreck where a portion or all of the snagged gear remains. While we review both datasets, more attention was placed on the lost net data found on shipwrecks, as we believe these data would provide a better understanding of how and where gear was being lost, whereas gear found on beaches limits evaluation to where some gear may be deposited.

A total of 69 derelict net locations were reviewed with the regional characteristics of the fishing grounds; bathymetry, substrate types, circulation, fetch, REI, well heads, shipwrecks, commercial waterways, and fishing effort. Using the *Extract Multi Values to Points* tool in ArcGIS Spatial Analyst toolset, the values from each raster dataset at each derelict gear point location were extracted into a new attribute field. Frequency distribution of values per variable were analyzed to identify which of the variables would be suitable as an indicator for ALDFG locations, and then investigated further. During

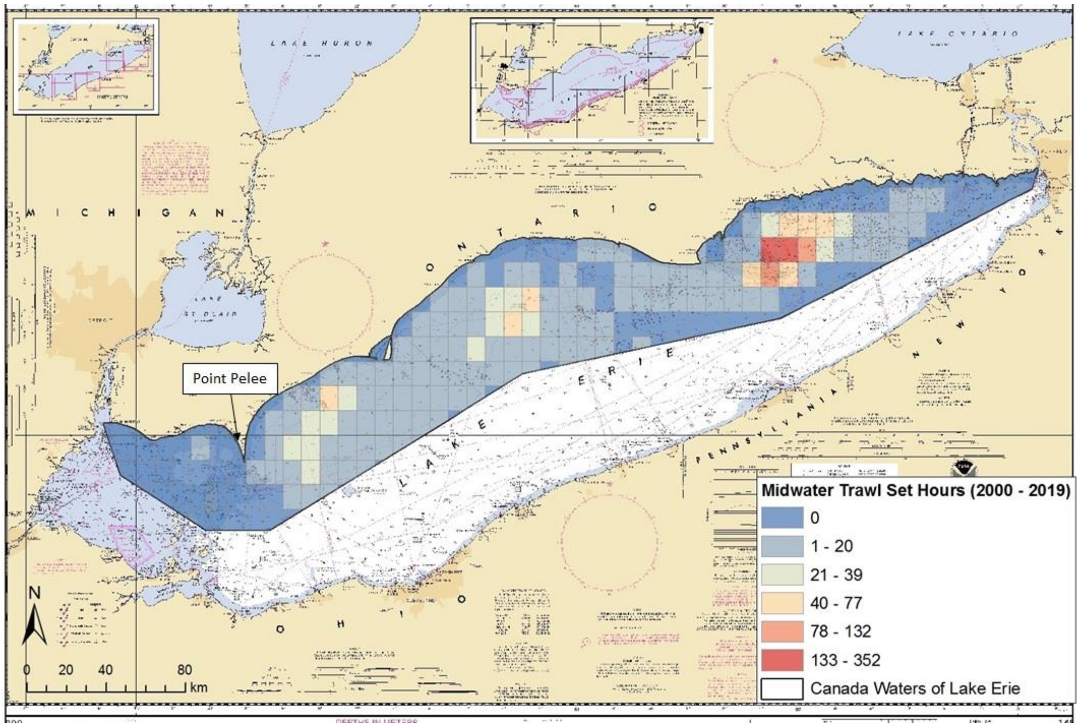

Figure 4. Midwater trawl fishing effort targeting rainbow smelt per 5 minute grid. Source: OMNRF data.

this phase, the primary goal was to identify frequency distributions that appear to have a bell-shaped (normal) curve, or skewed-left, positive association curves. We looked for data that resembles association with the derelict gear locations, and therefore predictability for other similar locations. Random, uniform frequency distributions provide little to no information to assist in identifying values that contribute to fishing gear loss, deposition, or accumulation.

The initial data exploration phase helped determine which of the variables show patterns of association with ALDFG occurrence. With some datasets, bathymetry most notably, association was identified, but in the end the dataset was not used due to the relative uniformity of values in Lake Erie. Essentially, the values at the ALDFG locations closely resembled the summary of values in the entire dataset. The two datasets that showed high levels of correlation with in-water ALDFG locations were effective fetch scaled by wind speed (REI) ($r = 0.893$), and proximity to commercial waterways ($r = 0.937$). These both also fit well with global records of reasons for gear loss being associated with poor weather conditions and conflicts with vessel traffic (Ayaz et al. 2008; Erzini et al. 2008; Gilman 2015; Macfadyen et al. 2009). Additionally, assuming the presence of lost fishing gear corresponds with the presence and intensity level of fishing effort; included in the model is concentration of fishing effort by gear type, represented as *Gillnet km*days per 5min grid* and *Trawl set hours per 5 min grid*. To represent snag points and underwater obstructions, the Lake Erie shipwreck database and the petroleum well head dataset were combined, and the total number of those features were summarized per 5 minute grid cell. Lastly, hydrogeoform features of ridges and irregular plains were summarized as km^2 per

5 minute grid and used in the model to depict areas of substrate relief where gear may have potential to become snagged. Assuming that ALDFG probability is higher where there is (a) greater concentration of fishing effort, (b) higher concentration of snags and obstructions on seafloor, (c) greater exposure to poor sea state and weather conditions, (d) higher concentrations of vessel traffic, and (e) any combination of these factors; the ranking factors for each dataset were highest where highest concentrations of each variable occurred.

Using the reclassify tool in ArcGIS, the mean REI values were re-classed so that each independent value was represented by an integer value, 1 – 3, with the highest rank equating to the highest REI values; as ALDFG presence increased with increasing values of REI (inclement weather) and shared space with vessel traffic lanes (Figure 5). The commercial waterways and hydrogeoform vector data were each summarized per 5 minute grid by using the Union and Calculate Geometry tools in ArcGIS. The count of well heads and shipwrecks, gillnet effort, and trawl effort per grid were summarized in the attribute table by using the Spatial Join feature. The Field Calculator feature in the attribute table was used to reclassify values per variable into probability bins from 0 to 3, with 3 being the highest probability of ALDFG occurrence. The reclassified values (probability bins) per variable; fishing effort, well heads and shipwrecks, commercial waterways, and ridges and irregular plains per 5 minute grid, were added together then converted to raster format. Using the Local Cell Statistics tool, the reclassified REI values were added to the sum of values, resulting in a single raster data layer with cell values from 0 to 13. The values represent the base for low (i.e., 0) to high (i.e., 13) probability of derelict fishing gear occurrence in two separate files; one for gillnets, and the other for trawl nets. These were separated due to the significant difference in amount of effort and spatial distribution of effort (Figure 2 and 4). To finalize each probability map, the raster datasets were masked by the geographic and administrative boundaries of Canadian Lake Erie and converted into vector shapefiles in coordinate system GCS North Amercian_1983 (NAD_1983).

