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VESSEL DRIFT AND RESPONSE ANALYSIS FOR THE STRAIT OF JUAN DE FUCA TO THE SOUTHERN STRAIT OF GEORGIA

PREPARED BY

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Project Contributors

San Juan County invited a group of Project Contributors to provide input to this vessel drift and response analysis. Their questions and suggestions informed the analysis and presentation of results. Project Contributors are listed below with appreciation for their time and inputs, but the authors do not suggest that those listed concur with the approach, inputs, and results of the analysis.

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Lovel Pratt (Friends of the San Juans, San Juan County Marine Resources Committee)
Jennifer Steele (Clear Seas Centre for Responsible Marine Shipping)
Jamie Stephens (San Juan County)
Kimbal Sundberg (San Juan County Clean Water Advisory Committee)
John Veentjer (Marine Exchange of Puget Sound)

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Cover Photo

A vehicle carrier transits past the Turn Point Lighthouse (cred: Marta Green)

Executive Summary

San Juan County's 428 islands are surrounded by major shipping routes linking Salish Sea ports to Pacific trade routes. The shipping routes around the islands saw more than 5,400 one-way ship transits as of 2019, presenting an ongoing risk of a catastrophic oil spill. Based on the success of the Neah Bay rescue tug, investment in an emergency response towing vessel (ERTV) to reduce the risk of an oil spill in Haro Strait and Boundary Pass is considered by many—including the Governor's Southern Resident Orca Task Force—to be a high priority risk mitigation measure. Having demonstrated the cost-benefit business case for an ERTV, San Juan County now seeks to better understand the potential effectiveness of an ERTV to reduce the likelihood of a disabled ship grounding in these waters.

San Juan County contracted Nuka Research and Planning Group, LLC, which partnered with the University of Washington Salish Sea Modeling Center at the Puget Sound Institute, to conduct a vessel drift and response analysis. Nuka Research has previously conducted a similar analysis for the west coast of Canada, and this study extends that analysis to inland waters.

The project team combined Nuka Research's Zone of No Save model and the Salish Sea Modeling Center's Salish Sea Model to estimate how long it may take an unescorted, drifting containership to ground in the study area based on the winds and currents from 2014-2017. Based on more than 6,500 model runs, the results presented show drift times for marine waters over 10-m deep that reflect both the median results and those resulting from bad, but not worst-case, conditions.

ERTV rescue times were calculated for seven origin points around the region: Roche Harbor, Sidney, Delta Port, Victoria, Anacortes, Port Angeles, and Neah Bay. Of these, Neah Bay is the only location that currently has a dedicated ERTV. Fast, mid-range, and slow ERTV response times were determined from each origin. These were presented along with the drift results for a hypothetical ship drifting from the shipping lane through Haro Strait, Turn Point, and Boundary Pass.

Based on this analysis, an ERTV located in Roche Harbor or Sidney would have the best chance of arriving in time to rescue more than 80% of the cases modeled. An ERTV located outside the immediate area would have a lower probability of arriving in time to rescue a disabled vessel drifting from the typical ship route.

Table of Contents

List of Figures

1 Introduction

San Juan County contracted Nuka Research and Planning Group, LLC (Nuka Research), which partnered with the University of Washington Salish Sea Modeling Center at the Puget Sound Institute, to conduct a vessel drift and response analysis. The County sought to understand how much time it may take a disabled ship drifting in marine waters around the San Juan Islands to run aground in different conditions. That time is then compared to an estimated range of times it may take for an emergency response towing vessel (ERTV) to reach the ship from different locations.

The project modeled vessel drift times throughout the study area, extending from the entrance to the Strait of Juan de Fuca to Burrard Inlet. The comparison to ERTV response times focused on the U.S. and Canadian waters to the north and west of the San Juan Islands, including Haro Strait, Turn Point, and Boundary Pass (see Figure 1-1).

This analysis seeks to answer two research questions:

1. Throughout the study area, how much time may be available for an ERTV to arrive at a disabled ship before the ship grounds, considering winds and currents?
2. Considering four focus areas around San Juan County, what is the probability that an ERTV could arrive before a ship drifting from the typical ship route grounds?

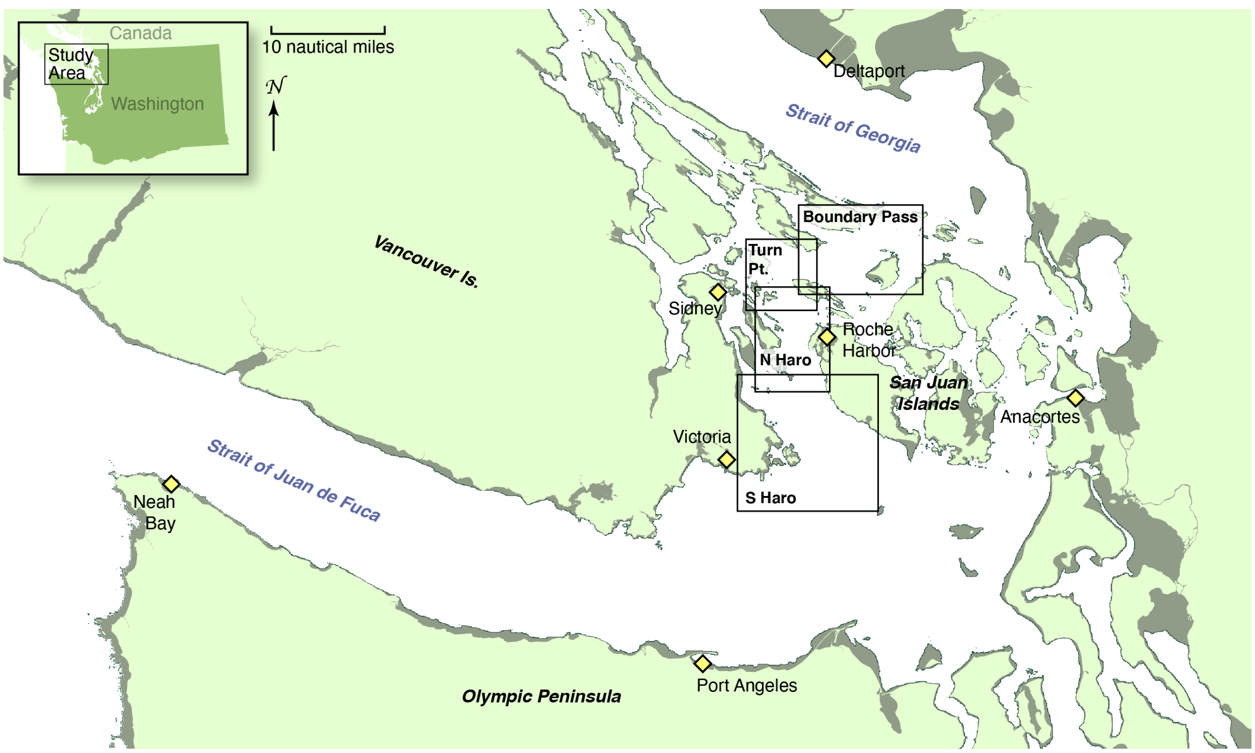

Figure 1-1: Study area within the Salish Sea, showing locations referenced in this project report and four focus areas used in analysis

2 Background

The San Juan Islands are located at the crossroads of the Salish Sea with high-value ecosystems distinct from the mainland and Vancouver Island. San Juan County hosts more than 400 miles of marine shoreline—more than any other county in the contiguous United States—with 13 miles of documented forage fish spawning beaches and four herring spawning grounds (Friends of the San Juans, 2004a). Twenty of the 22 stocks of Salish Sea Chinook salmon out-migrate through the nearshore areas (Beamer and Fresh, 2012), which include 140 shoreline miles with eelgrass and approximately one-third of all floating bull kelp in Puget Sound (Friends of the San Juans 2004b, 2012, 2017). The area is also critical foraging habitat for the Southern Resident Orcas (Ashe, 2010).

The County's 428 islands are surrounded by major shipping routes linking Salish Sea ports to Pacific trade routes, with the shipping route between the Strait of Juan de Fuca and Vancouver, BC passing through inland waters directly to the west and north. For 2019, the Department of Ecology reported just over 5,400 one-way ship transits that would have passed around the San Juan Islands, accounting for a large portion of the nearly 12,000 ship or barge entries and transits for Washington waters that year (Ecology, 2020).

Numerous local and regional governmental and non-governmental partners have identified investment in an ERTV to reduce the risk of an oil spill on the north and west sides of San Juan County as a priority risk mitigation measure (SJ-LIO, 2017). This measure also has been recommended by the Governor's Southern Resident Orca Task Force and was an outcome of the Department of Ecology's Salish Sea Oil Spill Risk Mitigation Workshop. The Workshop participants recommended a strategy including that a cost-benefit business case be developed (Washington Department of Ecology, 2016). Having demonstrated the cost-benefit business case in 2019, San Juan County is now analyzing the potential effectiveness of an ERTV for these waters.

Unescorted cargo ships are of particular concern to the County. They are not subject to all of the safety measures applied to laden tankers but may carry up to 3.6 million gallons of propulsion fuel (Clear Seas 2020). An unescorted ship that becomes disabled may drift aground and spill fuel, oil, or other harmful cargo if efforts to regain control of the vessel or otherwise mitigate its drift are unsuccessful. In addition to onboard efforts to prevent a drifting ship from grounding, a tug may respond and assist. That tug could be a dedicated ERTV or a 'tug of opportunity'.

Towing vessels operating in the area may serve as 'tugs of opportunity' deployed to assist in the event of a shipping vessel emergency. A study of tug activity in the Pacific waters of Canada in 2016 estimated that tugs with a bollard pull greater than 70 metric tons were present in Haro Strait and Boundary Pass approximately 30% of the time. However, commercial tugs may be engaged in other duties and unable to respond (Clear Seas, 2019). In addition to general commercial duties, a 'tug of opportunity' may also be an escort tug present in the region to escort tankers as required by state law (PSHSC, 2021).

