EMBROILED: VOLUME 1

Salmon, Tankers and the Enbridge Northern Gateway Proposal

RAINCOAST
CONSERVATION FOUNDATION

Acknowledgements

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Embroiled: Volume 2
will address salmon, tankers and the Kinder Morgan Trans Mountain Expansion.

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About Raincoast Conservation Foundation:

Raincoast is a team of conservationists and scientists empowered by our research to protect the lands, waters and wildlife of coastal British Columbia. We use peer-reviewed science and grassroots activism to further our conservation objectives.

Our vision for coastal British Columbia is to protect the habitats and resources of umbrella species. We believe this approach will help ensure the survival of all species and ecological processes that exist at different scales.

Our mandate: Investigate. Inform. Inspire.

We Investigate to understand coastal species and processes.
We Inform by bringing science to decision makers and communities.
We Inspire action to protect wildlife and their wilderness habitats.

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Executive Summary

PHOTO: M. CARWARDINE

This report was written in response to public concern regarding the threat posed to salmon by the marine component of Enbridge's proposed Northern Gateway project. Our aim with this report is to inform decision makers and communities, in BC and elsewhere, by presenting the science of what we know, and the uncertainty around what we do not know. We believe both show that implementing an oil corridor through Canada's most important wild salmon habitat is not a risk worth taking. We hope to inspire readers to protect wild salmon and the ecosystems they sustain.

PHOTO: J.RHODES

Our entanglement with oil

We live in a complicated world. Easy access to cheap, abundant, oil has created a high standard of living for many cultures and societies. At the same time, the extraction, refining, distribution, and use of this oil – as energy and in products – is increasingly undermining many of our planet's life forms and the fragile balance of conditions that support climate stability and human prosperity. These effects are occurring on local, regional, and global scales.

Canada's northwest coast stands alone as one of our planet's last unspoiled coastlines. Its assemblage of wild rivers, First Nations cultures, animals, and landscapes makes it qualitatively different from any other place in the world. British Columbians have increasingly come to cherish this maritime commons of waters, islands, and forests. And wild salmon – the foundation species on which this coastal bounty is built – are as important to British Columbians as the French language is to Quebec.

Recently, there has been an aggressive push to convert British Columbia's (BC) coast into an energy corridor for the export of tar sands oil. This initiative, proposed by the Enbridge pipeline company and backed by the Canadian federal government, would see the world's largest oil tankers routinely traverse the rare, natural labyrinth of islands and inlets to deliver diluted bitumen to global markets. Such a project would transform a place that has largely withstood the march of industrialization. It would inescapably subject its waterways to the chronic contamination and likelihood of spills that has accompanied the oil industry the world over.

This report is about the proposed transport of Canadian tar sands oil through the BC coast, and the implications such a project would have for wild salmon. We reviewed elements of risk and potential impacts to wild Pacific salmon in BC's Queen

Stretching from Dixon Entrance in the north, to Queen Charlotte Strait in the south, and west to the edge of the continental shelf, the region contains hundreds of coastal islands and inlets that form an archipelago with 27,000 km of shoreline in less than 1,000 km distance. Image: Google Earth

Photo: Cheadle/ Allcanadaphotos.com

On average, 25 million adult salmon return each year to watersheds of the Queen Charlotte Basin; however annual fluctuations in returns are large.[4] The commercial value of salmon returning to the Skeena River catchment alone has been estimated at $110 million annually.[5] In total, salmon from the Queen Charlotte Basin represent 58% of all salmon populations on Canada's west coast.[6] The Queen Charlotte Basin also supports populations of salmon from Washington, Oregon, and California.[7]

Charlotte Basin from the tanker and terminal components of Enbridge's proposed Northern Gateway Project. These risks stem from the presence of oil tankers loading and transporting tar sands oil (diluted bitumen), the toxicity of diluted bitumen from chronic and episodic oil exposure, and other effects to BC's wild salmon habitat from tanker and terminal operations.

The Queen Charlotte Basin

The Queen Charlotte Basin is a vital marine rearing and staging area, and migration corridor for wild salmon. An incredible diversity of habitat and environmental conditions occurs within this region.

There are more than 5,000 populations of spawning salmon within the 1,200 plus primary watersheds that drain to the Queen Charlotte Basin. The salmon runs from these watersheds are grouped into 267 units of irreplaceable salmon diversity called Conservation Units.

The basin hosts approximately 383 major runs of the five commercially managed salmon species[1], and another 3,000 smaller runs[2] that together form the foundation for the remarkable genetic diversity and biological complexity of salmon populations within this region. Wild salmon also play key roles in coastal ecosystems, nourishing a complex web of interconnected species.[3]

The archipelago nature of the Queen Charlotte Basin has created extensive, essential nearshore habitat for hundreds of millions of young salmon. Estuaries form a critical component of this essential habitat. Use of coastal estuaries is considered a cornerstone phase in a salmon's life history when adaptation to salt water, feeding, and refuge from predators is critical.[8]

The threat to salmon

Salmon naturally have poor odds for survival. At best, only one salmon for every thousand eggs that a female lays will return to spawn. Threats from predators, limited food supply, and environmental conditions challenge salmon at every life stage. Development activities in salmon watersheds and in the ocean drive survival rates even lower.

The severity of an oil spill on the BC coast would be exacerbated by the persistence of crude oil in cold water habitats, and the potential for strong winds, currents and freshwater to disperse oil over large distances.
PHOTO: MCALLISTER/RAINCOAST

Chum and pink salmon are the most vulnerable salmon to marine oil spills because of their tendency to spawn in the lower reaches of freshwater streams, where oil residue can accumulate.
PHOTO: M.CARWARDINE

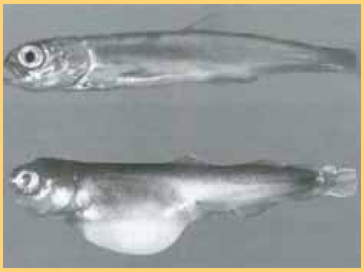
Oil tankers and spills in our coastal waters present a new, added threat to salmon survival. Adverse effects come from acute, chronic, and indirect exposure to oil products.[9] The most vulnerable period for salmon from an oil spill is during their embryonic-to-larval stage of incubation in the spawning gravels. Salmon embryos and larvae are highly sensitive to oil exposure (up to ten times that of adults), because their high lipid content attracts oil.[10] In the embryonic stage, chum and pink salmon are the most vulnerable species to marine oil spills because of their tendency to spawn in the lower reaches of freshwater streams, where oil residue could accumulate.

The early life phase of marine feeding, rearing, and migration is the next most vulnerable period for salmon from an oil spill. When young salmon first migrate to sea, all species are vulnerable because of a reliance on estuaries and nearshore waters for food, protection, and safe migration. However, chum, pink, and the ocean–rearing types of Chinook, coho, and sockeye salmon are the most vulnerable due to longer residency times.[11] Although acute exposure to crude oil will cause immediate death (largely through heart failure), the indirect exposures from contaminated food, loss of food resources, and degradation of nearshore habitat may be of greater risk to wild salmon.

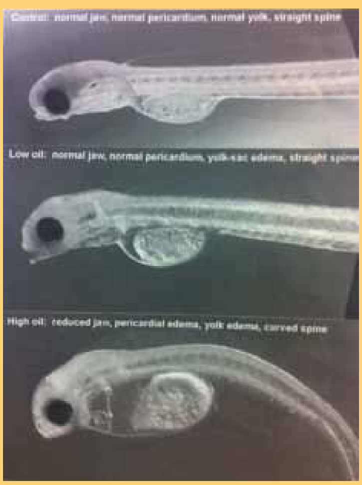
The component most associated with the toxic and persistent properties of petroleum products are the polycyclic aromatic hydrocarbons (PAHs).[12] Low levels of exposure to PAHs (at parts per billion, ppb), are known to have lethal and sub-lethal consequences for salmon.[13]

In addition, indirect effects to salmon habitat from oil contamination operate at multiple levels of the food web, which can adversely affect salmon.[14]

There are also threats to salmon without a marine oil spill. Oil tankers in confined channels have the potential to degrade and destroy sensitive habitats (such as eelgrass meadows) from the impacts of wake action.[15] Wakes can also strand juvenile salmon.[16] Less known are the potential impacts from acoustic disturbance on salmon by tankers.



The component most associated with the toxic and persistent properties of petroleum products are the polycyclic aromatic hydrocarbons or PAHs. Exposure to low levels of PAHs (in parts per billion) are known to have lethal and sublethal consequences for both juvenile salmon (above) and herring (below). PHOTOS: NOAA AUKBAY LAB



Salmon embryos and larvae are up to ten times more sensitive to oil than adult salmon. PHOTO: NOAA

Other potential problems relate to increased suspended sediments in Kitimat Arm and Kitimat estuary associated with terminal construction, operations, and maintenance. These activities have the potential to harm salmon directly and indirectly. Gill damage and smothering, combined with reduced feeding from visual impairment, will compromise young salmon survival. Increased sediments will affect habitat (particularly eelgrass, previously far more abundant in Kitimat Arm) and food abundance for juvenile salmon.

Food web and ecosystem toxicity concerns also exist from the potential to disturb existing PAHs that lie in the previously contaminated bottom sediments of Kitimat Arm. Biochemical processes have the ability to further transform these PAHs into other toxic compounds and make them available to the salmon food web.[17]

Lastly, chronic oiling from routine operations and small spills at terminals (where most spills occur) can represent a significant input of oil into the marine ecosystem. Studies from the Port of Valdez in Alaska show a clear correlation between PAH levels in sediment and volumes of oil shipped.[18] Other shipping activities associated with ports and terminals may deplete oxygen, degrade water quality, and negatively affect salmon habitat.

Misleading and flawed information

We also examine information that should have been considered by Enbridge, yet was either inadequately assessed, or ignored. We found that scientifically flawed studies and cursory reviews by Enbridge served to downplay the extent of, and impacts to, salmon presence within Kitimat Arm and the Queen Charlotte Basin.

The inadequate assessment of baseline conditions and project impacts is exacerbated by Enbridge's failure to adequately consider cumulative impacts, including climate change. Consequently, the conclusions arrived by Enbridge cannot be scientifically supported in many cases. The following are a summary of the primary inadequacies in Enbridge's impact assessment:

- Misleading, selective, and erroneous data used in Enbridge's contaminant study, which served to downplay and dismiss contamination and toxicity issues around PAHs,
- No adequate baseline surveys were conducted to determine the extent of habitat use by juvenile salmon within the Kitimat estuary and throughout Kitimat Arm,
- No empirical data were collected on juvenile salmon use within Kitimat Arm (or elsewhere),
- A literature review with notable omissions of:
  - Recognition of at least 15 salmon-bearing streams in Kitimat Arm that contain seven salmon species in 63 spawning populations; all of which spawn, feed, and rear in Kitimat Arm,
  - Recognition of more than 400 spawning populations within the Confined Channel Areas of the tanker route that contain some the highest densities of spawning salmon on the BC coast,
  - The presence of two unique Conservation Units (each) of chum and coho salmon that encompass the Confined Channel Area of the tanker route,
  - The presence of more than 30 unique Conservations Units of sockeye salmon within, or on the border of, the tanker route's Confined Channel Area.

In the absence of an adequate assessment of risk by Enbridge, (*risk* defined as the probability of an oil spill x the consequence of an oil spill), Raincoast performed a limited risk assessment to demonstrate the type of analysis that should have been undertaken.

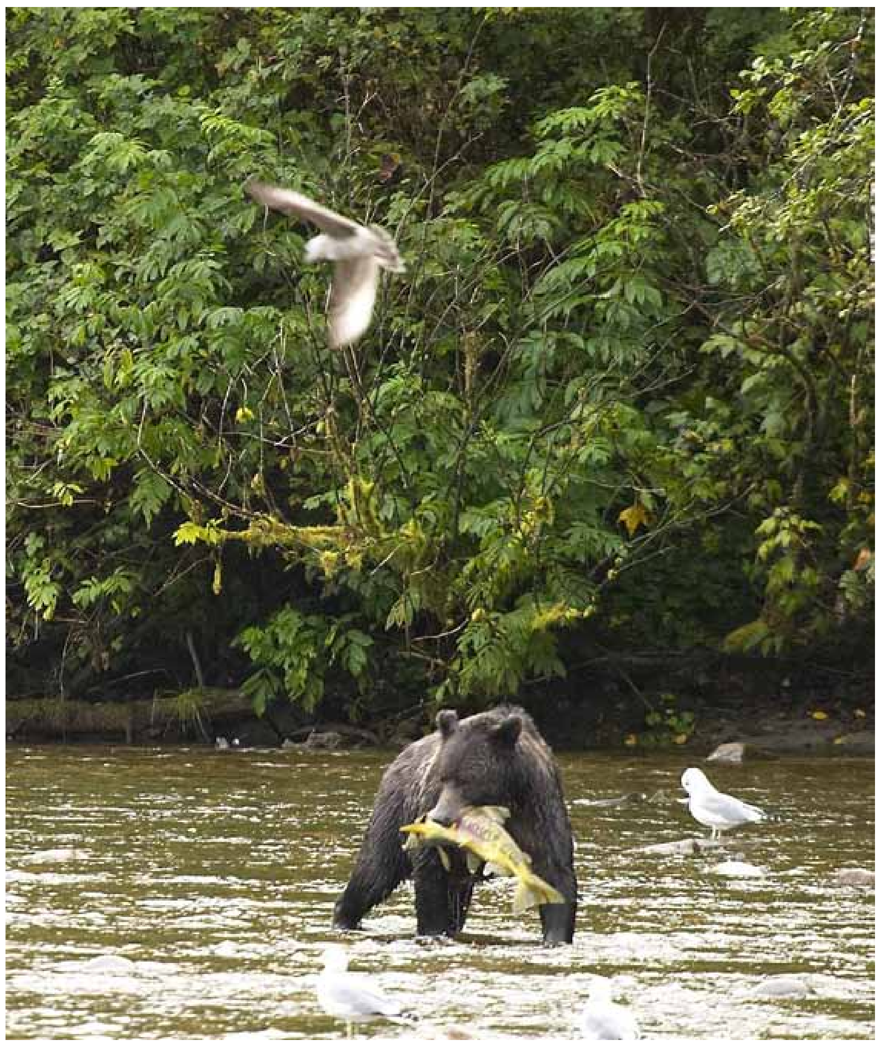
Our assessment used salmon densities, vulnerability, and Enbridge's own oil spill probabilities[19] to determine consequence and risk. Highly valued salmon populations that may incur adverse consequences from an oil spill occur throughout the Skeena watershed, and the central and north coasts of BC (Figure 7.4). In the event of a large spill within Enbridge's higher ranked risk areas, salmon populations within these regions could be severely affected for multiple generations, with concurrent impacts to human and non-human wild salmon dependants.

Eelgrass habitat is very important for young salmon and it grows in several locations near the proposed oil terminal and along the tanker route. Eelgrass is highly sensitive to poor water quality and has already suffered extensive loss from industrial activity in the upper Kitimat estuary. Photos: (top) marinebio.ca (bottom) J.M. Carroll

An example of vulnerable intertidal spawning grounds used by British Columbia's pink and chum salmon. PHOTO: M. MACDUFFEE/RAINCOAST

Conclusion

Salmon, and the interconnected biota that they support, are the very soul of British Columbia. Although it is difficult for a nation to set aside short-term profits, the decision to build Northern Gateway may come with irreparable cost in the long term. The prospect of losing this natural identity, livelihoods, and connection to the land and waters that British Columbians love, compels us to think large and long term. Our aim is to provide the fact-based information necessary for society to make the sound decision wild salmon and their dependents deserve.



Enbridge did not attempt to identify intertidal spawning habitat, holding areas, or important wildlife streams where key species (i.e., grizzly bears) rely on salmon. PHOTO: T. IRVING

1. Salmon of the Queen Charlotte Basin

In British Columbia, thousands of years of 'homing' by wild salmon to their natal streams has created 450 distinct salmon populations[22] or Conservation Units, within the five species of commercially recognized salmon. PHOTO: NOAA

Despite occupying less than 8% of the global ocean by area, continental shelves – like the Queen Charlotte Basin – contribute 69% of the world fish catch (89% if upwelling zones are included), support high biodiversity, and large populations of marine mammals and seabirds.[23] PHOTO: N.DIDLICK

For milennia, wild salmon have migrated throughout the north Pacific to spawn in freshwater rivers and streams from northern California to Alaska and the Yukon. Historically, these fish used every accessible freshwater system within 40–65° North Latitude.[20] The immense diversity of habitat and environmental conditions across this region, coupled with the strong tendency of salmon to "home" to natal streams and specific spawning sites, have driven the evolution of thousands of locally adapted populations.[21]

Wild salmon rivers that flow from the watersheds of BC's north and central coasts drain into Queen Charlotte Basin (Figure 1.1), a marine region of more than 30,000 km^2 (11,000 mi^2) that stretches from Dixon Entrance in the north to Queen Charlotte Strait in the south and west to the edge of the continental shelf. This region contains the islands of Haida Gwaii, and hundreds of other coastal islands and inlets that form an archipelago with 27,000 km (17,000 mi) of shoreline in less than 1,000 km (620 mi) distance. The continental shelf at the edge of the archipelago is also ecologically important.

The Queen Charlotte Basin is a vital migration corridor for rearing and feeding by BC's young and adult salmon, including those from the south coast mainland, the Fraser River, and the east and west coasts of Vancouver Island. The Queen

Salmon fuel the economy

The wild salmon harvest in BC, which includes commercial and sport fisheries, as well as the processing industry, has been estimated at $447 million per year.[24] Commercial salmon harvesting primarily targets pink and sockeye populations from the Fraser and Skeena River, providing approximately 1,600 full-time equivalent jobs. The salmon sport fishery, which targets Chinook and coho, provides roughly 2,300 full-time equivalent jobs.

Charlotte Basin also supports many salmon populations from Washington, Oregon, and California.[25]

Time spent in coastal estuaries by young salmon is considered a cornerstone phase in salmonid development where environmental adaptation, feeding, and refuge from predators is critical.[26] Importantly, growth and survival in this juvenile phase largely contribute to the overall survival and fitness of wild salmon.[27]

Fisheries scientists first assessed the region's major salmon runs in the 1960s.[29] Results suggested that the Queen Charlotte Basin hosted approximately 383 major runs[30] of the five commercially managed salmon species, specifically 131 pink, 94 coho, 67 chum, 55 sockeye, and 36 Chinook populations.[31]

In addition to these major runs in highly productive streams, an additional 3,000 runs are smaller and less productive, but form the foundation for the remarkable genetic diversity and biological complexity of salmon populations within this region.[32]

Figure 1.1. About 1,200 salmon-bearing streams and rivers drain from the headwaters of BC's mainland, Haida Gwaii, and northern Vancouver Island into the marine waters of the Queen Charlotte Basin. These waterways host more than 5,000 spawning populations of pink, chum, sockeye, coho, and Chinook salmon that are grouped into 250 Conservation Units, each one of which is unique and irreplaceable. These fish represent 58% of all salmon runs originating from Canada's west coast.[28]

A salmon culture
The return of spawning salmon over millennia has been fundamental to shaping the cultural identities of indigenous peoples of the Pacific Northwest. Salmon are embedded in coastal people's cultural traditions and narratives, their ceremonies, dances, songs, and discourse. Detailed names have been given to each salmon species, and much focus is given to activities and conversations around the annual cycle of salmon.

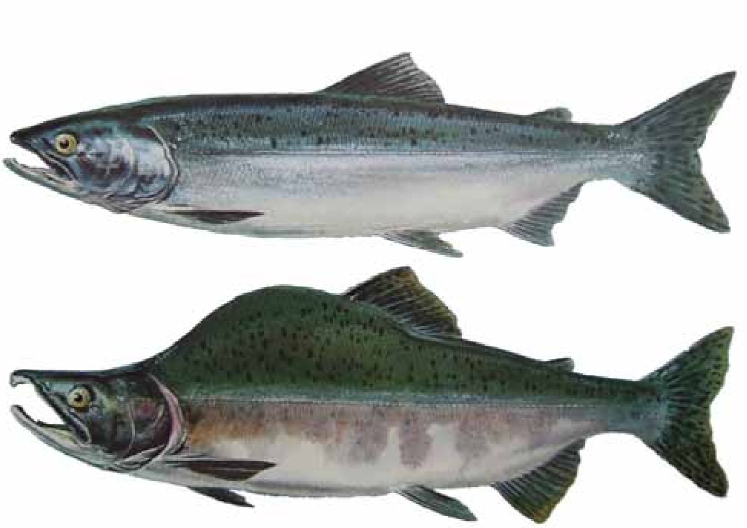
Salmon fishing, harvesting, and processing all provide opportunities for individuals to learn about one's territory and attendant ecosystem. These activities teach critical skills, unite families with opportunities for learning and teaching stories, songs, and language, and build connection between youth and elders.[33] These processes are critical to the maintenance and survival of coastal indigenous cultures, and in so being, would qualify salmon as a cultural keystone species. Photo: P. Paquet

Conservation Units: groups of irreplaceable salmon diversity

A Conservation Unit is a category that scientists use to describe a group of salmon populations that are distinct from all others. Conservation Units reflect the genetic and ecological differences within each species of salmon. This uniqueness stems from specific adaptations to particular river and watershed conditions, which influence everything from when and where salmon spawn in a river to their body shape and size.[34] In the Queen Charlotte Basin there are 267 Conservation Units,[35] each of which is an irreplaceable group of salmon diversity.[36] The preservation of such diversity is one of the most important objectives of conservation.[37]

Specialized adaptations further account for the difficulty in transplanting salmon from one river to another, rebuilding wild salmon populations in modified habitats, and restoring salmon in places where they have been extirpated.[38] Many local spawning populations give resilience to larger groups of salmon and Conservation Units. Just as a diverse portfolio of financial investments enables stable returns under various economic conditions, this biological complexity creates a diverse system with the resilience to withstand natural cycles and persist under stress.[39] If wild salmon are to persist through the natural ranges of environmental variability and human-induced stressors, such diversity is critical to their survival.

Photo: L. Travis



Pink salmon ocean-phase (top) and spawning male (bottom).
IMAGE: FISHERIES AND OCEANS CANADA (DFO)

Pink salmon

Pink salmon are the most numerically abundant species in the Queen Charlotte Basin, and second only to coho in terms of their distribution; they spawn in more than 1,200 coastal rivers and streams.[40] The discrete two-year cycle of pink salmon has given rise to distinct genetic lineages, where either odd or even years are dominant in a local stream. Twenty-six distinct Conservation Units of pink salmon are divided into 11 populations of even-year lines, and 15 odd-year lines (Figure 1.2, 1.3).

Even-year pink salmon are more abundant in Haida Gwaii and odd-year pink salmon are more abundant, and with greater diversity, on the mainland coast.[41] Pink salmon use the lower reaches of coastal streams, often spawning in intertidal areas. Their wide distribution and abundance in small and shallow

PHOTO: L. TRAVIS

Figures 1.2 and 1.3 The 26 distinct Conservation Units of odd-year (left) and even-year (right) pink salmon lineages. Pink salmon Conservation Units have been grouped according to their life history, run-timing, and genetic separation within over 1,200 watersheds and tributaries that drain into the Queen Charlotte Basin. Numbers follow DFO's Conservation Unit classification.

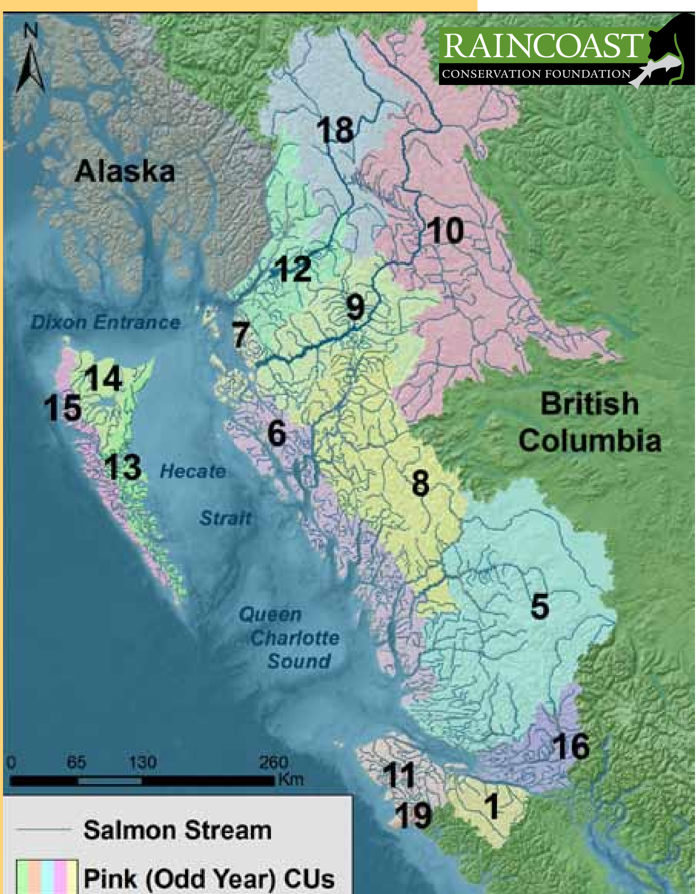
Pink (odd year) Conservation Units (15)
1-East Vancouver Island-Johnstone Strait, **5**-Homathko-Klinaklini-Smith-Rivers-Bella Coola-Dean, **6**-Hecate Strait-Lowlands, **7**-Nass-Skeena Estuary, **8**-Hecate Strait-Fjords, **9**-Lower Skeena, **10**-Middle & Upper Skeena, **11**-Nahwitti, **12**-Nass-Portland-Observatory, **13**-East Queen Charlotte Islands, **14**-North Queen Charlotte Islands, **15**-West Queen Charlotte Islands, **16**-Southern Fjords, **18**-Upper Nass, **19**-West Vancouver Island.

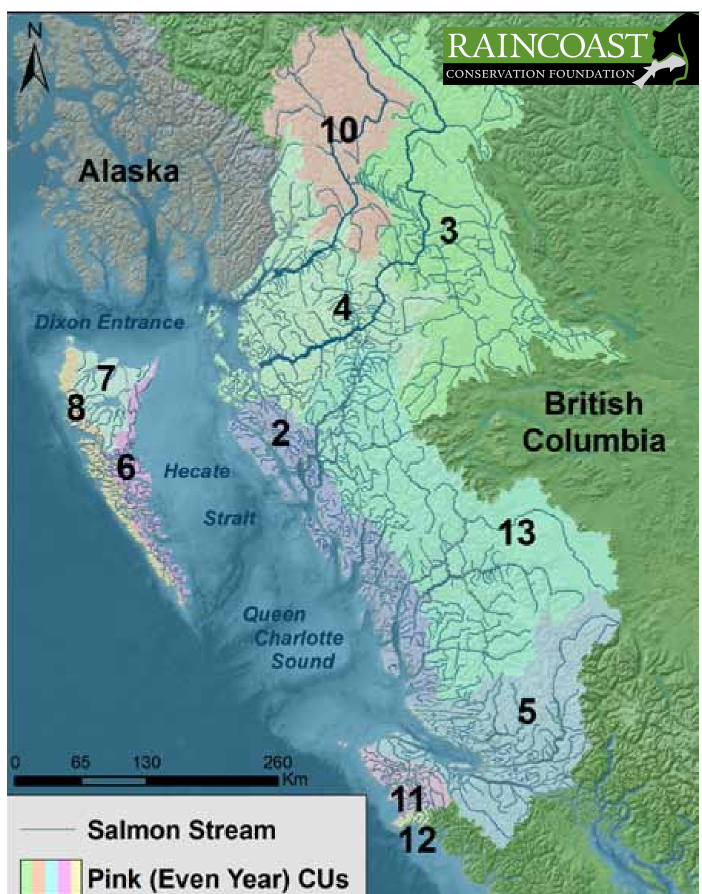
Pink (even year) Conservation Units (11)
2-Hecate Lowlands, **3**-Middle-Upper Skeena, **4**-Nass-Skeena Estuary, **5**-Southern Fjords, **6**-East Queen Charlotte Islands, **7**-North Queen Charlotte Islands, **8**-West Queen Charlotte Islands, **10**-Upper Nass, **11**-West Vancouver Island, **12**-Northwest Vancouver Island, **13**-Hecate Strait-Fjords.