Data from the ICC 2019 was reviewed separately from the in-water derelict net targets, but in similar fashion. Because the data points occurred primarily on land, each point was buffered by a 5 km radius to ensure data from physical features of the lake were being summarized. After a review of several datasets, a correlation was found between ICC ALDFG sites and gillnet effort. Gillnet effort was summarized as km*days per Walleye Fishery Management Unit (MU) to depict the general density of fishing effort occurring in the waters adjacent to the shorelines where ALDFG is deposited. Additionally, ALDFG locations from the ICC data showed signs of association with a raster dataset of mean wind-weighted fetch values from 2006 through 2014, specifically designed to show wave and wind exposure on shorelines (GLAHF, n.d.). The total gillnet effort per km^2 from 2000 through 2019 within each MU ranged from 4,099 km*days in the western basin, to 148 km*days in the eastern basin. The five values were each reclassified to three integers depicting low (1) to high (3) probability, corresponding with low to high fishing effort. Fetch values were reclassified with the highest fetch values given the highest probability value (3). Data was summarized within 5 km from shore, then the modeled probability values were transferred to the directly adjacent shoreline. The two reclassified values were added with low values of 2 and high values of 5.

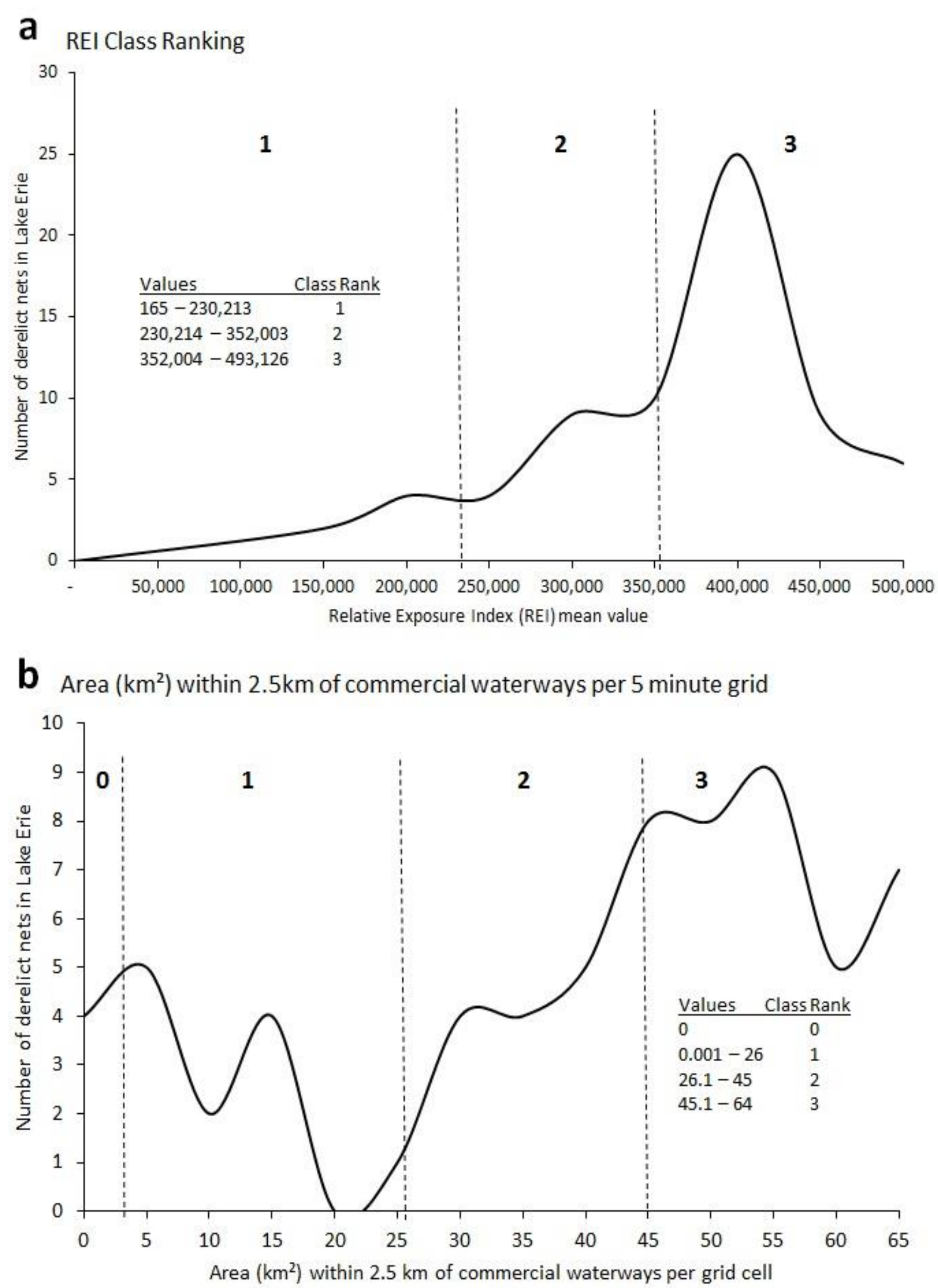

Figure 5. Frequency of occurrence of reported ALDFG locations at values for REI (fetch and wind speed (inclement weather)) and commercial waterway presence.

Results

Literature Review

No published peer-reviewed articles were found that specifically addressed ALDFG in Lake Erie either directly or indirectly as a source of microplastics. Articles addressed marine debris in general with very passing reference to lost fishing gear as a potential source of marine debris and marine plastics. Earn, et al (2020) note that fishing and fishing gear are sources of macro-plastic debris in the Great Lakes, including Lake Erie. They do not report specific data on ALDFG (Earn et al., 2021). The Great Lake Marine Debris Action Plan notes that ALDFG is a source of marine debris but makes no mention of any actions around the issue (National Oceanic and Atmospheric Administration Marine Debris Program, 2020). Driedger (2015) noted that fishing gear comprised only a small amount (about 1%) of shoreline debris along the Great Lakes from data from beach cleanups.

The problem of ALDFG is recognized in other areas of the Great Lakes. An education campaign was launched in 2016 by the Ohio Department of Natural Resources, aimed at preventing recreational anglers from running their boats into fishing nets. However, this campaign is focused mainly in the U.S. tributaries of Lake Erie where gillnets are also used (Ohio Department of Natural Resources, 2016). In Wisconsin, the NOAA Marine Debris Program and other partners have supported a multi-pronged effort to prevent loss of gillnets and to retrieve lost gillnets (Conklin, 2014; Seilheimer et al., 2018). This program included producing an educational video directed at recreational anglers (Wisconsin Sea Grant, 2015).

