Derelict Gillnets in the Salish Sea: Causes of Gillnet Loss, Extent of Accumulation and Development of a Predictive Transboundary Model

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Abstract

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Since 2002, a total of 4,358 derelict nets were removed from the Washington waters of the Salish Sea (WASS), 95% of which were gillnets. I investigated the causes and rates of gillnet loss from the WASS commercial salmon fishery through interviews with fishers and industry professionals and analysis of historical fishing effort. Major causes of gillnet loss included lack of experience, operator error, equipment malfunction, overcrowding of fishing grounds, mismatch of net depth with ocean depth, and more. The findings suggest that gillnet loss is currently much less frequent than in previous decades characterized by heavy fishing effort (i.e., 1970s – 1980s). Analysis of net removal records identified patterns of association between net fishing depths and depths at which derelict nets are found. Spatial analysis and ArcGIS were used to produce a simple model capable of identifying areas of high, moderate and low probability of derelict gillnet occurrence. This model was applied to the British Columbia waters of the Salish Sea (BCSS) where an organized derelict fishing gear removal operation has been identified as a need, but has not yet been implemented. This study refines previous estimates of derelict gillnet quantities in the WASS, identifies the major causes for derelict gillnet loss and produces an exportable model that can be used to assist the design and

implementation of derelict fishing gear surveys and removal efforts in British Columbia and beyond.

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1. Introduction

Derelict fishing gear is deliberately abandoned or unintentionally lost fishing nets, lines, pots, traps and other gear utilized in commercial and recreational fisheries. The synthetic materials that much of this equipment is composed of do not deteriorate in the marine environment, therefore if adequately attached to the seafloor may remain in a relatively fixed position for decades. Derelict gear presents hazards to navigation through entanglements with vessel propellers and rudders, while also posing significant safety hazards to other marine based human activities such as commercial and recreational diving. With or without disabling mechanisms in place, derelict gear can continue to mortally entangle marine organisms of all types (mammals, birds, fish and invertebrates) regardless of the target species the gear was intended to catch, while also causing degradation to the habitat where it is ensnared through scouring, obstructing and sediment entrapment (Gilardi et al., 2010; Good et al., 2010; Morton, 2005). Impacts of derelict fishing nets on fish, birds, mammals and invertebrates have been well documented across the globe (Erzini et al., 1997; Boland and Donohue 2003; Page et al 2004, Matsuoka, 2005; UNEP, 2005; Gilardi et al., 2010; Macfadyen et al., 2009; Good et al., 2010).

The Salish Sea, a name officially recognized in 2009 by British Columbia and Washington State as the inland body of water bounded by Vancouver Island and the Olympic Peninsula that includes the Puget Sound, Hood Canal, Strait of Juan de Fuca, Strait of Georgia and Desolation Sound (Freelan, 2009) has hosted significant commercial and recreational fishing effort over the last century and more. While a variety of species have been targeted at varying levels of effort with multiple gear types, paramount in this fishing activity has been the effort targeting the regionally iconic and highly coveted Pacific salmon species (*Oncorhynchus spp.*).

In 2002 the Puget Sound Derelict Gear Removal Program managed by the Northwest Straits Initiative (NWSI), began survey, removal and training operations to identify and remove derelict fishing gear under newly developed state guidelines (WDFW, 2002). Concurrently, the Washington State derelict fishing gear database (WA DGDB) was established to compile derelict fishing gear descriptions and observed impacts, along with the inclusion of a "no fault" reporting system; giving members of the public the opportunity to report any derelict fishing gear encountered while boating, diving, beach-walking, fishing, etc. Since then, data compiled from reported observations during removals and related research projects have guided the adaptive management of the program. In 2007, an advisory group that included state, federal and tribal agencies, non-profit groups, commercial fishers and industry experts, created by the NWSI, completed the process of prioritizing gear types and locations for derelict gear removal operations. Fishing nets were identified as the highest priority for derelict gear recovery and research based on the long lived nature of the nets, the high degree of damage caused by the nets in highly productive marine habitat areas, and their propensity to indiscriminately entangle and often kill various types of marine life (NWSF, 2007). During this process, survey-estimated derelict gear densities yielded a projected 4,500 derelict nets in Puget Sound. Among the many derelict gear associated projects, additional research estimated post-gear removal rates of habitat recovery (NRC, 2009), threats to protected marine species (Good et al., 2009; 2010) and long term catch and mortality rates and cost benefit analyses of gear removal (Gilardi et al., 2010; Antonelis et al., 2011), successfully increasing the understanding of the extent and impacts of derelict fishing gear in the region.

From 2002 through the end of 2012, a total of 4,358 portions of derelict nets were removed by the NWSI derelict gear removal program, in the WASS as defined by the outer boundaries of Puget Sound Salmon Management and Catch Reporting Areas (SMCRA) (WAC 220-22-030) (Figure 1), but not including SMCRA 10C, 10D, 10F and 10G which delineate the ship canal, Lake Washington and Lake Sammamish. As of the end of 2012, the WA DGDB held an additional 188 known derelict net targets remaining within the allowable diver safety depths and 166 in waters beyond 32 m depth (DGDB, 2013). The numbers of remaining targets reflect only those that have been documented by targeted surveys or public reports, and do not necessarily represent the total number of remaining derelict nets in the WASS. During all NWSI removal operations an onboard biologist records characteristics of the recovered gear item such as estimated length, width, relative age and condition, while also documenting counts of all species encountered and entangled. Gillnets primarily from the salmon gillnet fisheries, and to a much lesser extent the spiny dogfish and Pacific herring fisheries, represent 95% of the derelict nets removed. Since the salmon gillnet fleet and associated effort in the WASS has decreased significantly in the recent decades, it is assumed that the majority of derelict nets present (and removed) accumulated during the years of heavy fishing effort (1970s to early 1990s), thereby assuming the moniker of "legacy nets."

An official derelict gear removal program has not been established in the British Columbia waters of the Salish Sea (BCSS); however the impetus exists for such an endeavor. In 2008, Canadian and U.S. officials convened a transboundary workshop to discuss and demonstrate derelict fishing gear program structure and operational practices (NWSC, 2008), and in 2011, the NWSI conducted a pilot project with the British Columbia Ministry of Environment, focusing on the removal of a previously identified derelict seine net and survey and removal of derelict crab pots from the British Columbia waters of Semiahmoo Bay (B.C., NRC & NWSF, 2011). Additionally, two derelict net removals from Barkley Sound, B.C. were

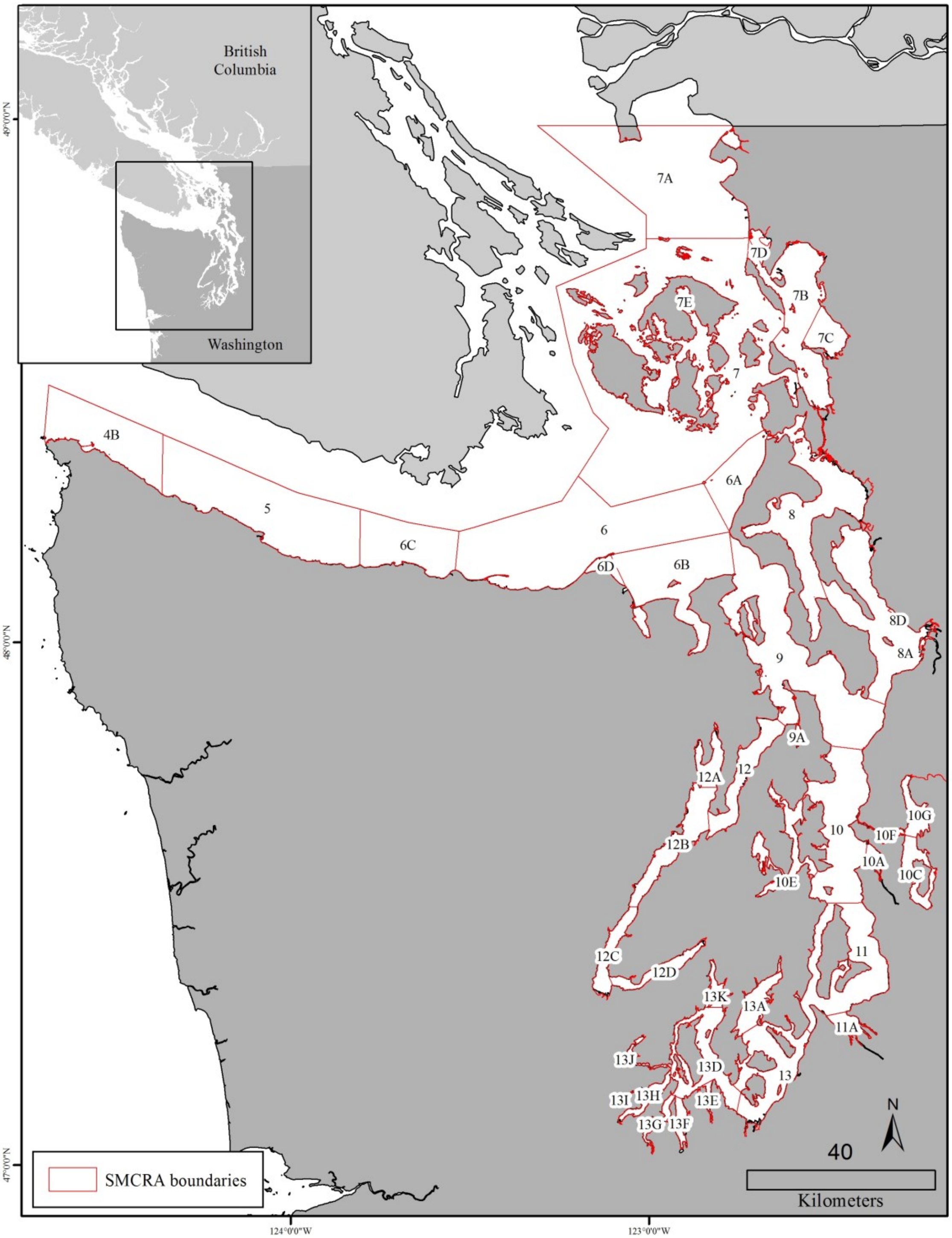

Figure 1: Puget Sound Salmon Management and Catch Reporting Areas (SMCRA) referred to in this document as Washington waters of the Salish Sea (Data source: Washington Department of Fish and Wildlife)

documented on *Youtube* in 2011 and 2012 by a recreational dive charter company who initiated local collaboration with volunteer divers, Canadian Department of Fisheries and Oceans (DFO) and the area gillnetters association to address newly lost derelict gillnets (Mieras, 2011; 2012).

Estimates of fishing gear debris in BCSS waters reported in Palsson et al. (2002; 2003) indicate that the accumulation of derelict fishing gear in BCSS may be lower than that in WASS. However, considering the extent of derelict fishing gear in the WASS, this should by no means discount any initiative for action. The cross-border similarities in gear types, target species, fishing effort and physical characteristics of fishing grounds, indicates potential for substantial accumulation of both pot and net gear in the BCSS. Considering that the Salish Sea is one unified body of water, sharing physical characteristics and biota on both sides of the Canada – US border, the extension of previous findings from the WASS to the BCSS, where derelict gear removal programs are in their early stages, can increase the benefits of gear removal to wildlife, habitat, commerce, and recreation.

Given the simultaneous benefits and challenges of removal of derelict gear from the Salish Sea, I sought to (1) refine previous estimates of historical gillnet loss and accumulation in the WASS; (2) identify the main causes of gillnet loss; and (3) use spatial analysis to develop a predictive model that identifies areas of high likelihood of derelict gillnets in BCSS. I used qualitative data from interviews conducted within the Salish Sea salmon gillnet industry and quantitative data from several sources to achieve the objectives of this research.