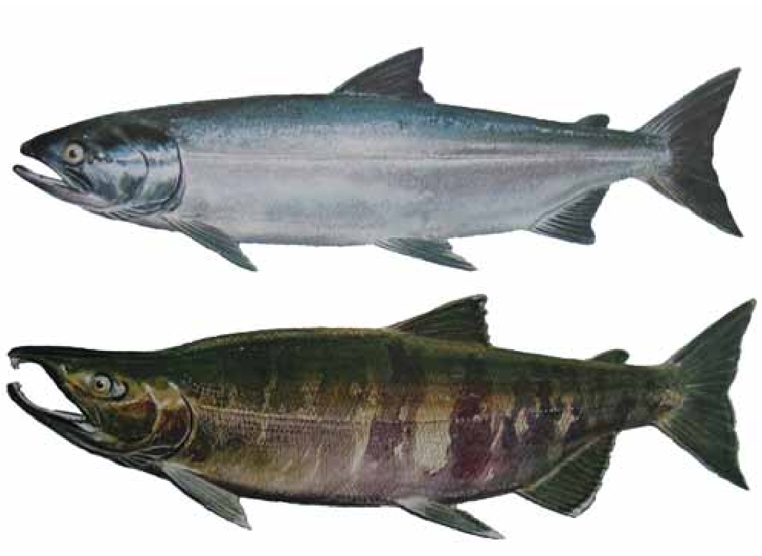
streams enable easy access for predators, which underscores the importance of pink salmon as a critical resource for bears, wolves, birds, and numerous other animals.[42]

Pink salmon typically lay eggs from late August to October, which then incubate over seven to eight months. Water surrounding the eggs must provide appropriate temperatures, hold adequate oxygen, and remove waste materials. Collectively, these requirements are only partially met even under the most favourable natural conditions. Overall, freshwater survival of pink salmon from egg to fry is only 10 to 20%, even in highly productive streams, and it can be as low as 1%.[43]

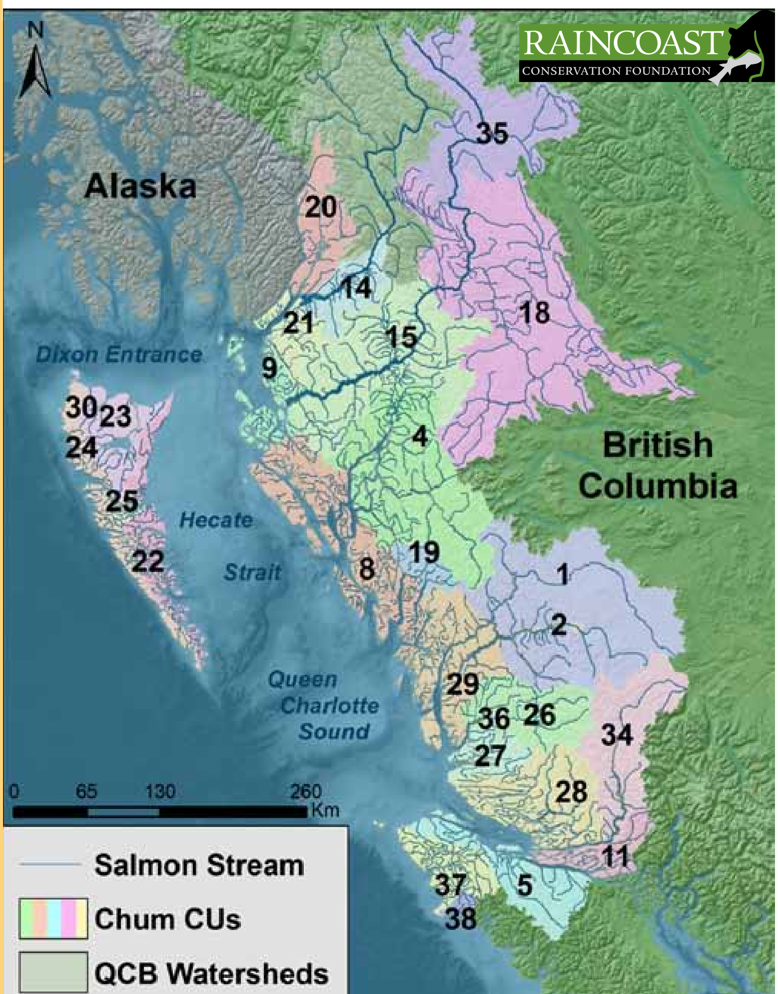
Once emerged from the gravels, the tiny pink fry immediately migrate to sea where they then spend several months feeding on zooplankton and other microscopic marine life near the surface. A large proportion of the natural marine mortality of pink salmon is thought to occur within the first few months before juveniles move offshore into deeper waters.[44]







Chum salmon ocean-phase (top) and spawning male (bottom).
Image: DFO



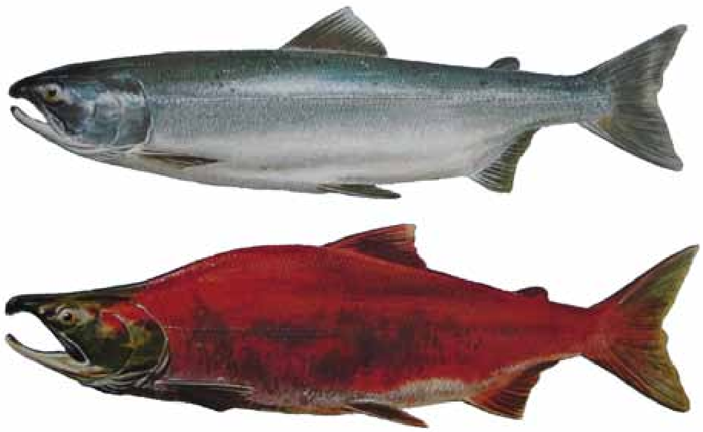
Chum salmon

Chum salmon are the second most abundant species of salmon in the Queen Charlotte Basin and exhibit the most similar life history to pink salmon. Their presence in more than 1,200 streams is divided into 27 Conservation Units (Figure 1.4). Spawning is concentrated from late September to early November, often in the lower and intertidal sections of rivers.

After roughly seven months of egg incubation, emerged fry can spend up to one month in freshwater backchannels before migrating to the ocean. As with pink salmon, the intertidal areas of bays and estuaries form critical habitat for chum (where they forage on zooplankton such as copepods) during the first six months of their ocean residency. The large size of spawning chum (3-6 kg), their broad distribution, and their presence in small, accessible, coastal streams means they are a critical food source for bears and other wildlife.[45] Resident killer whales also consume these fish in the autumn months.[46]

Figure 1.4 The 27 distinct Conservation Units of chum salmon that spawn in more than 1,200 streams in the Queen Charlotte Basin. Chum Conservation Units are delineated based on use of marine habitats, and genetic separation. Numbers follow DFO's Conservation Unit classification.

Chum Conservation Units (27)
1-Bella Coola-Dean Rivers, **2**-Bella Coola River-Late, **4**-Douglas-Gardner, **5**-Northeast Vancouver Island, **8**-Hecate Lowlands, **9**-Skeena Estuary, **11**-Loughborough, **14**-Lower Nass, **15**-Lower Skeena, **18**-Middle Skeena, **19**-Mussel-Kynock, **20**-Portland Canal-Observatory, **21**-Portland Inlet, **22**-East QCI, **23**-North QCI, **24**-West QCI, **25**-Skidegate, **26**-Rivers Inlet, **27**-Smith Inlet, **28**-Southern Coastal Streams, **29**-Spiller-Fitz-Hugh-Burke, **30**-North QCI-Stanley Creek, **34**-Upper Knight, **35**-Upper Skeena, **36**-Wannock, **37**-Northwest Vancouver Island, **38**-Southwest Vancouver Island.



Sockeye salmon: ocean-phase (top) and spawning male (bottom). IMAGE: DFO

Sockeye salmon

The most well-known sockeye populations in the Queen Charlotte Basin are the large runs from the lakes within the Nass, Skeena, and Owikeeno watersheds. These, and other smaller populations that typically rear for one or two years in lakes before migrating to sea, constitute 153 distinct lake-type Conservation Units (Figure 1.5).[47]

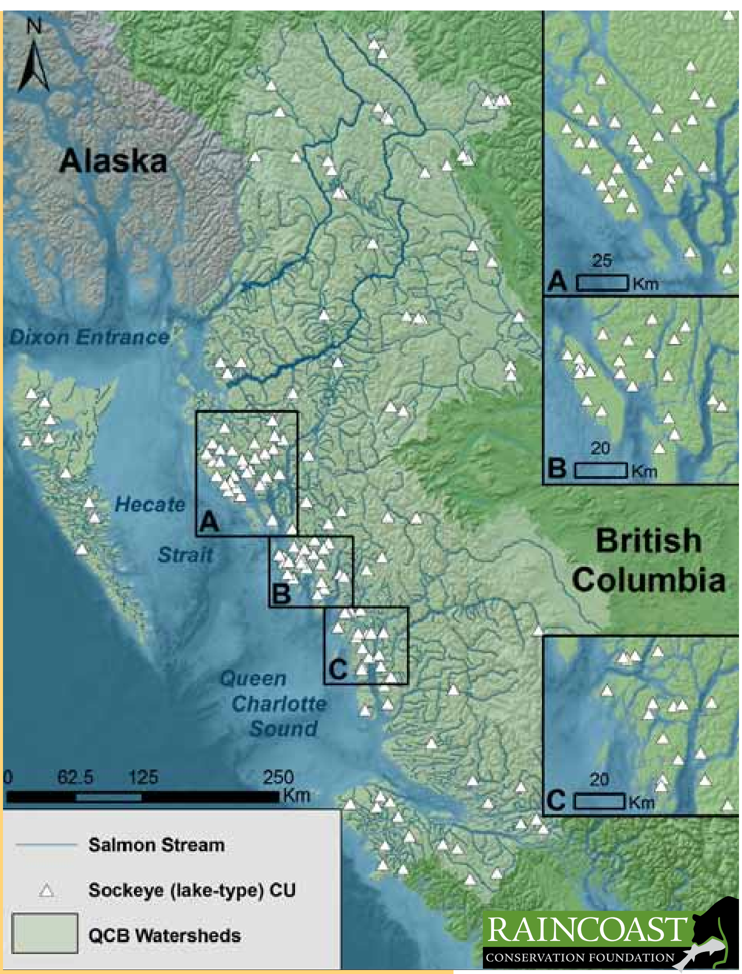


Figure 1.5 The locations of 153 Conservation Units of lake-type sockeye. Fry from these Conservation Units spend up to two years rearing in freshwater lakes, and are genetically and reproductively isolated from other lake sockeye populations. Numbers follow DFO's Conservation Unit classification.

Lake Type Sockeye Conservation Units (153)
Fulmore, Heydon, Kakweiken, Loose, Mackenzie, Tom Browne, Ida/Bonanza, Nahwitti, Nimpkish, Georgie/Songhees, Quatse, Schoen, Shushartie, Woss, Alice, Canoe Creek, O'Connell, Power, William/Brink, Long, Owikeno, Owikeno-Late timing, Wannock[Owikeno], South Atnarko Lakes, Ain/Skundale/Ian, Awun, Fairfax, Jalun, Marian, Mathers, Mercer, Skidegate, Yakoun, Backland, Canoona, Dome, Evelyn, Kainet Creek, Kimsquit, Kitkiata, Kitlope, Pine River, Soda Creek, Whalen, Banks, Bloomfield, Bolton Creek, Bonilla, Borrowman Creek, Busey Creek, Cartwright Creek, Chic Chic, Citeyats, Fannie Cove, Curtis Inlet, Dallain Creek, Deer, Devon, Douglas Creek, Elizabeth, Elsie/Hoy, End Hill Creek, Evinrude Inlet, Freeda, Hartley Bay, Hevenor Inlet, Higgins Lagoon, Kadjusdis River, Kdelmashan Creek, Keecha, Kent Inlet Lagoon Creek, Kenzuwash Creeks, Keswar Creek, Kildidt Creek, Kildidt Lagoon Creek, Kisameet, Koeye, Kooryet, Kunsoot River, Kwakwa Creek, Lewis Creek, Limestone Creek, Lowe/Simpson/Weir, Mary Cove Creek, Mcdonald Creek, Mcloughlin, Mikado, Monckton Inlet Creek, Namu, Port John, Powles Creek, Price Creek, Prudhomme, Roderick, Ryan Creek, Salter, Scoular/Kilpatrick, Shawatlan, Sheneeza Inlet, Ship Point Creek, Spencer Creek, Stannard Creek, Talamoosa Creek, Tankeeah River, Treneman Creek, Tsimtack/Moore/Roger, Tuno Creek East, Tuno Creek West, Tyler Creek, Wale Creek, Watt Bay, West Creek, Yaaklele Lagoon, Yeo, Alastair, Aldrich, Dennis, Ecstall/Lower, Johnston, Kitsumkalum, Lakelse, Mcdonell, Atna, Babine, Bulkley, Club Lake, Kitwancool, Maxan, Morice, Nilkitkwa, Stephens, Swan, Tahlo/Morrison, Asitika, Azuklotz, Bear, Damshilgwit, Johanson, Kluatantan, Kluayaz, Motase, Sicintine, Slamgeesh, Spawning, Sustut, Clements, Leverson, Bowser, Damdochax, Fred Wright, Kwinageese, Meziadin, Oweegee.

There are hundreds more small populations of river-type sockeye that do not rear in lakes. River-type sockeye are grouped into 14 distinct Conservation Units (Figure 1.6).[48] Fry from these populations are thought to migrate seaward at a much younger age and prefer the side channels of rivers and coastal estuaries for rearing, instead of lakes.[49]

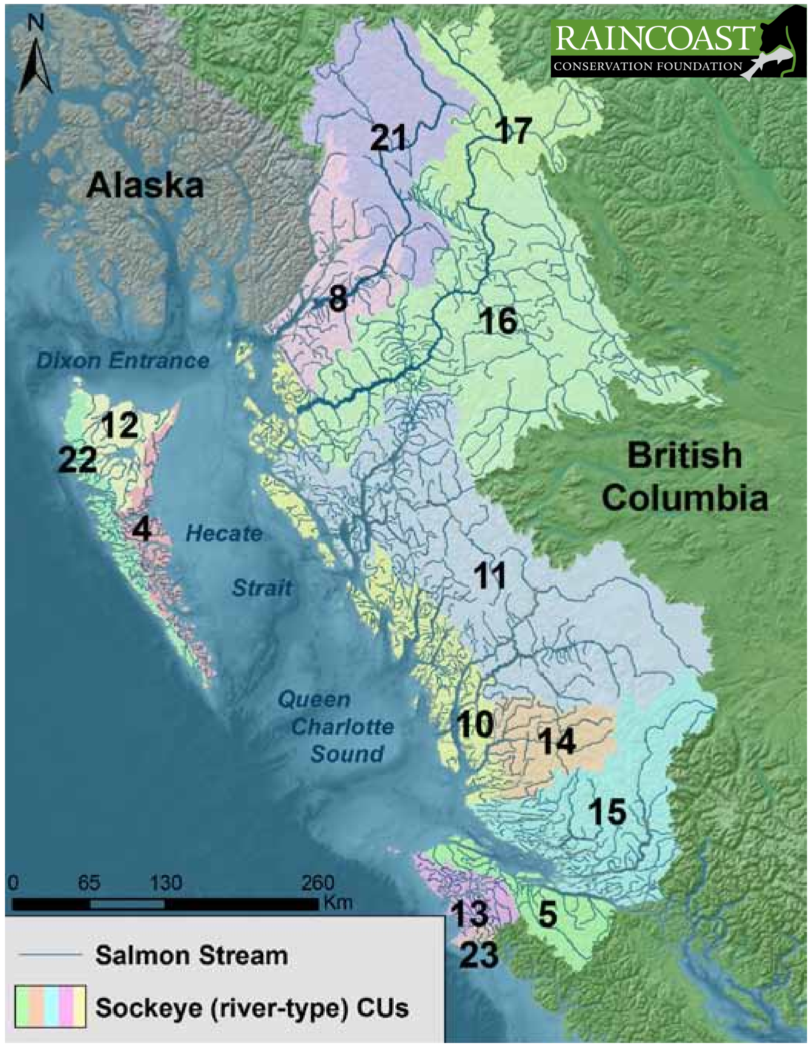


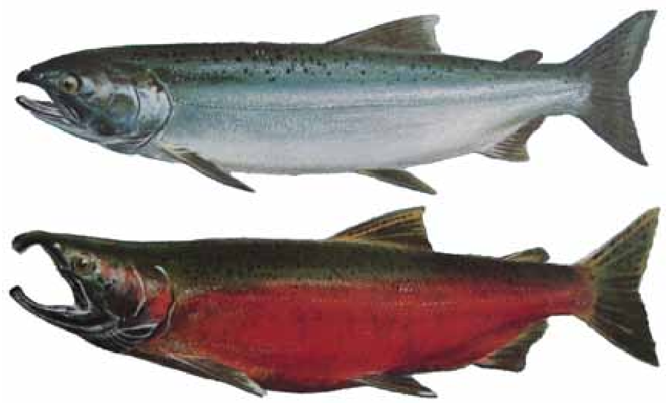
Figure 1.6 The 14 Conservation Units of river-type sockeye. River-type sockeye differ from lake-type based on their short residence time in fresh-water rivers and greater reliance on estuaries for rearing. Numbers follow DFO's Conservation Unit classification.

River Type Sockeye Conservation Units (14)
4-East Queen Charlotte Islands, **5**-East Vancouver Island & Georgia Strait, **8**-Lower Nass-Portland, **10**-Northern Coastal Streams, **11**-Northern Coastal Fjords, **12**-North Queen Charlotte Islands, **13**-NW Vancouver Island, **14**-Rivers-Smith Inlets, **15**-Southern Fjords, **16**-Skeena River, **17**-Skeena River-high interior, **21**-Upper Nass River, **22**-West Queen Charlotte Islands, **23**-West Vancouver Island.

Keystone versus foundation species

Ecologists have long understood that some species, by virtue of the roles they play in supporting an ecosystem, are essential to its integrity. These are often termed *keystone* or *foundation* species. A keystone species has an influence on its surroundings that is disproportionately large compared with its abundance. Salmon have a remarkable influence on coastal ecosystems, primarily because of their immense biomass. As such, they are more appropriately considered a *foundation* species, providing building blocks for ecological processes and food webs.

Photo: R. Olenik



Coho salmon ocean-phase (top) and spawning male (bottom).
Image: DFO

Coho salmon

Coho are elusive, powerful swimmers that can surmount high velocity waterfalls and other obstacles to penetrate far into the headwaters of very small tributary streams. This, coupled with their habitation of small coastal streams, makes them the most widely distributed of all salmon. The presence of these large fish (3-5 kg) late in the year (November and December) and in upper watersheds provides a critical resource to bears.[50] The rotting carcasses and remains of coho consumed by bears in these habitats also deliver nitrogen and phosphorous nutrients into generally nutrient-poor headwaters.[51]

At least 1,233 catalogued coho spawning populations occur in the Queen Charlotte Basin, with independent estimates much higher.[52] Coho spawning populations are grouped into 22 unique Conservation Units (Figure 1.7).[53] Juvenile coho may spend one-to-three years rearing in freshwater habitats before migrating to sea. Depending on their age at departure, juveniles will rely on the estuary to varying degrees and feed on a variety of plankton, invertebrate larvae, and other fish.

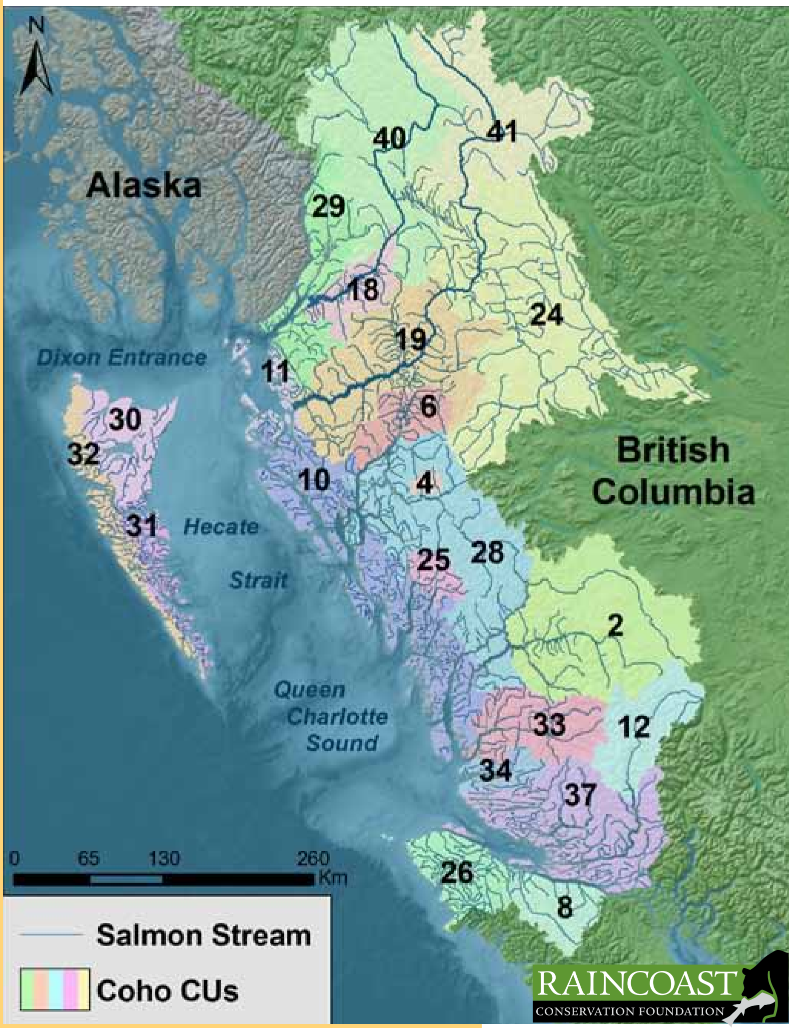


Figure 1.7 The 22 unique Conservation Units of coho salmon in Queen Charlotte Basin. These populations are based on life history, run-timings, different uses of freshwater and marine habitats, and genetic uniqueness. Numbers follow DFO's Conservation Unit classification.

Coho Conservation Units (22)
2-Bella Coola-Dean Rivers, **4**-Brim-Wahoo, **6**-Douglas Channel-Kitimat Arm, **8**-East Vancouver Island-Johnstone Strait-Southern Fjords, **10**-Hecate Strait Mainland, **11**-Skeena Estuary, **12**-Homathko-Klinaklini Rivers, **18**-Lower Nass, **19**-Lower Skeena, **24**-Middle Skeena, **25**-Mussel-Kynoch, **26**-Nahwitti Lowland, **28**-Northern Coastal Streams, **29**-Portland Sound-Observatory Inlet-Portland Canal, **30**-QCI-Graham Island Lowlands, **31**-QCI-East, **32**-QCI-West, **33**-Rivers Inlet, **34**-Smith Inlet, **37**-Southern Coastal Streams-Queen Charlotte Strait-Johnstone Strait-Southern Fjords, **40**-Upper Nass, **41**-Upper Skeena.

Chinook salmon ocean-phase (top) and spawning male (bottom). Image: DFO

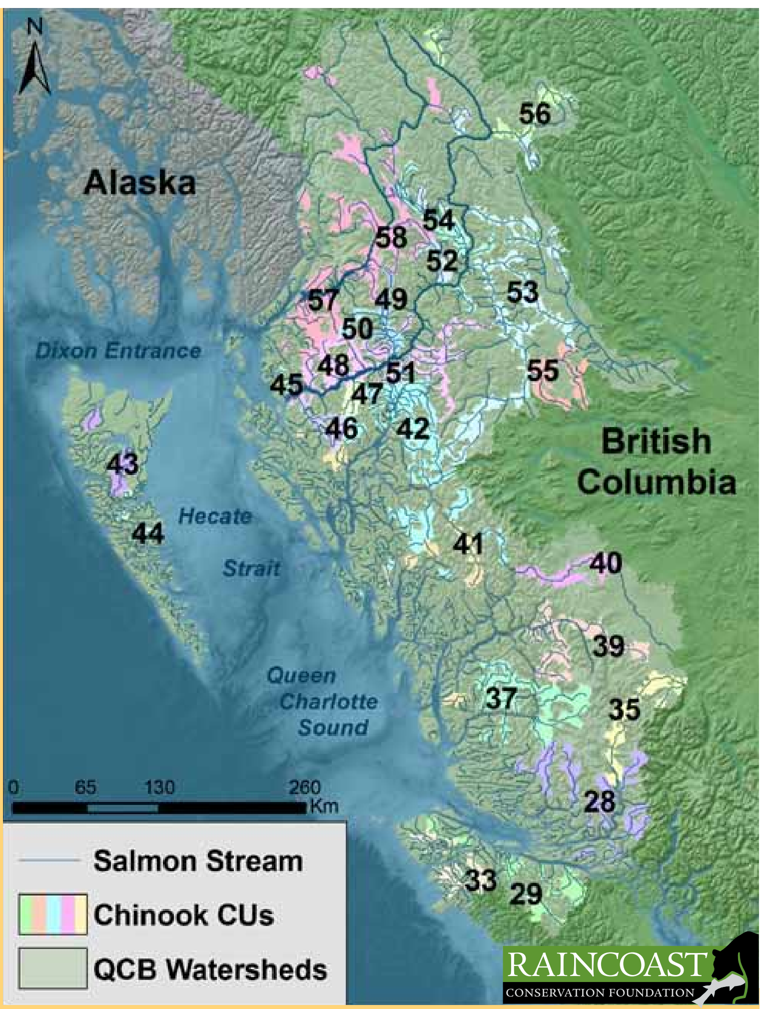


Figure 1.8 The 25 unique Conservation Units of Chinook salmon that have been assessed based on stream-type and ocean-type populations, run-timings, life history, and genetic uniqueness. Numbers follow DFO's Conservation Unit classification.

Chinook salmon

The life history patterns of Chinook salmon are more varied than any other salmon species but they are broadly of two types: stream, or ocean. After emerging from eggs, stream-type Chinook rear in streams for periods ranging from days, to weeks, to months and also years. Stream-types are most common in large watersheds like the Nass and Skeena.[54] Alternatively, ocean-type Chinook migrate to sea soon after emergence from eggs. Ocean-type Chinook have greater reliance on estuaries and nearshore habitats for rearing.