This analysis considers the time it may take an ERTV to respond from different locations, based on the assumption that such a vessel would be able to deploy almost immediately upon being notified and have the necessary design, equipment, and trained crew to secure a towline and control a drifting ship quickly. These assumptions imply that the ERTV is a relatively powerful, dedicated vessel standing by or on patrol for just this purpose. There is currently an ERTV at Neah Bay, Washington, but none other like it stationed full-time in the Salish Sea (Marine Exchange of Puget Sound, 2019).

3 Methodology

The analysis applied the Zone of No Save (ZONS) model (Clear Seas, 2018; Robertson et al., 2018). The analysis followed three steps to answer the research questions:

Research question #1: Throughout the study area, how much time may be available for an ERTV to arrive at a disabled ship before the ship grounds, considering winds and currents?

1. *Methodology step #1:* Model ship drift throughout the study area to estimate how long it will take a ship to ground (see Sections 3.1-3.3)

Research question #2: Considering four focus areas around San Juan County, what is the probability that an ERTV could arrive before a ship drifting from the typical shipping route grounds?

2. *Methodology step #2:* Estimate ERTV response times from different origins in the region to each of four focus areas (see Section 3.3)

3. *Methodology step #3:* Using the results of the drift model, estimate how long it would take a ship to drift to ground from the typical ship route through each of four focus areas (See Section 3.4) and compare to ERTV response times

The approach was adopted from a 2018 vessel drift and response analysis Nuka Research implemented for Clear Seas Centre for Responsible Marine Shipping. That analysis considered vessel drift in open waters off the British Columbia coast, using historic wind data and a simplified vessel drift algorithm along with other inputs and assumptions to estimate the probability that ERTVs from different locations could reach a drifting ship before it grounded (Clear Seas, 2018).

Modifications to the method used in the Clear Seas study were necessary for the San Juan County project. First, the model was adapted to incorporate currents as well as winds as critical drivers of vessel drift in the inland water environment. This was done using four years of hindcast hydrodynamic solutions (tide, currents, salinity, and temperature) from a high resolution (≈100 m) version of the Salish Sea Model (SSM) provided by the Salish Sea Modeling Center. Second, based on input from Project Contributors, the analysis was focused on the typical ship route through the four areas of interest and the probability that an ERTV could reach a disabled ship that began drifting from this route.

3.1 Drift model domain and mechanisms overview

The ZONS model domain included the waters from the seaward entrance of the Strait of Juan de Fuca to the southern Strait of Georgia, as depicted in Figure 1-1. The navigable waters in this space were divided into approximately 3.7 million 100-m x 100-m grid cells. Winds and currents from the SSM were rectified into this space. An estimate of the 10-m depth contour was assumed to be the grounding line for a drifting vessel.

The ZONS model considers the forces of the current and wind on a disabled vessel and calculates the drift trajectory of the vessel during successive timesteps. Fifteen hours of continuous wind and current forces are randomly drawn from a four-year geospatial dataset produced from the SSM to drive the drift trajectory calculations. The timestep used for calculating the disabled vessel's movement is 0.1 hours (6 minutes). In each timestep the disabled vessel location is moved from its present location to the next location based on the trajectory calculation. The duration of each iteration of the ZONS model run is limited to 15 hours.

The model's output is the amount of time required for a vessel beginning to drift from any cell until it reaches a cell containing a grounding line. The model was run for more than 6,500 iterations yielding 15.6 billion estimates of time to grounding across the model domain. These data were then further analyzed to answer the research questions. Each part of this overview is further explained below.

3.2 Estimating vessel trajectory and drift to grounding

The ZONS is a stochastic model developed by Nuka Research which was utilized to estimate the amount of time a disabled ship would drift before it reached a grounding line. As with all models, the ZONS model is a mathematical approximation of a complex real-world process. The ZONS model considers the speed and direction of the winds and currents on a selected ship type. Other factors such as momentum and actions of the crew are not considered for the purposes of this study. In a real incident, many factors would combine to influence the trajectory of a drifting ship. These would include the speed and direction of winds and currents; the sea state; the size, shape, and weight of the vessel; the momentum of the vessel prior to its loss of propulsion or steerage; and any mitigating efforts the vessel operator can achieve such as dragging an anchor or maneuvering the rudder (Holder et al., 1981).

Winds and currents

The SSM is a predictive coastal ocean model for estuarine research, restoration planning, water-quality management, and climate change response assessment. It was developed by the U.S. Department of Energy's Pacific Northwest National Laboratory in collaboration with the Washington State Department of Ecology with funding from the U.S. EPA (Khangaonkar et al. 2011, 2012, 2017, 2018). A high-resolution version of SSM (finer resolution of ≈ 100m along the shoreline, coarser away from the shore with an average resolution of ≈ 400m in the study area) was developed to establish a robust Operational Forecast System (OFS) for the Salish Sea that will be maintained and operated by the National Ocean Service's Center for Operational Oceanographic Products and Services. Winds and currents used in this analysis were extracted from the SSM-OFS version hindcast data set from the years 2014 through 2017.

As shown in Figure 3-1, the SSM encompasses Vancouver Island completely, allowing tides to propagate into the Salish Sea around Vancouver Island through Johnstone Strait and the Strait of Juan de Fuca. The model computes water-surface elevation, velocity, temperature, salinity, sediment, and water-quality constituents forced by river and wastewater inflows, tides, and meteorological drivers such as wind and solar radiation. The meteorological information in SSM, including wind, is derived from the 12-km and 4-

km resolution Weather Research and Forecasting (WRF) models operated by the University of Washington and National Oceanic and Atmospheric Administration (NOAA), respectively.

The SSM team completed a statistical error analysis including bias, root mean square error, index of agreement, or relative error using available monitoring data for the period 2014 to prior to releasing the product. Of particular importance was the availability of an extensive acoustic doppler current profile (ADCP) data set from a total of 137 ADCP stations in the Salish Sea collected by NOAA over a 3-year period (2015-2017). In addition to the ADCP data, model development also included 13 NOAA Tide and 23 Washington State Department of Ecology temperature, salinity, and water quality monthly profile stations. The overall model performance with respect to error statistics has improved significantly relative to prior versions (Premathilake et al. 2021 *in preparation*).

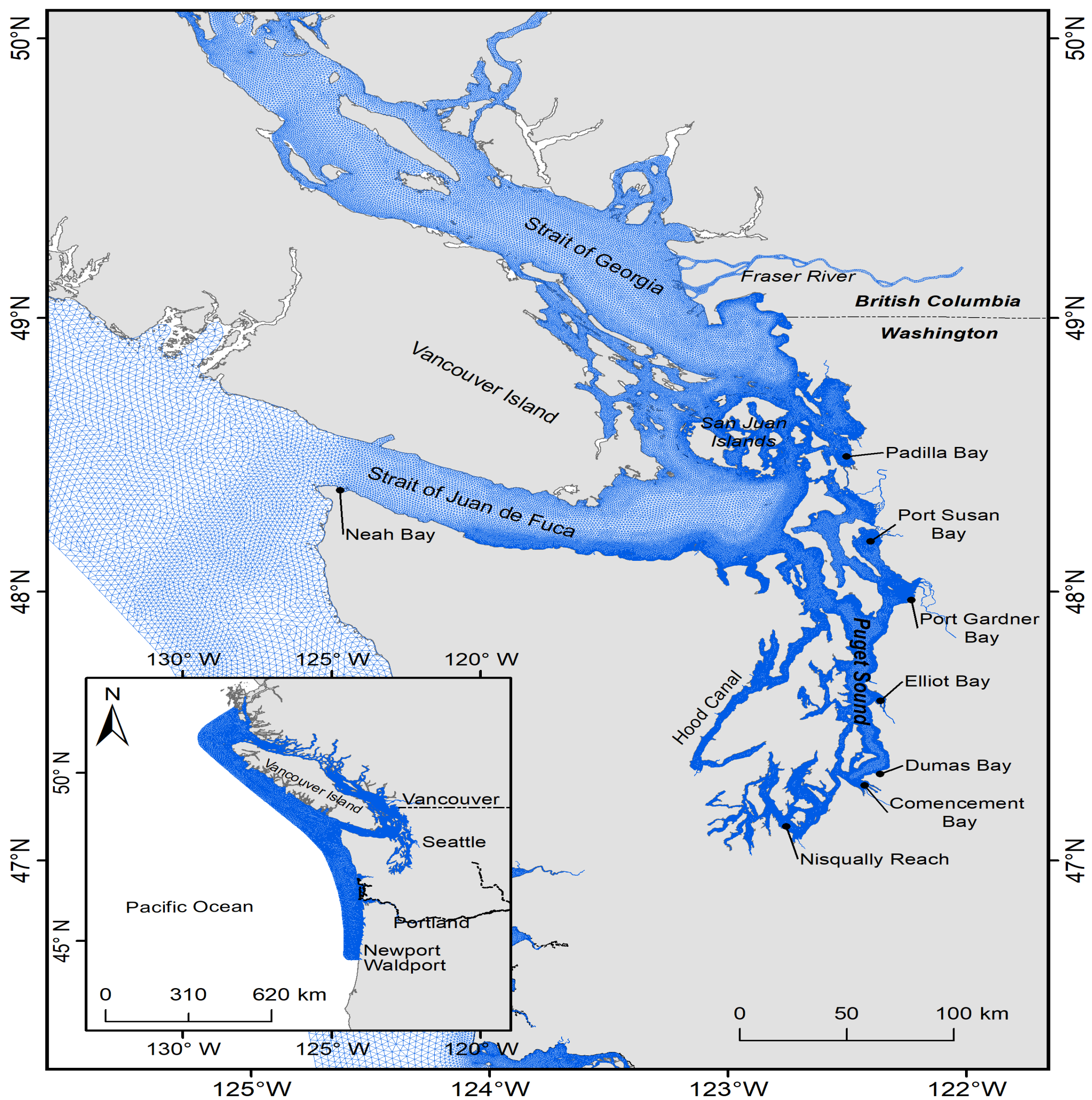

Figure 3-1: Geographic scope of the SSM showing the variable resolution of the model throughout the area

Figure 3-2 compares predicted (modeled) currents from 2017 (in red) to observed data (in blue) using an example station located in Rosario Strait between Lummi Island and Orcas Island. The figure provides plots of U (x, or East) and V (y, or North) components at four depths over the water column. The upper panel shows depth-averaged time series while the lower four panels show U and V components at 10%, 30%, 60%, and 80% of the water depth at the station.

