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Assessment of Marine Oil Spill Risk and Environmental Vulnerability for the State of Alaska

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RPS asa
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RPI
The Louis Berger Group, Inc.

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Background

Alaska's waters are rich in biological resources that are sensitive to spilled oil. These waters are also host to oil exploration/production activities and heavy vessel traffic, and are bordered by land-based facilities that transfer, store, and handle oil. This combination of sensitive resources and potential oil spill sources increases the risk of a damaging spill. In support of planning and preparation for oil spill responses, Natural Resource Damage Assessments (NRDAs), and restoration planning efforts, RPS ASA, Environmental Research Consulting (ERC), Research Planning, Inc. (RPI), and The Louis Berger Group, Inc. (LBG) were contracted by the National Oceanic and Atmospheric Administration's (NOAA) Restoration Center Northwest Region to conduct a screening-level analysis of the relative risk of oil spills to the marine waters of the state of Alaska (including the Arctic region of Alaska).

The objectives of this risk analysis were to determine the probabilities of spills occurring with respect to geographic region, oil type, and season, as well as the potential impacts from an oil spill, considering oil characteristics and the vulnerability of the state's environmental resources. This assessment involved the development of a detailed model of region- and season-specific environmental vulnerability for Alaska, which was combined with spill incident rates and potential volumes of oil spills to construct the overall risk model and determine the regions/seasons of highest relative risk. All factors contributing to risk were assessed on a broad regional basis, considering the region of origination of a potential spill (rather than oil spill trajectory and fates). The vulnerability of socioeconomic resources (such as recreation, commercial fishing, subsistence activities, cultural resources, tourism, etc.) was not included in the present risk model, but could be incorporated into future iterations.

The analysis also included an assessment of future relative risk for the year 2025, based on expected changes in oil spill likelihood and volume that might occur with changes in vessel traffic, oil exploration and production activities, and the regional economy. No future projections of environmental vulnerability were calculated for this project, as projecting future trends for environmental conditions (e.g., individual species' distributions, shoreline location/type, and ice coverage) is inherently complex and uncertain, and was beyond the scope of the current project.

Modeling Approach

Much of the conceptual foundation for the risk model developed for this study is provided by the Washington Compensation Schedule (WCS) (Washington Administrative Code 173-183), which provides a per-gallon relative impact score for oil spills, considering sensitivity of the locations oiled, relative density and seasonal distributions of sensitive biota, and factors related to oil type. Since the WCS cannot be directly applied to Alaska, it was first necessary to develop an environmental vulnerability and oil spill risk model specific to the state of Alaska. To support the development of the model, a literature review was conducted of environmental vulnerability and spill risk studies. Along with the extensive expertise of the project team, this review served as a basis for development of our novel oil spill risk model.

We approached the assessment of oil spill risk by applying the standard technical definition of risk that includes both the likelihood (i.e., probability) of spill incidents of various types and sizes and the consequences (i.e., impacts) of those incidents. In other words:

Spill risk = probability of spill x impacts of spill

The risk model developed for this project consists of three main elements: (1) vulnerability of the environment to oil spill impacts, (2) probability of a spill based on past and projected future incident rates, and (3) potential maximum most probable discharge (MMPD) and worst-case discharge (WCD) volumes that could result from an incident now or in the future. Each factor is assessed on a regional and seasonal basis by oil type.

In this study, "incidents" are defined as events involving vessels or facilities (including onshore facilities, pipelines, and offshore wells) that could potentially result in the spillage of oil, such as casualties, accidents, discharges, and leakages. For the MMPD and WCD volumes, this study employs the U.S. Coast Guard (USCG) definitions of MMPD and WCD depending on source type.

The MMPD volumes are defined as follows:

- Facility MMPD = the lesser of 1,200 bbl or 10% of the WCD;
- Vessel (<25,000 deadweight tonnage [DWT]) MMPD = 10% of the WCD; and
- Vessel (≥25,000 DWT) MMPD = 2,500 bbl.

Since there is no analogous equivalent for offshore wells in the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) regulations, the facility MMPD of 1,200 bbl was applied to offshore wells in this analysis.

For onshore facilities, deep-water ports, and offshore facilities, WCD is defined as "the largest foreseeable discharge in adverse weather conditions". In this study the WCD for facilities are based on the types of facilities present in each region and the known capacities of the facilities. For facilities for which there was no reported capacity, a typical capacity for the facility type was applied. These volumes range from 100 bbl to 200,000 bbl.

For offshore wells, the WCDs depend on the pressure in the well, the size and type of pipe or riser, the type of blowout preventer, the length of time before a discharge is detected, and the length of time to capping of the well or stemming of the flow of oil with relief wells. U.S. Environmental Protection Agency (EPA) regulations (40 CFR 112.20) stipulate that the WCD for a well is defined as "30 days of flow at the daily production rate for wells that are 10,000 feet or less, and 45 days of flow at the daily production rate for wells that are 10,000 feet or more." This definition of WCD for wells is applied in this study, with the exception of the WCDs for Beaufort and Chukchi Sea wells. For these regions, the WCDs for offshore wells are assumed to be those that are presented in BOEM's 2012-2017 OCS Oil and Gas Leasing Program Final Programmatic Environmental Impact Assessment as "Catastrophic Discharge Events" (CDEs) (BOEM, 2012), as these values resulted in higher WCD volumes than the EPA regulatory definition and represent the equivalent level of catastrophic event as a worst-case discharge tanker spill in which the entire contents of the tanker spills. The discharge volumes for the Beaufort and Chukchi Seas are 3.9 million bbl and 2.2 million bbl, respectively. For the Cook Inlet, Kodiak/Shelikof Strait, and Aniakchak regions, the discharge volume is 39,000 bbl, due to the differences in recorded production rates from the different regions, as well as differences in the durations of flow due to factors such as type of drilling rig and rig availability to drill relief wells during open-water season.

For vessels, the WCD is defined as the total capacity of the cargo and/or bunker fuel tanks of the vessel. This volume varies from 10 bbl for small recreational vessels to 1.9 million bbl for fully-loaded crude tankers (also called "tank ships").

The risk model is constructed at the level of resolution of 14 broad geographic zones covering Alaska's shoreline and marine waters (Figure ES-1). These zones are based on the Alaska Department of Environmental Conservation (ADEC) and the Alaska Regional Response Team (AART) Contingency Planning Regions. Although the regions include inland areas of Alaska, the model only considers coastal shorelines and marine waters of Alaska within the designated USCG oil spill response areas. Inland waters and upland habitats are not included in the model.

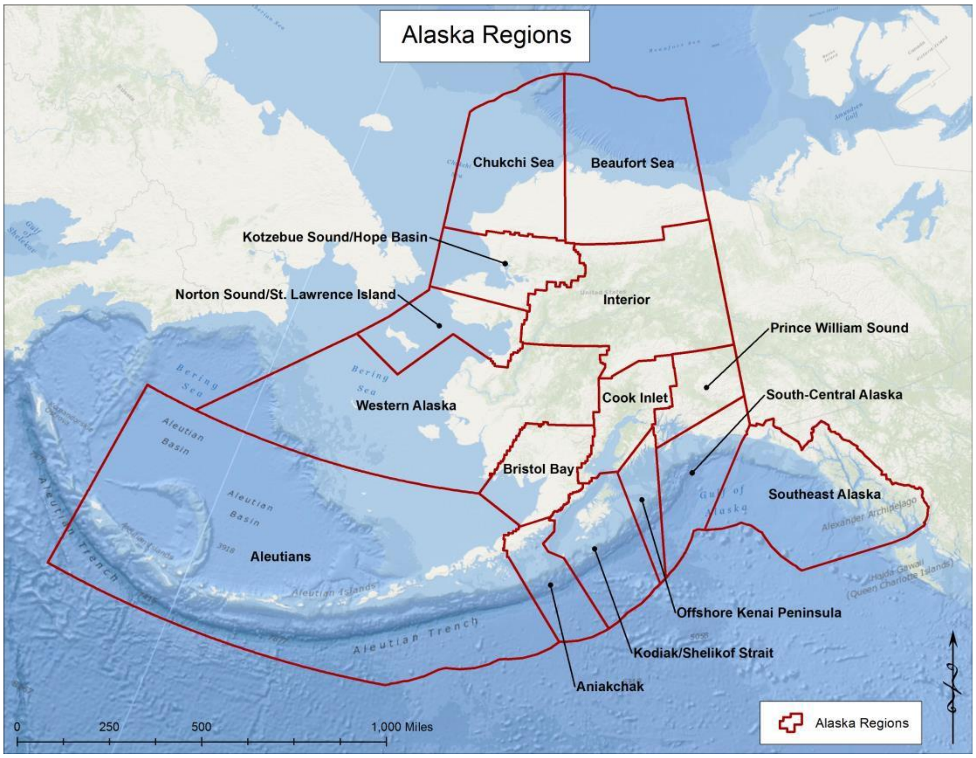


Figure ES-1. Broad geographic zones considered in the analysis. Note: ADEC/ARRT region 10 (Interior) was not included in the analysis, as it does not have a marine component.

Six seasonal periods are included in the model, each consisting of two months. To capture the varying effects of different oil types on the environment, the model considers four general oil types: crude oils, heavy oils, light oils, and distillates.

The environmental vulnerability portion of the risk model reflects the vulnerability of the environment to oil spill impacts, and is based on the underlying vulnerability of habitats and species representative of those present in each region and season. The three main habitat types considered in the habitat vulnerability score are shoreline habitats, bottom marine habitats (including submerged aquatic vegetation), and sea ice habitat. Species vulnerability is comprised of three main parameters: relative abundance, impact (how severely the species would be affected in the event of a spill), and recovery (how quickly the species population can recover from impact). These three parameters were assessed for individual species, based on unique scoring schemes. Species assessed in the risk model are divided into three broad species group categories: marine mammals and sea turtles, birds, and fish and invertebrates. For the initial application of the risk model, 36 species were selected for assessment, consisting of 12 species in each species group category and representing a wide range of behavior groups and ecological roles.

The spill risk portion of the risk model reflects (1) the probability of an incident that may result in an oil spill for each region, season, and oil type category based on past and projected future incidents, and (2) the potential MMPD and WCD volumes that could result from an incident now or in the future. To determine incident rates for each region, season, and oil type, historical vessel and facility incidents were analyzed for the years 1995–2012. This 18-year period was selected because it provided the most extensive spill and casualty data. Incidents in which oil spilled or in which oil could potentially have spilled into marine waters were included in the analysis. In total, 10,985 incidents were included in the analysis. Of these incidents, 3,581 (33%) were facility-related incidents, and 7,404 incidents (67%) were related to vessels. The incident numbers for this 18-year time period are assumed to reflect the relative probability that an incident might occur in the present time. Figure ES-2 shows the geographic distribution of incidents between 1995 and 2012.

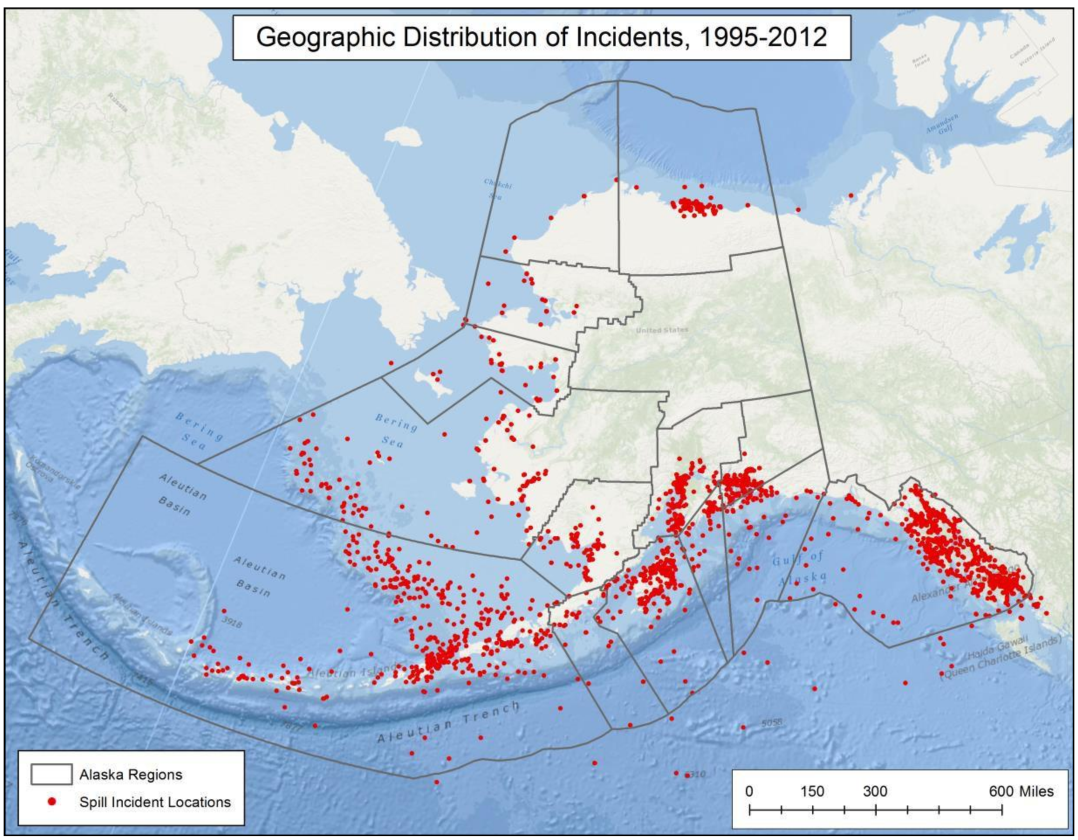


Figure ES-2. Geographic distribution of incidents from 1995–2012. Note: An individual red dot may represent multiple incidents.

Spill volumes associated with incidents in Alaska during 1995–2012 were very small, and many incidents did not involve any spillage (Table ES-1). Most spills (85%) involved less than 1 bbl. Over 99% of the spills involved less than 50 bbl and only 0.1% involved more than

500 bbl. Clearly, the "most likely" spill volume is less than 1 bbl. However, in order to assess relative risk and prioritize areas for future study, the risk model uses the MMPD and WCD volumes that could potentially result from a future incident in a given region/season. Both volumes represent scenarios for which the future likelihood are very low and are not reflective of the volumes actually spilled in past incidents. Although spills with MMPD and WCD volumes have a very low likelihood, they must be taken into account for contingency planning and risk mitigation development. In essence, the risk model reflects where future incidents are likely to occur, the likely oil types involved, and potential "maximum" (rather than most likely) spill volumes that could result from a future incident.

Table ES-1. Distribution of actual spill volumes in Alaska (1995-2012).

Spill Volume	Number of Incidents	Percent of Total Incidents	Percent of Total Spills
> 5,000 bbl	1	0.01%	0.01%
1,000 – 4,999 bbl	2	0.02%	0.02%
500 – 999 bbl	5	0.05%	0.06%
100 – 499 bbl	32	0.29%	0.37%
50 – 99 bbl	30	0.27%	0.35%
10 – 49 bbl	223	2.03%	2.57%
5 – 9 bbl	156	1.42%	1.80%
1 – 4 bbl	832	7.57%	9.60%
< 1 bbl	7,386	67.24%	85.22%
0 bbl (potential only)	2,318	21.10%	-
Total Incidents	**10,985**	-	-
Total Spills	**8,667**	-	-

For each region, period, and oil type, the MMPD volumes for all source types were weight-averaged so that the MMPD volumes were represented in proportion to their occurrence (i.e., incident rate) by source/oil type. For each region, period, and oil type, the WCD used in the risk model is the largest potential discharge from the sources that are likely to be present in the region during that time period, carrying that type of oil.

Based on a literature review of studies related to future spillage risk, a number of assumptions were applied to forecast incident rates for the year 2025 for this study. Several of these assumptions relate to factors that reduce the probability of an incident becoming a spill event. For example, risk mitigation practices and/or the use of double-hulled tanks reduce the potential for spillage in the event of an incident. Additional assumptions in the projection of future incident rates involve changes in vessel traffic patterns and the seasonal distribution of incidents (as ice coverage continues to decrease). For any time periods in which the current incident rate is zero for shipping, oil production, and other activities (with the exception of recreational boating and cruise ship transits), the incident rate was increased to reflect increased access to areas that were formerly ice-covered during the season. The future projections also include an assumed change in the distribution of oil types. A shift of 50% from heavy bunker fuel to diesel fuel on larger ships is assumed due to regulatory changes related to air emissions in nearshore and port areas.

Facility incident rates from oil exploration and production were assumed to increase in the Beaufort Sea, Chukchi Sea, and Cook Inlet regions. For any region/season/oil type combination that was not already adjusted based on the aforementioned assumptions, the incident rate was increased using assumed annual increases in economic growth and tempered by increased effectiveness of spill prevention and risk mitigation measures to reduce spillage. Future potential WCD and MMPD spill volumes for the year 2025 were adjusted from the present-day estimates based on the assumed changes in the underlying source incidents. The future estimates also include an assumed 50% reduction in WCD volumes for crude and product tankers due to reduced oil outflow with double-hulled tanks.

A flow diagram for the overall model is provided as Figure ES-3.

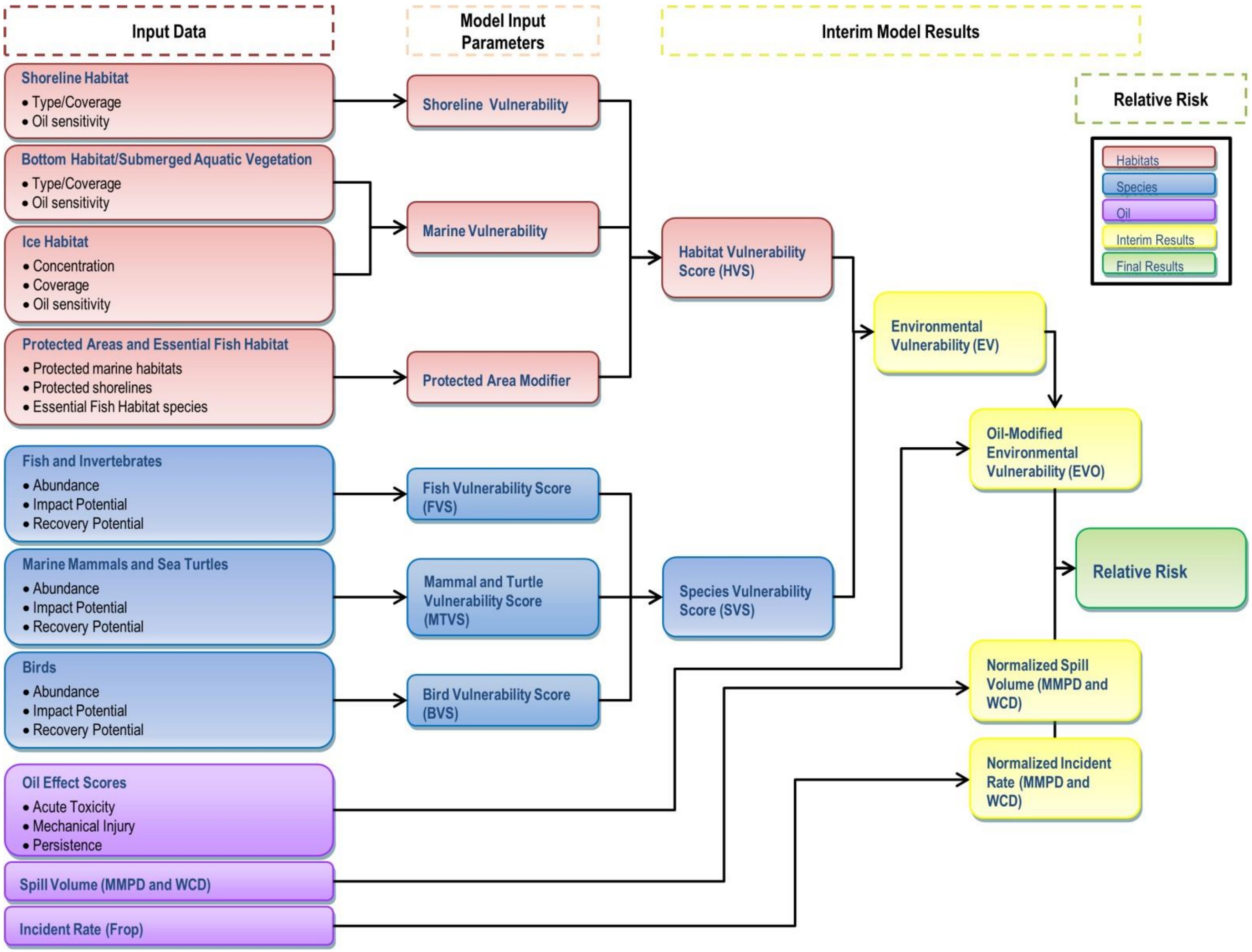


Figure ES-3. Model flow diagram.

Interim Model Results – Environmental Vulnerability, Incident Rate, and Spill Volume

<u>Environmental Vulnerability</u>

The environmental vulnerability (EV) parameter captures the vulnerability of species (birds, marine mammals and sea turtles, and fish and invertebrates) and habitats (bottom, ice, shoreline, protected areas) for each region during each period. Greater environmental vulnerability indicates a region/period that contains species and habitats that are relatively sensitive to oil spill impacts. The maximum possible environmental vulnerability score for any region/period is 2.0.

Table ES-2 presents the EV scores for each region and period, as well as the yearly mean score. The highest EV score is for the Aleutians region in June–July. The Aleutians region also had the highest yearly mean EV, followed by the Norton Sound/St. Lawrence Island and Kodiak/Shelikof Strait regions. Across all regions, the greatest EV scores occurred in late spring and early summer (April through July) while the lowest EV scores occurred in late fall (October through November). This is driven mainly by the migrations of species that spend the summer in Alaska.

Table ES-2. Environmental vulnerability (EV) scores for each region and period, sorted by yearly mean score.

Region	Period						Yearly Mean
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	
Aleutians	1.48	1.44	1.51	1.55	1.49	1.53	1.50
Norton Sound/St. Lawrence Is.	1.38	1.39	1.46	1.44	1.21	1.27	1.36
Kodiak/Shelikof Strait	1.27	1.24	1.37	1.36	1.33	1.27	1.31
Western Alaska	1.24	1.31	1.38	1.36	1.17	1.18	1.27
Kotzebue Sound/Hope Basin	1.09	1.08	1.30	1.27	1.14	1.10	1.17
Cook Inlet	1.20	1.21	1.32	1.14	1.09	1.02	1.16
Aniakchak	1.09	1.10	1.19	1.22	1.17	1.13	1.15
Chukchi Sea	0.99	0.98	1.19	1.31	1.16	1.06	1.12
Offshore Kenai Peninsula	1.09	1.04	1.14	1.14	1.11	1.03	1.09
Prince William Sound	1.02	1.03	1.16	1.05	1.00	0.91	1.03
Beaufort Sea	0.87	0.87	1.05	1.24	1.13	0.98	1.02
Southeast Alaska	0.94	0.93	1.08	1.09	1.07	0.98	1.01
Bristol Bay	1.01	1.05	1.05	0.95	0.88	0.98	0.99
South-Central Alaska	0.94	0.88	1.03	1.06	1.03	0.92	0.98
Seasonal Average	1.12	1.11	1.23	1.23	1.14	1.10	

Table ES-3 shows the yearly mean input values by region for each component of the EV score: the habitat vulnerability score (HVS), marine mammal and sea turtle vulnerability score (MTVS), bird vulnerability score (BVS), and fish and invertebrate vulnerability score (FVS). By examining these inputs, the main drivers of the EV score for each region become apparent. For example, the high mean EV score for the Aleutians region is driven by high mean species vulnerability scores, particularly for marine mammals/sea turtles and fish/invertebrates. Conversely, the high mean EV score for the Norton Sound/St. Lawrence Island region is driven by high mean habitat scores (HVS), due to sensitive shoreline, bottom habitats, and high seasonal ice coverage.

Table ES-3. Yearly mean environmental vulnerability (EV) scores for each region. Columns 2 through 5 display the yearly mean values for the input parameters to the EV equation. Table is sorted by the mean EV score.

Region	Mean HVS	Mean MTVS	Mean BVS	Mean FVS	Mean EV
Aleutians	0.63	0.90	0.74	0.97	1.50
Norton Sound/St. Lawrence Is.	0.89	0.42	0.43	0.56	1.36
Kodiak/Shelikof Strait	0.62	0.53	0.81	0.73	1.31
Western Alaska	0.71	0.47	0.47	0.75	1.27
Kotzebue Sound/Hope Basin	0.83	0.31	0.31	0.39	1.17
Cook Inlet	0.71	0.25	0.75	0.35	1.16
Aniakchak	0.58	0.34	0.75	0.63	1.15
Chukchi Sea	0.79	0.40	0.32	0.26	1.12
Offshore Kenai Peninsula	0.57	0.34	0.79	0.42	1.09
Prince William Sound	0.65	0.22	0.58	0.34	1.03
Beaufort Sea	0.73	0.34	0.30	0.24	1.02
Southeast Alaska	0.43	0.59	0.68	0.48	1.01
Bristol Bay	0.56	0.33	0.49	0.45	0.99
South-central Alaska	0.51	0.34	0.63	0.42	0.98

Incident Rate

Based on the analysis of historical incidents, the most frequent type of vessel incident is one involving a small fishing vessel. On average, small fishing vessel incidents in Alaska occurred every 2 days during 1995–2012. Recreational vessel incidents occurred every 3 days. Incidents involving smaller (<90,000 DWT) tank ships occurred about every 90 days, while larger tank-ship incidents occurred about every 111 days, on average. The greatest number of facility-sourced incidents in Alaska from 1995–2012 (55%) occurred from facilities involved in oil exploration and production activities. On average, an incident occurred at an oil exploration and production facility every 3.3 days. The next most frequent facility incidents were those that occurred at small boat harbors (from the facilities themselves, not from the vessels within the harbor), comprising 8% of the incidents and occurring about once every 23 days. On average, a facility incident occurred every 1.8 days or nearly 200 times per year. The highest numbers of facility incidents were from offshore oil exploration and production facilities in the Beaufort Sea and Cook Inlet regions. The majority of past incidents (nearly 87%) involved light oils, mainly diesel.

The region with the highest incident rate for all oil types summed was Southeast Alaska during the months of June–July (Table ES-4). Southeast Alaska also had the highest yearly mean incident rates, followed by the Aleutians and Beaufort Sea regions. On average (across all regions), incident rates were highest during the months of June through September. This is reflective of the high level of recreational boating and fishing that occurs during this time period.

Based on the projection of future incident rates for the year 2025, the region with the highest incident rate is predicted to be the Beaufort Sea region in February–March (Table ES-5). This is due to the fact that this season had the highest incident rate in the underlying historical data (see Table ES-4). The Beaufort Sea also has the highest yearly mean future incident rate, followed by Southeast Alaska and the Aleutians. Similar to the historic incident rates, 2025 average incident rates (across all regions) are predicted to be highest during the summer months.

Table ES-4. Current/historical incident rates (number per year) by period, sorted by the yearly mean incident rate. The yearly mean incident rate is based on the sum of all oil types. Coloring is based on the collective values from both the historical rates and the future rates (Table ES-5), and is directly comparable between the two tables.

Region	Current/Historical Incident Rate (# per year)						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Southeast Alaska	22.7	29.5	27.9	48.5	43.3	29.8	33.6
Aleutians	12.0	20.7	12.9	14.3	17.4	12.0	14.9
Beaufort Sea	12.5	16.8	15.9	14.6	12.4	10.2	13.7
Cook Inlet	8.8	10.1	14.3	16.1	15.8	9.2	12.4
Prince William Sound	7.0	7.3	8.9	14.0	9.1	6.5	8.8
Kodiak/Shelikof Strait	7.6	7.7	7.9	9.6	7.2	6.6	7.8
Western Alaska	1.5	1.8	3.2	4.8	5.0	2.3	3.1
Offshore Kenai Peninsula	1.5	2.3	2.8	3.2	2.6	1.8	2.4
Bristol Bay	0.3	0.6	2.6	7.1	1.5	0.6	2.1
South-Central Alaska	0.6	1.1	1.5	1.0	1.1	0.5	1.0
Norton Sound/St. Lawrence Is.	0.4	0.5	0.4	1.7	1.3	0.8	0.9
Aniakchak	0.2	0.9	0.5	0.7	0.7	0.4	0.6
Kotzebue Sound/Hope Basin	0.1	0.3	0.3	0.9	0.5	0.5	0.4
Chukchi Sea	0.3	0.2	0.2	0.2	0.7	0.2	0.3
Seasonal Average	5.4	7.1	7.1	9.8	8.5	5.8	

Table ES-5. Projected 2025 incident rates (number per year) by period, sorted by the yearly mean incident rate. The yearly mean incident rate is based on the sum of all oil types. Coloring is based on the collective values from both the historical rates (Table ES-4) and the future rates, and is directly comparable between the two tables.

Region	2025 Incident Rate (# per year)						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Beaufort Sea	61.3	82.8	78.0	72.8	60.8	50.3	67.7
Southeast Alaska	26.3	34.7	32.8	54.2	48.1	33.5	38.3
Aleutians	13.7	24.0	15.1	16.9	20.1	13.9	17.3
Cook Inlet	10.0	11.5	16.2	18.5	18.4	10.7	14.2
Prince William Sound	7.2	7.6	9.4	16.0	9.6	7.7	9.6
Kodiak/Shelikof Strait	8.7	8.7	9.1	11.0	8.1	7.4	8.8
Western Alaska	1.7	2.1	3.6	5.2	5.5	2.4	3.4
Offshore Kenai Peninsula	1.6	2.6	3.2	3.6	2.8	2.5	2.7
Bristol Bay	0.4	0.8	2.7	7.8	1.6	0.5	2.3
South-Central Alaska	0.6	1.2	1.5	1.0	1.2	0.6	1.0
Norton Sound/St. Lawrence Is.	0.5	0.6	0.4	1.8	1.3	0.9	0.9
Aniakchak	0.2	1.0	0.5	0.8	0.8	0.4	0.6
Chukchi Sea	0.3	0.4	0.3	1.1	0.8	0.6	0.6
Kotzebue Sound/Hope Basin	0.3	0.5	0.2	0.8	0.4	0.5	0.5
Seasonal Average	9.5	12.7	12.4	15.1	12.8	9.4	

Theoretical MMPD Spill Volume

Theoretical MMPD volumes by region and oil type are shown in Table ES-6 and Table ES-7. Current theoretical MMPD volumes are highest for crude and light oils in the Beaufort Sea region, at 1,200 bbl (Table ES-6). The next highest MMPD volumes are 830 bbl for all oil types in Cook Inlet and 800 bbl for distillate/heavy oil in the Beaufort Sea.

Based on the projection of future theoretical MMPDs for the year 2025, the largest MMPD volume is for crude oils in South-Central Alaska (2,500 bbl), followed by heavy oils in Aniakchak (2,300 bbl), and heavy oils in South-Central Alaska (2,200 bbl) (Table ES-7**Error! Reference source not found.**). These differences are attributable to expected changes in vessel traffic composition.

Table ES-6. Yearly mean current theoretical MMPD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPDs and future MMPDs (Table ES-7), and is directly comparable between the two tables.

Region	Current Theoretical MMPD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	1,200	800	800	1,200	4,000
Cook Inlet	830	830	830	830	3,320
South-Central Alaska	670	670	670	670	2,680
Aniakchak	560	560	560	560	2,240
Chukchi Sea	560	560	560	560	2,240
Prince William Sound	520	520	520	520	2,080
Kotzebue Sound/Hope Basin	0	527	527	790	1,843
Norton Sound/St. Lawrence Is.	0	650	433	650	1,733
Western Alaska	0	510	340	510	1,360
Bristol Bay	0	280	420	420	1,120
Southeast Alaska	230	230	230	230	920
Aleutians	0	250	250	250	750
Kodiak/Shelikof Strait	150	150	150	150	600
Offshore Kenai Peninsula	150	150	150	150	600

Table ES-7. Yearly mean projected 2025 theoretical MMPD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPDs (Table ES-6) and future MMPDs, and is directly comparable between the two tables.

Region	2025 Theoretical MMPD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
South-Central Alaska	2,500	300	2,200	400	5,400
Beaufort Sea	1,200	1,100	1,600	1,200	5,100
Aniakchak	1,900	400	2,300	400	5,000
Chukchi Sea	1,200	200	2,000	800	4,200
Prince William Sound	2,000	600	1,200	200	4,000
Cook Inlet	1,200	800	1,200	700	3,900
Kodiak/Shelikof Strait	1,700	300	1,200	100	3,300
Offshore Kenai Peninsula	1,900	300	700	100	3,000
Aleutians	600	400	1,500	200	2,700
Kotzebue Sound/Hope Basin	0	300	1,400	800	2,500
Southeast Alaska	1,200	200	900	200	2,500
Western Alaska	0	700	800	400	1,900
Bristol Bay	0	1,000	500	200	1,700
Norton Sound/St. Lawrence Is.	0	700	200	500	1,400

Theoretical WCD Spill Volume

The largest potential spill volumes in Alaska are associated with offshore oil wells. Theoretically, a very large or even a WCD-volume well blowout could occur in the future in Alaskan waters, in either the Beaufort Sea or the Chukchi Sea, as these regions are likely to have the highest oil production rates. The probability is extremely small, but certainly needs to be considered in risk planning. An analysis of international data on well blowouts indicates that since 1968, there have been 11 well blowouts over 50,000 bbl. Only two incidents involved more than 250,000 bbl. Of the 18 well blowouts that have been reported in the U.S., only two have involved 100,000 bbl or more – the 1969 Alpha Well 21 Platform A blowout off Santa Barbara, California, and the 2010 Macondo MC252 blowout in Gulf of Mexico. Of the 18 blowouts that have occurred in the U.S. over 45 years, one third have involved less than 50 bbl, and about 22% involved less than 10 bbl.

The next largest WCD spill volume would be a spill from a fully-loaded crude tanker. In U.S. coastal waters, between the years 1969 and 2013, there has never been a true WCD from an oil tanker with respect to volume of spillage. Despite its significant environmental and socioeconomic impacts, the 1989 Exxon Valdez spill was not a WCD. The tanker only spilled about 14% of its cargo load. Had it been a WCD, the volume of spillage would have been about 1.6 million bbl rather than 262,000 bbl. Average spillage volume from tankers in the U.S. is 435 bbl. While the likelihood of a WCD from a tanker is seemingly higher than a WCD due to a well blowout, this still represents a very low likelihood of occurrence. Again, risk planning and risk mitigation measures need to take into account the possibility of a WCD from a tanker.

Theoretical WCD volumes by region and oil type are shown in Table ES-8 and Table ES-9. Current theoretical WCD volumes are highest for crude oils in the Beaufort and Chukchi Seas, at 3,900,000 bbl and 2,200,000 bbl, respectively (Table ES-8). The next highest WCD volume (1,900,000 bbl) is for crude, heavy, and light oils in the Cook Inlet, Kodiak/Shelikof Strait, Prince William Sound, Southeast Alaska, and South-Central Alaska regions.

For the 2025 projection, the largest WCD volumes remain associated with crude oils in the Beaufort and Chukchi Sea regions (Table ES-9). The crude oil volumes for these two regions remain at 3,900,000 bbl and 2,200,000 bbl, respectively, because although the likelihood of a blowout may increase with increasing exploration/production activities, the potential volume remains the same. The next highest future WCD volume is 950,000 bbl (from tankers) and associated with a number of regions and all four oil types.

Table ES-8. Yearly mean current theoretical WCD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCDs and future WCDs (Table ES-9), and is directly comparable between the two tables.

Region	Current Theoretical WCD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Cook Inlet	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Kodiak/Shelikof Strait	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Prince William Sound	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Southeast Alaska	1,900,000	523,000	1,900,000	1,900,000	6,223,000
South-Central Alaska	1,900,000	348,667	1,900,000	1,900,000	6,048,667
Beaufort Sea	3,900,000	348,667	348,667	523,000	5,120,333
Chukchi Sea	2,200,000	50,000	20,000	50,000	2,320,000
Aniakchak	523,000	523,000	523,000	523,000	2,092,000
Offshore Kenai Peninsula	523,000	523,000	523,000	523,000	2,092,000
Aleutians	0	523,000	523,000	523,000	1,569,000
Bristol Bay	0	108,667	163,000	163,000	434,667
Norton Sound/St. Lawrence Is.	0	163,000	108,667	163,000	434,667
Western Alaska	0	163,000	108,667	163,000	434,667
Kotzebue Sound/Hope Basin	0	108,667	108,667	163,000	380,333

Table ES-9. Yearly mean projected 2025 theoretical WCD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCDs (Table ES-8) and future WCDs, and is directly comparable between the two tables.

Region	2025 Theoretical WCD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	3,900,000	950,000	950,000	950,000	6,750,000
Chukchi Sea	2,200,000	950,000	950,000	950,000	5,050,000
Aleutians	950,000	950,000	950,000	950,000	3,800,000
South-Central Alaska	950,000	950,000	950,000	950,000	3,800,000
Southeast Alaska	950,000	950,000	950,000	950,000	3,800,000
Cook Inlet	950,000	261,500	950,000	950,000	3,111,500
Kodiak/Shelikof Strait	950,000	261,500	950,000	950,000	3,111,500
Prince William Sound	261,500	950,000	950,000	950,000	3,111,500
Western Alaska	0	950,000	950,000	950,000	2,850,000
Aniakchak	261,500	261,500	261,500	261,500	1,046,000
Offshore Kenai Peninsula	261,500	261,500	261,500	261,500	1,046,000
Bristol Bay	0	163,000	163,000	163,000	489,000
Kotzebue Sound/Hope Basin	0	163,000	163,000	163,000	489,000
Norton Sound/St. Lawrence Is.	0	163,000	163,000	163,000	489,000

Final Model Results – Relative Risk

This section contains the final risk model results considering all three model components: environmental vulnerability, spill incident rate, and potential spill volumes. A flow diagram of the yearly mean model results (for all oil types) is shown in Figure ES-4. Additional results are described in detail in the following paragraphs.