Chinook exhibit a spectrum from resident to migratory behaviours once they reach the ocean. Some migrate off-shore immediately, some linger in coastal waters before moving off-shore, and others remain in the Queen Charlotte Basin as residents before returning to spawn.[55] These broadly diverse strategies have been grouped into 25 unique Conservation Units (Figure 1.8).[56] Chinook are the primary food source for BC's resident killer whales.[57] Estimates suggest that the northern residents, whose proposed and existing critical habitats are throughout the Queen Charlotte Basin, consume upwards of one million Chinook annually.[58]

Chinook Conservation Units (25)
28-South Coast-southern fjords, **29**-Northeast Vancouver Island, **33**-Northwest Vancouver Island, **35**-Klinaklini, **37**-Rivers Inlet, **39**-Bella Coola-Bentinck, **40**-Dean River, **41**-North & Central Coast-late timing, **42**-North & Central Coast-early timing, **43**-Queen Charlotte Islands-north, **44**-Queen Charlotte Islands-East, **45**-Skeena Estuary, **46**-Ecstall, **47**-Gitnadoix, **48**-Lower Skeena, **49**-Kalum-early timing, **50**-Kalum-Late timing, **51**-Lakelse, **52**-Middle Skeena, **53**-Middle Skeena large lakes, **54**-Middle Skeena-mainstem tributaries, **55**-Upper Bulkley River, **56**-Upper Skeena, **57**-Portland Sound-Observatory Inlet-Lower Nass, **58**-Upper Nass.

Nearshore habitats provide important nursery and rearing habitat for a wide range of fish, including salmon. These areas provide food and protection to young salmon that have just entered the marine environment, as well as those that stay in nearshore environments for weeks to months as they mature. Although generally very productive, nearshore and intertidal environments are often the most impacted biotic communities of spilled oil. PHOTO: MCALLISTER/RAINCOAST

The importance of nearshore environments and estuaries for juvenile salmon

The nearshore marine environment is a unique ecosystem that hosts consistently higher species diversity, density, and productivity than deep-water marine habitats. Kelp, saltmarsh, and eelgrass meadows that occupy nearshore habitats on the BC coast serve as nurseries for young salmon by providing shelter, food, and protection from predators.

These coastal habitats support many other juvenile fish and shellfish associated with salmon food webs.[59] Traditional perspectives, which assumed that most young salmon migrate out of nearshore habitats by early summer, are proving wrong. Growing evidence suggests that juvenile salmon use nearshore and estuarine habitats for far longer than previously thought, with residency time driven largely by their size (Table 1.1).

Generally, the longer fry spend in freshwater, the less they will rely on estuaries. Yet, even these less dependent types rely on intertidal habitats for feeding during their migration towards the open ocean. More dependent types will spend several months feeding, growing, and adjusting to saltwater.

Chum, pink, ocean-type Chinook, ocean-type coho, and river-type sockeye use estuaries, sloughs, and nearshore waters for weeks to several months.[60] Research, particularly for Chinook, suggests that the early life stages are the most important in determining survival rates later in life.[61]

Table 1.1 Use of local estuaries and nearshore habitats by different species and life history types.

More estuary use	Less estuary use
Pink – few weeks to few months	Stream-type Chinook
Chum – one to three months	Stream-type coho
Ocean-type Chinook – few months to a year	Lake-type sockeye
Ocean-type coho - up to a month	
River-type sockeye - weeks to months	
Nomadic coho fry – more than a year	

Female mink and river otter shift the timing of their reproductive cycle so that lactation coincides with the presence of spawning salmon.[62] PHOTO: L. BUCKLIN

When spawning salmon arrive in streams and rivers, coastal wolves shift from a diet of deer to a diet of salmon.[63] These fish are an especially important food source for pups, lone wolves, and old wolves that are unable to kill larger prey.[64] PHOTO: K. POMMERENKE

Between one and two million Chinook are consumed each year by BC's northern and southern resident killer whales. Their birth rate, mortality, and survival is linked to Chinook abundance and consumption.[65] PHOTO: NOAA

The benefits of large salmon runs

Different salmon species provide different watershed benefits. High densities of pink salmon bring a large pulse of food and nutrients into the lower watershed in late summer and early fall. Alternatively, coho spawn in lower numbers but over broader parts of the watershed and longer periods. This brings food and nutrients into the upper reaches of watersheds late in the year.

High numbers of sockeye spawning upstream of lakes in Alaska have been shown to increase phosphorous levels in receiving lakes by 90%.[66] These nutrients then support the food web upon which young sockeye depend. Accordingly, a decrease in spawning sockeye reduces the amount of phosphorus, which may in turn reduce the ecosystem's capacity to support subsequent generations of salmon.[67]

PHOTO: H. NAITO

When grizzly bears have access to abundant salmon runs they occur in higher densities, are larger, and have more cubs. When salmon abundance is low, grizzly bears have fewer cubs, occur at lower densities and are smaller in size.[68] Low salmon abundance may also exacerbate human-bear conflicts. PHOTO: E. SAMBOL

Spawning salmon benefit future generations of salmon. Young coho rearing in coastal streams feed on the eggs and carcasses of adult spawners which provide them with up to 50% of their dietary needs for the winter, and increases their chance of survival.[71] PHOTO: J. RHODES

Abundant salmon also boost the number of cubs to grizzly and black bears, and chicks to American Dippers.[72] PHOTO: L TRAVIS

Salmon deliver nutrients to coastal watersheds

Because of their geology, BC's coastal watersheds evolved under conditions where food and nutrients were often too limited to produce and support high numbers of large fish. The strategy of salmon to leave coastal streams for greener pastures, and then return to spawn, is a remarkable adaptation that benefits both salmon and ecosystems. In the time between their fresh-water departure as fry and return as spawning adults, salmon grow a thousand-fold. Roughly 3% of their adult body weight is composed of nitrogen and 0.3% is composed of phosphorous acquired from the ocean. Thus, spawning salmon are fertilizer packages for the watershed.

Specifically, the nitrogen, phosphorous, and carbon delivered in salmon to estuaries, rivers, and forests via consumption by wildlife, and subsequent decomposition of carcasses and animal waste, are the biochemical building blocks of coastal water-sheds.[68]

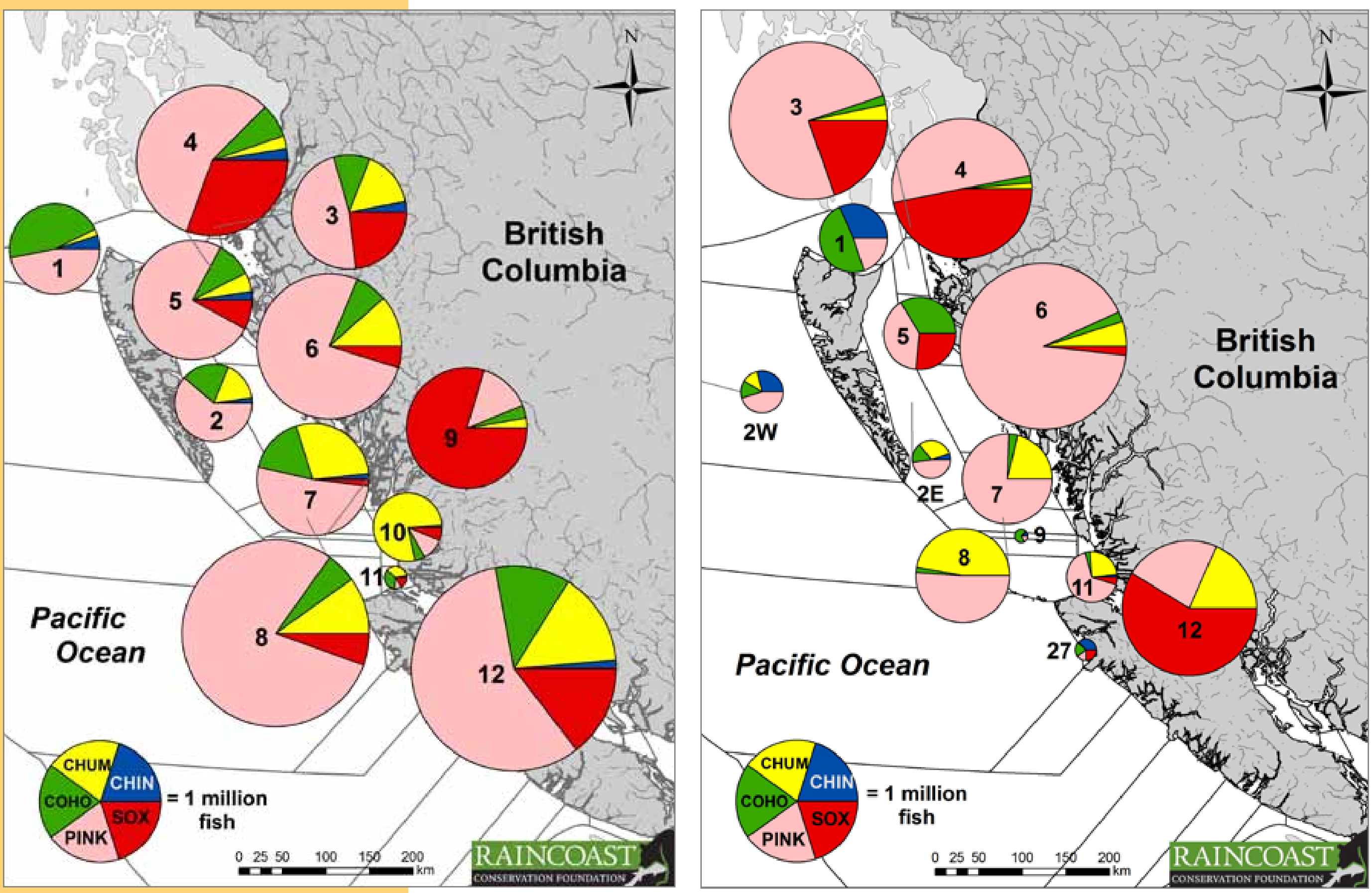
Status of salmon populations in the Queen Charlotte Basin

Many Pacific salmon populations have declined over the last century. In the US Pacific Northwest, salmon have disappeared from more than 40% of their historic range, with 17 populations listed as threatened or endangered under the US Endangered Species Act.[69]

In Canada, the status of salmon is less clear. Federal records that track salmon escapement (i.e. salmon that "escape" the fishery and reach their spawning grounds) didn't begin until 1950, long after industrial fishing and other human activities that affected salmon abundance were pervasive. Salmon catch data based on cannery records, however, have been compiled since the 1870s. On BC's north coast – in the Skeena watershed – researchers used salmon catch data from cannery records along with details of the fishery to build a picture of chum salmon abundance at the onset of the commercial harvest of chum between 1916-1919.[70]

These reconstructions show that chum salmon were an order of magnitude more abundant a century ago. Close to half a million chum likely returned to the Skeena River at the time of the First World War.[73] When these figures are compared with the decades after 1980, chum abundance dropped 10-fold (to an average annual abundance of 40,000). Alarmingly, chum salmon have declined further, with the most recent 4-year average of less than 9,000 chum per year. In total, Skeena chum are now 30- to 50-times less abundant than they were only a century ago.

Analyses performed by Raincoast, which examined the years since 1950, capture this more recent decline in abundance of chum salmon. Using federal and global scientific criteria to determine the status of endangered salmon,[74] almost half of the Conservation Units examined met the criteria for *endangered* and another 20% could not be assessed owing to deficient data. When the same criteria were applied to other species, roughly



Figures 1.10a and 1.10b
The distribution of average catch for the period 1952-1962 (a) and 2000-2010 (b) in Fisheries Management Areas 1-12 and 27. Pie charts are scaled to the catch size. Catch from 1952 to1962 was collected by DFO from sales. Catch statistics from 2000-2010 consist of commercial and recreational statistics. Odd-year pink salmon are an exception to the trend of declining abundance, with increased contribution to catch especially in Area 6. Note that sockeye caught in Area 12 are largely Fraser River bound fish.

Chums. PHOTO: NOAA

one-third of BC's salmon Conservation Units met standards for *threatened* or *endangered*, one-third were not a concern, and one-third could not be assessed owing to poor information. The decade from 2000 to 2010 also had the lowest catch numbers on record[75] and extremely low numbers of spawning salmon.[76] Consistent with this decline in abundance, the number of salmon populations contributing to the catch has also declined, shifting over the decades from many diverse wild runs to fewer large runs that are often enhanced by hatcheries.[77] Only odd-year pink salmon were stable or increasing.[78]

The low abundance of most wild salmon populations today is due to cumulative, and in some cases specific, stressors from habitat loss, fishing pressure, salmon aquaculture, salmon enhancement (i.e., hatcheries), and shifts in productivity as a result of climate warming; all of which negatively affect survival.[79]

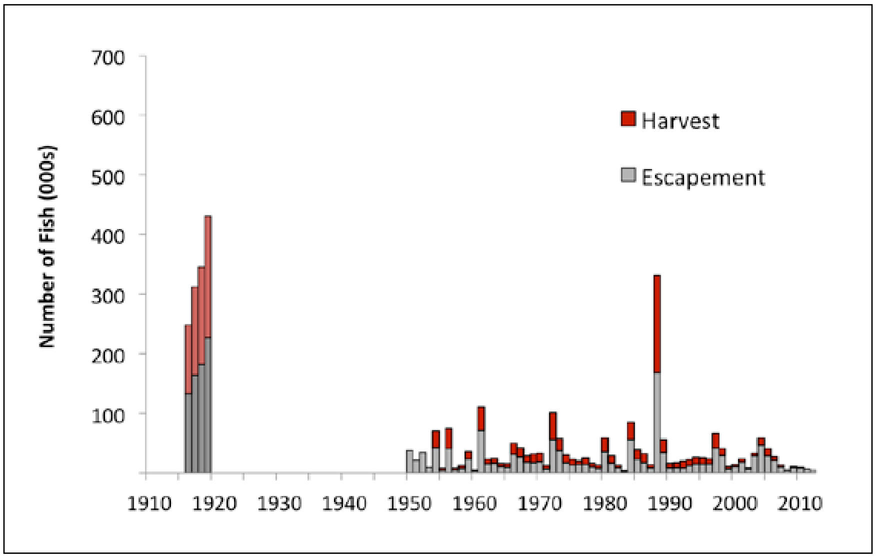


Figure 1.11 Documenting the long-term trend in Canada's salmon abundance is often problematic, owing to the lack of consistent data. Recently, cannery and fishery records have been used by scientists to reconstruct salmon abundance at the start of the 20th century. Reconstructions of chum salmon show that they were 30 to 50 times more abundant in the Skeena Watershed a century ago.

2. Northern Gateway: A Crude Proposal

Project overview

The proposed project consists of four distinct segments, each of which carries significant risk. Twinned pipelines will carry oil and condensate between the tar sands and the BC coast; a tank terminal will temporarily store the oil and condensate while awaiting transport; a marine terminal will load oil onto tankers and offload condensate; and oil tankers will transit the waters of coastal BC to China and California.

Development of the Alberta Tar Sands has become the world's largest mining initiative.[80] Many have argued that this development and the accompanying export agenda have occurred without consideration for Canada's own domestic energy security and future sustainability, or concerns for water, air, human health, agriculture, and fish and wildlife impacts that are being affected by such extraction. Currently, Canada lacks a sustainable national energy strategy.[81]

To export the oil to overseas markets, tar sands development must undertake vast expansion (Figure 2.1). Such expansion is accompanied by proposals for associated pipelines and oil tankers. This chapter describes one such proposal, Enbridge's Northern Gateway project.

Alberta's tar sands, the source of oil to be pumped through the proposed Northern Gateway pipeline, lie under vast tracts of boreal forest. This "overburden" (the industry term for soil and vegetation) is the breeding ground for 80 to 240 million birds of more than 200 species, and is home to endangered caribou, wolves, and numerous wildlife species that are being severely affected by tar sands development. Photos (above left) St. Albert Gazette, (above right) Peter Essick, (inset) Greenpeace

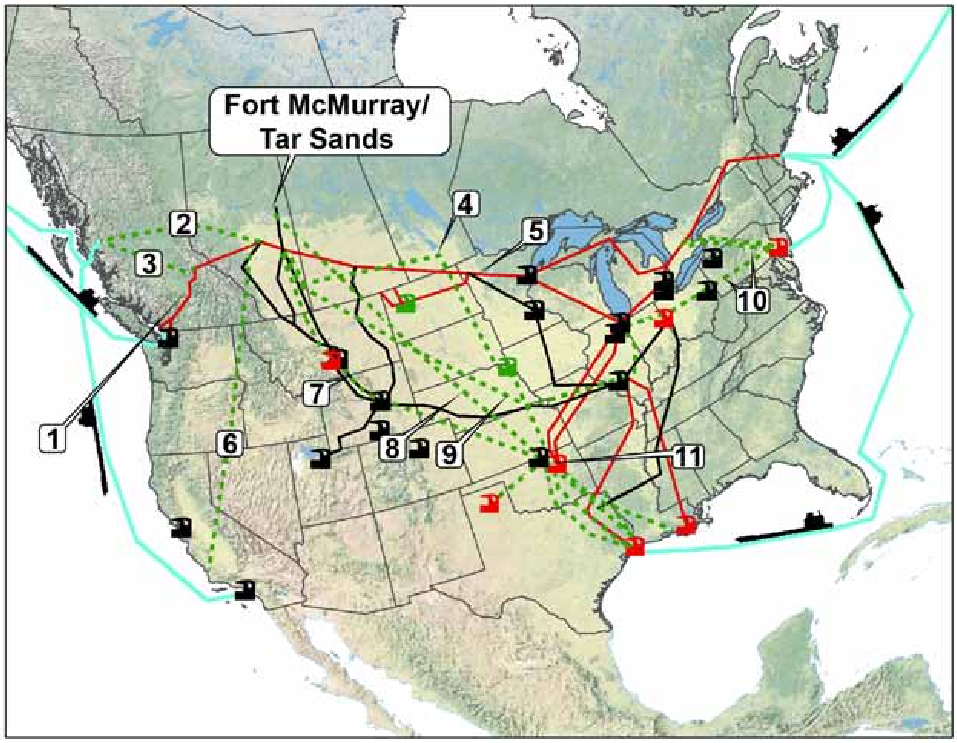


Figure 2.1 Major pipelines being proposed primarily for the export of bitumen and synthetic oils from the tar sands to the US and Asia. Top among these are Enbridge's Northern Gateway Project, Kinder Morgan's TMX, and TransCanada Pipeline's Keystone XL. At their stated capacity[82] these pipelines are proposed to transport more than 2 million barrels per day to the US and BC's west coast. They have the physical capacity to carry much more.

- Existing refineries known to have used tar sands oil
- Existing refineries planning to take tar sands oil
- New refineries planning to take tar sands oil
- Proposed/Existing tanker routes
- Existing major pipelines
- Proposed major pipeline expansions
- Proposed major new pipelines

1 Kinder Morgan Transmountain Express and Expansion
2 Enbridge Northern Gateway
3 Kinder Morgan Transmountain Express Northern Leg
4 TransCanada Keystone – Completed 2010.
5 Enbridge Southern Lights, Southern Access and Southern Clipper
6 TransCanada Alberta California
7 Kinder Morgan Chinook Maple Leaf
8 Altex Energy
9 TransCanada Keystone XL
10 Enbridge Pioneer – Options 1 and 2
11 Centurion Pipeline Reversal – Online 2009

What is diluted bitumen?

Bitumen is the raw product of oil sands extraction – it is a thick, corrosive hydrocarbon with toxic components such as polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds. For bitumen to flow, it must be mixed with light petroleum products known as condensate. Condensate is light, highly flammable petroleum by-product that is acutely toxic to many organisms. Combined, they form diluted bitumen.

According to the Canadian Association of Petroleum Producers (CAPP), oil consumption in Canada has been virtually unchanged in the last 30 years, despite our growing population. Consumption declined from 287,000 m³ daily in 1980 to 260,000 m³ daily in 2010. The trend is due to improvements in energy efficiency and a decline in the country's manufacturing base.[86]

PHOTOS: (TOP) LEDCOR, (BOTTOM) CATERPILLER.

The pipeline

The Northern Gateway Project involves constructing two parallel pipelines: one flowing west to export diluted bitumen or synthetic crude oil, and one flowing east to import condensate. Condensate is a diluent that enables bitumen – the raw oil product of extraction – to flow. Together, the two form diluted bitumen. Enbridge has applied for an average throughput of 525,000 barrels of oil and 165,000 barrels of condensate per day. Meeting this capacity would require a 30% increase in the current daily output from the tar sands, which would generate a corresponding increase of 6.5 million tonnes of greenhouse gas emissions annually.[83]

Alarmingly, the pipelines are proposed to be built so as to carry more product than Enbridge's application declares: delivering 60% more oil and 40% more condensate.[84] At full capacity, these pipelines could transport 1.1 million barrels of diluted bitumen and condensate daily over 1,564 watercourses; 669 of which are fish bearing streams[85] of the Skeena, Kitimat, Upper Fraser, and Mackenzie watersheds.

Figure 2.2 The proposed pipelines would run 1,172 km (727 miles) through a 1-km wide clearcut corridor from Bruderheim, Alberta to Kitimat on BC's north coast. The pipelines will be buried along most of the route, except at certain river crossings, and at the Clore and Hoult tunnels.

Broken cargo stanchions on the log carrier *Dry Beam*, February 2012. The vessel issued a mayday after 11 m seas and hurricane-force winds damaged and endangered the ship northwest of Vancouver Island. Enbridge's associated oil tankers would sail through these same seas. Photo: D. Stone.

The terminus and tank terminal

The twin pipelines will terminate/begin near Kitimat, BC, on an undevelopedsection of Kitimat Arm. The proposed terminal consists of two sections: the shipping berths for the transfer of oil and condensate to/from tankers, and a tank farm for storage of oil and condensate. The shipping berths are proposed to occur within the lower Kitimat estuary, immediately upstream from Bish Creek.

The 500-hectare tank terminal (1200 acres) is the proposed holding area for more than five million barrels of oil as it awaits

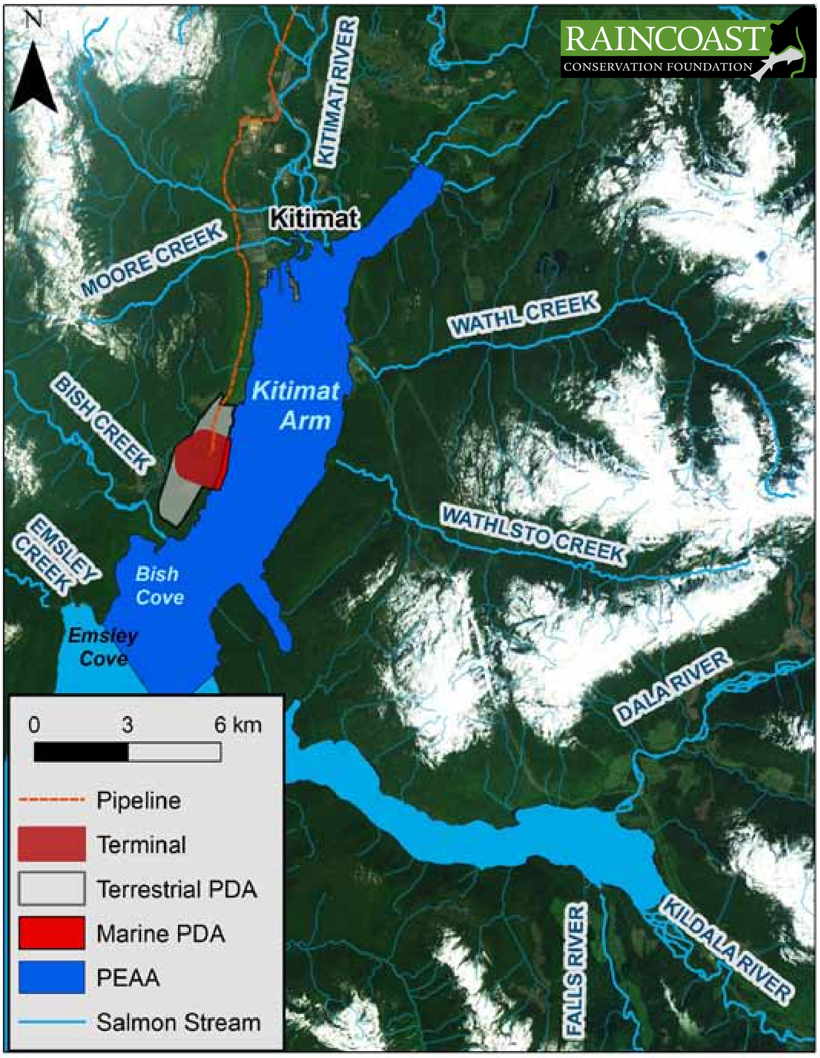


Figure 2.3 Enbridge's Project Development Areas (PDA), Project Effects Assessment Area (blue PEAA), and key salmon streams that drain into Kitimat Arm.

transport to sea, and 1.5 million barrels of condensate before it flows east to Alberta.[87] Construction of the terminal will involve numerous infrastructure developments,[88] including an impoundment reservoir that allows for the containment of *one* of the storage tanks plus rainfall.[89] Enbridge estimates (using the minimum capacity) that oil tanks will be emptied and filled 450 times per year and the condensate tanks will be emptied and filled 165 times per year.[90] All of this is proposed to occur within a geological zone that is vulnerable to earthquakes, submarine slope failures, and tsunamis.[91]

Marine terminal

The marine terminal will consist of two tanker berths with the capacity to unload condensate at a rate of 70,000 barrels/hour and load oil at a rate of 100,000 barrels/hour.[94] These rates are significant when considering the possibility of loading failure. Despite Enbridge's review application that states an estimated 220 oil and condensate tankers will visit the Kitimat terminal annually (440 transits),[95] pipeline operation at full capacity actually translates to 340 per year (680 transits) — nearly one oil tanker per day.

Explosion in China's Dalian port

Most petroleum spills occur at the facilities where oil is stored or processed.[92] In July 2010, while the world's attention was focused on the BP spill in the Gulf of Mexico, an explosion and fire at PetroChina's Dalian Terminal preceded a huge spill of crude oil.[93] Independent estimates suggest that between 400,000 and 600,000 barrels of oil emptied into the South China Sea.

1 barrel
= 42 US gallons
= 35 Imperial gallons
= 159 litres

1 tonne
= 1,000 kg
= 7 barrels

At 42 million litres, the Exxon spill would fill 17 Olympic swimming pools.

Figure 2.4 Oil volume conversions

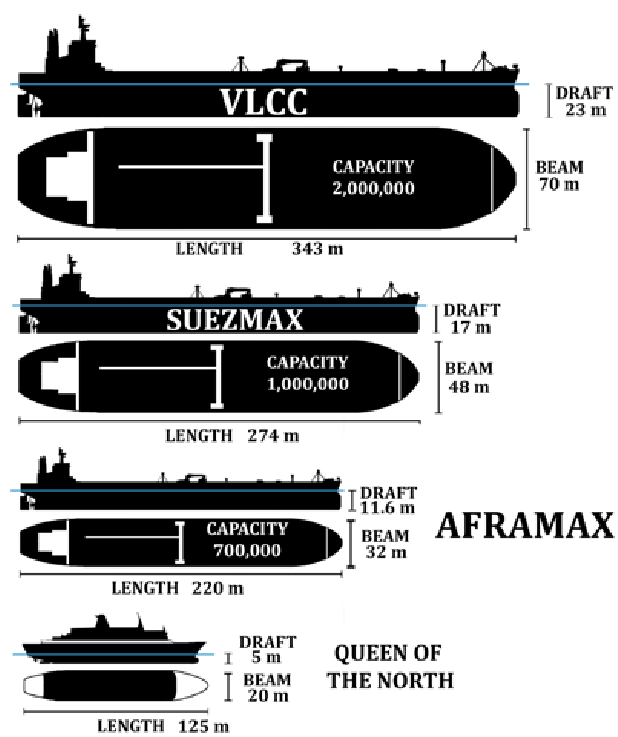


Figure 2.5 Oil tankers are classed according to the size of the ports they can access. Most tankers visiting Kitimat will be the size of the *Exxon Valdez* (Suezmax class), capable of carrying 1.5 million barrels of oil. Others will be Aframax class tankers carrying 880,000 barrels, and Very Large Crude Carriers (VLCCs) with a maximum capacity of 2.3 million barrels of oil.