One of the first comprehensive assessments of lost fishing gear in the United States was conducted in 1990 by Natural Resources Consultants (NRC). NRC estimates gillnet loss rates of 10% in the U.S. portions of Lake Ontario (New York), Lake Superior (Michigan), Lake Michigan (Michigan) and Lake Huron (Michigan). They estimate only a 1% gillnet loss rate in Lake Erie (Pennsylvania). While the report focused only on the United States, the authors note that lost gillnets in Lake Erie could potentially affect lake trout populations (Natural Resources Consultants, 1990). This assessment is consistent with other literature which identifies vulnerability of lake trout in entangling nets (Gislason et al., 2010; Johnson et al., 2004). Also, consistent with other literature, gillnets are identified as having the highest impact factor of any gear used in Lake Erie (Gilman et al., 2021; Huntington, 2016; Natural Resources Consultants, 1990).

The Lake Erie Multi-species Commercial Public Certification Report assessed the Lake Erie yellow perch and walleye fisheries against the Marine Stewardship Council Assessment Tree. The fisheries, using anchored gillnets, were determined to meet the MSC certification, based in part on the fisheries management framework and the low-levels of habitat and ecosystem impacts of the fisheries. The report noted that local fisheries managers did not consider lost fishing gear and ghost fishing to be a significant problem.

Loss of nets was reported during site visits with stakeholders during the assessment for this report. The assessment notes anecdotal comments indicating that nets are lost infrequently and that biofouling with dreissenids *(Dreissenid sp.)* adds weight to any lost net, eventually collapsing it and diminishing its fishing capacity (SAI Global, 2021).

The MSC certification for Lake Erie Yellow Perch and Walleye fisheries noted that the soft-bottom habitat results in limited risk to habitats from demersal gillnets. They acknowledge that the unseen mortality from lost fishing gear is unknown. This is consistent with other studies identifying habitat damage from Great Lake gillnet fisheries as a low risk (Li et al., 2011). However, Adlerstein and Scott (2015) note that the Great Lakes is an area lacking comprehensive research on effects of marine debris on habitats (Adlerstein and Scott, 2015).

As of March 1, 2021, the online survey received one response with coordinates for two lost nets encountered on shipwrecks in Lake Erie. See Appendix 2. The response included exact coordinates of the wreck and a description of the nets as “partial nets/floats (Shipwreck) in the Pelee Passage, between the mainland and Pelee Island.” The respondent indicated that there are ‘lots of wrecks here, so things get caught.” The survey respondent indicated that both recreational and commercial ALDFG have been encountered both on the shoreline and underwater. All options of gear type were identified as encountered: recreational fishing line, fishing net or part of net, and rope/buoy.

Further investigation of the nexus between ALDFG and shipwrecks yielded information provided by local wreck diver enthusiasts, Georgann and Mike Wachter and a salvage diver. The Wachter’s compiled information on abandoned fishing gear on wrecks in Lake Erie for this project. Their report identified 69 wrecks documented with lost nets. The authors noted instances of ghost fishing and also reported that some of the lost nets were responsible for damaging the wrecks themselves and creating diver safety hazards (Wachter and Wachter, 2021). Of the 69 total nets identified on shipwrecks, 62 of them were inside Canadian waters. Of the seven inside U.S. waters, four were within 5 km of the Canada – U.S. border, one was within 20 km of the border, and one was further than 20 km from the border. Only four were specifically identified by gear type as trawl nets, and the remainder were presumed to likely be gillnets, based on the description of the gear by the reporters. See Figures 6 and 7.

The authors of this report met with staff from the Lake Erie Management Unit, Fish and Wildlife Services Branch of the Ontario Ministry of Natural Resources and Forestry (OMNRF) as well as conducted informal interviews with two highly experience gillnet fishermen, and an experienced salvage diver active in the area for over 45 years.

Meetings with fishers also included the director and a biologist from the Ontario Commercial Fisheries Association. All persons consulted agreed that loss of whole nets is very rare. If there is any loss, it is of small parts of nets or ‘shards.’ If fishers do lose control of large portions or panels of nets, they all have sonar on their vessels and easily can find the lost net and retrieve it with grapples.

Figure 6. Photos of lost nets in Lake Erie. Top left, fish in lost net. Top right, net on sidewheel steamer *Northern Indiana*. Bottom left, net on steamer *Persian* (photo Tom Wilson). Bottom right, burbot (*Lota lota*) caught in net on schooner *Crystal* (possibly the *E.S.J. Bemis*). Source: Wachter and Wachter, 2021

When asked if gillnets are ever lost because of freighters or other vessels running over them they said, no. Tankers can sail right over the nets and fishers do not fish in vessel traffic lanes. Relative to the lost nets documented on shipwrecks, both fishers suggested those nets might be very old.

Fishers discussed the various methods they use to keep track of their nets. They all have GPS units on board, especially during winter months. They have depth sounders and charts with locations of shipwrecks and wellheads. They log the location of north/south net ends in their logbooks. They are restricted to eight days of soak time during the winter. This is in place to prevent spoilage of fish. Before these requirements, fishers could leave their nets to soak longer. Sometimes ice would set in and fishers would not retrieve their nets in time to avoid spoilage.

Don R., a gillnet fisher with over 25 years of experience, who was interviewed during this project, noted that his father fished as well. In the 60s and 70s, the only instrumentation they had was a watch and a compass. Now we have GPS units and depth sounders and accurate weather forecasts. Mr. Rutgers said he had been fishing for 28 years and never lost a net.

While fishers are required to report lost nets, shards of lost net do not need to be reported. Willie C., another experienced gillnet fisher interviewed who also has experience as a trawler, reported that he had heard of fishers reporting lost nets to enforcement officers about five times in the last ten years.

Telephone meetings with staff at OMNRF included discussion of the fisheries management strategies in place in the gillnet fishery, such as reporting requirements and limited soak times. Nets can be in the water only eight days, and this time period can be reduced to 24 hours depending on weather conditions. Licenses require logbooks and daily catch reports. OMNRF inspects approximately 50% of the catches. An estimation was noted that more than 90% of any lost gear is retrieved by the fisher. During winter months, fishers are required to have GPS transponders on their vessel primarily for safety reasons. OMNRF can track vessel activity during this time and can locate any gear that is reported lost. Gear loss can be more of a concern with ice and poor weather conditions. Other causes of fishing gear loss could be interactions with recreational fishing gear, such as downrigger weights and cables becoming entangled in static fishing gear, and intentional discard.