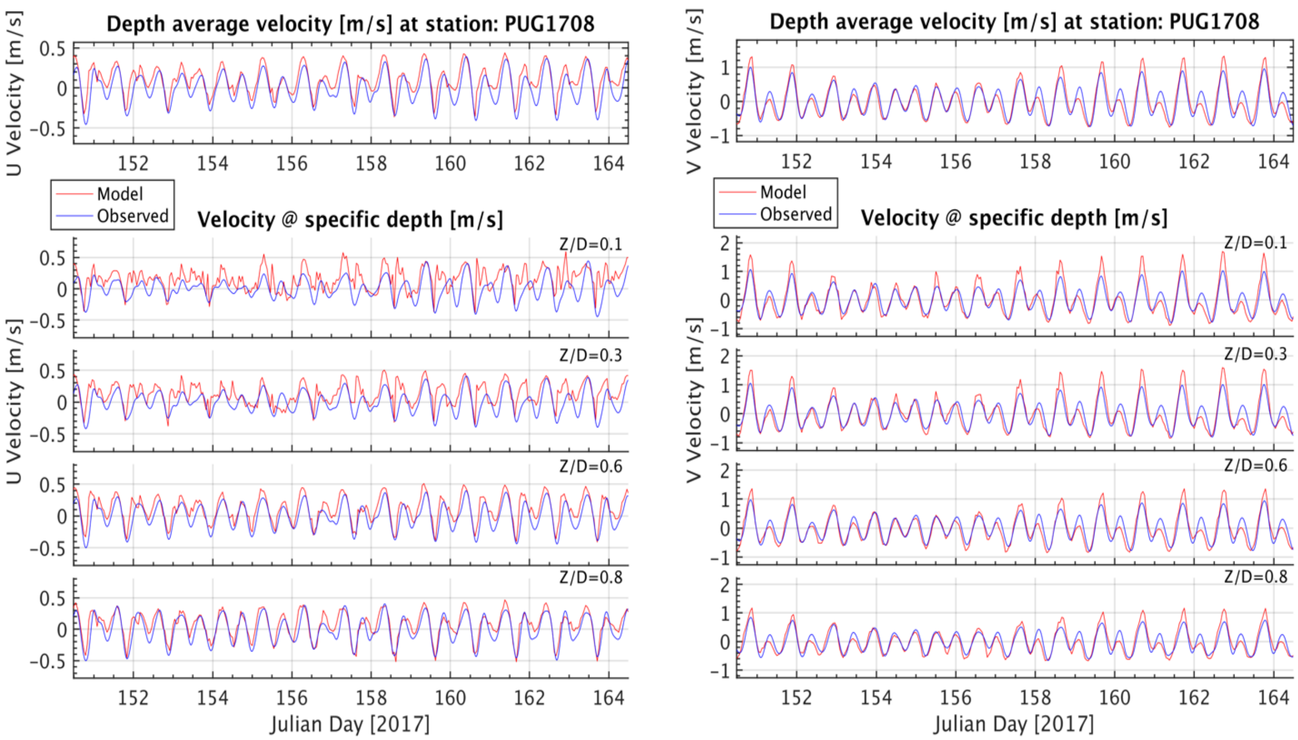

Figure 3-2: Comparison of predicted currents from the SSM to observed current data at a single station in 2017

Figure 3-3 shows predicted surface currents distribution for the San Juan Islands region. The figure demonstrates the ability of the model to incorporate current patterns and eddies around the region that are created by the interaction of complex shorelines, bathymetry, and tidal currents. Wind data from the 3-km High-Resolution Rapid Refresh (HRRR) meteorological data product from NOAA are included in the model for year 2017. These data were spatially interpolated onto the SSM-OFS grid. For years 2014, 2015, and 2016, University of Washington modeled data sets from WRF 4-km and 12-km versions were used.

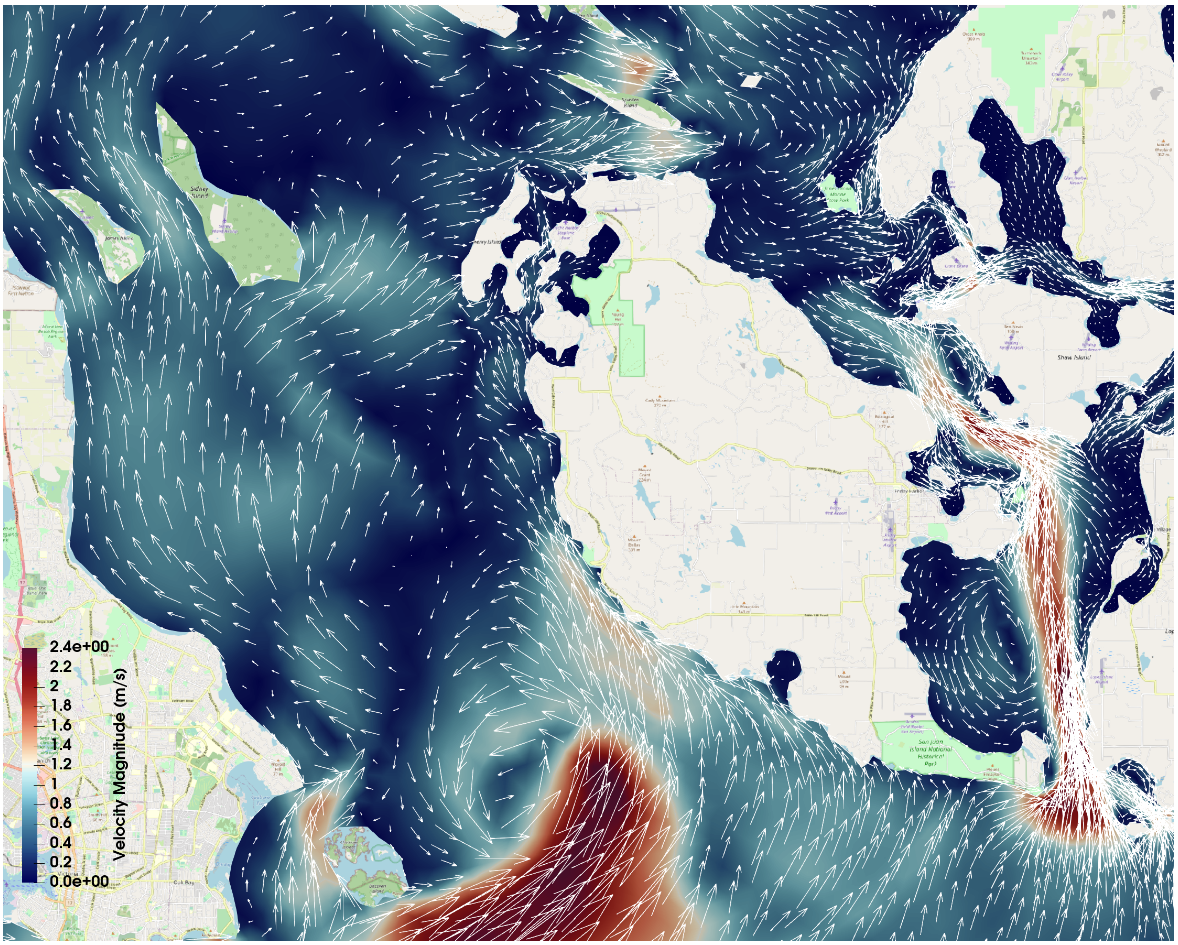

Figure 3-3: Predicted surface currents distribution from SSM on 1/1/2017 2:00:00 AM

Ship drift trajectory

The ZONS model uses an algorithm to apply the winds and currents predicted by the SSM to estimate the direction and speed of a ship drifting in the study area, from the point that it begins drifting subject to those winds and currents. The algorithm uses 100% of the current speed and direction, plus a proportion of the wind speed[1] calculated from a wind drift analysis conducted by The Glosten Associates (2013) for a loaded, mid-size containership (7,500 TEU or 83,000 DWT).[2] The drift direction relative to the downwind wind direction is varied randomly by a function drawn from a normal distribution of drift angles between 45 degrees left or right of the wind to account for uncertainty of the vessel sailing off of the wind. The drift angle is then assumed to remain constant. Figure 3-4 depicts the function used for the relationship between wind speed and drift speed developed by The Glosten Associates. The dashed lines depict drift speed as a percentage of wind speed for reference.