In February 1993, the tanker *Overseas Chicago* was in rough seas just south of Valdez, Alaska, when it was hit broadside by an 18 m wave. The accompanying photos show the wave striking the tanker, rolling over the deck (which is 18 m above the water-line) and the ship heeling hard to port as the water pours over (see following page). According to NOAA, a smaller ship would likely have been sunk by the wave.
PHOTO: R. WILSON/NOAA

Tanker traffic and coastal weather

The marine approaches to BC's north coast and the port of Kitimat are a dangerous coastline for ships. Intense winter storms routinely batter this region. A storm wave reaching 30 m (98 feet) was observed on October 23, 1968, and in 1977 the second highest wave height ever measured occurred off BC's north coast.[96] This area requires far more intricate navigation than Prince William Sound, where the *Exxon Valdez* hit Bligh Reef in Valdez Arm, Alaska, a channel almost 10 km (6.2 miles) wide. Upon approach to Kitimat, super tankers must maneuver around several 90° corners before entering Douglas Channel, which is only 1.35 km (0.84 mi) wide at its narrowest point.

Severe weather heightens the risk of shipping accidents, as does vessel traffic. Loaded tankers will pass directly through Wright Sound, a body of water through which transit more than 5,000 vessels per year.

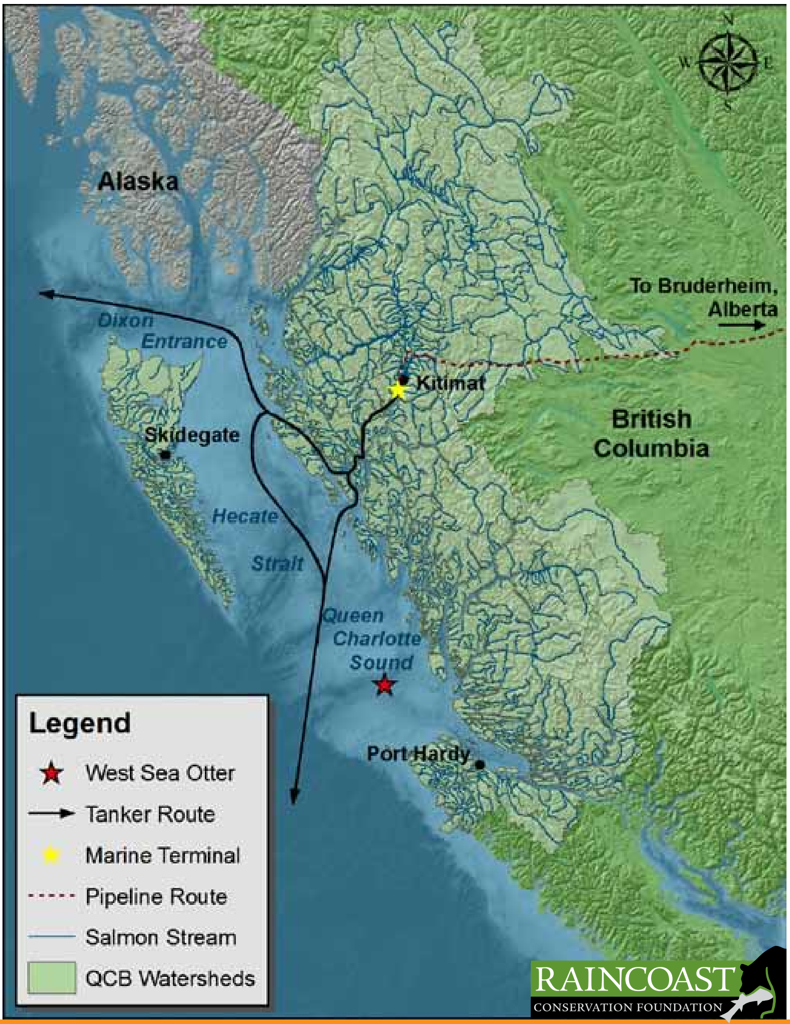
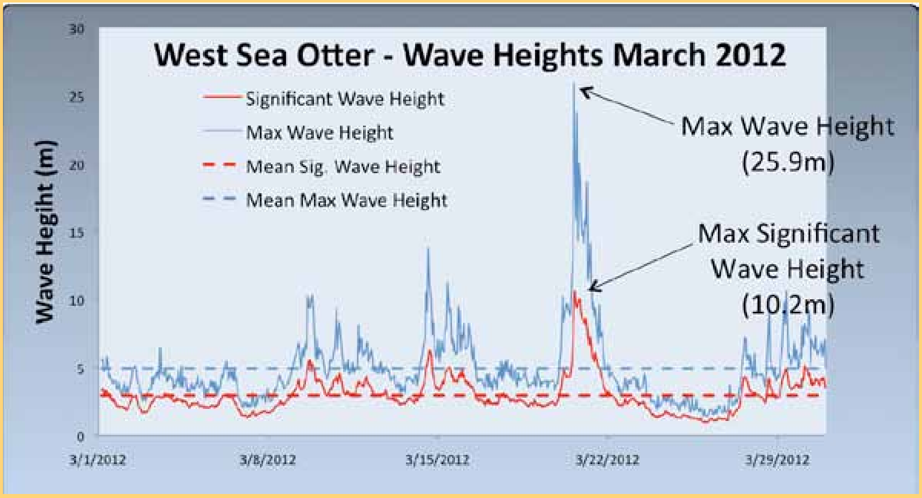


Figure 2.6 North and south tanker approaches to Kitimat (for Asian and North American routes, respectively), Enbridge's Confined Channel Assessment Area, and the West Sea Otter Weather Buoy.

Figure 2.7 West Sea Otter Weather Buoy Data, March 2012. Data from the weather buoy at West Sea Otter routinely recorded wave heights above 9 m, with a maximum wave height of just under 26 m for March 2012. However, Enbridge presented its weather data using averages. Accordingly, Enbridge's maximum mean wave height would be only 10.2 m, not 25.9 m. These methods, also used for wind and fog, imply a much lower hazard than is reasonable.[97]



Do waves like this occur in Queen Charlotte Sound? Yes. Figure 2.7 shows a 26 m wave in March 2012 at a weather buoy just southeast of the proposed oil tanker route. When shipping tragedies occur, they are caused less frequently by a single event and more often by a series of events, with weather often being a significant factor. Enbridge stated in the 2013 Joint Review Panel hearings that its rescue tugboats will not operate in hazardous conditions described above, but their tankers will.

Based on the failure rate of steering or propulsion for commercial vessels operating in California, we expect two failures per year for oil tankers on BC's coast.[98] What then, are the chances that one of those failures will occur during a period when Northern Gateway's rescue tugs cannot operate? Photo: R. Wilson/NOAA

3. The Basics of Bitumen and the Fate of Crude Oils at Sea

Unlike conventional crude, the bitumen contained within tar sands cannot be pumped from the ground; the sand must be mined, separated, and diluted with solvents in order to flow. Photo: Greenpeace

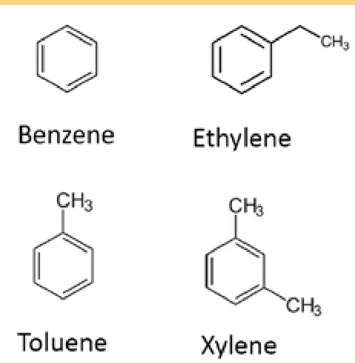


Figure 3.1 Aromatics are ringed hydrocarbons that range from nontoxic to extremely toxic. BTEX molecules (benzene, toluene, ethylbenzene and xylene) are simple, single-ringed hydrocarbons that can be acutely toxic to aquatic life and humans. There is no safe level of benzene exposure in humans.[101]

Petroleum oils are a complex mix of hydrogen-carbon compounds with various components of minerals, metals, and other impurities. Petroleum can take many forms: highly refined gases and gasolines, diesels and light crude oils (light because they contain smaller hydrocarbon compounds), bunker and fuel oils, heavy crude oils, and tar-like substances such as bitumen that contain the largest (and therefore heaviest) hydrocarbon compounds.

The composition of crude (i.e., unrefined) oil varies depending on the proportions of specific compounds. Light crude oils are generally high in saturated (single bond) and small aromatic hydrocarbons, whereas heavy crude oils are high in resin (asphaltene), and large aromatic hydrocarbons.

The properties of bitumen and diluted bitumen differ from conventional crude oil in their acidity, higher abrasive content (sand, fines and silicates), higher sulphur content, and the higher temperature and pressure required to make them flow.[99]

Each type of oil has unique characteristics that affect its behaviour and persistence in water. Different compositions can result in short-term but lethal effects (in the case of light refined oil and condensate), to persistent chronic effects that last for decades (such as with heavier crudes and bitumen). This long-term persistence of crude, with potential for shoreline or sub-surface contamination lasting decades, is one of the largest threats and most difficult problems of oil spills. Oil can remain in shoreline sediments long after clean-up operations are deemed complete.[100]

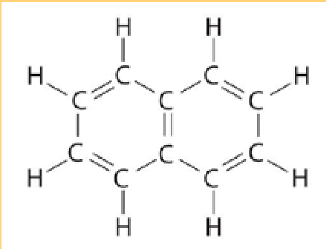


Figure 3.2 Naphthalene, showing the detailed hydrogen-carbon rings and the alternating single and double bonds, which make PAHs stable and hence persistent.

Toxic components of crude oil

Smell; it's one of the first things you notice when encountering an oil spill. Impossible to capture in a photograph, it leaves a lasting impression. The strong vapours from crude oil contain highly toxic aromatic hydrocarbons. Foremost among these are single-ringed benzene, toluene, ethyl benzene, and xylene compounds, often grouped together as BTEX.[102]

BTEX compounds, along with other small aromatics that contain few rings, are acutely toxic to life (as neurotoxins). Although volatile and evaporate quickly, they are also soluble in water.

Conversely, oil compounds with many rings are the poly aromatic hydrocarbons, (PAHs). PAHs are often more chronically toxic[103] and can persist for decades in the tissues of organisms and sediments.[104] In addition, PAHs can contain methyl groups. The methyl PAHs generally constitute the greatest percentage of PAHs in oil and appear to be most toxic to fish.[105]

Some PAHs are known cancer-causing agents. They can also have sub-lethal impacts on the growth and development of fish at very low concentrations of oil in water (i.e., in the parts per billions).

Diluted bitumen combines petroleum products across the full spectrum of oils, making it volatile, acutely toxic, chronically toxic, and persistent.

See Chapter 5 for a full discussion of oil toxicity.

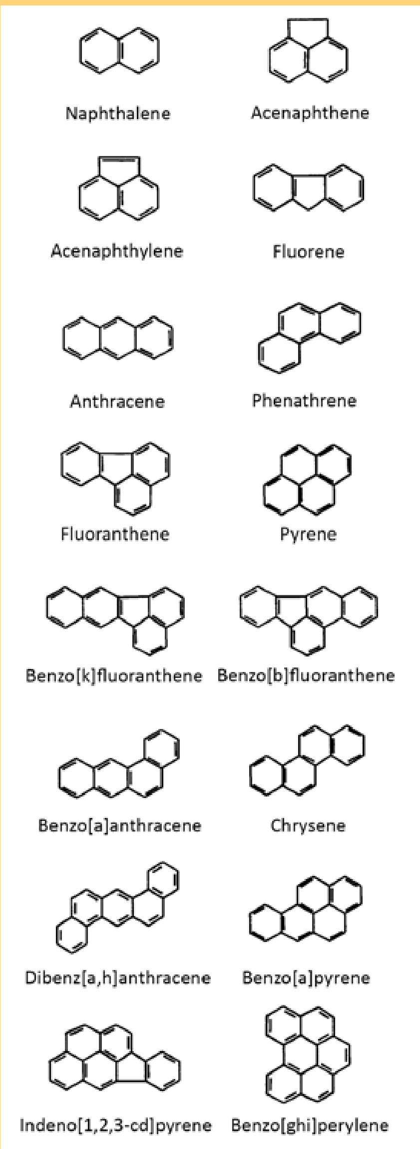


Figure 3.3 Multi-ringed (poly) aromatic hydrocarbons (PAH) can persist for a long time. They include molecules that affect growth and development even from exposure to very low concentrations. Shown are 16 of the 32 priority (i.e., of environmental concern) PAHs listed by the U.S. EPA. These toxic compounds can also have carcinogenic, mutagenic, or teratogenic (birth defect) properties.

In the early stages of an oil spill, gravity spreads the slick into a thin film if the ocean is calm (top). Eventually, wind and waves break-up, submerge, and mix oil into the water column where it can penetrate at rates of one-to-two times the wave height, and deeper.[110] Weathering can transform oil into a thick emulsion (above), or create tar balls and deposits that wash ashore over time (bottom). PHOTOS: (TOP TO BOTTOM) N. KIRSHNER, D. RENCHER, NOAA .

Stage One: the oil slick

With conventional spills, oil is thick when it hits the water's surface. During the first 24 hours, gravity spreads the oil into a thin film, and current, tide, and wind disperse the slick horizontally. While 'spreading' is a short-term process, 'dispersion' occurs as long as oil is in the water. Oil may undergo several weathering fates once in the water.

Stage Two: weathering begins

Evaporation

Evaporation is particularly relevant for light crude oils and refined products, such as gasoline or condensate. Light crude oils can lose as much as 75% of their volume in the first few days of a spill. In contrast, only 10% of heavy oils, such as crudes and bitumen, evaporate in the first few days.[106] The evaporation of volatile compounds like BTEX can create highly toxic vapours.

Emulsification

Once the lighter compounds evaporate, the heavier compounds (like asphaltene and resins) concentrate. Wave energy will then emulsify and submerge oil (creating mousse or tar balls), which ultimately render response and clean-up efforts useless.[107] Following emulsification, natural processes of biodegradation generally become negligible.[108]

Oxidation

In the presence of sunlight and oxygen, the bonds of larger oil molecules break-apart and form simpler (often more water soluble) products. Generally, smaller compounds oxidize before heavier ones; this concentrates heavier PAHs over time, and causes oil to be more toxic on a weight-by-weight basis.[109]

Biodegradation

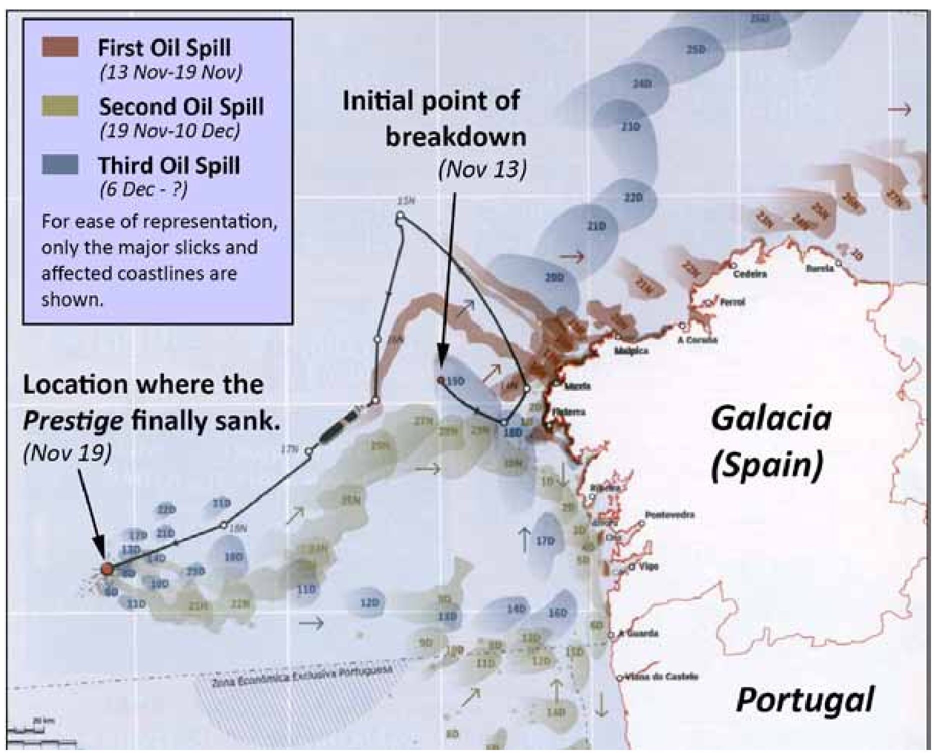
In the presence of oxygen, bacteria degenerate oil. This biological degradation is a key mechanism for the break-down of oil in

water.[111] In a large surface oil-slick, when little oil is accessible to bacteria, response crews use dispersants to separate the slick and form smaller droplets.[112] However, dispersants have their own inherent risks; knowledge of their toxicity, reaction with oils, or problems with dispersed oil, remain uncertain.

Wind and Waves

Wind and waves can break-up, submerge, and mix oil deep into the water column.[113] Heavier oils, like bitumen, contain diluents that improve their viscosity in pipelines, but change their predicted behaviour in water. After initially floating, these oils can sink and resurface later resulting in repeated oiling of coastlines.[114] Heavy fuel, or crude oils, can also form submerged tar balls that eventually wash ashore, sometimes hundreds of kilometers from the initial spill.[115]

Figure 3.4 The track of 225,000 barrels of oil spilled from the *Prestige* 250 km off the coast of Spain in 2002.



Oil and water can mix

Although the physics of oil behaviour at sea are generally understood, the ability to predict their performance is poor. The type of oil, weather, and ocean conditions all determine the fate of spilled oil, which in turn affects the response, clean-up attempts, toxicity, severity, and persistence of an oil spill. The Canadian Coast Guard emphasized this point to the Review Panel assessing the Northern Gateway project.[116]

Photo: D. Martin

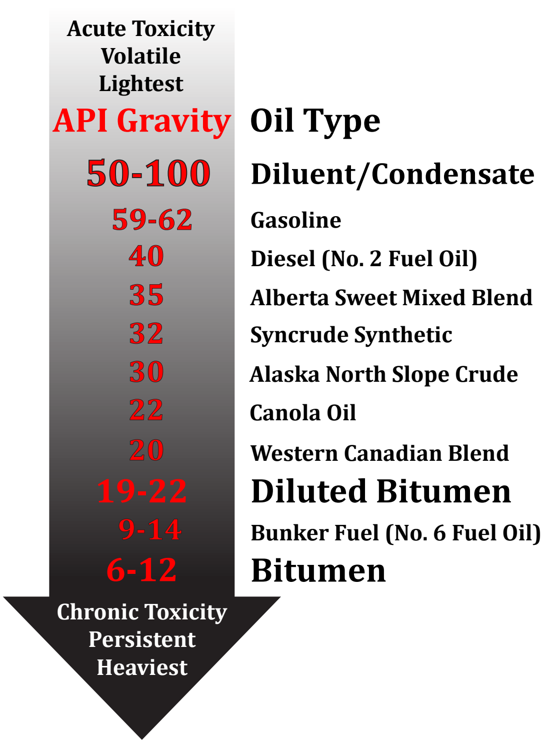


Figure 3.5 The spectrum of API gravity for light to heavy petroleum. API reflects the density of oil relative to water. High API oils containing smaller (lighter) molecules are likely to float. Low API oils with larger (heavier) compounds, like bitumen, will likely sink.

Sinking and Sedimentation

Oil will sink under two circumstances: i) when it is denser than water, and ii) when it combines with enough sediment to become denser than water. In calm conditions, only oil that is heavier than water will sink. In areas with high wind and wave energy or where currents keep oil from settling, heavy oil may not sink until it adheres to sediment.[117] The more buoyant oils can adhere to sediment, sink, and then refloat as the sediment re-separates from the oil. This process can occur repeatedly, and ultimately may create areas where oil has settled to the bottom, yet remains on the surface, and has portions in between.[118] Regardless of whether oils sink or remain suspended in the water column, they pose risks to organisms not normally affected by floating oils.

Will diluted bitumen sink, float, or submerge?

API, the density/gravity measurement for petroleum products, indicates the likelihood of oil sinking in water. API will change as oil weathers. Although raw bitumen has a very low API (which suggests sinking), diluted bitumen contains high API condensate. It is likely that diluted bitumen would float until the lighter compounds dissipate, at which point it would sink until it reaches different layers of temperature and water density. The same physical processes that float and submerge the coloured liquid waxes of lava lamps could continually drive spilled oil.

Far left: Heavy oil from a double-hulled tanker and barge collision in 2005 lies on the bottom of the Gulf of Mexico.

Left: Diluted bitumen spilled in the Kalamazoo River floats submerged below the surface.

Sinking and re-submerging

A worrisome prospect of a crude oil spill is that it can sink; making recovery difficult, expensive, and often impossible. Sunken oil can then re-float, pick-up sediment and sink in repeating cycles.[128] In 1994, a barge went aground in Puerto Rico and released roughly 19,000 barrels of heavy fuel oil (API gravity 9.5). Much of the oil sank in nearshore lagoons after mixing with sand. The clean-up of submerged oil was only possible because of high visibility and shallow depths, which is an unlikely situation in coastal B.C.

Can stranded oil outlive your grandchildren?

Two and a half years after the 1989 *Exxon Valdez* spill an estimated 13% (33,000 barrels) of the oil remained in sub-tidal sediments, and 2% remained in intertidal areas, most of which was highly weathered.[119] By 2007, roughly 500 barrels of oil still remained below the surface sediments, and was degrading very slowly (0-4% per year).[120]

Even today, oil pockets exist that are comparatively unchanged since the spill.[121] Although researchers initially thought that the weathered oil was inert, they now believe otherwise.[122] Weathered oil concentrates PAHs and makes it more toxic on a weight-per-weight basis than non-weathered oil.[123] There are concerns that Exxon's weathered oil will remain toxic for decades.[124]

In 2006, more than 36 years after the Arrow oil spill in Nova Scotia (1970), hard weathered oil remained on the beaches. The soft underside however still released sheens in concentrations toxic to zooplankton. Previous studies on the heavy fuel oil (bunker C) spilled in this incident suggested that it might persist in low energy environments for more than 150 years.[125]

In other cases, fuel oil residues containing PAHs from the Florida (1969) and Bouchard 65 (1974) oil spills were found in intertidal sediments more than 30 years after the spills.[126] Highly weathered asphalt pavements covering un-weathered oil residuals were still present when sampled on Chile's beaches and salt-marsh sediments more than 30 years after the spill of 380,000 barrels of Arabian light crude and Bunker C fuel oil from the Metula in 1974.[127]

Oil spills are unpredictable

In 1998, 177 barrels of fuel oil spilled during tanker fuelling operations in Hawaii. It re-surfaced two weeks later as tar balls over 160 km away, intermittently oiling 30 km of shoreline.[129]

In 1997, the Evoikos collided with a VLCC off the coast of Singapore. The resulting spill of 200,000 barrels of heavy marine bunker fuel contaminated a dozen nearby small islands. The fuel then drifted submerged over 500 km to Malaysia, contaminating roughly 40 km of the Malaysian coastline.[130]

The realities of oil spill clean-up

One of the most important conclusions from examining efforts to clean-up oil spills is that no response is possible in rough weather, high seas, or dangerous conditions. Importantly, these conditions often precede, or follow, oil spills. Pumping and skimming recovery options are simply not possible in over one knot of tide or in waves over two to three metres. In rough conditions or offshore spills, 'response' is limited to the use of dispersants because containment and recovery is near impossible. Dispersants, effective at encouraging oil to sink in some cases, are far less successful with bitumen, water-in-oil emulsions, or with oil that has weathered. Furthermore, the toxicity of dispersants is a growing concern.[131]

The most successful clean-up operations have used relatively poor technology and relied on the availability of thousands of workers (e.g., 2010 PetroChina spill). With grossly over-stated oil spill response capabilities revealed after the 2010 *Deepwater Horizon* disaster, it is evident that improvements to oil spill technology have been negligible. Responders in the 1989 *Exxon Valdez* spill indicated that clean-up technology was no further ahead than in the 15 years prior to the spill.[132] Responders in the *Deepwater Horizon* spill claimed that response and clean-up technologies were the same as the *Exxon Valdez* spill.[133] Thus, despite some minor improvements, oil spill response remains largely unchanged in the last 35 years.

Emerging science suggests that dispersants are not benign, and synergistic actions with oil may make them far more toxic to wildlife than oil alone. PHOTOS: (ABOVE) NOAA , (BELOW) C. NEITO

Spill booms can be effective when seas are calm or when used in protected harbours, but they perform poorly in wind and waves. PHOTOS: (ABOVE) NOAA , (RIGHT) L. GUANG

We can respond to oil spills, but rarely do we clean them up. PHOTOS: (ABOVE) NOAA, (BELOW) STRINGER/REUTERS

Effectiveness of clean-up operations

At best, only 10 to 15% of the oil from a marine spill is recovered.[134] Given this, four major factors influence the recovery: i) location, ii) oil type, iii) weather conditions, and iv) resources. First, oil spills in busy ports or harbours are more likely to be effectively contained and cleaned when there is fast response by spill equipment, workers, and boats.

Second, the type of oil is key. Lighter crude oils disperse more quickly than heavier crudes, which renders them hard to capture and contain. Although this leads to less shoreline contamination, lighter crude oils can cause extreme loading of the water column with acutely toxic components.

Third, even light winds and small waves can render spill booms and fences ineffective. Poor weather also increases the likelihood of water-in-oil emulsions that make clean-up difficult.

Finally, pre-planning, skill, resources, coordination, and the attitude of the response agency are essential for successful spill recovery. The 2010 *Deepwater Horizon* spill demonstrated that industry and government were critically unprepared to respond to the catastrophe,[135] even with the resources at hand and the relatively slow unfolding of the event. The *Exxon Valdez* oil spill demonstrated something similar, complete with pre-spill assurances to the contrary.[136]

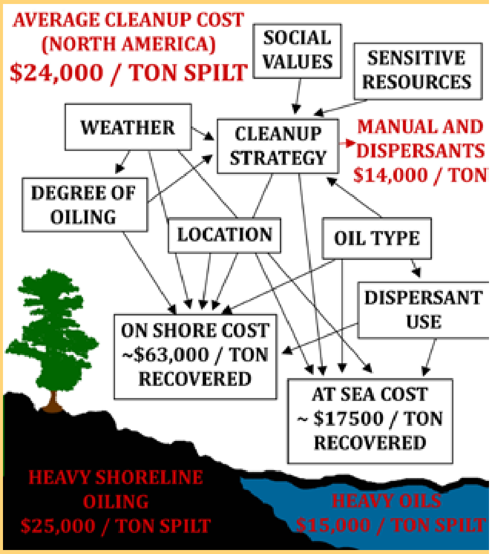
Would Kitimat pay its residents to clean up oil with their hands?