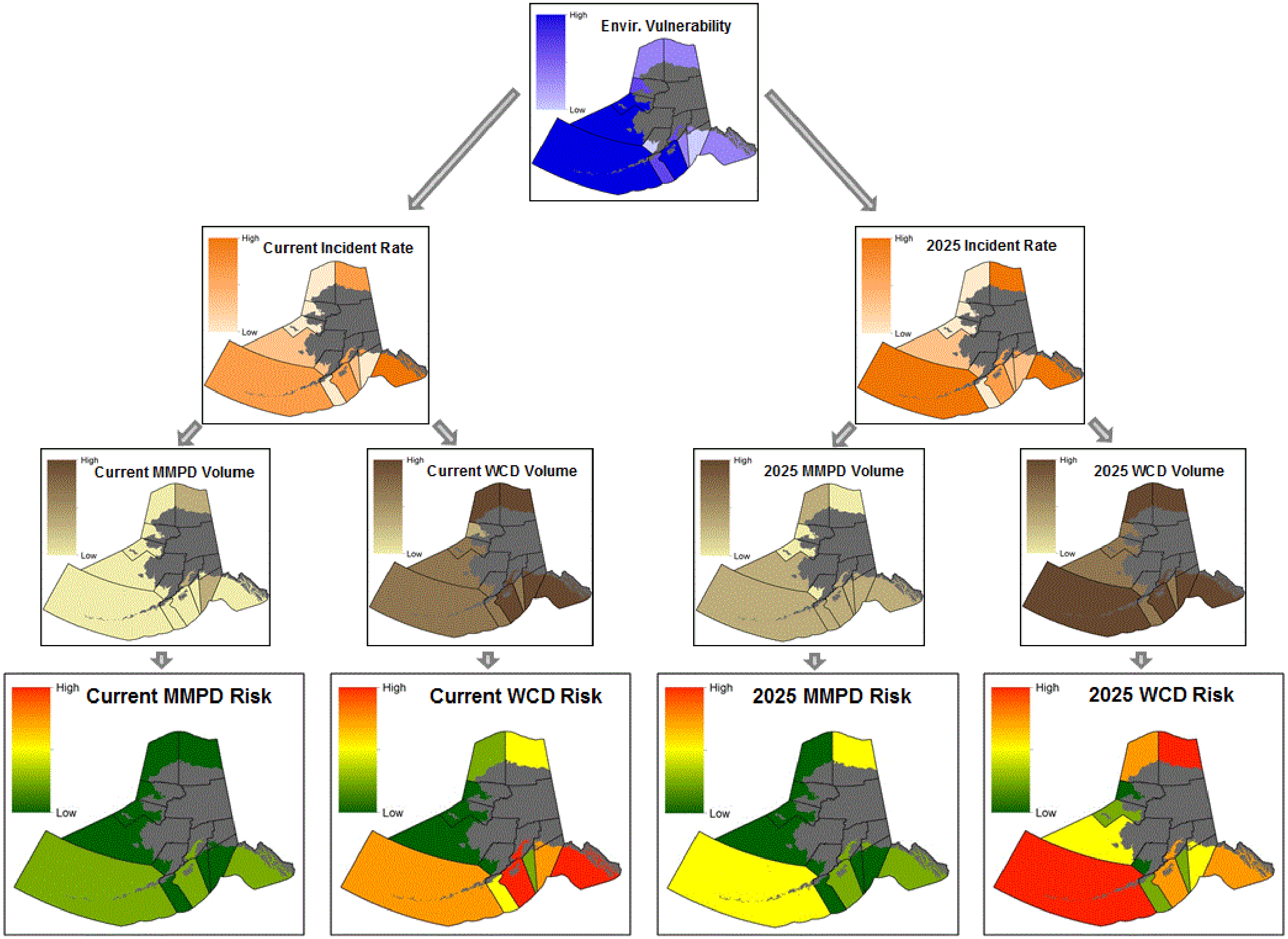


Figure ES-4. Flow diagram of yearly mean relative risk model results (for all oil types). Figures of the same type (e.g., all volume figures) are shown on the same color scale and are directly comparable.

MMPD Relative Risk

Table ES-10 and Table ES-11 list the MMPD relative risk scores by region and period, based on the sum of all oil types. The highest MMPD current relative risk scores are for Southeast Alaska in June–September (Table ES-10). The next highest scores are for the Cook Inlet region in April–May and the Aleutians region in February–March. Based on the yearly mean risk score, the Southeast Alaska region has the highest MMPD relative risk, followed by the Aleutians and Kodiak/Shelikof Strait regions. On average (across all regions), MMPD relative risk scores tend to be the greatest during spring and summer months (April through September) and lowest during winter (December through March). The greatest seasonal differences in risk scores within regions occur in the Arctic regions (e.g., Beaufort Sea, Chukchi Sea).

For the 2025 future projection, the highest MMPD relative risk scores are for the Beaufort Sea region in April to September (Table ES-11). The next highest score is for the Aleutians region in February–March. Based on the yearly mean risk score, the Beaufort Sea region has the highest 2025 MMPD relative risk, followed by the Aleutians and Southeast Alaska regions. These results are based on the 2025 incident rates and volumes and the “current” environmental vulnerability, as environmental vulnerability was not projected into the future for this study.

Table ES-10. MMPD current relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current MMPD risk score and future MMPD risk score (Table ES-11), and is directly comparable between the two tables.

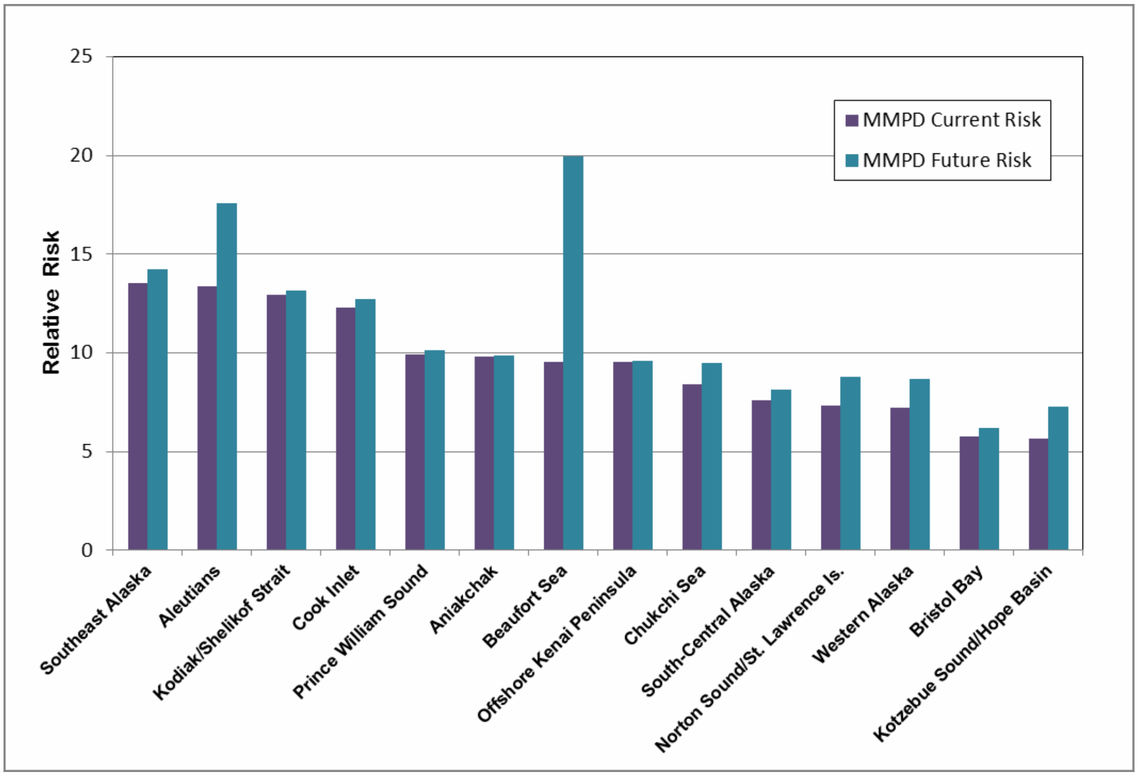
Region	MMPD Current Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Southeast Alaska	10.7	11.5	13.6	17.1	15.9	12.4	13.5
Aleutians	12.5	14.2	13.0	13.8	13.9	13.0	13.4
Kodiak/Shelikof Strait	12.5	12.1	13.7	14.0	13.1	12.3	13.0
Cook Inlet	11.9	12.4	14.7	12.7	12.1	10.0	12.3
Prince William Sound	9.6	9.7	11.4	11.0	9.6	8.2	9.9
Aniakchak	9.2	9.3	10.2	10.6	10.1	9.6	9.8
Beaufort Sea	5.0	5.6	11.5	13.8	11.9	9.6	9.6
Offshore Kenai Peninsula	9.4	9.0	10.1	10.1	9.7	8.8	9.5
Chukchi Sea	5.1	5.0	10.2	11.4	9.9	8.8	8.4
South-Central Alaska	6.6	6.1	8.7	9.0	8.7	6.4	7.6
Norton Sound/St. Lawrence Is.	4.5	4.5	9.5	9.6	7.7	8.1	7.3
Western Alaska	4.1	4.4	9.5	9.7	8.1	7.7	7.2
Bristol Bay	4.9	5.1	6.7	6.6	5.3	5.9	5.8
Kotzebue Sound/Hope Basin	1.9	1.9	8.3	8.1	7.1	6.8	5.7
Seasonal Average	7.7	7.9	10.8	11.3	10.2	9.1	

Table ES-11. MMPD 2025 relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current MMPD risk score (Table ES-10) and future MMPD risk score, and is directly comparable between the two tables.

Region	MMPD 2025 Relative Risk						
	Dec-Jan	**Feb-Mar**	**Apr-May**	**Jun-Jul**	**Aug-Sep**	**Oct-Nov**	**Yearly Mean**
Beaufort Sea	15.1	18.1	22.4	26.6	21.3	16.0	19.9
Aleutians	16.5	18.4	17.1	18.1	18.1	17.1	17.6
Southeast Alaska	11.2	12.2	14.4	18.1	16.7	12.9	14.3
Kodiak/Shelikof Strait	12.7	12.3	14.0	14.3	13.3	12.4	13.2
Cook Inlet	12.3	12.7	15.2	13.2	12.7	10.3	12.7
Prince William Sound	9.7	9.8	11.6	11.6	9.7	8.5	10.1
Aniakchak	9.2	9.4	10.3	10.6	10.1	9.6	9.8
Offshore Kenai Peninsula	9.4	9.0	10.1	10.2	9.8	8.9	9.6
Chukchi Sea	8.2	8.1	10.2	11.6	10.0	8.9	9.5
Norton Sound/St. Lawrence Is.	8.9	9.0	9.5	9.6	7.7	8.1	8.8
Western Alaska	8.1	8.6	9.5	9.8	8.2	7.7	8.7
South-Central Alaska	7.7	7.2	8.7	9.0	8.8	7.5	8.2
Kotzebue Sound/Hope Basin	6.7	6.7	8.2	8.1	7.1	6.8	7.3
Bristol Bay	6.1	6.5	6.7	6.7	5.3	5.9	6.2
Seasonal Average	10.1	10.6	12.0	12.7	11.3	10.1	

Yearly mean MMPD relative risk scores are shown as a bar graph in Figure ES-1. This graph shows the changes in relative risk between the current scores and the 2025 scores. In general, all regions experienced an increase in risk scores for the year 2025. The largest increase by far was for the future relative risk scores in the Beaufort Sea region, followed by the future scores in the Aleutians region. These increases in risk are attributable to the increased likelihood of an incident due to assumed increases in offshore exploration and production activity in the Beaufort Sea region and increases in vessel traffic in the Aleutians region. Other regions, such as Prince William Sound, Aniakchak, and Offshore Kenai Peninsula, experienced little change in relative risk scores.

Figure ES-5. MMPD current and 2025 yearly mean relative risk scores by region.



<u>WCD Relative Risk</u>

Table ES-12 and Table ES-13 list the WCD relative risk scores by region and period, based on the sum of all oil types. The highest WCD current relative risk scores are for the Southeast Alaska region in June–September (Table ES-12). The next highest scores are for the Cook Inlet region in April–May and the Kodiak/Shelikof Strait region in June–July. Based on the yearly mean risk score, the Southeast Alaska region has the highest WCD relative risk, followed by the Kodiak/Shelikof Strait and Cook Inlet regions. On average (across all regions), WCD relative risk scores tend to be the greatest during spring and summer months (April through September) and lowest during winter (December through March).

For the 2025 future projection, the highest WCD relative risk scores are for the Beaufort Sea region (Table ES-13), mainly attributable to a substantial projected increase in oil exploration and production activities (potentially resulting in both greater incident rates and spill volumes). Scores within the Beaufort Sea region are highest in the spring and summer and lower in the winter and fall. Based on the yearly mean score, the Beaufort Sea region has the highest 2025 WCD relative risk, followed by the Aleutians and Southeast Alaska regions. These results are based on the 2025 incident rates and volumes and the “current” environmental vulnerability, as environmental vulnerability was not projected into the future for this study.

Table ES-12. WCD current relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current WCD risk score and future WCD risk score (Table ES-13), and is directly comparable between the two tables.

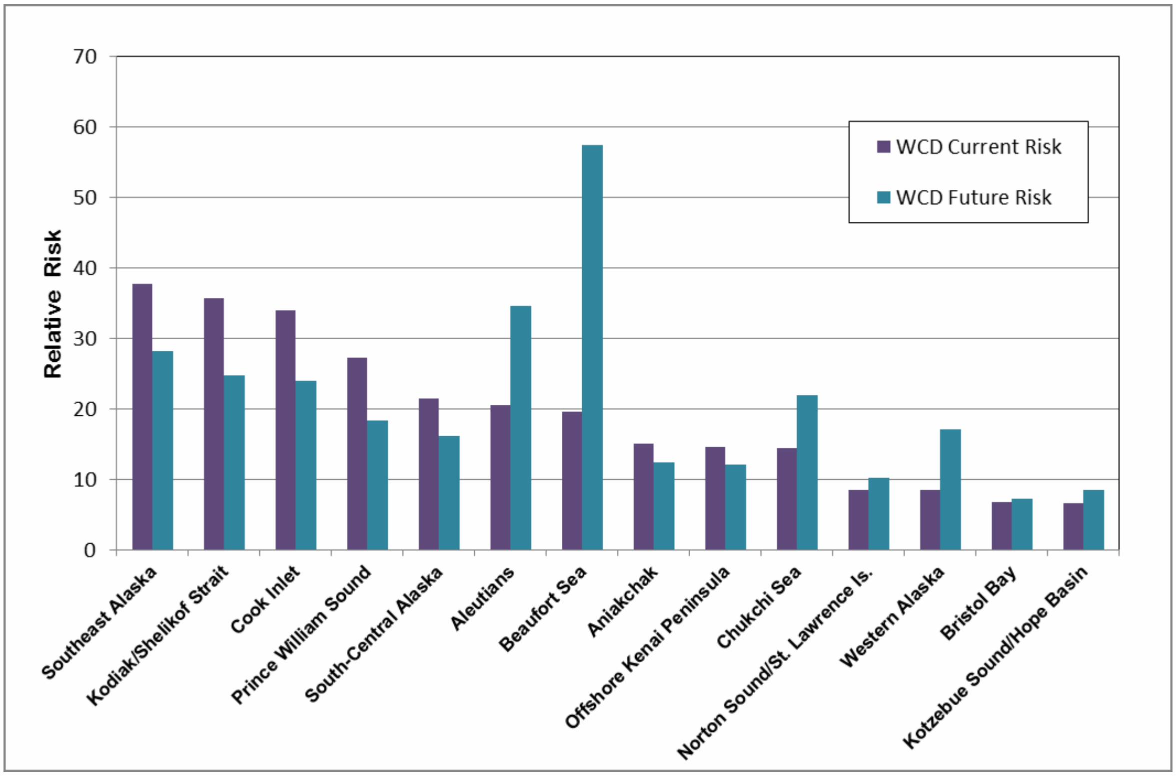
Region	WCD Current Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Southeast Alaska	29.7	32.2	37.9	48.0	44.4	34.4	37.8
Kodiak/Shelikof Strait	34.5	33.5	37.8	38.6	36.1	33.7	35.7
Cook Inlet	32.9	34.2	40.6	35.1	33.5	27.5	34.0
Prince William Sound	26.4	26.7	31.4	30.4	26.5	22.5	27.3
South-Central Alaska	19.5	18.1	23.9	24.6	23.9	18.9	21.5
Aleutians	19.2	21.8	19.9	21.2	21.4	19.9	20.6
Beaufort Sea	15.2	12.0	22.1	27.0	23.0	18.5	19.6
Aniakchak	14.1	14.3	15.7	16.3	15.5	14.7	15.1
Offshore Kenai Peninsula	14.5	13.8	15.5	15.6	14.9	13.5	14.6
Chukchi Sea	10.3	10.1	16.8	18.8	16.3	14.5	14.5
Norton Sound/St. Lawrence Is.	5.2	5.3	11.0	11.2	9.0	9.5	8.5
Western Alaska	4.8	5.2	11.0	11.3	9.4	8.9	8.4
Bristol Bay	5.7	6.0	7.8	7.7	6.1	6.9	6.7
Kotzebue Sound/Hope Basin	2.2	2.2	9.6	9.5	8.3	8.0	6.6
Seasonal Average	16.7	16.8	21.5	22.5	20.6	18.0	

Table ES-13. WCD 2025 relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current WCD risk score (Table ES-12) and future WCD risk score, and is directly comparable between the two tables.

Region	WCD 2025 Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Beaufort Sea	40.6	50.8	64.6	81.2	61.3	46.1	57.4
Aleutians	32.5	36.3	33.8	35.8	35.8	33.7	34.7
Southeast Alaska	22.1	24.1	28.3	35.8	33.0	25.5	28.1
Kodiak/Shelikof Strait	23.9	23.2	26.2	26.8	24.9	23.2	24.7
Chukchi Sea	19.0	18.7	23.7	26.9	23.1	20.7	22.0
Cook Inlet	23.1	23.9	28.6	25.0	24.0	19.4	24.0
Prince William Sound	17.4	17.6	20.9	21.1	17.5	15.2	18.3
Western Alaska	16.0	17.1	18.8	19.3	16.1	15.2	17.1
South-Central Alaska	15.3	14.1	17.2	17.8	17.2	14.9	16.1
Aniakchak	11.6	11.9	13.0	13.4	12.8	12.1	12.5
Offshore Kenai Peninsula	12.0	11.4	12.9	13.0	12.4	11.3	12.1
Norton Sound/St. Lawrence Is.	10.4	10.5	11.0	11.2	9.0	9.5	10.3
Kotzebue Sound/Hope Basin	7.8	7.8	9.6	9.4	8.3	7.9	8.5
Bristol Bay	7.1	7.5	7.9	7.8	6.1	6.9	7.2
Seasonal Average	18.5	19.6	22.6	24.6	21.5	18.7	

Yearly mean WCD relative risk scores are shown as a bar graph in Figure ES-6. This graph shows the changes in relative risk between the current scores and the 2025 scores. Unlike the MMPD risk scores (Figure ES-5), where all regions experienced an increase for the future projection, for the WCD relative risk scores, half of the regions had a small decrease for the 2025 scores. The decrease in relative risk in certain regions is attributable to a projected increase in risk mitigation practices and/or use of double-hulled tanks that reduce the potential WCD spillage from a vessel incident. The largest increase by far was for the future relative risk scores in the Beaufort Sea region, followed to a lesser degree by the future scores in the Aleutians region. Again, these increases in risk are attributable to the increased likelihood of an incident due to assumed increases in offshore exploration and production activity in the Beaufort Sea region and increases in vessel traffic in the Aleutians region.

Figure ES-6. WCD current and 2025 yearly mean relative risk scores by region.



Conclusions

The model and results developed herein are intended for use as a screening-level assessment of relative marine oil spill risk in areas of Alaska. This study does not attempt to determine the exact size, location, transport, fate, and impacts of a particular future oil spill in Alaska. This study also does not consider what response technologies may be applied to future oil spills and ways in which those responses might mitigate or increase impacts. Rather, it is intended to identify broad regions and seasons within Alaska having both high relative environmental vulnerability and high relative oil spill probabilities and spill volumes. Each factor contributing to the risk model is computed for each broad geographic region as a whole.

The model results reveal a number of general patterns. Environmental vulnerability, incident rate, and final relative risk scores are typically higher in the summer months than during the winter. This is a reflection of the presence of migratory species and greater vessel traffic activities during the warmer months. Regarding oil type, light and heavy oils are the biggest contributors to risk for the current MMPD, current WCD, 2025 MMPD, and 2025 WCD scenarios (on average across all regions).

The top three highest relative risk regions (based on yearly mean score) for each model scenario (i.e., current MMPD, 2025 MMPD, current WCD, and 2025 WCD) are summarized in Table ES-14. For the current time period and both volumes (MMPD and WCD), the region with the highest relative risk was Southeast Alaska. For the 2025 projection, the region with the highest relative risk for both volumes was the Beaufort Sea. Across the 4 different model scenarios, the Southeast Alaska region occurs 4 times in the top 3 highest relative risk ranking, followed by the Aleutians region with 3 occurrences, the Beaufort Sea and Kodiak/Shelikof Strait regions with 2 occurrences each, and the Cook Inlet region with 1 occurrence. These regions are recommended for further study to investigate various aspects of the factors constituting risk – particularly spill volume and location, location of species and habitats within a region, and fate and transport of spilled oil.

Table ES-14. Highest ranking (i.e., highest relative risk) regions for each model scenario.

Relative Risk Rank	MMPD Current Risk	WCD Current Risk	MMPD 2025 Risk	WCD 2025 Risk
1	Southeast Alaska	Southeast Alaska	Beaufort Sea	Beaufort Sea
2	Aleutians	Kodiak/Shelikof Strait	Aleutians	Aleutians
3	Kodiak/Shelikof Strait	Cook Inlet	Southeast Alaska	Southeast Alaska

Because the relative risk model is highly data-intensive, the quality of the model results is inherently dependent on the quality of the input data. Certain environmental vulnerability data inputs are known to be of poor quality and should be updated when additional information becomes available. In particular, bottom habitat and submerged aquatic vegetation data coverage was lacking for much of the area assessed in this study. Because of the relatively high sensitivity of submerged aquatic vegetation habitats to spilled oil, the addition of more complete data for this parameter would likely result in some shifting of the environmental vulnerability scores (and potentially the final relative risk scores).

We were only able to assess a limited number marine mammal, sea turtles, bird, fish and invertebrates species for this analysis, but there are a wide variety of species using Alaska's habitats. Model sensitivity testing suggests that the number of species used for this study was sufficiently robust, but the addition of more species to the model could refine the risk scoring to some degree. Additional species should be added to the model where possible. Also, for many of the species assessed, reliable abundance estimates were not available. Even for those species where some information was available, data did not provide the spatiotemporal resolution required for this study. As a result, the assignment of abundance scores is based heavily on best professional judgment.

Due to the complexity of predicting the flow rate and duration of blowouts from offshore oil platforms and wells, the WCD volumes used in this study have a considerable amount of uncertainty. The WCD volumes for these facilities were based on the best available information at the time of the study, and should be updated if additional information becomes available in the future.

Another data limitation is the incident rates and potential spillage volumes forecasted for the year 2025. The outcomes of the forecasting analysis are integrally dependent on the assumptions applied. Given the uncertainty in these assumptions, there is considerable uncertainty in the forecasts for 2025 spillage. A more detailed analysis of the factors in the forecast for 2025 and beyond is outside the scope of the current project, but merit consideration for a future analysis.

Also, no future projections were made for environmental vulnerability. While modified environmental vulnerability scores would change the final relative risk results somewhat, drastic changes would be unlikely because the environmental vulnerability score is not overly sensitive to any individual input parameter. Also, environmental vulnerability is only moderately correlated with the MMPD relative risk score, and is minimally correlated with the WCD relative risk score.

Despite the inherent limitations of such a broad-scale assessment effort, this study provides valuable information to guide the prioritization of risk planning and further study in Alaska. One of the main benefits of the risk model is that the various inputs, assessment criteria, and assumptions are explicitly-stated and analyzed in a quantitative manner. Without such a transparent approach, it would be difficult to combine the large number of disparate input data sets required into an objective, repeatable result. Another benefit of the risk model is the flexibility to quickly update the results as new or improved data inputs become available. These updates are easily accomplished using the Alaska Spill Risk Calculator interface tool provided as Appendix E.

The results of this screening-level analysis identify broad regions of Alaska with high relative risk based on oil spill probability and environmental vulnerability. For regions identified as having high relative risk (e.g., the Southeast Alaska, Aleutians, Beaufort Sea, Kodiak/Shelikof Strait, and Cook Inlet regions), further study is recommended. In particular, trajectory and fates modeling would be a natural next step to this study to examine the magnitude of potential consequences from oil spills originating from these high relative risk regions. In the assessment of environmental vulnerability for each region/season, vulnerability scoring is based on the assumption that an oil spill would result in oiling of each type of shoreline and marine habitat within a region. Similarly, each species present during a particular region/season (as determined by the abundance scoring) is assumed to have potential overlap with oiling. Furthermore, the risk model only considers the region of origin of spills, not the location of the spill site within the region, the geographic extent of oiling, or direction of spill transport. In reality, some spills, such as those occurring far offshore, may not impact Alaska's shorelines, and only certain species and habitats would overlap with the oil. Spills occurring near the boundary of a region, or large volume spills, would likely affect multiple regions. It is also possible for a spill originating in one region to affect only shoreline of an adjacent region.

These factors illustrate the value of stochastic trajectory and fates modeling in further refining the risk results and supporting sound strategic planning. Stochastic modeling could be used to determine the probability of impact from spills of varying oil types and volumes originating at different locations on different dates (thus sampling the range of potential environmental conditions). This modeling would provide statistics regarding the magnitude of potential consequences for shorelines, water column habitats, surface waters, and species likely to overlap with the spilled oil and allow for finer-scale comparison of the regions identified by this study as having high relative risk.

1.0 INTRODUCTION

Alaska's waters are rich in biological resources that are sensitive to spilled oil. These waters are also host to oil exploration/production activities and heavy vessel traffic, and are bordered by land-based facilities that transfer, store, and handle oil. This combination of sensitive resources and potential oil spill sources increases the risk of a damaging spill. In support of planning and preparation for oil spill responses, Natural Resource Damage Assessments (NRDAs), and restoration planning efforts, RPS ASA, Environmental Research Consulting (ERC), Research Planning, Inc. (RPI), and The Louis Berger Group, Inc. (LBG) were contracted by the National Oceanic and Atmospheric Administration's (NOAA) Restoration Center Northwest Region to conduct a screening-level analysis of the relative risk of oil spills to the marine waters of the state of Alaska (including the Arctic region of Alaska).

The objectives of this risk analysis were to determine the probabilities of spills occurring with respect to geographic region, oil type, and season, as well as the potential impacts from an oil spill, considering oil characteristics (e.g., toxicity, persistence) and the vulnerability of the state's environmental resources. This assessment involved the development of a detailed model of region- and season-specific environmental vulnerability for Alaska based on marine and shoreline habitat characteristics, relative abundance of species present, species vulnerability to oil spill impacts, and species recovery potential. This information was combined with incident rates and potential volumes of oil spills by region, oil type, and season to construct the overall risk model and determine the regions/seasons of highest relative risk.

The analysis also included an assessment of future relative risk for the year 2025, based on expected changes in the likelihood and volume of spills that might occur with changes in vessel traffic, oil exploration and production activities, and the regional economy. These changes may affect the location of spills, volume of spills, relative proportion of source types, oil types, and the frequency of spill events.

The results of this study are intended to provide NOAA, NRDA practitioners, and oil spill response planners with a broad-scale assessment of regions within Alaska having high environmental vulnerability and high oil spill probability. This information can further be used to help guide strategic planning and prioritize future research activities.

With input from the project team, RPS ASA was responsible for developing the structure of the overall risk model, including a novel approach for assessment of environmental impact-related (consequence) factors. ERC was responsible for conducting the analysis of spill incident rates and volumes, the results of which were incorporated into the risk model developed by RPS ASA. RPI provided technical oversight and quality control, and LBG was responsible for management of the overall team.

The main findings of a literature review of existing oil spill risk and environmental vulnerability studies are summarized in Section 2.0. The structure and data inputs for the oil spill risk model are described in Sections 3.0 (overall model structure), 4.0 (environmental vulnerability component) and 5.0 (spill incident rate/volume component). Key results of the risk analysis are presented in Section 6.0. Additional permutations of results can be viewed using the "Alaska Spill Risk Calculator" interface tool developed for this project. Conclusions and recommendations are discussed in Section 7.0.

The full report pertaining to ERC's spillage analysis is provided as Appendix A. Appendix B contains the full list of references for the modeling effort, including an annotated bibliography of papers evaluated during the literature review. Documentation for the model database, as well as instructions for adding new/revised data to the model is provided as Appendix C. Appendix D contains tables of all data inputs used in the application of the model. The Alaska Spill Risk Calculator software tool developed for this project is provided as a digital appendix (Appendix E). The Microsoft Access® project database is included with the software tool.

2.0 LITERATURE REVIEW

The conceptual foundation for the risk model developed herein is provided by two key documents, the Washington Compensation Schedule (WCS) (Washington Administrative Code 173-183, “Pre-assessment Screening and Oil Spill Compensation Schedule Regulations”) and the "Final report: Oil spill risk analysis review" submitted to the Washington Joint Legislative Audit and Review Committee (JLARC) (French McCay et al., 2008). The WCS provides a per-gallon relative impact score for oil spills, considering sensitivity of the locations oiled, relative density and seasonal distributions of sensitive biota, and factors related to oil type (toxicity, persistence). The JLARC report combined a modified version of the WCS with an analysis of spill probability to identify the relative risk of oil spills to the navigable and inland areas of Washington State (similar to the objectives of this current study).

Since the WCS cannot be directly applied to Alaska, it was first necessary to develop an environmental vulnerability and oil spill risk model specific to the state of Alaska. Each of the two main references (i.e., the WCS and the JLARC report) provided examples of studies that incorporated oil spill magnitude, oil effects, and environmental vulnerability. Additional applicable environmental vulnerability and spill risk studies were collected and reviewed. Published, peer-reviewed, English language studies (or those that provided English language abstracts) indexed in scientific databases were the primary focus of the review, although relevant books, book chapters, government and industry technical reports, and websites were also included. Along with the extensive expertise of the project team, this review served as the basis for development of our novel oil spill risk model.

A formal written literature review summary was outside of the scope of this project, but many studies influenced the current analysis (see Appendix B for a full list of categorized references). Project literature was stored and managed in a project database using the EndNote® reference management software. Once references were selected by the study team (based on their inclusion into model decisions), bibliographic data for the references were downloaded directly to the project database. Standard bibliographic data were collected for each reference (e.g., author, date, title, publisher, volume, pages, reference type). The Uniform Resource Locators (URLs) were also collected for websites or documents accessed online. Copyright status was reviewed for each reference, and where restrictions allowed, the abstract (if available) and full-text copy (in .pdf format) of documents were included in the database. Subject categories were used to organize the references using custom groups within the database.

A key focus of the literature review was methods and approaches to support the development of a new environmental vulnerability model for Alaska (following the same general structure of the WCS). Methods to assess vulnerability of species to oil spill impacts were of particular interest. Based on this review, a number of common ecological “themes” used to assess vulnerability of environmental resources were identified, and can be generally grouped into abundance, impact potential (probability of encountering oil, physiology, concentration/aggregation, and indirect trophic effects), and recovery potential (conservation/population status, reproductive potential, and geographic range). These themes form the core of the species vulnerability scoring, which is described in Sections 3.3.2 and 4.2. The application of these themes in selected key studies is summarized in Table 1.

Table 1. Species vulnerability “themes” utilized in relevant studies. Species group codes used in this table are defined as follows: F/I = fish and invertebrates; M/T = marine mammals and sea turtles; and B = birds.

Study Name/Citation	Study Location	Species Groups	Abundance/ Relative Abu	Impact Potential				Recovery Potential		
				Encounter	Physiology	Indirect Trophic Effe	Concentration/ Agg	Conservation/ Popu Status	Reproductive Pote	Geographic Range
Aleutian Islands Risk Assessment Project (Wolniakowski et al., 2011)	Alaska	F/I, M/T, B	■	■	■	■	■	■	■	■
Cook Inlet Risk Assessment (Johnson et al., 2002)	Alaska	F/I, M/T, B	■							■
Washington Compensation Schedule (WAC 173-183)	Washington	F/I, M/T, B	■	■		■	■		■	■
Oil Vulnerability Index (Manuwal et al., 1979; King and Sanger, 1979)	Northeast Pacific	B	■	■		■	■		■	■
Cumulative Use Evaluation Model (French McCay et al., 2012)	U.S.-wide	F/I, M/T, B	■					■	■	■
Marine Biological Valuation (Derous et al., 2007)	N/A	F/I, M/T, B	■	■						■
BRISK Project (HELCOM and NORDEN, 2013)	Baltic Sea	F/I, M/T, B	■	■	■	■	■		■	
MarLIN (Hiscock and Tyler-Walters, 2006)	Northeast Atlantic	F/I, M/T, B	■	■	■	■	■	■	■	■
Wind Farm Vulnerability Index (Garthe and Hüppop, 2004)	North Sea	B	■	■				■	■	
SensMap Project (Cook and McMath, 2001)	Irish Sea	F/I	■	■	■				■	■
AK/Arctic Oil Spill Risk Assessment (present study)	Alaska	F/I, M/T, B	■	■	■	■	■	■	■	■

In addition to environmental vulnerability literature, past studies on spill risk in Alaska and the Arctic were reviewed to derive any relevant perspectives or data that could be applied to forecasting future spill risk in the region. These studies are reviewed and discussed in Appendix A.

3.0 RISK MODEL STRUCTURE

We approached the assessment of oil spill risk by applying the standard technical definition of risk that includes both the likelihood (i.e., probability) of spill incidents of various types and sizes and the consequences (i.e., impacts) of those incidents. In other words:

Spill risk = probability of spill x impacts of spill

The risk model developed for this project consists of three main elements: (1) vulnerability of the environment to oil spill impacts, (2) probability of a spill based on past and projected future incident rates, and (3) potential maximum most probable discharge (MMPD) and worst-case discharge (WCD) volumes that could result from an incident now or in the future. Each factor is assessed on a regional and seasonal basis by oil type.

In this study, "incidents" are defined as events involving vessels or facilities (including onshore facilities, pipelines, and offshore wells) that could potentially result in the spillage of oil, such as casualties, accidents, discharges, and leakages. Incidents are described in detail in Section 5.2.1. For vessels and facilities, this study employs the U.S. Coast Guard (USCG) definitions of MMPD and WCD depending on source type. For offshore oil wells, U.S. Environmental Protection Agency (EPA) regulatory definitions of WCDs were applied in the Cook Inlet, Kodiak/Shelikof Strait, and Aniakchak regions. For the Beaufort Sea and Chukchi Sea regions, the Bureau of Ocean Energy Management's (BOEM) estimations of catastrophic discharge events were applied for offshore oil wells, as theses estimations yielded higher discharge volumes than the EPA regulatory definition. These volumes are discussed in Section 5.2.2.

A flow diagram for the overall model is provided as Figure 1. The scope of the risk model (including the regions, seasons, and oil types assessed) is discussed in Section 3.1. Key model assumptions are discussed in Section 3.2. Model algorithms are contained within Section 3.3. Further description of the environmental vulnerability model may be found in Reich et al. (2014).

3.1 Scope

The risk model is constructed at the level of resolution of 14 broad geographic zones covering Alaska's shoreline and marine waters (Figure 2). These zones are based on the nine marine Alaska Department of Environmental Conservation (ADEC) and Alaska Regional Response Team (ARRT) Contingency Planning Regions, which were further subdivided for increased resolution of analysis. Although the regions include inland areas of Alaska, the model only considers coastal shorelines and marine waters of Alaska that lie within the designated USCG oil spill response areas. Inland waters and upland habitats are not included in the model.

Each region was assigned a code corresponding to the ADEC/ARRT region codes; these codes are listed in Table 2.

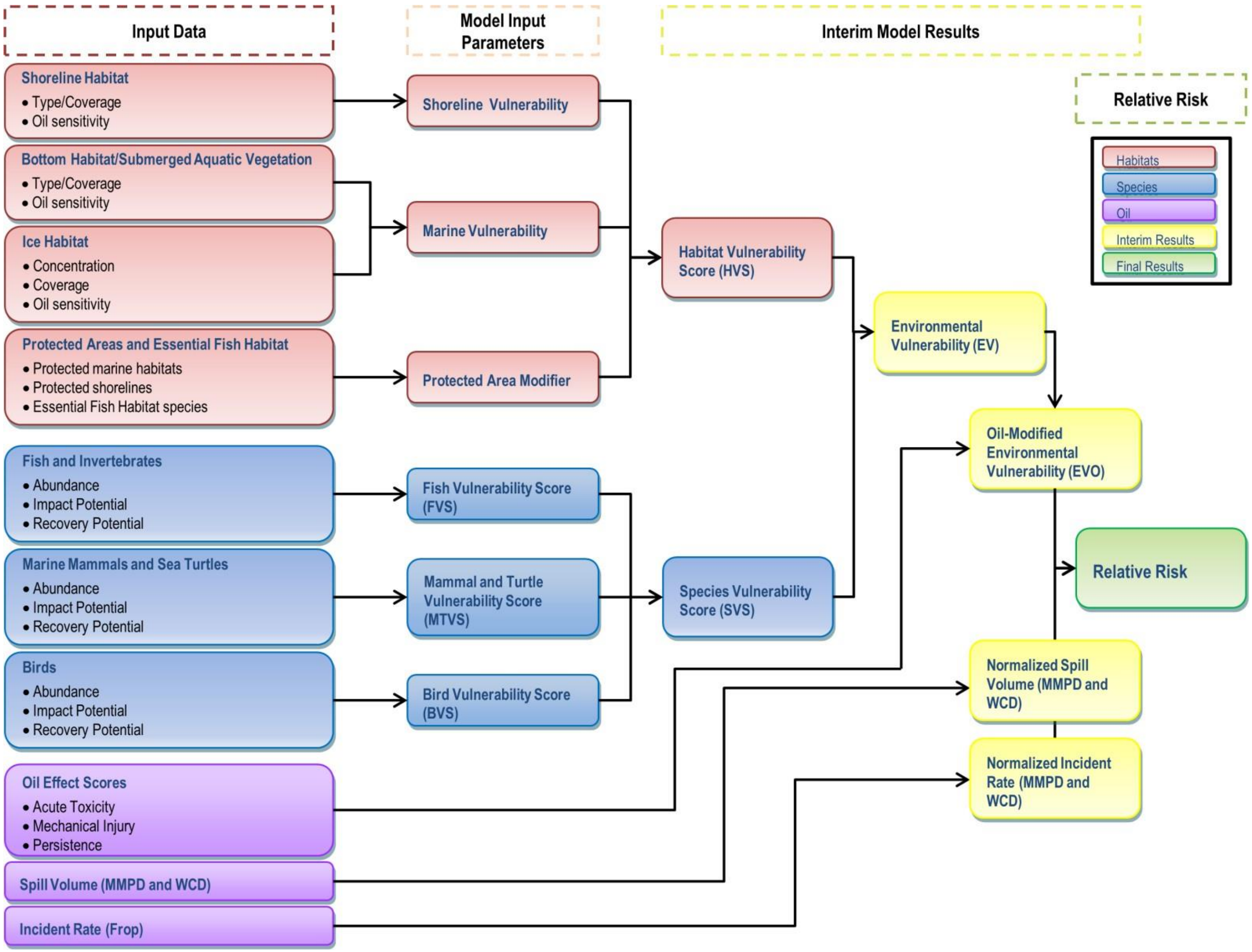


Figure 1. Model flow diagram.