1.1 Background: Description of the fisheries and gear

The commercial salmon fishery in the Washington waters of the Salish Sea utilizes purse seine nets, gillnets and reef nets for harvesting both wild and hatchery stocks of sockeye (*Oncorhynchus nerka*), chum (*O. keta*), Chinook (*O. tshawytscha*), coho (*O. kisutch*) and pink

(*O. gorbuscha*) during their return as adults to their spawning grounds. Several management adjustments have been made over the history of the fishery, but none as significant as those following the Boldt Decision of 1974 (U.S. v. Washington 1974) which mandated equitable harvest of the salmon resource between the state and the regional Indian tribes within their "Usual and Accustomed Areas" (U&A). As a result of the Boldt Decision, co-management of the salmon resource between Washington State and Puget Sound Treaty Tribes was implemented. Since then, the commercial fleet has been defined by two separate sectors; treaty (aka: tribal or Indian) and non-treaty (aka: state or all-citizen). The non-treaty sector is managed by the Washington Department of Fish and Wildlife (WDFW) and treaty fisheries are managed by the separate tribes. The Northwest Indian Fisheries Commission (NWIFC) contributes to the co-management of the salmon and other resources. Management of the fishery includes a variety of spatial, temporal and gear restrictions depending on the target species, location and other considerations such as habitat conservation and bycatch concerns. The commercial gillnet fleet and associated effort in the WASS has decreased significantly since the 1970s as the result of a series of license limitations, buyback programs, attrition, conservation measures related to reduced stock abundance, bycatch and endangered species act (ESA) concerns (NOAA 1999; Mathews, 2012). From 2001 to 2011, the number of active participants (those who have reported landings) in the gillnet fishery per year has ranged from 530 to 894, compared to over 3,000 active participants during the late 1970s.

A gillnet consists of three major components: corkline, mesh (webbing) and leadline. Corkline includes a strong, lightweight line with small hard-foam floats attached approximately every 3 meters (10 feet). The mesh is the primary component of gillnets, comprised of varying mesh sizes depending on the target species. Gillnet mesh employed in the WASS salmon fisheries are commonly made of monofilament as well as multi-filament line. During the 1950s, the production of gillnet mesh transitioned from linen to nylon (Good et al., 2010) and it is probable that by the mid - 1960s (possibly earlier), all gillnet mesh utilized in the Puget Sound was made from some type of synthetic material. Leadline is heavy line that is weighted by lead surrounded by a nylon jacket. The thickness and weight of leadline varies depending on fisher preference and other variables associated with the fishery. The corkline suspends the mesh along the top of the water column below which the mesh forms a wall along its length. Mesh size and mesh count determine the depth of gillnets and the lower extent of the mesh is terminated where it is attached to the leadline. Three types of gillnets are commonly fished in commercial salmon fisheries of the WASS. The drift gillnet fleet generally utilizes the full complement of allowable gear in accordance with WDFW regulation (WAC 220-47-302) not to exceed 549 meters (1,800 feet) in length. There are no depth restrictions on drift gillnet gear and while depths vary depending on user preference, it is common for these drift gillnets to reach 30 meters (100 feet) in depth and sometimes more (this study; Washington, 1992). Drift gillnets are deployed and retrieved from vessels using power-driven reels or "drums." At the terminal end the net is connected to a large float or buoy and the other end remains connected to the tending vessel. Set gillnets (set nets), which in Washington are used only in the treaty fisheries, are stationary; with one end attached to the beach, the net extends out into the water perpendicular to the shore and the terminal end is anchored offshore and marked with a float. Set nets generally can reach 183 meters (600 feet) in length and typically reach 8 to 9 meters (25 to 30 feet) deep. The skiff gillnet fisheries operate from smaller vessels in a few specific locations, utilizing gear in a similar fashion as the drift gillnet fleet, but deploying and retrieving gear by hand without the assistance of power driven reels. Skiff gillnets in the non-treaty fishery are limited to 183 meters

(600 feet) in length with mesh counts of 60 (Port Gamble only) to 90 meshes equating to approximately 8 to 14 meters (25 to 45 feet) in depth. Skiff gillnets in the treaty fishery vary in size and can reach 366 meters (1,200 feet) in length with depths similar to those in the non-treaty skiff fleet. The length and depth of gillnets utilized in salmon fisheries in the WASS vary within the regulated size limits depending on user preference and the physical features (water depth, tidal flow, etc.) of the fishing grounds where effort takes place. The purse seine and reef net fisheries consists of much smaller fleets and very different fishing practices than the gillnet fisheries. While seine nets have been identified during derelict gear survey and removals, these differences are enough to suggest that compared to gillnets, very few purse seines and little to no reef nets are lost within the depth range of 0 to 32 m.

In the British Columbia waters of the Salish Sea (BCSS) the commercial salmon fisheries target the same species and sometimes the same stocks (i.e. Fraser River sockeye) as their WASS counterparts. These fisheries in British Columbia are managed by the Canadian Department of Fisheries and Oceans (DFO), catch management is divided into 32 statistical areas (Stat Areas) where three major gear types are used: purse seine nets, gillnets and hook-and-line trolling. Ten Stat Areas (13 - 20, 28 and 29) (Figure 2) are within the boundaries of the Salish Sea as described by Freelan (2009). Native (First Nations) participation in the commercial salmon fisheries constitutes a significant portion of the fleet through a variety of license types (James, 2003; DFO, 2012a). While the First Nations fisheries are managed under the same regulations of the commercial fleet as a whole, the Aboriginal involvement in the planning and implementation of the fisheries has been a priority since the 1992 implementation of the Aboriginal Fisheries Strategy (AFS) (DFO, 2012a). Since 1965, the gillnet fleet of the BCSS has faced significant reduction in fleet size, activity and landings similar to those seen in the WASS. The Davis Plan in 1968 introduced license limitations and buy-back options (ECC, 1981). In 1996 the Canadian government enacted the Pacific Salmon Revitalization Strategy (PSRS) otherwise known as the Mifflin Plan, a conservation measure including another buy-back program that when combined with the Pacific Fisheries Adjustment and Restructuring Program (PFARP) of 1998, significantly reduced the number of participants in the fishery through the mid to late 1990s (Schwindt et al., 2003; Noakes et al., 2002). In general, the impetuses for such measures were similar to those in the WASS regarding concern over species conservation along with economic efficiency of the fleet. From 2001 to 2011, the number of active vessels in the BCSS gillnet fishery per year has ranged from 250 to 502, compared to over 2,000 in 1989 and 1990. To remain consistent with the scope of this research, the purse seine nets and set gillnet fisheries in the BCSS were not included in this research.

The salmon gillnet fleet in the BCSS utilizes gear similar to their WASS counterparts; however the Canadian government imposes more stringent gear restrictions. Mesh size limitations vary by target species, location and time of year, ranging from a minimum of 115 mm (4 in) to 216 mm (8.5 in) (Canada, 1993). Gillnets depths are limited to 60 or 90 meshes, depending on the target species and management area. In general, drift gillnets in the BCSS are approximately 6 to 14 meters (20 to 45 feet) in depth. Gillnet lengths in B.C. vary from 135 meters to 550 meters, but within all management areas of the BCSS gillnet length limits are 375 meters (1,230 feet).

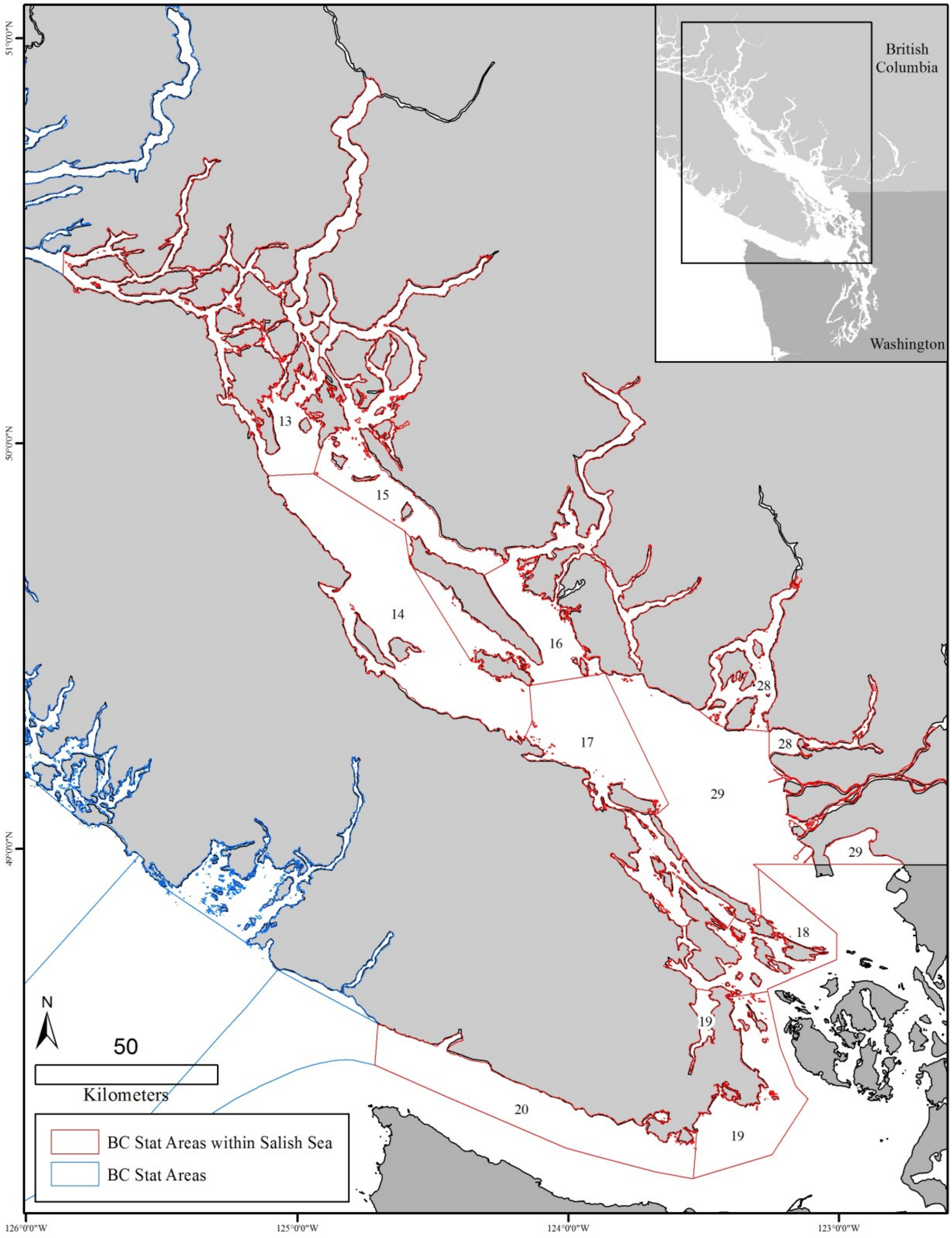

Figure 2: Fishing statistical areas in British Columbia waters of the Salish Sea (Data source: Department of Fisheries and Oceans Canada)

2. Methods

2.1 Quantifying historical fishing effort

Fishing effort metrics, such as days fished, pounds landed and number of active vessels, provide insight into fisher activity and assists in correlating such activity to derelict fishing gear projecting estimates of derelict gear throughout a fishery over several years. In Washington, fish receiving tickets (fish tickets) are generated upon each delivery or sale of commercially caught salmon in Salish Sea waters. Each fish ticket is eventually cataloged in a database maintained by WDFW. While required information differs between treaty and non-treaty fish tickets (WAC 220-69), several information variables are similar, and these can be used to quantify fishing effort across both sectors. The data requests made for purposes of this analysis included number of fish tickets generated and number of pounds landed per fisher per SMCRA per year from 1977 to 2011. 'Tribal ID' for treaty fishers and 'Vessel ID' for non-treaty fishers were anonymously coded and used to distinguish active participants in the fishery without disclosure of personal identification. In British Columbia, the "multiple sales slip system" was established by the DFO in 1951. Similar to the fish ticket database in Washington, the B.C. salmon catch database holds multiple attributes associated with each sales slip generated in the commercial salmon fishery; including gear type, date of sale, number of days fished, statistical area (Stat Area) of catch, species and weight (Wong 1983; Holmes and Whitfield 1991). For this study the DFO Catch Statistics Unit provided a dataset consisting of number of sales slips generated and number of pounds landed per gillnet vessel (anonymously coded) per Stat Area per year from 1983 to 2011.