In July 2010, an explosion and fire preceded a large spill of crude oil at PetroChina's terminal in the Port Dalian. Despite its large size (up to 600,000 barrels),[137] the clean-up and response were surprisingly effective. Oil recovery was credited to the 10-20,000 fishers and workers on 1,000-2,000 boats who manually collected oil from a calm harbour, and filled barrels by hand. According to the China Daily, NGOs and citizens collected household materials to make booms and soak-up oil.[138]

Remarkably, about 400,000 barrels of oil were recovered but with little or no regard for personal safety.[139] Despite the basic methods, a greater amount of oil was recovered than in the clean-up operations for BP's *Deepwater Horizon* spill at a cost of over $2 billion.[140] Unfortunately, the remaining PetroChina slick still spread 430 km^2, affected shore-lines and shellfish operations, resulted in fishing closures, and had severe human health implications.

Costs of oil spills and recovery

Figure 3.7 Some of the factors affecting the cost of clean-up for an oil spill.[151]



Oil spills, while creating obvious environmental and social impacts, can also be enormously expensive. Following the *Deepwater Horizon* oil spill (~4.9 million barrels), BP estimated that the disaster would ultimately cost the company as much as US$40.9 billion (including a $20 billion escrow account for compensation, and $17.7 billion effectively incurred for 2010 in clean-up and containment costs).[141] This figure does not include the loss of services[142] that healthy ecosystems provide, which is predicted to be a monumental $34 to $670 billion.[143] The clean-up of the *Exxon Valdez* spill in 1989 cost more than $2.5 billion (inflation adjusted to over $4 billion in 2012), with total costs and damages exceeding $9.5 billion.[144]

Clean-up costs associated with the 2002 *Prestige* oil spill off the coast of Spain ranged from US$600 million to $1.1 billion[145], which does not include short or long-term damages (such as future loses and compensation of an estimated $3.3 billion in property damage[146], or economic and environmental damage costs estimated as high as 12 billion).[147]

Recovery cost to clean up one barrel of oil in 1995 ranged from $2,500 for at-sea recovery to $8-9,000 for shore-line clean-up operations ($3,700 and $11,800-13,000 in 2012 dollars respectively).[148] Smaller, more remote, and widely dispersed spills with international responses are typically much costlier per unit of oil recovered. Oil recovery from the 1988 *Nestucca* oil spill was estimated as high as $23,000/barrel, which is an enormous $39,000/barrel in 2012 dollars.[149]

The type of oil, amount, location, resources, weather, degree of shore-line oiling, and clean-up strategy all influence the cost (Figure 3.5).[150] Heavy shore-line oiling can be seven times more expensive than minimal oiling to clean up. Heavy fuel oils and crude oils can be five times more expensive than light, non-persistent oils, and clean-up strategies involving manual/mechanical recovery and dispersants can increase the cost by a factor of seven.

Canada's oil spill response plan includes the use of conventional spill equipment, dispersants and burning. These strategies may be insufficient and ultimately more toxic than the oil alone. PHOTO: E. DREGER

Is Canada prepared?

Agencies on Canada's Pacific coast are not prepared for a major oil spill. Should an accident occur involving a large ship, serious inadequacies in response capabilities would hinder clean-up and containment operations. On BC's south coast, Canada relies heavily on rescue tugs from Washington State. In 2011, the U.S./Canada Transboundary Spill Planning and Response Project released a report with 130 recommendations to improve oil spill planning and response capabilities.[152]

Response coordination between the Canadian federal and BC provincial governments is also not well harmonized; an arrangement that is critical for clean-up. A 2010 federal Auditor General report identified risks, gaps, inadequacies, and insufficient capacity in Canada's ability to respond to marine oil spills.[153] In BC, this dysfunction has resulted in delays or even no response at all.[154] Drastic budget cuts to agencies responsible for oil spills, such as those that Environment Canada and Fisheries and Oceans received in 2012, and the transfer of BC's Oil Spill Response Centre to eastern Canada, further undermine the capacity to respond.[155]

Table 3.1 Cleanup costs associated with a variety of oil spills.

Year	Incident	Area Affected	Volume Spilt (tonnes)	Cleanup Costs (millions in 2012 USD)
1978	M/T *Amoco Cadiz*	Breton, France	223,000	120 (410)
1998	Barge *Nestucca*	Washington / B.C.	875	4.4 (6.1)
1989	M/T *Exxon Valdez*	Alaska	81,000 – 122,000 Exxon official = 37,000	2,500 (4,100)
1997	M/T *Nakhoda*	Japan	6000	219 (294)
1999	M/T *Erika*	Brittany, France	31,000	180 (238)
2002	M/T *Prestige*	Spain	77,000	>1,000 (1,450)
2004	M/V *Selendang Ayu*	Alaska	1,200	100
2010	Kalamazoo River	Michigan	~ 2,700	~ 700
2010	*Deepwater Horizon*	Gulf of Mexico	700,000	~ 18,000
2011	Yellowstone River Pipeline Spill	Montana	~214	~ 220

What would a small oil spill look like in BC?

The cost to keep harbours and shorelines free from liquid and solid contaminants is increasingly understood by coastal municipalities, especially as other agencies download responsibility for debris clean-up. The persistent, toxic nature of diluted bitumen in cold water, even from small spills, may be very costly for local governments, especially if oil contaminates shorelines and harbours that provide important sources of sustenance and revenue.

In response to public fears around oil spills, Canada's federal energy minister announced plans to establish "world-class oil spill response and prevention" in 2013. Lost in the minister's rhetoric about increased tanker inspections, tanker safety panels and new navigational aids is the fact that human failures account for up to 80% of the world's oil spills. Underscoring the fact there is no accounting for human error, BC's largest oil spill response vessel ran aground en route to the minister's news conference.

The Canadian Coast Guard has also identified uncertainty around the effectiveness of spill recovery with the products that Enbridge plans to transport. In evidence submitted to the National Energy Board panel assessing Northern Gateway, the Coast Guard stated it was "not aware of a scientific consensus regarding how these products will behave once introduced into the marine environment or the effects over time of the products being in the water. The Canadian Coast Guard, therefore, is uncertain whether or not traditional oil spill recovery methods would be effective."[156]

4. The Trouble with Tankers and Other Sources of Oil Spills

The history of oil spills is one of repeated human error and often enduring environmental damage. Major oil spills show that despite assurances of low risk and advanced technology, poor decisions still lead to major incidents. Groundings, collisions, equipment failures, and explosions are all cited as causes for accidents, but these are actually consequences, not causes. Root causes of incidents are more insidious; human error, cost cutting, and miscommunication are foremost among them.[157]

In fact, human failures account for up to 80% of oil spills.[158] These spills can cause impacts over a range of time scales, from days to years, or even decades. Though the frequency of large oil spills from oil tankers has declined over the last 40 years (about 3.3 large spills occurred annually between 2000-2009)[159], tankers remain the primary source of large oil spills in the United States.[160] More than two-thirds of large oil spills occurred while vessels were underway in open or inland waters.

Only about 30% of the tanker incidents that occurred between 1997 and 2007 were reported in the international shipping database that tracks shipping safety.

More importantly, most oil tanker incidents are not reported. One of the most widely used sources of information for evaluating shipping safety is the Lloyd's Register FairPlay database. A 2010 study found that only about 30% of tanker incidents between 1997 and 2007 were reported in this database.[161] Notably, this is the same database used by Enbridge to present probabilities of tanker incidents along their proposed Northern Gateway route. The sustained occurrence of low probability, high consequence oil spills like the *Exxon Valdez, Prestige*, and *Deepwater Horizon* demonstrates that progress in safety regulations and navigational technology cannot override poor judgement, human nature, and our inherent capacity for error.

Two forces – human nature and physical nature – have often combined to produce tragedies at sea. Overconfidence in our ability to reduce risk and under capacity to respond, can result in disaster. Photo: Telegraph.co.uk

Small oil spills, however, are responsible for most spill incidents, and they occur with disturbing regularity. Of more than

10,000 oil tanker spills since 1970, 80% have spilled less than 50 barrels of oil.[162] Unfortunately, the resulting effects are not inconsequential. Small spills can be very costly, difficult to clean up, and ecologically damaging. Smaller spills also are most common during loading, unloading, and fuelling, and have lead to chronic contamination at terminals and ports.[163]

In 2004, the bulk cargo ship, M/V *Selendang Ayu*, ran aground in Alaska after its engine failed and assist tugs could not tow the drifting ship. Six crew-members died when a rescue helicopter was engulfed by a breaking wave and crashed. The ship broke in half spilling more than 10,000 barrels of fuel oil dramatically affecting seabird colonies, other marine life, and fisheries. Photo: USFWS

Oil Spills: size doesn't always matter

One common public misconception is that large oil spills cause greater environmental damage than smaller spills. But what really matters are when and where spills occur, the weather conditions during and following the spill, and the type of oil spilled. In 1988, the fuel barge Nestucca spilled 6,125 barrels of heavy fuel oil when it collided with a tug-boat.[164] Although the spill occurred only 3 km off the Washington coast, prevailing winter conditions spread the oil onto shorelines from Oregon to Vancouver Island, which subsequently resulted in the deaths of an estimated 56,000 birds, oiled salmon spawning grounds, and caused significant harm to nearshore populations of herring, crab, and shellfish.[165]

The *Exxon Valdez* accident ranks 36th in terms of volume spilled, yet its impacts on the health of ecosystems, and human society and economy, have been estimated at $9.5 billion; a financial and ecological cost far greater than most spills of larger size. Alternatively, serious clean-up costs and economic consequences from some of the largest oil spills[166] have been avoided by fortuitous combinations of location, sea and weather conditions, and the properties of oil.

Figure 4.1 Main cause of accidents at sea, with human error accounting for 80%.[167]

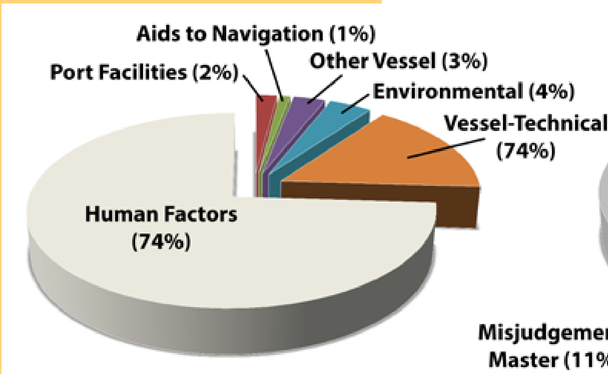
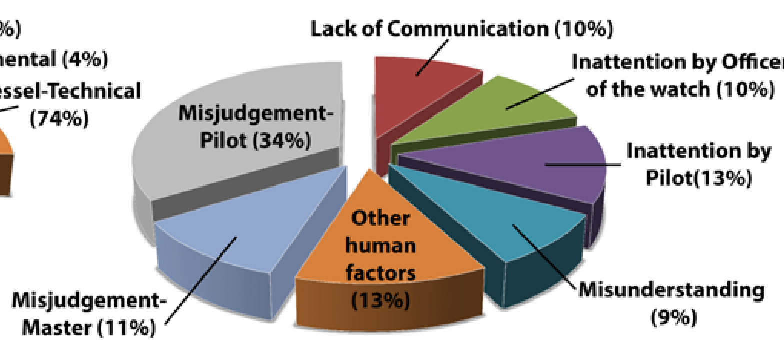
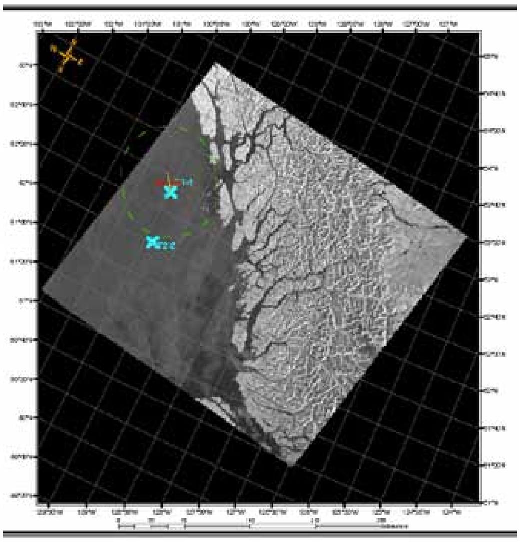


Figure 4.2 Categories of human error for accidents at sea.[168]





Chronic oil spills
A 19 km oil slick detected by Canada's satellite tracking program on BC's central coast in July 2012. The yellow line is the slick, and blue crosses are the potential sources (ships). About 35 of these unreported spills were detected on BC's coast between 2006 and 2011. More than half of all seabird carcasses recovered on the west coast of Vancouver Island were oiled,[170] and may have been the result of these types of unreported spills.
PHOTO: GOVERNMENT OF CANADA

Port of Burnaby spill in June 2007. Spills such as these are a large contributor to the chronic contamination and toxic state of large seaports.
PHOTO: GOVERNMENT OF CANADA

The chronic problem from repeated small spills

Chronic oil pollution is the persistent release of oil at low (and often unreported) concentrations that result from its extraction, transportation, and human use. These releases account for nearly 70% of the annual oil spilled into the world's oceans. In North America, roughly 85% of anthropogenic inputs (630,000 barrels) are from slow chronic releases, which dwarfs the 38,000 barrels spilled annually from large ships.[169] Undoubtedly, small continuous discharges degrade sensitive habitats. This is especially true in nearshore waters adjacent to oil ports and terminals, which are often chronically oiled from small spills and vessel activity.

Risk, probability and consequence

Risk is a combination of probability and consequence. Though frequency is statistically predictable, no one can predict when and where accidents will happen. The risk of marine accidents increases with increasing vessel traffic, and poor weather conditions. More than 400,000 vessel movements occur annually on the BC coast,[171] so it is not surprising that accidents (including collisions, groundings, and gear failures) are common. In the winter of 2012, the deep-sea cargo ship, *Tern Arrow*, lost power in Hecate Strait and drifted for three hours before emergency power was restored.[172] Even vessels with state-of-the-art navigational equipment have grounded.[173]

The tanker shipping industry ranks the following as the leading causes of tanker accidents: hull structural failures, failure to follow navigation rules, machinery failure, conning and navigation errors, improper hotwork (i.e. welding, grinding), improper channels and buoy markings, and problems during cargo transfers.[174] The consequences from these accidents are increasingly more significant, as cumulative pressures (including pollution and climate change) stress organisms and habitats, and reduce their ability to recover.

In 2010, two major spills from double-hulled tankers occurred: the *Eagle Otome* in Port Arthur, Texas, and the *Bunga Kelana III* in the Strait of Singapore. These two tankers spilled 29,000 barrels of oil in relatively low energy collisions (i.e., the types of collisions that double hulls were designed to prevent). PHOTO: WIKIMEDIA COMMONS

Double hulls: solve one problem, create another

Double hull tankers were built to solve the issue of spills from ruptured hulls. However, this recent technology has developed its own set of problems since implementation began in the 1990s. Now, 20-years on, these tankers are beginning to age. The build-up of gases between tanks, increased corrosion, and inspection and maintenance difficulties mean these tankers might offer a false sense of security when it comes to preventing major oil spills. Double-hull tankers operate with stress levels 30% higher than single-hull vessels, which increases the risk of buckling failure.[175] This is a particular concern given the conditions that tankers may encounter on BC's coast.[176]

A similar situation exists with the regulation of ballast tanks. In 1979, regulations to address chronic oiling were implemented that involved the segregation of ballast tanks.[177] Before this, tankers would fill empty cargo tanks with seawater on their ballast leg, and release it when the ballast water was exchanged for oil. Segregated ballast tanks were implemented in all oil tankers built after the 1990s.[178] Though this did decrease the intentional release of oil, tanks became taller, which subsequently increased the internal surface area exposed to corrosion, and (in the case of groundings) increased the potential amount of oil spilt by up to 90%.[179]

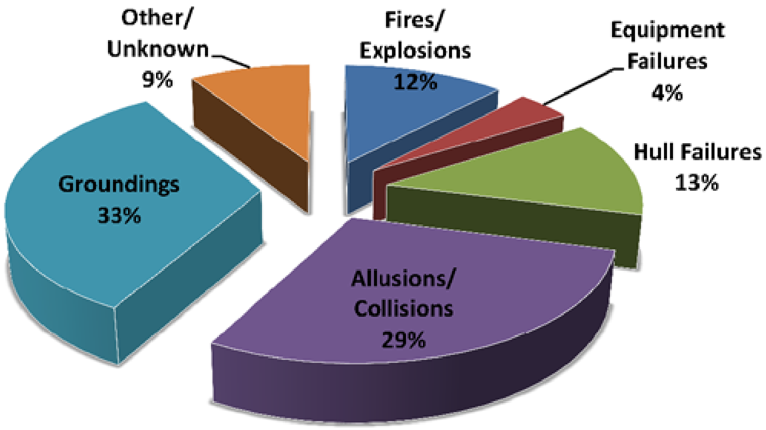


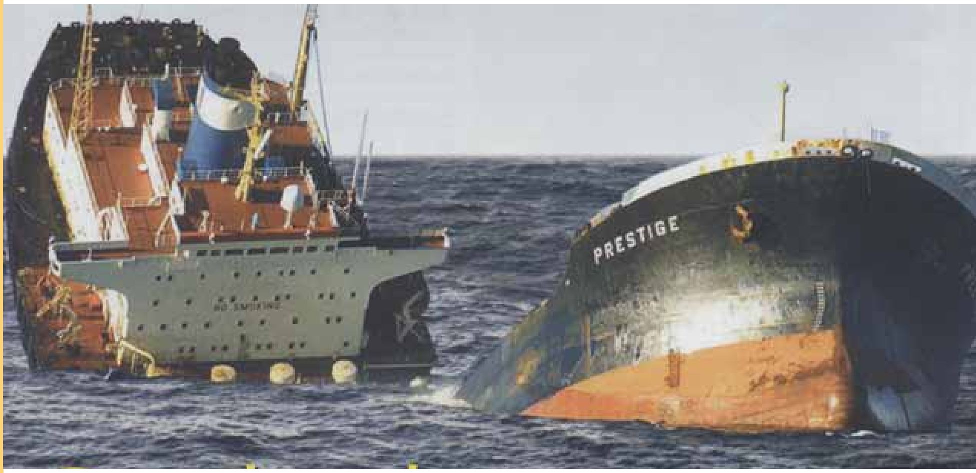
Figure 4.4 Causes of oil spills over 700t

Black Swans: highly improbable and unpredictable events that carry immense impact

Statistician Nassim Taleb describes a black swan event as having three features. First, the event is an outlier, as it lies beyond the realm of regular expectations, where nothing in the past can convincingly point to its possibility in the future. Second, it carries an extreme consequence. Third, in spite of being an outlier, human nature destines us to concoct explanations for its occurrence after the fact, as if it were explainable and predictable.

A black swan occurrence depends also on the observer (i.e., some observers may not have been surprised). For example, a turkey

is fed for 1,000 days; every day confirms to the statistical department that the human race cares about its welfare with ever increasing statistical significance. Yet, the statistical department receives a grand surprise on the 1001st day.



The *Prestige* sinks off the coast of Spain in 2002 after metal fatigue caused a hull failure. PHOTO: MERACATOR MEDIA

The *Prestige* oil spill

On November 13, 2002, the *Prestige* (registered under Bahamian 'flag of convenience', Liberian owned, Greek operated, US certified) was carrying more than 560,000 barrels of heavy fuel oil, when one of its 12 tanks burst in a storm 400 km (248 mi) off northwestern Spain. Fearing that the ship would sink, the captain called for help. After Spanish, French, and Portuguese authorities refused assistance and ordered the ailing ship further off the coast, the hull began to break. On November 19, the ship split in two releasing upwards of 460,000 barrels of oil that washed onto 1,900 km (1,180 mi) of shoreline in six countries. The cost of the clean-up on Spain's Galacian coast alone exceeded one billion euros. Their damage claim to the American Shipping Bureau was $US 700 million. The ROV submersible used to remove oil remaining in the wreck cost $US 100 million. However, after oil slicks began to appear in 2006 investigations revealed more than 100,000 barrels of oil remained. Although the ship was suffering metal fatigue, it had been certified by the American Bureau of Shipping (committed to 'standards of excellence') because it met all applicable laws.

Remarkably, violent storms carried the worst of the *Braer*'s 588,000 barrels of crude oil into the North Sea instead of onto the Shetland Islands. Still, the spill did extensive damage to salmon in aquaculture pens and wildlife.
PHOTO G. BURNS

Terminally oiled

Terminals and ports are where oil spills occur most frequently because these areas are the receptacles and outflow points for the vast amounts of crude oil imported and exported globally.[180] Most spills are small in volume, but are much larger than the estimates reported to spill response centers.[181] Spills at terminals usually occur during loading and unloading, although accidents also occur at the entrance and exit zones for tankers. In Enbridge's Quantitative Risk Assessment, the safety of modern terminals is emphasized. Upheld as exemplary are terminals from northern Europe such as Sullom Voe (Scotland) and Mongstadt (Norway). However, the history at these terminals reveals a different story.

In the first year of operation at Sullom Voe, a major oil spill occurred. The tanker, *Esso Brenicia*, was attempting to dock in relatively high winds when an explosion and fire struck the tethered tug. Fearing the fire would spread to the tanker, the tug captain disconnected the tug from the tanker; the tanker subsequently crashed into the terminal. Seventy-seven thousand (77,000) barrels of crude oil spilled into the bay and along the surrounding coastline.

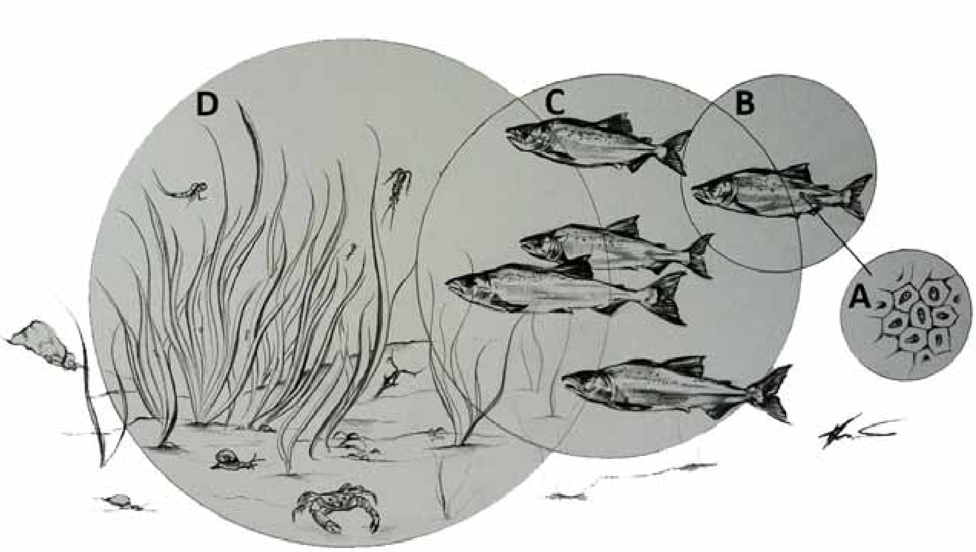
At Mongstadt, four years after the terminal was built in 1989, the tanker *Braer* departed with 595,000 barrels of crude. In very bad weather, the *Braer* lost power and drifted onto the rocks among the Shetland Islands. Because of the weather conditions, nearby assist vessels were helpless to prevent the accident; the entire cargo emptied into the North Sea.

Not mentioned by Enbridge is the Millford Haven terminal on the west coast of England. The first ship to unload its cargo suffered an explosion and spilled its oil. Many other spills subsequently followed, including the massive 500,000-barrel spill from the *Sea Empress* in 1996.

22 years since the *Exxon Valdez* oil spill

In March 1989, the *Exxon Valdez* ran aground on Bligh Reef in Alaska. Between 250,000 and 750,000 barrels of crude oil emptied from its ruptured hull into Prince William Sound. The severity of the spill was compounded by the heavy, persistent, properties of North Slope crude oil, a three-day lag in Exxon's emergency response, and the heavy storm conditions that ensued. The immediate impacts included 2,000 km of oiled shoreline,[182] deaths of an estimated 250,000 seabirds, 2,800 sea otters, unknown numbers of porpoises and dolphins, countless intertidal shellfish, and smothered kelp and eelgrass habitats over a 3,400 km^2 area.

Other adverse effects surfaced in time: 22 killer whales died (devastating two pods), the herring population precipitously declined and has not recovered (though possibly confounded by other factors), subsistence gathering of intertidal resources has only partially returned, and more than 500 barrels of oil still remain buried beneath the surface, much of it nearly as toxic as the initial few weeks after the spill.[183] As many as 3,000 clean-up workers have now suffered from spill related illnesses.[184] Estimates of economic, social, and ecological damages are $9.5 billion, of which Exxon has paid only $3.4 billion; US taxpayers have had to cover the shortfall.[185]



Scientific studies, many of which were done following the *Exxon Valdez* spill, have shown that impacts from oil exposure are not just immediate. Weathered oil can remain toxic at low concentrations for decades, and produce delayed and sub-lethal effects that can affect wildlife and associated food webs for years. Spilled oil can affect living organisms at four broad levels: i) cellular, ii) the whole organism, iii) the population, and iv) the community.[186]
GRAPHICS: MAYA KAMO/RAINCOAST

In 2007, the container ship M/V *Cosco Busan* collided with one of the towers of the San Francisco Bay Bridge in heavy fog, resulting in a large rip in the hull. The subsequent damage released about 1400 barrels of fuel oil into San Francisco Bay.[191] The spill affected about 190 km of shoreline, killed more than 2,500 birds, impaired 15-30 percent of the herring spawn,[192] closed a fishery temporarily, and cost more than $70 million for environmental clean up, not including restoration.[193] The map below shows the extent of shoreline oiling.

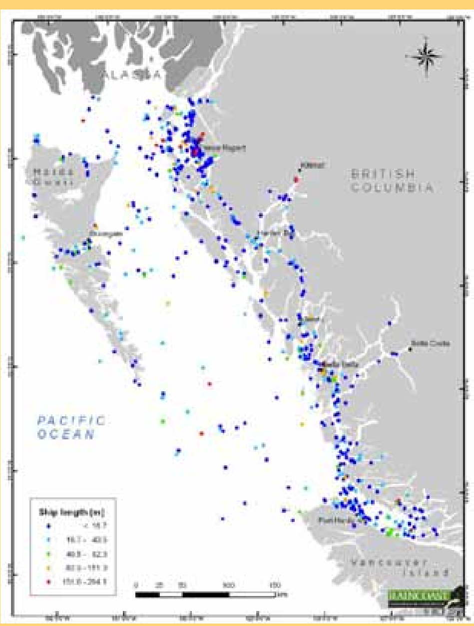


Figure 4.3 Vessel incidents as reported to Transport Canada 1999–2008. Most of the 812 incidents shown were groundings.

Groundings and Enbridge

The grounding of a tanker is listed by Enbridge as being the primary risk for a Northern Gateway oil tanker spill.[187] As such, Enbridge proposes to use escort tugs, which it claims will reduce the incident frequency by three-fold.[188] However, this ostensive increase in safety comes without justification or evidence to suggest that escort tugs can manoeuvre fully loaded VLCCs in emergencies and through the confined channels of BC's coast. Also overlooked are situations where escort tugs have caused accidents and grounded themselves.[189] In 2007 and 2009, two Crowley tugs – operated by highly trained crews using modern navigation equipment – went aground in well-marked shipping routes. The *Sea Voyager* grounded on a reef at Serpent Point near Bella Bella on BC's central coast (2007), and *Pathfinder* grounded on Alaska's Bligh Reef (2009). Tug effectiveness and operation can also be limited by severe weather conditions.[190]

Table 4.2 Vessel groundings and their causes. Groundings have resulted in the highest percentage of major oil spills. Groundings, however, are not causative, but result from navigational mistakes, machinery failure, and other errors,[194] many of which are ultimately attributable to human failings.