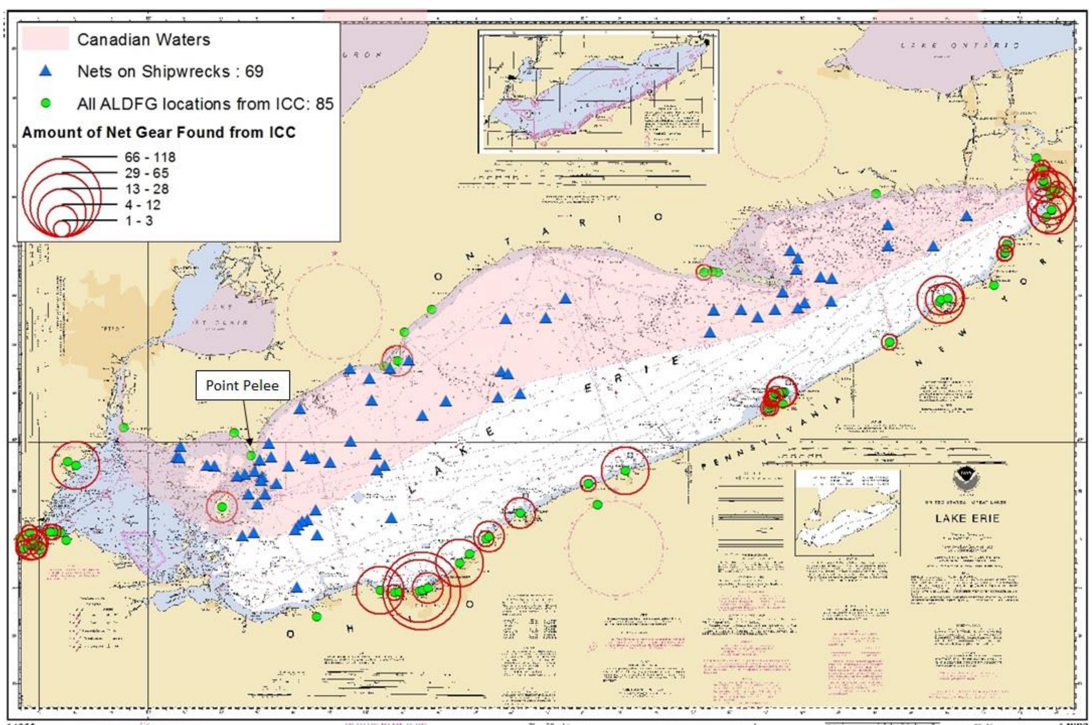

Figure 7. Locations of known ALDFG in Lake Erie. Nets on wrecks (blue triangles) and collection points (green) from International Coastal Cleanup 2019 and quantity for fishing net pieces found (red circles) along United States and Canadian shorelines of Lake Erie. Source: ICC 2019 and Wachter 2021.

Allan K., an experienced salvage diver, was also interviewed. He reported on his own experience as a salvage diver and also relayed conversations he had had with two gillnet fishers. He reported a low-level but regular need to remove net remnants from fishers' propellers. He estimated this was needed from 20-25 times per year, indicating that pieces of net are potentially lost that frequently. Don R. noted that these instances usually occur when fishers accidently run over their own net and rarely result in loss of gear. Allan K. also said that every couple years he is asked to find a trawl net. He said that the fishers know where their nets are because they use GPS. They will work together to help each other retrieve any larger net that is lost. He also noted that while wrecks do sometimes have net on them, he cautioned that they do not reflect the extent of net loss, because some fishers snag their nets on wellheads and other obstructions not associated with nets. Fishers also avoid wrecks, and all have maps of wreck locations.

He also noted that fishers reported to him that they snag their nets as frequently as weekly, but that they are generally able to get them unsnagged with no associated gear loss. He summarized that gear snags occur more frequently in the western basin, where more rocks and geologic structures exist. In the eastern basin, where gear snags occur less, nets become torn and damaged from interactions with lake freighters where the vessel traffic lanes are less defined than they are in the western basin. He agreed with the findings of SAI Global that lost gillnets are quickly covered with dreissenids *(Dreissenid sp.)*, causing them to lose the ability to ghost fish. He compared this with his experience in the 1970s and 1980s before dreissenids had invaded the lake. At that time, he had become concerned about the amount of ghost fishing by lost gillnets, but it no longer concerns him.

In summary, meetings and interviews with agency and industry personnel and fishers and divers indicated that loss of whole nets or net panels is rare. But loss of shards of net are not uncommon. It was evident that the loss of small pieces of net (20 feet or so) was not necessarily seen as 'lost fishing gear.' Causes of lost fishing gear mentioned during these meetings and interviews included, in order of importance:

- Bad weather, ice
- Snagging on bottom obstructions
- Vessel conflicts (both commercial and recreational)
- Conflicts with recreational fishing gear
- Intentional discard

Further information on ALDFG was gleaned from International Coastal Cleanup data obtained for the year 2019. Data was provided for 1,469,907 pieces of debris collected during cleanups on both the Canadian and U.S. shores of Lake Erie. In total, 2,230 ALDFG items were recorded in ICC data at 85 locations around Lake Erie; 2,091 items at 73 locations in the United States, and 139 items at 12 locations in Canada (Figure 7 and Figure 8). The amount of fishing-related debris represents 0.15% of the over 1.3 million total pieces of debris collected on Lake Erie's shores. Table 1 shows the numbers of these items collected from Lake Erie. It is important to note that community beach cleanup data can be skewed toward more accessible beaches, areas close to population centers, and debris size.

A wide selection of plastic materials is used in different types of fishing gear. The main types of plastics used are polypropylene (PP), polyethylene (PE), polyamide (PA6 or nylon) and polyester (PET). Gillnets, like those used in Lake Erie, are made of Polyamide (PA) (nylon). Trawl gear components can be made from PP and PE (netting and rope) and high—density Polyethylene (HDPE) (doors, small parts. Floats commonly used are made from Polystyrene or Polyurethane (PU). (Driedger et al., 2015; OSPAR Commission, 2020). These plastics enter the water in whole gears and when they are lost, they are generally macro-plastics (greater than 5mm). Exposure to UV radiation, waves, and other forces can cause fragmentation and degradation, producing much smaller pieces defined as microplastics (1 µm to 5mm) (Cera et al., 2020).