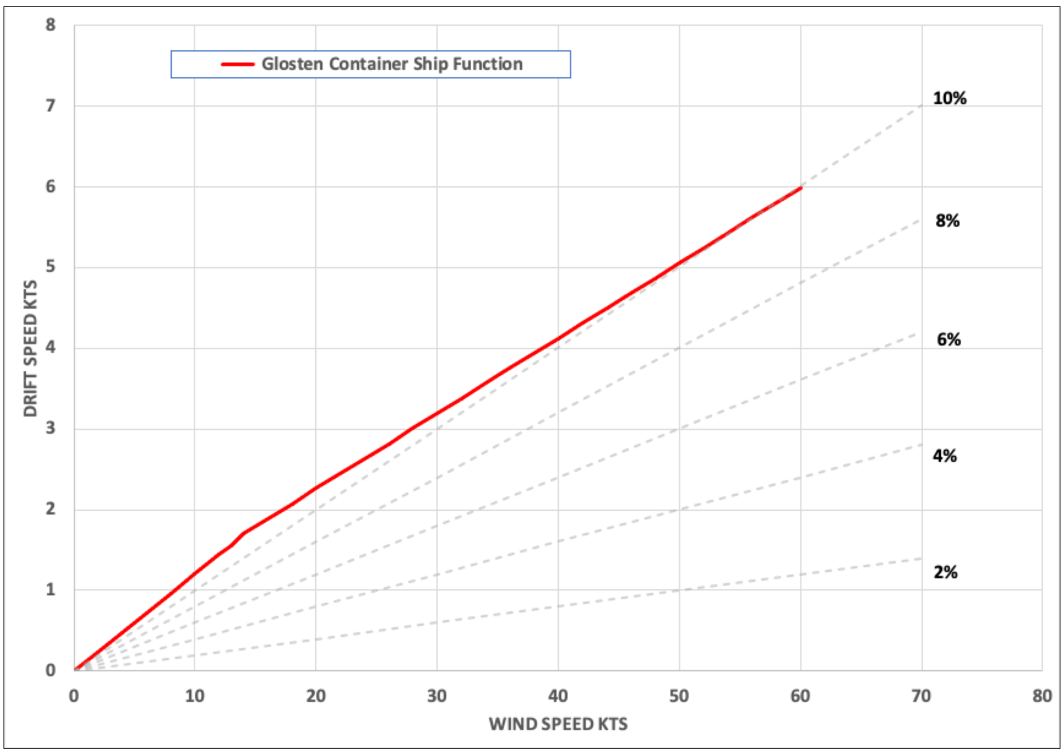

Figure 3-4: Plot of drift function (drift speed vs. wind speed) for a 7,500 TEU containership developed by The Glosten Associates (2013).

[1] Relative to current speed.
[2] TEU (twenty-foot equivalent unit) and DWT (deadweight tonnage) are ways of measuring ships, typically used for container or cargo ships and tankers, respectively.

Figure 3-5 shows how current and a range of wind vectors were incorporated into the ZONS model, based on an approach developed by Galt and Hanson (2015). Other researchers have used similar estimates of trajectory and speed as well (Dongdong, et. al. 2018, NOAA, 1997; Holder, et. al. 1981; Jurdzinski, 2020). This approach was determined to be the best available option since hydrodynamic modeling (or field measurements) was out of the scope of this study.

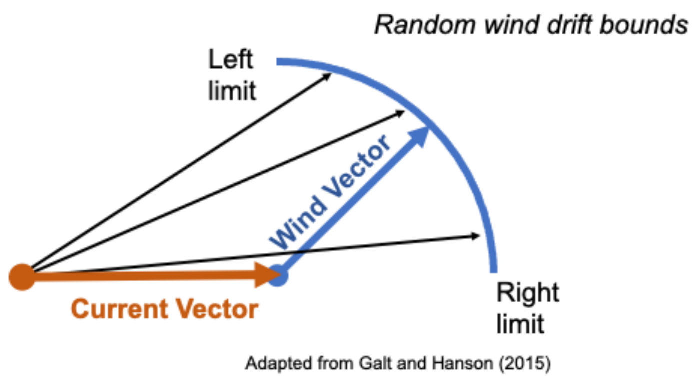

Figure 3-5: Graphical depiction of how the ZONS model incorporates current and wind data to estimate the direction and speed a ship may drift

The drift model does not account for the disabled vessel's momentum, either as it slows from the loss of power or as the forces on the vessel change direction during the trajectory. The momentum of the disabled vessel as it slows after the loss of power is affected by the vessel's speed before power loss, the specifics of the vessel (shape, draft, and how much of the vessel is exposed to winds), sea state, and the actions of the crew. Modeling vessel's trajectory during this initial phase of transition from a power-driven vessel to a drifting object is beyond the scope of this study.

Grounding line

The ZONS model assumes that a disabled ship would ground at a depth of 10 m. A grounding line was established within the model domain along the 10-m bathymetric contour using data from NOAA's National Centers for Environmental Information (NOAA, 2017; 2019) and the Tombolo Mapping Lab (n.d.), as well as NOAA nautical charts.

Applying modeled conditions to estimate drift time to grounding

Based on the methods described above, estimated ship drift times to grounding are calculated for approximately 6,500 model runs for each grid cell in the study area depicted in Figure 3-6. For each grid cell, the varying effects of winds and currents from the SSM over the four years yield a range of possible drift times. These could be plotted as a distribution curve. By way of explanation, a normalized curve is shown (on the right side of Figure 3-6).

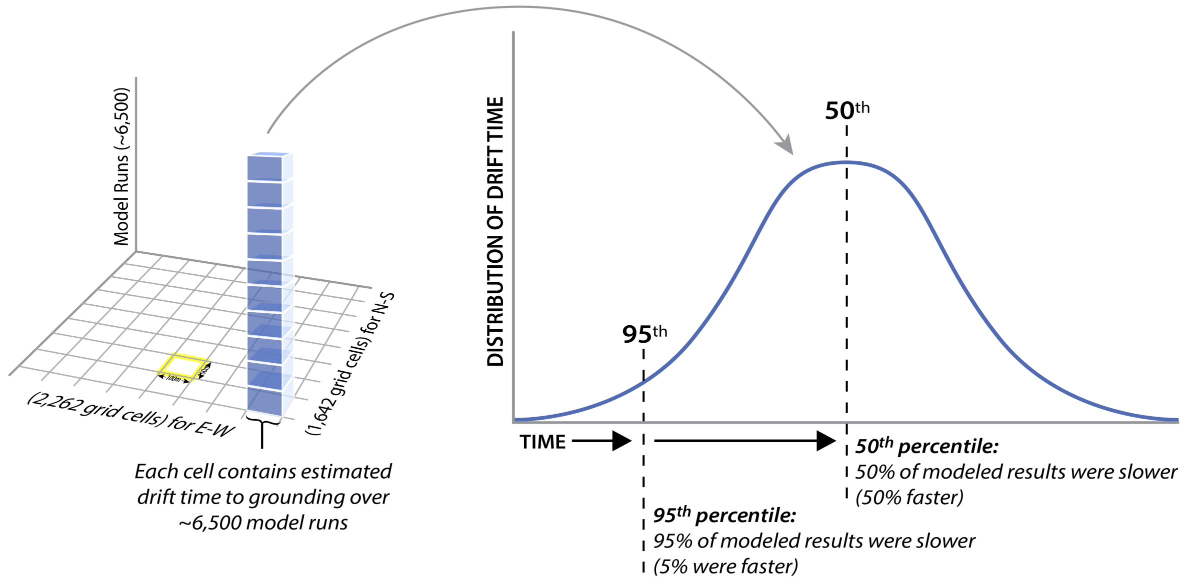

Figure 3-6: Simplified depiction of how the ZONS drift model results is generated

These results are used in two different ways. To generally characterize drift times (in answering the first research question), results presented in Section 4 illustrate the 50th percentile drift times and the 95th percentile drift times. The 50th percentile means that half the estimated drift times modeled were slower than those shown in the results maps and half faster. The 95th percentile results are used as indicative of a bad case, where most (95%) of the time a modeled ship drifted more quickly than those presented. This indicates that, given sufficient model runs, drift times would be less than the times shown in the 95th percentile map in 1 of 20 scenarios on average. When considering how often an ERTV from different origin points may arrive before a ship would drift aground, as described in Section 3.3 (to answer the second research question), all drift times are used.

3.3 Estimating response time required for ERTV to rescue a ship

While the underlying information about how long it may take a ship to drift to the grounding line from different locations is informative, the overarching question this analysis seeks to answer is whether an ERTV from different locations could arrive on scene in time to prevent that grounding. The actual response time an ERTV would take to get to a disabled vessel will vary considerably based on the ERTV speed and mobilization time, sea state, tidal currents, and other factors. For this study, we chose to estimate a range of reasonable times that an ERTV may take to get from a starting location to the areas of interest. We developed a calculation for fast, mid-range, and slow response times to bound the estimate with an expression of the uncertainty associated with response time.

The response time can be broken down into the time it takes for the ERTV to:

1. Be notified of the need for a response,
2. Mobilize to get underway,
3. Travel to the drifting vessel (a function of both distance and speed), and

4. Establish a tow and take control of the drifting vessel. Table 3-1 presents the assumptions used for each of the above components of the analysis.

Table 3-1: Summary of parameters and inputs related to ERTV response time

Parameter (time)	Input (hours)	Explanation
Notification	0	Notification time is not included. It is assumed that this would have occurred during the time when the ship was decelerating due to loss of power and before it actually began to drift solely controlled by winds and currents.
Mobilization	0.3 (20 min)	Based on mobilization time for Neah Bay ERTV, this mobilization might occur before the drift phase begins, but it may also take longer.
Transit	Variable (a function of distance and speed)	See discussion below.
Control drifting ship	0.2 (12 min)	Will also be highly variable depending on the ERTV's capability, crew training, and equipment, the towing procedure used, weather, and the drifting ship's proximity to the grounding line.

Estimating ERTV transit time

Estimating ERTV arrival is a function of both distance and speed. Estimates were developed for ERTV transit time to the four focus areas of interest, shown in Figure 3-4. The following steps were used:

1. Seven potential ERTV origin locations were identified: Neah Bay, WA; Port Angeles, WA; Anacortes, WA; Roche Harbor, WA; Victoria, BC; Sidney, BC; and Deltaport, BC. Of these locations, Neah Bay is the only one with a dedicated ERTV present. Neah Bay was selected because there is a dedicated ERTV based there. Port Angeles, Anacortes, and Deltaport were selected because they are locations where commercial tugs are frequently found in the region. Victoria, Sidney, and Roche Harbor were selected because of their proximity to the four focus areas.