Because the transition from biodegradable cotton and linen to nylon occurred in the 1950s, the preferred dataset for this study would include fishing effort data back to 1960. Number of gillnet deliveries (sales slips) and landings in weight per B.C. Stat Area per year were collected from DFO Commercial Catch Statistics Annual Reports from 1965 through 1982 (DFO, 2012b). To estimate the number of active vessels within the BCSS from 1965 to 1982, the five year average (1983 to 1987) percentage of active B.C. gillnet vessels that delivered salmon in the BCSS was applied to the total B.C. gillnet licenses for each year. The number of active vessels per Stat Area was estimated by applying the five year average number of deliveries per vessel per year to the number of deliveries per Stat Area per year. Salmon landings were collated from WDFW fisheries statistical reports for the years 1965 to 1976; however these were not separated by SMCRA. To estimate landings per SMCRA, the four year average (1977 to 1980) percent of catch per SMCRA from fish ticket data was applied to the total Puget Sound gillnet salmon catch for the years 1965 through 1976. To estimate the number of associated fish tickets the average number of pounds per fish ticket per SMCRA over the same period was derived from logbook data and then applied to the estimated landings per SMCRA. This produced estimates of landings (round pounds) and fish tickets per SMCRA per year for 1965 to 1976. The number of active vessels per SMCRA for the years 1965 to 1976 were estimated by multiplying the number of state gillnet licenses by the four year average (1977-1980) ratio of vessels per SMCRA per overall active vessels. An additional number of vessels were added to each SMCRA to account for treaty fisheries by using the reported percentage of treaty catch per total WASS catch from Jewel et al. (1972) and Schlosser (1978). Interpolations were made based on increase in percentage per year to account for the years not reported (1971 to 1973).

While ‘boat days’ would be the preferred metric for gillnet effort, such records are not consistent for either B.C. or WA data. Landings (weight) can be compared back to 1965 and number of deliveries (fish tickets in Washington, fish slips in B.C.) back to 1977 in Washington and earlier in B.C. As in DFO Statistical Reports, counts of salmon deliveries by gillnet fishers were used as a proxy for days fished. Discrepancies between these two metrics include multiple deliveries or no deliveries per vessel per day fished. However, if potential biases associated with this process are assumed to be consistent throughout the sampling period, then valid comparisons can be made from year to year (Campbell, 1969). Additionally, using 'Tribal ID' in place of 'Vessel ID' has the potential to overestimate the number of vessels within the treaty fleet, because in some cases multiple fishers may generate fish tickets from the same vessel, however, several inquiries into the ratio between fisher per vessel did not produce enough information to apply a correction factor. Conversely, using Vessel ID for the non-treaty fleet accurately depicts the number of vessels but lacks information on whether the operator was the owner or an alternate, therefore, potentially underestimating the number of individuals involved in operating vessels. Nevertheless, the conclusion was made based on the data available that these metrics would be the most useful for the purpose of quantifying fishing effort for both treaty and non-treaty sectors since the Boldt Decision was enacted.

2.2 Interviews and fleet dynamics

A series of semi-structured interviews (Weiss, 1994) were conducted to obtain local knowledge regarding the gillnet fishery and gear loss in the Salish Sea from the perspective of those directly involved. Because derelict fishing gear is a professionally sensitive subject among some fishers, the level of interview participation by fishers was anticipated to be relatively low. Original interviews targeted potential participants who have either shown interest in the derelict gear removal program by reporting observed derelict nets or by supplying information to improve effectiveness of the program. Additionally, resource managers provided names of fishers who they assumed would want to be involved in discussion of this topic. The list of potential interviewees grew with the number of interviews completed, as many of the interviewed fishers supplied contact information for their colleagues whom they assumed would be willing participants. Beyond members of the gillnet fleet, sources familiar with the industry such as net suppliers, fisheries enforcement officers, resource managers and scientists from agencies and tribes were contacted for various pieces of information related to the gillnet fishery and specifically, gillnet loss.

Methods for approaching interview subjects consisted of a telephone call, an email, or a combination of both, explaining the purpose of the project and a request to discuss the Salish Sea salmon fishery and derelict fishing gear. In addition to interviews scheduled by phone or email, several impromptu interviews were conducted at marinas hosting commercial fishing fleet members. All interviewees participated voluntarily and were informed that their identities would be anonymous. A semi-structured interview technique (Weiss, 1994) was used to elicit responses to a few specific questions through informal and (hopefully) candid conversations. Interviews lasted between ten minutes and three hours. Amongst the range of topics that the interviews touched, the one question that was asked of each participant was, *"Do you have an estimate of how many portions of gillnets are lost in the Puget Sound each year?"* or some iteration thereof. Additionally, fishers were asked if they had ever lost a net or a portion of a net in the Salish Sea gillnet fishery. Interviews performed in person were recorded with a digital voice recorder upon agreement from the participant; otherwise careful notes were taken using pen and notepad. All recorded interviews were transcribed, after which the recordings were destroyed and all content that could identify the interviewee was made anonymous through coding.

Using an issue-focused approach (Weiss 1994), information was coded into nine separate categories: *Locations, Loss Rates, Reasons, Enforcement, Fishery Description, Gear Description, Main Points, Perception* and *Suggestions.* The interview data were organized so that they would provide subjective insight into the WASS gillnet fishery and derelict fishing gear, and were used to provide context to the quantitative analysis of derelict gear removal data and fleet statistics. Emphasis was placed on summarizing comments related to reasons for net loss, rates of net loss and the nexus between fleet activity/behavior and net loss. Several interesting points were made related to resource management, enforcement of regulations, salmon conservation and the distribution of harvest between sectors and gear types; however, these data fell outside the scope of this research and were not included in the analysis.

Of the ten fishers interviewed, nine were active members of the gillnet fleet in the WASS and one was retired. Each fisher who shared information had over 20 years, and some over 40 years, of active fishing in the WASS. Many participate in other fisheries in Alaska and Washington, and are involved in or retired from other endeavors both related and unrelated to the fishing industry. In terms of years of active fishing in the WASS, the set of interviewees were among the more experienced members of the current gillnet fleet, many of whom were fishing prior to the enactment of the Boldt Decision. Nine of the ten fishers interviewed were members of the WA non-treaty fleet and only one was a treaty fisher. Based on the difference in participation and activity between sectors, it is clear that personal accounts from members of the treaty fleet are underrepresented in in this study. Most gear loss information and estimates provided by interviewees were specific to one or a portion of one sector of the gillnet fleet (i.e., treaty, non-treaty, full time/part time fishers) and in some cases specific to geographic location or target species (i.e., sockeye, chum). Three of the ten fishers interviewed provided estimates of gillnet loss rates in WASS and eight of the ten fishers provided information about the amount of net loss they have incurred over the course of their fishing career in the Salish Sea. Additionally, three enforcement officers provided estimates of yearly net loss within their jurisdiction based on observations and reports.

All estimates of gillnet loss rates in the WASS provided by respondents were made with the caveat that the information was anecdotal, speculative or a "best guess" and should not be considered empirical evidence. Nevertheless, documentation of their information and opinions refine previous estimates and assist in better understanding the causes of gillnet loss and the culture of the fishery.

In British Columbia, federal and provincial resource managers and fishery enforcement officers were contacted to discuss conditions and observed behaviors of the salmon gillnet fishery in the BCSS and the potential for derelict gillnet accumulation. Additionally, inquiries were made by telephone within the commercial surface supplied air (SSA) and recreational SCUBA diving communities regarding sightings or encounters with derelict fishing gear, and gillnet suppliers were contacted to gain information related to gear dimensions used. Interviews produced valuable information regarding the gillnet fisheries in the BCSS (and elsewhere); however little information specific to derelict gillnets from the salmon fishery was obtained. Three of the recreational SCUBA divers interviewed had knowledge of derelict nets of multiple types (i.e. trawl net, seine net, gillnet) in a few different locations only one of which was within the Salish Sea study area. Nearly all interviewees identified derelict pot gear from the spot prawn and Dungeness crab fisheries as problems that should be addressed. Multiple resource managers and fishery enforcement officers expressed opinions that the herring gillnet fishery in B.C. has historically exhibited a higher probability of gear loss than the salmon fishery. While further investigations related to this are underway, the focus of this study remains with the salmon gillnet fishery.

2.3 Derelict gillnet removal data

All records documenting derelict net removals in the WASS were extracted from the WA DGDB for analysis. On occasion multiple site visits and therefore multiple database entries were needed for the complete removal of a derelict net due to factors such as weather and tidal conditions, size of gear, water depth and underwater visibility. In such cases, data were tied to the original net target to avoid inflating the number of derelict nets removed. Data were analyzed for dimensional characteristics (i.e., length and width) and distribution patterns across a variety of habitat types and water depths. Using a net depth survey of actively fishing gear conducted by Washington State Department of Fisheries (WA, 1992), average and most common fishing depths for salmon gillnets in the WASS were calculated and compared with the depths at which derelict nets were found. Additionally, the ratio of average derelict net length to water depth at point of occurrence was calculated as an indication of the relationship between derelict gillnets and water depth.

2.4 Spatial analysis

A simple linear additive model was designed to distinguish varying levels of the likelihood of derelict gillnet occurrence based on fishing effort, bathymetry, results from interviews, and observations from derelict gillnet removal operations. The three characteristics of the fishery identified as necessary to model for this purpose were: (1) physical structure of the fishing grounds, (2) biological behavior of the target species, and (3) the human behavior exhibited within the fishery. This was accomplished by using (1) variance in seafloor depth (point depth – focal mean depth), (2) bathymetry (depth of water), and (3) fishing effort as variables to represent these characteristics, respectively. Complete bathymetric raster coverage of the WASS at 30 meter resolution was provided by NOAA (Davies, 2009) and ArcGIS vector polygon shapefiles delineating WA SMCRAs were provided by WDFW (WAC-220-022-030).

All spatial analysis was performed by using ESRI ArcGIS 10.1 with the Spatial Analyst Tools extension. Because one of the goals of the study was to export findings from WASS to BCSS, choosing the spatial scale used to calculate variance in bathymetry for WASS data (30 x 30 m cell resolution) included identifying an appropriate scale that could be compared to variance of the BCSS (75 x 75 m cell resolution). Recent benthic terrain mapping of the waters of British Columbia suggests that an appropriate scale to define fine scale features in B.C. is an inner annulus of 75 meters and an outer annulus of 525 meters (BCMCA, 2010). To achieve a comparable scale in WASS, an inner annulus of 90 meters (3 cells) and an outer annulus of 540 meters (18 cells) were used to identify focal mean depth of WASS with which to calculate a variance from focal mean values.