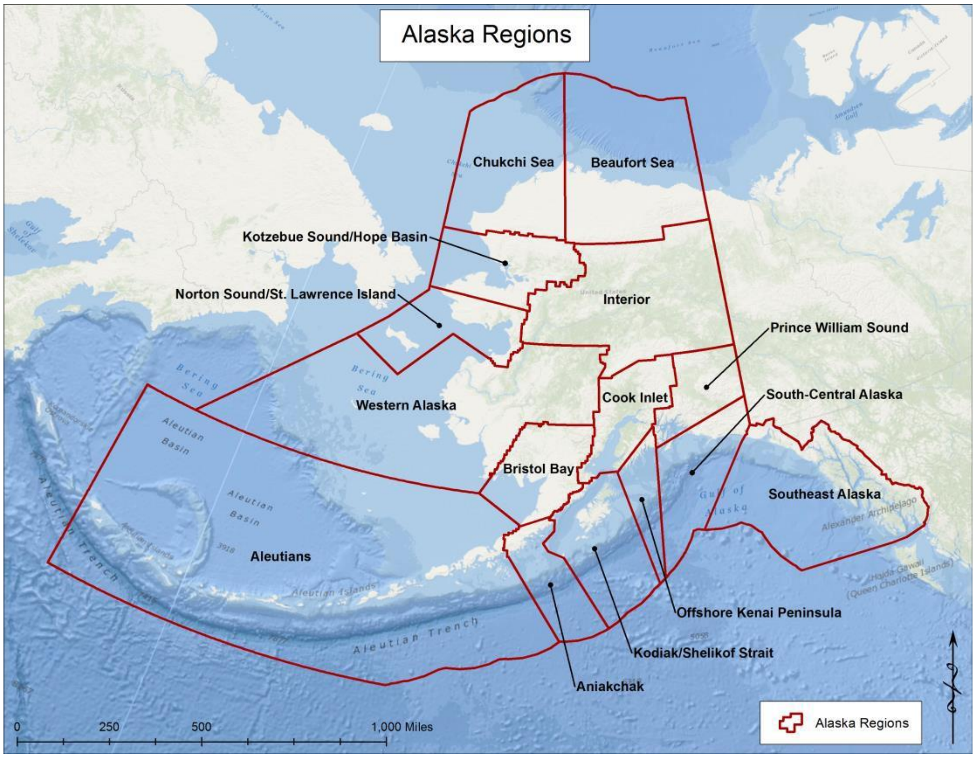


Figure 2. Broad geographic zones considered in the analysis. Note: ADEC/ARRT region 10 (Interior) was not included in the analysis, as it does not have a marine component.

Table 2. Geographic region codes and names.

Region Code	Region Name
1	Southeast Alaska
2a	Prince William Sound
2b	South-Central Alaska
3a	Cook Inlet
3b	Offshore Kenai Peninsula
4	Kodiak/Shelikof Strait
5	Aleutians
6a	Bristol Bay
6b	Aniakchak
7	Western Alaska
8a	Norton Sound/St. Lawrence Island
8b	Kotzebue Sound/Hope Basin
9a	Chukchi Sea
9b	Beaufort Sea

Six “seasonal” periods are included in the model, each consisting of two months. These periods are defined in Table 3. For the purposes of this report, the terms “period” and “season” are used interchangeably.

Table 3. Two-month "seasonal" periods considered in the analysis.

Period	Months Included
1	December, January
2	February, March
3	April, May
4	June, July
5	August, September
6	October, November

To capture the varying effects of different oil types on the environment, the model considers four general oil types: crude oils, heavy oils, light oils, and distillates. The oil types included in each category are listed in Table 4.

Table 4. Oil type categories used in the analysis.

Oil Category	Oil Types Included[1]
Crude Oils	crude oil, crude condensate
Heavy Oils	heavy fuel oil, intermediate fuel oil, Bunker C, No. 6 fuel oil, No. 5 fuel oil, asphalt, wax
Light Oils	diesel, mineral oil, motor oil, low-sulfur marine gas oil, lubricating oil, hydraulic oil, No. 2 fuel, home heating oil, bilge slops, waste oils, naphthas
Distillates	jet fuel (kerosene), gasoline

[1] For incidents where the oil type was listed as unknown, the most likely oil type category was assigned.

3.2 Key Assumptions and Limitations

The model and results developed herein are intended for use as a screening-level assessment of relative oil spill risk in areas of Alaska. This study does not attempt to determine the exact size, location, transport, fate, and impacts of a particular future oil spill in Alaska. This study also does not consider what response technologies may be applied to future oil spills or ways in which response may mitigate or increase impacts. Rather, it is intended to identify broad regions and seasons within Alaska having both high relative environmental vulnerability and high relative oil spill probabilities and spill volumes. The vulnerability of socioeconomic resources (such as recreation, commercial fishing, subsistence activities, cultural resources, tourism, etc.) is not included in the present risk model, but could be incorporated into future iterations.

Each factor contributing to the risk model is computed for each region as a whole. In reality, incidents are not evenly distributed within each region, and tend to be clustered in port areas, vessel traffic lanes, and at specific facility locations. Likewise, the environmental vulnerability of each region also varies within the larger regional boundaries.

Only the region of origin of a spill is considered in the risk model, not the ultimate fate and transport of the spilled oil. The only exception to this was the inclusion in the incident rate analysis of a limited number of incidents located outside of the boundaries of the study regions (see Section 5.2.1). Transport and fates modeling is recommended as a natural next step to this study.

In the assessment of environmental vulnerability for each region/season, vulnerability scoring is based on the assumption that an oil spill would result in oiling of each type of shoreline and marine habitat within a region. Similarly, each species present during a particular region/season (as determined by the abundance scoring) is assumed to have potential overlap with oiling. This leads to a conservative assessment of environmental vulnerability. In reality, some spills, such as those occurring far offshore, may not impact Alaska's shorelines, and only certain species and habitats would overlap with the spread of spilled oil.

Incident rates used in the risk model are based on past spills (and past potential spills) in Alaska from 1995–2012. These past incidents are assumed to predict where future incidents are likely to occur. In most cases, the actual spill volumes associated with the past spill incidents were very small (only 0.1% involved more than 500 bbl). However, to assess relative risk and prioritize areas for future study, the risk model uses the MMPD and WCD volumes that could potentially result from a future incident in a given region/season. Both volumes represent scenarios that have a very low likelihood and are not reflective of the volumes actually spilled in past incidents. Although the MMPD and WCD volumes have a very low likelihood of occurrence, they must be taken into account for contingency planning and risk mitigation development. In essence, the risk model reflects where future incidents are likely to occur and potential "maximum" (rather than most likely) spill volumes that could result from a future incident.

For offshore oil platforms and wells in particular, calculation of WCD volumes is highly imprecise, due to the numerous factors that influence the flow rate and duration of a well blowout. As a result, the WCD volumes used in this study have a considerable amount of uncertainty. The WCD volumes for these facilities were based on the best available information at the time of the study, and should be updated if additional information becomes available in the future.

No future projections of environmental vulnerability were calculated for this project, as projecting future trends for environmental conditions (e.g., individual species' distributions, shoreline location/type, and ice coverage) is inherently complex and uncertain, and was beyond the scope of the current project. Only spill volumes and incidents rates were projected for the year 2025.

3.3 Algorithms

The risk model algorithms are described in the following sections. In all equations below, j = season and k = region.

3.3.1 Habitat Vulnerability Score (HVS)

Three main habitat types are considered in the habitat vulnerability score (HVS) are shoreline habitats, bottom marine habitats, and sea ice habitats. Descriptions and data sources for each of these habitats are found in Section 4.1.1.

Shoreline vulnerability for each region is determined by the relative percentage of each shoreline type (e.g., rocky shore, gravel beach) within a region and the corresponding total oil effects score for each type (see Section 4.1.2). A "shore proportion" modifier (i.e., the relative proportion of shoreline area, assuming an even 1 km width shoreline, to open marine water area within a region) serves as a proxy to relate the general likelihood of an oil spill encountering shoreline habitats compared with marine habitats. A region with a relatively high proportion of shoreline relative to open marine water (e.g., Prince William Sound) is generally more likely to experience shoreline oiling than a region with a low shoreline to open marine water ratio (e.g., Aleutians). A shoreline proportion modifier is applied to account for these differences among planning areas.

$$Shoreline\ Proportion_k = 1 + \left(\frac{Shoreline\ Area_k}{Marine\ Area_k}\right)$$

$$Shoreline\ Vulnerability_k = Shoreline\ Proportion_k * \sum(\%Shore\ Habitat\ type_k * Oil\ Effects\ Score)$$

Marine area vulnerability is determined by the bottom habitat vulnerability (including submerged aquatic vegetation) for each region, the sea ice habitat vulnerability for each region and season, and the corresponding total oil effects score for each unique habitat type.

$$Marine\ Vulnerability_{jk} = \left(\sum(\%Bottom\ Habitat\ Type_k * Oil\ Effects\ Score)\right) + \left(\sum(\%Ice\ Habitat\ Type_{jk} * Oil\ Effects\ Score)\right)$$

Protected area coverage serves as a modifier to the overall habitat vulnerability score and is comprised of protected marine area coverage, protected shoreline length, and relative number of species/life stages with Essential Fish Habitat (EFH) designated in each region (see Section 4.1.3 for further detail). The proportion of protected marine area is calculated by dividing the total areal coverage of protected areas in a given region by the total marine area of the region. Marine areas are either considered "protected", or "not protected", therefore marine areas where multiple protection designations may overlap are not double counted (maximum protected area of any given region is 100%). The proportion of protected shoreline length is calculated by dividing the total length of protected shoreline in a given region by the total shoreline length of the region. Shorelines are either considered "protected", or "not protected", therefore shorelines where multiple protection designations may overlap are not double counted (maximum protected shoreline of any given region is 100%). For each region, the total number of species' life stages with EFH designated in the region is divided by the region with the highest total number of species' life stages to calculate the relative prevalence of EFH within the planning area. The final protected area modifier for each region is then calculated as:

$$Protected\ Area\ Modifier_k = 1 + \left(\frac{\frac{Protected\ Marine\ Area_k}{Total\ Marine\ Area_k} + \frac{Protected\ Shore\ Length_k}{Total\ Shore\ Length_k} + \frac{\#\ of\ EFH\ Life\ Stages_k}{Max.\ \#\ of\ EFH\ Life\ Stages}}{3}\right)$$

The maximum attainable protected area modifier is 2.0, a score that would effectively double the habitat vulnerability score of a given region.

The final HVS equation for each region and season is calculated as:

$$HVS_{jk} = (Shoreline\ Vulnerability_k + Marine\ Vulnerability_{jk}) * Protected\ Area\ Modifier_k$$

Each HVS_{jk} is then normalized to a 0 to 1 scale by dividing by the region/season with the highest HVS score.

3.3.2 Species Vulnerability Score (SVS)

Species vulnerability scores for each region and season are calculated based on the relative abundance, impact potential, and recovery potential of individual species (see Section 4.2 for details on each of these parameters). A separate species vulnerability score is then calculated for each species group: marine mammals and sea turtles (MTVS), birds (BVS), and fish and invertebrates (FVS). These three values are then averaged to give the final species vulnerability score (SVS).

Because the impact scoring parameters are different for each species group, the total possible impact score for each group varies. To put all species groups on the same scale, the sum of the impact scores for each individual species is divided by the total possible score for its corresponding species group. The sum of the recovery scores for each individual species is divided by 5 to convert recovery potential to a modifier that ranges from 0.6 (i.e., representing species that are globally distributed, have high population levels, and have high fecundity) to 3 (i.e., representing species that are endemic to Alaska, endangered, and have low fecundity). Dividing by 5 structures the recovery modifier such that it essentially applies additional risk to species that have low recoverability and reduces risk for species with high recoverability. The total possible score of impact/recovery score is 300 for each species. The impact/recovery scores are multiplied by the species relative abundance (0 to 1 scale) in each region/season to determine individual species' vulnerability.

$$MammSpecies_{njk}\,,\,BirdSpecies_{njk}\,,\,or\ FishSpecies_{njk} = Abundance_{njk} * \left(\frac{\sum Impact\ Scores_n}{Total\ Possible\ Score_g} * 100\right) * \frac{\sum Recovery\ Scores_n}{5}$$

Where *n* = species number and *g* = species group.

Overall species group vulnerability is calculated by summing the vulnerability scores for each individual species in the group.

$$MTVS_{jk} = \sum_{1}^{n} MammSpecies_{njk}$$

$$BVS_{jk} = \sum_{1}^{n} BirdSpecies_{njk}$$

$$FVS_{jk} = \sum_{1}^{n} FishSpecies_{njk}$$

MTVS, BVS, and FVS are then each normalized to a 0 to 1 scale by dividing by the region/season with the highest MTVS, BVS, and FVS score, respectively. This normalization step makes the three species group vulnerability scores contribute equally to the risk model. It also eliminates the need to assess the same number of species in each group.

The final species vulnerability score (SVS) for each region/season is calculated as the average of all the individual species group scores occurring therein:

$$SVS_{jk} = \frac{MTVS_{jk} + BVS_{jk} + FVS_{jk}}{3}$$

3.3.3 Environmental Vulnerability (EV)

The overall environmental vulnerability (EV) for each region and season is calculated as the sum of habitat vulnerability (HVS) and species vulnerability (SVS). In this equation, the habitat vulnerability and species vulnerability scores contribute equally to the environmental vulnerability score.

$$EV_{jk} = HVS_{jk} + SVS_{jk}$$

3.3.4 Oil-Type-Modified Environmental Vulnerability (EVO)

The environmental vulnerability (EV) for each region and season is then multiplied by an oil type effects score (see Section 5.1) to calculate an oil-type-modified environmental vulnerability (EVO) for each oil type, region, and season:

$$EVO_{ijk} = EV_{jk} * (AT_i + MI_i + PER_i)$$

Where i = oil type category (crude, light, heavy, or distillate); AT = acute toxicity score; MI = mechanical injury score; and PER = persistence score.

EVO is then normalized to a 1 to 5 scale using linear normalization based on the highest EVO in any region and season.

3.3.5 Relative Risk

The final relative risk equation incorporates the oil-type-modified environmental vulnerability (EVO) with spill incident rates and potential spill volumes (MMPD and WCD) by region, season, and oil type. See Sections 5.2 and 5.3 for a discussion of incident rates and spill volumes used in this study.

Spill incident rates are normalized to a 1 to 5 scale using linear normalization based on the highest incident rate in any region and season. MMPD and WCD volumes are also normalized to a 1 to 5 scale using linear normalization based on the highest WCD volume and the lowest MMPD volume from any region and season. Because both spill volumes are normalized to the same scale, the relative risk results are directly comparable between MMPD and WCD volumes. The normalized incident rate and volume values are then multiplied by the EVO for each oil type and summed to yield a relative risk quotient for each region and season:

$$Relative\ Risk_{jk} = \sum(EVO_{ijk} * Incident\ Rate_{ijk} * Spill\ Volume_{ijk})$$

Where i = oil type category (crude, light, heavy, or distillate).

Note that EVO, incident rate, and spill volume all enter this equation on the same (1 to 5) scale. This transformation was selected because it results in a moderate and roughly equal contribution of environmental vulnerability and incident rate scores to relative risk (see Section 6.4.1).

When all components of the relative risk equation are included (i.e., EVO, incident rate, spill volume, and all four oil types), the maximum possible risk score is 500. If elements of the equation are excluded to investigate various permutations of the results (e.g., risk for crude oil spills only; risk with environmental vulnerability and incident rate only), this maximum possible risk score is reduced.

4.0 MODELING APPROACH: ENVIRONMENTAL VULNERABILITY

The environmental vulnerability portion of the risk model reflects the vulnerability of the environment to oil spill impacts, and is based on the underlying vulnerability of habitats and species present in each region and season. The scoring methodologies and data inputs for habitat and species vulnerability scoring are described in Sections 4.1 and 4.2, respectively.

4.1 Habitat Scoring

For each region and season, the habitat vulnerability score is meant to account for the vulnerability of the physical habitat itself, as well as for the species occupying that habitat that are not assessed elsewhere in the risk model. The various factors contributing to the habitat score, as well as the data inputs used, are described in the following sections. The final input values for each component of the habitat vulnerability score can be found in Appendix D.

4.1.1 Habitat Types

The three main habitat types considered in the habitat vulnerability score are bottom habitats, shoreline habitats, and sea ice habitats.

4.1.1.1 Bottom Habitat and Submerged Aquatic Vegetation

Subtidal bottom habitat was divided into eight habitat types depending on substrate type, the presence of submerged aquatic vegetation (i.e., kelp or seagrass), and depth. These types are defined as:

- Shallow subtidal hard bottom – areas predominated by large hard substrate (e.g., boulder, rock, cobble) or bedrock in waters shallower than 20 m deep. Sediments do not completely cover bedrock/rock.

- Shallow subtidal soft bottom – areas predominated by soft, unconsolidated bottom (e.g., mixed coarse, gravel, sand, silt, mud, clay) in waters shallower than 20 m deep.

- Deep subtidal hard bottom – areas predominated by large hard substrate (e.g., boulder, rock, cobble) or bedrock in waters deeper than 20 m deep.

- Deep subtidal soft bottom – areas predominated by soft, unconsolidated bottom (e.g., mixed coarse, gravel, sand, silt, mud, clay) in waters deeper than 20 m deep.

- No data (shallow subtidal) – areas with unknown bottom substrate type in waters shallower than 20 m deep.

- No data (deep subtidal) – areas with unknown bottom substrate type in waters deeper than 20 m deep.

- Kelp – areas containing kelp beds, regardless of the bottom substrate type.

- Seagrass – areas containing seagrass beds, regardless of the bottom substrate type.

Note that in applying these categories to a given region, the presence of kelp/seagrass supersedes the substrate type. The oil effects scores applied to each bottom habitat type are described in Section 4.1.2.

For the division of bottom habitat categories into "deep" versus "shallow," bathymetry was based on data from the ETOPO1 1 Arc-Minute Global Relief Model (Amante and Eakins, 2009). The raster data were contoured and smoothed in ESRI® ArcGIS to construct the 20 m bathymetric contour. The 20 m contour was used as the delineating feature because this depth corresponds to the typical approximate pycnocline depth in Alaska's marine waters, based on data from the Natural Resource Damage Assessment Models for Coastal and Marine Environments (NRDAM/CME) (French et al., 1996). The NRDAM/CME was developed for the U.S. Department of the Interior as the basis of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 Natural Resource Damage Assessment regulations for Type A assessments.

Several data sources were combined to obtain as much substrate type and submerged aquatic vegetation data coverage as possible, but information is lacking for a considerable portion of the study area, particularly the Gulf of Alaska, offshore Arctic, and outer Aleutian Islands. Figure 3 shows available data grouped into our bottom habitat types. Data inputs are discussed in detail below.

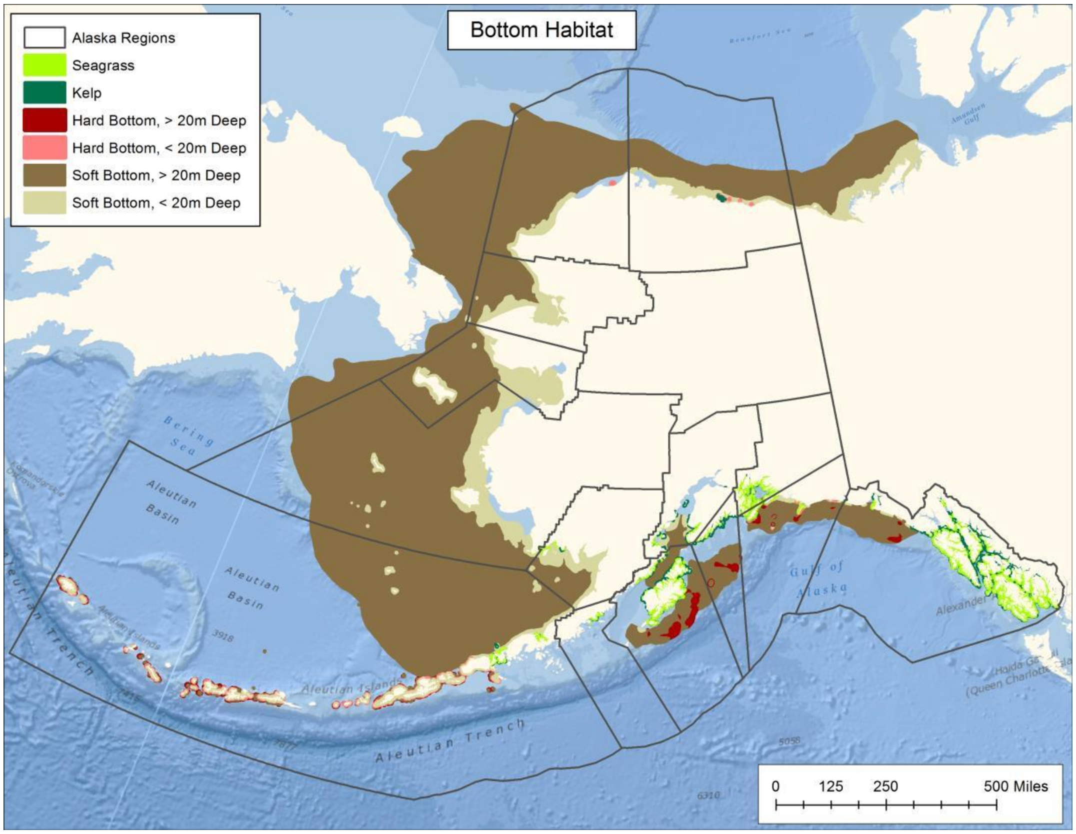


Figure 3. Bottom habitat data used in the analysis.

Bottom Substrate

Substrate data for the southern Beaufort and Chukchi Seas, and much of the Bering Sea were obtained as shapefiles from the Audubon Arctic Marine Synthesis (Smith, 2010) via the Arctic Environmental Response Management Application (https://www.erma.unh.edu/arctic/). This dataset provided a relatively high level of coverage for these areas, with the exception of some nearshore areas and offshore Arctic areas with no data.

Substrate data for the Gulf of Alaska were not readily available. The only data identified were paper maps of discrete areas on the continental shelf in Shelikof Strait, south and east of Kodiak Island, and South-Central Alaska (Evans et al., 2000). These paper maps were hand-digitized into polygons in ArcGIS.

The only source of substrate data identified for the Aleutians region was point data from Zimmermann et al. (2013). These data were created by digitizing surficial sediment descriptions from the smooth sheet products of 234 historic hydrographic surveys. To process the point data into a useable product for our analysis, we first mapped the 608 unique sediment categories in the dataset to either a soft or hard bottom sediment type. From these points, “Thiessen polygons” were derived in ArcGIS. These polygons define individual areas of influence by creating a boundary around each point where everything within that boundary is closest to that point instead of any other. These polygons were then dissolved into hard and soft bottom type polygons. Portions of the polygons overlapping land or other sediment type data sources were removed. In general, the original data points were densely clustered nearshore the Aleutian Islands, and increasingly sparse farther from shore. To exclude areas with insufficient point data for generating reliable sediment type polygons, clusters of points were defined based on a specified density tolerance. This process resulted in polygons showing where point data were present at an acceptable density. These polygons were smoothed and buffered by 2 km, and the previously created sediment polygons were clipped to this coverage. Since this dataset required substantial processing and spreading for use in the risk model, the quality of the data is assumed to be relatively low, but was used in the absence of better information.

The usSEABED program at the U.S. Geological Survey is currently working on a sediment dataset for Alaska/Hawaii (http://walrus.wr.usgs.gov/usseabed/data.html). This dataset was not available for use at the time of this study, but should ideally be incorporated into future applications of the risk model.

Submerged Aquatic Vegetation

Kelp and seagrass beds are important habitat features in coastal Alaska. However, the spatial distribution data for kelp and seagrass beds were not available for the entire state. The most extensive spatial coverage of kelp and seagrass data was available from the ShoreZone Coastal Habitat Mapping Program database (NOAA, 2013). The ShoreZone program maps and classifies the geomorphic and biological features of the intertidal and nearshore environment based on low-altitude aerial imagery. Coverage of ShoreZone data is shown in Figure 4 – kelp and seagrass bioband data were available for the southern Alaska areas shown in blue. Although this figure shows data coverage for the Chukchi Sea and Beaufort Sea shorelines, these data were not publically available for download at the time of this study. These data should ideally be incorporated into future applications of the risk model.

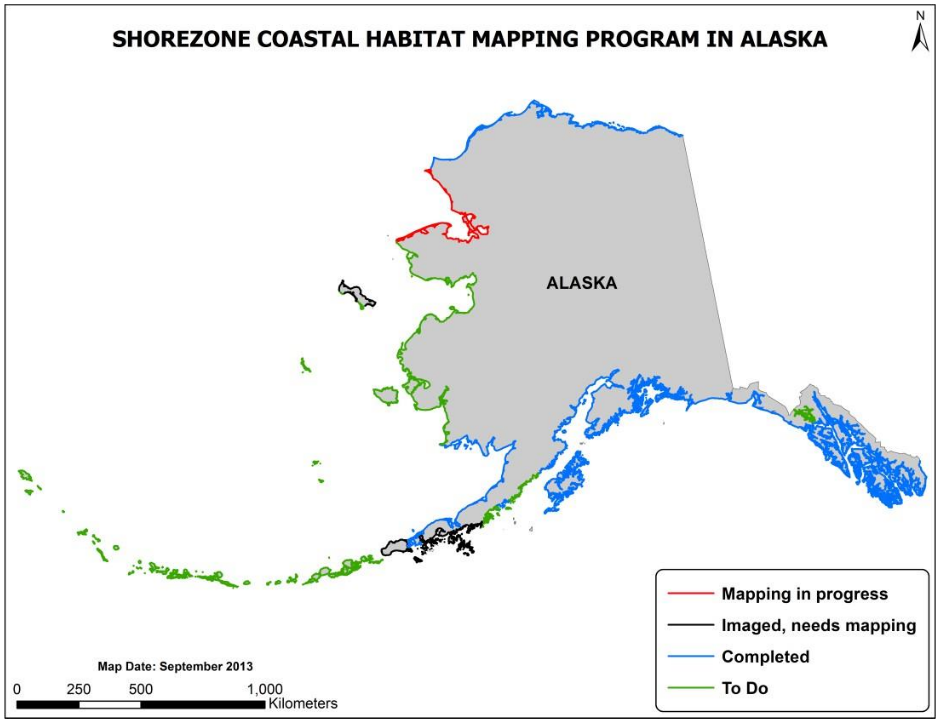


Figure 4. Extent of ShoreZone imagery in Alaska as of September 2013. Kelp and seagrass bioband data were available for the southern Alaska areas shown in blue. Note: although this figure also shows data coverage for the Chukchi Sea and Beaufort Sea shorelines, these data were not publically available for download at the time of this study. Image provided by J. Harper of Coastal and Ocean Resources, Inc. (a ShoreZone partner) and reproduced with permission.

The biological component of ShoreZone includes mapping of the occurrence and extent of species assemblages, referred to as “biobands” (Harney et al., 2008). Biobands are named for the dominant species or group within the band and described as a patchy (observed in less than half of the unit length) or continuous (observed in more than half of the unit length) along-shore linear feature. Kelp and seagrass biobands included in this initial application of the risk model are listed in Table 5. The biobands were downloaded from the Alaska ShoreZone website (http://mapping.fakr.noaa.gov/szflex/) and assembled into single layers of linear features for kelps and seagrasses. To convert the kelp and seagrass biobands to an area for use in the bottom habitat areal coverage calculations, we applied a 2 km buffer to the seagrass data and a 3 km buffer to the kelp data. These buffers are based on the average distance from shore to the 10 m and 30 m bathymetric contours, and they reflect an assumed average depth range for the species within the bioband.

Table 5. ShoreZone submerged aquatic vegetation biobands included in the analysis. Source: Harney et al., 2008.

Bioband Name	Indicator Species
KELPS	
Alaria	*Alaria* sp.
Soft Brown Kelps	*Saccharina latissima* *Cystoseira* sp.
Dark Brown Kelps	Stalked *Laminaria* sp. *Cymathere* sp. Other bladed kelps
Dragon Kelp	*Alaria fistulosa*
Giant Kelp	*Macrocystis integrifolia*
Bull Kelp	*Nereocystis luetkeana*
SEAGRASSES	
Surfgrass	*Phyllospadix* sp.
Eelgrass	*Zostera marina*

Also included in the submerged aquatic vegetation analysis is a mapped kelp community in the Beaufort Sea identified as one of the most environmentally sensitive areas (MESAs) along the Alaska coast (ADFG, 2001a). A polygon for this community, called the Stefansson Sound Boulder Patch, was downloaded from the Alaska Department of Fish and Game (ADFG, 2001b) and used in the model calculations.

As mentioned above, kelp and seagrass coverage was not available for the entire state. Other regions are likely to have kelp and seagrass that is not reflected in the current risk model. As a result, habitat vulnerability scores are likely slightly underestimated for regions without complete submerged aquatic vegetation data coverage (i.e., Beaufort Sea, Chukchi Sea, Kotzebue Sound/Hope Basin, Norton Sound/St. Lawrence Island, Western Alaska, Aleutians, and Aniakchak).

4.1.1.2 Shoreline

In the risk model, shoreline and intertidal habitats were divided into fourteen habitat types depending on substrate type, vegetation, exposure, and elevation. These habitat types are based on WCS shoreline types and defined as follows:

- Exposed and semi-exposed rocky shores – areas of bedrock and boulder habitats exposed to the full range of wave energies.
- Exposed mixed coarse beaches – beaches composed of both sand and gravel and exposed to moderate wave action; or beaches exposed to somewhat less wave action, with a mix of gravel and sand where no one component occupies more than 70% of the surface. Algae may grow on larger cobbles, and animals live both on the surface and in the sediment. Species vary widely with degree of wave exposure and composition of the sediment.
- Exposed peat shorelines – areas predominated by peat scarps, eroded peat, and peat slurries. Includes peat scarps where the peat is frozen.

- Exposed sand-scoured rocky shores – rocky headlands or sea stacks directly adjacent to high energy sandy beaches such that there is much suspended sand in the water, which scours the rock. Unique plants and animals are found in this habitat.

- Exposed sand beaches – pure marine sands found in moderate to high-energy areas.

- Sheltered gravel beaches – gravel beaches in areas of low to moderate wave action.

- Sheltered high salt marshes – areas above normal high water but salt influenced, with organic/peat substrata. Salinities and associated plant communities will vary.

- Sheltered riprap – rocky intertidal areas (including hardpan and riprap) in areas exposed to low to moderate waves or currents.

- Sheltered rocky shores – bedrock and boulder habitats lacking oceanic swell and extensive wave fetch.

- Sheltered saline lagoons – areas where water-borne sediments are deposited into a spit closing off an embayment, which is flushed regularly or irregularly. Salinities vary with evaporation and runoff, but are generally high.

- Sheltered sand beaches and tidal flats – common habitats of gently sloping beaches with low to moderate wave action; may have gravel on the upper shore and have tidal flats on lower shore areas.

- Sheltered tidal flats – areas lacking in gravel or significant amounts of sand due to limited exposure to waves and currents. Usually found in the heads of bays and inlets. Includes undisturbed channels and sloughs which drain slowly through a tidal cycle, and which may contain some sand.

- Sheltered transition zone wetlands – areas transitional between salt marshes and uplands, where salt water only rarely inundates. Substrata are peat or fine silts.

- Sheltered vegetated low banks – found in backwaters or deltas away from large channels, where the substrate is mixed sand and mud, sometimes with patches of gravel or peat. Substrate is stable and organic-rich. Marsh communities vary with salinity.

Shoreline habitat data were extracted primarily from NOAA Environmental Sensitivity Index (ESI) geodatabases (NOAA, 2005). Shoreline habitat coverage was supplemented for the Southeast Alaska region from the Alaska ShoreZone Coastal Habitat Mapping Program database (NOAA, 2013), which follows the same general protocol as the ESI shoreline classification. Together, these two datasets provide near-complete coverage of Alaska’s shoreline, with the exception of the Pribilof Islands, St. Matthew/Hall Islands, and St. Lawrence Islands (Figure 5). In regions lacking complete coverage, only classified shoreline was incorporated into the risk model calculations.

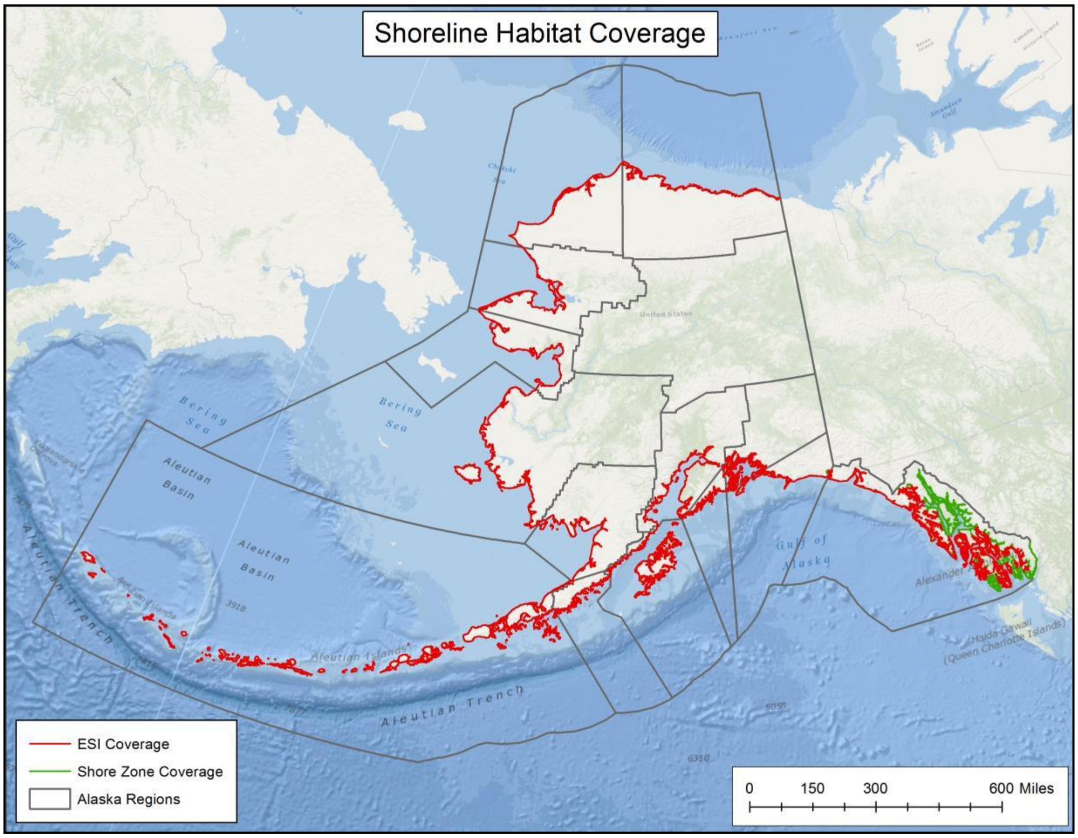


Figure 5. Extent of shoreline habitat data coverage used in the analysis. ESI shoreline data coverage in Alaska is shown in red. Areas supplemented with ShoreZone shoreline data are shown in green.

As described in Section 4.1.2 below, each shoreline type was mapped to a WCS shoreline type (Washington Administrative Code 173-183-410) to determine the oil effects score to be applied in the risk model. In the WCS, shoreline types are divided into estuarine (sheltered) and marine (exposed) shoreline types; thus, it was first necessary to determine which ESI codes refer to sheltered or exposed habitats. For the purposes of oil effects scoring, any shoreline segment with an ESI code of greater than 7 was considered to be sheltered and any segment with a code of less than or equal to 7 was considered to be exposed, with the exception of ESI code 6A (gravel beaches).

To divide gravel beaches (ESI code 6A) into sheltered and exposed, RPI carried out an analysis of estimated relative wave energy exposure. In areas where ShoreZone biological wave exposure data existed (Harney et al., 2008; NOAA, 2013**)**, these data were used to classify each individual gravel shore segment in the ESI data by transferring the attributes of the nearest ShoreZone line segment via a spatial join in ArcGIS. The six ShoreZone biological wave exposure descriptors were classified as exposed or sheltered as described in Table 6. In areas with no ShoreZone wave exposure data, a buffer-rebuffer method was carried out in ArcGIS to identify ESI shoreline segments within smaller bays and estuaries that exist landward of inlets or estuary mouths. These areas were classified as sheltered. The resulting assignments were then reviewed by RPI coastal geomorphologists using aerial and satellite imagery and other data to classify remaining ESI shoreline segments and correct any erroneous assignments.