Table 1. Fishing gear reported collected at Lake Erie during the 2019 International Coastal Cleanup

Item description	Number reported	
	Canada	United States
Fishing buoys, pots, and traps (Pot Gear)	70	237
Fishing net and pieces (Net Gear)	18	456
Fishing line (1 yard/meter = 1 piece)	0	585
Rope (1 yard/meter = 1 piece)	51	457
Fishing gear (general category in online Clean Swell app)	0	356
Total	139	2,091

An estimated 10,000 tonnes of plastic waste enters the Great Lakes annually (Earn et al., 2021). Of the studies reviewed by Earn (2021), none identified current fishing gear or fishing activities as a source of the plastics in the Great Lakes. Several studies documented the impacts of plastics in the Great Lakes with an emphasis on microplastics, yet none specifically addressed microplastic impacts from ALDFG. Currently, a staggering 170.8 metric tons of microplastics are deposited in Lake Erie sediments every six months (Daily and Hoffman, 2020). Assuming Lake Erie has been collecting microplastics in its sediment for as long as Lake Ontario, this sedimentation has likely been happening for 40 years, though likely at slower rates (Corcoran et al., 2015). Ten species of Great Lakes fishes have been reported to be contaminated with plastic debris. The most contaminated of these was the invasive bottom-feeder, the round goby (*Neogobius melanostomus*), containing an average of 19 particles/individual (McNeish et al., 2018).

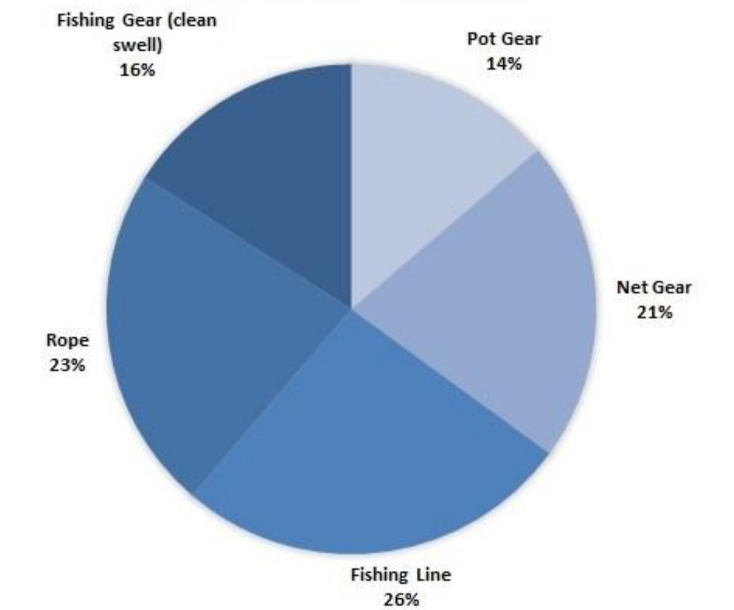

Figure 8. ICC 2019 ALDFG data for Lake Erie (Canadian and US data)

Studies of microplastics in the Great Lakes have generally focused on microplastics generated by land-based activities by sampling close to shorelines, at river mouths, in stormwater, and in discharges from wastewater treatment plants (WWTP) (Ballent et al., 2016; Cable et al., 2017; Hoffman and Hittinger, 2017). Considering that studies have shown that nylon and other plastics commonly used in fishing nets release microplastics under laboratory conditions (Montarsolo et al., 1990), it is likely that ALDFG is contributing its share of microplastics to Lake Erie.

Probability Mapping Analysis

Using values derived from distribution of fishing effort, REI, hydrogeoforms, commercial waterways, and possibly underwater snags and obstructions at 69 ALDF net locations in Lake Erie, the probability model provides integer values from 0 to 13 binned in four categories representing Remote, Low, Moderate, and High probability of ALDFG occurrence for both gillnet gear and trawl gear separately. In these iterations of predicting derelict fishing gear probability areas the linear additive model assumes equal weighting of all variables in the equation. Once the probability value is calculated there is no way to distinguish the combination of variables at a given location, and therefore locations with the same probability value may exhibit different characteristics.

In total the predictive models cover 12,882 km^2, which essentially covers all areas of Canadian Lake Erie. Table 2 shows the total amount of area of high, moderate, and low probability rankings in the Canadian waters of Lake Erie. Areas of high probability (value: 9 – 13) account for 33% (4,297 km^2) of the gillnet model and contain 61% (n = 38) of the in-water ALDFG locations. Gillnet areas of moderate probability (value: 6 – 8) account for 59% of the total area, and host 37% (n = 23) of the in-water ALDFG items, while the low probability areas (value: 0 – 5) only cover 7% of the total area, with only one (2%) of the ALDF nets inside. The trawl model has a smaller high probability area of 2,075 km^2, or 16% of the total area, and contains 29% (n = 18) of the in-water ALDFG items. The moderate trawl area is 58% of the total area and hosts 53% (n = 33) of the in-water ALDF nets. The low trawl areas area larger than those of the gillnets, covering 26% of the total area and hosting 18% (n = 11) of the in-water ALDFG items.

Areas of high ALD gillnet probability in the Canadian waters of Lake Erie is prevalent in both the western and eastern portion of the lake, with the largest continuous area covering a large amount of the eastern basin (Figure 8). These high probability gillnet areas in the east are reflective of the highly concentrated well heads, commercial waterways, REI, and a more dynamic substrate than in the central part of the lake. Further west, near Pelee Point, Pelee Island and Pelee Passage, the high probability gillnet areas are mostly reflective of the heavy gillnet fishing effort combined with the highly concentrated commercial waterways, several shipwrecks, and some substrate features. The high probability areas for the trawl model occur almost exclusively in the eastern basin, where condensed commercial waterways, a high concentration of seafloor obstructions, and nearly all trawl effort occurs. Hence, there are only some small high probability areas in other parts of the lake (Figure 9).

Table 2. Amount of area (km^2) within Canadian Lake Erie in high, moderate, low, and remote probability areas for ALDF gillnets and trawl gear occurrence identified in probability analysis.

Probability Rank	Area (km^2)		% of Total Area	
	Gillnet Model	Trawl Model	Gillnet Model	Trawl Model
High	4,297	2,075	33%	16%
Moderate	7,629	7,509	59%	58%
Low	956	3,299	7%	26%
Total	12,882	12,882	100%	100%

The ICC data model resulted in a polyline depicting the Canadian shoreline of Lake Erie with 16 segments, classified in probability bins from 2 to 5. This based on data from the coastal cleanups was designed to identify levels of probability along the Lake Erie coast, where ALDFG could accumulate by washing up on shore. All those with a value of 2 were considered low probability areas; those with values of 3 – 4 were labeled moderate probability, and high probability was ranked 5. High probability shoreline areas covered 77 linear km, 10% of the total, along the central basin coast, and the east side of Pelee Island. Shoreline with moderate probability for accumulating debris accounted for 57% of the shoreline (449 km), while the low probability areas covered 256 linear km or 33% of the shoreline (Figure 10).