The sum of fish tickets per SMCRA from 1965 to 2011 were joined as attributes to the SMCRA vector shapefile which was then converted into raster format at 30 meter cells, giving a value for each cell that represents the amount of fishing effort exerted within the SMCRA it lies within. This method applies a uniform fishing effort value for each cell within each SMCRA; however, fishing effort is known not to be evenly dispersed throughout these areas and is often concentrated in a few specific regions due to salmon migration patterns, fisher behavior and regulatory closures. To spatially define the exact areas of major effort and the varying degrees of effort at each location was deemed beyond the scope of this simple model and therefore the resolution of fishing effort values remain at the SMCRA level.

Spatial data indicating the locations in the WASS from which derelict gillnets were removed between 2002 through 2012 were converted into a vector point shapefile and overlaid onto the bathymetry, variance and fishing effort rasters in ArcGIS. Values for the three raster datasets were extracted at the recorded location of each derelict gillnet point. Most often derelict gillnets cover an area much greater than that represented by the single pair of latitudinal and longitudinal coordinates that are reported during surveys and removal, and multiple site visits for the removal of a single derelict gillnet often results in multiple reported coordinates. While using multiple data points for single targets would exaggerate estimates of derelict gillnet accumulation, they provide useful additional information when analyzing seafloor characteristics where derelict gillnets are found. Because the purpose of the spatial analysis study was to identify the types of areas where derelict gillnets are likely to exist rather than estimate the number of derelict gillnets that could exist, all recorded locations of derelict gillnet removals were used, including those identified as portions of previously partially removed targets. Bathymetric data at the location of 82 (2%) derelict gillnet locations were found to be inaccurate when compared to the depths reported during dive removals. In such cases the bathymetric values were replaced with the value representing the midpoint between the minimum and maximum depth reported during removals. Depth and variance were ranked by their values most associated with derelict gillnet occurrences; and fishing effort was ranked by percent of total.

Figures 3a-c depict the frequency of occurrence of derelict gillnets by bathymetry, variance and effort with classification ranks. Derelict gillnet occurrences at bathymetric values display semi-normal distribution. Classification of bathymetry was performed by binning the frequency of occurrences of derelict gillnets by every 0.5 standard deviations (1 st dev = 7.89 m) from the mean (-20.44 m). Each group was then assigned an integer value from 0 to 6 with the

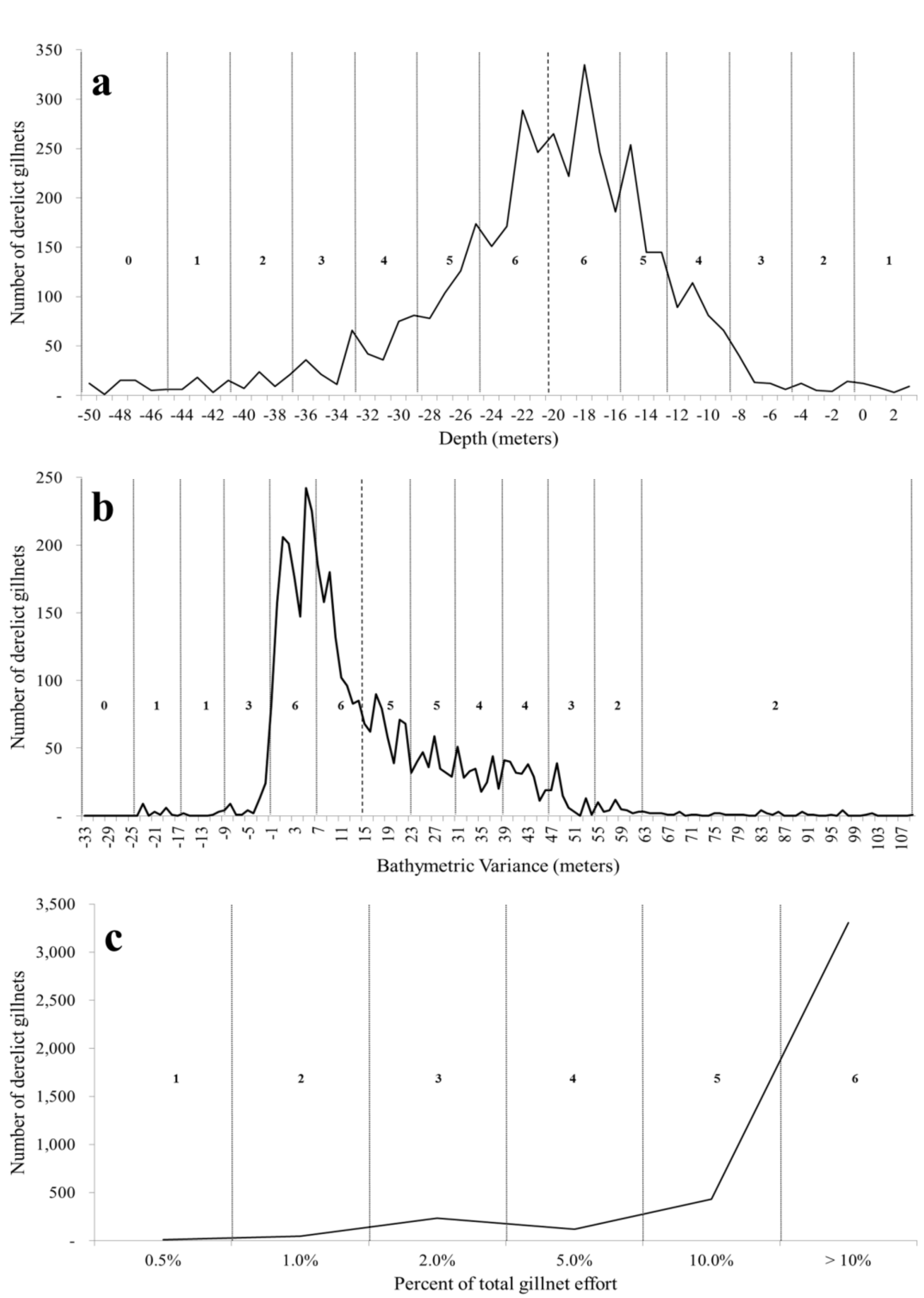

Figure 3a-c: Derelict gillnet frequency of occurrence at values for bathymetry, variance and effort (a-c) in the WASS. The top chart (a) shows number of derelict gillnets by bathymetry values with class ranks, the center chart (b) shows number of derelict gillnets at variance values with class ranks, and the lower chart (c) shows the number of derelict gillnets by percent of total gillnet effort (number of fish tickets). Dotted lines indicate class breaks and dashed line indicates mean.

highest rank equating to the value set with the highest frequency of occurrences. To limit the study area to the focused removal depths, all bathymetric data beyond -50 m was reclassified as "NoData" and excluded from the model. Frequency of occurrence of derelict gillnets at variance displays a right-skewed distribution. Class breaks were designated every 0.5 standard deviations (1 st dev = 15.87 m) from the mean (15.07 m), and integer values from 0 to 6 were offset to adjust for the skewed data. The 82 derelict gillnets for which bathymetric data were suspect were omitted from the variance analysis, because comparable data from removal operations were not available. Fishing effort values (total fish tickets from 1965 to 2011) by SMCRA were re-classed to integer values from 1 to 6 with breaks established by percent of total fishing effort in the WASS. The three reclassified rasters were added together using the Map Algebra tool, resulting in a single raster with cell values from 1 to 18, representing low to high probability of derelict gillnet occurrence. A flow chart of the major steps involved in the model building is illustrated in Figure 4.

For the BCSS, bathymetry at 75 meter resolution was provided by British Columbia Marine Conservation Analysis (BCMCA) obtained from Natural Resources Canada (Kung, 2003). Vector polygon shapefiles delineating B.C. Statistical Areas were provided by DFO – Pacific Region (DFO, 2006). A focal mean depth raster of the BCSS bathymetry was calculated with an inner annulus of 75 meters (1 cell) and an outer annulus of 525 meters (7 cells) and used to derive the bathymetric variance at a scale comparable to the WASS model. Based on the WASS linear additive model, two models of the BCSS were produced to identify areas of potential high probability for derelict gillnets from the salmon fishery. In the first model (BC1), bathymetry and bathymetric variance were reclassified using the same class breaks and rankings used in the WASS model, and fishing effort breaks for BCSS were ranked relative to the effort in the WASS. A second model for the BCSS (BC2) was produced with an adjusted fishing effort classification scheme that ranked BCSS fishing effort only, without the WASS effort. Because of the correspondence between depths at which derelict gillnets in WASS are found and the fishing depths of the nets employed (this study), the bathymetry classification for the BC2 model used the same range size of 0.5 standard deviations from a mean depth adjusted to correspond with the shallower fishing depths of BCSS salmon gillnets. Each model produced a single raster layer with integer values from 1 to 18 representing low to high probability of derelict gillnet occurrence.

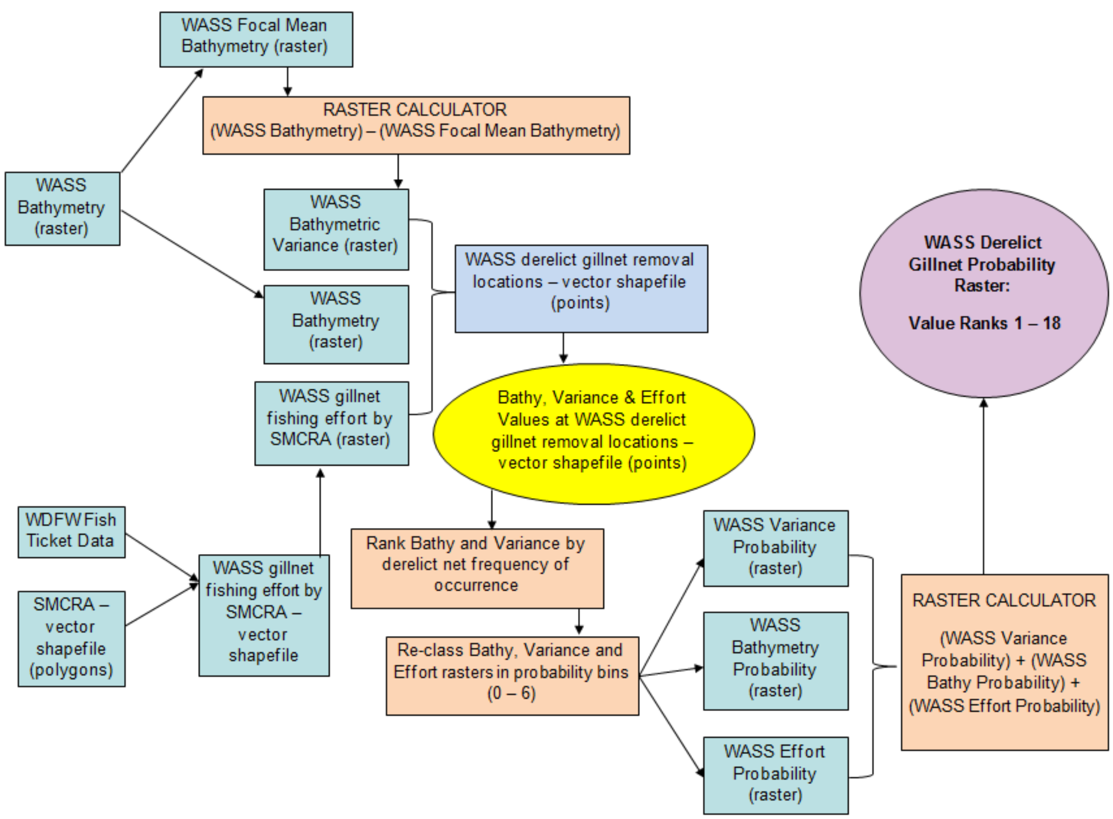

Figure 4: Illustration of inputs and steps of the linear additive model built from WASS bathymetry, fishing effort and derelict gillnet removal data.