Table 6. Mapping of ShoreZone biological wave exposure categories to exposed/sheltered categories.

ShoreZone Exposure Descriptor	Exposed/Sheltered Classification Assigned
Very Exposed	Exposed
Exposed	Exposed
Semi-exposed	Exposed
Semi-protected	Sheltered
Protected	Sheltered
Very Protected	Sheltered

4.1.1.3 Sea Ice Concentration

In the risk model, sea ice habitats were divided into eight habitat types based on ice concentration and geographic location. Average sea ice concentration was binned into four different concentration ranges, as varying ice concentrations differ in their habitat function and effects on oil behavior. The eight ice habitat types are defined as follows:

- Arctic very open pack ice – areas north of and including the Aleutians Islands with up to 30% ice cover.
- Arctic open pack ice – areas north of and including the Aleutians Islands with 30–60% ice cover.
- Arctic closed pack – areas north of and including the Aleutians Islands with 60–90% ice cover.
- Arctic consolidated pack ice – areas north of and including the Aleutians Islands with greater than 90% ice cover.
- Southern Alaska very open pack ice – areas south of the Aleutians Islands and in the Gulf of Alaska with up to 30% ice cover.
- Southern Alaska open pack ice – areas south of the Aleutians Islands and in the Gulf of Alaska with 30–60% ice cover.
- Southern Alaska closed pack – areas south of the Aleutians Islands and in the Gulf of Alaska with 60–90% ice cover.
- Southern Alaska consolidated pack ice – areas south of the Aleutians Islands and in the Gulf of Alaska with greater than 90% ice cover.

This breakdown in percent cover (i.e., <30%, 30–60%, 60–90%, >90%) is taken directly from the NRDAM/CME (French et al., 1996), in which the sea ice concentration bins were based on limited literature documenting oil behavior in various ice concentrations. When ice cover is less than 30%, open water conditions tend to dominate. At concentrations greater than 30%, evaporative losses of oil decrease and transport is limited. When ice cover is greater than 90%, the ice field functions as pack ice, limiting the ability of oil to spread, disperse, evaporate, or penetrate the ice field.

Because Arctic ice and southern Alaska ice function differently as habitat, ice habitats were further subdivided based on geography. The dividing line between these two subsets is the Aleutian Islands. The study team assumed that the majority of the ice south of the Aleutians and in the Gulf of Alaska (with the exception of in Cook Inlet) is likely to be ice that was formed on land and released into the sea by calving glaciers. This type of ice is typically used by seals and birds as haul-out and resting places. In contrast, Arctic ice is formed at sea and has a unique community of ice-associated species. In the risk model, Arctic ice habitat is treated as more vulnerable than southern Alaska ice habitat. The oil effects scores applied to each ice habitat type are described in Section 4.1.2.

Monthly average sea ice concentration data were obtained from a public dataset hosted by the National Snow and Ice Data Center (NSIDC) (Cavalieri et al., 1996). This dataset is produced by the NSIDC and the NASA Goddard Space Flight Center based on brightness temperature data from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), the Defense Meteorological Satellite Program (DMSP) -F8, -F11 and -F13 Special Sensor Microwave/Imagers (SSM/Is), and the DMSP-F17 Special Sensor Microwave Imager/Sounder (SSMIS). The resolution of the dataset is 25 x 25 km grid cells.

Monthly sea ice concentration rasters (grids) were downloaded and compiled for 2002 through 2012. Using ArcGIS, we combined the monthly data for each year into one raster for each of the six periods of interest by averaging each cell concentration. Figure 6 shows the resulting average sea ice concentration for two example periods.

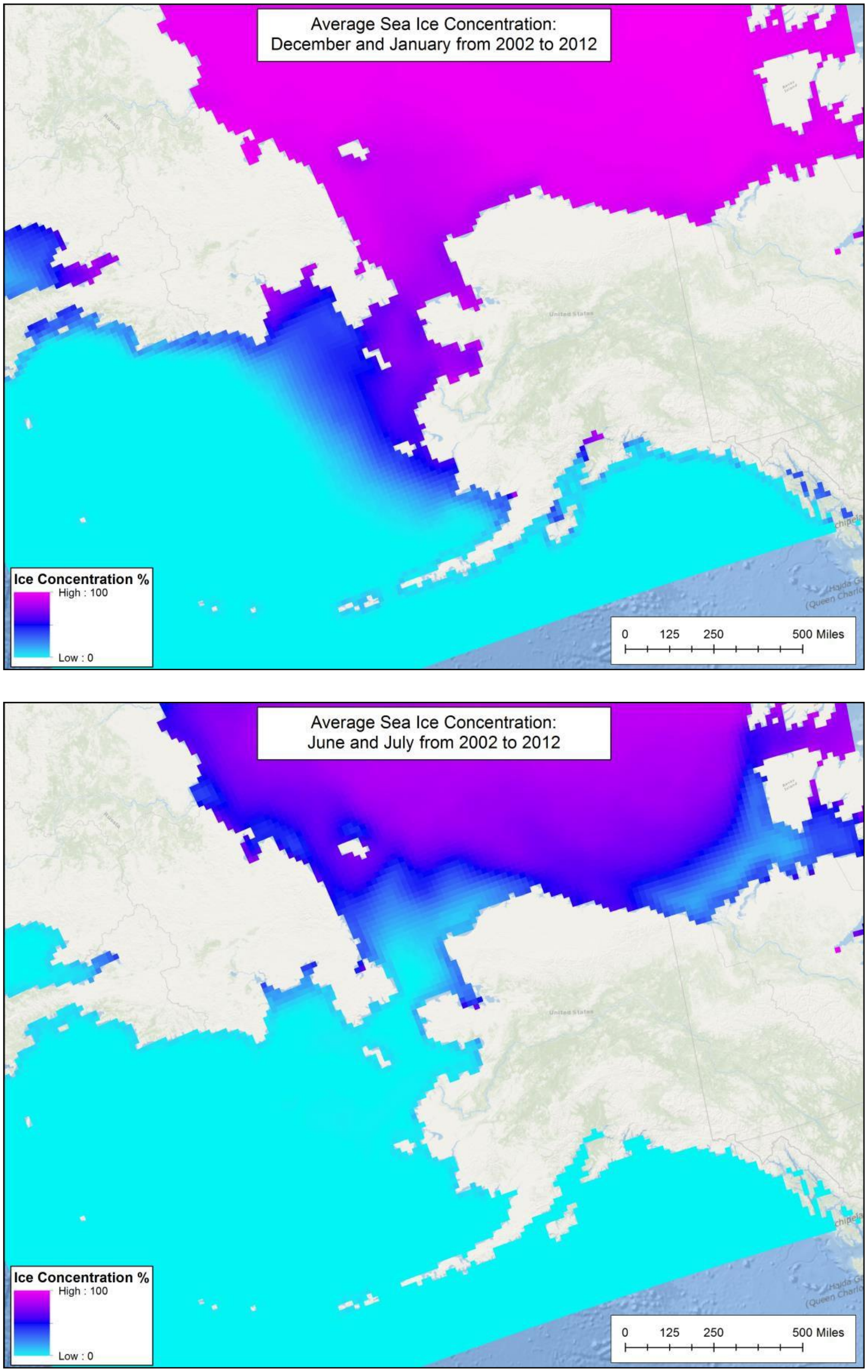


Figure 6. Average ice concentration (2002–2012) for two example periods, December through January (top) and June through July (bottom).

4.1.2 Habitat Oil Effects

The oil effects scores applied to each habitat type follow the same scheme as codified in the WCS (Washington Administrative Code 173-183-410). Each habitat type is scored for vulnerability to three oil effects: (1) acute toxicity, (2) mechanical injury, and (3) persistence effects of oil based on the propensity of the habitat to entrain oil and the energy regime of the habitat. These scores also reflect the vulnerability of species occupying that habitat that are not assessed elsewhere in the risk model. Each factor is scored on a 1 to 5 scale, where a score of 5 represents the greatest vulnerability and a score of 1 represents the least vulnerability.

The WCS oil effects rankings were originally developed by Leschine et al. (1991); they were subsequently reviewed by an oil effects committee and modified by Geselbracht and Logan (1993). We further reviewed and modified the rankings for this project. For most shoreline habitats, ESI codes were grouped into similar types and mapped to WCS habitat types, using the WCS scores directly. New scoring was developed for marine habitats (i.e., ice, bottom substrate, and submerged aquatic vegetation) and peat shorelines, using similar WCS scores as a starting point. The resulting oil effects scores for each habitat type are shown in Table 7.

Table 7. Oil effects scores for each habitat type used in the risk model.

Habitat Type	Oil Effects Scores				Rationale
	Acute Toxicity	Mechanical injury	Persistence	Total Oil Effects Score	
SHORELINE HABITATS					
Sheltered vegetated low banks	4.3	4.3	4.3	12.9	Consists of ESI code 9B. Scores taken directly from WCS estuarine intertidal type "Mixed-fine beaches and low marshes."
Sheltered saline lagoons	3.7	3.7	4.1	11.5	Consists of ESI code 9 (from ShoreZone). Scores taken directly from WCS estuarine intertidal type "Saline lagoons."
Sheltered high salt marshes	3.0	3.5	3.9	10.4	Consists of ESI codes 10A, 10B, and 10E. Scores taken directly from WCS estuarine intertidal type "High salt marshes."
Sheltered tidal flats	3.7	2.6	4.1	10.4	Consists of ESI code 9A. Scores taken directly from WCS estuarine intertidal type "Mud flats."
Sheltered transition zone wetlands	3.0	3.5	3.9	10.4	Consists of ESI codes 10C and 10D. Scores taken directly from WCS estuarine intertidal type "Transition zone wetlands."
Sheltered riprap	3.0	3.5	3.0	9.5	Consists of ESI codes 6B and 6C. Scores taken directly from WCS estuarine intertidal type "Open rocky shores."
Sheltered rocky shores	3.0	3.5	3.0	9.5	Consists of ESI codes 8A, 8B, 8C, and 8D. Scores taken directly from WCS marine intertidal type "Protected rocky shores."
Sheltered sand beaches and tidal flats	3.3	2.8	2.3	8.4	Consists of ESI code 7. Scores taken directly from WCS estuarine intertidal type "Open sandy beaches."
Sheltered gravel beaches	3.4	1.5	2.2	7.1	Consists of sheltered shorelines of ESI code 6A (as determined by the exposed/sheltered classification process described in Section 4.1.1.2). Scores taken directly from WCS estuarine intertidal type "Open gravel beaches."
Exposed and semi-exposed rocky shores	3.7	4.3	3.1	11.1	Consists of ESI codes 1A, 1B, 1C, 2A, and exposed shorelines of ESI code 6A (as determined by the exposed/sheltered classification process described in Section 4.1.1.2). Scores taken directly from WCS marine intertidal type "Exposed and semi-exposed rock shores."
Exposed sand-scoured rocky shores	3.3	3.8	2.7	9.8	Consists of ESI code 3C. Scores taken directly from WCS marine intertidal type "Sand-scoured rocky shores."
Exposed mixed coarse beaches	3.2	3.2	3.2	9.6	Consists of ESI code 5. Scores taken directly from WCS marine intertidal type "Semiexposed cobble and mixed-coarse beaches."

Habitat Type	Oil Effects Scores				Rationale
	Acute Toxicity	Mechanical injury	Persistence	Total Oil Effects Score	
Exposed peat shorelines	2.2	2.4	1.8	6.4	Consists of ESI code 8E. The intertidal zone of peat shorelines is not particularly important as biological habitat, as exposed peat scarps occur where the peat is frozen. Additionally, this shoreline is highly erosional and displays limited oil absorbance and thus minimal persistence. Light oil may penetrate when peat is dry. Heavy oils are resisted, even when peat is dry.
Exposed sand beaches	2.9	1.3	1.8	6.0	Consists of ESI codes 2B, 3A, 3B, and 4. Scores taken directly from WCS marine intertidal type “Exposed sandy beaches.”
BOTTOM HABITATS					
Shallow subtidal hard bottom	3.7	3.7	3.1	10.5	Scores taken directly from WCS marine subtidal type “Shallow subtidal rock and boulders.”
Deep subtidal hard bottom	2.1	2.4	3.1	7.6	Based on a combination of WCS marine subtidal types “Deep subtidal rock and boulders” and “Deep subtidal cobble and mixed coarse.”
No data – shallow subtidal	3.5	3.4	3.0	9.9	Average of shallow subtidal soft bottom and shallow subtidal hard bottom scores.
Shallow subtidal soft bottom	3.2	3.0	2.9	9.1	Based on a combination of WCS marine subtidal types “Shallow subtidal mixed-coarse to mixed-fine” and “Shallow subtidal gravel or mixed-fine.”
Deep subtidal soft bottom	1.8	2.0	2.2	6.0	Based on a combination of WCS marine subtidal types “Deep subtidal muddy areas” and “Deep subtidal sand.”
No data – deep subtidal	2.0	2.2	2.7	6.9	Average of deep subtidal soft bottom and deep subtidal hard bottom scores.
Seagrass	4.3	4.2	4.3	12.8	Seagrass beds are scored higher than kelp beds for mechanical injury because there would potentially be more vegetation at the water surface. Other scores are taken from the WCS estuarine intertidal type “Mixed-fine beaches and low marshes.”
Kelp	4.1	3.9	3.0	11.0	Kelp beds assumed to have a persistence score in-between that of deep subtidal hard bottom and deep subtidal soft bottom, as kelp are found across a variety of substrate types. The mechanical injury score is slightly higher than that of hard bottom because of the potential for kelp to reach the water surface. The acute toxicity score is increased because of the much higher density of invertebrates and other organisms associated with kelp beds.
ICE HABITATS					
Arctic very open pack ice	2.1	2.4	3.1	7.6	Areas of less than 30% ice cover are assumed to function mainly as open water, with increased sensitivity due to the presence of ice-associated organisms. Scores are assumed to be the same as those developed for deep subtidal hard bottom (because having some hard bottom is assumed to be similar to having some ice in terms of habitat value and biodiversity).

Habitat Type	Oil Effects Scores				Rationale
	Acute Toxicity	Mechanical injury	Persistence	Total Oil Effects Score	
Arctic open pack ice	3.0	3.5	4.0	10.5	Broken ice serves as habitat to a wide variety of organisms. The presence of polynyas is important for numerous species. Because of the tendency of ice to "herd" oil, the presence of 30-60% ice cover is assumed to increase the acute toxicity score relative to very open pack ice because of the greater concentration of oil and the slowing of evaporative losses. Mechanical injury is assumed to be moderate for both open pack ice and closed pack ice. Persistence is assumed to increase with increasing ice concentration.
Arctic closed pack ice	4.0	3.5	4.5	12.0	Broken ice serves as habitat to a wide variety of organisms. The presence of polynyas is important for numerous species. Because of the tendency of ice to "herd" oil, the presence of 60–90% ice cover is assumed to increase the acute toxicity score relative to open pack and consolidated pack ice because of the greater concentration of oil and the further slowing of evaporative losses. Mechanical injury is assumed to be moderate for both open pack ice and closed pack ice. Persistence is assumed to increase with increasing ice concentration.
Arctic consolidated pack ice	3.0	2.5	5.0	10.5	Pack ice edge provides important habitat and is frequently used by both micro- and macro-fauna. The acute toxicity score of consolidated pack ice is assumed to be similar to that of open pack ice. Mechanical injury is assumed to be less than for the other ice habitat types because oils are not able to penetrate very far into consolidated ice. Persistence is assumed to be high both above and below the ice, as evaporative losses are decreased.
Southern Alaska very open pack ice	1.1	1.4	3.1	6.6	The persistence score is set to be the same as for Arctic very open pack ice, as oil is assumed to behave similarly in both types. The acute toxicity and mechanical injury scores are reduced by one point because southern Alaska ice is assumed to have less habitat value than Arctic ice.
Southern Alaska open pack ice	2.0	2.5	4.0	9.5	The persistence score is set to be the same as for Arctic open pack ice, as oil is assumed to behave similarly in both types. The acute toxicity and mechanical injury scores are reduced by one point because southern Alaska ice is assumed to have less habitat value than Arctic ice.
Southern Alaska closed pack ice	3.0	2.5	4.5	11.0	The persistence score is set to be the same as for Arctic closed pack ice, as oil is assumed to behave similarly in both types. The acute toxicity and mechanical injury scores are reduced by one point because southern Alaska ice is assumed to have less habitat value than Arctic ice.
Southern Alaska consolidated pack ice	2.0	1.5	5.0	9.5	The persistence score is set to be the same as for Arctic consolidated pack ice, as oil is assumed to behave similarly in both types. The acute toxicity and mechanical injury scores are reduced by one point because southern Alaska ice is assumed to have less habitat value than Arctic ice.

4.1.3 Protected Areas Modifier

Protected area coverage serves as a modifier to the overall habitat vulnerability score and is comprised of protected marine area coverage, protected shoreline length, and relative number of species/life stages with Essential Fish Habitat designated in each region.

4.1.3.1 Parks, Refuges, and Critical Habitat

The coverage of protected areas within a given region is assessed for both marine area and shoreline length. The types of protected areas considered in this study included the following:

- National Wildlife Refuges;
- National Estuarine Research Reserves;
- National Parks;
- Federally-designated critical habitats;
- Habitat Areas of Particular Concern;
- State refuges;
- State critical habitat areas; and
- State sanctuaries.

As this analysis pertains to marine habitats and coastal shorelines of Alaska, only those protected areas in Alaska with a marine area or shoreline expression were included. The names of the state and federal protected areas included in the analysis are listed in Table 8 and shown in Figure 7.

Table 8. Names of state and federal protected areas included in the analysis.

Federal Protected Areas		State Protected Areas
NATIONAL WILDLIFE REFUGES		**STATE REFUGES**
Alaska Maritime National Wildlife Refuge		Anchorage Coastal Wildlife Refuge
Alaska Peninsula National Wildlife Refuge		Cape Newenham State Game Refuge
Arctic National Wildlife Refuge		Goose Bay State Game Refuge
Becharof National Wildlife Refuge		Izembek State Game Refuge
Izembek National Wildlife Refuge		McNeil River State Game Refuge
Kenai National Wildlife Refuge		Mendenhall Wetlands State Game Refuge
Kodiak National Wildlife Refuge		Palmer Hay Flats State Game Refuge
Selawik National Wildlife Refuge		Susitna Flats State Game Refuge
Togiak National Wildlife Refuge		Trading Bay State Game Refuge
Yukon Delta National Wildlife Refuge		Yakataga State Game Refuge
NATIONAL ESTUARINE RESEARCH RESERVES		**STATE CRITICAL HABITAT AREAS**
Kachemak Bay National Estuarine Research Reserve		Cinder River Critical Habitat Area
NATIONAL PARKS		Clam Gulch Critical Habitat Area
Aniakchak National Monument and Preserve		Copper River Delta Critical Habitat Area
Bering Land Bridge National Park and Preserve		Egegik Critical Habitat Area
Cape Krusenstern National Monument		Fox River Flats Critical Habitat Area
Glacier Bay National Park and Preserve		Kachemak Bay Critical Habitat Area
Katmai National Park and Preserve		Kalgin Island Critical Habitat Area
Kenai Fjords National Park		Pilot Point Critical Habitat Area
Lake Clark National Park and Preserve		Port Heiden Critical Habitat Area
Sitka National Historic Park		Port Moller Critical Habitat Area
Wrangell-St. Elias National Park and Preserve		Redoubt Bay Critical Habitat Area
FEDERAL CRITICAL HABITAT		Tugidak Island Critical Habitat Area
Beluga Whale Critical Habitat		**STATE SANCTUARIES**
North Pacific Right Whale Critical Habitat		McNeil River State Game Sanctuary
Polar Bear Critical Habitat		Stan Price State Wildlife Sanctuary
Sea Otter Critical Habitat		Walrus Islands State Game Sanctuary
Spectacled Eider Critical Habitat		
Steller Sea Lion Critical Habitat		
Steller’s Eider Critical Habitat		
HABITAT AREAS OF PARTICULAR CONCERN		
Alaska Seamount Habitat Protection Area		
Bowers Ridge Habitat Conservation Zone		
Gulf of Alaska Coral Habitat Protection Area		

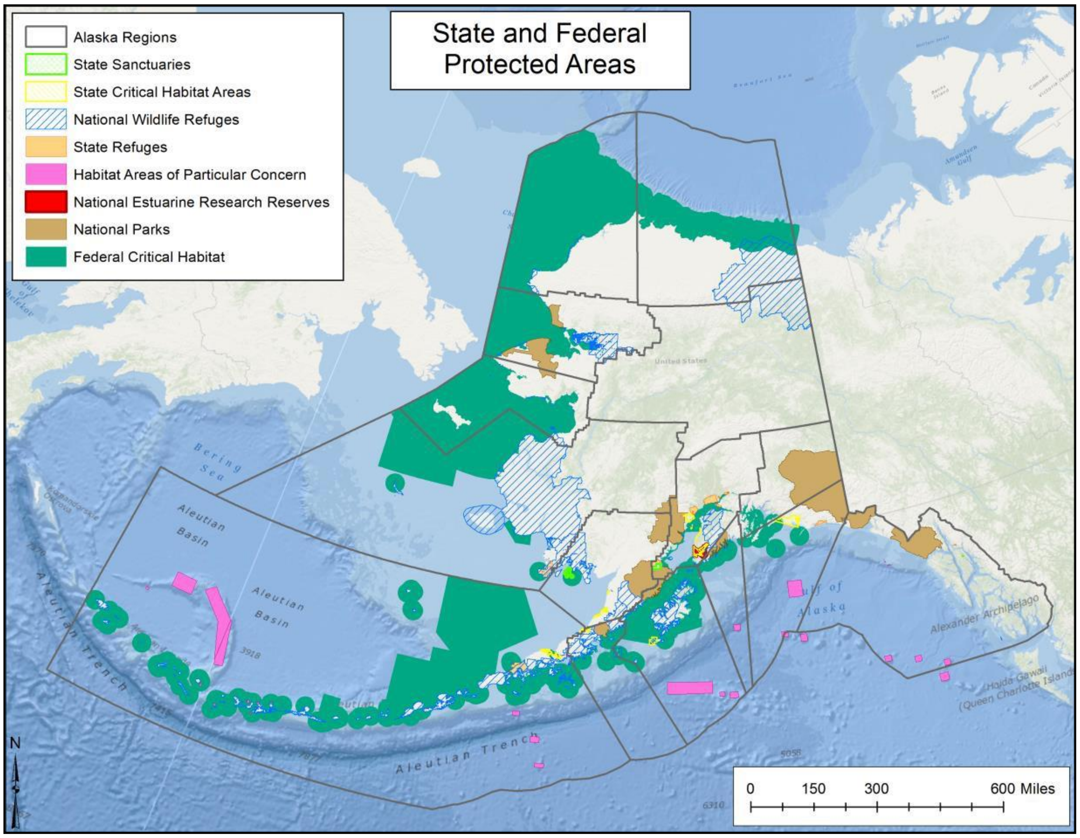


Figure 7. State and federal protected areas included in the analysis.

Shapefiles of these areas were obtained from a variety of public sources. Federally designated critical habitats were mostly obtained through the Arctic Environmental Response Management Application (https://www.erma.unh.edu/arctic/). The boundaries for the North Pacific right whale critical habitat areas were digitized from coordinates given in the critical habitat designation notice in the Federal Register (73 FR 19000). Habitat Areas of Particular Concern were obtained from the Alaska Regional Office of NOAA Fisheries (NOAA, 2006). National park boundaries were obtained from the National Park Service (NPS, 2012). The National Estuarine Research Reserve boundaries, as well as the boundaries of certain national wildlife refuges, were available from the National Marine Protected Areas Center's Marine Protected Areas (MPA) Inventory (NOAA, 2012). Boundaries for national wildlife refuges not included in the MPA inventory were downloaded from the U.S. Fish and Wildlife Service (USFWS, 2013). The boundaries of state protected areas were obtained from the Alaska Department of Fish and Game (ADFG, 2013).

4.1.3.2 Essential Fish Habitat

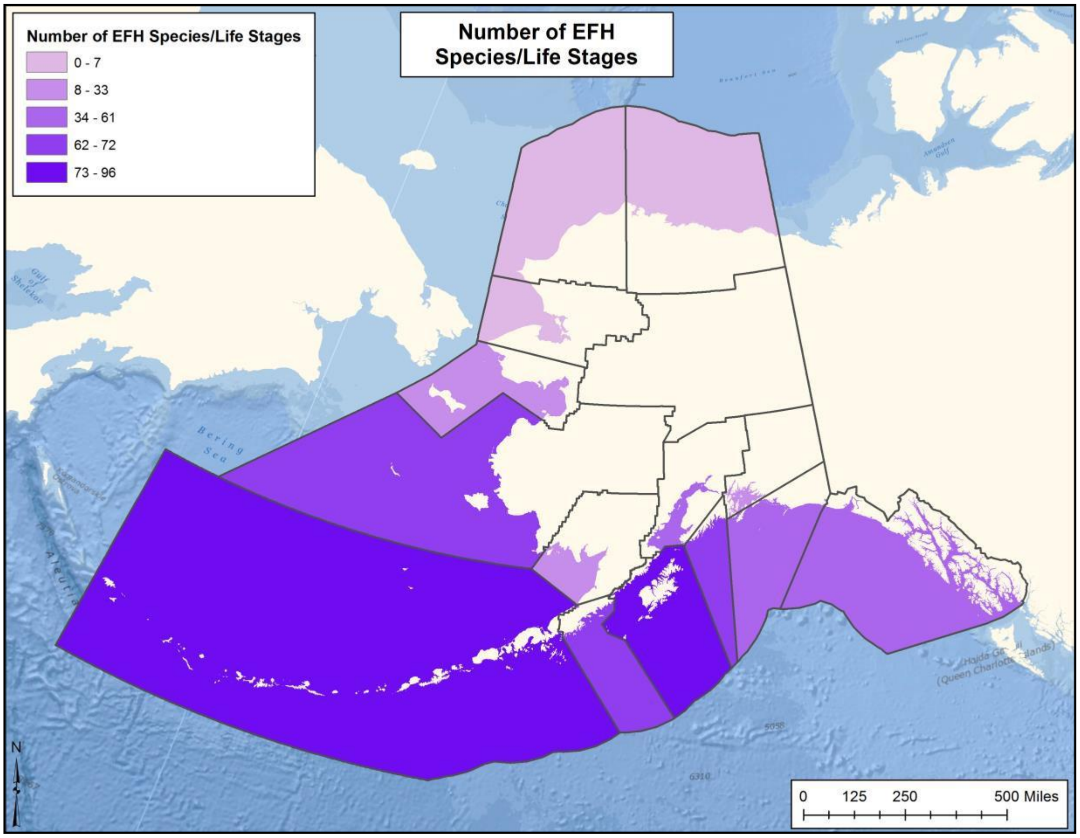
Under the statutory authority of the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (as amended), NOAA Fisheries works in concert with the various regional fishery management councils to identify and designate essential habitat for all life stages of federally managed fishery species. EFH is defined as those waters and substrate necessary to fishery resources for spawning, breeding, or growth to maturity.

EFH was included in the risk model to account for the special regulatory status given to these areas, as well as to reflect fishery species that are not assessed elsewhere in the model. Spatial data for EFH was obtained from the Alaska Regional Office of NOAA Fisheries (NOAA 2010). Only species with spatial data were included in the analysis. EFH species and life stages included in the analysis are listed in Table 9. For each region, we quantified the number of species/life stages with designated EFH in that region (Figure 8).

Table 9. Essential Fish Habitat species and life stages included in the analysis.

EFH Species	Life Stage					
	Eggs	Larvae	Late Juvenile	Mature	Marine Juvenile	Marine Immature & Maturing Adults
Alaska plaice	X	X	X	X		
Arctic cod			X	X		
Arrowtooth flounder		X	X	X		
Atka mackerel		X		X		
Blue king crab	X		X	X		
Chinook salmon					X	X
Chum salmon					X	X
Coho salmon					X	X
Dover sole	X	X	X	X		
Dusky rockfish		X	X			
Flathead sole	X	X	X	X		
Golden king crab	X		X	X		
Greenland turbot	X	X	X	X		
Grooved tanner crab	X		X	X		
Northern rockfish		X		X		
Pacific cod	X	X	X	X		
Pacific ocean perch		X	X	X		
Pink salmon					X	X
Red king crab	X		X	X		
Rex sole	X	X	X	X		
Rock sole		X	X	X		
Sablefish	X	X	X	X		
Saffron cod			X	X		
Sculpin			X	X		
Shortraker and rougheye rockfish		X		X		
Skate				X		
Snow crab	X		X	X		
Sockeye salmon					X	X
Squid			X	X		
Tanner crab	X		X	X		
Thornyhead rockfish		X	X	X		
Triangle tanner crab	X		X	X		
Walleye pollock	X	X	X	X		
Weathervane scallop			X	X		
Yelloweye rockfish		X	X	X		
Yellowfin sole	X	X	X	X		

Figure 8. Total number of EFH species/life stages in by region.



NOAA Fisheries and the fishery management councils also designate Habitat Areas of Particular Concern. These are specific subsets of Essential Fish Habitat that are rare, sensitive, have important ecological function, or are particular vulnerability to human impact. There are three Habitat Areas of Particular Concern designated in Alaska; these areas are included with the protected areas in Section 4.1.3.1 above.

4.2 Species Scoring

In the risk model, species vulnerability is comprised of three main parameters:

1. Relative abundance – measure of population size within a region/season (i.e., how much of the population in Alaska would be affected in the event of a spill);

2. Impact – in the event of a spill, how severely would the species be affected; and

3. Recovery – in the event of a spill, how quickly would the species population be able to recover from impact.

These three parameters were assessed for each individual species, based on a number of scoring schemes. Ideally, each stock or distinct population segment (DPS) of a species would be scored separately, as subpopulations may differ in their geographic distribution, seasonality, etc. The scoring schemes for each parameter, as well as the species selected for analysis, are described in Sections 4.2.2 through 4.2.4.

4.2.1 Species Selection

Species assessed in the risk model were divided into three broad species groups: marine mammals and sea turtles, birds, and fish and invertebrates. For the initial application of the risk model, 36 species were selected for assessment, consisting of 12 species in each species group category. Because we were only able to assess a limited number of species for this analysis, species selection was based on several specific goals. These goals were to:

1. Include wide-ranging species, as well as those that are more endemic to particular regions;
2. To the extent possible, include species in Alaska listed as threatened or endangered under the Endangered Species Act, as well as species that are candidates for listing;
3. Equally represent both Arctic and southern Alaska species; and
4. Include species from a variety of behavior groups and ecological roles/niches.

To ensure selection of species from a variety of behavior groups and ecological roles, the three species groups were divided into subcategories, with one or more species selected for each subcategory. These species group subcategories are listed in Table 10. The 36 species selected are shown in Table 11. Each of these species was scored based on adults in the Alaska population as a whole (i.e., separate stocks/DPSs within Alaska were not scored separately).

Table 10. Species group sub-categories.

Species Group	Subcategories
Marine Mammals & Sea Turtles	• Sea turtles • Baleen whales • Toothed whales • Fur-bearing pinnipeds • Other pinnipeds (walrus, sea lion, phocid seals) • Other fur-bearing marine mammals (polar bear, sea otter)
Birds	• Waterfowl • Seabirds (aerial divers) • Seabirds (surface divers) • Shorebirds/wading birds • Raptors
Fish & Invertebrates	• Small pelagic fishes • Large pelagic fishes • Semi-demersal fishes • Demersal fishes • Anadromous fishes • Pelagic invertebrates • Demersal invertebrates • Benthic invertebrates

Table 11. Species selected for scoring in the initial application of the model.

Species Group	Subcategory	Species Selected
Marine Mammals & Sea Turtles	Sea turtles	*Leatherback sea turtle (*Dermochelys coriacea*)
	Baleen whales	*North Pacific right whale (*Eubalaena japonica*) *Humpback whale (*Megaptera novaeangliae*) *Bowhead whale (*Balaena mysticetus*)
	Toothed whales	*Sperm whale (*Physeter macrocephalus*) *Beluga whale (*Delphinapterus leucas*)
	Fur-bearing pinnipeds	Northern fur seal (*Callorhinus ursinus*)
	Other pinnipeds	*Steller sea lion (*Eumetopias jubatus*) *Pacific walrus (*Odobenus rosmarus divergens*) *Ringed seal (*Phoca hispida*)
	Other fur-bearing marine mammals	*Polar bear (*Ursus maritimus*) *Northern sea otter (*Enhydra lutris kenyoni*)
Birds	Waterfowl	*Steller's eider (*Polysticta stelleri*) Northern pintail (*Anas acuta*) Harlequin duck (*Histrionicus histrionicus*)
	Seabirds (aerial divers)	Short-tailed shearwater (*Puffinus tenuirostris*) Black-legged kittiwake (*Rissa tridactyla*) *Short-tailed albatross (*Phoebastria albatrus*)
	Seabirds (surface divers)	Red-necked phalarope (*Phalaropus lobatus*) *Marbled murrelet (*Brachyramphus marmoratus*) Common murre (*Uria aalge*)
	Shorebirds/wading birds	Western sandpiper (*Calidris mauri*) Dunlin (*Calidris alpina*)
	Raptors	Bald eagle (*Haliaeetus leucocephalus*)
Fish & Invertebrates	Small pelagic fishes	*Pacific herring (*Clupea pallasii*) Arctic cod (*Boreogadus saida*)
	Large pelagic fishes	Pacific halibut (*Hippoglossus stenolepis*)
	Semi-demersal fishes	Atka mackerel (*Pleurogrammus monopterygius*) Walleye pollock (*Theragra chalcogramma*)
	Demersal fishes	Arrowtooth flounder (*Atheresthes stomias*)
	Anadromous fishes	Pink salmon (*Oncorhynchus gorbuscha*) Arctic cisco (*Coregonus autumnalis*)
	Pelagic invertebrates	Squids (multiple species) Euphausiids (multiple species)
	Demersal invertebrates	Snow crab (*Chionoecetes opilio*)
	Benthic invertebrates	Weathervane scallop (*Patinopecten caurinus*)

*Species is listed as endangered, threatened, or candidate for listing.

4.2.2 Relative Abundance

The relative abundance parameter assesses the abundance of a species in a particular region and season relative to all other regions and seasons. The goal of this parameter is to reflect how much of a species' population in Alaska would be affected in the event of a spill. Ideally, this would be accomplished using population estimates for each region and season assessed. However, attaining comprehensive seasonal data with spatial coverage for the entire state of Alaska is currently not feasible. For many of the species assessed, reliable abundance estimates are simply not available. Even for those species where some information is available, data are typically focused on a particular area/season of concern, and do not provide the spatiotemporal resolution required for this study. Therefore, to assess abundance for this study, a relative index of abundance was constructed for each species. This allowed for the most flexibility in the use of available datasets.

Relative abundance scores were assigned for each species/region/period combination using a 0 to 1 scale, with 0 representing that the species is not present and 1 representing the highest relative abundance of the species in any region/period within Alaska (Table 12). This relative abundance is in reference to only the regions assessed within Alaska, not the species' worldwide distribution, and each species is relative only to itself. For example, humpback whale abundance in a particular region/season of Alaska is only relative to humpback whale abundance in all other regions/seasons of Alaska. It is not relative to humpback whale abundance outside of Alaska, the abundance of another marine mammal species, or the abundance of a member of another species group. Using this system, all species have a relative abundance score of 1 in at least one region/season. As a result, all species are treated as equally important in the risk model.

Table 12. Relative abundance scores.

Abundance Score	Description
1	Species is in highest abundance relative to other seasons/areas of Alaska
0.8	Species is in high abundance relative to other seasons/areas of Alaska
0.6	Species is in moderate abundance relative to other seasons/ areas of Alaska
0.4	Species is in low abundance relative to other seasons/areas of Alaska
0.2	Species is rare or infrequent relative to other seasons/areas
0	Species is not present in the region/season

Multiple data sources were used to assign the relative abundance scores for each species. Primary sources included stock assessments, abundance and sighting databases, survey data, published reports/articles, species profiles from government websites, and range maps. In the absence of spatially- and temporally-varying data, we relied on text descriptions of species aggregation locations, geographic range, and migratory patterns to construct an estimate of relative abundance for each region/season. Using the available data for each species, abundance scores were assigned using best professional judgment. The scores were then reviewed and revised by RPS ASA biologists in a panel setting. The final abundance scores and their rationales and references can be found in Appendix D.

4.2.3 Impact Potential

The impact parameter evaluates how severely a species would be affected in the event of spatiotemporal overlap with spilled oil. These scoring schemes were designed to reflect generalized potential impacts from both subsurface and surface spills. If future applications of the risk model are focused on a particular type of spill, these impact scoring schemes could be modified to better reflect that specific spill type.

The impact parameter is assessed using the same general ecological themes across all three species groups; however, each theme is implemented in a manner appropriate to each group. The themes used in this risk model are common to a number of previous environmental vulnerability studies (see Table 1). The ecological themes used in the assessment of impact potential are:

- Encounter – likelihood of overlap with oil. Based on behaviors such as escape behavior, time spent on the water surface, and attraction/avoidance responses to oil. Species more likely to encounter spilled oil are assumed to be more vulnerable. While different types of spills (e.g., deep subsea blowout vs. surface spill) and products spilled (e.g., heavy crude vs. diesel) would result in varying amounts of oil in the water column, on the water surface, in the sediments, and on the shoreline, the encounter scoring was designed to assess the likely location of spilled oil *in general*. Because most spills (subsurface or surface) result in oil on the water surface, surface-associated species/life stages typically receive high encounter scores. Species inhabiting the shoreline and intertidal areas are assumed to be highly susceptible to encountering spilled oil as well. Relatively high encounter scores are also assigned to stationary species that would be unable to escape water column contamination and species that disturb bottom sediments (as these sediments may be contaminated by oil).

- Concentration (Aggregation) – the degree to which a species aggregates in a given location. Species that aggregate into large groupings are considered to be more vulnerable to spilled oil because a large portion of the population could be affected at once.

- Physiology – reflects certain physiological characteristics (e.g., fur) that may affect the magnitude of impact from exposure to spilled oil.

- Indirect Trophic Effects (Feeding Specificity) – addresses how the effects of an oil spill on lower trophic levels may affect the species of interest. A species that feeds in a very specific ecological niche is considered to be more vulnerable than a species that can readily switch between various forage items.