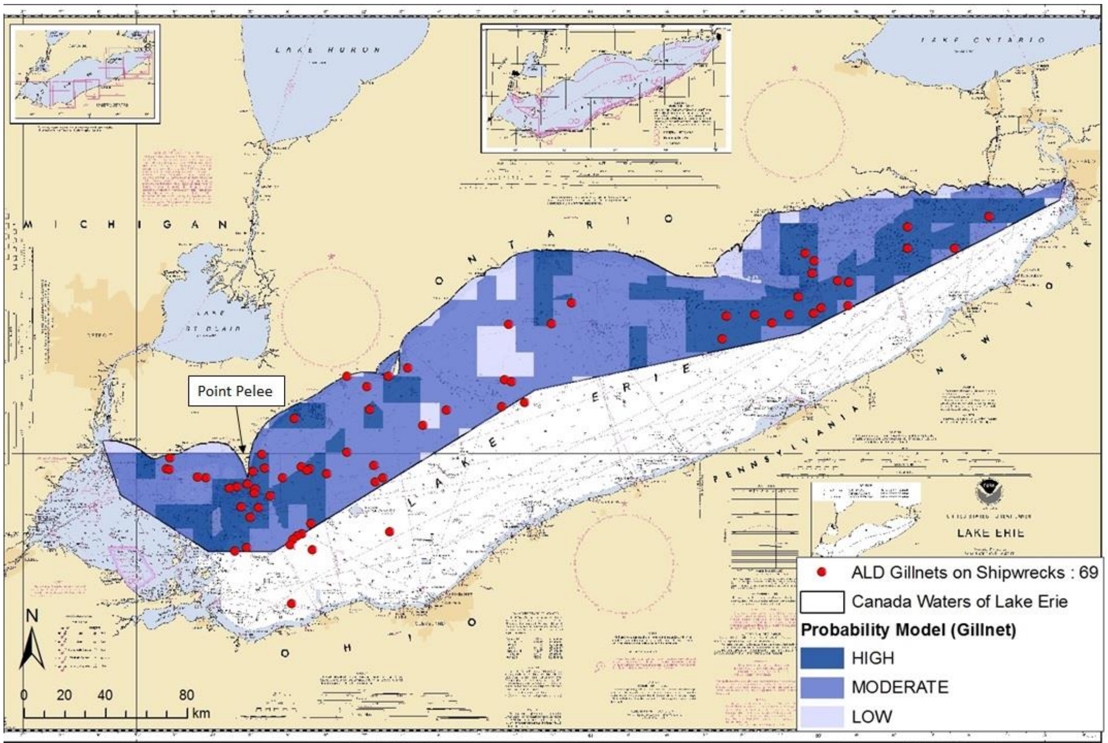

Figure 9. Probability map showing varying levels (High – Moderate – Low) of potential for commercial gillnet loss and accumulation based on a predictive model.

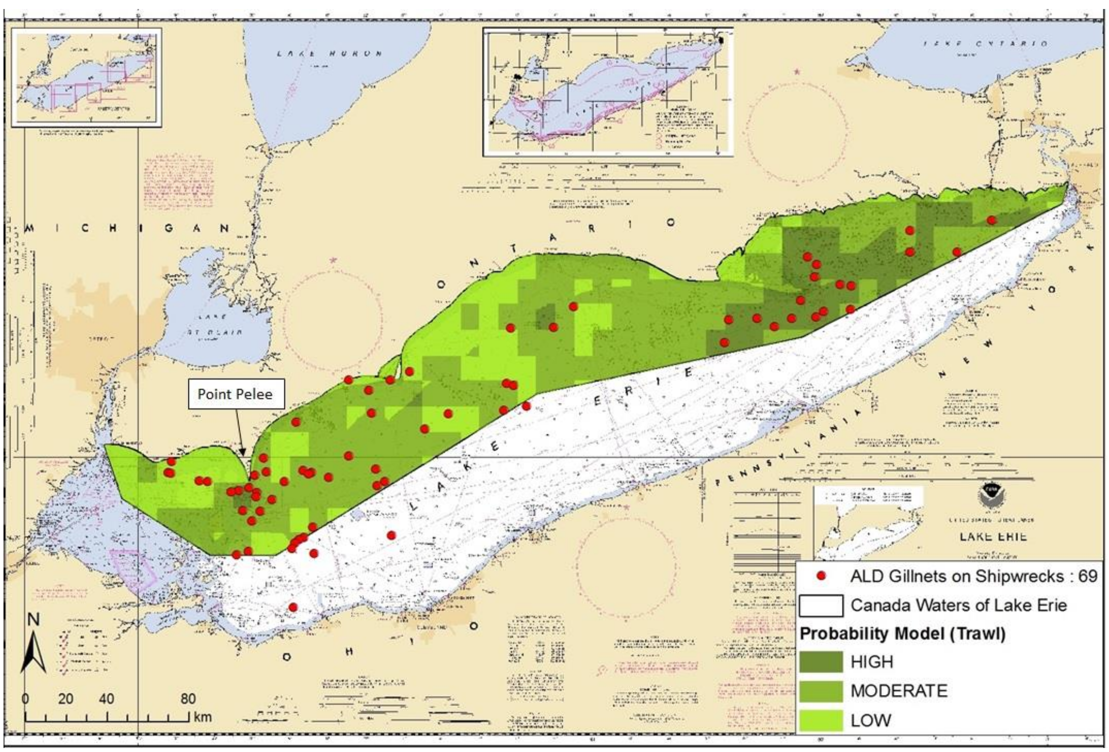

Figure 10. Probability map showing varying levels (High – Moderate – Low) of potential for commercial trawl loss and accumulation based on a predictive model.