2. For each focus area, the center point along the typical ship route was identified as well as the grounding line points within that area that are closest to and farthest from each of the seven ERTV base locations.

3. Routes were plotted from each ERTV base location to the nearest and farthest grounding lines, as well as the center point of each focus area. Potential routes were selected using nautical charts and a chart plotter, and ensuring that routes were marked by aids to navigation and maintained a minimum water depth of 5 fathoms (30 feet).

4. Distance in nautical miles was determined for each of the routes.

5. Three ERTV speeds were used to bracket a range of possible ERTV transit times to reach the areas of interest using the routes selected: 13 knots to the closest grounding line (fastest), 10 knots to the center (mid-range), and 7 knots to the farthest grounding line (slowest). These speeds were chosen based on best professional judgment.

In a real incident, the ERTV starting point may be different from the seven origin locations used here, and actual ERTV routes would be chosen based on a variety of factors and may or may not be the same as those used in this analysis. Similarly, ERTV speed will depend on a combination of factors such as the vessel's power, design, and environmental conditions at the time.

3.4 Estimating ability of an ERTV to arrive before a ship drifts to grounding

As explained, the model estimates the drift trajectory of a ship from each grid cell in the study area. However, while a ship could drift *to* any particular location, ships do not travel throughout all grid cells in the study area equally but are concentrated along a typical ship route.

To understand how long it may take a ship to drift to the grounding line from typical ship route, two steps were taken:

1. Establish a typical ship route through each of the four focus areas. See Figure 3-7.
2. For each focus area, estimate the time to grounding for a ship starting to drift from points along the typical ship route. This is calculated with the average drift time to grounding (all drift times to grounding from all the model runs) for grid cells every 300 m along the typical ship route. It is presented as a cumulative distribution curve showing the percentage of disabled ships that have grounded as a function of time. The inverse of this cumulative curve shows the percentage of disabled ships that have not yet grounded. See Figure 3-8.

The estimated ERTV response times can be compared to this inverse curve to judge what percentage of disabled vessels have not grounded and are thus available to be rescued during the range of response times expected for an ERTV traveling from a given location.

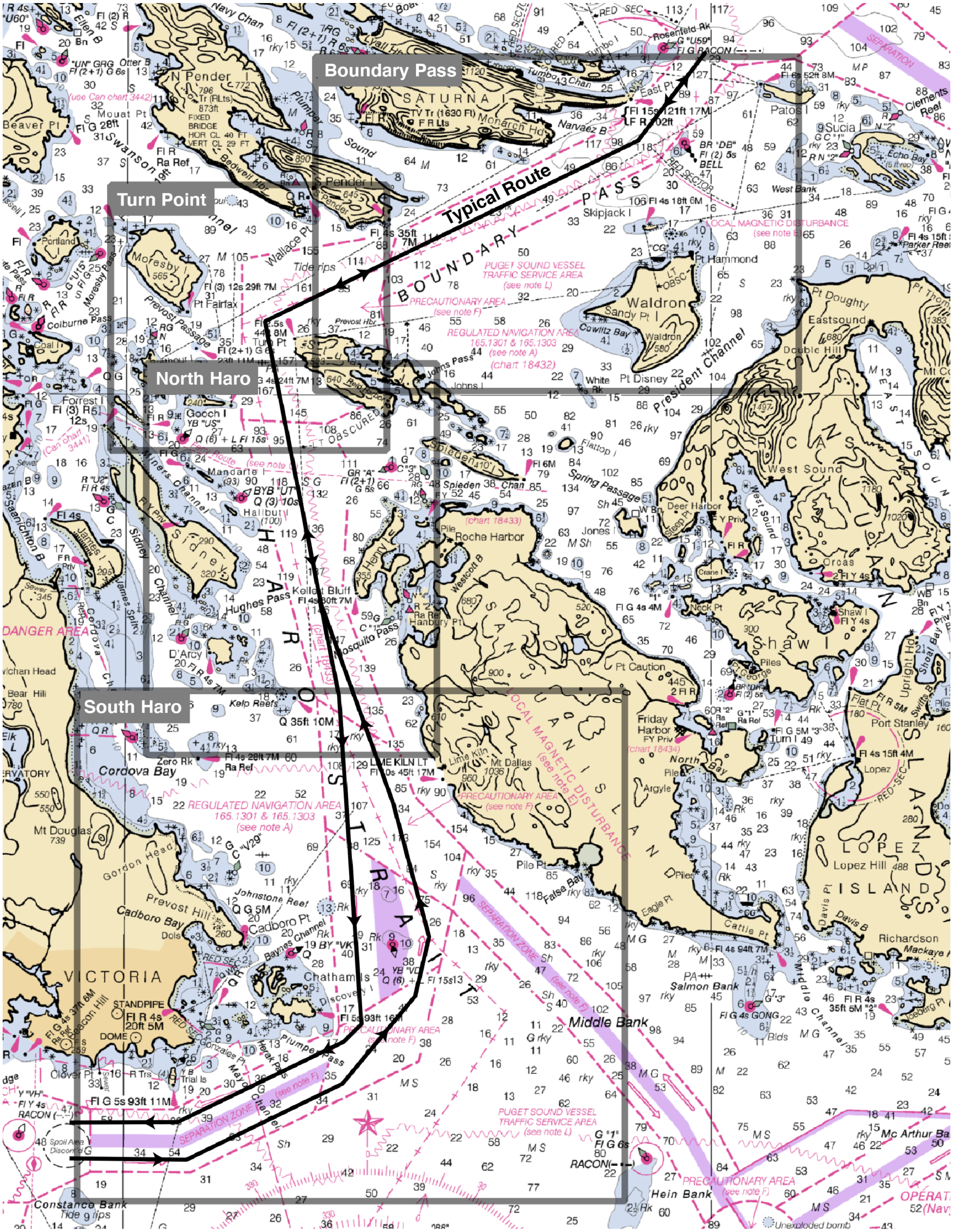

Figure 3-7: Typical ship route through four focus areas

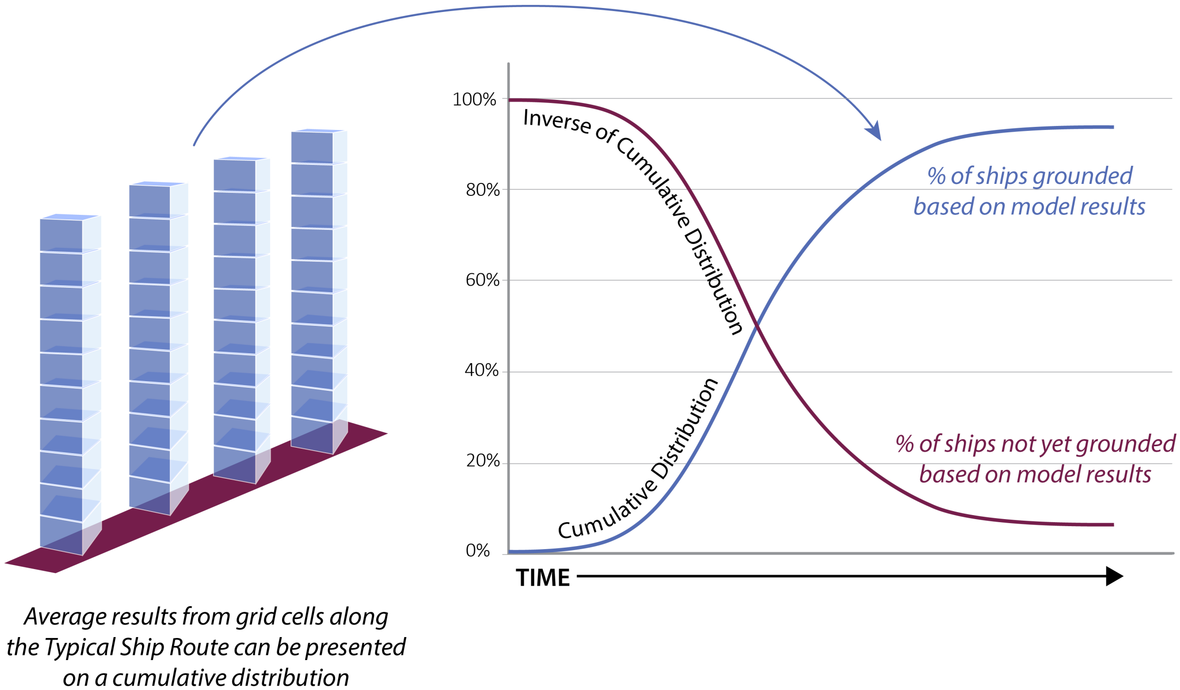

Figure 3-8: Cumulative distribution of the averaged results from model runs along the typical ship route in each focus area; shown also with the inverse of the curve which is used in the results

3.5 Limitations and assumptions

This model provides a view of the statistical characteristics of many possible grounding scenarios but should not be used to predict the outcome of a specific drift scenario. Within the scope of the analysis, the following limitations are noted:

- The ship drift characteristics used were chosen because they were fit for the purpose of the study, but a different vessel may drift differently. In general, ships with lower windage, such as a bulk carrier, will be affected less by winds than the modeled container ship. Vessels with higher windage, such as a vehicle carrier or containership larger than the type modeled, will be affected more by wind than the modeled ship.
- Winds and currents used are themselves predicted from a model and based on just four years of data.
- Results are based entirely on past conditions, which may be different in the future.
- ERTV speeds are approximations based on best professional judgment.
- ERTV availability and capability are not modeled; the ERTV locations used are intended to illustrate the likelihood of a save based on the model outputs if an ERTV was available to depart quickly from those locations.
- Grounding is assumed to occur at the 10-m depth.