Each species group has a unique set of impact scoring parameters that utilize these themes. For each individual species assessed, the impact parameters are scored on a 0 to 5 scale with 5 indicating the greatest negative impact potential from a spill and 0 indicating no impact. In instances where multiple scores were possible for a given species and parameter, the most conservative (i.e., greater number) score was assigned. The scoring schemes for each species group are detailed in the following sections.

The final impact scores for each species and their rationales and references can be found in Appendix D.

4.2.3.1 Marine Mammals and Sea Turtles

The marine mammal and sea turtle species group is assessed using seven impact scoring parameters:

1. *Habitat use in Alaska (Encounter)* – the vertical and horizontal distribution of marine mammals and sea turtles is important in determining the likelihood of encounter with an oil slick. Species that regularly interact with the water surface are most likely to encounter an oil spill/slick. Species inhabiting the shoreline and intertidal areas are also highly susceptible to encountering oil spills. Species that interact minimally with marine and shoreline environments inherently have reduced rates of encounter with marine oil spills.

2. *Site fidelity (Encounter)* – species exhibiting site fidelity within Alaska's waters are considered more likely to encounter spilled oil, as they would try to return to, or remain in, the same area even if it were to become oiled. Site fidelity refers to fixed locations utilized by a species for habitat, feeding, or breeding, for which alternate sites are not utilized. The site fidelity parameter only refers to fidelity during the time period the species is present within Alaska's waters. For example, leatherback turtles typically return to their natal beaches to lay eggs, but because this occurs outside the area of interest of this study, it does not affect the likelihood of encounter with an oil spill while in Alaska's waters.

3. *Feeding method (Encounter/Physiology)* – the foraging strategy of a species is important in determining the likelihood of encounter with spilled oil, as well as the potential mechanism by which oil could enter the species' system. Filter-feeding organisms are likely to be severely impacted by oil due to compromised feeding capabilities. Species feeding at the water surface are likely to have relatively high encounter rates with oil spills. Pelagic piscivores are likely to have relatively low encounter rates with spilled oil as compared to surface-associated and filter-feeding species, and therefore are considered to have the lowest vulnerability to oil spills.

4. *Avoidance/attraction (Encounter)* – some species have been documented as either being actively attracted to, or actively avoiding oil in the environment. This parameter assesses those responses; however, data on this topic are rarely available for specific species. As a result, all species are assigned a conservative "no data" score, unless specific literature was identified. Species actively attracted to oil spills (most often as scavengers) would have relatively greater encounter rates with oil spills. Species noted to ignore or be unaware of the presence of oil also have greater relative encounter rates. Species noted to actively avoid the presence of oil are considered to have relatively lower encounter rates with spilled oil.

5. *Fur bearing (Physiology)* – some species of marine mammals utilize fur as their primary means of thermoregulation. Oil adversely affects the ability of fur to thermoregulate. Species affected by oil spills that utilize fur for thermoregulation would be more adversely affected than species that do not use fur for thermoregulation. Species utilizing blubber or other means of thermoregulation may be relatively more capable of surviving contact with an oil spill.

6. *Aggregation (Concentration)* – if a species forms large aggregations while in Alaska, an oil spill could potentially affect a large portion of the population at once. A species that only forms small aggregations or is solitary is considered to be relatively less vulnerable.

7. *Feeding specialization (Indirect Trophic Effects)* – an oil spill of any size is likely to alter trophic interactions to some degree. Feeding generalists are more capable of withstanding food web changes and are thereby assumed to be less vulnerable than a feeding specialist.

The scoring schemes for each of these parameters are listed in Table 13.

Table 13. Marine mammal/sea turtle impact scores.

Impact Score	Category	Description
HABITAT USE IN ALASKA		
5	All or large portion of time spent on water surface	Species maintains contact with water surface and/or uppermost water column (top few meters) for most of its daily activity.
4	All or large portion of time spent on shoreline	Species actively utilizes shoreline, intertidal, and nearshore subtidal habitats for most of its daily activity.
3	Entire life history spent in marine habitats (water column)	Species uses pelagic water column as main habitat. Water surface is used for breathing or occasional excursions only.
1	Life history not entirely dependent on marine/shoreline habitats	A portion of species life history is not dependent on marine habitats. May spend extensive amount of time inland or on non-edge pack ice.
SITE FIDELITY		
3	Demonstrates persistent site fidelity in Alaska	Species displays persistent site fidelity while in Alaska.
2	Demonstrates seasonal/transient site fidelity in Alaska	Species displays seasonal or transient site fidelity while in Alaska.
1	No site fidelity in Alaska	Species does not display site fidelity while in Alaska's waters.
FEEDING METHOD		
5	Feeds at surface or filter feeding	Species feeds at the water surface and/or uppermost water column (top few meters), or species utilizes filter-feeding strategies to extract plankton from water column.
3	Forages in benthic sediments	Species extracts infauna from benthic substrates (disturbs substrate).
1	Pelagic piscivore	Species is a pelagic piscivore or pelagic scavenger.
AVOIDANCE/ATTRACTION		
5	Attraction documented, or lack of avoidance documented	Species has been documented as being attracted to oil spill sites (most frequently as scavengers), or as not actively avoiding the presence of oil (i.e., ignores the presence of oil, to the species detriment).
3	No data	No documentation is available about the attraction/avoidance response of the species to oil.
1	Documented oil avoidance behavior	Species has been documented as capable of detecting and avoiding oiled areas.
FUR-BEARING		
5	Uses fur for thermoregulation	Species uses fur as a primary mean of thermoregulation.
1	Does not use fur for thermoregulation	Species does not use fur as a primary mean of thermoregulation.
AGGREGATION/CONCENTRATION		
5	Forms persistent large aggregations in Alaska	While in Alaska, species forms persistent large colonies or aggregations.
3	Forms persistent small aggregations or seasonal/ transient aggregations in Alaska	While in Alaska, species forms persistent small aggregations or seasonal (usually breeding- or feeding- related) colonies or aggregations. Large colonies/aggregations do not persist throughout the year.
1	Solitary or mostly solitary in Alaska	While in Alaska, species is solitary, or forms very small transient groups.
FEEDING SPECIALIZATION		
5	Highly specialized (narrow)	Species has limited diet at single trophic level. Substitution of preferred prey not likely.
3	Moderately adaptable	Species has limited diet at one or two trophic levels. Substitution of preferred prey possible.
1	Generalist	Species consumes variety of prey at multiple trophic levels, or wide variety of prey within a trophic level.

4.2.3.2 Birds

Several impact parameters used for assessing bird impact potential are taken directly from, or adapted from, the “Bird Oil Index” (BOI) developed in part by NOAA (Manuwal et al., 1979). The BOI was developed to quantify the various aspects of behavior, biology, distribution, and abundance as related to exposure to oil spills. BOI scores are available for the majority of bird species assessed in this study, and were used where possible.

The bird species group is assessed using seven impact scoring parameters:

1. *Night roosting (Encounter)* – this parameter is taken directly from the BOI and reflects the night roosting behavior of a species. A species' roosting location is important in determining its relative encounter rate with an oil spill. Species that always, or nearly always, roost on water are considered to have the greatest relative likelihood of encountering spilled oil. Species that do not roost on water are considered to have no additional vulnerability attributed to this behavior, and receive a score of zero for this parameter.

2. *Site fidelity (Encounter)* – species exhibiting site fidelity within Alaska's waters are considered more likely to encounter an oil spill, as they would likely try to return to or remain in the same area even if it were to become oiled. Site fidelity refers to fixed locations utilized by a species for habitat, feeding, or breeding, for which alternate sites are not utilized. The site fidelity parameter only refers to fidelity during the time period the species is present within Alaska’s waters. For example, short-tailed albatross exhibit site fidelity by returning to the same breeding grounds each year; however, because these breeding grounds are located outside of Alaska, this site fidelity does not alter the likelihood of encounter with an oil spill while in Alaska.

3. *Feeding method (Encounter/Physiology)* – the foraging strategy of a species is important in determining the likelihood of encounter with spilled oil, as well as the potential mechanism by which oil could enter the species’ system. Species feeding at the water surface or in the intertidal are likely to have relatively high encounter rates with spilled oil. Pelagic piscivores are likely to have relatively low encounter rates with spilled oil, and therefore are considered to have the lowest vulnerability to oil spills.

4. *Avoidance/attraction (Encounter)* – this parameter is modified from escape behavior scoring in the BOI, and reflects the likely response of a species to oil in the environment. Some species have been documented as either being actively attracted to, or actively avoiding oil; however, data on this topic are rarely available for specific species. As a result, all species are assigned a conservative “no data” score, unless specific literature was identified. Species actively attracted to spilled oil (most often as scavengers) would have relatively greater encounter rates with oil spills. Species that have a startle reaction to swim or dive are also likely to have high encounter rates with spilled oil. Conversely, species that have a startle reaction to fly from danger are likely to have relatively low encounter rates with spilled oil. Species noted to actively avoid the presence of oil are considered to have relatively lower encounter rates with spilled oil.

5. *Flocking on water (Concentration)* – this parameter is taken directly from the BOI, and reflects the tendency of the species to congregate on the water surface. Increased exposure to water surface habitats increases the likelihood of bird species interacting with spilled oil. Bird species occurring in greater concentrations on marine waters (flocking) have a greater likelihood of encounter with an oil spill, and a potentially greater magnitude of impact due to the high concentration of individuals. Species that do not flock on water are considered to have no additional vulnerability attributed to flocking and receive a score of zero for this parameter.

6. *Nesting concentration (Concentration)* – this parameter is adapted from the BOI and addresses the nesting concentration of the species. Bird species that nest in high concentrations are at greater relative risk of adverse impacts from an oil spill than species that nest solitarily, because an oil spill could potentially affect a large portion of the population at once. In the risk model, species that nest outside of Alaska are considered to have no additional vulnerability attributed to nesting behavior, and receive a score of zero for this parameter.

7. *Feeding specialization (Indirect Trophic Effects)* – an oil spill of any size is likely to alter trophic interactions to some degree. Feeding generalists are more capable of withstanding food web changes and are thereby assumed to be less vulnerable than a feeding specialist. This parameter was modified from the BOI to be consistent with the other species groups in this study.

The scoring schemes for each of these parameters are listed in Table 14.

Table 14. Bird impact scores.

Impact Score	Category	Description
NIGHT ROOSTING		
5	Nearly always roosts on water	Species nearly always roosts on marine waters.
3	Spends moderate amount of time roosting on water	Species actively roosts on marine waters, but may also roost on land.
1	Spends minimal time roosting on water	Species actively roosts on land but may spend a small amount of time roosting on marine waters.
0	Never roosts on water	Species does not roost on marine waters in Alaska.
SITE FIDELITY		
3	Demonstrates persistent site fidelity in Alaska	Species displays persistent site fidelity while in Alaska.
2	Demonstrates seasonal/transient site fidelity in Alaska	Species displays seasonal or transient site fidelity while in Alaska.
1	No site fidelity in Alaska	Species does not display site fidelity while in Alaska's waters.
FEEDING METHOD		
5	Feeds at surface or in intertidal	Species feeds at the water surface (e.g., dabble, surface dip, shallow surface dive), or feeds in intertidal areas.
3	Forages in benthic sediments	Species dives or stands and feeds on benthic infauna.
1	Pelagic piscivore	Species dives and feeds in pelagic water column.
AVOIDANCE/ATTRACTION		
5	Attraction documented	Species has been documented as being attracted to oil spill sites (most frequently as scavengers), or as not actively avoiding the presence of oil (i.e., ignores the presence of oil, to the species detriment).
4	Avoidance behavior – swims or dives	When startled, species reacts by swimming or diving from perceived danger.
3	No data	No documentation is available about the attraction/avoidance response of the species to oil.
1	Avoidance behavior – flies, or has documented avoidance of oil	When startled, species reacts by flying away from perceived danger, or species has been documented as capable of detecting and avoiding oiled areas.
FLOCKING ON WATER		
5	Forms large flocks	Species forms large flocks while in Alaska's waters.
3	Variable	Species forms flocks of variable sizes (including large and small) while in Alaska's waters.
1	Forms small flocks	Species forms small flocks while in Alaska's waters.
0	Does not flock in marine waters	Species does not flock in marine waters.
NESTING CONCENTRATION		
5	Forms large colonies in Alaska	While in Alaska, species forms relatively large colonies when nesting.
3	Forms small colonies in Alaska	While in Alaska, species forms relatively small colonies when nesting.
1	Nests solitarily in Alaska	While in Alaska, species is solitary nester.
0	Does not nest while in Alaska	Species does not nest in Alaska.
FEEDING SPECIALIZATION		
5	Highly specialized (narrow)	Species has limited diet at single trophic level. Substitution of preferred prey not likely.
3	Moderately adaptable	Species has limited diet at one or two trophic levels. Substitution of preferred prey possible.
1	Generalist	Species consumes variety of prey at multiple trophic levels, or wide variety of prey within a trophic level.

4.2.3.3 Fish and Invertebrates

The fish and invertebrates group is assessed using eight impact scoring parameters:

1. *Egg location (Encounter)* – oviposition and egg physiology are important in determining the likelihood of encounter with spilled oil during the egg stage. Floating eggs, particularly those found at or near the water surface (neustonic), and eggs found in the intertidal zone, are highly susceptible to surface oil slicks and are considered to have the greatest relative impact from oil spills. Eggs that occupy deeper subtidal habitats are relatively less likely to encounter spilled oil. Eggs laid in freshwater habitats are assigned a score of zero, as they would not be vulnerable to a marine oil spill. Species without an external egg stage (e.g., certain sharks) also receive a zero for this parameter.

2. *Larval location (Encounter)* – larval vertical distribution in the water column is important in determining the likelihood of encounter with spilled oil during the larval stage. Larvae found at or near the water surface (neustonic), or in the intertidal zone, are highly susceptible to surface oil slicks and are considered to have the greatest relative impact from oil spills. Larvae that occupy deeper subtidal habitats are relatively less likely to encounter spilled oil. Larvae in freshwater habitats are assigned a score of zero, as they would not be vulnerable to a marine oil spill. Species without a larval stage also receive a zero for this parameter.

3. *Juvenile/adult location (Encounter)* – juvenile/adult vertical distribution in the water column is important in determining the likelihood of encounter with spilled oil. Juveniles and adults found at or near the water surface (neustonic), or in the intertidal zone, are highly susceptible to surface oil slicks and are considered to have the greatest relative impact from oil spills. Juveniles and adults that occupy deeper subtidal habitats are relatively less likely to encounter spilled oil.

4. *Movements (Encounter)* – the movements of a species (e.g., swimming speed) may increase or decrease its time of residency in a body of water affected by an oil spill. Drifting or planktonic species present at the time of an oil spill would tend to be carried by ocean currents along with the oil, and thereby have a long duration of exposure relative to other species. Similarly, stationary species (e.g., benthic infauna) would not be able to move away from contaminated waters. Fast-moving species or those with a large home range are considered to be the least vulnerable relative to other species. This parameter is analogous to the avoidance/attraction parameter used for the other species groups.

5. *Site fidelity (Encounter)* – species exhibiting site fidelity within Alaska's waters are considered relatively more likely to encounter spilled oil, as they would likely try to return to or remain in the same area even if it were to become oiled or contaminated. Site fidelity refers to fixed locations utilized by a species for habitat, feeding, or breeding, for which alternate sites are not utilized. The site fidelity parameter only refers to fidelity during the time period the species is present within Alaska's waters.

6. *Feeding method (Encounter/Physiology)* – the foraging strategy of a species is important in determining the likelihood of encounter with oil, as well as the potential mechanism by which oil could enter the species' system. Filter-feeding species are

most likely to encounter oil due the volume of water filtered and the indiscriminate nature of this feeding method. Species that forage in benthic sediments are also given a relatively high impact score because of the potential to disturb contaminated sediments. Pelagic piscivores/scavengers are likely to have relatively low encounter rates with spilled oil and are therefore considered to have the lowest vulnerability to oil spills.

7. *Aggregation (Concentration)* – if a species forms large aggregations while in Alaska, an oil spill could potentially affect a large portion of the population at once. A species that only forms small aggregations or is solitary is considered to be relatively less vulnerable.

8. *Feeding specialization (Indirect Trophic Effects)* – an oil spill of any size is likely to alter trophic interactions to some degree. Feeding generalists are more capable of withstanding food web changes and are thereby assumed to be less vulnerable than a feeding specialist.

The scoring schemes for each of these parameters are listed in Table 15.

Table 15. Fish and invertebrate impact scores.

Impact Score	Category	Description
EGG LOCATION		
5	Neustonic or intertidal	Eggs are neustonic, or occupy intertidal habitats.
4	Estuarine/brackish	Eggs occupy estuarine waters or river mouths.
3	Epipelagic	Eggs are neutrally buoyant and occupy the upper water column (0–200 m).
2	Pelagic	Eggs are neutrally buoyant and occupy the mid-water column (below 200 m).
1	Demersal or semi-demersal	Eggs are semi-demersal, demersal, or adhered to benthic substrates in subtidal habitats.
0	In freshwater or life stage not applicable	Species does not have an external egg life stage, or eggs occupy freshwater environments.
LARVAL LOCATION		
5	Neustonic or intertidal	Larvae are neustonic, or occupy intertidal habitats.
4	Estuarine/brackish	Larvae occupy estuarine waters or river mouths.
3	Epipelagic	Larvae mainly occupy the upper water column (0–200 m).
2	Pelagic	Larvae mainly occupy the mid-water column (below 200 m).
1	Demersal or semi-demersal	Larvae are semi-demersal, demersal, or benthic in subtidal habitats.
0	In freshwater or life stage not applicable	Species does not have a larval life stage, or larvae occupy freshwater environments.
JUVENILE/ADULT LOCATION		
5	Neustonic or intertidal	Juveniles/adults are neustonic, or occupy intertidal habitats.
4	Estuarine/brackish	Juveniles/adults occupy estuarine waters or river mouths.
3	Epipelagic	Juveniles/adults mainly occupy the upper water column (0–200 m).
2	Pelagic	Juveniles/adults mainly occupy the mid-water column (below 200 m).
1	Demersal or semi-demersal	Juveniles/adults are semi-demersal, demersal, or benthic in subtidal habitats.
0	In freshwater	Juveniles/adults exclusively occupy freshwater environments.
MOVEMENTS		
5	Drifting/planktonic	Species is incapable, or minimally capable, of directed swimming, and drifts with ocean currents.
4	Stationary	Species is stationary.
3	Slow moving	Species swims slowly or moves only small distances.
1	Fast moving or large home range	Species is fast-swimming, or has a large home range.
SITE FIDELITY		
3	Demonstrates persistent site fidelity in Alaska	Species displays persistent site fidelity while in Alaska.
2	Demonstrates seasonal/transient site fidelity in Alaska	Species displays seasonal or transient site fidelity while in Alaska.
1	No site fidelity in Alaska	Species does not display site fidelity while in Alaska's waters.
FEEDING METHOD		
5	Filter feeding planktivore	Species utilizes filter-feeding strategies to extract plankton from the water column.
4	Forages in benthic sediments	Species extracts infauna from benthic substrates (disturbs substrate).
3	Non-filter feeding planktivore	Species primarily consumes plankton, but without a filter-feeding appendage/mechanism.
1	Non-filter feeding piscivore / scavenger	Species is a pelagic or demersal piscivore/scavenger.

Impact Score	Category	Description
AGGREGATION/CONCENTRATION		
5	Forms persistent large aggregations in Alaska	While in Alaska, species maintains large schools or aggregations.
3	Forms persistent small aggregations or seasonal/ transient aggregations in Alaska	While in Alaska, species forms persistent small aggregations/schools or seasonal (usually breeding- or feeding-related) aggregations/schools. Large aggregations/schools do not persist throughout the year.
1	Solitary or mostly solitary in Alaska	While in Alaska, species is solitary, or forms very small transient groups.
FEEDING SPECIALIZATION		
5	Highly specialized (narrow)	Species has limited diet at single trophic level. Substitution of preferred prey not likely.
3	Moderately adaptable	Species has limited diet at one or two trophic levels. Substitution of preferred prey possible.
1	Generalist	Species consumes variety of prey at multiple trophic levels, or wide variety of prey within a trophic level.

4.2.4 Recovery Potential

Scoring for recovery potential assesses how quickly a species population would be able to recover in the event of an oil spill. This is an important counterpoint to the impact scoring, as certain species may suffer a large impact from an oil spill, but are considered to be less vulnerable overall if they can recover quickly (e.g., euphausiids). In contrast, the loss of just a few individuals from a depleted, late-maturity/low fecundity species could result in a substantial long-term impact to a population. Along with the impact scoring, the recovery scoring attempts to capture this dynamic.

Three parameters are used to determine recovery potential. These three parameters are applied to all three of the species groups:

1. *Conservation/population status* – species* with greatly reduced breeding population numbers are compromised in their ability to recover from an impact. This parameter uses special conservation status as a proxy for population status. Species designated as endangered or threatened in Alaska are of particular regulatory and conservation concern and could be jeopardized by an oil spill. Conversely, non-listed species with "healthy" population levels are likely the most capable of recovering from an oil spill impact.

   *Note: Because individual stocks/DPSs were not scored separately in this initial application of the risk model, if a species was listed as endangered, threatened, or candidate anywhere in Alaska, the entire species was scored as such. For example, the Southeast Alaska DPS of Pacific herring is a candidate species for listing, so Pacific herring was given a score of 3 for this parameter, even though Pacific herring in other regions of Alaska do not have special status.

2. *Reproductive potential* – the reproductive capacity of individuals of a species is a key contributor to population recovery. If individuals have low reproductive capacity, the population would likely be slow to recover from adverse impacts, even if population levels are relatively high. Species with low fecundity rates and late maturation exhibit

reduced recovery potential relative to other species, and are therefore considered to be more vulnerable. Species exhibiting relatively high reproductive capacity are inherently more capable of population recovery from adverse oil spill impacts and are considered to be less vulnerable.

3. *Range when in Alaska* – the geographic range inhabited by a species is related to the proportion of a population that may be adversely affected by an oil spill in Alaska. A species endemic to Alaska is considered to be at relatively greater risk than a species with a global distribution. The geographic range of a species is also related to the population's relative ability to recolonize an area after significant adverse effects; however, this parameter only addresses recolonization potential in broad terms, as assessing population connectivity was beyond the scope of this project. This parameter is assessed only for the time period in which the species is present within Alaska. For example, during the summer, most of the world's population of western sandpiper is found in Alaska and the Northern Pacific, so the species is given a score of 4 for this parameter, despite the fact that it is found in both hemispheres and multiple ocean basins during other seasons.

The scoring schemes for each of these parameters are listed in Table 16. In instances where multiple scores were possible for a given species and parameter, the most conservative (i.e., greater number) score was assigned. The final recovery scores for each species and their rationales and references can be found in Appendix D.

Table 16. Recovery scores.

Recovery Score	Category	Description
CONSERVATION/POPULATION STATUS		
5	Federally or state listed as endangered	Federally- or state-listed as endangered in Alaska.
4	Federally or state listed as threatened	Federally- or state-listed as threatened in Alaska.
3	Candidate species; or species with very low population levels relative to historic	Candidate species for listing under the Endangered Species Act; or a species with very low population levels relative to historic (e.g., categorized as Vulnerable or higher on the IUCN Red List; NMFS "Species of Concern," or NatureServe state rank of Vulnerable of higher).
2	Low population levels relative to historic, or a population level in noted decline	Species is not listed, but the population in Alaska is low compared to historic levels (e.g., categorized as Near-Threatened on the IUCN Red List), or species remains abundant with a population in marked decline.
1	Healthy population levels relative to historic	Species is not listed, and the population in Alaska is "healthy" or relatively near historic levels (e.g., categorized as Least Concern on the IUCN Red List).
REPRODUCTIVE POTENTIAL		
5	Low reproductive capacity – Low fecundity/late maturing	Species has low reproductive capacity, with *low* fecundity (less than about 100 offspring per year) and a *late* age of sexual maturation (greater than about 4 years).
4	Low reproductive capacity – Low fecundity/early maturing	Species has low reproductive capacity, with *low* fecundity (less than about 100 offspring per year) and an *early* age of sexual maturation (less than about 4 years).
3	Moderate reproductive capacity	Species reproductive capacity falls between categories 4 and 2.
2	High reproductive capacity – High fecundity/late maturing	Species has high reproductive capacity, with *high* fecundity (greater than about 100 offspring per year) and a *late* age of sexual maturation (greater than about 4 years).
1	High reproductive capacity – High fecundity/early maturing	Species has high reproductive capacity, with *high* fecundity (greater than about 100 offspring per year) and an *early* age of sexual maturation (less than about 4 years).
RANGE WHEN IN ALASKA		
5	Endemic to Alaska	When the species is present in Alaska, the entire population is within Alaska.
4	Regional Pacific and/or regional Arctic	When the species is present in Alaska, the entire population is within the regional Pacific (i.e., the northeast Pacific Ocean) and/or within the regional Arctic Ocean.
3	Northern hemisphere Pacific or circumpolar	When the species is present in Alaska, the entire population is within the northern hemisphere Pacific Ocean, or is circumpolar.
2	Northern and southern hemisphere Pacific; or multiple ocean basins, northern hemisphere only	When the species is present in Alaska, the entire population is within both the northern and southern hemisphere Pacific Ocean; or in the northern hemisphere only, but in multiple ocean basins (e.g., in both the north Pacific and north Atlantic).
1	Multiple ocean basins, northern and southern hemispheres	When the species is present in Alaska, the population is distributed across multiple ocean basins and in the northern and southern hemispheres.

5.0 MODELING APPROACH: SPILL INCIDENTS AND VOLUMES

The spill risk portion of the risk model reflects (1) probability of an oil spill for each region, season, and oil type category based on past and projected future incidents; and (2) the potential MMPD and WCD volumes that could result from an incident now or in the future. Each oil type is considered separately in the model, as different oil types vary in their environmental effects (Section 5.1).

A detailed spill risk analysis was conducted for this study by ERC. The general approach for this analysis is summarized in Sections 5.2 and 5.3. The full report describing ERC's spill risk analysis is provided as Appendix A.

5.1 Oil Type Effects

In the risk model, oil type effects scores are applied to the overall environmental vulnerability for each region and season to calculate environmental vulnerability specific to the oil type potentially spilled (see Section 3.3.4). These oil type effects scores are taken directly from the WCS and evaluate the relative potential of spilled oil to cause acute toxicity and mechanical injury, and persist in the environment. Each parameter is rated on a 1 to 5 scale, where a 5 represents the most potential harm and a 1 represents the least potential harm.

The acute toxicity (AT) score is based on the percentage of bioavailable components (i.e., 1- to 3-ring aromatic compounds) in the oil and reflects the degree to which the oil is capable of causing adverse effects on fish, invertebrates, and wildlife after short-term exposure (hours to days). The acute toxicity score is calculated in the WCS (Washington Administrative Code 173-183-340) as:

$$AT_i = \frac{(SOL_{1i} * PCTWT_{1i}) + (SOL_{2i} * PCTWT_{2i}) + (SOL_{3i} * PCTWT_{3i})}{107}$$

Where: i = oil type; SOL_n = solubility in seawater of n-ring aromatic hydrocarbons, where n=1, 2 or 3; and $PCTWT_n$ = percent weight of n-ring aromatic hydrocarbons in the oil, where n = 1, 2 or 3. The final acute toxicity score is determined by rounding to the nearest tenth.

The mechanical injury (MI) score is based on the propensity of oil to coat or smother flora and fauna. In the WCS, heavier (denser) oils receive higher scores based on the following equation:

$$MI_i = \frac{(SP_i - 0.688)}{0.062}$$

Where: i = oil type and SP = specific gravity of the oil. The final mechanical injury score is determined by rounding to the nearest tenth.

The persistence score (PER) is based on the length of time oil is known (or likely) to persist in the environment. WCS oil persistence categories are listed in Table 17.

Table 17. Washington Compensation Schedule oil persistence categories and scores.

Expected Oil Retention Time	Persistence (PER)
5 to 10 years or more	5.0
2 to 5 years	4.0
1 to 2 years	3.0
1 month to 1 year	2.0
Days to weeks	1.0

The oil type effects scores for acute toxicity, mechanical injury, and persistence applied in the risk model are listed in Table 18.

Table 18. Oil type effects scores used in the analysis.

Oil Category	Acute Toxicity (AT)	Mechanical Injury (MI)	Persistence (PER)
Crude Oils	0.9	3.6	5.0
Heavy Oils	2.3	5.0	5.0
Light Oils	2.3	3.2	2.0
Distillates[1]	3.2	1.7	1.0

[1]Scores for distillates are based on an average of the WCS scores for kerosene and gasoline.

5.2 Historical/Current Spills

An analysis of historical vessel and facility incidents for the years 1995 through 2012 that led to oil spillage or could potentially have led to spillage in Alaska's marine waters and coastal areas was conducted by ERC to determine incident rates and potential volumes by region, source, oil type, and period. This 18-year period was selected because it provided the most extensive spill and casualty data. Prior to 1995, the ADEC Prevention and Emergency Response Program did not maintain a comprehensive spill database. The use of the data from this time period also allowed for analysis of post-Oil Pollution Act of 1990 spill rates, which are markedly lower than those for prior years due to implementation of spill prevention measures (Etkin, 2010; Homan and Steiner, 2008). The full report describing ERC's spill risk analysis is provided as Appendix A.

5.2.1 Incident Rates

In this study, "incidents" are defined as events involving vessels or facilities (including onshore facilities, pipelines and offshore wells) that could potentially result in the spillage of oil, such as casualties, accidents, discharges, and leakages.

To determine incident rates for each region, season, and oil type, ERC analyzed historical vessel and facility incidents for the years 1995 through 2012. Incidents in which oil spilled, or in which oil could potentially have spilled into marine waters, were included in the analysis. This approach allowed a broader spectrum of incidents to be evaluated with respect to characterizing probabilities of incidents and potential spillage. In total 10,985 incidents were included in the analysis. Of these incidents, 3,581 (34%) were facility-related incidents, and 7,404 incidents (67%) were related to vessels.

This analysis included a limited number of incidents located outside the boundaries of the study regions. These included incidents located in the Canadian Beaufort Sea and near British Columbia, as well as incidents in the Gulf of Alaska and south of the Aleutians. These incidents were included in the analysis because of the potential for oil to be transported to within the study regions (based on prevailing winds and currents).

Figure 9 shows the geographic distribution of incidents between 1995 and 2012.

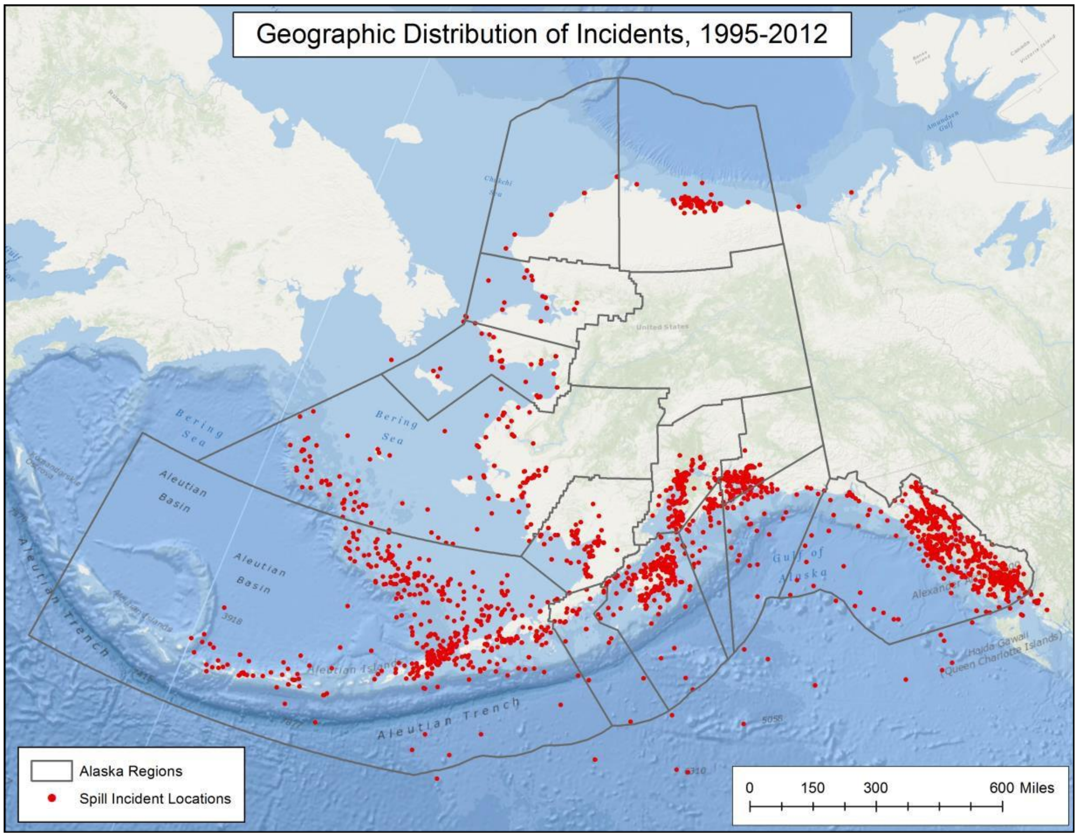


Figure 9. Geographic distribution of incidents, 1995–2012. Note: An individual red dot may represent multiple incidents.

The incident numbers for this 18-year time period reflect the relative probability that an incident might occur in the present time (future projections of incident frequencies are discussed in Section 5.3). The current/historical incident frequencies, F_{rop}, were calculated as follows:

$$F_{rop} = \frac{\sum_{y=0}^{y=t} (n_{rop})_y}{t}$$

Where: r = region; o = oil type; p = period, y = year number (1 to 18); and t = total number of years (18).

Out of the 336 possible region/oil type/period combinations (i.e., 14 region x 4 oil types x 6 periods), there are 99 instances in which there were no recorded incidents during the 18-year time period. There are a number of potential reasons for these zero values:

- There is no transport or usage of that particular type of oil in that region at any time of year or at particular times of year (e.g., no crude oil tanker transport or crude production and storage, or no larger vessels using heavy bunker fuel);

- The transport or usage of that particular oil type in that region at that time of year is very infrequent and there have been very few opportunities for an incident to occur during 18 years (i.e., the return year period is actually considerably longer than 18 years);

- There are particular prevention measures in place that have eliminated or greatly reduced the frequency of such incidents; or

- By chance there have been no incidents of that type during the 18-year time period, though it is possible that incidents could occur given the nature of the oil transport and usage in that region.

Considering these factors, each zero value was assessed to determine whether it was a true zero value, or simply due to lack of data. These F_{rop} values were then adjusted based on this information. For example, some values were left at zero, and others were filled with data from other seasons. The rationale for each adjustment is described in Table 19.

Table 19. Rationale for adjusting zero F_{rop} values.

Region	Oil Type	Period(s)	Reason(s) and Approach
Aleutians	Crude	All	Crude incidents have never occurred in this region in 18 years. While crude tankers may infrequently transit the Great Circle Route, in the absence of specific data, it is assumed that there is no crude transport or handling in this region. The incident rates were kept at zero for all time periods.
Aniakchak	Crude	1, 2, 4, 5, 6	There have been two incidents in 18 years (1999 and 2000), both occurring in Apr–May at a facility. The incident rates were averaged across all periods.
	Distillate	1, 2, 5	There have been three incidents in 18 years in different periods (Apr–May, Jun–Jul, and Oct–Nov). The incident rates were averaged across all periods.
	Heavy	2, 3, 5	There have been four incidents in 18 years involving cargo vessels. The incidents occurred in winter, spring, and fall periods. The incident rates were averaged across all periods.
Beaufort Sea	Distillate	1, 2, 3, 6	There have been four incidents in 18 years, all at facilities in summer. Incident rates were averaged over spring and fall months but not over winter months.
	Heavy	1, 2, 3, 4	Five incidents have occurred in 18 years, all during Aug–Nov from work boats and drilling facilities. It is assumed that these activities might also occur during spring and summer months but not in winter. The incident rates were averaged across all non-winter periods.

Region	Oil Type	Period(s)	Reason(s) and Approach
Bristol Bay	Crude	All	There have been no incidents involving crude oil in this region. There is also no known crude transport or handling in this region. The incident rates were kept at zero for all periods.
	Distillate	1, 2	There have been no distillate incidents in the winter months. With ice cover in this area, it is unlikely that smaller vessels using gasoline will be in use. The incident rate was kept at zero for the winter months.
	Heavy	1, 6	There have been no incidents of heavy oil spills in the winter months. However, because there is evidence of shipping and oil handling activity during this time based on incidents involving light oils, it is assumed that there is a possibility of heavy oil incidents in winter. The incident rate was averaged over these months.
Chukchi Sea	Crude	1, 2, 3, 5, 6	There is evidence of crude oil handling during winter months. The very low incident rate was averaged over all months.
	Distillate	1, 6	There is some evidence of transfer and usage of distillates during winter months. The very low incident rate was averaged over all months.
	Heavy	1, 2, 3, 4, 6	The most likely source of heavy oil in this region is from vessels. Due to the presence of ice during winter months, it is assumed that there would be no incidents during Dec–Mar. The very low incident rate was averaged over the other months.
	Light	3	There is evidence of light oil handling and transport in all other periods. The incident rate was averaged over all periods.
Kodiak/Shelikof Strait	Crude	1, 4, 5	There is evidence of crude oil handling/and transport during winter and summer months. The low incident rate was averaged over these months.
Kotzebue Sound/Hope Basin	Crude	All	There are no crude oil handling or transport activities in this region, so the incident rate was kept as zero for all periods.
	Distillate	1, 2	The most likely source of distillate in this region is smaller vessels, which are unlikely to operate during the winter, so the incident rate was kept as zero for these periods.
	Heavy	1, 2, 3, 4	The most likely source of heavy fuel in this region is large vessels, which are unlikely to operate during the winter. The low incident rate was averaged over spring and summer months only.
Norton Sound/St. Lawrence Island	Crude	All	There is no evidence of crude transport or handling in this region, so the incident rate was kept at zero for all time periods.
	Heavy	1, 2, 3, 6	The most likely source of heavy oil in this region is vessel bunkers. With ice coverage during winter, it is assumed there would be no vessel traffic of larger vessels during this period. The incident rate was kept at zero for winter months but averaged over spring and fall months.
Offshore Kenai Peninsula	Crude	1, 3, 4, 5, 6	There is the potential for crude transport in this area during all months. The very low incident rate was averaged over all months.
	Distillate	1	There is potential for distillate usage during this time. The incident rate was averaged over all months.
	Heavy	4, 6	There is potential for heavy oil usage during this time. The incident rate was averaged over all months.
South-Central Alaska	Crude	5	There is potential for crude transport during this time. The incident rate was averaged over this period.
	Distillate	1, 2, 6	The most likely source of distillates in this time period is recreational boating, which is unlikely during fall and winter months. The incident rate was kept at zero for these periods.
	Heavy	6	There is potential for heavy oil transport in bunkers during this time period. The incident rate was averaged over this period.