Year	Vessel	Cause of grounding	Approx volume spilt in barrels
1973	*Dona Marika*	Anchor dragging	22,000 gasoline
1976	*Urquiola*	Unmarked shoal	700,000 crude oil
1976	*Argo Merchant*	Navigational error	200,000 fuel oil
1978	*Amoco Cadiz*	Machinery failure	1,600,000 crude oil
1989	*Bahai Paraiso*	Navigational error	3,800 fuel oil
1989	*Exxon Valdez*	Navigational error	260,000 crude oil
1993	*Braer*	Machinery failure	600,000 crude oil
1996	*Sea Empress*	Conning error	500,000 crude oil
1997	*Nakhodka*	Structural failure	45,000 medium fuel oil
1997	*Diamond Grace*	Conning error	10,000
1967	*Torrey Canyon*	Navigational error	997,000 crude oil
1971	*Wafra*	Machinery failure first, then towing failure	200,000 crude oil
1992	*Aegean Sea*	Insufficient manoeuvrability	560,000 crude oil
1999	*New Carissa*	Anchor dragging	1,600 bunker fuel
2003	*Tasman Spirit*	Navigational error	88,000 crude oil
2004	*Selendang Ayu*	Machinery failure	8,000 bunker fuel
2009	*Gulsar Ana*	Unknown	4,000 fuel oil
2010	*Shen Neng 1*	Not properly piloted	22 bunker fuel

A leak of 28,000 barrels of crude oil near the Peace River in April 2011 from a Plains Midstream Pipeline was Alberta's largest leak since the Bow River spill in 1975.[195] PHOTO: I. JACKSON

Pipeline spills

Enbridge is a pipeline company with no history in the oil tanker business. They do have, however, an abysmal history with oil spills. Canada has more than 700,000 km (435,000 mi) of crude oil and natural gas pipelines, with 23,000 km (14,000 mi) of crude oil transmission lines; most of which operate under two companies: Enbridge Pipelines Inc., and Kinder Morgan Canada. Although the Canadian Energy Pipelines Association (CEPA), the Canadian Association of Petroleum Producers (CAPP), and the Government of Alberta all emphasize the safety of pipelines relative to other forms of transportation, a 2013 report by Global News found that pipelines were Alberta's largest source of spills, accounting for 47% of the 28,600 hydrocarbon spills since 1976.

In July 2010, Enbridge's Line 6B ruptured, releasing about 20,000 barrels of diluted bitumen into Talmadge Creek, Michigan, contaminating 48 km (30 mi) of the Kalamazoo River.[196] Although Enbridge detected corrosion in their pipe in 2004, and identified 1.3 m (4.3 feet) of cracking in 2005, they neglected to make repairs.[197] When the pipe eventually ruptured, 17 hours elapsed before it was shut off. A report into the incident by the US National Transportation Safety Board likened Enbridge staff to the farcical Keystone Cops,[198] very different from staff delivering the "world leading" safety standards that Enbridge contends. The Kalamazoo spill was followed by another unfortunate spill (6,100 barrels) from Enbridge's Lakehead system Line A in Romeoville, Illinois, later in 2010.[199]

Small leaks may not make headlines, but they can have chronic and significant effects locally, especially in remote areas or near watercourses. In May 2011, Enbridge discovered a pinhole leak in their Norman Wells pipeline system near Wrigley, NWT. Although the original estimate of leakage was roughly four barrels, Enbridge upgraded their estimate to 1,500 barrels when oil was detected in sediments. A pinhole leak in Kinder Morgan's BC TransMountain pipeline in April 2011 was only discovered because landowners noticed oil flowing into a small creek.[200]

West coast oil exploration

Although a moratorium on offshore gas and oil drilling was first agreed to in 1972, and still exists for Canada's Pacific waters, the extraction pressure has far from subsided. Gwyn Morgan, founder and former CEO of Encana, and a key advisor to BC Premier Christy Clark, stated in 2005 "we applaud the government for trying to open-up the offshore because it is truly a resource for all of BC".[207]

A 2007 report by Alberta's Energy Resource Conservation Board (ERCB) documented the number of pipeline hits, ruptures, and corrosion leaks that occurred during 1990-2005.[201] Although the ERCB states that pipeline leaks are rare relative to the number of active pipelines in Canada, the number of annual incidents showed no decline. Following 411 incidents over the 15-year period, there were 700 crude oil and bitumen spills in the year 2012 alone.[202]

Enbridge claims that their pipeline failure rates are 40% below the industry standard, yet this does not mean few incidents. Between 1999 and 2009, Enbridge admitted to 699 "reportable" spills that released more than 132,000 barrels of oil products onto farms, wetlands, and waterways in North America.[203] Their US affiliate, Enbridge Energy Partners, agreed to pay US$1.1 million to settle a lawsuit brought against them by the State of Wisconsin for 545 individual environmental violations.[204]

It's not just Enbridge

Since 2005, four pipeline incidents have occurred along Kinder Morgan's Trans Mountain pipeline into BC's lower mainland.[205] All are considered minor in terms of pipeline accidents, but the implications have been significant for local communities. A pipeline rupture at the Sumas Tank Farm in Abbotsford occurred in January 2012, which spilled approximately 690 barrels of tar sands crude oil. Another spill occurred in July 2005, when approximately 1,320 barrels of crude were released into the area surrounding the Sumas facility, and eventually flowed into Kilgard Creek on Sumas Mountain.[206] Regulations, improved technology, and promises for heightened safety may reduce the frequency of oil spills over time, but they undeniably fail to prevent their occurrence, constrain their magnitude, or restrict when and where they happen.

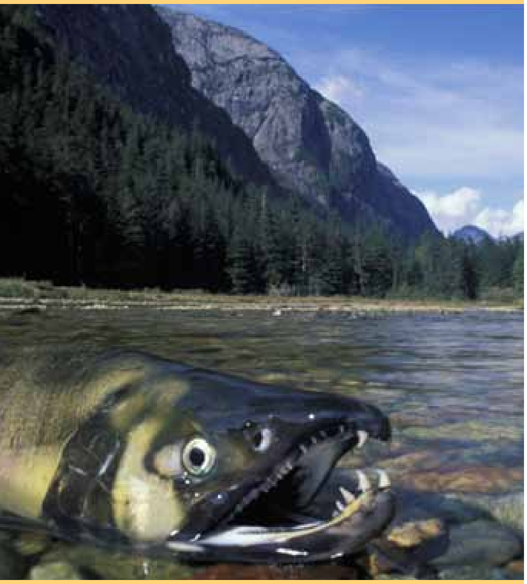
5. The Toxicity of Oil

The *Exxon Valdez* oil spill occurred in the relatively pristine habitat of Alaska's Prince William Sound. The high quality of this habitat was a critical factor in assessing and attributing the long-term impacts of the spill. In most environments where oil spills occur, habitats have been previously degraded. Thus, teasing apart long-term oil spill effects from other influences can be extremely problematic. PHOTO: FLICKR CREATIVE COMMONS: TIDAL LIFE BY 'SOMEWHEREINAK'

Lessons from the *Exxon Valdez* oil spill

It is well established that petroleum products are toxic to fish. However, only a few of the hundreds of large oil spills that have happened globally occurred where salmon were present; this changed with the *Exxon Valdez* oil spill.

Following the *Exxon Valdez* spill, unprecedented studies on the toxicity of oil to pink salmon and Pacific herring began. These studies targeted fish that were commercially important to the region and required nearshore habitats subjected, or not, to oil.[208] Despite scientific and public debate between government and Exxon-funded scientists, most scientific evidence showed that significant damage occurred to pink salmon in the years following the spill.[209] Chum salmon were likely affected to a similar degree. Importantly, decades of studies have now demonstrated that components of weathered oil — specifically, the PAHs — are orders of magnitude more toxic than previously believed, and can kill juvenile salmon and herring at very low concentrations.



Chum and pink salmon are particularly vulnerable to marine oils pills because of their tendency to spawn in the intertidal portions of freshwater streams where oil residue can persist. PHOTO: MCALLISTER/RAINCOAST

Oil spill impacts didn't surface immediately

Roughly one-third of the salmon streams in Prince William Sound flow into nearshore habitats that were oiled by the *Exxon Valdez*. The spill occurred just before the spring out-migration of pink, chum, and other salmon fry.[210] When the fry emerged from the gravel and migrated to sea, concentrations of oil were relatively low and the young salmon appeared to survive. Their growth rate however, was significantly reduced compared with fry from the un-oiled parts of Prince William Sound (Figure 5.1).[211] Although reduced growth has implications for survival, scientists initially thought that the young salmon had been spared; no mass mortalities were observed as fish transited into the Sound to begin their 18-month ocean migration.

In the summer of 1989 (several months after the most toxic stages of the spill had passed), pink and chum salmon from the previous years returned to spawn. Concerns for these fish were minimal because oil contamination of the spawning grounds appeared minor, and the prevailing thought on oil spills was that the impacts were immediate. However, numbers of pink salmon returning to spawn in Prince William Sound declined markedly over the years after the spill, including salmon from generations that were not in the streams when the spill occurred. At some point in their life cycle, salmon from Prince William Sound had been exposed to toxic levels of oil.

An oiled beach and salmon stream (with surrounding oil boom) on LaTouche Island, Prince William Sound, Alaska, in the fall of 1989. Roughly, one-third of Prince William Sound's salmon streams flow onto shorelines contaminated by oil. Although oil could be seen on the beaches and stream banks, it was not visible on the stream's spawning gravels. This puzzled scientists trying to explain why salmon abundance from these streams was in decline compared with the region not hit by the oil spill. Eventually it was understood that oil, which had been buried in the beaches and tidal reaches of river mouths, was forced up into the spawning gravels with the flood of each tide. PHOTO: ARLIS.ORG

Early salmon life stages
Top: Salmon embryos. Fertilized eggs with developing fish. PHOTO: WA DEPT OF FISH & GAME

Mid: Salmon larvae (called alevins). Egg case is gone but yolk sac is present. PHOTO: STREAMNET.ORG

Bottom: Pink salmon fry (yolk sac is absorbed). PHOTO: SEYMOURSALMON.COM

Fish larvae are up to ten-times more sensitive to oil than adult fish.[220] Salmon embryos, the stage before larvae emerge, appear equally sensitive. Embryos attract oil because they are high in lipids, which mean they accumulate and concentrate hydrocarbons at much higher levels than the surrounding water.

Exposure to low concentrations of oil

The mortality of young salmon (eggs and larvae) that were born in the years after the oil spill, (i.e., their salmon parents experienced the initial spill), was in fact higher than the parent generation. A resounding question followed: why?

The oil exposure pathways were eventually explained: contamination occurred during the months of egg incubation. Even though the surface of a given stream's spawning gravels did not appear to be covered with oil, oil was visible on the stream banks. Small amounts of oil were also hidden deep in the spawning gravels.[212] With each flood tide, oily water was forced upward through the gravels and over the eggs.[213] This exposure to very low concentrations of PAHs in the water resulted in stunted growth and increased mortality through repeated generations of salmon that spawned on oiled gravels.

Toxicity to developing salmon

Impacts on pink salmon embryos exposed to oily water with low PAH concentrations (less than 20 parts per billion; ppb) can be both lethal and sub-lethal. Embryos that survive to the larval stage can emerge with sub-lethal effects in the form of deformities (to their heads, eyes, jaws, mouths and fins), edema (swelling and inflammation), and external hemorrhaging. Lab studies have shown that the number of mortalities and deformities of embryos increased with increasing oil concentrations (i.e., from 1 to 100 ppb).[214]

Fresh oil is not the only type to cause harm. Pink salmon embryos exposed to years of weathered oil at levels consistent with those following the *Exxon Valdez* spill[215] exhibited signs of compromised heath, including deformities,[216] premature fry emergence, and slow development.[217] In the years after the spill, field and lab studies showed that the embryos from oiled streams had much higher mortality than embryos from non-oiled streams.[218] Exposure to low concentrations of oil (i.e., less than 20 ppb), reduced marine survival of pink salmon by nearly 40%.[219]

Early development is the most oil-sensitive life stage for salmon. Toxic effects, such as reduced growth, deformities, and disease, can occur at very low concentration of PAHs in oily water (below 20 ppb). These effects can reduce survival in the current and second generation. The severity of these effects (including mortality) increases with increasing concentrations of PAHs (20-100 ppb). Edema, shown here, can occur in salmon larvae when exposed to oily water, even at low concentrations. PHOTO: M. CARLS, AUKE BAY LAB NOAA

Pacific herring larvae are very sensitive to oil. Low concentrations of PAHs in oily water can produce spinal deformities, heart defects, and edema (abnormal swelling of stored fluid) after just four days of exposure to very low PAH concentrations (1 ppb).[227] PHOTO: M. CARLS, AUKE BAY LAB, NOAA

Impacts to salmon offspring whose parents were exposed to oil

Indirect exposure to oil can also harm and kill salmon embryos and larvae. In Prince William Sound, high egg mortalities were observed upstream of oiled spawning grounds in the years after the *Exxon Valdez* spill. Experiments performed to explain why young salmon not exposed to oil were dying, found that oil toxicity in the adults could appear in their offspring. In other words, the sub-lethal damage caused to the parents (from oil exposure), was passed through to the next generation. This is a very concerning phenomenon.

Studies have demonstrated that salmon, which survived exposure as embryos to very low level PAHs (i.e., less than 10 ppb), exhibited harmful physiological changes as they matured.[221] These sub-lethal effects suggest that subtle changes to reproductive and other organs were the likely causes for the reduction in pink salmon survival observed in unexposed offspring following the Exxon oil spill; linking individual based toxicity with a population level response. Although this theory has been challenged,[222] this kind of effect has led scientists to postulate that salmon populations chronically exposed to low levels of oil could be extirpated over relatively few generations due to decreases in population productivity and growth.[223]

It's not just salmon

Numerous studies on other species of fish are consistent with these findings.[224] Studies on zebra fish have shown similar responses to PAHs as salmon. Zebra fish exposed as embryos to equally low levels of PAHs showed reduced heart capacity and swimming performance nearly one year later.[225] Other non-lethal organ and cell function problems that occurred in zebra fish embryos later surfaced as reproductive impairment in adults.[226]

Herring are equally, if not more sensitive, than salmon. Herring embryos exposed to very low concentration of PAHs in oily water hatched earlier, weighed less, and emerged with head, spine, and fin deformities upon hatching.

The effect of dispersants

Dispersants do not make oil disappear; they simply break-it-up and transport it to another area of the ecosystem. When applied before the spilled oil reaches coastlines, dispersants can potentially decrease the risk to water surface and shoreline organisms. Conversely, the dispersants can increase the risk to water column organisms and those inhabiting the ocean floor.[233] Dispersants also make oil more toxic by creating smaller droplets that are more easily taken-up by organisms.

Corexit,® the solvent used in the Gulf of Mexico spill, contains a toxin that first ruptures red blood cells,[234] and then causes bleeding, and liver and kidney damage.[235] Corexit also contains petroleum solvents that mix with crude oil, thereby increasing the up-take of oil and associated toxins by organisms.[236] The same properties that ease the movement of dispersants through oil also make it easier for them to move through cell walls, the skin, and membranes of vital organs. Photo: Lehmann/US CG

Detoxification enzymes: evidence of oil exposure

Pink salmon fry from oiled streams showed reduced growth[228] and higher concentrations of PAHs in their tissues[229] following the Exxon spill compared with salmon fry from un-oiled streams. Pink and chum salmon from oiled streams also showed increased levels of detoxification enzymes[230] which play a critical role in metabolizing PAHs and protecting fish from the toxicity of these chemicals.

The activation of these detoxification enzymes (CYP1A from the cytochrome 450 group of enzymes), after an oil spill suggests that fish were exposed to contaminants. The increased levels of the CYP1A activity in chum salmon indicate that they were equally affected as pink salmon by the *Exxon Valdez* spill.[231] Trout and prickleback fish that consumed oil-contaminated prey also showed elevated levels of CYP1A activation.

Although CYP1A aids survival of oiled embryos, it cannot prevent adverse physiological effects from emerging later in life. In fact, the degree of activation of the CYP1A enzyme can predict the fish's survival: probability of survival decreases with increasing enzyme activation.[232]

The activation of CYP enzymes might also signal an onset of cancer, which further reinforces the carcinogenic implications of exposure to oil.

Weathering of oil: sunlight and oxygen

The toxicity of heavy oils increases with exposure to sunlight and oxygen.[237] One reason is because weathering processes concentrate the larger, heavier, PAH molecules, thereby making weathered oil more toxic than fresh oil on a weight-by-weight basis.[238]

A second reason is photo-induced toxicity; a process where sunlight triggers PAHs to form highly reactive oxygen molecules inside cells, increasing the toxicity of PAHs. This can occur in a variety of translucent fish, including juvenile Pacific herring, crustaceans, and invertebrate larvae.[239] Young pink salmon appear less sensitive to photo-induced toxicity than herring, perhaps because of their higher degree of pigmentation.

Salmon: the Great Provider

As a seasonal food source, salmon influence coastal food webs and affect countless plants and animals.[246] Over seventy birds, mammals, and other vertebrates eat salmon and salmon eggs[247] with countless others using the nutrients released from the decaying carcasses.[248] By eating spawning salmon, bears and wolves transfer nutrients to the forest via their excrement and urine,[249] and through the uneaten remains.[250] These remains, scattered along streams after spawning, provide food for aquatic insects and fish.[251]

Terrestrial insects rapidly decompose salmon carcasses on the forest floor[252], which in turn become food for birds, mammals, fish, and other insect eaters.[253] Lastly, streamside plants and other organisms absorb remaining nutrients. The entire cycle drives a legacy of nutrient enrichment believed to supply future biological diversity with vital habitat.[254]

Photo: L. Travis

Stunted growth from oil exposure

Salmon can metabolize hydrocarbons but it comes at a cost. When young salmon first arrive in the sea after leaving their freshwater streams, their chance of survival is strongly dependent on their size and growth.[240] Slow growth can be deadly. If salmon consume oil-contaminated prey, their ability to absorb nutrients is reduced, resulting in slower growth.[241]

Consumption of oiled prey and the high energy required to metabolize contaminated food, are the most probable causes of the reduced growth that was observed in juvenile pink and chum salmon after the *Exxon Valdez* oil spill.[242]

Stunted and reduced growth has also been observed in other studies examining oil effects on salmon fry, even at low concentrations of crude oil.[243] Salmon exposed to certain PAHs have also shown decreased resistance to disease and increased vulnerability to immune system suppression.[244]

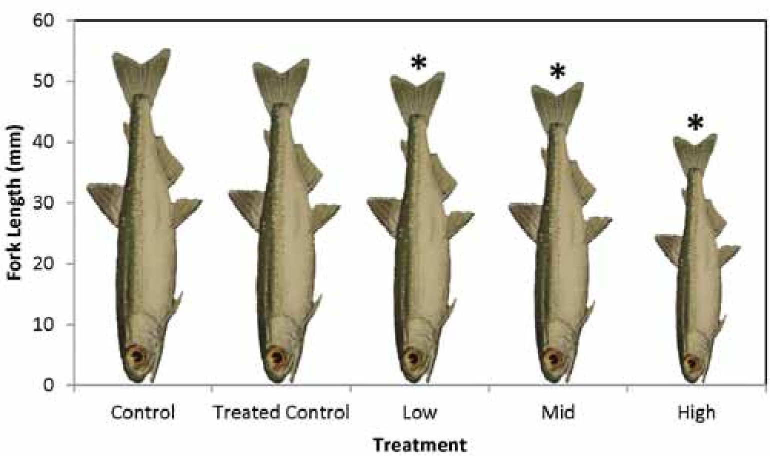


Figure 5:1 Laboratory studies and field research during the spill showed reduced growth in pink salmon fry after exposure to very low concentrations of oil in water. Asterisks indicate significantly shorter groups.[245]

PHOTO: G. BURNS

Light oils still incur heavy costs

Whereas spills of heavy oils can visibly contaminate shorelines, spills of light oil such as from the *Braer* in 1993 and the *North Cape* in 1996, show how the properties of oil and weather conditions conspire to be equally lethal. Both spills occurred in severe weather, so much of the oil was quickly dispersed into the water column.

In the case of the *North Cape*, the immediate loading of the water column by highly soluble and toxic BTEX components caused mass mortalities, including highly valued lobsters.[255] In the case of the *Braer*, light crude oil dispersed into the water column, where it combined with suspended sediments, sank, and was deposited on the ocean floor. In addition to wildlife impacts, 23 aquaculture operations over 4,000 km^2 were contaminated; forcing the killing of millions of mature farmed salmon.[256]

The number of sea otters that have died since the 1989 *Exxon Valdez* oil spill – due to eating contaminated food – may meet or exceed the number of sea otters that died from acute oil spill exposure in 1989.[258] The same exposure-channel was identified for seabirds like Harlequin ducks and Barrows golden-eye, which continued to feed among oiled intertidal areas, and have yet to fully recover even 20 years later.[259] PHOTO: K. WAHLQUIST/ SHUTTERSTOCK

Ecosystem impacts

Food webs

Scientists are beginning to understand the ways by which long-term impacts occur from oil spills. Beyond the chronic oil exposure and delayed population-level impacts, effects at different levels of the food web may 'cascade' into ecosystem influences.[257] These "cascades of indirect effects" are ecological chain reactions that affect different species and different levels of the food web.

When oil first washed onto the intertidal shores of Prince William Sound, it caused acute mortality of rockweed (a seaweed), limpets and periwinkles (herbivore snails), and dogwhelks (a snail that eats barnacles). The loss of these consumers enabled algae to proliferate between six months and 1.5 years after the spill. Two and a half years later, barnacles increased far above their former abundance because of reduced predation by the snails.

Oil also remained on surfaces used by mussels and other bivalves. The chronic exposure of the bivalves, which stored oil in their tissues, provided contaminated food to other animals. An alarming example of this was the high mortality rates of Prince William Sound's sea otters in the years after the oil spill due to the ongoing consumption of contaminated bivalves, their preferred food.

Pacific herring

Pacific herring are an important food for salmon. Adult and juvenile salmon eat adult, juvenile, and larval stages of herring.[260] Herring are one of the most important food items for Chinook salmon.

Pacific herring are particularly sensitive to oil spills. Their reliance on nearshore habitats for spawning and their behaviour of air-gulping and surfacing exposes them to oil and oil vapour at the water's surface. PHOTO: HERRING SPAWN ON BC COAST; FISHERIES AND OCEANS CANADA

The cause of the Prince William Sound herring collapse after the Exxon spill is a tale of competing theories and lack of conclusive evidence.[261] The paucity of adequate data before 1993 makes it hard to identify the year that herring began to decline, but 1993 was one of the lowest herring catches on record. The prevailing theory is that the oil spill caused significant damage to larvae and adults beginning in 1989.[262]

The *Exxon Valdez* oil spill occurred at the time when adult herring were spawning in Prince William Sound. Studies on Pacific herring after the spill showed that newly hatched herring from oiled spawning habitats exhibited abnormalities, reduced growth, and higher mortality than unexposed fish.[263] An estimated 40-50% of all herring eggs deposited in Prince William Sound during 1989 were exposed to oil, which subsequently resulted in a 40% reduction of the 1989 brood class.

Pacific herring are particularly sensitive to oil spills. Their behaviour of air-gulping and surfacing exposes them to oil and oil vapour at the water's surface.[264] Disease, or oil-induced disease, that emerged in the early 1990s has been a dominant explanation for the collapse of Prince William Sound herring populations.[265] The failure of herring to recover has prompted other theories. The most noteworthy is that hatchery-reared pink salmon released in enormous abundance into Prince William Sound are outcompeting herring for food.[266] Whether or not the Exxon spill was causative, food web interactions and altered carrying capacity might be limiting the recovery of herring. Certainly, the documented effects from the Exxon spill on ecosystems that support primary and secondary productivity should not be overlooked. The herring fishery in Prince William Sound remains closed and the population has never fully recovered.

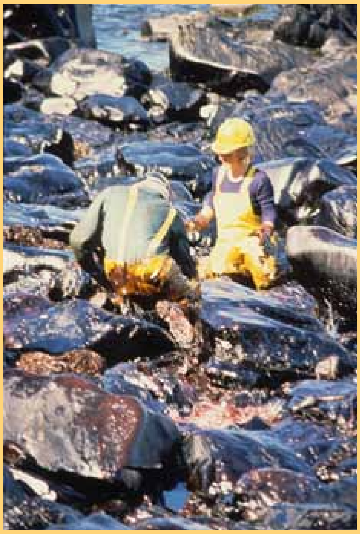


Photo: www.arlis.org

Exxon Valdez — A paradigm shift for oil spill impacts.

Before the Exxon spill, scientists assumed that impacts to wildlife from marine oil spills were primarily from acute toxicity (which causes immediate mortality).[267] What we subsequently learned from the Exxon spill, and the extensive number of wildlife deaths and scientific studies that followed, is that weathered oil can be toxic at low concentrations for decades, and produce delayed and sub-lethal effects that harm wildlife and food webs for years.[268]

Because these findings have severely damaged Exxon's public image and increased their liability, Exxon has made it their priority since the spill to challenge any incriminating scientific evidence. For example, Exxon has funded research that questions or contests the oil spill deaths of killer whales, the persistence of oil in sediments, the toxicity of crude oil at low concentrations to salmon, and the long-term effects of oil on wildlife.[269] Though many of the Exxon-supported studies are scientifically questionable, the findings effectively serve to present inconsistency in the scientific conclusions of the impacts from the *Exxon Valdez* oil spill.

Eelgrass beds

Oil spills adversely affect eelgrass communities[270] and the repercussions to salmon can be significant. Eelgrass can require years to recover when subjected to an oil spill because of the damage that oil does to marine sediments.[271] In addition, juvenile salmon that are forced to forage elsewhere because of contamination to eelgrass habitat, use more energy and become more at risk to predation.

Studies from the *Exxon Valdez* spill and elsewhere show that eelgrass recovery and the associated prey that young salmon rely on (such as amphipods) can take years to recover.[272] Although this may not seem long in evolutionary time, loss or contamination of food supply can severely reduce survival. Several years of low survival, followed by lower numbers of new parents with each generation, can then have long-term population-level implications.

Shallow, nearshore, eelgrass beds that occur on the Pacific coast are important for many fish species.[273] These habitats provide food, safety, and cover while fish mature. As such, they are considered critical nursery grounds for young salmon.[274] The use of eelgrass meadows by juvenile salmon can increase survival and the loss of eelgrass has been implicated in local salmon declines.[275] Photo: J. Russell

Little creatures, big roles
Zooplankton are tiny animals critical to sustaining life in the oceans. They include species that spend their entire life cycle as plankton and those which are the larval stages of fish, molluscs, and shellfish. Young salmon rely on many types of zooplankton

What are trophic cascades?
Trophic cascades are ecological chain reactions. A Pacific coast example is the interaction between sea otters, urchins, and kelp forests. Kelp forests provide habitat, shelter, and a buffer from waves and currents for numerous fish and aquatic species. By eating sea urchins, which eat kelp, sea otters keep urchin numbers low and allow kelp communities to thrive.[281] In places where sea otters have been extirpated (for a variety of reasons), urchins have flourished and, in turn, kelp forests have been severely reduced.[282] The decline in kelp then cascades in a way that reduces fish and other fauna that use these habitats.