3. Results

3.1 Historical fishing effort

Figure 5a-c depicts the changes in fleet size, activity and landings since 1965 for both the WASS and the BCSS. In general, gillnet fishing activity was highest in the 1970s and 1980s. During this period, fishing activity in the WASS generally exceeded that in the BCSS. Fishing activity in both areas declined sharply in the early to mid-1990s. Activity on both sides of the border since then has been relatively steady with minor fluctuations from year to year.

3.2 Interviews and derelict gillnet estimates in Washington

Each fisher interviewed made it very clear that losing an entire drift gillnet never happens in today's fishery. When net gear is lost, it is typically portions of web and/or leadline approximately 18 m in length. Replacing a full drift gillnet costs anywhere from US$7K to $15K and would likely be enough of a financial hardship to discontinue that fisher's gillnet activity in the WASS. Historically, crowding on the fishing grounds was a major cause for gear loss because competition for fishing areas drove some fishers to marginal areas where snags and heavy tidal activity increased the chances of gear being snagged and lost. While crowding still occurs in certain areas (e.g., Hood Canal and Point Roberts), especially when allowable fishing days are few and the target species provides high ex-vessel value, compared to years past the diminished fleet size has reduced this problem substantially.

Operator inexperience was identified as one of the most important underlying reasons for gillnet loss to occur. However, it was pointed out that within the WASS, tides and currents vary by area, and even fishers experienced in one or more location may not be experienced in others. Additionally, participants explained that gear loss is often caused by operator error, regardless of experience, but that eventually the fleet is "self-correcting" and the fishers that continue to make

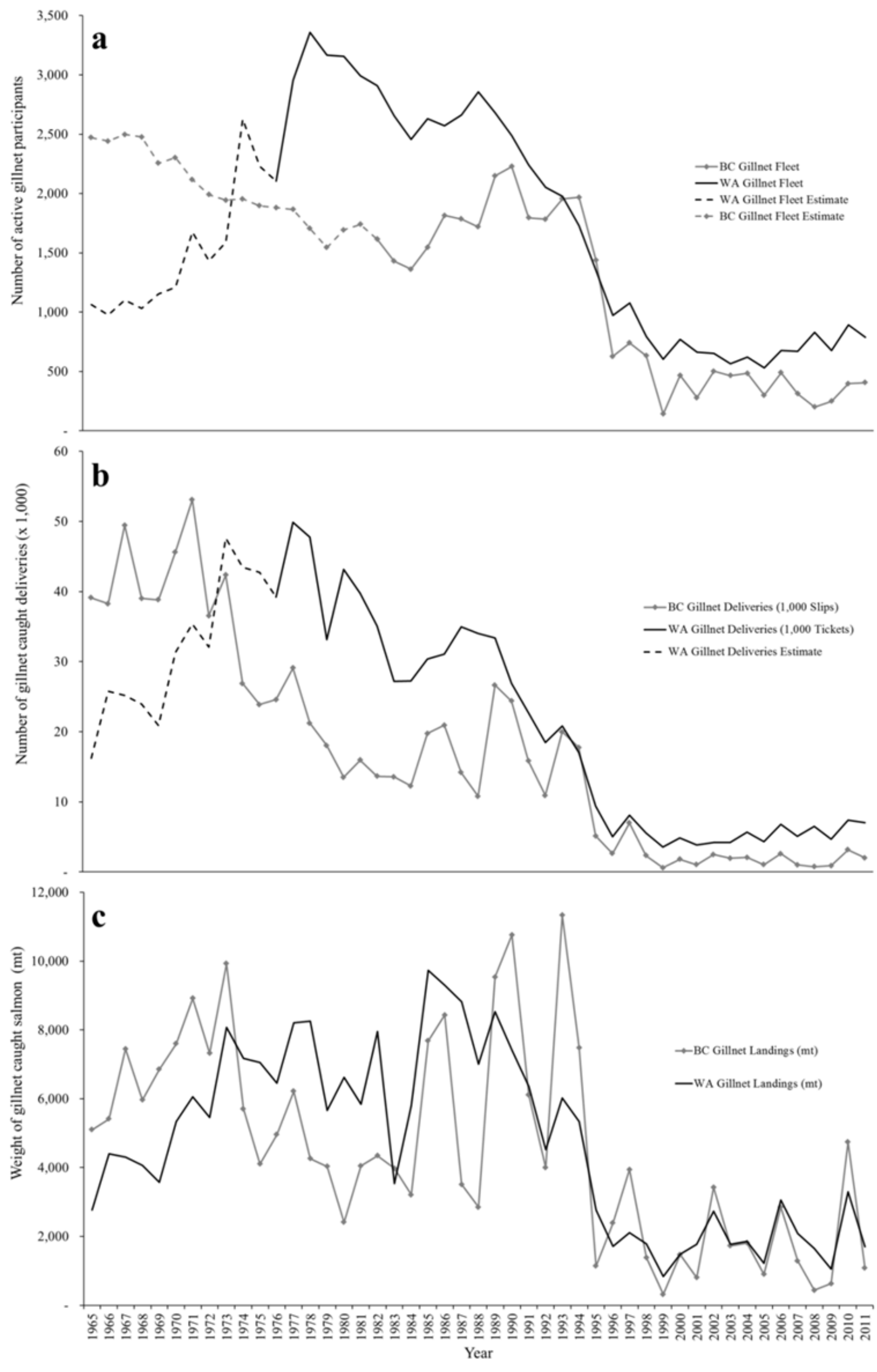

Figure 5a – c: Commercial salmon gillnet fleets, effort and landings (a-c) in the Salish Sea. The top chart (a) shows number of active participants, the center chart (b) shows number of gillnet salmon deliveries and the lower chart (c) shows the weight (metric tons) landed from 1965 to 2011. Dashed lines represent estimates from this study.

mistakes and/or lose gear will eventually no longer participate. Undercapitalized vessels and/or those that sit idle for the majority of the year due to the reduction of fishing opportunities in the WASS operate on only a small number of days a year. For these the likelihood of engine, hydraulic or other mechanical malfunctions increase substantially. Additionally, some vessels may be in poor condition simply due to a lack of regular maintenance and safety checks. Equipment failure, while probably more common on undercapitalized vessels, can occur on any vessel and was described by interviewees as one of the two most common reasons for derelict gear loss. When a vessel becomes immobilized by mechanical malfunction while a net is deployed, vessel and gear are often forced by the current into shallow water or other compromising situations where gear becomes snagged and must be cut free in order to save the vessel and its personnel. Often when this happens, the fisher ties some type of marker buoy on the cut end of the discarded portion of net with plans to return later, but this does not always occur. Increased technology on vessels (i.e., depth sounders, radar, GPS navigation, charting software, cellular phones, etc.) over the years has reduced mistakes that may lead to loss of net gear by giving the operator a better understanding of his/her situation such as proximity to reefs/snags, water depth, rate of drift, etc. However, not every vessel in the fleet is equipped with such equipment.

Some of the fishers interviewed, particularly those that target terminal fisheries with relatively shallow gear (i.e., 60 mesh), proposed that net depth plays a large role in the loss of gillnets, referring to gillnet depth restrictions (by mesh count) in Alaska and British Columbia. This argument is based on the concept that a shallow (i.e., 8 m) net will not become snagged on a rock pinnacle or reef with the same likelihood as a deeper (i.e., 30 m) net. However, shallow nets have been identified as derelict in the WASS and some of the interviewees discussed their experience witnessing gillnet loss in other places, such as southeast Alaska, where net depth restrictions are in place. Gillnet loss was also associated with gillnet length by one of the interviewed fishers, as he referred to a "whiskey shackle" as an extra portion of gear added to the maximum allowable 549 m. This fisher reported that in the 1970s and 80s whiskey shackles were intentionally snagged on reefs by fishers in order to maintain their set without drifting away, then once the set was complete the excess net was discarded and left to become derelict. While none of the other fishers interviewed said that they had witnessed or heard of this behavior, many did claim that they have witnessed fishers using extra lengths of gear, sometimes as much as an extra 91 m, and that the increase in length of gear would easily increase the chances of a portion of it becoming snagged and/or derelict. Interviewee comments regarding size of gear being related to loss of gear was summarized well by one fisher's statement that, *"Three hundred fathoms* [549 m] *of these deep nets is about all anybody can handle…these deep nets basically fish you."*

Information obtained early in the NWSI derelict gear removal program provided estimates that 3% to 5% of gillnet fishers lose a whole or part of a net during each active year of fishing. When applied to the fleet statistics reported in this study, this yields a range of 2,366 to 3,944 derelict gillnets accumulated in WASS since 1965. Qualitative information provided by interview participants during this study suggests that gillnet loss is currently lower than 3% to 5%, but during the years of heavy fishing effort and greater participation the number of gillnet fishers losing gear in a given year was closer to 5% to 9%, and even up to 20% in some areas of heavily concentrated effort. The estimated rate of gillnet loss at 5% to 9% was applied to fleet statistics for the years 1965 to 1994, and then adjusted to 2% to 4% for the years 1995 to 2011. The resultant estimate of historical derelict gillnet accumulation in the WASS is 3,550 to 6,442.

3.3 Removal data and spatial analysis

Analysis of operational records shows that 4,031 separate derelict gillnets were represented among the total 4,151 derelict gillnet removal operations. Records showed that 157 (4%) of the derelict gillnets removed were made of cotton/linen material and therefore had probably been lost prior to 1965. Of the 4,031 derelict gillnets, gear dimensions (length, width, maximum suspension) were recorded for 4,028. Length of gear removed ranged from < 1 m to 549 m, with the majority (55%) being 50 m or less. Net lengths > 50 m to 100 m accounted for 31% of the total and 14% were longer than 100 m (Figure 6). Derelict gillnet width ranged from < 1 m to 30.5 m. These values fit a normal distribution with a mean of 7.47 m (95% CI = 5.99 – 8.96). Derelict gillnet area ranged from < 1 m^2 to 13,935 m^2; with 47% being ≤ 200 m^2 , 36% between 200 and 1,000 m^2, and 17% were > 1,000 m^2 (Figure 6).