Region	Oil Type	Period(s)	Reason(s) and Approach
Southeastern Alaska	Crude	3, 4, 6	There is potential for crude transport and handling in all months. The very low incident rate was averaged over all months.
Western Alaska	Crude	All	There is no evidence of crude transport or handling in this region, so the incident rate was kept at zero for all periods.
	Distillate	6	There is evidence of distillate usage in this region in other time periods, so the incident rate was averaged over this period.
	Heavy	1, 2, 4	The most likely source of heavy oil is from large vessel bunkers. Due to ice coverage in winter, it is unlikely that there will be heavy oil incidents. The incident rate was kept at zero in winter but averaged over the summer period.

5.2.2 Spill Volumes

The degree of environmental impact from spills varies not only by the oil type, season, and region, but also by the relative volume of spillage. For each incident, there is a certain probability that a spill will ensue. This probability is related to the cause of the incident, the characteristics of the source, and various other factors. Not all incidents would result in actual spillage. The risk model reflects the probability of an incident with the potential for spillage occurring in a region, not the probability of actual spillage.

For each potential spill, there is a theoretical distribution of potential spill volumes. These distributions of spill volume are based on the source type (category of vessel or facility) and source sizes (volume of oil capacity). In most cases of spillage, the volume spilled is likely to be very small. Based on spill volumes for the years 1995–2012, most spills in Alaska (85%) involved less than 1 bbl (Table 20). Over 99% of the spills involved less than 50 bbl and only 0.1% involved more than 500 bbl. Clearly, the “most likely” spill volume is less than 1 bbl.

Table 20. Distribution of actual spill volumes in Alaska (1995-2012).

Spill Volume	Number of Incidents	Percent of Total Incidents	Percent of Total Spills
> 5,000 bbl	1	0.01%	0.01%
1,000 – 4,999 bbl	2	0.02%	0.02%
500 – 999 bbl	5	0.05%	0.06%
100 – 499 bbl	32	0.29%	0.37%
50 – 99 bbl	30	0.27%	0.35%
10 – 49 bbl	223	2.03%	2.57%
5 – 9 bbl	156	1.42%	1.80%
1 – 4 bbl	832	7.57%	9.60%
< 1 bbl	7,386	67.24%	85.22%
0 bbl (potential only)	2,318	21.10%	-
Total Incidents	**10,985**	-	-
Total Spills	**8,667**	-	-

Though large spills have a very low likelihood of occurrence, they must be taken into account for contingency planning and risk mitigation development. To assess the volumes that are likely to cause the most environmental damage, WCD and MMPD volumes are applied in the risk model.

5.2.2.1 Maximum Most Probable Discharge

The USCG defines the MMPD (33 CFR 154.1020 and 155.1020) as follows:

- Facility MMPD = the *lesser* of 1,200 bbl or 10% of the WCD;
- Vessel (<25,000 deadweight tonnage [DWT]) MMPD = 10% of the WCD; and
- Vessel (≥25,000 DWT) MMPD = 2,500 bbl.

Since there is no analogous equivalent for offshore wells in the BOEM or the Bureau of Safety and Environmental Enforcement (BSEE) regulations, the facility MMPD of 1,200 bbl was applied to offshore wells in this analysis.

For each region, period, and oil type, the MMPD volumes for all source types were weight-averaged so that the MMPD volumes were represented in proportion to their occurrence (i.e., incident rate) by source type within each oil type.

5.2.2.2 Worst-Case Discharge

According to USCG regulations (33 CFR 155.1020), the WCD volume for a particular vessel is defined as the total release of the maximum capacity of oil on board. For a tank vessel (e.g., tank barge or tanker), this would include both the bunker fuel tanks and the oil cargo tanks. For a non-tank vessel (e.g., cargo vessel), this would include the bunker fuel tanks. The calculations for determining the WCD for vessels are relatively straightforward if the size (gross tonnage [GT] or DWT) of the vessel or the actual bunker and/or oil cargo capacities are known. Note that all vessels contain other oils used for lubrication and various functions on the vessel. The volumes of these products are generally considerably smaller than the oil cargo/bunker tanks and are not generally factored into the calculation of total capacity, as they would constitute a minor fraction of total spillage in a WCD.

For each region, season, and oil type, the estimated WCD volumes for vessels are based on the largest vessel capacity in that category (e.g., the largest bulk carrier's capacity).

The estimated WCD volume for tankers and tank barges is based on the formula:

$$K_o = 6.795 * DWT$$

Where K_o = actual tank ship cargo load (in barrels) and *DWT* = deadweight tonnage of tank vessel (Etkin, 1999; Etkin and Michel, 2003; Etkin et al., 2009; French-McCay et al., 2008; State of WA JLARC, 2009; Nuka et al., 2006). Based on this calculation, the WCD for the largest crude oil tanker is 1.9 million barrels. This volume is about 7 times the volume of the 1989 *Exxon Valdez* spill.

The bunker capacity for general cargo vessels, bulk carriers, and other larger vessels is based on a regression of known bunker capacities and DWTs according to this formula:

$$K_b = 0.0238 * DWT + 2{,}545$$

Where K_b = bunker capacity (in barrels).

For other vessels, typical bunker capacities based on vessel size, as derived from inspection of ERC vessel databases, were applied.

For offshore and onshore oil platforms and wells, calculating the actual WCD is more complex, as was duly experienced during the 2010 Macondo MC252 well blowout in the Gulf of Mexico. NOAA defines a well blowout as "an uncontrolled flow of gas, oil, or other fluids from a well into the atmosphere or into an underground formation." BOEM and BSEE define a "loss of well control" as "uncontrolled flow of formation or other fluids, including flow to an exposed formation (an underground blowout) or at the surface (a surface blowout), flow through a diverter, or uncontrolled flow resulting from a failure of surface equipment or procedures." For offshore wells, the WCDs depend on the pressure in the well, the size and type of pipe or riser, the type of blowout preventer, the length of time before a discharge is detected, and the length of time to capping of the well or stemming of the flow of oil with relief wells. EPA regulations (40 CFR 112.20) stipulate that the WCD for a well is defined as "30 days of flow at the daily production rate for wells that are 10,000 feet or less, and 45 days of flow at the daily production rate for wells that are 10,000 feet or more." This definition of WCD for wells is applied in this study, with the exception of the WCDs for Beaufort and Chukchi Sea wells. For these regions, the WCDs for offshore wells are assumed to be those that are presented in BOEM's 2012-2017 OCS Oil and Gas Leasing Program Final Programmatic Environmental Impact Assessment (BOEM, 2012) as "Catastrophic Discharge Events" (CDEs), as these values resulted in higher WCD volumes than the EPA regulatory definition and represent the equivalent level of catastrophic event as a worst-case discharge tanker spill in which the entire contents of the tanker spills. The discharge volumes for the Beaufort and Chukchi Sea regions are 3.9 million bbl and 2.2 million bbl, respectively. For the Cook Inlet, Kodiak/Shelikof Strait, and Aniakchak regions, the discharge volume is 39,000 bbl, due to the differences in recorded production rates from the different regions, as well as differences in the durations of flow due to factors such as type of drilling rig and rig availability to drill relief wells during open-water season.

The WCD volumes for facilities are also difficult to calculate. For an onshore facility or deep-water port or facility, the WCD is defined as "the largest foreseeable discharge in adverse weather conditions" (33 CFR 154.1020). The WCD for each facility will depend on the capacity of storage tanks, the numbers and lengths of pipelines between control points (shut-off valves, etc.), the pressure in the pipelines, the diameters of the pipelines, the lengths of time between pipeline inspections and the time it would typically take to detect a loss of oil, and other factors. WCD volumes were assumed for each facility type based on review of typical oil capacities in EPA-regulated facilities (Etkin, 2002, 2003, 2004, 2006; Etkin et al., 2009). Resulting WCD volumes are listed in Table 21.

Table 21. WCD volumes assumed for each facility type.

Facility Type	Estimated WCD Volume (bbl)
Airport	50,000
Barge Terminal	1,000
Bulk Chemical	10,000
Construction	100
Container Terminal	1,000
Cruise Ship Terminal	1,000
Drydock	1,000
Ferry Terminal	1,000
Fuel Terminal	30,000
Logging	1,000
Marine Services	1,000
Military	10,000
Mining	100
Municipal Fuel Storage	1,000
Offshore Services	1,000
Oil Exploration/ Production (Beaufort)	3,900,000
Oil Exploration/Production (Chukchi)	2,200,000
Oil Exploration/Production (other regions)	39,000
Other	100
Petroleum Terminal	200,000
Pipeline Transport	45,000
Power Plant	50,000
Refinery	200,000
Residential	10
Seafood Industry	1,000
Ship Terminal	10,000
Small Boat Harbor	1,000
Unknown	100
Vehicle	2

For any region, period, and oil type combination, the WCD used in the risk model is the largest discharge of the sources that are likely to be present in the region at that time period, carrying that type of oil.

5.3 Projected Future Spillage

Forecasting patterns of future spillage in Alaska is a challenging task. There are a large number of interrelated economic and environmental factors to consider, along with a great deal of uncertainty. Future changes in spillage patterns could result from changes in the frequency (annual probability) of spillage, the volume of spillage, spill locations, and/or oil types spilled. Potential factors that could conceivably affect future incident rates in Alaska are described in Table 22.

Only incidents rates and MMPD/WCD spill volumes were projected for the year 2025. As stated earlier, no future projections of environmental vulnerability were calculated for this project, as projecting future trends for environmental conditions (e.g., individual species' distributions, shoreline location/type, and ice coverage) is inherently complex and uncertain, and was beyond the scope of the current project.

Table 22. Potential factors impacting future incident rates.

Factor	Confounding Factors	Potential for Incident Increases by 2025	Potential for Incident Decreases by 2025
Cargo Shipping Vessel Traffic	• U.S. economic conditions • World markets for commodities • Traffic routes (opening of Arctic shipping routes) • Implementation of double hull regulations on bunker tanks • Changes in conditions of cargo vessel fleets • Changes in vessel traffic management and safety regulation enforcement. • Changes in USCG inspection rates. • Increases in sizes of cargo vessels (fewer trips) • Expansion of Roberts Bank Terminal in Vancouver, BC	If cargo shipping (bulk commodities, containers) increases or if Arctic shipping routes increase, there will be increased pass-through vessel traffic, particularly in the Aleutians. With expansion of the Roberts Bank Terminal, there may be more incidents involving container ships and bulk carriers in the Southeast.	If there is decreased overall shipping due to economic conditions, there may be less traffic. This would particularly affect the Aleutians. Continued implementation of double hull regulations on bunker tanks will reduce spillage due to collisions, allisions, and groundings. Improved enforcement of safety regulations and better vessel traffic management in ports and higher-volume shipping lanes will reduce spills. Increases in port state vessel inspections will decrease incidents.
Crude Tanker Vessel Traffic	• World markets for oil • Degree of production on Alaska North Slope and other areas • Relative reliance on Trans-Alaska Pipeline vs. tankers for transport of crude from North Slope to Valdez • Changes of conditions in tanker fleets • U.S. economic conditions	Increased oil production in the Beaufort Sea and Chukchi Sea along with other production could increase the need for tanker traffic out of Valdez.	Decreased oil production could lead to decreases in crude oil tanker transport.
Product Tanker and Tank Barge Vessel Traffic	• Changes in demands for refined products • Changes in refinery throughput rates • U.S. economic conditions	Increased demand for refined products and increased refinery throughput could lead to increases in product traffic.	Decreased demand for refined products and decreases refinery throughput could lead to decreases in product traffic.
Fishing Vessel Traffic	• Changes in levels of fishing activity • Changes in fisheries (overfishing, available catches) • Native tribe populations	Increased fishing activity due to discovery of new fishing grounds or increases in fish populations due to environmental factors could increase fishing vessel traffic.	Decreased fishing activity due to decreases in fish populations or changes in environmental factors could decrease fishing vessel traffic.
Cruise Vessel Traffic	• U.S. economic conditions • Tourism industry changes	Increased tourism to Alaska could lead to increased cruise ship traffic.	Decreased tourism to Alaska could lead to decreased cruise ship traffic.
Other Vessel Traffic	• Changes in local economic conditions • Population changes	Increased population levels and general increased economic activity could lead to increased vessel traffic.	Decreased population levels and general decreased economic activity could lead to decreased vessel traffic.
Oil Exploration and Production Activities	• U.S. and world economic conditions • Regulatory issues • Reliance on alternative energy	Increased oil production could lead to increased potential for spillage.	Decreased oil production could lead to decreased potential for spillage.

5.3.1 Incident Rates

Based on a literature review of studies related to future spillage risk, various assumptions were applied to forecast incident rates for the year 2025 for this study, as discussed below.

Several of these assumptions relate to factors that reduce the probability of an incident becoming a spill event. For example, risk mitigation practices and/or the use of double-hulled tanks reduce the potential for spillage in the event of an incident. As such, an incident that no longer has the potential to result in a spill is removed from the incident rates used in the risk model (as the incident rates in the model are intended to reflect only incidents potentially resulting in spills). Assumptions applied in the projection of future incident rates include:

- Potential reduction in overall tanker spill incidents by 34% attributable to additional changes in risk mitigation measures for causes other than impact accidents. This is based on a conservative application of the 68% reduction rate potential described in the Prince William Sound Risk Assessment (Harrald et al., 1996; Merrick et al., 2002; Grabowski, 2005).
- A decrease in the probability of spillage from non-tank vessels by 23% due to the presence of double hulls on bunker tanks on 45% of vessels (based on Kirtley et al., 2012; Etkin, 2002 with modifications for findings in Yip et al., 2011 and NRC, 1991; and Etkin 2013).
- Reduction in spill probability based on full implementation of double hulls for tank vessels (tankers and tank barges) due to impact accidents (i.e., collisions, allisions, and groundings), which make up 2% of tanker incidents and 16% of barge incidents in Alaska, as follows (based on Kirtley et al., 2012; Etkin, 2002 with modifications for findings in Yip et al., 2011 and NRC, 1991; and Etkin 2013):
    - Crude tankers: 67% reduction;
    - Product tankers: 63% reduction; and
    - Tank barges: 58% reduction.

Additional assumptions in the projection of future incident rates involve changes in vessel traffic patterns. These changes in vessel traffic (based on Det Norske Veritas and ERM-West, 2010) are assumed to be directly proportional to the changes in future incident rates:

- Increase of vessel traffic in Cook Inlet and other regions (except Aleutians, Beaufort Sea, and Chukchi Sea) by 25%;
- Increase in vessel traffic in the Aleutians, Beaufort Sea, and Chukchi Sea regions as follows:
    - Container ships: 34% increase;
    - Bulk carriers: 6% increase;
    - General cargo vessels: 82% increase; and
    - Product tankers: 133% increase.

Seasonal distribution of incidents is assumed to change as ice coverage continues to decrease and marine engineering advances improve the ability of vessels to transit through ice. For any time periods for which the current incident rate is zero for shipping, oil production, or other activities (with the exception of recreational boating and cruise ship transits), the incident rate was increased to reflect increased access to areas that were formerly ice-covered during the season.

The future projections also include an assumed change in the distribution of oil types. A shift of 50% from heavy bunker fuel to diesel fuel on larger ships is assumed due to regulatory changes related to air emissions in nearshore and port areas (IMO, 2006).

Facility incident rates are assumed to change as follows:

- Increase in Beaufort Sea oil exploration and production-related incident rates by 400% (Bercha 2002, 2011).
- Increase in Chukchi Sea oil exploration and production-related incident rates by 150% (Bercha, 2011).
- Increase of 20% in Cook Inlet incident rates from oil exploration and production. This is based on a slight decrease predicted by U.S. Energy Information Administration forecasts coupled with potential increase in production predicted by Eley (2012).

For any region/season/oil type combination that was not already adjusted based on the assumptions listed above, an incident rate increase of 14% was applied. This percentage is based on an assumed annual increase in economic growth of 2.5% tempered by a 30% increase in the effectiveness of spill prevention and risk mitigation measures to reduce spillage.

5.3.2 Spill Volumes

Future potential WCD and MMPD spill volumes for the year 2025 were adjusted from the present-day estimates based on the assumed changes in the underlying source incidents (as described in Section 5.3.1 above). The future estimates also include an assumed 50% reduction in WCD volumes for crude and product tankers (based on Etkin and Michel, 2003; Rawson, 1998; NRC, 1991; NRC 1998).

6.0 RESULTS

Selected key results of the initial application of the model are discussed in the following sections. Additional permutations of the results can be viewed through the Alaska Spill Risk Calculator (Appendix E), a simple interface tool developed for this project to allow easy viewing and export of model results.

6.1 Environmental Vulnerability

The environmental vulnerability (EV) parameter captures the vulnerability of species (birds, marine mammals and sea turtles, and fish and invertebrates) and habitats (bottom, ice, shoreline, protected areas) for each region during each period. Greater environmental vulnerability indicates a region/period that contains species and habitats that are relatively sensitive to oil spill impacts. The maximum possible environmental vulnerability score for any region/period is 2.0. See Sections 3.3.3 and 4.0 for a detailed description of the environmental vulnerability portion of the model. It should be noted that no future projections of EV were calculated for this project (unlike spill incident rates and volumes). Projecting future trends for environmental conditions (e.g., individual species' distributions, shoreline location/type, and ice coverage) is inherently complex and uncertain, and was beyond the scope of the current project.

Table 23 presents the EV scores for each region and period, as well as the yearly mean score. The highest EV score is for the Aleutians region in June–July. The Aleutians region also had the highest yearly mean EV, followed by the Norton Sound/St. Lawrence Island and Kodiak/Shelikof Strait regions. The Bristol Bay and South-Central Alaska regions have the lowest yearly mean EV scores. Overall (across all regions), the greatest EV scores occurred in late spring and early summer (April through July) while the lowest EV scores occurred in late fall (October through November). This result is driven mainly by the migrations of species that spend the summer in Alaska.

Table 23. Environmental vulnerability (EV) scores for each region and period, sorted by yearly mean score.

Region	Period						Yearly Mean
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	
Aleutians	1.48	1.44	1.51	1.55	1.49	1.53	1.50
Norton Sound/St. Lawrence Is.	1.38	1.39	1.46	1.44	1.21	1.27	1.36
Kodiak/Shelikof Strait	1.27	1.24	1.37	1.36	1.33	1.27	1.31
Western Alaska	1.24	1.31	1.38	1.36	1.17	1.18	1.27
Kotzebue Sound/Hope Basin	1.09	1.08	1.30	1.27	1.14	1.10	1.17
Cook Inlet	1.20	1.21	1.32	1.14	1.09	1.02	1.16
Aniakchak	1.09	1.10	1.19	1.22	1.17	1.13	1.15
Chukchi Sea	0.99	0.98	1.19	1.31	1.16	1.06	1.12
Offshore Kenai Peninsula	1.09	1.04	1.14	1.14	1.11	1.03	1.09
Prince William Sound	1.02	1.03	1.16	1.05	1.00	0.91	1.03
Beaufort Sea	0.87	0.87	1.05	1.24	1.13	0.98	1.02
Southeast Alaska	0.94	0.93	1.08	1.09	1.07	0.98	1.01
Bristol Bay	1.01	1.05	1.05	0.95	0.88	0.98	0.99
South-Central Alaska	0.94	0.88	1.03	1.06	1.03	0.92	0.98
Seasonal Average	1.12	1.11	1.23	1.23	1.14	1.10	

Table 24 shows the yearly mean input values by region for each component of the EV score: the habitat vulnerability score (HVS), marine mammal and sea turtle vulnerability score (MTVS), bird vulnerability score (BVS), and fish and invertebrate vulnerability score (FVS). By examining these inputs, the main drivers of the EV score for each region become apparent. For example, the high mean EV score for the Aleutians region is driven by high mean species vulnerability scores, particularly for marine mammals/sea turtles and fish/invertebrates. Conversely, the high mean EV score for the Norton Sound/St. Lawrence Island region is driven by high mean habitat scores (HVS), due to sensitive shoreline, bottom habitats, and high seasonal ice coverage.

Table 24. Yearly mean environmental vulnerability (EV) scores for each region. Columns 2 through 5 display the yearly mean values for the input parameters to the EV equation. Table is sorted by the mean EV score.

Region	Mean HVS	Mean MTVS	Mean BVS	Mean FVS	Mean EV
Aleutians	0.63	0.90	0.74	0.97	1.50
Norton Sound/St. Lawrence Is.	0.89	0.42	0.43	0.56	1.36
Kodiak/Shelikof Strait	0.62	0.53	0.81	0.73	1.31
Western Alaska	0.71	0.47	0.47	0.75	1.27
Kotzebue Sound/Hope Basin	0.83	0.31	0.31	0.39	1.17
Cook Inlet	0.71	0.25	0.75	0.35	1.16
Aniakchak	0.58	0.34	0.75	0.63	1.15
Chukchi Sea	0.79	0.40	0.32	0.26	1.12
Offshore Kenai Peninsula	0.57	0.34	0.79	0.42	1.09
Prince William Sound	0.65	0.22	0.58	0.34	1.03
Beaufort Sea	0.73	0.34	0.30	0.24	1.02
Southeast Alaska	0.43	0.59	0.68	0.48	1.01
Bristol Bay	0.56	0.33	0.49	0.45	0.99
South-Central Alaska	0.51	0.34	0.63	0.42	0.98

The EV score for each region and season is then multiplied by an oil-type effects score (see Section 5.1) to calculate an oil-type-modified environmental vulnerability (EVO) for each oil type, region, and season. The EVO score accounts for the environmental vulnerability of the region and scales it based on oil-specific acute toxicity, mechanical injury, and persistence of types of oil that could be spilled. Heavy oils and crude oil have the highest overall oil effects score. This leads to the greatest EVO scores occurring for heavy and crude oils during summer months (due to greater EV scores in summer months). EVO scores scale directly with EV scores because the oil effects scores do not vary by region or season. As such, mean annual EVO scores by oil type are greatest in the Aleutians and Norton Sound/St. Lawrence Island regions (Table 25).

Table 25. Yearly mean oil-type-modified environmental vulnerability (EVO) by oil type. Table is sorted based on the sum of all oil types.

Region	Yearly Mean EVO				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Aleutians	6.9	3.4	9.6	4.9	24.8
Norton Sound/St. Lawrence Is.	6.0	2.9	8.5	4.3	21.6
Kodiak/Shelikof Strait	5.7	2.7	8.1	4.0	20.4
Western Alaska	5.5	2.5	7.8	3.8	19.7
Kotzebue Sound/Hope Basin	4.8	2.1	6.9	3.3	17.2
Cook Inlet	4.8	2.1	6.9	3.3	17.2
Aniakchak	4.7	2.1	6.8	3.3	16.9
Chukchi Sea	4.5	1.9	6.5	3.1	16.1
Offshore Kenai Peninsula	4.4	1.8	6.3	3.0	15.5
Prince William Sound	4.0	1.6	5.8	2.7	14.1
Beaufort Sea	4.0	1.6	5.8	2.6	14.0
Southeast Alaska	3.9	1.5	5.7	2.6	13.7
Bristol Bay	3.7	1.5	5.5	2.5	13.2
South-Central Alaska	3.7	1.4	5.5	2.4	13.0

6.2 Spill Incident Rates and Volumes

The full results of the spill incident rate and volumes analysis are described in Appendix A. Key results carried through to the risk model are summarized here.

6.2.1 Incident Rates

Based on the analysis of historical incidents, the most frequent type of vessel incident is one involving a small fishing vessel. The next most frequent incident is one involving a small recreational vessel, followed by a large fishing vessel. On average, small fishing vessel incidents in Alaska occurred every 2 days during 1995–2012. Recreational vessel incidents occurred every 3 days. Incidents involving smaller (<90,000 DWT) tank ships occurred about every 90 days, while larger tank ship incidents occurred about every 111 days, on average.

The greatest number of facility-sourced incidents in Alaska from 1995–2012 (55%) occurred from facilities involved in oil exploration and production activities. On average, an incident occurred at an oil exploration and production facility every 3.3 days. The next most frequent facility incidents were those that occurred at small boat harbors (from the facilities themselves, not from the vessels within the harbors), comprising 8% of the incidents and occurring about once every 23 days. On average, a facility incident occurred every 1.8 days or nearly 200 times per year. The highest numbers of facility incidents were from offshore oil exploration and production facilities in the Beaufort Sea and Cook Inlet regions.

The region with the highest incident rate for all oil types summed was Southeast Alaska during the months of June–July (Table 26). Southeast Alaska also has the highest yearly mean incident rates, followed by the Aleutians and Beaufort Sea regions. On average (across all regions), incident rates are highest during the months of June to September. This is reflective of the high level of recreational boating and fishing that occurs during this time period.

Based on the projection of future incident rates for the year 2025, the region with the highest incident rate is predicted to be the Beaufort Sea region in February–March (Table 27). This is due to the fact that this season had the highest incident rate in the underlying historical data (see Table 26). The Beaufort Sea also has the highest yearly mean incident rate, followed by Southeast Alaska and the Aleutians (Table 27). Like the historic incident rates, 2025 average incident rates (across all regions) are predicted to be highest during the summer months.

Table 26. Current/historical incident rates (number per year) by period, sorted by the yearly mean incident rate. The yearly mean incident rate is based on the sum of all oil types. Coloring is based on the collective values from both the historical rates and the future rates (Table 27), and is directly comparable between the two tables.

Region	Current/Historical Incident Rate (# per year)						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Southeast Alaska	22.7	29.5	27.9	48.5	43.3	29.8	33.6
Aleutians	12.0	20.7	12.9	14.3	17.4	12.0	14.9
Beaufort Sea	12.5	16.8	15.9	14.6	12.4	10.2	13.7
Cook Inlet	8.8	10.1	14.3	16.1	15.8	9.2	12.4
Prince William Sound	7.0	7.3	8.9	14.0	9.1	6.5	8.8
Kodiak/Shelikof Strait	7.6	7.7	7.9	9.6	7.2	6.6	7.8
Western Alaska	1.5	1.8	3.2	4.8	5.0	2.3	3.1
Offshore Kenai Peninsula	1.5	2.3	2.8	3.2	2.6	1.8	2.4
Bristol Bay	0.3	0.6	2.6	7.1	1.5	0.6	2.1
South-Central Alaska	0.6	1.1	1.5	1.0	1.1	0.5	1.0
Norton Sound/St. Lawrence Is.	0.4	0.5	0.4	1.7	1.3	0.8	0.9
Aniakchak	0.2	0.9	0.5	0.7	0.7	0.4	0.6
Kotzebue Sound/Hope Basin	0.1	0.3	0.3	0.9	0.5	0.5	0.4
Chukchi Sea	0.3	0.2	0.2	0.2	0.7	0.2	0.3
Seasonal Average	5.4	7.1	7.1	9.8	8.5	5.8	

Table 27. Projected 2025 incident rates (number per year) by period, sorted by the yearly mean incident rate. The yearly mean incident rate is based on the sum of all oil types. Coloring is based on the collective values from both the historical rates (Table 26) and the future rates, and is directly comparable between the two tables.

Region	2025 Incident Rate (# per year)						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Beaufort Sea	61.3	82.8	78.0	72.8	60.8	50.3	67.7
Southeast Alaska	26.3	34.7	32.8	54.2	48.1	33.5	38.3
Aleutians	13.7	24.0	15.1	16.9	20.1	13.9	17.3
Cook Inlet	10.0	11.5	16.2	18.5	18.4	10.7	14.2
Prince William Sound	7.2	7.6	9.4	16.0	9.6	7.7	9.6
Kodiak/Shelikof Strait	8.7	8.7	9.1	11.0	8.1	7.4	8.8
Western Alaska	1.7	2.1	3.6	5.2	5.5	2.4	3.4
Offshore Kenai Peninsula	1.6	2.6	3.2	3.6	2.8	2.5	2.7
Bristol Bay	0.4	0.8	2.7	7.8	1.6	0.5	2.3
South-Central Alaska	0.6	1.2	1.5	1.0	1.2	0.6	1.0
Norton Sound/St. Lawrence Is.	0.5	0.6	0.4	1.8	1.3	0.9	0.9
Aniakchak	0.2	1.0	0.5	0.8	0.8	0.4	0.6
Chukchi Sea	0.3	0.4	0.3	1.1	0.8	0.6	0.6
Kotzebue Sound/Hope Basin	0.3	0.5	0.2	0.8	0.4	0.5	0.5
Seasonal Average	9.5	12.7	12.4	15.1	12.8	9.4	

Across all regions, the majority of past incidents (nearly 87%) involved light oils, mainly diesel. The region with the highest incident rate for light oils was the Southeast Alaska region (Table 28). The next highest incident rates are for light oil in the Aleutians and Beaufort Sea regions. For the 2025 projection, light oil spills remain the most frequent incident type overall, with light oil spills in the Beaufort Sea region projected to be the most frequent (Table 29). The next highest future incident rates are for light oil in Southeast Alaska and crude oil in the Beaufort Sea.

Table 28. Yearly mean current/historical incident rates (number per year) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the historical rates and the future rates (Table 29), and is directly comparable between the two tables.

Region	Yearly Mean Current/Historical Incident Rate (# per year)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Southeast Alaska	0.03	2.6	0.5	30.5	33.6
Aleutians	0	0.3	0.5	14.1	14.9
Beaufort Sea	3.1	0.04	0.05	10.5	13.7
Cook Inlet	2.1	0.7	0.4	9.3	12.4
Prince William Sound	0.6	0.6	0.1	7.5	8.8
Kodiak/Shelikof Strait	0.05	0.2	0.2	7.3	7.8
Western Alaska	0	0.4	0.05	2.7	3.1
Offshore Kenai Peninsula	0.01	0.1	0.06	2.1	2.4
Bristol Bay	0	0.2	0.1	1.8	2.1
South-Central Alaska	0.07	0.07	0.07	0.7	1.0
Norton Sound/St. Lawrence Is.	0	0.1	0.03	0.7	0.9
Aniakchak	0.02	0.03	0.04	0.5	0.6
Kotzebue Sound/Hope Basin	0	0.06	0.02	0.3	0.4
Chukchi Sea	0.01	0.07	0.01	0.2	0.3

Table 29. Yearly mean projected 2025 incident rates (number per year), sorted by the sum of all oil types. Coloring is based on the collective values from both the historical rates (Table 28) and the future rates, and is directly comparable between the two tables.

Region	Yearly Mean 2025 Incident Rate (# per year)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	17.1	0.4	0.06	50.2	67.7
Southeast Alaska	0.04	2.7	0.4	35.2	38.3
Aleutians	0.07	0.6	0.3	16.3	17.3
Cook Inlet	1.9	0.8	1.3	10.1	14.2
Prince William Sound	0.3	0.7	1.0	7.6	9.6
Kodiak/Shelikof Strait	0.01	0.4	0.09	8.3	8.8
Western Alaska	0	0.3	0.04	3.1	3.4
Offshore Kenai Peninsula	0.003	0.2	0.03	2.5	2.7
Bristol Bay	0	0.1	0.03	2.1	2.3
South-Central Alaska	0.04	0.04	0.04	0.9	1.0
Norton Sound/St. Lawrence Is.	0	0.1	0.01	0.8	0.9
Aniakchak	0.008	0.04	0.02	0.5	0.6
Chukchi Sea	0.06	0.03	0.03	0.5	0.6
Kotzebue Sound/Hope Basin	0	0.1	0.02	0.3	0.5

6.2.2 Volumes

As discussed in previous sections and shown in Table 20, the spill volumes associated with incidents in Alaska during 1995–2012 were very small. Most spills (85%) involved less than 1 bbl. Over 99% of the spills involved less than 50 bbl and only 0.1% involved more than 500 bbl. Clearly, the “most likely” spill volume is less than 1 bbl.

Though large spills have a very low likelihood of occurrence, they must be taken into account for contingency planning and risk mitigation development. To assess the volumes that are likely to cause the most environmental damage, theoretical MMPD and WCD volumes are applied in the risk model and discussed in the following sections. It is important to note that these volumes are not reflective of actual past incidents in Alaska.

6.2.2.1 Maximum Most Probable Discharge

For each region, period, and oil type, the MMPD volumes for all source types were weight-averaged so that the MMPD volumes were represented in proportion to their occurrence (i.e., incident rate) by source type. The resulting theoretical MMPD volumes by region and oil type are shown in Table 30 and Table 31. Current theoretical MMPD volumes are highest for crude and light oils in the Beaufort Sea region, at 1,200 bbl (Table 30). The next highest MMPD volumes are 830 bbl for all oil types in Cook Inlet and 800 bbl for distillate/heavy oils in the Beaufort Sea.

Based on the projection of future theoretical MMPDs for the year 2025, the largest MMPD volume is for crude oil in South-Central Alaska (2,500 bbl), followed by heavy oils in Aniakchak (2,300 bbl), and heavy oils in South-Central Alaska (2,200 bbl) (Table 31**Error! Reference source not found.**). These differences are attributable to expected changes in vessel traffic composition.

Table 30. Yearly mean current theoretical MMPD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPDs and future MMPDs (Table 31), and is directly comparable between the two tables.

Region	Current Theoretical MMPD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	1,200	800	800	1,200	4,000
Cook Inlet	830	830	830	830	3,320
South-Central Alaska	670	670	670	670	2,680
Aniakchak	560	560	560	560	2,240
Chukchi Sea	560	560	560	560	2,240
Prince William Sound	520	520	520	520	2,080
Kotzebue Sound/Hope Basin	0	527	527	790	1,843
Norton Sound/St. Lawrence Is.	0	650	433	650	1,733
Western Alaska	0	510	340	510	1,360
Bristol Bay	0	280	420	420	1,120
Southeast Alaska	230	230	230	230	920
Aleutians	0	250	250	250	750
Kodiak/Shelikof Strait	150	150	150	150	600
Offshore Kenai Peninsula	150	150	150	150	600

Table 31. Yearly mean projected 2025 theoretical MMPD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPDs (Table 30) and future MMPDs, and is directly comparable between the two tables.

Region	2025 Theoretical MMPD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
South-Central Alaska	2,500	300	2,200	400	5,400
Beaufort Sea	1,200	1,100	1,600	1,200	5,100
Aniakchak	1,900	400	2,300	400	5,000
Chukchi Sea	1,200	200	2,000	800	4,200
Prince William Sound	2,000	600	1,200	200	4,000
Cook Inlet	1,200	800	1,200	700	3,900
Kodiak/Shelikof Strait	1,700	300	1,200	100	3,300
Offshore Kenai Peninsula	1,900	300	700	100	3,000
Aleutians	600	400	1,500	200	2,700
Kotzebue Sound/Hope Basin	0	300	1,400	800	2,500
Southeast Alaska	1,200	200	900	200	2,500
Western Alaska	0	700	800	400	1,900
Bristol Bay	0	1,000	500	200	1,700
Norton Sound/St. Lawrence Is.	0	700	200	500	1,400

6.2.2.2 Worst-Case Discharge

For each region, period, and oil type, the WCD used in the risk model is the largest discharge from the sources that are likely to be present in the region during that time period, carrying that type of oil. The largest potential spill volumes in Alaska are associated with present/future offshore oil wells in the Beaufort Sea or Chukchi Sea regions (as these regions are likely to have the highest oil production rates), though the probability of such an event is considered to be very small. Because of the potential magnitude of impacts from such an event, it must be considered in risk planning. While there were an average of 81 incidents per year (based on 1995–2012 data) involving Beaufort Sea oil exploration and production facilities, none of these incidents involved a blowout; 85% of the incidents involved less than 1 bbl or no spillage, and the total volume of spillage from these incidents is 2,020 bbl.

For the 40 years prior to the 2010 Macondo MC252 spill in the Gulf of Mexico, the volume of spillage from U.S. offshore wells and platforms had totaled 277,000 bbl. Of this, 80% had spilled during 1969 and 1970. Between 1978 and 2009, average annual spillage in the U.S. was 1,500 bbl (Etkin, 2009). The estimated 4.9 million bbl of spillage from the Macondo MC252 incident skewed all previous data, making up about 90% of the total spillage from U.S. wells over the course of 45 years. An analysis of international data on well blowouts indicates that since 1968, there have been 11 well blowouts involving more than 50,000 bbl. Only two incidents involved more than 250,000 bbl. Though the term “blowout” seemingly implies a WCD, this is not actually the case. Of the 18 well blowouts that have been reported in the U.S., only two have involved 100,000 bbl or more – the 1969 Alpha Well 21 Platform A blowout off Santa Barbara, California, and the Macondo MC252 blowout. Of the 18 blowouts that have occurred in the U.S. over 45 years, one third have involved less than 50 bbl, and 22% have involved less than 10 bbl.

Following blowouts, the next largest theoretical WCD volume for Alaska would be a spill from a fully loaded crude tanker. In U.S. coastal waters, between the years 1969 and 2013, there has never been a true WCD from an oil tanker. Despite its significant environmental and socioeconomic impacts, the 1989 *Exxon Valdez* spill was not technically a WCD. The tanker only spilled about 14% of its cargo load. Had it been a WCD, the volume of spillage would have been about 1.6 million bbl rather than 262,000 bbl. Average spillage volume from tankers in the U.S. is 435 bbl. Since 1969, there have been 13 tanker spill incidents involving 100,000 bbl or more in the U.S. (Etkin, 2009). While the likelihood of a WCD from a tanker is seemingly higher than a WCD due to a well blowout, this still represents a very low likelihood occurrence. Again, risk planning and risk mitigation measures need to take into account the possibility of a WCD from a tanker.