Assessing the likelihood of a ship becoming disabled and drifting in the first place, the effectiveness of maneuvers that may be used to slow or stop a drifting ship, or the outcome and consequences should a grounding occur are all outside the scope of the analysis.

4 Results

This section presents the analysis results using the methodology, inputs, and assumptions described in the previous section. The results are shown as answers to the two research questions.

QUESTION #1: Throughout the study area, how much time may be available for an ERTV to arrive at a disabled ship before the ship grounds, considering winds and currents?

Figures 4-1 and 4-2 show the estimated drift time to grounding throughout the study area based on the ZONS model and inputs used. The results are displayed as a set of contours outlining areas from within which a ship would be expected to take a certain amount of time to ground. In other words, the model results indicate that a ship that started drifting from a grid cell within the contour representing the 5-hour contour would take 5 hours to reach a cell on the grounding line. Two different maps are shown: one showing the results for the 50^{th} percentile, or median, drift times (Figure 4-1) and one with the 95^{th} percentile, or bad case, drift times (Figure 4-2).

The median results show that a ship transiting the typical route to Vancouver, Canada, will have at least 10 hours of drift time before grounding through the Strait of Juan de Fuca. When the ship turns north into Haro Strait, this median time drops to less than 3 hours at Turn Point and then increases to 5 hours in Boundary Pass and the southern Strait of Georgia. However, the 95^{th} percentile results map shows that in 5% of cases, the drift time to grounding at the western end of the Strait of Juan de Fuca is about 4 hours, falls to less than two hours in Haro Strait, and is less than one hour at Turn Point. It only increases to 2 hours after the ship travels into the southern Strait of Georgia.

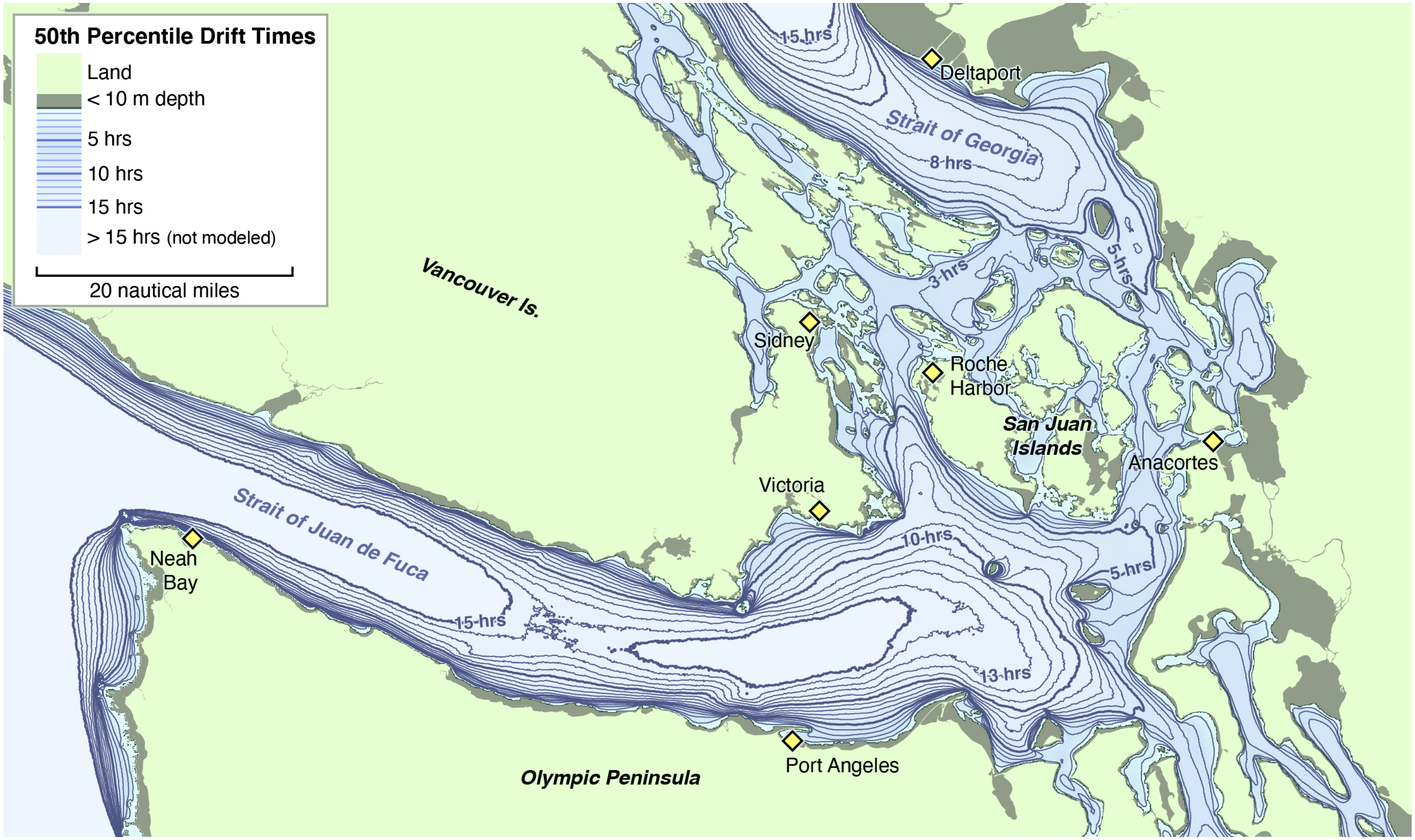

Figure 4-1: Estimated time for a ship to drift to grounding based on the model based on the 50th percentile drift times, or median case

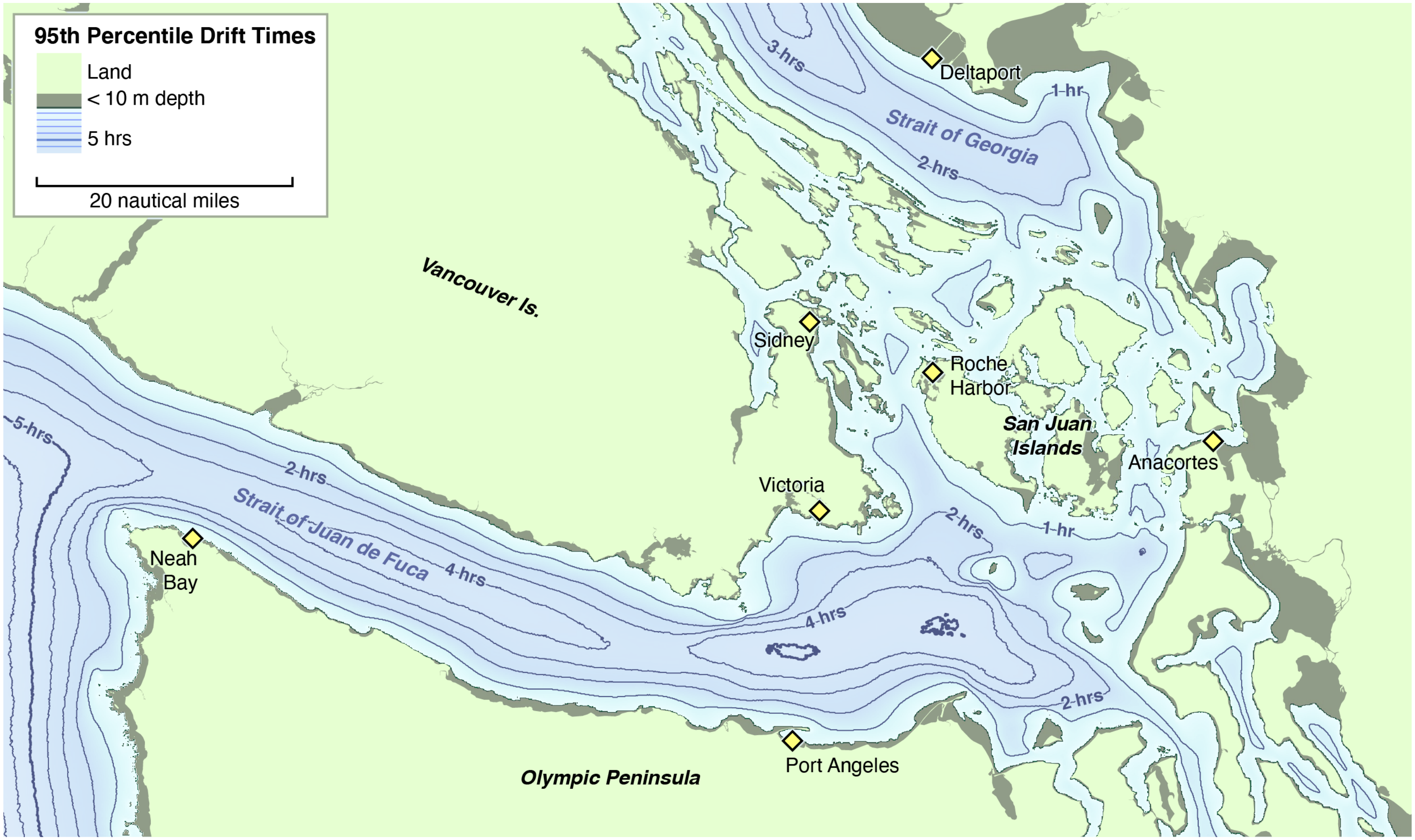

Figure 4-2: Estimated time for a ship to drift to grounding based on the 95th percentile drift times, or bad case

QUESTION #2: Considering four focus areas around San Juan County, what is the probability that an ERTV could arrive before a ship drifting from the typical ship route grounds?