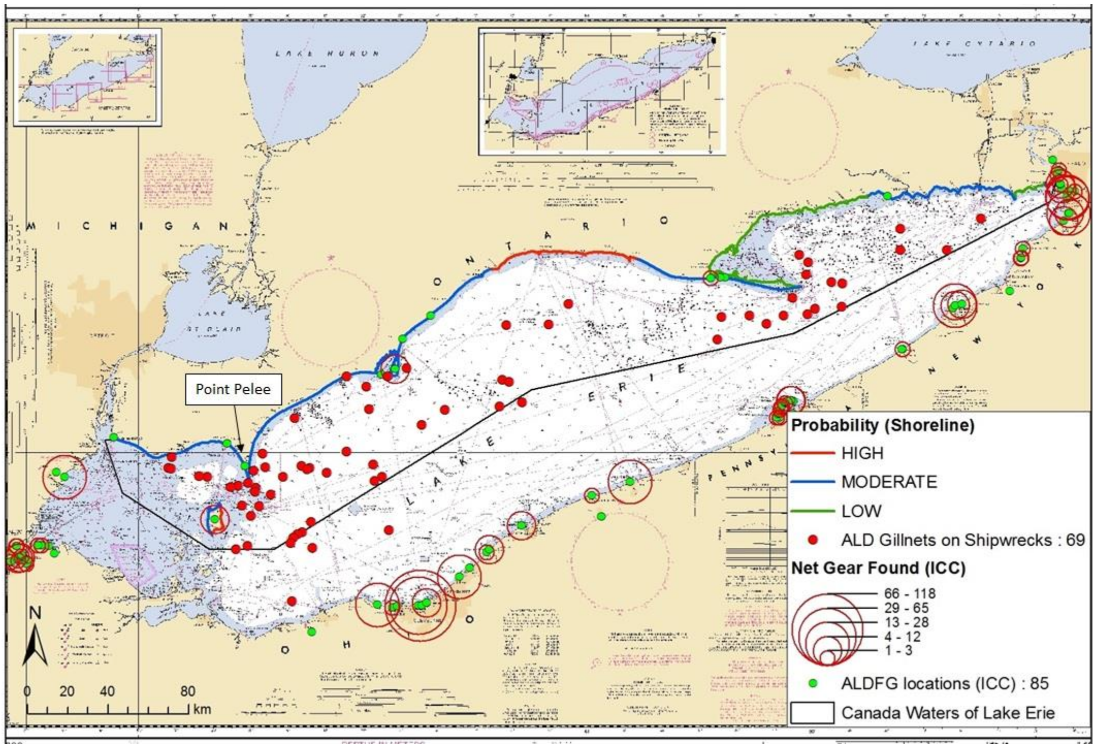

Figure 11. Probability map showing varying levels (High – Moderate – Low) of potential ALDFG deposition and/or accumulation on shoreline of Canadian Lake Erie, based on a predictive model.

Discussion and Recommendations

Of the fishing gears used in Lake Erie, gillnets are widely documented to pose the greatest risk of ghost fishing (continuing to catch target and non-target species after gear is lost) (Breen, 1990; Gilman, E., Chopin, F., Suuronen, P. & Kuemlangan, 2016; Uhlmann and Broadhurst, 2015). Gillnets are identified by the Global Ghost Gear Initiative (GGGI) as the most harmful types of ALDFG due to their risk of loss and the negative impacts they cause after loss (Huntington, 2016). Trawl nets pose a lower risk of ghost fishing but may damage sensitive habitats (Huntington, 2016; National Oceanic and Atmospheric Administration Marine Debris Program, 2016).

Sources agree that gillnet (and sometimes trawl) loss occurs regularly in Canadian Lake Erie but is generally of a small part of a net and is caused by inclement weather or ice, snagging, vessel conflict, interactions with recreational fishing gear and intentional discard. It should be noted that the predictive models reported here were specifically developed to identify where possible gear accumulation or loss areas occur, they are not meant to say that there are significant derelict gear problems in the high probability areas. Because all the known, in-water ALDFG locations that were analyzed were at shipwreck locations, the available data is heavily skewed towards large underwater obstructions. Also, the nets found at shipwrecks were incidental to the dive expeditions at shipwrecks only. Basically, the reason why all 69 in-water nets were found at shipwrecks, is because shipwrecks were the only locations where such investigations were conducted, and while we know that derelict gear often accumulates on underwater obstructions such as shipwrecks, shipwreck presence is not the only reason for gear to occur in these places. If such were the case, derelict nets would have been reported at all of the 322 shipwreck locations recorded.

Because of the infestation of Zebra mussels (*Dreissena polymorpha*) in Lake Erie, it is generally believed that lost gillnets do not remain suspended in the water column for long. Sources suggest that growth and biofouling on any lost net would render it unfishable within one to two days, thereby minimizing any direct species impacts from ghost fishing (SAI Global, 2021). This perception is supported in the literature, with studies of lost gillnets and experimentally lost gillnets completely losing catching capacity after time due to biofouling and other causes (Ayaz et al., 2006; Erzini et al., 2008). However, consistent, low-levels of ghost fishing are also well-documented in the literature (Baeta, F., Jose Costa, M., & Cabral, 2009; Gilardi et al., 2010; Tschernij and Larsson, 2003). Revill and Dunlin (2003) also documented low-level ghost fishing for up to two year on nets lost on shipwrecks in the United Kingdom.

While collapse of netting due to biofouling does eliminate potential animal entanglement and navigation hazards, it presents potential problems related to plastic degradation which is linked to multiple harmful impacts to benthic biota, water quality, and human health (Earn et al., 2021).

Habitat damage from lost fishing nets has not been studied in Lake Erie but also appears to be minimal and consistent with assessed habitat damage from active fishing nets (SAI

Global, 2021). Anecdotal information from divers suggest that many lost nets and other debris are quickly covered by sediments in Lake Erie's soft-bottomed habitats (pers. com. Allan King, February 26, 2021).

It is not possible to estimate the loss rate for gillnets in Lake Erie from available data. However, a recent study of global rates of fishing gear loss developed from mostly Northern hemisphere sources, estimated that 5.7% of all fishing nets used globally are abandoned, lost or discarded into the environment (Richardson et al., 2019). Lively and Good (2018) estimate that 3-7 panels/boat/year are lost. With an average of 35,000km of gillnet deployed annually in Lake Erie, even a 1% loss rate would introduce significant amounts of netting into the lake every year. Though it should be noted that the global loss rate, like the reported loss in Lake Erie, refers to parts of nets, rather than whole nets.

The GGGI launched the Best Practice Framework (BPF) for the Management of Fishing gear is 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, 2018; Gilman, 2015; Macfadyen et al., 2009; OSPAR Commission, 2014).

The BPF includes categories of management options specific to each stakeholder group including fisheries managers and control officers. The BPF provides guidance on common fisheries management strategies to help prevent and mitigate gear loss including spatio/temporal separation of fishing fleets, registration, seasonal restrictions, and gear marking.