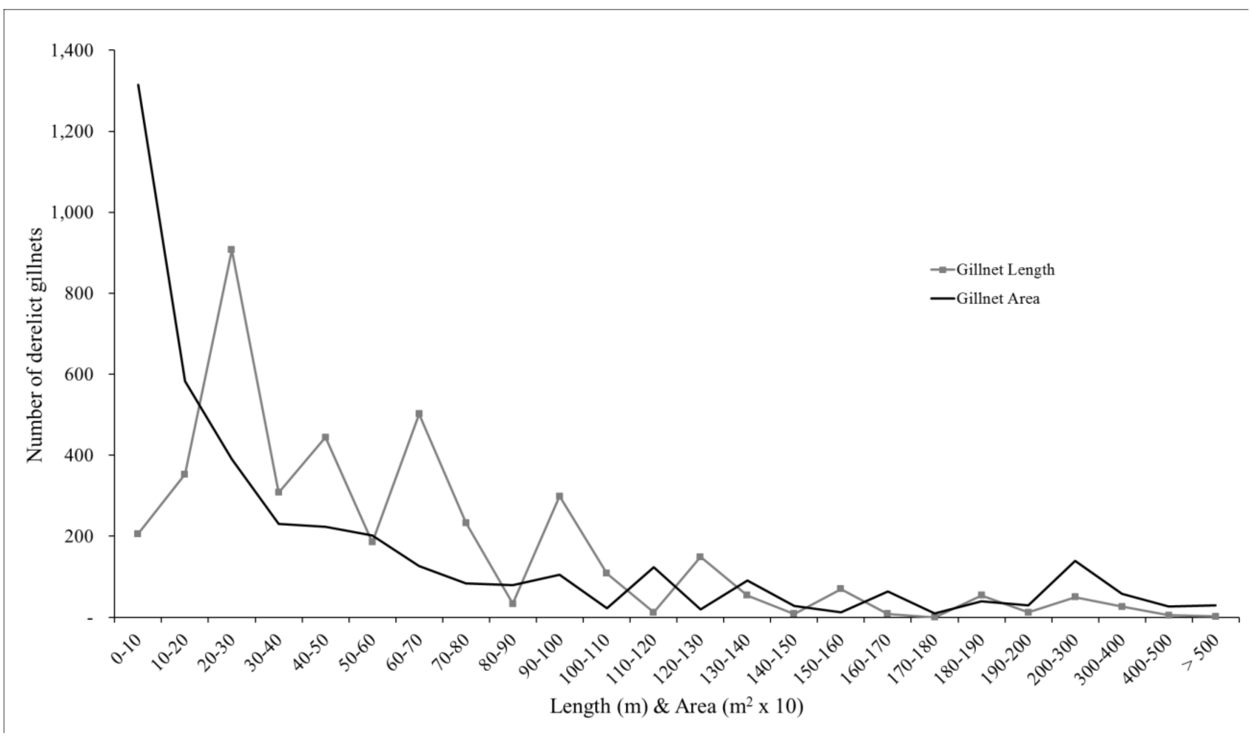

Figure 6: Graph showing the length and area frequency for derelict gillnets removed from WASS from 2002 through 2012.

Minimum and maximum observed depths (based on values recorded during removals) at derelict gillnet locations both ranged from 0 m (at the surface) to -101 m depth, with means of -17.58 m (95% CI = -14.80 to -20.37 m) and -19.88 m (95% CI = -16.46 to -23.29 m) respectively (Table 1). The mean mid-point of these depth ranges was -18.73 m (95% CI = -15.72 to -21.74 m). It should be noted that water depths recorded during removal operations are the depths observed at that given time and have not been adjusted for tidal oscillation. Depth values extracted from bathymetric raster data in ArcGIS, with corrections applied to outlying data, ranged from +3 m to -101 m depth, with a mean of -20.44 m (95% CI = -15.53 to -25.34 m). The mean minimum, mid- and maximum depths reported during derelict gillnet recovery are 86%, 92% and 97% of the mean depths extracted from the bathymetric raster layer, respectively. Bathymetric variance values at derelict gillnet locations, omitting outliers caused by either poor coordinates or poor bathymetric data, ranged from -22.81 m to +108.85 m, exhibiting a mean of 15.07 m (95% CI = 7.72 to 22.43 m). Fishing effort values at derelict gillnet recovery sites ranged from 499 to 230,754 fish tickets (mean = 169,074; median and mode = 209,385) (Table 1).

Of 1,450 gillnets surveyed by the Washington Department of Fisheries Puget Sound Net Management Unit (WA, 1992), 1,355 (93%) were being used in SMCRAs where derelict gillnet removals have since occurred. Of these, the most common (n = 185) estimated gillnet fishing depth was -24.3 m. The estimated mean depth of these nets was -20.14 m; 0.30 m (1.5%) shallower than the average bathymetric values at derelict gillnet locations and 0.26 (1.3%) to 2.55 m (14.5%) deeper than the average maximum and minimum depths observed (Figure 7).

Table 1: Number of derelict gillnets per SMCRA with the associated effort, depth and variance of derelict gillnet locations. SMCRAs without derelict gillnet removals are omitted.

SMCRA	Total Fish Tickets (1965 - 2011)	Percent of Total Fish Tickets	Derelict Gillnet Removals	Number of Derelict Gillnets	Percent of Total Derelict Gillnets	Mean Variance (meters)	Mean Min Depth Observed (meters)	Mean Mid Depth Observed (meters)	Mean Max Depth Observed (meters)	Mean Depth Bathy (meters)
7E	499	0.1%	1	1	0.0%	3.92	-12.19	-14.63	-17.07	-13.00
6B	2,407	0.3%	1	1	0.0%	2.20	-16.76	-17.37	-17.98	-17.00
13	3,799	0.4%	1	1	0.0%	13.26	0.00	-1.52	-3.05	-4.00
10E	4,554	0.5%	7	7	0.2%	12.59	-13.76	-14.91	-16.07	-13.57
6A	6,752	0.7%	43	42	1.0%	11.68	-16.17	-17.76	-19.35	-22.14
4B	9,717	1.0%	3	3	0.1%	2.82	-8.53	-9.19	-9.86	-7.67
10A	10,736	1.1%	8	8	0.2%	5.10	-0.99	-2.51	-4.04	-6.25
11	14,441	1.5%	5	5	0.1%	35.31	-14.63	-16.86	-19.08	-18.60
9	15,674	1.6%	221	220	5.5%	6.28	-15.02	-16.17	-17.32	-14.67
13A	17,971	1.9%	2	2	0.0%	-1.45	-12.19	-15.24	-18.29	-15.50
12C	23,113	2.4%	2	2	0.0%	32.64	-15.24	-17.22	-19.20	-10.00
7C	25,564	2.7%	9	9	0.2%	24.22	-6.64	-11.92	-17.20	-6.56
8	33,573	3.5%	53	51	1.3%	2.27	-4.26	-5.00	-5.75	-4.92
12	42,834	4.5%	57	57	1.4%	12.45	-14.73	-15.78	-16.83	-16.47
8A	62,839	6.6%	7	7	0.2%	3.15	-5.70	-6.47	-7.23	-6.00
10	77,291	8.1%	424	418	10.4%	7.39	-17.86	-18.51	-19.16	-18.97
7A	161,368	16.9%	761	729	18.1%	4.15	-18.20	-18.91	-19.63	-19.52
7	209,385	22.0%	2,349	2,276	56.5%	20.32	-18.25	-19.54	-20.84	-21.87
7B	230,754	24.2%	197	192	4.8%	24.54	-16.43	-18.32	-20.21	-24.02
Total	**953,271**	**100%**	**4,151**	**4,031**	**100%**	**15.07**	**-17.58**	**-18.73**	**-19.88**	**-20.44**

If a net becomes snagged and is unrecoverable, fishers interviewed reported that a fisher can minimize net loss by positioning the vessel directly over the snag point, making an approximate vertical line between the seafloor and vessel prior to cutting the net loose while also retrieving much of the webbing and corkline, suggesting that the length of derelict nets would typically be equal to or slightly greater than the depth of water where the net was lost. This is not supported by the finding that the estimated derelict net lengths range from 1 to 549 meters, far exceeding the bathymetric depths of the dataset; however the average water depth to derelict gillnet length ratio was 0.74 m (95% CI = 0.69 – 0.78 m) from GIS bathymetric values and 0.64 m (95% CI = 0.60 – 0.67 m) minimum and 0.71 meters (95% CI = 0.67 – 0.75 m) maximum from the observed depth values.

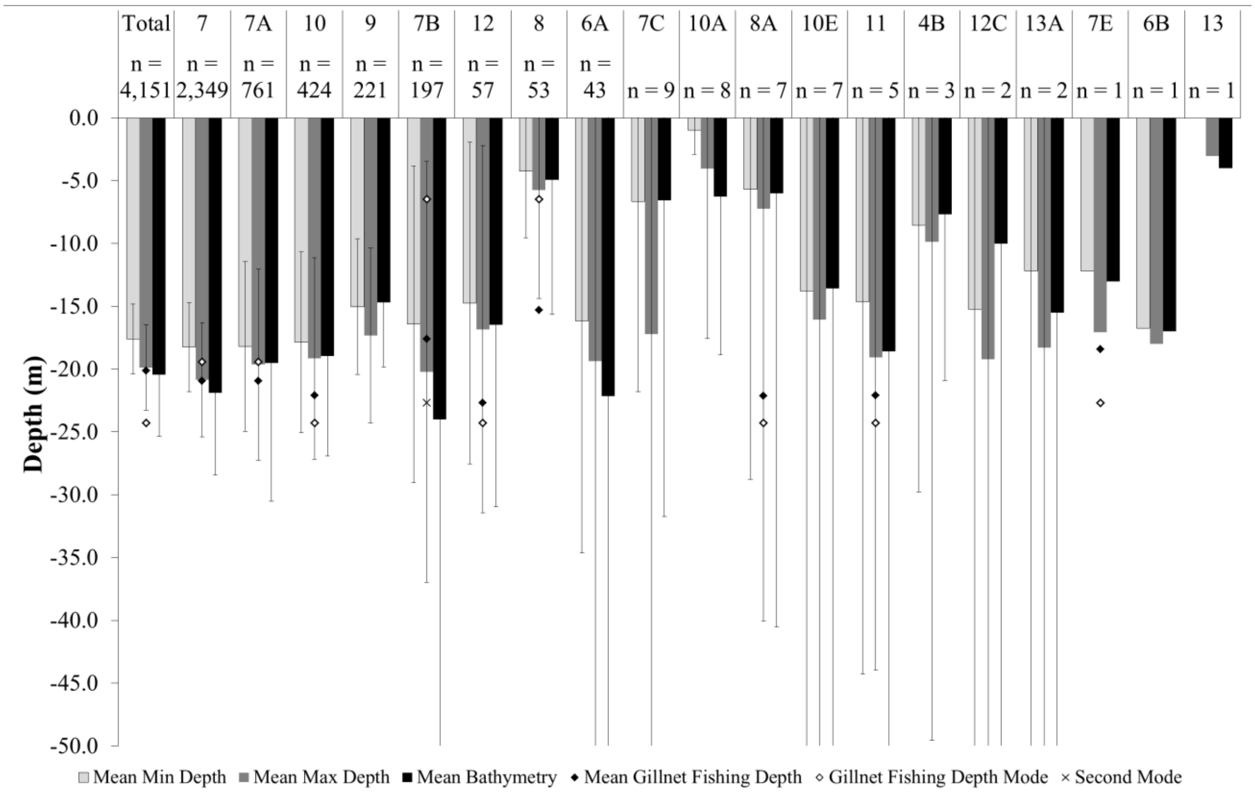

Figure 7: Graph showing the mean minimum and maximum observed depths and bathymetric depths (from ArcGIS) for derelict gillnets throughout WASS (total column) and for each SMCRA (labeled at top) where derelict gillnets have been removed; error bars depict 95% confidence intervals. Diamond shapes depict mean and mode of gillnet fishing depths derived from WA 1992.