Question #2 considers the four focus areas around San Juan County and the modeled results for ships that begin drifting from the typical ship route (shown in Section 3.4). As a first step to understanding ship drift time from the route, it is useful to examine the results from Question #1 in a zoomed-in view of the focus areas. Figures 4-3 and 4-4 also show the typical ship route.

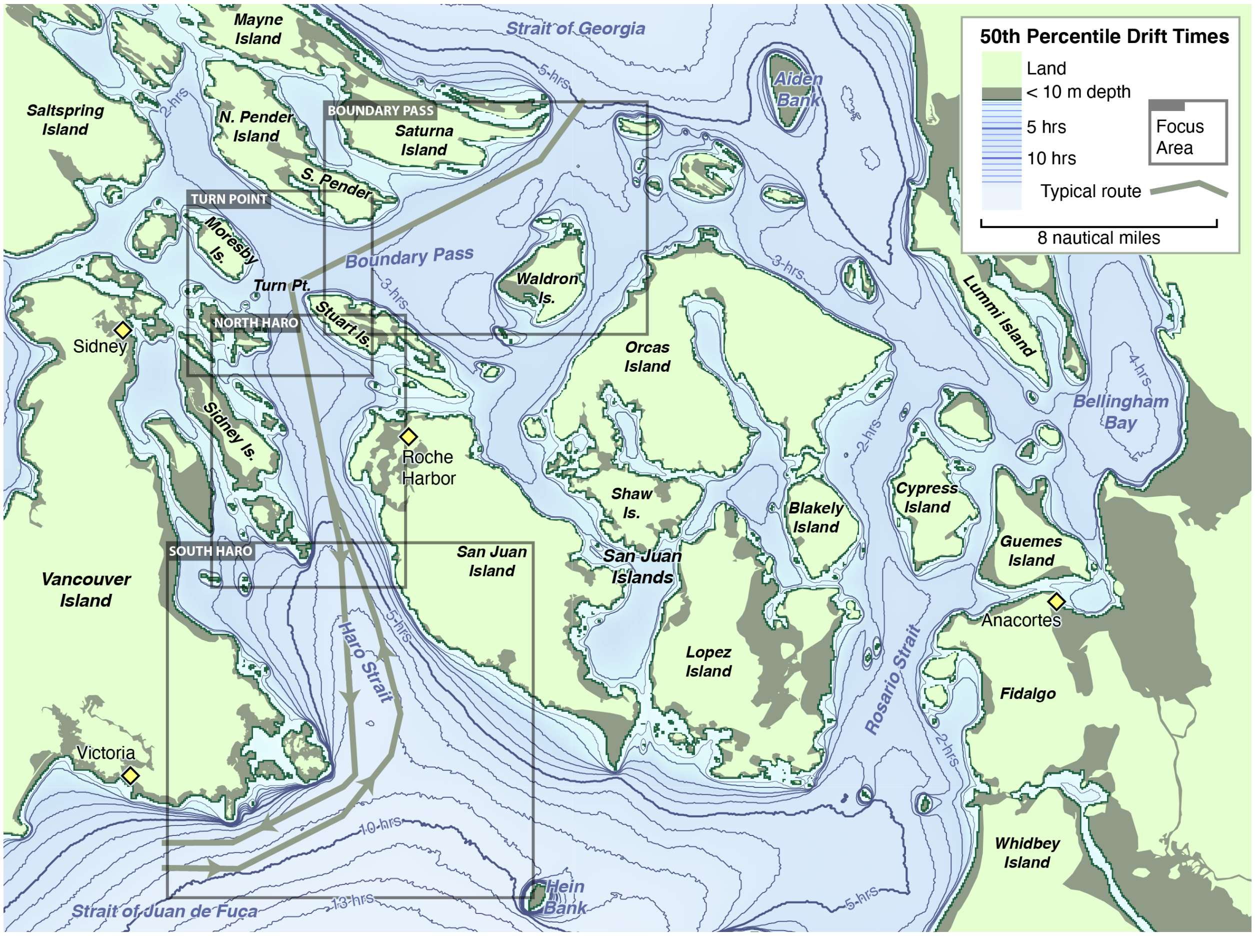

Figure 4-3: Model results for the 50th percentile, or median case; here shown with the four focus areas and the typical ship route.

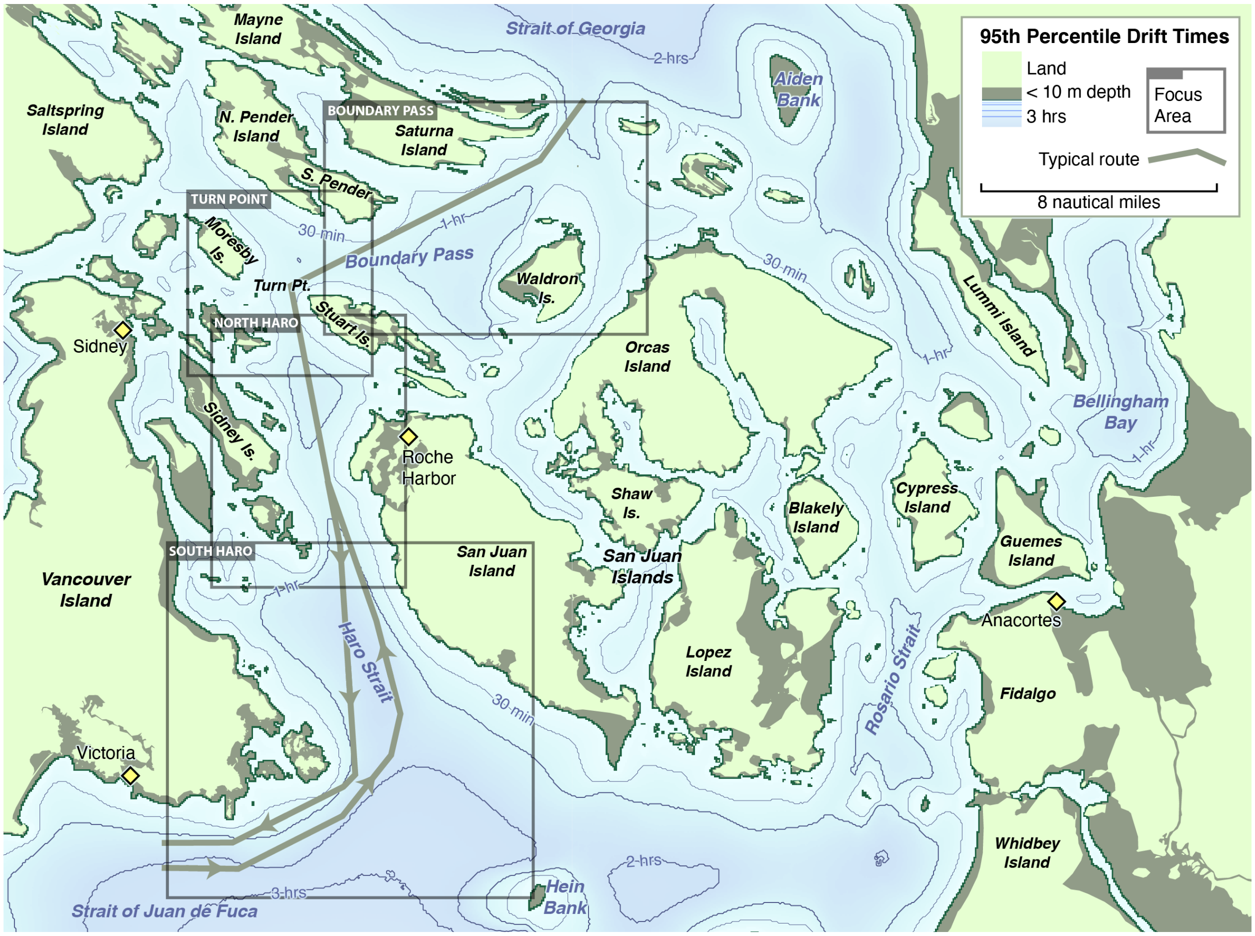

Figure 4-4: Model results for the 95th percentile, or bad case; here shown with the four focus areas and the typical ship route

Next, the estimated response times for an ERTV departing different locations are determined. Table 4-1 shows the fast, mid-range, and slow times estimated for an ERTV to secure a tow from the various locations based on the approach described in Section 3.4.

Table 4-1: Estimate time to rescue for each focus area from different ERTV origins (hours)

TURN POINT				BOUNDARY PASS			
ERTV origin	Fast	Mid	Slow	ERTV origin	Fast	Mid	Slow
Sidney	0.7	1.2	1.8	Roche Harbor	1.0	1.5	2.7
Roche Harbor	0.7	1.2	1.9	Sidney	1.1	1.9	3.3
Victoria	2.1	3.0	4.4	Delta Port	1.5	2.3	3.8
Delta Port	2.2	3.0	4.8	Anacortes	2.2	3.2	5.1
Anacortes	2.5	3.6	5.3	Victoria	2.3	3.5	5.5
Port Angeles	2.9	4.0	5.9	Port Angeles	3.2	4.7	7.0
Neah Bay	5.9	7.9	11.6	Neah Bay	6.2	8.7	12.9
NORTH HARO				**SOUTH HARO**			
ERTV origin	Fast	Mid	Slow	ERTV origin	Fast	Mid	Slow
Roche Harbor	0.6	0.9	1.9	Victoria	0.6	1.4	2.5
Sidney	0.8	1.3	2.4	Roche Harbor	1.0	1.7	3.3
Victoria	1.6	2.3	3.8	Sidney	1.1	2.0	4.0
Anacortes	2.4	3.4	5.3	Port Angeles	1.4	2.6	4.4
Port Angeles	2.4	3.5	5.3	Anacortes	2.1	3.3	5.3
Delta Port	2.4	3.5	5.5	Delta Port	3.0	4.4	7.4
Neah Bay	5.4	7.4	11.1	Neah Bay	4.4	6.4	10.0

Finally, for each focus area, the proportion of ships that had not grounded (in other words, ships still "available" to be saved by a capable ERTV) is compared to the ERTV arrival times. This is shown in Figure 4-5, using the inverse cumulative distribution curve for each focus area (the percentage of vessels not yet grounded and how that changes over time) and, below each of those, bars showing the range of time it would take for an ERTV to arrive on scene and, if all goes well, achieve a tow to secure the drifting ship.