Some of these recommended fisheries management practices are implemented in the gillnet fishery in Lake Erie, serving to minimize both loss of gear and negative impacts from lost gear. For yellow perch trap net fishery, there are restrictions on setting gear on reefs or near islands during set times of the year. This may help reduce snagging (SAI Global, 2021). The practice of "daylighting" gillnets, meaning that nets are set in the morning and brought in the same day, is common in the warmer months. Though this practice is adopted to minimize spoilage, it is consistent with consensus recommendations that reducing soak times and/or actively tending a net is an effective method to avoid gear loss (Brown and Macfadyen, 2007; Gilman, E., Chopin, F., Suuronen, P. & Kuemlangan, 2016). Fishers are required to report lost or stolen nets to a Conservation office (SAI Global, 2021). The requirement to report lost nets and to retrieve nets within eight days during winter fishing is also consistent with best practices to minimize negative impacts from ALDFG after loss (FAO, 2018; Gilman, E., Chopin, F., Suuronen, P. & Kuemlangan, 2016; Gilman, 2015; Huntington, 2017).

Recommendations

In 2018, a Canada-wide Strategy on Zero Plastic Waste (the Strategy) was approved to reduce plastic waste and pollution and recover the value of plastics through reuse, repair, remanufacture, refurbishment and recycling.

Federal, provincial and territorial governments agreed to develop an Action Plan to implement the Strategy.

The following **recommendations** align with Canada's commitments under its Action Plan on Zero Plastic Waste: Phase 2 to:

- improve consumer, business and institutional awareness to prevent and manage plastic waste responsibly
- reduce plastic waste and pollution generated by aquatic activities
- advance plastics science to inform decision-making and measure performance over time
- address plastics in the environment through capture and clean-up
- contribute to global action on plastic pollution reduction.

(Canadian Council of Ministers of the Environment, 2020)

Recommendation: Advance plastics science, improve institutional awareness, and contribute to global action
To appropriately address negative impacts of ALDFG in Lake Erie, developing a predictive model of where gear is lost is an appropriate first step. 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, 2018).

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.

For Lake Erie, an appropriate next step could be to determine baseline of loss rate for gillnets and trawls and direct ecological and economic impacts of ALDFG. We recommend working closely with the fishing industry to determine loss rates. Our initial interviews were a good start, but more systematic interviews, with carefully considered questions, executed with a larger segment of the fishing fleet will provide a broader picture of gear loss. These interviews will also improve fishers' understanding of the problem of ALDFG and spark conversations and considerations about which fishing practices can be used to prevent gear loss. Documenting a defensible rate of loss of fishing gear in Lake Erie will contribute to the global effort to develop ALDFG loss rates and lead to more informed global ALDFG prevention strategies (Gilardi et al., 2020).

No research on microplastic input specifically from ALDFG or its negative impacts has been conducted to date. After a better understanding of the amount of ALDFG entering Lake Erie each year, managers can determine the level of effort to invest on researching the indirect impacts of ALDFG as it relates to degradation to microplastics.

Recommendation: Advance plastic science and reduce pollution

Daily and Hoffman (2020) noted the importance of developing a mass balance of plastics and microplastics to understand the amount of plastics in the lake ecosystem. To understand how much fishing gear is lost, abandoned or discarded into the lake, a mass budget for fishing gear could be calculated (Turrell, 2020). Simply put, this would involve inventorying the amount of fishing gear in use at the beginning of the season and at the end of the season and documenting any end-of-life gear placed in disposal bins. Fishing gear items collected during beach cleanups and during ALDFG retrieval activities should also be considered in this budget. Compliance with the new requirement to report lost nets will aid in this mass budget exercise and should be monitored.

Interviews with fishers and others showed that the reporting requirement is generally interpreted to mean whole or large sections of net. Smaller shards of lost net resulting from snagging are not reported under the requirement. This discrepancy should be clarified. Reports should be logged in a database for easy data retrieval and analysis. Challenges with compliance should be identified collaboratively with fishers to ensure lost gear reporting processes are appropriate to the fishery.

This effort can be combined with a more thorough documentation of the life-cycle of fishing gear used in Lake Erie. While interviews suggested that nylon fishing netting is being recycled, this should be confirmed, and the waste streams of other plastic fishing gear components should be articulated. This can lead to eventual development of appropriate recycling schemes for all plastic gear components.

Recommendation: Cleanup plastics, advance plastic science, and increase institutional awareness

Considering the probability that sediments in Lake Erie have served as a sink for microplastic deposition for decades, preventing future deposition from ALDFG is a worthy endeavor. Now that locations of dozens of legacy lost gillnets are documented. A targeted retrieval effort using trained divers could serve to eliminate future indirect impacts from this ALDFG and provide helpful data related to the ALDFG itself, including potentially when and from which fishery it was lost.

Further coordination of lost gear reports should include a documented response and retrieval protocol. Additionally, asking fishers to document retrieval of any snagged net or pieces of lost net, even for a short time as a focused research study, will help to both validate their practices and assist in calculating loss rates. Recruiting fishers to participate in research efforts will build awareness of the issue of ALDFG and help to develop solutions that are both feasible and palatable to the industry.

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Appendix 1. Online survey questions

1. Contact Information

Name

City/Town

State/Province

Country

Email Address

2. Have you ever encountered lost or discarded fishing gear in Lake Erie?

- ◯ Yes
- ◯ No

3. Type of lost fishing gear encountered

- ☐ Recreational fishing line
- ☐ Fishing net or part of net
- ☐ Rope/buoy

Other (please specify)

4. What part of the lake have you encountered lost or discarded fishing gear

- ☐ Shoreline/beach
- ☐ Intertidal area
- ☐ Underwater

Other (please specify)

5. Provide locations of gear encountered by type. Please use coordinates if possible. You may email a google map with a pin to jdrinkwin@nrccorp.com.

Appendix 2. Online survey response

Lost fishing gear in Lake Erie

#1

COMPLETE

Collector:	Web Link 1 (Web Link)
Started:	Tuesday, February 16, 2021 9:59:16 AM
Last Modified:	Tuesday, February 16, 2021 10:02:26 AM
Time Spent:	00:03:09
IP Address:	104.195.132.133

Page 1

Q1

Contact Information

Name	*Removed for anonymity*
City/Town	**Kingsville**
State/Province	**ON**
Country	**Canada**
Email Address	*Removed for anonymity*

Q2

Have you ever encountered lost or discarded fishing gear in Lake Erie?

Yes

Q3

Type of lost fishing gear encountered

Recreational fishing line,

Fishing net or part of net,

Rope/buoy

Q4

What part of the lake have you encountered lost or discarded fishing gear

Shoreline/beach,

Underwater

Q5

Provide locations of gear encountered by type. Please use coordinates if possible. You may email a google map with a pin to jdrinkwin@nrccorp.com.

GPS: 41 53.249 82 33.248, partial nets/floats (Shipwreck here)
N41°49'22.3788" W82°32'10.2012", partial nets/floats (Shipwreck)

In the Pelee Passage, between the mainlaind and Pelee Island. There are a lot of wrecks here, so things get caught.

1 / 1