3.4 Model Analysis

Based on depth, structure and fishing effort at derelict gillnet removal locations in the WASS, the model provides integer values from 1 to 18 binned in four categories representing low to high probability of derelict gillnet occurrence between 0 and 50 m depth (Figure 8). The nature of the linear additive model assumes equal weighting of all variables in the equation. Once the probability value is calculated, there is no distinguishing the combination of variables at any given location except at the value of 1 and 18 (i.e., 0 + 0 + 1 = 1 and 6 + 6 + 6 = 18). Probability values from 2 to 17 can be calculated by multiple combinations of individual values for each variable. For example, one location with a value of 12 may exhibit a low to moderate depth value of 3, a high variance value of 6 and a low to moderate fishing effort value of 3, while another location with a value of 12 may have a high depth value of 6, a very low variance value of 0 and a high fishing effort value of 6. Therefore, while interpreting results it should be considered that locations with the same probability value may exhibit very different characteristics. Areas of high probability (value: 16 – 18) comprise 16% (476 km^2) of the 3,063 km^2 study area, and included 67% (n = 2,728) of derelict gillnet locations. Areas of moderate probability (value: 13 – 15) comprise 32% (987 km^2) of the study area and contained 27% (n = 1,109) of the derelict gillnet locations. Areas of low probability (value: 11 – 12) totaled 23% (719 km^2) of the study area and included 4% (n = 170) of the derelict gillnets. The remaining 1.5% (n = 62) of derelict gillnets fell within the remote probability areas (value: 6 – 10) which comprised 27% (821 km^2) of the study area. Probability values from 1 to 5 contained no derelict gillnet sites and accounted for the remaining 2% (60 km^2) of the study area (Table 2).

Using class and ranking schemes from the WASS model, two predictive models were built for the BCSS between 0 and 50 m depth (Figures 9 and 10). The first model (BC1) ranked areas of probability based on classification of all Salish Sea fishing effort and bathymetry based on WASS derelict gillnet locations, while the second model (BC2) used classification of B.C. fishing effort only, and an adjusted bathymetric ranking to account for the differences in gillnet fishing depths between WASS and BCSS. In both models the study area totals 2,036 km^2. Of the total study area, areas of high probability of derelict nets accounted for 14% (282 km^2) in BC1 and 17% (353 km^2) in BC2, while areas of moderate probability totaled 29% (582 km^2) and 23% (477 km^2) respectively. Areas of low probability accounted for 22% (439 km^2) of the study area in BC1 and 21% (429 km^2) in BC2, while remote probability areas in both BC1 and BC2 equaled 33% (666 km^2) of the study area (Table 2).

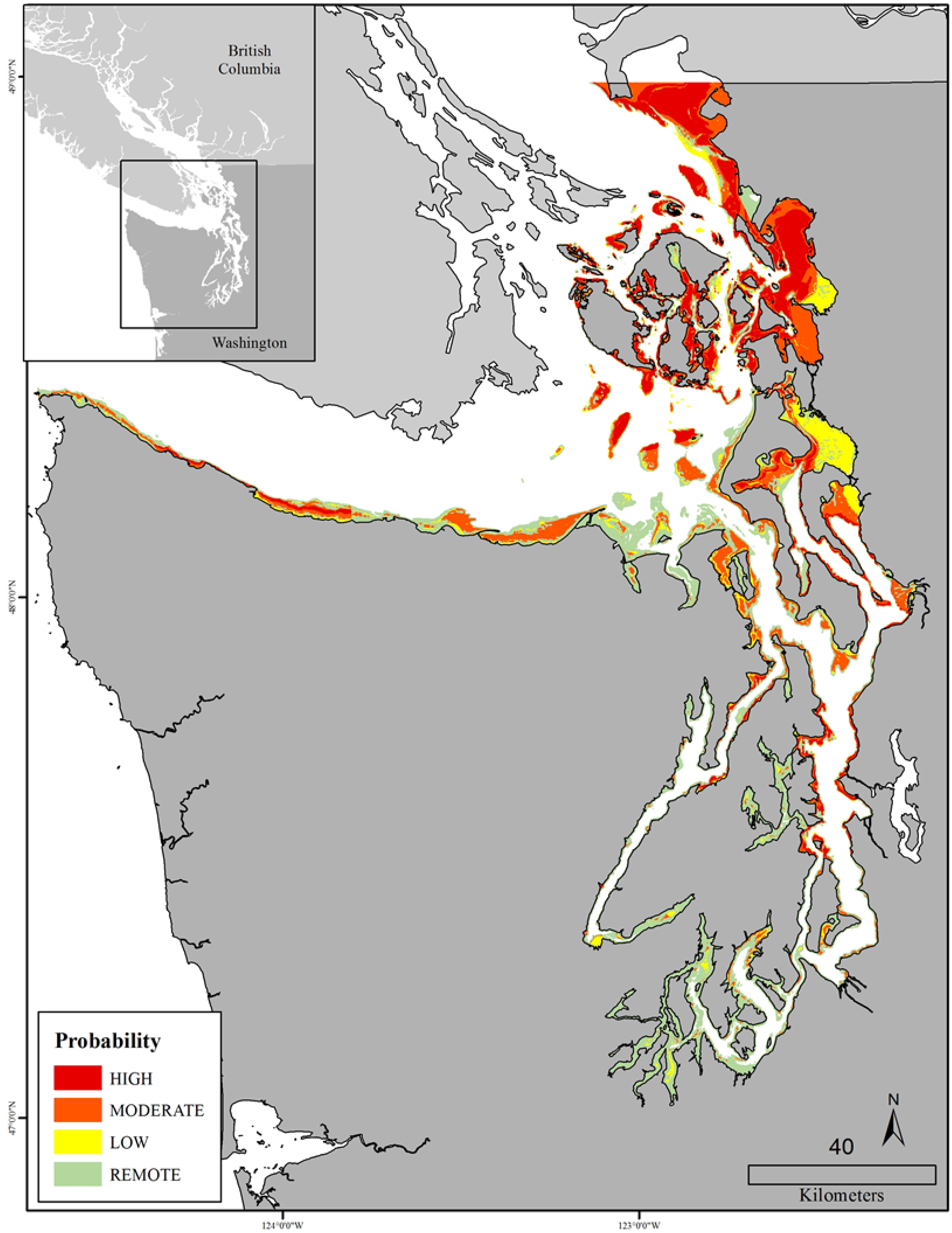

Figure 8: Probability of occurrence of derelict gillnets in the WASS based on model outputs.

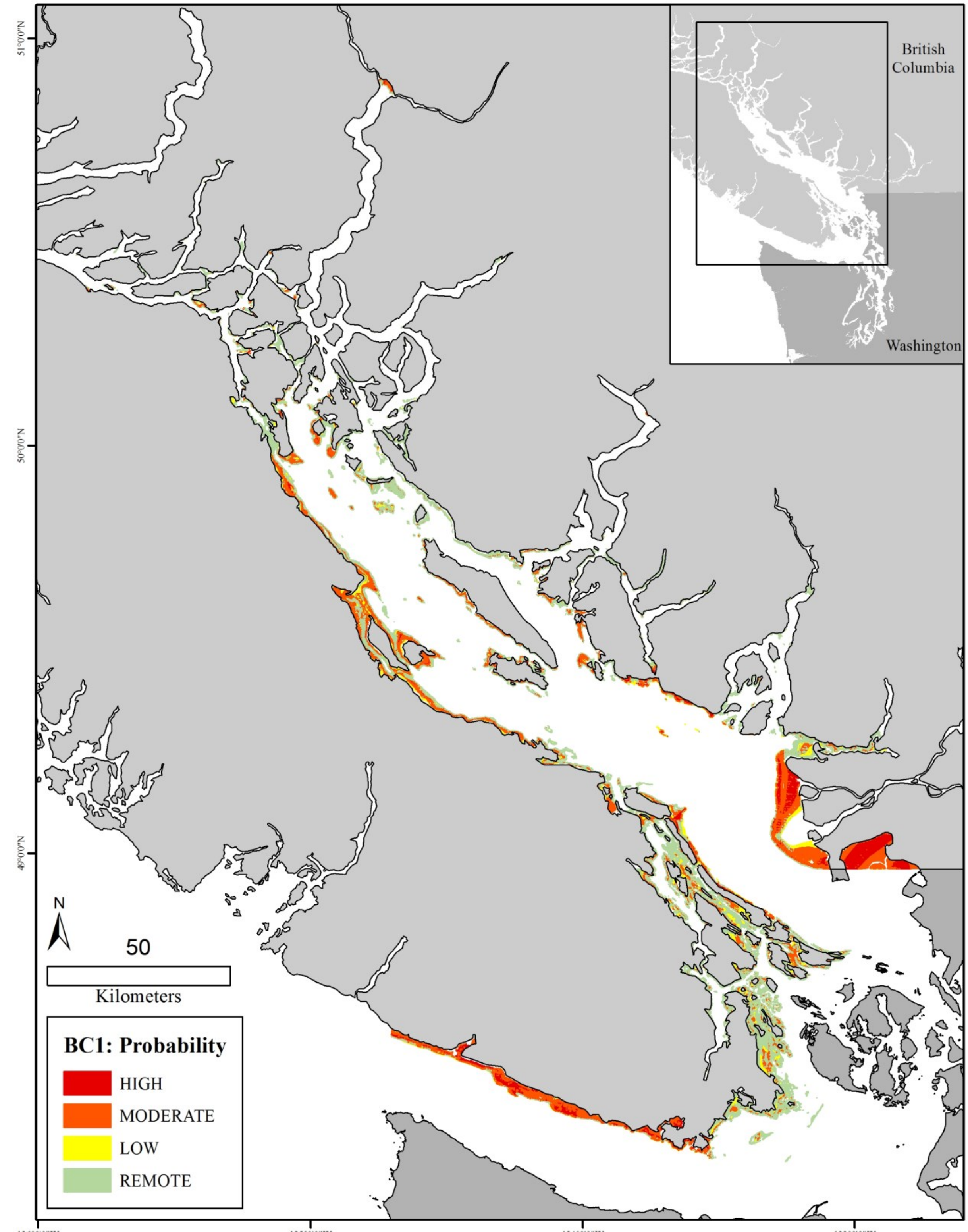

Figure 9: Probability of occurrence of derelict gillnets in the BCSS based on BC1 model outputs.