Zooplankton

Juvenile salmon consume abundant amounts of zooplankton during their early marine migration. These plankton include copepods, amphipods, euphasiids, crustacean larvae, insect larvae, and other floating invertebrates[276] that they consume in the coast's shallow shorelines and estuaries.

Oil spills have been implicated in several zooplankton die offs.[277] Studies from the Gulf of Mexico (before and after the *Deepwater Horizon* spill) show that copepod and amphipod abundances decreased after hydrocarbon pollution from oil and gas platforms.[278] Amphipods were also affected after the *Amoco Cadiz* spill and the *Aegean Sea* oil spill, where some species had not recovered more than four years after the spills.[279]

Whereas fish can often metabolize PAHs with detoxification enzymes, most bivalves and zooplankton cannot. As such, these animals can concentrate PAHs and other petroleum toxins, potentially causing bioaccumulation and sub-lethal effects in salmon and other fish that consume them.[280]

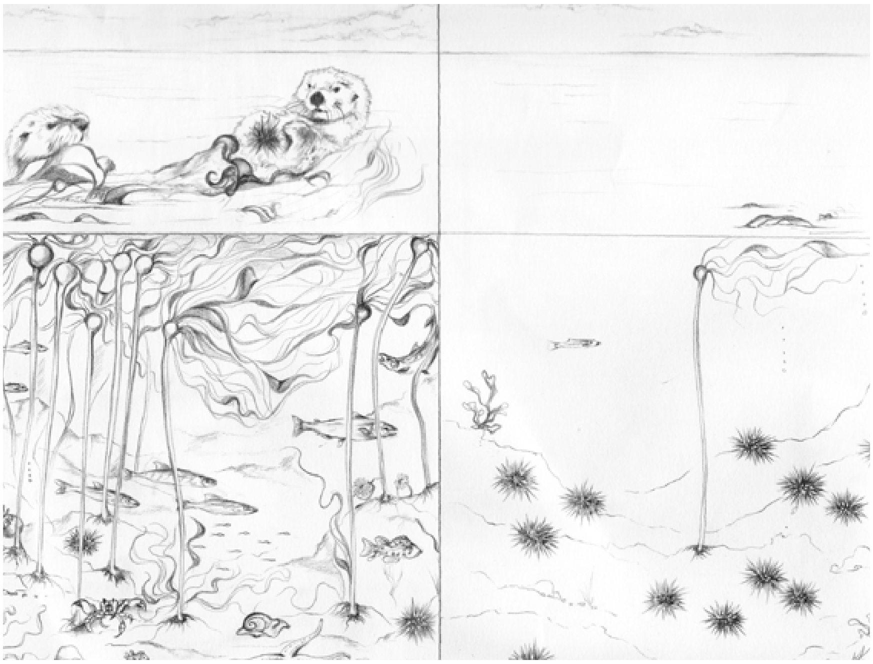


Figure 5.3 A simplified example of trophic cascade interactions. A) In the presence of sea otters, kelp forests flourish providing habitat to young fish and other species. B) In the absence of sea otters, kelp forests become overgrazed by urchins and no longer support fish and other species that depend on kelp habitats. Graphics: Maya Kamo/Raincoast

6. Terminal Impacts

The Kitimat estuary and essential fish habitat

The shoreline kelp and plant communities of Kitimat Arm contribute to the physical and structural features considered *Essential Fish Habitat* for salmon.[286] Because the Kitimat estuary is critical for the recovery of salmon populations, but has already suffered extensive damage to habitat quality and quantity, additional declines in estuary health could facilitate the near complete loss of wild salmon from this area.

Construction and operation of an oil tank farm and marine shipping terminal in Kitimat Arm will negatively influence salmon and salmon habitat in the short and long term. The predicted impacts represent steady cumulative stressors, and potentially catastrophic incidents, to local salmon populations already affected by degraded marine and freshwater habitat, climate warming, hatcheries, and over-fishing.

Salmon runs in the Kitimat region[283] contribute to commercial pink and chum fisheries, and recreational coho and Chinook fisheries.[284] Most of these salmon runs are depressed relative to their abundance several decades earlier, particularly wild populations of chum, sockeye, Chinook, and coho.[285] The proposed industrial oil activities in Kitimat Arm, especially when combined with other current and proposed developments, will further degrade the estuary as well as key salmon rearing and spawning habitats. These activities will also affect other species and process that are integral to the food web that supports young salmon.

Essential salmon habitat

Juvenile salmon experience the highest growth rates of their lives while in estuaries and nearshore waters. The US federal government has defined and mapped Essential Fish Habitat under the Magnuson-Stevens Act for all five species of Pacific salmon within watersheds, rivers, estuaries, and marine shorelines. In coastal marine waters, US definitions mean that nearly every estuary, river mouth, slough, bay, foreshore and extended shoreline from California to Alaska are classified as *Essential Fish Habitat* for salmon. Although still falling short of adequate protection, the designation underscores the importance of these habitats to wild salmon.

Extensive armouring and dyking of the northwest side of the Kitimat estuary and lower Kitimat River have changed historical flow and circulation patterns, and removed productive shoreline habitat.[293]

Aerial view of Kitimat River estuary.

Figure 6.1. General locations of remaining eelgrass in Kitimat Arm based on surveys conducted since 2002.[294] Eelgrass in the upper estuary is now at an estimated 10% of its historical presence.[295]

Figure 6.2
Six vegetation biobands (species assemblages) that contribute to *Essential Fish Habitat* for juvenile salmon in Kitimat Arm and estuary. Dominant species within these biobands are: soft brown kelp, bull kelp, red algae, saltmarsh, eelgrass, and sedges.

The Kitimat estuary

The Kitimat River estuary has provided critical nursery and rearing habitat to many species of fish, birds, and wildlife. It is one of the five largest estuaries in northern BC and considered one of the nine most important estuaries on Canada's west coast. Properly, the Kitimat estuary extends from the highest tidal influence up-river to the point where seawater is diluted by freshwater in lower Kitimat Arm.

Unfortunately, the combined stressors of forestry, urbanization, and heavy industry[287] have cumulatively and extensively degraded the estuary since the 1950s. In addition to excessive sediment loading,[288] chemical inputs (including PAHs, fluorides, sulphur dioxide, and metals),[289] and other pollutants[290] have led to chronic deposition of contaminants into the intertidal and sub-tidal portions of the estuary, exposing young salmon to a suite of pollutants.[291]

Furthermore, these industrial operations have changed many of the properties, features, and processes within the lower Kitimat River and estuary, impairing the ability of this important habitat to support healthy populations of salmon and other fish species.[292]

Figure 6.1

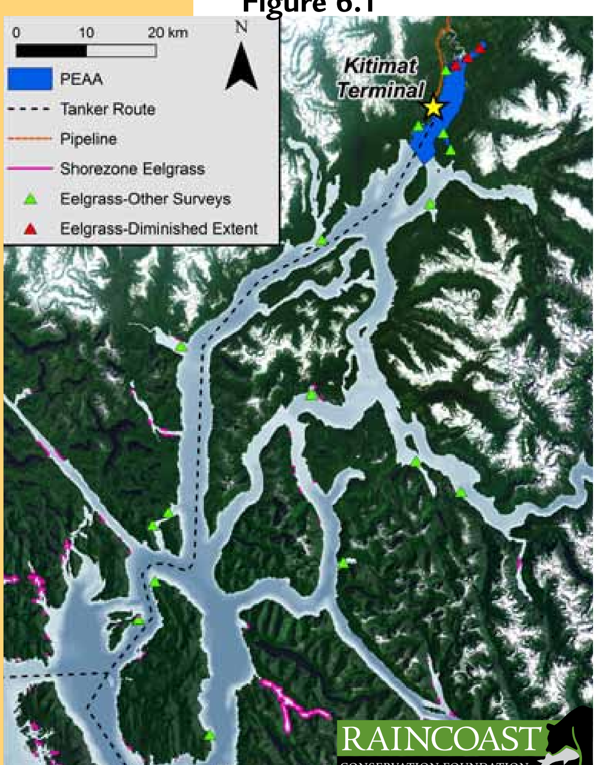
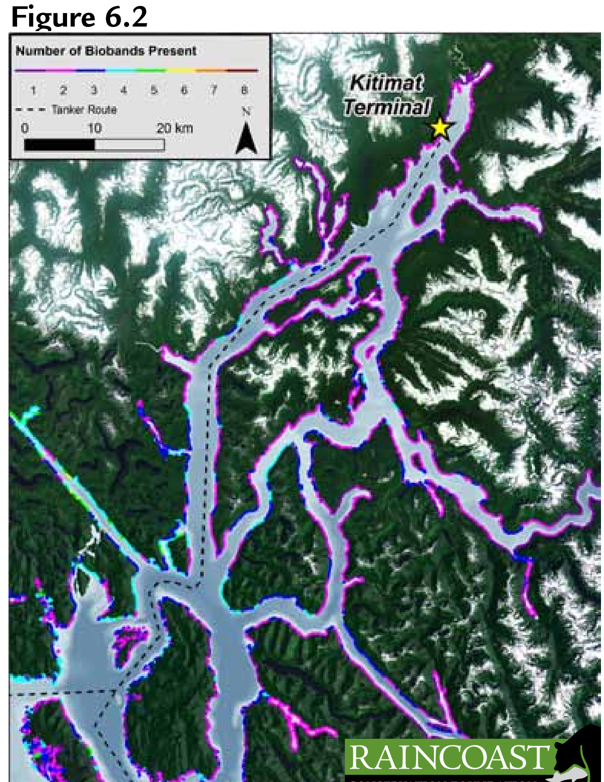


Figure 6.2



Unacceptable loss of salmon habitat

Enbridge estimates that three hectares of marine shoreline and 110 hectares of forest will be destroyed during construction for the marine oil terminal.[300] This will affect kelp communities within Kitimat Arm and Douglas Channel,[301] with potential impacts to saltmarsh and eelgrass habitats in Bish Cove, upper Kitimat estuary, and sites north and south of Kildala Arm.

Short- and long-term impacts from construction and operational activities will likely increase suspended sediments, decrease oxygen concentrations, contribute chronic and episodic chemical pollutants, generate wake action from ships, and create underwater noise; all of which will cause loss and degradation of critical habitat for juvenile salmon.

Sensitive habitats

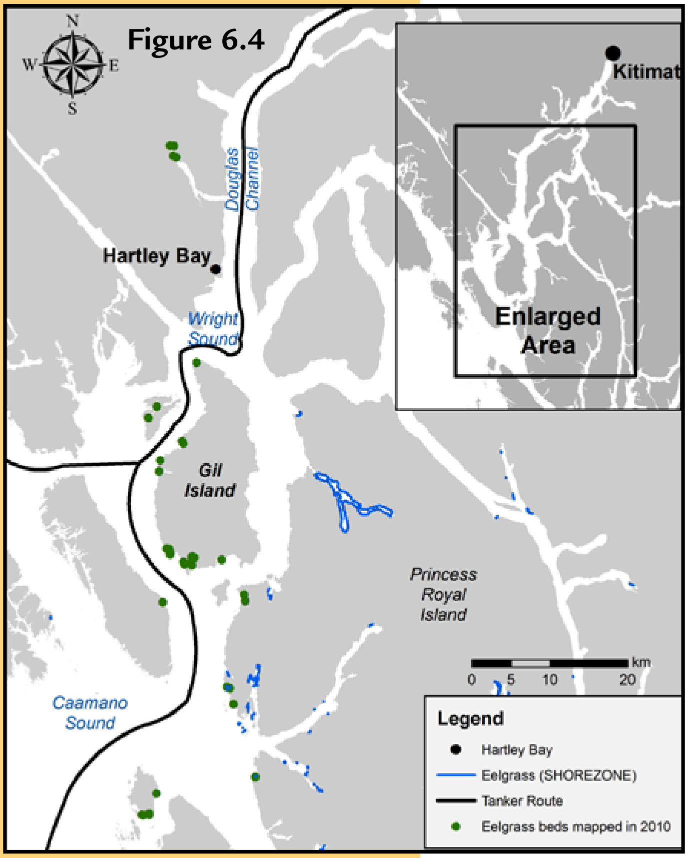
Estuaries, kelp, saltmarsh, eelgrass, and rockweed communities found in foreshore zones of Kitimat Arm are productive habitats that serve as nurseries for young salmon, and offer shelter, food, and protection from predators.[296] These plant communities support other juvenile fish and shellfish associated with salmon food webs, and are critical to maintaining processes at the base of marine food webs.[297] These communities also provide other benefits by reducing the action of waves and filtering freshwater run-off.[298]

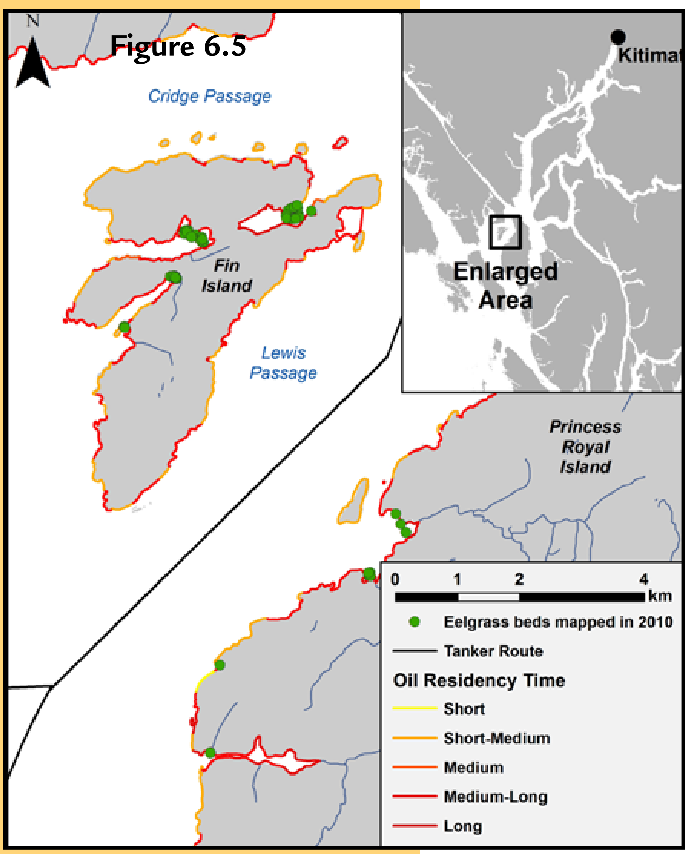
Kitimat Arm is used year-round by salmon. Adult pink, chum, coho, Chinook, and sockeye use its marine waters from July through October during spawning migration to freshwater streams. The eggs and larvae of pink and chum salmon are present in intertidal gravel from late summer through to the following spring.

From March onward, hundreds of thousands of young salmon leave the streams and rivers of Kitimat Arm and seek its shallow shoreline waters. While most juvenile salmon leave their streams during April and May, outmigration for Chinook can begin as early as February. Young salmon remain in coastal inlets, bays, and estuaries for many months.[299]

The importance of foreshore habitat.

The foreshore zone provides important nursery and rearing habitat for a wide variety of fish, including salmon. These areas provide food and protection for young salmon that recently entered the marine environment, as well as those that remain in near-shore environments for weeks to months as they mature. Although generally very productive, near-shore environments are usually the communities most affected by oil spills. Photo: Shutterstock





Impacts to eelgrass

The abundance and distribution of eelgrass in the Kitimat estuary has declined dramatically over the past 50 years. Specifically, estuarine eelgrass is now at an estimated 10% of the abundance observed in the 1970s.[302] Eelgrass is highly sensitive to increased sediments, where even settlement of fine particles on blades can lead to mortality from decreased photosynthesis.[303] Eelgrass can also be damaged by the mechanical impacts of waves and ship-wake action.

In 2010, Raincoast and partners[304] surveyed eelgrass beds outside Kitimat Arm and along the tanker route as it passes through Wright Sound (Figure 6.4). Our fieldwork found many eelgrass beds near the proposed tanker route that were not identified in common datasets. These habitats would be highly susceptible to oiling and tanker wakes. When the oil-retention time[305] of the shoreline material is considered along with eelgrass beds (Figure 6.5), most are associated with shorelines that have medium to long-term oil residency in the event of a spill. This highlights the importance of comprehensively mapping critical habitats like eelgrass beds, from the perspective of both spill response and environmental impact.

Figure 6.4 Eelgrass habitats documented along selected regions of the tanker route in 2010 confirm that much more eelgrass is present than the SHOREZONE[306] mapping database identifies.

Figure 6.5 Oil residency time, which ranks the likely persistence of oil based on shoreline materials, is mapped with eelgrass habitat along the tanker route. Soft sediments have longer residence times than rock.

In Kitimat Arm and its 15+ streams and rivers with estuarine salmon habitat, salmon eggs, embryos, larvae, fry, smolts, or adults are present year-round and vulnerable to nearshore, foreshore, and upriver activities throughout this entire period. PHOTO: K. SWANN

Terminal impacts to salmon health and habitat

Large oil spills are only one risk that Northern Gateway poses to salmon. Construction and operation of the tank farm and marine terminal present immediate and long-term threats to salmon habitat and physical injury to salmon and salmon eggs, regardless of a large spill. These impacts come from increased levels of suspended solids, redistribution and mobilization of heavily contaminated sediment, chronic oiling and associated declines in water quality, wake impacts, noise and vibration, and the potential introduction of invasive species.

Suspended solids are particles that contribute to water turbidity and oxygen availability. Construction of the tank terminal will include the clearing of 110 hectares of forest (270 acres), which will generate 3,000,000 m^3 of 'waste' (2,400 acre ft).[307] This scale of operation will create high surface water run-off, which will carry sediment and possible pollutants into Kitimat Arm. Suspended sediments are often accompanied by excessive nutrients, which can lead to overproduction of organic matter and result in cloudy water that blocks sunlight and consumes oxygen.

Table 6.1 Summary of known salmon populations that rely on the lower reaches of freshwater rivers, streams, estuarine, and nearshore marine habitats in Kitimat Arm.[308] These essential habitats for salmon are vulnerable to chronic and episodic oiling, increased suspended sediments, and degraded water quality

Stream Name	coho	chum	pink	Chinook	sockeye	steelhead	cutthroat	Dolly Varden
Bish Creek	x	x	x	x		x		
Emsley Creek	x	x	x				x	x
Minette Bay Creek	x		x					
Eagle Bay Creek	x	x	x					x
Cordella Creek	x		x					
Wathlsto Creek		x	x					
Dala River	x	x	x	x		x		x
Big Tilhorn Creek	x	x	x	x				
Kildalla River	x	x	x	x			x	x
Hugh Creek	x	x	x		x			
Pike Creek	x	x	x		x			
Kitimat River	x	x	x	x	x	x	x	x
Falls River	x	x	x			x	x	
Kihess Creek	x	x	x					
Fosh River	x	x	x	x	x	x	x	

Dredging up a legacy of contamination

The construction of Enbridge's proposed terminal will require extensive dredging and blasting.[309] Poly Aromatic Hydrocarbons and other pollutants from heavy industry are already present in Kitimat Arm and its resident flatfish.[310] Flatfish from Kitimat Arm have been documented with PAH-associated liver disease and DNA damage.[311] Even though these fish have greater exposure to contaminated sediments due to their long residency time, salmon are exposed to PAHs in Kitimat Arm via prey consumption.

Poly Aromatic Hydrocarbon concentrations in juvenile salmon from Kitimat Arm have been reported at levels known to reduce disease resistance in wild populations.[312] Dredging will increase suspended sediment and re-mobilize hydrocarbon pollutants lying in bottom sediments, with the potential to form more toxic compounds, and ultimately deliver these toxins to salmon food webs.[313] Dredging can also affect the migration patterns of juvenile salmon because of noise, turbulence, and physical disturbance.[314] These disturbances should be considered cumulatively, as impacts associated with dredging may combine or interact synergistically with other processes.[315]

Given the choice, salmon will avoid areas disturbed with heavy sediment. Suspended sediments are known to negatively affect salmon health, migration, feeding, and habitat. Heavy sedimentation can injure the gills of salmon, increase stress, reduce growth, and cause mortality.[316] It can also destroy salmon food sources. Finally, suffocation can occur when silt deposits on incubating eggs in the spawning gravels.

Re-circulation of contaminated sediment

Poly Aromatic Hydrocarbons, copper, chromium, dioxins, and furans already exceed guidelines for sediment quality in Kitimat Arm.[321] Terminal construction and operation will likely increase the circulation of these pollutants and release weathered hydrocarbons from bottom sediments into circulation, introducing contaminated particles back into the food web.

Chronic oiling

Marine oil terminals pose the risk of longer-term pollution and chronic oiling. Most oil spills occur during terminal operations[317] and can represent a significant input of oil into the marine ecosystem. Even with the best of intentions and mitigation efforts, episodic and chronic oiling events almost always occur. Repeated over many years, in an already degraded environment, these cumulative impacts will further impede the recovery of depressed salmon populations and may precipitate the complete loss of wild salmon from polluted areas.

Once operational, surface water run-off (containing sediment and oil) from the tank farm and terminal will drain into Kitimat Arm. Although Enbridge plans to limit oil concentrations to below 15 ppm,[318] laboratory studies have shown components of crude oil are toxic to salmon and herring eggs at levels far below this limit.[319]

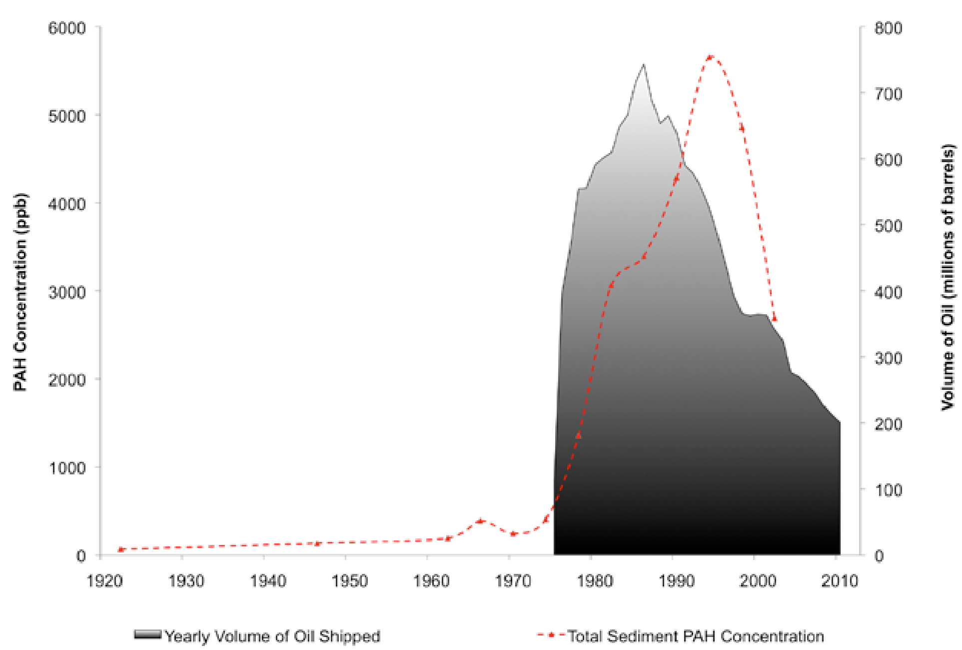
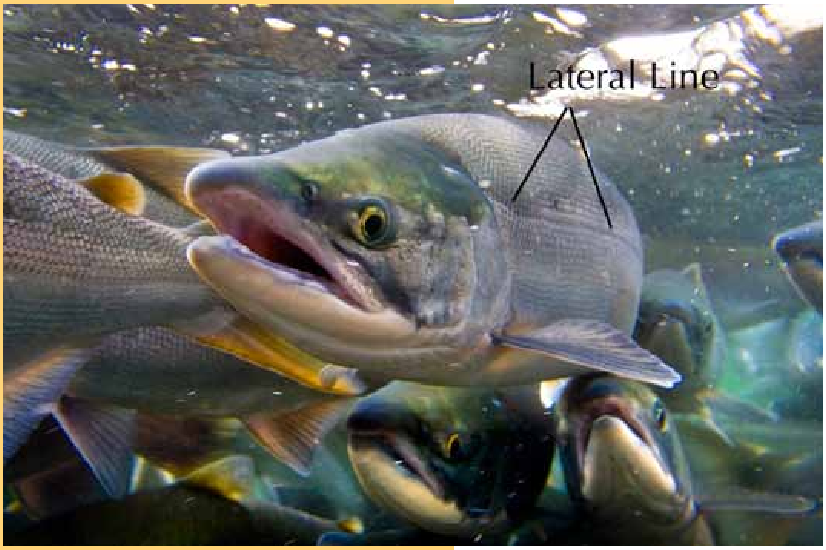


Figure 6.6 Studies from the Port of Valdez in Alaska show a clear correlation between levels of Poly Aromatic Hydrocarbons in sediment and volumes of oil shipped.[320]



The lateral line system on fish works in a similar manner to the human inner ear. By detecting changes in pressure waves, salmon identify predators, prey, communicate, and reproduce. Construction activities such as blasting, dredging, and drilling can interfere with fish sending and receiving the signals they need to thrive and survive.

Fish can hear too

Fish have hearing, balance, and vibration sensors that are important for detection of predators, identification of prey, reproduction, and protection of territory. Their primary vibration sensors are in the lateral line system along the sides of the fish. Background noises can mask signals that fish send and receive, so they tend to avoid areas disturbed by introduced noise.[322]

In general, little is known about how the range of sounds that accompany construction of the marine terminal will affect salmon. Explosive blasts can be fatal, and cause hearing impairment, physiological stress, and other harm, especially to swim bladders.[323] Enbridge did not assess how blasting or drilling might disturb or harm salmon, yet concluded that salmon will not be significantly affected by noise.

Acoustic impacts: many unknowns

Tugs and tankers will also introduce consistent sound disturbance. Although Enbridge has attempted some basic assessments, the thresholds where acoustic disturbance could affect salmon are uncertain, which limits Enbridge's ability to evaluate or dismiss the impacts.

Chum salmon rely on upwelling ground water for spawning and incubation.[324] Yet, the hydrology of upwelling ground water into stream gravel is highly complex and poorly understood. Activities such as blasting and drilling, which can potentially change the amount and quality of ground water that upwells, would likely affect chum salmon survival.[325]

Enbridge has identified water extraction plans for Bish Creek but provides no detail on predicted volumes, extraction location or timing.[329] Water extraction represents a significant threat to salmon habitat. Bish Creek supports pink, chum, coho, Chinook and steelhead salmon. The adjacent Bish Cove is being transformed from its current forest, nearshore and foreshore habitat to the Kitimat LNG facility (photo), which contributes to cumulative ecosystem effects. Photo: bearcreekcontracting.ca

Risky business: inadequate studies and a poor reputation

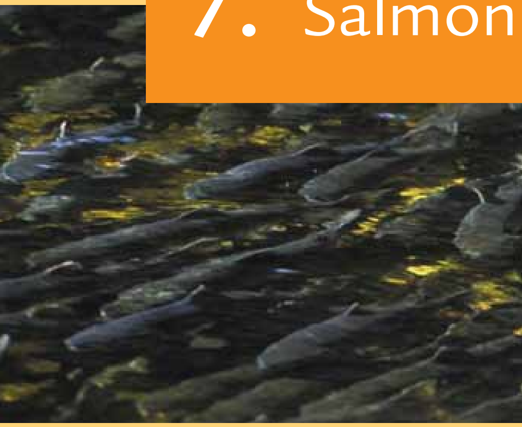
Ultimately, Enbridge is speculating that their construction and operations will not affect salmon or their habitat. Their conclusions are based on limited studies, selective data, and unsupported claims.[326] Enbridge also assumes that their mitigation measures will be fully implemented and work effectively. However, their track record demonstrates otherwise.