The following discussion of the four focus areas considers the mid-range estimate of time that an ERTV would take to respond, and percentages are rounded to the nearest 5%. This part of the analysis used all model runs, not just the 50^{th} and 95^{th} percentile results shown for the general characterization of model results in the first research question.

When considering all model runs across all conditions for the **Southern Haro Strait focus area**, the proportion of vessels available to save curve declines relatively slowly with time, as would be expected in this area with more sea room and less tidal current. An ERTV traveling from Victoria, BC, would be expected to be on-scene, with greater than 90% of disabled vessels drifting from the typical ship route still available to be saved. However, an ERTV transiting from Neah Bay would arrive after 35% of the disabled vessels drifting from the typical route would have grounded.

In the **Northern Haro Strait focus area**, the curve becomes steeper as the sea room constricts and the tidal currents increase. An ERTV traveling from Roche Harbor, WA, would be expected to be on-scene, with greater than 95% of disabled vessels drifting from the typical ship route still available to be saved. However, an ERTV transiting from Neah Bay would arrive after 60% of the disabled vessels drifting from the typical route would have grounded.

In the **Turn Point focus area**, the curve is the steepest, where the sea room is sometimes less than a mile, and the tidal currents are the highest of all the areas. An ERTV traveling from Roche Harbor, WA or Sidney, BC would be expected to be on-scene, with about 85% of disabled vessels drifting from the typical ship route still available to be saved. However, an ERTV transiting from Neah Bay would arrive after 85% of the disabled vessels drifting from the typical route would have grounded.

In the **Boundary Pass focus area**, the curve is similar to Northern Haro Strait. But because of the longer travel distances, an ERTV traveling from Roche Harbor, WA, would be expected to be on-scene, with about 80% of disabled vessels drifting from the typical ship route still available to be saved. ERTV transiting from Neah Bay would arrive after 70% of the disabled vessels drifting from the typical route would have grounded.

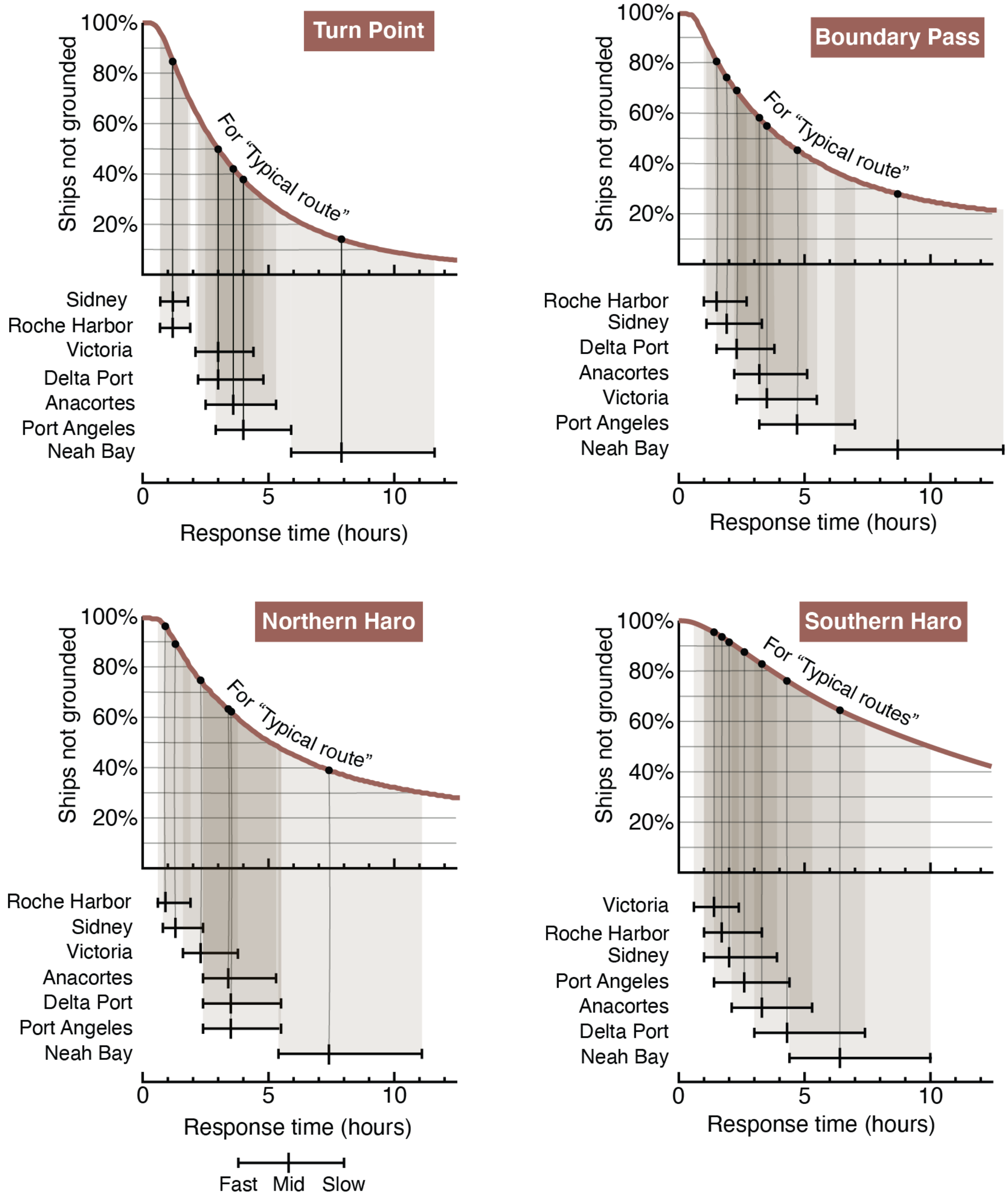

Figure 4-5: Drift times to grounding over time and estimated ERTV rescue times from different ERTV origins (for each of four focus areas)

5 Findings

This section summarizes the findings from the study.

Strait of Juan de Fuca

- In the median case (50th percentile), the time to grounding in the Strait of Juan de Fuca is generally greater than 10 hours.
- In a bad case (95th percentile), the time to grounding is at least 3 hours.

Southern Strait of Georgia

- In the median case (50th percentile), the time to grounding in the Southern Strait of Georgia is generally greater than 5 hours.
- In a bad case (95th percentile), the time to grounding is at least 2 hours.

Boundary Pass

- In the median case (50th percentile), the time to grounding in Boundary Pass is generally greater than 3 hours.
- In a bad case (95th percentile), the time to grounding is less than 1 hour.
- When considering the mid-time for an ERTV to arrive to a vessel drifting from the typical route, an ERTV stationed at Roche Harbor would arrive in time to rescue more than 80% of disabled vessels.

Turn Point

- In the median case (50th percentile), the time to grounding in Turn Point is generally less than 3 hours.
- In a bad case (95th percentile), the time to grounding is less than 1 hour.
- When considering the mid-time for an ERTV to arrive to a vessel drifting from the typical route, an ERTV stationed at Roche Harbor or Sidney would arrive in time to rescue more than 85% of disabled vessels.

North Haro Strait

- In the median case (50th percentile), the time to grounding in North Haro Strait is generally at least 3 hours.
- In a bad case (95th percentile), the time to grounding is less than 1 hour.
- When considering the mid-time for an ERTV to arrive to a vessel drifting from the typical route, an ERTV stationed at Roche Harbor would arrive in time to rescue about 95% of disabled vessels.

South Haro Strait

- In the median case (50th percentile), the time to grounding in South Haro Strait is generally at least 5 hours.
- In a bad case (95th percentile), the time to grounding is greater than 1 hour.

- When considering the mid-time for an ERTV to arrive to a vessel drifting from the typical route, an ERTV stationed at Victoria, Roche Harbor, or Sidney would arrive in time to rescue more than 90% of disabled vessels.

6 Future Opportunities

There are opportunities to use the dataset assembled for this project for further analysis to answer other research questions, such as:

- What are the variations in drift times to grounding under different tidal current regimes (ebb, flood, spring, and neap)?
- What are the variations in drift times to grounding under different wind regimes (wind direction and strength)?
- What are the variations in drift times to grounding for different vessel types (vehicle carrier, bulk carrier, etc.)?
- What is the probability that an ERTV could arrive before a vessel drifting from the typical ship route grounds in a Rosario Strait focus area?

Additional studies may be required to determine the characteristics and capabilities of an ERTV necessary to successfully perform emergency towing of the ships commonly transiting in these waters. This research could also consider the towing procedures best suited to this operating environment.

7 Conclusion

This project estimated how long a disabled ship may drift in the waters of the central Salish Sea using the best available high-resolution model of both winds and currents. The purpose of this effort was to understand how quickly a rescue would need to be achieved in these areas to prevent a drift grounding incident. The results indicate the shortest drift time to grounding along the typical shipping route through the region are in the confined waters of Haro Strait, Turn Point, and Boundary Pass. Based on wind and current conditions from 2014 through 2017, a disabled ship could ground in less than an hour if onboard mitigation efforts were not affected or were not successful. A hypothetical ERTV responding from Roche Harbor or Sidney would have the best chance of arriving in time to rescue more than 80% of the cases modeled. An ERTV located outside the immediate area would have a lower probability of arriving in time to rescue a disabled vessel drifting from the typical shipping route.

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