The resulting theoretical WCD volumes by region and oil type used in the model are shown in Table 32 and Table 33**Error! Reference source not found.**. Current theoretical WCD volumes are highest for crude oils in the Beaufort and Chukchi Seas, at 3,900,000 bbl and 2,200,000 bbl, respectively (Table 32). The next highest WCD volume (1,900,000 bbl) is for crude, heavy, and light oils in Cook Inlet, Kodiak/Shelikof Strait, Prince William Sound, Southeast Alaska, and South-Central Alaska.

For the 2025 projection, the largest WCD volumes remain associated with crude oils in the Beaufort and Chukchi Sea regions (Table 33). The crude oil volumes for these two regions remain at 3,900,000 bbl and 2,200,000 bbl, respectively, because although the likelihood of a blowout may increase with increasing exploration/production activities, the potential volume remains the same. The next highest future WCD volume is 950,000 bbl (from tankers) and associated with a number of regions and all four oil types.

Table 32. Yearly mean current theoretical WCD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCDs and future WCDs (Table 33), and is directly comparable between the two tables.

Region	Current Theoretical WCD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Cook Inlet	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Kodiak/Shelikof Strait	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Prince William Sound	1,900,000	523,000	1,900,000	1,900,000	6,223,000
Southeast Alaska	1,900,000	523,000	1,900,000	1,900,000	6,223,000
South-Central Alaska	1,900,000	348,667	1,900,000	1,900,000	6,048,667
Beaufort Sea	3,900,000	348,667	348,667	523,000	5,120,333
Chukchi Sea	2,200,000	50,000	20,000	50,000	2,320,000
Aniakchak	523,000	523,000	523,000	523,000	2,092,000
Offshore Kenai Peninsula	523,000	523,000	523,000	523,000	2,092,000
Aleutians	0	523,000	523,000	523,000	1,569,000
Bristol Bay	0	108,667	163,000	163,000	434,667
Norton Sound/St. Lawrence Is.	0	163,000	108,667	163,000	434,667
Western Alaska	0	163,000	108,667	163,000	434,667
Kotzebue Sound/Hope Basin	0	108,667	108,667	163,000	380,333

Table 33. Yearly mean projected 2025 theoretical WCD volumes (bbl) by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCDs (Table 32) and future WCDs, and is directly comparable between the two tables.

Region	2025 Theoretical WCD (bbl)				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	3,900,000	950,000	950,000	950,000	6,750,000
Chukchi Sea	2,200,000	950,000	950,000	950,000	5,050,000
Aleutians	950,000	950,000	950,000	950,000	3,800,000
South-Central Alaska	950,000	950,000	950,000	950,000	3,800,000
Southeast Alaska	950,000	950,000	950,000	950,000	3,800,000
Cook Inlet	950,000	261,500	950,000	950,000	3,111,500
Kodiak/Shelikof Strait	950,000	261,500	950,000	950,000	3,111,500
Prince William Sound	261,500	950,000	950,000	950,000	3,111,500
Western Alaska	0	950,000	950,000	950,000	2,850,000
Aniakchak	261,500	261,500	261,500	261,500	1,046,000
Offshore Kenai Peninsula	261,500	261,500	261,500	261,500	1,046,000
Bristol Bay	0	163,000	163,000	163,000	489,000
Kotzebue Sound/Hope Basin	0	163,000	163,000	163,000	489,000
Norton Sound/St. Lawrence Is.	0	163,000	163,000	163,000	489,000

6.2.3 Incident Rates and Volumes by Source

This section provides additional information about the underlying source types associated with the incident rates, MMPD, and WCD volumes used in this study. Further detail regarding various source types is provided in Appendix A.

Table 34 lists the incident rate by source type (1995-2012) across all 14 regions, along with the percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown are the MMPD and WCD volumes used in the risk model, which are not associated with the historical incident rates. The most likely incident source in Alaska is small fishing vessels (<400 GT), followed by small recreational vessels (<400 GT) and oil exploration/production facilities. Although the incident rates are high for the small fishing and recreational vessels, the potential WCD volumes are quite small (200 and 10 bbl, respectively), whereas the WCDs for oil exploration/production facilities in the Beaufort Sea or Chukchi Sea regions are 3,900,000 bbl and 2,200,000 bbl, respectively.

Table 34. Incident rate by source type (1995-2012) across all regions, along with the percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown are the MMPD and WCD volumes used in the risk model.

Source	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
		% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD [1]
Fishing Vessel <400GT	154.167	40.40%	3.7	731	20	200
Recreational Vessel <400GT	117.890	11.10%	0.5	143	1	10
Oil Exp/Prod Facility (Beaufort)	81.556	1.00%	1.4	262	1,200	3,900,000
Oil Exp/Prod Facility (Other Regions)	28.500	17.90%	2.1	214	1,200	39,000
Fishing Vessel >400GT	22.611	50.90%	11.5	833	250	2,500
Passenger Ship <400GT	18.222	62.50%	0.6	12	5	50
Small Boat Harbor	16.111	10.00%	0.4	14	100	1,000
Ferry >400GT	14.222	82.00%	1.6	71	250	2,500
Towing Vessel <400GT	13.222	42.90%	5.3	357	50	500
Refinery	12.779	1.30%	4.2	200	1,200	200,000
Cruise Ship >400GT	9.778	46.60%	0.3	19	2,500	11,000
Fuel Terminal	9.000	11.10%	4.1	128	1,200	30,000
Military Vessel >400GT	8.000	4.90%	0.5	18	300	3,000
Seafood Facility	7.500	8.90%	16.8	1,637	100	1,000
Tank Barge >400GT	7.389	29.30%	1.7	62	2,500	163,000
Municipal Fuel Storage	7.333	4.50%	5.9	119	100	1,000
Power Plant	7.000	4.00%	7.9	238	1,200	50,000
Industrial Vessel <400 GT	6.778	13.90%	1.8	143	50	500
Petroleum Terminal	5.611	34.70%	1.6	90	1,200	200,000
Unknown Land Source	5.611	36.60%	6.1	238	10	100
Tanker <90,000DWT	4.056	42.50%	0.4	10	2,500	523,000
Tank Barge <400GT	3.611	50.80%	0.8	12	2,500	163,000
Freight Barge >400GT	3.333	53.30%	0.7	7	300	3,000
Tanker >90,000DWT	3.278	45.80%	0.3	5	2,500	1,900,000
General Cargo Ship >400GT	3.000	46.30%	37.5	929	2,500	8,000
Towing Vessel >400GT	2.722	8.20%	0.6	7	50	500
Military Facility	2.444	22.70%	26.4	619	1,000	10,000
Cruise Terminal	2.278	12.20%	0.03	0.4	100	1,000
Recreational Vessel >400GT	2.222	7.50%	1.1	18	1	10
Freight Barge <400GT	2.000	44.40%	1.4	16	20	200
Container Ship >400GT	1.889	88.20%	0.6	1	2,500	11,000
Offshore Supply Vessel <400GT	1.889	26.50%	6.2	143	10	100
Other Facility	1.889	26.50%	8.3	167	10	100
Research Vessel <400GT	1.389	52.00%	0.1	0.5	80	800

Source	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
		% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD [1]
General Cargo Ship <400GT	1.389	24.00%	7.6	71	5	50
Oil Recovery Vessel <400GT	1.333	20.80%	0.1	0.6	50	500
Bulk Carrier >400GT	1.222	72.70%	1,139	7,944 [2]	2,500	12,000
Ferry <400GT	1.222	86.40%	0.2	0.5	5	50
Bulk Chemical Facility	1.167	9.50%	0.3	2	1,000	10,000
Residential Facility	1.167	71.40%	1.3	4	1	10
Barge Terminal	1.000	5.60%	2.2	24	100	1,000
Ferry Terminal	1.000	5.60%	0.3	2	100	1,000
Airport	0.944	23.50%	165	2,009	1,200	50,000
Passenger Ship >400GT	0.944	41.20%	0.2	2	400	4,000
Container Terminal	0.944	11.80%	0.7	3	100	1,000
Logging Facility	0.889	47.10%	0.2	1	100	1,000
Construction Site	0.889	25.00%	1	6	10	100
Oil Recovery Vessel >400GT	0.833	26.70%	0.7	7	500	5,000
Marine Services Facility	0.813	0%	1.8	14	100	1,000
Industrial Vessel >400 GT	0.778	0%	1	5	100	1,000
Offshore Supply Facility	0.667	0%	0.2	1	100	1,000
Military Vessel <400GT	0.611	27.30%	2.6	24	300	3,000
Vehicle	0.556	50.00%	0.1	0.2	1	2
Oil Exp/Prod Facility (Chukchi)	0.556	40.00%	9.2	39	1,200	2,200,000
Ship Terminal	0.500	22.20%	0.08	0.4	1,000	10,000
Mining Facility	0.389	14.30%	0.4	1	10	100
Pipeline Facility	0.278	40.00%	0.02	0.02	1,200	45,000
Drydock Facility	0.222	25.00%	0.5	1	100	1,000
Vehicle Carrier Ship >400GT	0.111	100%	0	0	2,500	6,000
MODU <400GT	0.111	50.00%	0.002	0.002	10	100
Offshore Supply Vessel >400GT	0.056	42.90%	0.04	0.1	300	3,000

[1] In some cases an actual spill event may have exceeded the WCD as estimated across all regions because the particular source (usually a vessel) was unusually large or had an usually high volume of oil on board.
[2] This volume is associated with the M/V *Selendang Ayu* incident in 2004.

Table 35 lists the source types with the five highest incident rates for each region, along with the percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown are the MMPD and WCD volumes used in the risk model. In the majority of the 14 regions, the highest incident rates are associated with small fishing vessels (<400 GT) or small recreational vessels (<400 GT). The exceptions are the Beaufort Sea, Chukchi Sea, and Cook Inlets regions, where oil exploration/production facilities had the highest incident rates, and the Kotzebue Sound/Hope Basin and Norton Sound/St. Lawrence Island regions where the highest incident rates were associated with power plants and municipal fuel storage, respectively.

Table 35. Source types with highest incident rates by region (1995-2012), along with the percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown are the MMPD and WCD volumes used in the risk model.

Region	Source Type	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
			% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD [1]
Aleutians	Fishing Vessel <400GT	42.389	64.6%	6.7	476	20	200
	Fishing Vessel >400GT	14.611	43.8%	6.7	731	250	2,500
	Recreational Vessel <400GT	10.778	5.3%	0.7	14	1	10
	Seafood Facility	5.056	5.5%	20.9	1,637	100	1,000
	Fuel Terminal	2.111	2.6%	1.6	14	1,200	30,000
Aniakchak	Fishing Vessel <400GT	1.222	86.4%	12.2	48	20	200
	Seafood Facility	0.611	9.1%	12.6	100	100	1,000
	Fishing Vessel >400GT	0.278	100%	0	0	250	2,500
	Tank Barge >400GT	0.167	25%	0.3	1	2,500	163,000
	Bulk Carrier >400GT	0.111	100%	0	0	2,500	12,000
Beaufort Sea	Oil Exp/Prod Facility	81.000	0.3%	1.4	262	1,200	3,900,000
	Fishing Vessel <400GT	0.167	0%	0.4	1	20	200
	Industrial Vessel <400 GT	0.167	66.7%	0.4	0.4	50	500
	Passenger Ship <400GT	0.167	100%	0	0	5	50
	Freight Barge >400GT	0.111	50.0%	0.02	0.02	300	3,000
Bristol Bay	Fishing Vessel <400GT	5.667	60.8%	0.8	6	20	200
	Recreational Vessel <400GT	1.056	15.5%	0.7	6	1	10
	Fuel Terminal	0.667	16.7%	3.9	24	1,200	30,000
	Seafood Facility	0.667	16.7%	9.2	67	100	1,000
	Fishing Vessel >400GT	0.556	60.0%	18.5	67	250	2,500
Chukchi Sea	Oil Exp/Prod Facility	0.556	40%	9.2	39	1,200	2,200,000
	Towing Vessel >400GT	0.444	0%	1.4	7	50	500
	Municipal Fuel Storage	0.389	14.3%	1.4	6	100	1,000
	Power Plant	0.167	0%	1.2	2	1,200	50,000
	Industrial Vessel <400 GT	0.056	100%	0	0	50	500
Cook Inlet	Oil Exp/Prod Facility	28.389	18.0%	2.1	214	1,200	39,000
	Fishing Vessel <400GT	11.056	24.6%	0.4	7	20	200
	Refinery	10.056	1.1%	3.4	124	1,200	200,000
	Recreational Vessel <400GT	5.944	10.8%	0.4	10	1	10
	Passenger Ship <400GT	2.111	52.6%	1.0	7	5	50

Region	Source Type	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
			% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD [1]
Kodiak/ Shelikof Strait	Fishing Vessel <400GT	24.333	45.2%	6.1	192	20	200
	Recreational Vessel <400GT	9.611	11.5%	0.3	10	1	10
	Military Vessel <400GT	3.611	1.4%	0.9	24	300	3,000
	Towing Vessel <400GT	0.944	42.1%	6.4	36	50	500
	Small Boat Harbor	0.722	0%	0.7	5	100	1,000
Kotzebue Sound/ Hope Basin	Power Plant	0.556	0%	2.9	14	1,200	50,000
	Mining Facility	0.333	0%	0.4	1	10	100
	Fuel Terminal	0.222	0%	33.2	128	1,200	30,000
	Municipal Fuel Storage	0.222	0%	13.2	48	100	1,000
	Tank Barge >400GT	0.222	25.0%	0.02	0.02	2,500	163,000
Norton Sound/ St. Lawrence Is.	Municipal Fuel Storage	1.278	0%	2.9	12	100	1,000
	Tank Barge >400GT	0.667	46.2%	3.8	11	2,500	163,000
	Fuel Terminal	0.444	25.0%	27.1	119	1,200	30,000
	Power Plant	0.389	0%	38.4	238	1,200	50,000
	Fishing Vessel <400GT	0.278	80.0%	0.02	0.02	20	200
Offshore Kenai Peninsula	Fishing Vessel <400GT	4.333	43.6%	1.5	19	20	200
	Recreational Vessel <400GT	3.722	20.6%	0.2	4	1	10
	Passenger Ship <400GT	1.833	67.6%	0.1	0.2	5	50
	Towing Vessel <400GT	0.611	45.5%	0.3	1	50	500
	Industrial Vessel <400 GT	0.389	28.6%	0.3	1	50	500
Prince William Sound	Recreational Vessel <400GT	11.278	10.0%	1.1	143	1	10
	Fishing Vessel <400GT	9.167	33.9%	3.2	83	20	200
	Petroleum Terminal	4.389	38.0%	0.2	3	1,200	200,000
	Refinery	2.611	2.1%	7.3	200	1,200	200,000
	Towing Vessel <400GT	2.611	31.7%	4.5	153	50	500
South-Central Alaska	Fishing Vessel <400GT	2.222	52.5%	6.0	49	20	200
	Recreational Vessel <400GT	0.444	37.5%	1.3	4	1	10
	Tanker >90,000DWT	0.444	50.0%	0.2	1	2,500	1,900,000
	Power Plant	0.389	0%	8.6	36	1,200	50,000
	Tanker <90,000DWT	0.278	100%	0	0	2,500	523,000
Southeast Alaska	Recreational Vessel <400GT	71.389	6.0%	0.3	24	1	10
	Fishing Vessel <400GT	49.944	34.7%	1.8	119	20	200
	Ferry >400GT	10.722	80.3%	2.1	71	250	2,500
	Small Boat Harbor	10.722	8.3%	0.3	12	100	1,000
	Passenger Ship <400GT	10.667	66.5%	0.4	7	5	50

Region	Source Type	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
			% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD [1]
Western Alaska	Fishing Vessel <400GT	3.333	55.0%	1.6	12	20	200
	Municipal Fuel Storage	3.333	3.3%	3.4	36	100	1,000
	Fishing Vessel >400GT	3.167	87.7%	0.4	1	250	2,500
	Power Plant	1.667	6.7%	12.2	190	1,200	50,000
	Fuel Terminal	1.222	0%	5.1	76	1,200	30,000

[1] In some cases an actual spill event may have exceeded the WCD as estimated across all regions because the particular source (usually a vessel) was unusually large or had an usually high volume of oil on board.

Table 36 lists the source types with the highest potential WCD volumes for each region, along with the incident rate, percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown is the MMPD volume. In the Beaufort Sea and Chukchi Sea regions, the highest WCD volume is associated with oil exploration/production facilities. In the rest of the regions, the highest WCD volume is associated with tankers and tank barges.

Table 36. Source types with highest WCD volume by region (1995-2012), along with the incident rate, percentage of incidents that did not result in spillage and the average and maximum spill volumes associated with incidents that had actual spillage. Also shown is the MMPD volume.

Region	Source Type	Incident Rate (#/year)	Actual Spillage (bbl)			Volumes Used in Risk Model (bbl)	
			% of Incidents with No Spillage	Average Volume Spilled	Maximum Volume Spilled	MMPD	WCD
Beaufort Sea	Oil Exp/Prod Facility	81.000	0.3%	1.4	262	1,200	3,900,000
Chukchi Sea	Oil Exp/Prod Facility	0.556	40.0%	9.2	39	1,200	2,200,000
Cook Inlet	Tanker >90,000DWT	0.111	50.0%	0.6	1	2,500	1,900,000
Kodiak/Shelikof Strait	Tanker >90,000DWT	0.056	100%	0	0	2,500	1,900,000
Prince William Sound	Tanker >90,000DWT	2.500	42.2%	0.3	5	2,500	1,900,000
South-Central Alaska	Tanker >90,000DWT	0.444	50.0%	0.2	1	2,500	1,900,000
Southeast Alaska	Tanker >90,000DWT	0.167	66.7%	0.01	0.01	2,500	1,900,000
Aleutians	Tanker <90,000DWT	0.222	75.0%	0.1	0.1	2,500	523,000
Aniakchak	Tanker <90,000DWT	0.111	50.0%	0.02	0.02	2,500	523,000
Offshore Kenai Peninsula	Tanker <90,000DWT	0.056	100%	0	0	2,500	523,000
Bristol Bay	Tank Barge >400GT	1.056	21.1%	1.5	12	2,500	163,000
Kotzebue Sound/ Hope Basin	Tank Barge >400GT	0.222	25.0%	0.02	0.02	2,500	163,000
Norton Sound/ St. Lawrence Is.	Tank Barge >400GT	0.722	46.2%	3.8	11	2,500	163,000
Western Alaska	Tank Barge >400GT	1.556	25.0%	0.6	3	2,500	163,000

6.3 Relative Risk

This section contains the final risk model results considering all three model components: environmental vulnerability, spill incident rate, and potential spill volumes. A flow diagram of the yearly mean model results (for all oil types) is shown in Figure 10. Additional results are described in detail in the following sections.

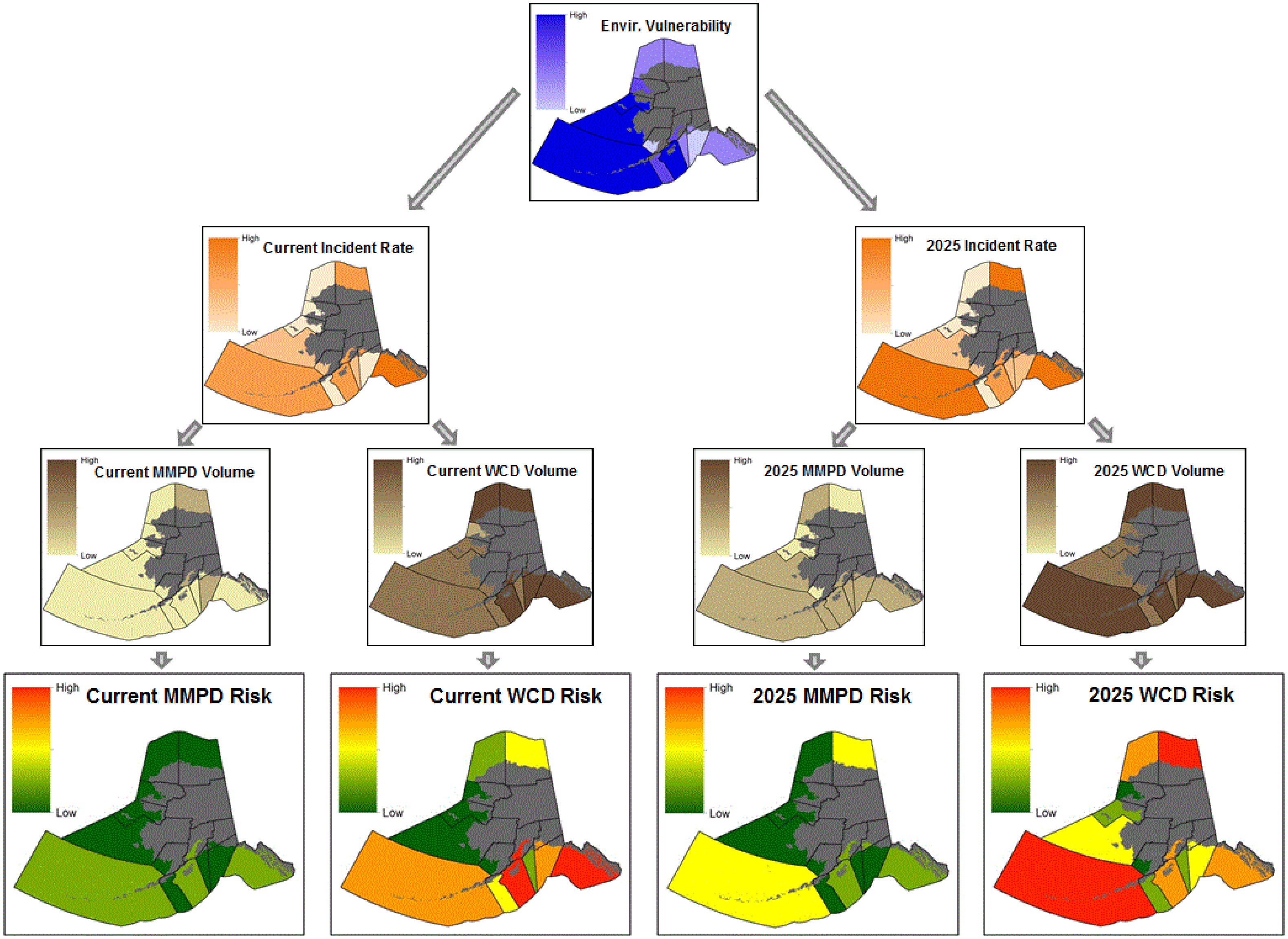


Figure 10. Flow diagram of yearly mean relative risk model results (for all oil types). Figures of the same type (e.g., all volume figures) are shown on the same color scale and are directly comparable.

6.3.1 Maximum Most Probable Discharge

The MMPD relative risk score for each region and period is computed by summing the risk scores for each individual oil type (see Section 3.3.5). Table 37 and Table 38 list the resulting relative risk scores by period. The highest MMPD current relative risk scores are for Southeast Alaska in June–September (Table 37). The next highest scores are for the Cook Inlet region in April–May and the Aleutians region in February–March. Based on the yearly mean risk score, the Southeast Alaska region has the highest MMPD relative risk, followed by the Aleutians and Kodiak/Shelikof Strait regions. The lowest yearly mean MMPD relative risk scores are found in the Bristol Bay and Kotzebue Sound/Hope Basin regions. On average (across all regions), MMPD relative risk scores tend to be the greatest during spring and summer months (April through September) and lowest during winter (December through March). The greatest seasonal differences in risk scores within regions occur in the Arctic regions (e.g., Beaufort Sea, Chukchi Sea).

For the 2025 future projection, the highest MMPD relative risk scores are for the Beaufort Sea region in April to September (Table 38). The next highest score is for the Aleutians region in February–March. Based on the yearly mean risk score, the Beaufort Sea region has the highest 2025 MMPD relative risk, followed by the Aleutians and Southeast Alaska regions. These results are based on the 2025 incident rates and volumes and the "current" environmental vulnerability, as environmental vulnerability was not projected into the future for this study.

Table 37. MMPD current relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current MMPD risk score and future MMPD risk score (Table 38), and is directly comparable between the two tables.

Region	MMPD Current Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Southeast Alaska	10.7	11.5	13.6	17.1	15.9	12.4	13.5
Aleutians	12.5	14.2	13.0	13.8	13.9	13.0	13.4
Kodiak/Shelikof Strait	12.5	12.1	13.7	14.0	13.1	12.3	13.0
Cook Inlet	11.9	12.4	14.7	12.7	12.1	10.0	12.3
Prince William Sound	9.6	9.7	11.4	11.0	9.6	8.2	9.9
Aniakchak	9.2	9.3	10.2	10.6	10.1	9.6	9.8
Beaufort Sea	5.0	5.6	11.5	13.8	11.9	9.6	9.6
Offshore Kenai Peninsula	9.4	9.0	10.1	10.1	9.7	8.8	9.5
Chukchi Sea	5.1	5.0	10.2	11.4	9.9	8.8	8.4
South-Central Alaska	6.6	6.1	8.7	9.0	8.7	6.4	7.6
Norton Sound/St. Lawrence Is.	4.5	4.5	9.5	9.6	7.7	8.1	7.3
Western Alaska	4.1	4.4	9.5	9.7	8.1	7.7	7.2
Bristol Bay	4.9	5.1	6.7	6.6	5.3	5.9	5.8
Kotzebue Sound/Hope Basin	1.9	1.9	8.3	8.1	7.1	6.8	5.7
Seasonal Average	7.7	7.9	10.8	11.3	10.2	9.1	

Table 38. MMPD 2025 relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current MMPD risk score (Table 37) and future MMPD risk score, and is directly comparable between the two tables.

Region	MMPD 2025 Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Beaufort Sea	15.1	18.1	22.4	26.6	21.3	16.0	19.9
Aleutians	16.5	18.4	17.1	18.1	18.1	17.1	17.6
Southeast Alaska	11.2	12.2	14.4	18.1	16.7	12.9	14.3
Kodiak/Shelikof Strait	12.7	12.3	14.0	14.3	13.3	12.4	13.2
Cook Inlet	12.3	12.7	15.2	13.2	12.7	10.3	12.7
Prince William Sound	9.7	9.8	11.6	11.6	9.7	8.5	10.1
Aniakchak	9.2	9.4	10.3	10.6	10.1	9.6	9.8
Offshore Kenai Peninsula	9.4	9.0	10.1	10.2	9.8	8.9	9.6
Chukchi Sea	8.2	8.1	10.2	11.6	10.0	8.9	9.5
Norton Sound/St. Lawrence Is.	8.9	9.0	9.5	9.6	7.7	8.1	8.8
Western Alaska	8.1	8.6	9.5	9.8	8.2	7.7	8.7
South-Central Alaska	7.7	7.2	8.7	9.0	8.8	7.5	8.2
Kotzebue Sound/Hope Basin	6.7	6.7	8.2	8.1	7.1	6.8	7.3
Bristol Bay	6.1	6.5	6.7	6.7	5.3	5.9	6.2
Seasonal Average	10.1	10.6	12.0	12.7	11.3	10.1	

MMPD current yearly mean relative risk scores by oil type are shown in Table 39. The highest scores are for light oils in the Southeast Alaska region, followed by light oils in the Aleutians and heavy oils in the Aleutians. Across all regions, light and heavy oils have the highest risk scores on average, followed by crude oils and distillates. For the 2025 projection, light oils in the Beaufort Sea region receive the highest MMPD relative risk score, followed by light oils in the Southeast Alaska and Aleutians regions (Table 40). Across all regions, light and heavy oils still have the highest risk scores.

Table 39. MMPD current yearly mean relative risk by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPD risk score and future MMPD risk score (Table 40), and is directly comparable between the two tables.

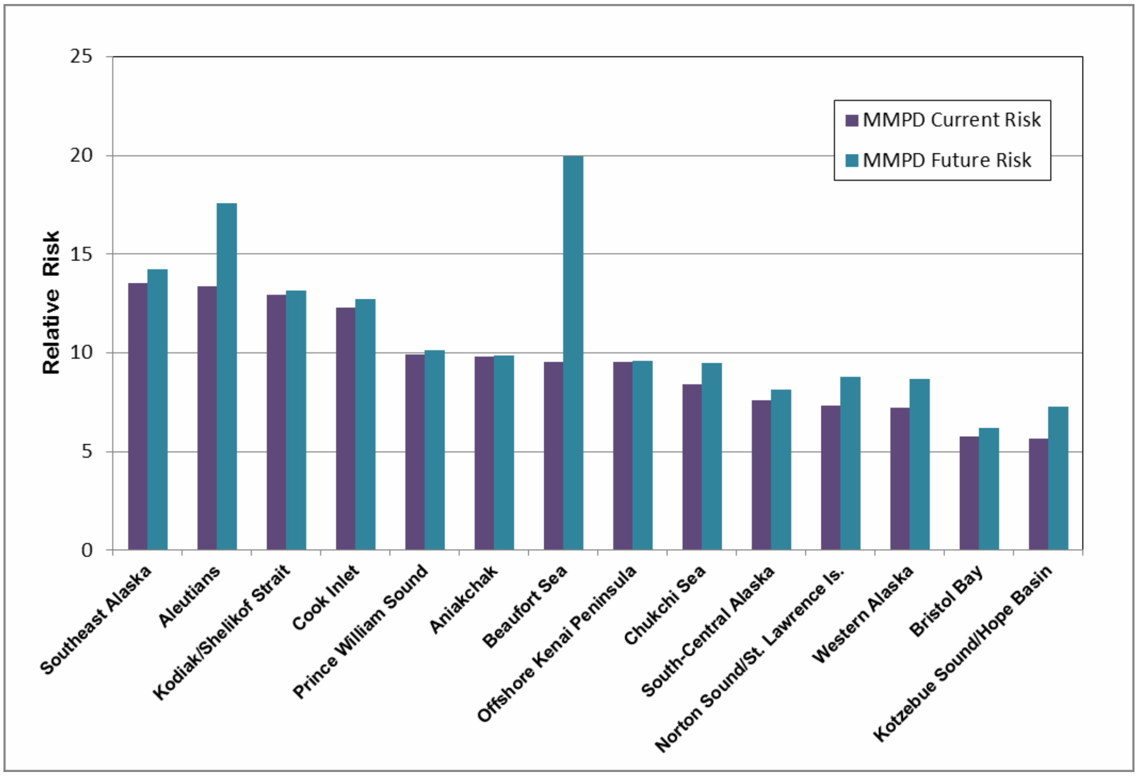
Region	MMPD Current Relative Risk				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Southeast Alaska	2.3	1.5	3.2	6.5	13.5
Aleutians	0.0	2.1	5.0	6.3	13.4
Kodiak/Shelikof Strait	3.1	1.8	4.2	3.9	13.0
Cook Inlet	3.2	1.6	3.8	3.7	12.3
Prince William Sound	2.5	1.3	3.2	2.9	9.9
Aniakchak	2.7	1.5	3.6	2.1	9.8
Beaufort Sea	3.0	0.9	2.3	3.4	9.6
Offshore Kenai Peninsula	2.5	1.4	3.4	2.2	9.5
Chukchi Sea	2.6	1.4	2.5	2.0	8.4
South-Central Alaska	2.2	0.7	3.0	1.7	7.6
Norton Sound/St. Lawrence Is.	0.0	1.8	2.9	2.6	7.3
Western Alaska	0.0	1.7	2.7	2.8	7.2
Bristol Bay	0.0	0.8	3.0	1.9	5.8
Kotzebue Sound/Hope Basin	0.0	1.1	2.5	2.1	5.7

Table 40. MMPD 2025 yearly mean relative risk by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current MMPD risk score (Table 39) and future MMPD risk score, and is directly comparable between the two tables.

Region	MMPD 2025 Relative Risk				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	6.0	1.3	3.1	9.5	19.9
Aleutians	3.6	2.2	5.0	6.8	17.6
Southeast Alaska	2.3	1.5	3.2	7.2	14.3
Kodiak/Shelikof Strait	3.1	1.8	4.2	4.1	13.2
Cook Inlet	3.2	1.6	4.1	3.9	12.7
Prince William Sound	2.4	1.3	3.4	2.9	10.1
Aniakchak	2.7	1.5	3.6	2.1	9.8
Offshore Kenai Peninsula	2.5	1.4	3.4	2.3	9.6
Chukchi Sea	2.6	1.4	3.5	2.0	9.5
Norton Sound/St. Lawrence Is.	0.0	1.9	4.3	2.6	8.8
Western Alaska	0.0	1.7	4.0	2.9	8.7
South-Central Alaska	2.2	1.2	3.0	1.8	8.2
Kotzebue Sound/Hope Basin	0.0	1.5	3.6	2.1	7.3
Bristol Bay	0.0	1.2	3.0	2.0	6.2

Yearly mean MMPD relative risk scores are shown as a bar graph in Figure 11; this graph shows the changes in relative risk between the current scores and the 2025 scores. In general, all regions experienced an increase in risk scores for the year 2025. The largest increase by far was for the future relative risk scores in the Beaufort Sea region, followed by the future scores in the Aleutians region. These increases in risk are attributable to the increased likelihood of an incident due to assumed increases in offshore exploration and production activity in the Beaufort Sea region and increases in vessel traffic in the Aleutians region. Other regions, such as Prince William Sound, Aniakchak, and Offshore Kenai Peninsula, experienced little change in relative risk scores.

Figure 11. MMPD current and 2025 yearly mean relative risk scores by region.



6.3.2 Worst-Case Discharge

Like the MMPD scores, the WCD relative risk score for each region and period is computed by summing the risk scores for each individual oil type (see Section 3.3.5). The WCD results are shown in Table 41 and Table 42. The highest WCD current relative risk scores are for the Southeast Alaska region in June–September (Table 41). The next highest scores are for the Cook Inlet region in April–May and the Kodiak/Shelikof Strait region in June–July. Based on the yearly mean risk score, the Southeast Alaska region has the highest WCD relative risk, followed by the Kodiak/Shelikof Strait and Cook Inlet regions. The lowest yearly mean WCD relative risk scores are found in the Bristol Bay and Kotzebue Sound/Hope Basin regions, which also had the lowest MMPD relative risk scores. On average (across all regions), WCD relative risk scores tend to be the greatest during spring and summer months (April through September) and lowest during winter (December through March). The more western regions of Alaska, including Kotzebue Sound/Hope Basin, Western Alaska, Norton Sound/St. Lawrence Island, and Bristol Bay have particularly low WCD current relative risk scores during winter months as compared to all other regions.

For the 2025 future projection, the highest WCD relative risk scores are for the Beaufort Sea region in June–July (Table 42), mainly attributable to a substantial projected increase in oil exploration and production activities (resulting in both greater incident rates and spill volumes). The next highest scores all occur within the Beaufort Sea, with higher scores in the spring and summer than in the winter and fall. Based on the yearly mean risk score, the Beaufort Sea region has the highest 2025 WCD relative risk, followed by the Aleutians and Southeast Alaska regions. These results are based on the 2025 incident rates and volumes and the “current” environmental vulnerability, as environmental vulnerability was not projected into the future for this study.

Table 41. WCD current relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current WCD risk score and future WCD risk score (Table 42), and is directly comparable between the two tables.

Region	WCD Current Relative Risk						
	Dec-Jan	**Feb-Mar**	**Apr-May**	**Jun-Jul**	**Aug-Sep**	**Oct-Nov**	**Yearly Mean**
Southeast Alaska	29.7	32.2	37.9	48.0	44.4	34.4	37.8
Kodiak/Shelikof Strait	34.5	33.5	37.8	38.6	36.1	33.7	35.7
Cook Inlet	32.9	34.2	40.6	35.1	33.5	27.5	34.0
Prince William Sound	26.4	26.7	31.4	30.4	26.5	22.5	27.3
South-Central Alaska	19.5	18.1	23.9	24.6	23.9	18.9	21.5
Aleutians	19.2	21.8	19.9	21.2	21.4	19.9	20.6
Beaufort Sea	15.2	12.0	22.1	27.0	23.0	18.5	19.6
Aniakchak	14.1	14.3	15.7	16.3	15.5	14.7	15.1
Offshore Kenai Peninsula	14.5	13.8	15.5	15.6	14.9	13.5	14.6
Chukchi Sea	10.3	10.1	16.8	18.8	16.3	14.5	14.5
Norton Sound/St. Lawrence Is.	5.2	5.3	11.0	11.2	9.0	9.5	8.5
Western Alaska	4.8	5.2	11.0	11.3	9.4	8.9	8.4
Bristol Bay	5.7	6.0	7.8	7.7	6.1	6.9	6.7
Kotzebue Sound/Hope Basin	2.2	2.2	9.6	9.5	8.3	8.0	6.6
Seasonal Average	16.7	16.8	21.5	22.5	20.6	18.0	

Table 42. WCD 2025 relative risk score by period, summed for all oil types and sorted by the yearly mean relative risk score. Coloring is based on the collective values from both the current WCD risk score (Table 41) and future WCD risk score, and is directly comparable between the two tables.

Region	WCD 2025 Relative Risk						
	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov	Yearly Mean
Beaufort Sea	40.6	50.8	64.6	81.2	61.3	46.1	57.4
Aleutians	32.5	36.3	33.8	35.8	35.8	33.7	34.7
Southeast Alaska	22.1	24.1	28.3	35.8	33.0	25.5	28.1
Kodiak/Shelikof Strait	23.9	23.2	26.2	26.8	24.9	23.2	24.7
Chukchi Sea	19.0	18.7	23.7	26.9	23.1	20.7	22.0
Cook Inlet	23.1	23.9	28.6	25.0	24.0	19.4	24.0
Prince William Sound	17.4	17.6	20.9	21.1	17.5	15.2	18.3
Western Alaska	16.0	17.1	18.8	19.3	16.1	15.2	17.1
South-Central Alaska	15.3	14.1	17.2	17.8	17.2	14.9	16.1
Aniakchak	11.6	11.9	13.0	13.4	12.8	12.1	12.5
Offshore Kenai Peninsula	12.0	11.4	12.9	13.0	12.4	11.3	12.1
Norton Sound/St. Lawrence Is.	10.4	10.5	11.0	11.2	9.0	9.5	10.3
Kotzebue Sound/Hope Basin	7.8	7.8	9.6	9.4	8.3	7.9	8.5
Bristol Bay	7.1	7.5	7.9	7.8	6.1	6.9	7.2
Seasonal Average	18.5	19.6	22.6	24.6	21.5	18.7	

WCD current yearly mean relative risk scores by oil type are shown in Table 43. The highest score is for light oil in the Southeast Alaska region, followed by heavy oil in the Kodiak/Shelikof Strait region. On average (across all regions), light and heavy oils have the highest risk scores on average, followed by crude oils. For the 2025 projection, crude oils in the Beaufort Sea region receive the highest WCD relative risk score, followed by light oils in the Beaufort Sea region and light oils in the Southeast Alaska region (Table 44). On average (across all regions), light and heavy oils have the highest risk scores, followed by crude oils.