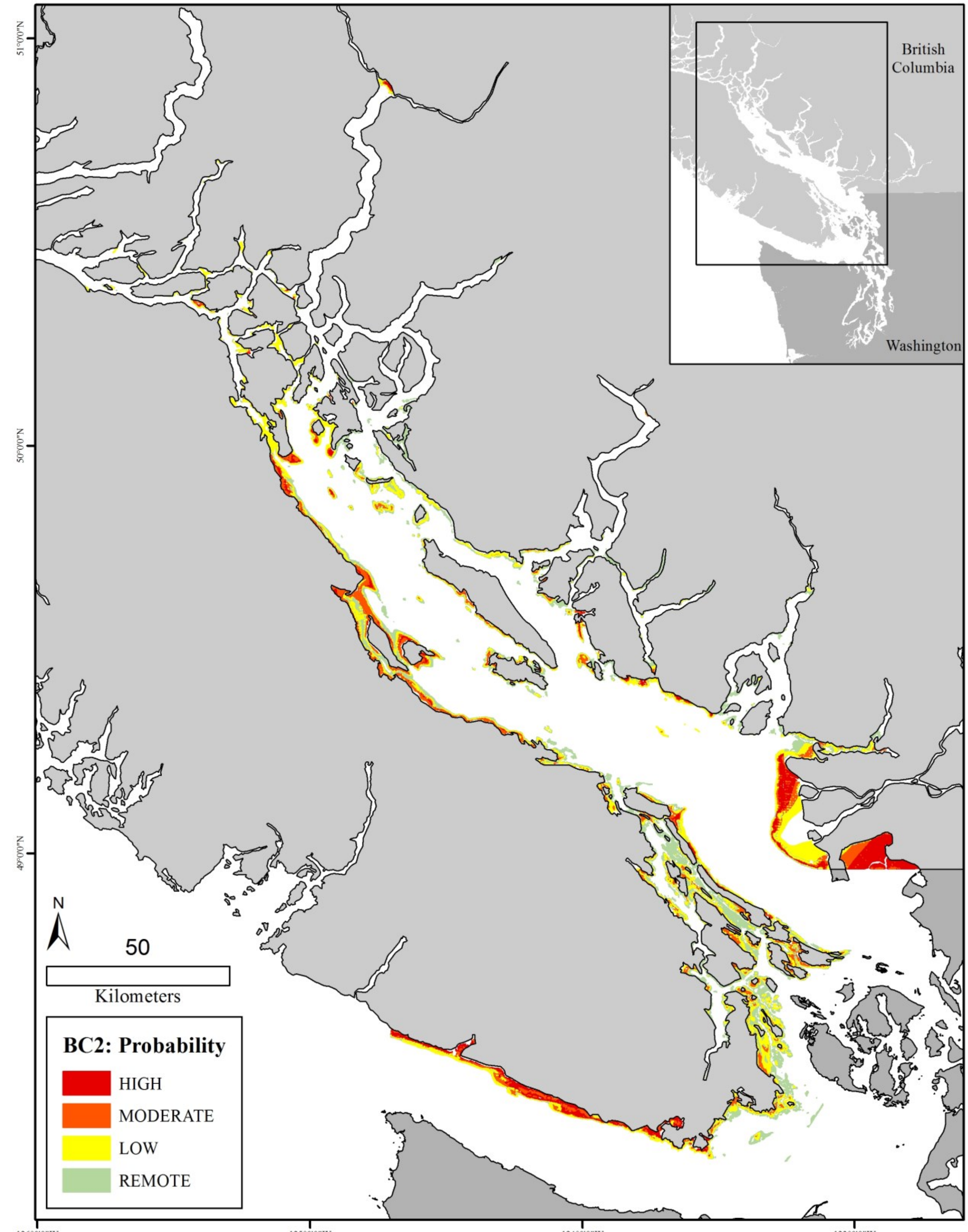

Figure 10: Probability of occurrence of derelict gillnets in the BCSS based on BC2 model outputs.

Table 2: Probability ranking and individual values with associated area and derelict gillnet removal locations in WASS.

Rank	Probability Value	WA Area (km^2)	Percent of WA Study Area	Number of Derelict Gillnet Removals	Percent of Derelict Gillnet Removals	BC 1 Area (km^2)	BC 1 Percent of Study Area	BC 2 Area (km^2)	BC 2 Percent of Study Area
None	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	2	5	0.2%	0	0.0%	1	0.0%	3	0.1%
	3	3	0.1%	0	0.0%	6	0.3%	7	0.3%
	4	24	0.8%	0	0.0%	20	1.0%	52	2.6%
	5	28	0.9%	0	0.0%	40	2.0%	49	2.4%
Remote	6	47	1.5%	1	0.0%	37	1.8%	52	2.6%
	7	100	3.3%	21	0.5%	111	5.5%	164	8.1%
	8	176	5.7%	5	0.1%	124	6.1%	146	7.2%
	9	242	7.9%	17	0.4%	142	7.0%	143	7.0%
	10	256	8.4%	18	0.4%	252	12.4%	161	7.9%
Low	11	294	9.6%	73	1.8%	196	9.6%	182	8.9%
	12	425	13.9%	97	2.4%	243	11.9%	247	12.1%
Moderate	13	422	13.8%	238	5.8%	233	11.4%	196	9.6%
	14	278	9.1%	375	9.2%	212	10.4%	144	7.1%
	15	287	9.4%	496	12.2%	137	6.7%	137	6.7%
High	16	182	5.9%	720	17.7%	135	6.6%	138	6.8%
	17	148	4.8%	1086	26.7%	65	3.2%	100	4.9%
	18	146	4.8%	922	22.7%	82	4.0%	115	5.6%
Total		**3,063**		**4,069**		**2,036**		**2,036**	

4. Discussion

4.1 Estimates of historical gillnet loss and accumulation in the WASS

Combining qualitative information from interviews with analysis of fleet dynamics, I estimated that 3,550 to 6,442 derelict gillnets have accumulated in the WASS between 1965 and 2011. This estimate exceeds prior estimates by 34% to 64% and indicates the substantial range of variation in the estimate. The estimates can be refined by applying findings from derelict gear surveys and removals from 2002 to 2012. Of the 4,031 derelict gillnets removed from the WASS, records show that 157 (4%) were made of linen style material indicative of net gear manufactured and used prior to the 1960s. The 3,874 individual gillnet pieces assumed to have been lost since 1965 are represented in the WA DGDB and this number alone exceeds my lower estimate by 324. The lower estimate may be exceeded by even more when considering the known and potentially unknown derelict gillnets remaining in the WASS. These numbers suggest that as of December 31, 2012 at least 60% of the total number of gillnets in the WASS that have become derelict since the shift from linen to nylon webbing have been removed.

These estimates could also be used to gain a better understanding of the cumulative number of derelict nets of all net gear types throughout the WASS. Derelict gillnets assumed to have been lost since the 1960s comprise of 89% of the total number of derelict net items removed from 2002 to 2012. If we assume that this is a consistent ratio throughout the WASS, then we can assume that 3,550 and 6,442 are each 89% of the estimated total number of derelict nets. If such is the case, then the estimated number of derelict nets (removed and remaining) in the WASS would be 3,989 to 7,238. Of course, the lower range could be raised to 4,358 to account for those that have been removed already, and raised again to account for those identified but not yet removed.

The treaty set net fishery is extensive and only a small portion of the data provided for this research includes information regarding potential set net loss. Since 2000, the set net fleet in the WASS has been comparable to the treaty drift gillnet fleet in both number of participants and fish tickets generated. Derelict set nets have been recovered by fisheries enforcement officers and NWSI derelict gear removal personnel. Like other gillnet types, set nets are prone to vessel strikes and can become snagged in floating debris, drift away and/or sink. However, because they are utilized in relatively shallow water and are often accessible from land and/or small vessels, there is greater potential for derelict set nets to be removed by enforcement teams, fishers, and others, possibly limiting their accumulation. Whether set net or drift gillnet, considering the portion of the WASS fleet comprised by the treaty sector, it is clear that treaty fishers were underrepresented in the pool of interviewees from this study. Further research into current gillnet activity and potential loss should include a greater number of representatives from both the drift gillnet and set net fleets of the treaty sector. Interviewees reported that differences between treaty and non-treaty sectors in levels of activity and regulations regarding fishing locations have become large enough for some to believe the two sectors are now incomparable.

4.2 Main causes of gillnet loss

Of all the causes of gillnet loss provided by the interviewed fishers, the one that could be identified in spatial analysis of derelict gillnet removal locations was the association between net fishing depth and water depth. Other main causes such as operator inexperience, operator error, equipment failure and crowding on the fishing grounds are all related to this association as well. These causes often result in a portion of gillnet becoming snagged on the seafloor in water depths shallower than the fishing depth of the net. The net depth survey of 1992 was the only official documentation available to summarize the depths of gillnets used by the active fleet, and the interviewees who examined the report agreed that the current net depths used are similar to those reported or slightly larger. Some of the net suppliers and fishers interviewed explained that the gillnet depths in the WASS have not always been so deep, that for some time in the late 1960s and early 1970s the more common gillnets were closer to 120 meshes (approx. 16 meters) deep. Moreover, the data used to calculate common fishing depths of gillnets in the WASS reflects only the non-treaty sector. Nevertheless, the results show an association between the depths at which derelict gillnets in the WASS are found and the fishing depth of actively fishing gillnets. This association is seen in both the water depths reported during derelict net removals and the depths at each derelict gillnet location extracted from the bathymetric layer in GIS. While evidence is available that derelict gillnets exist in the WASS at depths beyond gillnet fishing depths, oftentimes the nets found at these depths have, or at one point had a shallower component near the point where it was originally snagged. The association between water depth and net fishing depth becomes weaker when the causes of net loss are deliberate discards, vessel strikes, or the sinking of nets due to excess volume of catch. In cases such as these it would make sense that a derelict net may be found at any depth, regardless of the distance between corkline and leadline.

Considering the association between net depths and gear loss, some of the interviewees suggested that placing mesh depth restrictions on the nets in the WASS similar to those in Alaska or British Columbia would help reduce current and future net loss. Others suggested that this would only be a viable restriction if one maximum depth was imposed across gear types and sectors (i.e., gillnets, purse seines, treaty, non-treaty), otherwise unfair competition would result.

4.3 Predictive model for derelict gillnets in BCSS

Results from the derelict gillnet probability model suggest that there exists a greater area of seafloor habitat with a moderate and high probability of derelict gillnet occurrence in the WASS compared with the BCSS. While these differences seem to be most defined by the area of seafloor between 0 and -50 meters in depth (Table 2), the percent of total moderate and high probability areas are generally similar (WA = 48%; BC1 = 42%; BC2 = 40%). Because the BC2 model was adjusted from the original to account for differences in gillnet fishing depths across borders, the BC2 model may be a more accurate predictor of derelict gillnet "hot spots" than the BC1 model.

Limitations exist with the additive model used here. For instance, additional variables such as benthic terrain, bottom type, fetch and current velocity could be used to build a more complex, weighted model (J. Davies, personal communication, March 4, 2013; M. Logsdon, personal communication, March 7, 2013). In 2009, a derelict net hot spot analysis using multiple weighted variables (Davies et al., 2009) assisted in determining high priority areas for derelict net recovery efforts in the WASS. Similar to data reported in Good et al. (2010), the model was based on much less derelict net removal locations than were available for this study. Recently, additive models have been used to successfully identify hot spots for derelict lobster trap gear in Florida by ranking depth and habitat types by likelihood of occurrence (Martens and Huntington, 2012). The model from Florida included an iteration that incorporated only hard-bottom seafloor types, which significantly narrowed the focus of derelict gear hot spots. The linear additive model described here was specifically designed for simplicity and exportability. The probability maps for derelict gillnets in the BCSS were produced to assist resource managers and planners in identifying locations or regions of focus for derelict gillnet surveys and removal operations. The BC2 model depicts the estimated probability of derelict gillnet occurrence throughout the BCSS to -50 m depth based on relative historical fishing effort and bathymetry that is adjusted to match the estimated fishing depth of gillnets used. Updating the model with new information could increase predictive capabilities of the model as it is applied in the BCSS. Moreover, the model could be refined further by adding details regarding spatial and temporal closures of the fishing grounds, seafloor types, First Nations subsistence fishing activity and local knowledge of heavy fishing effort areas with potential areas of net loss.

More than one Canadian resource manager and fisheries enforcement officer suggested that the herring fishery in the BCSS may be the source of as many or more derelict gillnets than the salmon fishery. A brief investigation into the herring fishery provided useful information that could be used either separately or in combination with the salmon fishery data to assist in identifying potential areas of high probability of derelict gillnets. However, analysis of this information was beyond the scope of this project, as the goal was to focus on the salmon gillnet fishery.

5. Conclusion

The research presented here provides estimates of historical gillnet loss and major causes of gillnet loss as described by members of the WASS gillnet fleet. Such information increases the understanding of the extent of the issue and assists in planning further actions to address derelict gear in the WASS. An association was observed between gillnet fishing depths and the depths at which derelict gillnets are found, suggesting that fishing depth influences the potential for gillnets to be lost. Through spatial analysis, a simple model was generated that can be utilized to plan derelict gillnet survey and removal operations in the BCSS. With minimal data (bathymetry and fishing effort) the same model could be exported to other regional locations such as Johnstone Strait, North British Columbia and Southeast Alaska where the historical fishing effort could suggest the potential for derelict net accumulation.

6. References

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