Table 43. WCD current yearly mean relative risk by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCD risk score and future WCD risk score (Table 44), and is directly comparable between the two tables.

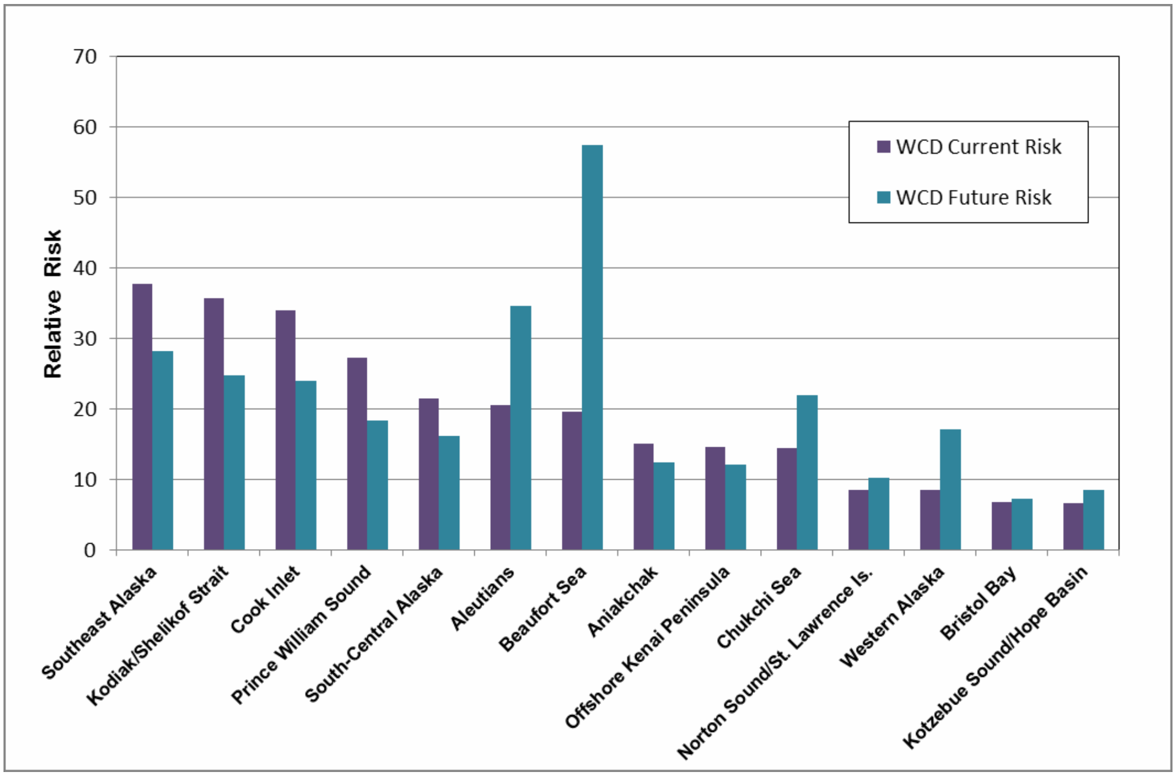
Region	WCD Current Relative Risk				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Southeast Alaska	6.8	2.4	9.5	19.1	37.8
Kodiak/Shelikof Strait	9.1	2.7	12.4	11.5	35.7
Cook Inlet	9.4	2.4	11.1	11.0	34.0
Prince William Sound	7.2	2.1	9.4	8.7	27.3
South-Central Alaska	6.5	1.0	8.8	5.1	21.5
Aleutians	0.0	3.3	7.7	9.6	20.6
Beaufort Sea	9.6	1.4	3.5	5.1	19.6
Aniakchak	4.1	2.3	5.5	3.2	15.1
Offshore Kenai Peninsula	3.8	2.1	5.2	3.4	14.6
Chukchi Sea	8.4	1.5	2.5	2.1	14.5
Norton Sound/St. Lawrence Is.	0.0	2.2	3.3	3.0	8.5
Western Alaska	0.0	2.0	3.1	3.3	8.4
Bristol Bay	0.0	0.9	3.5	2.2	6.7
Kotzebue Sound/Hope Basin	0.0	1.2	2.9	2.4	6.6

Table 44. WCD 2025 yearly mean relative risk by oil type, sorted by the sum of all oil types. Coloring is based on the collective values from both the current WCD risk score (Table 43) and future WCD risk score, and is directly comparable between the two tables.

Region	WCD 2025 Relative Risk				
	Crude	Distillate	Heavy	Light	Sum of All Oil Types
Beaufort Sea	30.0	2.6	6.2	18.7	57.4
Aleutians	7.2	4.3	9.8	13.4	34.7
Southeast Alaska	4.5	3.0	6.3	14.2	28.1
Kodiak/Shelikof Strait	6.1	2.3	8.2	8.1	24.7
Cook Inlet	6.3	2.0	8.0	7.7	24.0
Chukchi Sea	8.4	2.8	6.8	4.0	22.0
Prince William Sound	3.0	2.7	6.8	5.8	18.3
Western Alaska	0.0	3.4	7.9	5.7	17.1
South-Central Alaska	4.3	2.4	5.9	3.5	16.1
Aniakchak	3.4	1.9	4.6	2.7	12.5
Offshore Kenai Peninsula	3.2	1.8	4.3	2.9	12.1
Norton Sound/St. Lawrence Is.	0.0	2.2	5.0	3.1	10.3
Kotzebue Sound/Hope Basin	0.0	1.8	4.2	2.4	8.5
Bristol Bay	0.0	1.4	3.5	2.3	7.2

Yearly mean WCD relative risk scores are shown as a bar graph in Figure 12; this graph shows the changes in relative risk between the current scores and the 2025 scores. Unlike the MMPD relative risk scores (Figure 11), where all regions experienced an increase for the future projection, for the WCD relative risk scores half of the regions had a decrease for the 2025 scores. The decrease in relative risk in certain regions is attributable to a projected increase in risk mitigation practices and/or use of double-hulled tanks that reduce the potential WCD spillage from a vessel incident. The largest increase by far was for the relative risk scores in the Beaufort Sea region, followed to a lesser degree by the scores in the Aleutians region. Again, these increases in risk are attributable to the increased likelihood of an incident due to assumed increases in offshore exploration and production activity in the Beaufort Sea region and increases in vessel traffic in the Aleutians region.

Figure 12. WCD current and 2025 yearly mean relative risk scores by region.



6.4 Correlation Analysis and Sensitivity Testing

Examinations of driving factors to the model were conducted to determine model sensitivity to both input parameters and calculated parameters. Model parameters were correlated with model interim results (e.g., HVS, EV) and final risk results (relative risk scores) to determine the strength of the relationship between each parameter and result. The correlation analysis is summarized in Section 6.4.1.

Although a full sensitivity analysis was not included in the scope of this project, we conducted a few key sensitivity tests on parameters reliant on data inputs with known potential issues. These tests are discussed in Section 6.4.2.

6.4.1 Model Parameter Correlations

Several calculated model parameters were correlated with model interim results and final relative risk results. Pearson correlation coefficients were calculated to determine how well each model parameter predicts each interim result and each relative risk result. Strong, positive, significant correlations are indicative of parameters that are actively driving model interim and final results.

Three sets of model parameter correlations were performed: the correlation between HVS input parameters and HVS scores by region and season, correlations between EV input parameters and EV scores by region and season, and correlations between risk input parameters and final relative risk scores by region, season, and oil type.

Among HVS input parameters, ice concentration/coverage was most highly correlated with the final HVS score (Table 45). Shoreline and bottom habitat scores had almost no correlation with HVS scores. This is due to the numerical range found in the three habitat input parameters (ice, shorelines, bottom habitats). The range of input values for the ice parameter is much larger than those of shoreline and bottom habitats. Ice may cover nearly all of a region during one season and may be completely absent from that same region a few periods later. This seasonal variability (which also occurs regionally) leads to a large range of potential ice parameter values. On the other hand, shoreline and bottom habitats are considered to be present year round, leading to no seasonal variation in those parameters. Additionally, most regions have most of the possible shoreline and bottom habitat types present in some percentage, meaning overall variability is rather low among regions. Finally, the oil effects scores (many derived from the WCS) for each shoreline and bottom habitat type do not exhibit a large range of differences in sensitivity. Due to these three factors, shoreline and bottom habitat scores do not strongly correlate with HVS scores. Because the protected area modifier parameter is multiplicative, it is not surprising to see it moderately and significantly correlated with final HVS scores.

Table 45. Pearson correlation coefficients between HVS input parameters and final HVS scores for each region and season (n=84). Bold values indicate significant relationships ($p<0.05$).

HVS Input Parameter	Pearson Correlation Coefficient
Shoreline Habitat	-0.152
Bottom Habitat	-0.039
Ice Coverage/Concentration	**0.853**
Protected Area Modifier	**0.527**

Among EV input parameters, all input parameters were found to be significantly ($p<0.05$), positively correlated with final EV results. The relationships ranged from low (0.315 for birds) to moderate (0.706 for fish/invertebrates) (Table 46). No single input parameter to the EV equation is driving the final EV results.

Table 46. Pearson correlation coefficients between EV input parameters and final EV scores for each region and season (n=84). Bold values indicate significant relationships (p<0.05).

EV Input Parameter	Pearson Correlation Coefficient
HVS	**0.384**
SVS (=(FVS+MTVS+BVS)/3)	**0.672**
FVS	**0.706**
MTVS	**0.640**
BVS	**0.315**

The correlation strength among high-level model parameters (i.e., EVO, spill volume, and incident rate) and relative risk scores shifts between MMPD and WCD model runs (Table 47). All high-level model parameters were significantly correlated ($p<0.05$) with relative risk results; however, not all parameters were strongly correlated with relative risk results. In both model runs (MMPD and WCD) the EVO and incident rate parameters contribute roughly equally to the final risk results (i.e., both have a correlation of about 0.6 for the MMPD run, and about 0.4 for the WCD run), but their contribution to the final risk result varies depending on the volume scenario.

Table 47. Pearson correlation coefficients between high level model parameters and final relative risk scores for each region and season (n=287). Bold values indicate significant relationships (p<0.05).

Relative Risk Model Parameter	Pearson Correlation Coefficient	
	MMPD	WCD
EVO	**0.65**	**0.37**
Volume	**-0.13**	**0.82**
Incident Rate	**0.63**	**0.40**

For the MMPD model run, both the EVO and incident rate parameters are moderately positively correlated with the final relative risk score. Correlation coefficients are nearly identical for these two parameters (Table 47). However, the volume parameter is not correlated with the final relative risk score for the MMPD model run. This is due to the MMPD parameter values having a very small range in value for all regions, periods, and oil types. In the model, the influence of these small volumes is diminished because all oil volumes are calculated relative to the maximum WCD volume, which is much greater than even the largest region/period/oil type MMPD value.

For the WCD model run, the EVO and incident rate parameters are minimally positively correlated with relative risk scores (Table 47). The volume parameter is the major driving factor in the WCD model run, and is strongly positively correlated with relative risk scores.

These differences indicate that the MMPD and WCD model runs are indicative of unique relative risk results, and therefore should be interpreted individually. The MMPD model run produces results that are nearly devoid of influence from the volume parameter, while the WCD model results are highly driven by the volume parameter.

6.4.2 Selected Sensitivity Tests

Four model parameters (i.e., ice concentration/coverage, the protected area modifier, species abundance, and the number of species analyzed) were explored in more detail to determine their variability and influence on final risk model results. Each of these four parameters was systematically altered to determine their influence in the model and how susceptible each parameter was to changes in data collection/use protocols.

6.4.2.1 Sea Ice Coverage/Concentration

Because ice coverage and concentration varies from year to year depending on global and local climactic conditions, there is no exact historic time frame that perfectly captures mean ice coverage in Alaska. Utilizing too short a time period (e.g., 1–3 years) may result in anomalous data that falls well outside mean conditions, while utilizing too broad a time frame (e.g., 25 years) may not adequately capture recent trends in seasonal ice coverage. Thus, sea ice coverage and concentrations were calculated based on a ten-year average for use in the risk model. As a sensitivity test, we explored how using only the most recent year's (2012) ice coverage and concentration data would affect overall habitat scores and subsequently, relative risk scores (**Error! Reference source not found.**).

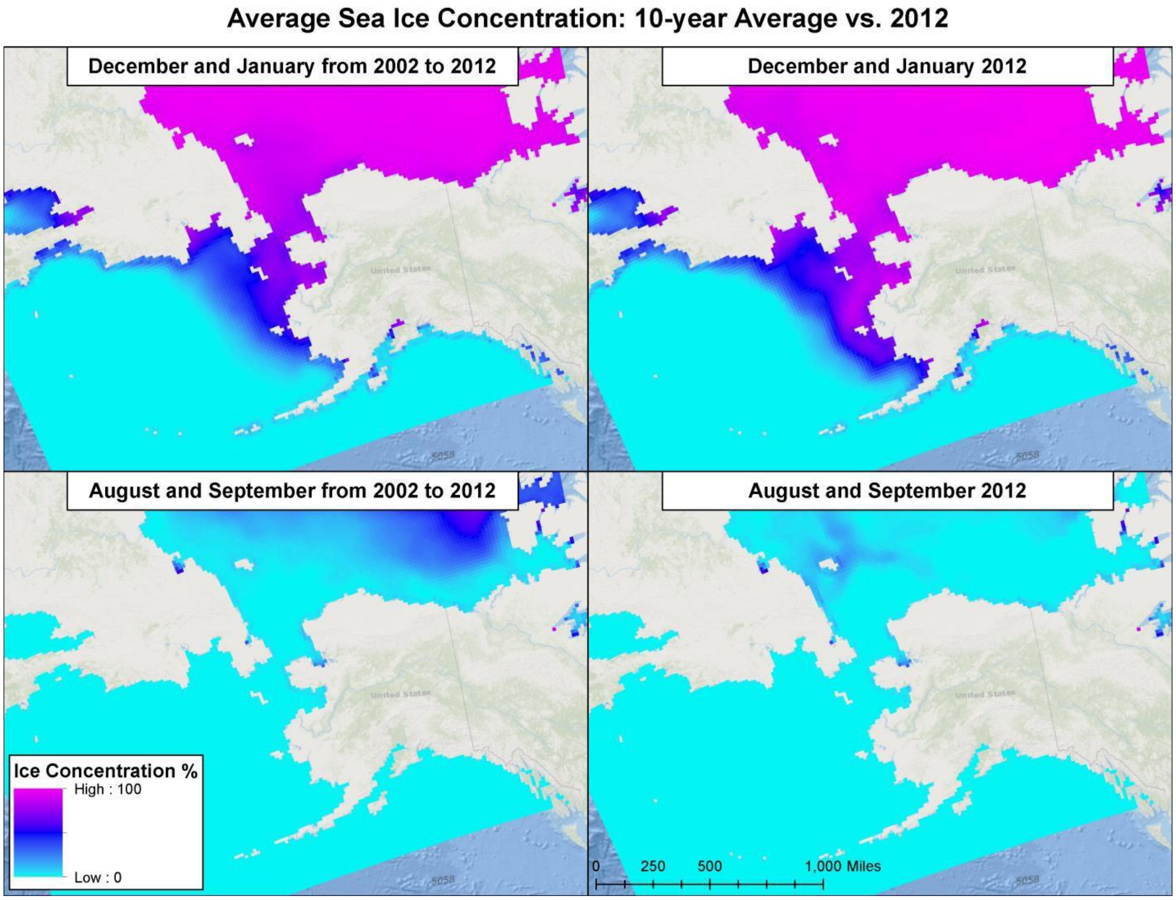


Figure 13. Comparisons of ten-year average (2002–2012) and 2012 ice coverage data for December–January and August–September.

Results from the sea ice coverage and concentration sensitivity test suggest minimal differences in regional mean relative risk scores when utilizing 2012 ice data in comparison with a ten-year average (Table 48 and Table 49). A few regions do change rank when using 2012 ice data; however, the overarching order and distribution of relative risk ranks do not change for either MMPD or WCD model runs. For example, although the Norton Sound/St. Lawrence Island and Western Alaska regions change MMPD risk ranks when using 2012 ice data, they remain in the same quartile of results and experience a very small total percent change in risk scores (Table 48). The largest differences occurred in the Bristol Bay and Beaufort Sea regions. The Beaufort Sea region experienced a low ice year in 2012 in comparison with the ten-year average. Furthermore, despite a 4.0% (MMPD) and 3.7% (WCD) reduction in relative risk scores when using 2012 ice data, the Beaufort Sea region only changed a single rank position for MMPD risk scores and did not change rank positions for WCD risk scores. While the model is sensitive to changes in ice coverage/concentration data, this sensitivity test shows that year-to-year fluctuations in ice data do not substantially alter the overall structure of relative risk scores in Alaska.

Table 48. Comparison of MMPD regional mean relative risk scores using ten-year average (2002–2012) sea ice concentration/coverage data versus 2012 sea ice concentration/coverage data. The % difference column indicates the magnitude of change between model results and results of running the model with 2012 ice data. The rank change column indicates where a region has "changed places" in the 2012 ice model data run in comparison with the base model run.

Region	MMPD Risk	MMPD 2012 Ice Risk	% Difference	Rank Change?
Southeast Alaska	13.5	13.6	0.7	No
Aleutians	13.4	13.2	-1.1	No
Kodiak/Shelikof Strait	13.0	12.8	-1.3	No
Cook Inlet	12.3	12.5	1.5	No
Prince William Sound	9.9	10.0	1.3	No
Aniakchak	9.8	9.8	-0.5	No
Beaufort Sea	9.6	9.2	-4.0	Yes
Offshore Kenai Peninsula	9.5	9.3	-2.6	Yes
Chukchi Sea	8.4	8.5	0.3	No
South-Central Alaska	7.6	7.5	-1.1	No
Norton Sound/St. Lawrence Is.	7.3	7.2	-1.9	Yes
Western Alaska	7.2	7.3	1.1	Yes
Bristol Bay	5.8	5.9	3.0	No
Kotzebue Sound/Hope Basin	5.7	5.7	0.4	No

Table 49. Comparison of WCD regional mean relative risk scores using ten-year average (2002–2012) sea ice concentration/coverage data versus 2012 sea ice concentration/coverage data. The % difference column indicates the magnitude of change between model results and results of running the model with 2012 ice data. The rank change column indicates where a region has "changed places" in the 2012 ice model data run in comparison with the base model run.

Region	WCD Risk	WCD 2012 Ice Risk	% Difference	Rank Change?
Southeast Alaska	37.8	38.0	0.6	No
Kodiak/Shelikof Strait	35.7	35.2	-1.3	No
Cook Inlet	34.0	34.4	1.4	No
Prince William Sound	27.3	27.7	1.3	No
South-Central Alaska	21.5	21.2	-1.2	No
Aleutians	20.6	20.3	-1.1	No
Beaufort Sea	19.6	18.9	-3.7	No
Aniakchak	15.1	15.0	-0.5	No
Offshore Kenai Peninsula	14.6	14.3	-2.6	Yes
Chukchi Sea	14.5	14.5	0.3	Yes
Norton Sound/St. Lawrence Is.	8.5	8.4	-1.9	Yes
Western Alaska	8.4	8.5	1.1	Yes
Bristol Bay	6.7	6.9	3.0	No
Kotzebue Sound/Hope Basin	6.6	6.7	0.4	No

6.4.2.2 Protected Area Modifier

The inclusion of protected areas as a metric of vulnerability for habitats and species carries with it a certain weight of socioeconomic concerns that are not necessarily central to an environmental vulnerability and oil spill relative risk model. Simply because a marine area or shoreline is designated as protected, does not necessarily mean that those areas are more sensitive to oil spills. For the purposes of the risk model, protected area designation is considered to make a region more sensitive. To determine the effect of the protected area modifier on interim and final risk results, it was removed from model equations and new relative risk results were calculated.

Results from this sensitivity test suggest that the model is moderately sensitive to the protected area modifier (Table 50 and Table 51). Because most regions have similar, high values for the protected area modifier, the large majority of regions only see minimal changes in relative risk scores with and without the modifier. However, those regions that have the low outlier scores for the protected area modifier (i.e., Southeast Alaska, Beaufort Sea, Bristol Bay) experience large relative increases in risk scores when the modifier is removed from the model. Based on these results, it is important that the model user carefully consider the importance of protected areas in relation to environmental vulnerability and oil spill contingency planning and the implications they carry to final relative risk results.

Table 50. Comparison of MMPD regional mean relative risk scores using the protected area modifier parameter versus omitting the modifier parameter. The % difference column indicates the magnitude of change between base model results and results of running the model without the protected area modifier. The rank change column indicates where a region has "changed places" in the no-modifier model data run in comparison with the base model run.

Region	MMPD Risk	MMPD No Modifier Risk	% Difference	Rank Change?
Southeast Alaska	13.5	16.1	18.9	No
Aleutians	13.4	13.1	-2.2	No
Kodiak/Shelikof Strait	13.0	12.7	-2.3	No
Cook Inlet	12.3	12.1	-1.8	No
Prince William Sound	9.9	10.2	2.5	Yes
Aniakchak	9.8	9.8	-0.3	Yes
Beaufort Sea	9.6	10.9	14.3	Yes
Offshore Kenai Peninsula	9.5	9.8	2.5	No
Chukchi Sea	8.4	8.8	4.5	No
South-Central Alaska	7.6	7.9	3.8	No
Norton Sound/St. Lawrence Is.	7.3	7.0	-4.1	Yes
Western Alaska	7.2	7.2	-0.2	Yes
Bristol Bay	5.8	6.8	17.6	No
Kotzebue Sound/Hope Basin	5.7	5.7	-0.5	No

Table 51. Comparison of WCD regional mean relative risk scores using the protected area modifier parameter versus omitting the modifier parameter. The % difference column indicates the magnitude of change between base model results and results of running the model without the protected area modifier. The rank change column indicates where a region has "changed places" in the no-modifier model data run in comparison with the base model run.

Region	WCD Risk	WCD No Modifier Risk	% Difference	Rank Change?
Southeast Alaska	37.8	45.0	19.1	No
Kodiak/Shelikof Strait	35.7	35.0	-2.0	No
Cook Inlet	34.0	33.5	-1.5	No
Prince William Sound	27.3	28.1	2.8	No
South-Central Alaska	21.5	22.3	4.0	Yes
Aleutians	20.6	20.1	-2.2	Yes
Beaufort Sea	19.6	22.5	14.6	Yes
Aniakchak	15.1	15.1	-0.3	Yes
Offshore Kenai Peninsula	14.6	15.0	2.5	Yes
Chukchi Sea	14.5	15.2	4.9	Yes
Norton Sound/St. Lawrence Is.	8.5	8.2	-4.1	Yes
Western Alaska	8.4	8.4	-0.2	Yes
Bristol Bay	6.7	7.9	17.6	No
Kotzebue Sound/Hope Basin	6.6	6.6	-0.5	No

6.4.2.3 Species Presence/Absence

In the base model run, the species abundance parameter was determined for each species, region, and period. For each of these 3,024 unique combinations (i.e., 36 species x 14 regions x 6 periods) a relative abundance value ranging from 0 to 1 (at 0.2 unit intervals) was assigned (see Section 4.2.2). This was accomplished via a time-consuming process of using all available datasets to make a professional judgment for each species/region/period combination. Because of the lack of high-quality seasonal abundance data for most species, the repeatability of these assignments is relatively low.

In this sensitivity test, the species abundance parameter was changed to a binary presence/absence metric (0 and 1), to determine how influential the abundance parameter is to the final model results. This metric was also tested in order to provide recommendations regarding future model development. By testing the influence of this parameter, and determining its potential influence on model results, future iterations of the risk model may be simplified. A significant decrease in effort would result if the abundance parameter only needed to be populated with presence/absence data as opposed to the more nuanced system currently prescribed by the risk model.

Results from the presence/absence sensitivity test determined that the model is moderately sensitive to the abundance parameter (Table 52 and Table 53). This sensitivity resulted in the abundance parameter being a strong driving factor in final relative risk scores. The mean change in relative risk scores for both MMPD and WCD model runs was 8.1%. Several regions (i.e., South-Central Alaska, Offshore Kenai Peninsula, and Bristol Bay) experienced over 16% increases in relative risk scores when using the presence/absence abundance metric. Additionally, several regions changed rank position by two positions. These results suggest that utilizing a presence/absence abundance scheme will fundamentally alter the results of this risk assessment model, and will not produce comparable results with the base model (run with graded abundance values). Based on this information, we recommend that the abundance metric continue to be used for future applications of the model.

Table 52. Comparison of MMPD regional mean relative risk scores using relative abundance versus presence/absence. The % difference column indicates the magnitude of change between base model results and results of running the model with presence/absence scoring. The rank change column indicates where a region has "changed places" in the presence/absence model data run in comparison with the base model run.

Region	MMPD Risk	MMPD Pres./Abs. Risk	% Difference	Rank Change?
Southeast Alaska	13.5	14.3	5.4	No
Aleutians	13.4	12.4	-7.7	Yes
Kodiak/Shelikof Strait	13.0	12.6	-2.4	No
Cook Inlet	12.3	13.8	12.5	Yes
Prince William Sound	9.9	11.3	13.9	No
Aniakchak	9.8	10.7	9.1	Yes
Beaufort Sea	9.6	9.9	3.3	Yes
Offshore Kenai Peninsula	9.5	11.1	16.4	Yes
Chukchi Sea	8.4	8.8	4.9	Yes
South-Central Alaska	7.6	9.0	18.3	Yes
Norton Sound/St. Lawrence Is.	7.3	7.8	6.3	Yes
Western Alaska	7.2	8.0	10.9	Yes
Bristol Bay	5.8	6.7	16.5	No
Kotzebue Sound/Hope Basin	5.7	6.0	6.0	No

Table 53. Comparison of WCD regional mean relative risk scores using relative abundance versus presence/absence. The % difference column indicates the magnitude of change between base model results and results of running the model with presence/absence scoring. The rank change column indicates where a region has "changed places" in the presence/absence model data run in comparison with the base model run.

Region	WCD Risk	WCD Pres./Abs. Risk	% Difference	Rank Change?
Southeast Alaska	37.8	39.8	5.3	No
Kodiak/Shelikof Strait	35.7	34.8	-2.5	Yes
Cook Inlet	34.0	38.1	12.3	Yes
Prince William Sound	27.3	31.1	13.7	No
South-Central Alaska	21.5	25.5	18.5	No
Aleutians	20.6	19.0	-7.7	Yes
Beaufort Sea	19.6	20.2	2.9	Yes
Aniakchak	15.1	16.5	9.1	Yes
Offshore Kenai Peninsula	14.6	17.0	16.4	Yes
Chukchi Sea	14.5	15.1	4.6	No
Norton Sound/St. Lawrence Is.	8.5	9.1	6.3	Yes
Western Alaska	8.4	9.4	10.9	Yes
Bristol Bay	6.7	7.8	16.5	No
Kotzebue Sound/Hope Basin	6.6	7.0	6.0	No

6.4.2.4 Addition of Species

Due to time and budget constraints, we were limited in the number of species we could assess for this study. In the base model run, 36 species were included, 12 for each of the three species groups. To determine whether this number of species was sufficient (i.e., such that an individual species does not have undue influence on the final relative risk score), a sensitivity test was conducted with three additional species added to each species group, for a new total of 45 species. The new species for each group were randomly selected from existing species in the group and added to the group a second time. The species that were randomly selected to be repeated in each group were:

- Marine Mammals and Sea Turtles – bowhead whale, beluga whale, and northern fur seal;
- Birds – harlequin duck, short-tailed shearwater, and black-legged kittiwake; and
- Fish and Invertebrates – Pacific herring, euphausiids, and Arctic cisco.

Results from the sensitivity test determined that the model is minimally sensitive to the addition of more species into the risk analysis (Table 54 and Table 55). The mean change in relative risk scores across both MMPD and WCD model runs was -0.9%. The largest change was for the Southeast Alaska region, which had reductions of 6.0% (MMPD) and 5.9% (WCD) in relative risk scores when using the additional species. For the MMPD model run, several regions changed rank positions, but only by a narrow difference in scores. For the WCD model run, none of the regions changed rank positions. These results suggest that while adding additional species to future applications of the model could further refine the relative risk results, the current number of species is sufficiently robust.

Table 54. Comparison of MMPD regional mean relative risk scores using 36 versus 45 species. The % difference column indicates the magnitude of change between base model results and results of running the model with additional species. The rank change column indicates where a region has "changed places" in comparison with the base model run.

Region	MMPD Risk	MMPD Additional Species Risk	% Difference	Rank Change?
Southeast Alaska	13.5	12.8	-6.0	Yes
Aleutians	13.4	13.2	-1.8	Yes
Kodiak/Shelikof Strait	13.0	12.6	-2.7	No
Cook Inlet	12.3	12.1	-1.8	No
Prince William Sound	9.9	9.7	-2.2	Yes
Aniakchak	9.8	9.7	-1.5	Yes
Beaufort Sea	9.6	9.7	1.7	Yes
Offshore Kenai Peninsula	9.5	9.3	-2.4	No
Chukchi Sea	8.4	8.3	-1.7	No
South-Central Alaska	7.6	7.4	-2.1	Yes
Norton Sound/St. Lawrence Is.	7.3	7.5	2.7	Yes
Western Alaska	7.2	7.4	1.6	No
Bristol Bay	5.8	5.9	1.8	No
Kotzebue Sound/Hope Basin	5.7	5.8	1.9	No

Table 55. Comparison of WCD regional mean relative risk scores using 36 versus 45 species. The % difference column indicates the magnitude of change between base model results and results of running the model with additional species. The rank change column indicates where a region has "changed places" in comparison with the base model run.

Region	WCD Risk	WCD Additional Species Risk	% Difference	Rank Change?
Southeast Alaska	37.8	35.7	-5.9	No
Kodiak/Shelikof Strait	35.7	34.8	-2.7	No
Cook Inlet	34.0	33.4	-1.8	No
Prince William Sound	27.3	26.7	-2.2	No
South-Central Alaska	21.5	21.1	-2.1	No
Aleutians	20.6	20.2	-1.8	No
Beaufort Sea	19.6	19.9	1.6	No
Aniakchak	15.1	14.9	-1.5	No
Offshore Kenai Peninsula	14.6	14.3	-2.4	No
Chukchi Sea	14.5	14.2	-1.7	No
Norton Sound/St. Lawrence Is.	8.5	8.8	2.7	No
Western Alaska	8.4	8.6	1.6	No
Bristol Bay	6.7	6.8	1.8	No
Kotzebue Sound/Hope Basin	6.6	6.8	1.9	No

7.0 DISCUSSION AND CONCLUSIONS

The results of this analysis are intended for use as a screening level assessment of relative marine oil spill risk in broad regions of Alaska. This study does not attempt to determine the exact size, location, transport, fate, and impacts of a particular future oil spill in Alaska. This study also does not consider what response technologies may be applied to future oil spills or ways in which response might mitigate or increase impacts. Rather, it is intended to identify broad regions and seasons within Alaska having both high relative environmental vulnerability and high relative oil spill probabilities and spill volumes. Each factor contributing to the risk model is computed for each broad geographic region as a whole.

Incident rates used in the risk model are based on past spills (and past potential spills) in Alaska from 1995–2012. These past incidents are assumed to predict where future incidents are likely to occur. In most cases, the actual spill volumes associated with the past spill incidents were very small (only 0.1% involved more than 500 bbl). However, to assess relative risk and prioritize areas for future study, the risk model uses the MMPD and WCD volumes that could potentially result from a future incident in a given region/season. Both volumes represent scenarios for which the future likelihood are very low and are not reflective of the volumes actually spilled in past incidents. Although spills with MMPD and WCD volumes have a very low likelihood, they must be taken into account for contingency planning and risk mitigation development. In essence, the risk model reflects where future incidents are likely to occur and potential “maximum” (rather than most likely) spill volumes that could result from a future incident.

The model results reveal a number of general patterns. Environmental vulnerability, incident rate, and final relative risk scores are typically higher in the summer months than during the winter. This is a reflection of the presence of migratory species and greater vessel traffic activities during the warmer months. Regarding oil type, light and heavy oils are the biggest contributors to risk for the current MMPD, current WCD, 2025 MMPD, and 2025 WCD scenarios (on average across all regions).

The top three highest relative risk regions (based on yearly mean score) for each model scenario (i.e., current MMPD, 2025 MMPD, current WCD, and 2025 WCD) are summarized in Table 56. For the current time period and both volumes (MMPD and WCD), the region with the highest relative risk was Southeast Alaska. For the 2025 projection, the region with the highest relative risk for both volumes was the Beaufort Sea. Across the 4 different model scenarios, the Southeast Alaska region occurs 4 times in the top 3 highest relative risk ranking, followed by the Aleutians region with 3 occurrences, the Beaufort Sea and Kodiak/Shelikof Strait regions with 2 occurrences each, and the Cook Inlet region with 1 occurrence. These regions are recommended for further study to investigate various aspects of the factors constituting risk – particularly spill volume and location, location of species and habitats within a region, and fate and transport of spilled oil.

Table 56. Highest ranking (i.e., highest relative risk) regions for each model scenario.

Relative Risk Rank	MMPD Current Risk	WCD Current Risk	MMPD 2025 Risk	WCD 2025 Risk
1	Southeast Alaska	Southeast Alaska	Beaufort Sea	Beaufort Sea
2	Aleutians	Kodiak/Shelikof Strait	Aleutians	Aleutians
3	Kodiak/Shelikof Strait	Cook Inlet	Southeast Alaska	Southeast Alaska

Because the relative risk model is highly data-intensive, the quality of the model results is inherently dependent on the quality of the input data. Certain environmental vulnerability data inputs are known to be of poor quality and should be updated when additional information becomes available. In particular, bottom habitat and submerged aquatic vegetation data coverage was lacking for much of the area assessed in this study. Because of the relatively high sensitivity of submerged aquatic vegetation habitats to spilled oil, the addition of more complete data for this parameter would likely result in some shifting of the environmental vulnerability scores (and potentially the final relative risk scores).

We were only able to assess a limited number of species for this analysis, but there are a wide variety of species using Alaska's habitats. Model sensitivity testing suggests that the number of species used for this project was sufficiently robust (see Section 0), but the addition of more species to the model could refine the risk scoring to some degree. Additional species should be added to the model where possible. Also, for many of the species assessed, reliable abundance estimates were not available. Even for those species where some information was available, data did not provide the spatiotemporal resolution required for this study. As a result, the assignment of abundance scores is based heavily on best professional judgment.

Due to the complexity of predicting the flow rate and duration of blowouts from offshore oil platforms and wells, the WCD volumes used in this study have a considerable amount of uncertainty. The WCD volumes for these facilities were based on the best available information at the time of the study, and should be updated if additional information becomes available in the future.

Another data limitation is the incident rates and potential spillage volumes forecasted for the year 2025. The outcomes of the forecasting analysis are integrally dependent on the assumptions applied. Given the uncertainty in these assumptions, there is a good measure of uncertainty in the spillage forecasts for 2025. A more detailed analysis of the factors in the forecast for 2025 and beyond is outside the scope of the current project, but merits consideration for a future analysis.

Also, no future projections were made for environmental vulnerability. While modified environmental vulnerability scores would change the final relative risk results somewhat, drastic changes would be unlikely because the environmental vulnerability score is not overly sensitive to any individual input parameter. Also, environmental vulnerability is only moderately correlated with the MMPD relative risk score, and is minimally correlated with the WCD relative risk score.

Despite the inherent limitations of such a broad-scale assessment effort, we believe that this study provides valuable information to guide the prioritization of risk planning and further study in Alaska. One of the main benefits of the risk model is that the various inputs, assessment criteria, and assumptions are explicitly stated and analyzed in a quantitative manner. Without such a transparent approach, it would be difficult to combine the large number of disparate input data sets required into an objective, repeatable result. Another benefit of the risk model is the flexibility to quickly update the results as new or improved data inputs become available. These updates are easily accomplished using the Alaska Spill Risk Calculator interface tool provided as Appendix E.

The results of this screening-level analysis identify broad regions of Alaska with high relative risk based on oil spill probability and environmental vulnerability. For regions identified as having high relative risk (e.g., the Southeast Alaska, Aleutians, Beaufort Sea, Kodiak/Shelikof Strait, and Cook Inlet regions) further study is recommended. In particular, trajectory and fates modeling would be a natural next step to this study to examine the magnitude of potential consequences from oil spills originating from these high relative risk regions. In the assessment of environmental vulnerability for each region/season, vulnerability scoring is based on the assumption that an oil spill would result in oiling of each type of shoreline and marine habitat within a region. Similarly, each species present during a particular region/season (as determined by the abundance scoring) is assumed to have potential overlap with oiling. Furthermore, the risk model only considers the region of origin of spills, not the location of the spill site within the region, the geographic extent of oiling, or direction of spill transport. In reality, some spills, such as those occurring far offshore, may not impact Alaska's shorelines, and only certain species and habitats would overlap with the oil. Spills occurring near the boundary of a region, or large volume spills, would likely affect multiple regions. It is also possible for a spill originating in one region to affect only shoreline of an adjacent region.

These factors illustrate the value of stochastic trajectory and fates modeling in further refining the risk results and supporting sound strategic planning. Stochastic modeling could be used to determine the probability of impact from spills of varying oil types and volumes originating at different locations on different dates (thus sampling the range of potential environmental conditions). This modeling would provide statistics regarding the magnitude of potential consequences for shorelines, water column habitats, surface waters, and species likely to overlap with the spilled oil and allow for finer-scale comparison of the regions identified by this study as having high relative risk.

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