Serious failures in meeting regulatory requirements,[327] deficient management, poorly trained employees, and sub-standard safety and performance standards have been identified in reviews of Enbridge's operations.[328] While fines for destroyed habitat can be levied, the value of the original habitat for local salmon populations is irreplaceable. The construction and operation of the oil facility will almost certainly damage rearing habitat for juvenile salmon and migrating adults over a much wider area than simply the footprint of the marine terminal.

Enbridge's track record

In 2009, Wisconsin's Department of Justice settled a lawsuit with Enbridge after filing a complaint that documented more than 500 environmental violations, including 176 specifically relating to land disturbance and erosion control violations.[330] In 2012, the U.S. National Transportation Safety Board found deficient management, incompetent employees, inadequate safety and performance standards, and lax self-regulatory standards as factors contributing to the Kalamazoo River oil spill of July 2010.[331] Photo: wisconsin dept. of natural resources

7. Salmon at Risk



Before the Exxon spill, biologists assumed that harm and injury to wildlife from oil spills were almost exclusively from acute mortality.[333] The Exxon spill, however, demonstrated that unexpected persistence of toxic sub-surface oil could hinder species recovery for decades. Substantial amounts of research carried out after the spill resulted in significant changes in oil toxicity standards for fish and other aquatic life.

The *Exxon Valdez* oil spill occurred in a biogeoclimatic region similar to the coast of BC. Thus, specific insights were gained that are particularly relevant and applicable to region. These include the persistence of crude oil in cold-water habitats and the sub-lethal effects of long-term exposure.[334]

Preface

The use and meaning of the word "risk" have been broadly construed and applied. Risk has been incorporated into everything from consideration of daily activities and choices to finance and engineering. The many inconsistent and ambiguous meanings attached to risk have lead to widespread confusion, resulting in very different approaches to the management of risk in different fields. For the purposes of environmental assessment, risk is the potential of loss resulting from a given action, activity and/or inaction, foreseen or unforeseen.

By definition, "risk" is distinct from uncertainty and threat, both of which generally lack a measurable evaluation of their consequence. Quantified risks (also known as expected values) provide information to evaluate and manage potential environmental hazards; they are the product of the probability of an event occurring multiplied by the expected harm caused by that event. Simply put, Risk = Probability × Consequence. This definition is used by risk consultants to Canada's federal government and Enbridge..[332]

Consequence

To this point, we have discussed factors that help us understand prospects for ecological harm to BC's salmon from a marine oil spill. We know that chronic and episodic oil spills have the potential for impairing salmon populations in serious, long-lasting, and unforeseen ways. These conclusions are derived from the well-documented consequences to Prince William Sound's pink and chum salmon following the *Exxon Valdez* Oil Spill, as well as supplementary studies that explained the toxicity, persistence, degradation, and oil exposure pathways to salmon.

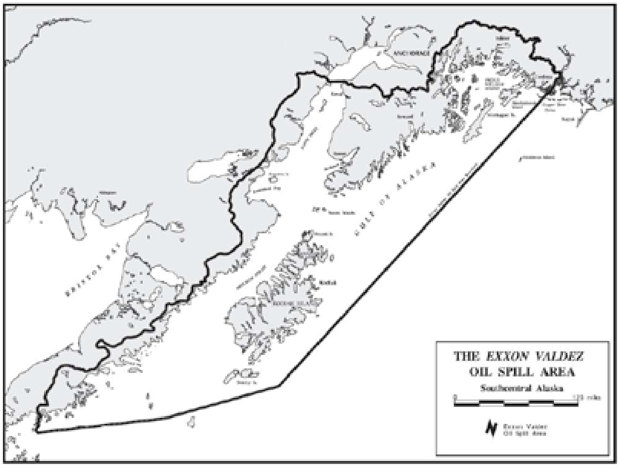
In addition, field and laboratory studies have provided insight into how oil spills might affect salmon species such as Chinook, sockeye, and coho that were not present in intertidal habitats or exposed to the most hazardous stages of the Exxon spill. Ingestion of contaminated food sources, reduced food supply, and lowered survival from loss of critical nearshore habitats are the primary routes for impacts to young salmon growing in nearshore waters.[335] In BC, the timing of salmon in these intertidal and estuarine environments may differ from Prince William Sound; thus, depending on the location and season of a spill, consequences to salmon may extend beyond pink and chum.

Locally, we know that regardless of a large oil spill, construction and operation of an oil terminal in Kitimat Arm would further degrade the area's essential estuarine habitat and stress populations that are already suffering substantial declines.

Caveats

Despite an increased understanding of the destructive consequences of oil spills, caveats on how the BC coast might be affected by a spill of diluted bitumen are warranted. First, a marine spill of a highly viscous petroleum product blended with a diluting agent has never occurred.[336] Therefore, we can only speculate about the behavior and pathways of diluted bitumen in the ocean and intertidal reaches of rivers.

Spills of petroleum oils, from heavy crudes to light refined products, can undergo a multitude of different behaviors and fates upon contacting the ocean, depending on the type of oil, its density, and the sea conditions during and following the spill (see Chapter 3). All of these will affect the exposure of salmon. Having a better understanding of how diluted bitumen behaves in seawater would also inform spill response. At present, the appropriateness of available cleanup technologies to reduce the harmful effects of a marine spill is unknown.



The boundaries of Raincoast's Spill Risk Assessment Area were derived from the size of the area affected by the *Exxon Valdez* oil spill in Alaska, shown above.

Figure 7.1 The polygon represents the 28,500-km^2 area in Alaska, overlaid onto the BC coast.

Nine crew members died in 2009 when a fully loaded tanker carrying 370,000 barrels of naphtha (condensate) collided with a charcoal-laden cargo ship in the Strait of Malacca.

Worst-case scenario

The U.S. Oil Protection Act, enacted following the 1989 *Exxon Valdez* oil spill, states that a facility response plan should be based on the worst case oil spill in the most adverse weather conditions. This has become the standard for environmental assessments worldwide. In comparison, Enbridge's maximum oil spill scenario is only 223,000 barrels or about one-tenth the volume of a fully loaded VLCC.[340]

For purposes of decision-making, contingency planning, and response preparedness, Enbridge's worst-case oil tanker scenario should have considered a fully loaded outbound VLCC colliding with a fully loaded inbound condensate tanker, with loss of both vessels and their cargo. This would have provided a much better understanding of the potential environmental impact and the spill response requirements.

Finally, the recovery of Prince William Sound's salmon populations occurred under conditions where habitat was pristine and human stressors minimal. The situation in BC is decidedly different, where the rebuilding of wild salmon populations from the current depressed levels is meeting with limited success. We can expect that in the case of an oil spill, multiple stressors -from climate change to many forms of habitat destruction and degradation (see Chapter 8) – will conspire synergistically or cumulatively with oil exposure to seriously impair salmon populations.

The spill risk area: identification of "at risk" salmon populations

Our identification of salmon populations at risk to a catastrophic oil spill began with the use of the Queen Charlotte Basin by commercially recognized salmon species. The vulnerability of the streams and salmon populations within this region were determined based on a potential zone of influence from a theoretical marine spill occurring along the tanker route proposed by Enbridge for the Northern Gateway Project. We based the geographic influence and extent of the spill on the size of the area affected by the *Exxon Valdez* spill (Figure 7.1). Although the most seriously affected area of Alaska was Prince William Sound, crude oil spread more than 750 km (466 mi) to the southwest and contaminated 1,990 km (1,180 mi) of shoreline.[337]

Within the Queen Charlotte Basin, resident and transient adult salmon originate from within and outside the Basin.[338] Also present are juveniles that dwell from a few days to many months in estuaries and other nearshore habitats before migrating northward. The Basin is also an important feeding ground and critical migratory corridor for salmon populations from southern BC, and the US Pacific northwest.[339]

Assessing the risk to salmon in the Queen Charlotte Basin

Enbridge's 'risk' analysis for the Northern Gateway project, (the Marine Shipping Quantitative Risk Analysis) estimates the *probability* of an oil spill occurring in locations along the proposed tanker route and the resulting economic consequences of the hypothetical spill for Enbridge (e.g. damaged or lost tankers). Remarkably, the possible environmental and social *consequences* of such an event are not included in their assessment.

Lacking such an assessment by Enbridge, Raincoast carried out a *limited* quantitative risk assessment that evaluated the potential environmental impact of marine tanker spills to commercially important salmon occurring within the Queen Charlotte Basin. Our risk considerations were for a *marine* (including *intertidal*) spill only and ignored the threats to freshwater ecosystems from a pipeline spill. A full risk assessment to salmon would consider both.

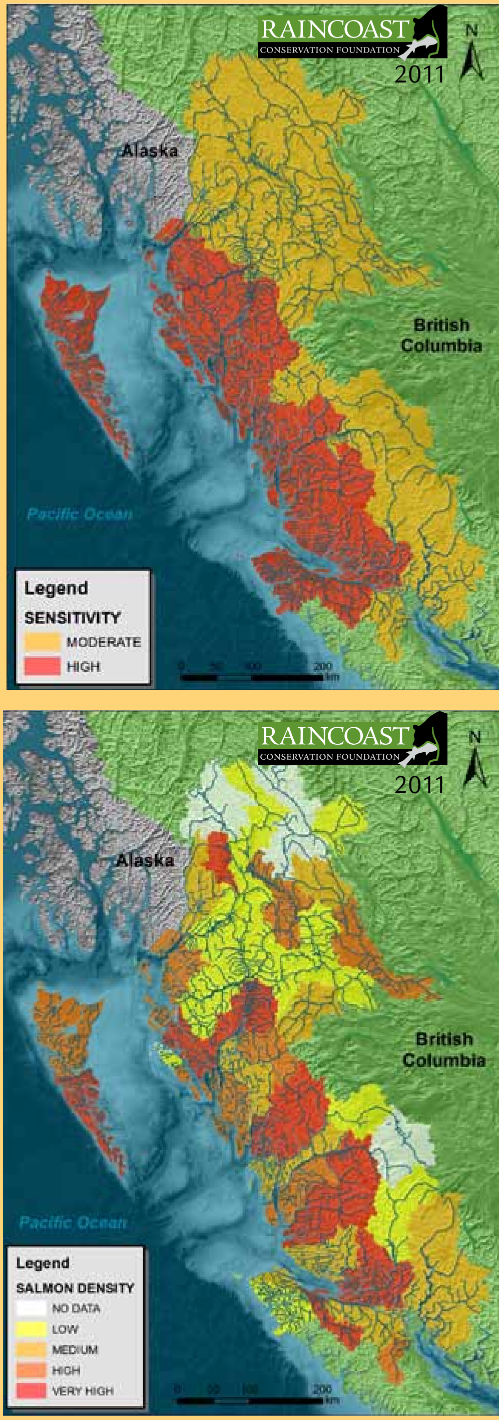


Figure 7.2. (a) Vulnerability of salmon watersheds based on potential impact of an oil spill on spawning and rearing habitat (red), or rearing habitat only (yellow), and (b) ranked density of salmon.

Assessing consequence

We assumed that impacts to the natural variability in density and distribution of salmon were a proxy for consequence. The consequence portion of our assessment, therefore, comprised two factors: vulnerability of habitat used by salmon, and the density of salmon in an individual watershed. The vulnerability of a watershed was assigned high consequence for those where spawning and rearing habitat for salmon would both be affected by an oil spill, and medium for salmon from watersheds where only rearing habitat would be affected (Figure 7.2b).

The density of salmon in a watershed was determined using the relative salmon biomass of consistently enumerated streams from Fisheries and Oceans Canada NuSEDS database.[341] Watersheds with infrequent enumeration were ranked based on available data. All data were then quartile ranked (Figure 7.2a.).

The two indices of salmon consequence were then combined; vulnerability of spawning and rearing habitat to oil spills, and salmon abundance based on density within watersheds (using relative biomass; Figure 7.4a).

Worst-case terminal spill

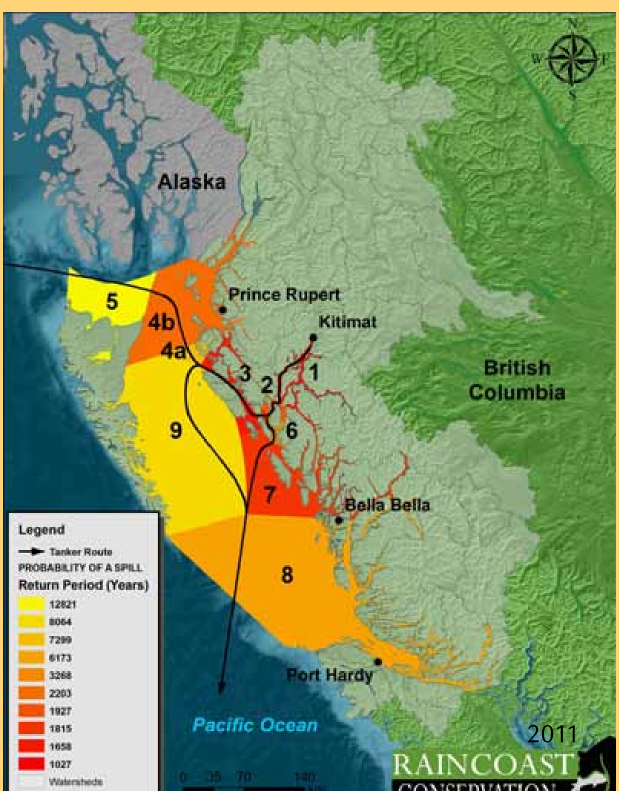
In addition to not considering a worst-case tanker accident, Enbridge did not consider a worst-case oil terminal spill. A 2013 explosion in Qingduo, China from a leaking Synopec pipeline killed 55 people and spilled an undetermined quantity of oil into JIaozhou Bay.[342] This is China's second deadly oil terminal explosion with a marine oil spill in three years.

Assessing probability

We quantified the probability of a spill occurring near the shoreline of a particular watershed using Enbridge's proposed tanker routes[343] and assigned hazard probabilities for specific route segments as provided in Enbridge's Marine Shipping Quantitative Risk Analysis Technical Data Report.[344] Segment probabilities were then extended geographically to create polygons with a uniform value (Figure 7.3). Our use of Enbridge's probabilities is not an endorsement of their validity.

Salmon density and distribution, combined with the probability for a spill, provide a method for quantifying risk.[345] In this type of analysis, watersheds with low and medium salmon density can have higher risk associated with them because of their presence in a high probability spill zone. Equally, watersheds with lower probability for an oil spill can be elevated to higher risk because of the high consequence ranking (Figure 7.4b).

Figure 7.3. Enbridge's probabilities of an oil spill in the 10 segments of the oil tanker routes to and from the Kitimat Marine Terminal. Enbridge's highest risk areas are in the inside approaches to Kitimat from Hecate Strait and within the confined channels areas of the tanker route.



Raincoast's risk assessment contains five steps

1. Identify the vulnerability of salmon based on the proximity of their habitat to an oil spill. Primary watersheds are more vulnerable because they have both spawning habitat and marine rearing habitat. Salmon that spawn in upper watersheds only have rearing habitat at risk. 'High' and 'moderate' are the two rankings for vulnerability (Figure 7.2a.).
2. Identify the density of salmon populations from these watersheds. There are four rankings from 'low' to 'high' (Figure 7.2 b).
3. Combine the vulnerability and the density rankings into one category called 'consequence' (Figure 7.4a).
4. Assign Enbridge's spill probabilities to all segments of the tanker route (Figure 7.3).
5. Combine all of these rankings together into one risk option (Figure 7.4b).

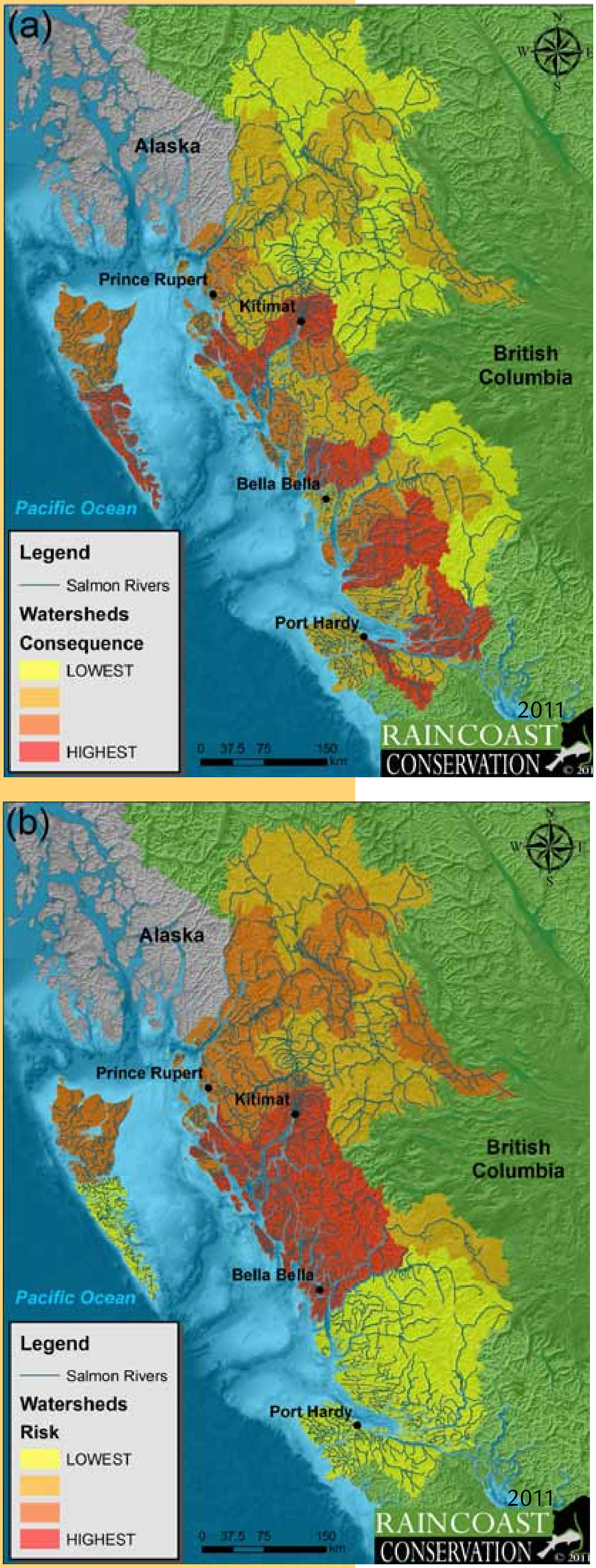


Figure 7.4b shows that BC's watersheds and salmon populations at the greatest risk from a marine oil spill are those situated along the confined channel tanker route from Kitimat to Hecate Strait, north to the entrance of the Skeena estuary, and down the central coast to south of Bella Bella.

This exercise is illustrative of an elementary risk assessment using ecologically appropriate indices. This is the type of evaluation that Enbridge failed to undertake; a serious inadequacy in their environmental impact assessment. A comprehensive risk assessment would include many additional factors (e.g., animal use of intertidal zones, archaeological sites, social values, cultural values, and economic values like ecotourism or fisheries), each assigned values and then related to the probability of a spill. Such an assessment would more effectively portray the true risks to the regions surrounding the project footprint.

Figure 7.4 (a) Combined map of oil spill consequence to salmon in the watersheds of the Queen Charlotte Basin. Areas of highest consequence (red) and lowest (blue) are displayed according to the density of spawning salmon within watersheds and their vulnerability to oil exposure in nearshore juvenile marine rearing habitat and intertidal spawning grounds.

Figure 7.4 (b) Risk is displayed from highest (red) to lowest (blue) based on consequence x probability of a spill. Probability of an oil spill was taken from Enbridge's Marine Shipping Quantitative Risk Assessment.[346]

8. Cumulative Effects

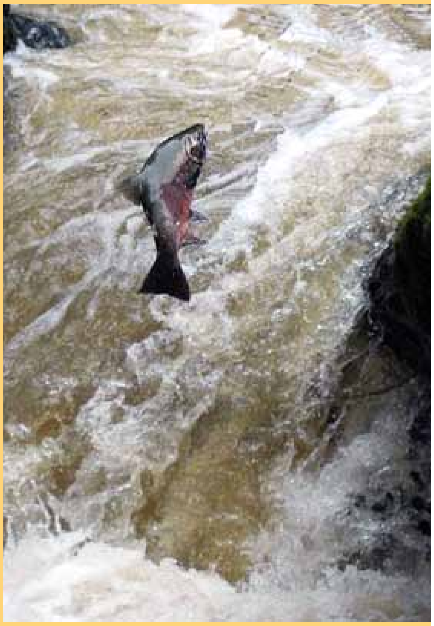
The death of many bottlenose dolphins after the 2010 *Deepwater Horizon* oil spill is an example of cumulative effects that manifested with oil exposure. The combination of cold weather, reduced food supply (linked to the oil spill), and increased freshwater inputs are the likely cause for the large number of sick and dying dolphins. Healthy animals likely would have been able to withstand these individual changes and stress.[349]

Ocean conditions were once the primary force that determined abundance and survival of Pacific salmon. Over the past century, however, the abundance and persistence of wild salmon have become entwined with the presence and intensity of human activities. The ability for small, seemingly independent actions, to combine into large consequences over the long term is the essence of cumulative effects. As salmon wane and disappear from their historic ranges, their diversity – the collection of unique adaptations to each river – also declines. Salmon populations with lower diversity are less resilient to stressors such as disease, pollution, or changing climate, and the risk of extinction is increased.

In the US, cumulative effects are defined as those that result from the incremental impact of an action when added to other past, present, and future actions, regardless of what agency or person undertakes them.[347] In Canada, Cumulative Effects Assessments were legislated in 1995 under the federal Canadian Environmental Assessment Act (CEAA). However, the breadth and effectiveness of Canadian legislation, especially CEAA, has come into question recently due to many failings to protect diverse and valuable ecosystem components.[348]

Cumulative effects facing salmon in Queen Charlotte Basin

Cumulative effects emerge when single events compound; the combined effects of which are often greater than the sum of their parts.[350] The removal of marine life, changes to watershed hydrology and habitat, destruction of natural shorelines, compromised estuaries, chemical and biological pollution, introduced species, pathogens and subsequent diseases, and increasing carbon dioxide (CO_2) inputs may be independently and cumulatively acting to compromise salmon survival at all stages of their life.[351]



Resilience is the capacity to recover from or withstand stressors; an important factor for the persistence of salmon. Photo: P. Bouley

Loss and decline in salmon abundance has implications for wildlife and ecosystem processes that rely on salmon.[352] Herein, with an emphasis on climate change, we highlight some of the current and growing cumulative threats facing salmon.

Habitat loss

The loss of natural shoreline features (everything from trees and fallen logs to marshes and grasses) along with changes to water quality and quantity, are all forms of habitat destruction.[353] In addition, watershed urbanization can change hydrology so that rivers no longer support self-sustaining salmon populations. Physical destruction by dredging, excavation, armouring waterfront (from erosion), and construction all eliminate important foreshore habitat in streams, rivers, and lakes. The same is true at sea, where the conversion of natural foreshore features (like shallow embayments, sea grasses, and kelps) to docks, berths, and bulkheads eliminate places for young salmon to thrive.

Fishing pressure

Many salmon populations have been reduced in abundance by excessive fishing pressure that has existed over the past hundred years. For example, populations of Chinook and chum were orders of magnitude more abundant in the Queen Charlotte Basin

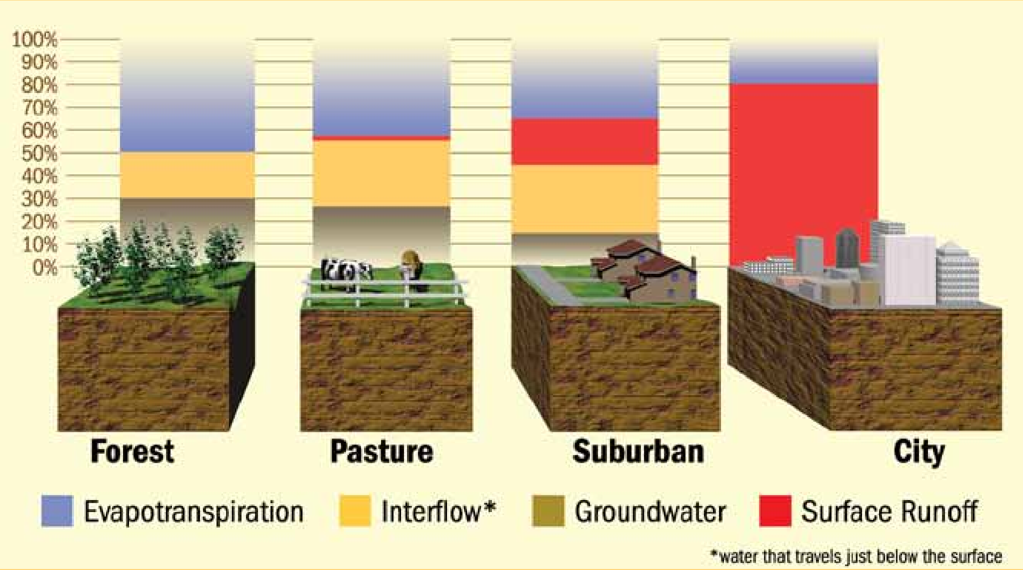


Figure 8.1 Changes to watershed function in relation to land-use. As land-use activities transition from natural to urbanized, irreparable damage occurs to salmon habitat. At less than 20% impervious surface coverage (i.e., roads, parking lots, and buildings), there can be an accompanying 90% loss of salmon.[354] Graphic: King County, WA

during the early 20th century.[355] Although levels of exploitation have declined over the last 20 years, the ghosts of past overfishing persist.

Today's salmon harvest problems, however, are more tightly associated with overfishing in mixed-stock fisheries that capture non-targeted (usually wild) populations when they co-migrate with stronger (often enhanced) populations. Ongoing pressure has driven most wild salmon populations below their historic levels, especially those from less productive runs.[356]

Salmon aquaculture

Impacts to wild salmon from salmon fish farms in BC have been well documented, and include the transfer of pathogens (such as sea lice) from farmed to wild fish.[357] This occurs because the net-pens used to raise dense concentrations of salmon cannot contain pathogens and, often, the farmed fish themselves. These problems remain unaddressed as long as net-pens share the same fluid environment as wild salmon. The solution is to replace net-pens with closed-containment systems or move them to land. As of 2013, however, BC continues to host hundreds of net-pen salmon farms that are situated along the migration routes of wild salmon.

Salmon hatcheries and enhancement

Growing evidence suggests that the overreliance on salmon hatcheries and enhancement jeopardizes the diversity and resilience of wild salmon in several ways.[358] These include: interbreeding between enhanced salmon and wild salmon that results in lower genetic integrity and fitness, competition with wild salmon for limited food, and predation on young wild salmon.[359] Enhanced salmon may increase the transfer of pathogens to wild salmon,[360] and have the potential to replace wild salmon with no net increase in production.[361] Eliminating the negative influence of hatchery salmon is necessary to protect the wild salmon gene pool and rebuild wild populations.

Managing fisheries in changing climates

Fisheries models rely on past relationships between the number of spawning parents and their offspring to predict future salmon returns and set harvest levels. An educated guess at best, predicting future population size is inherently uncertain; it can lead to errors in estimates of abundance, and result in overfishing.[362] Over the last 20 years, dramatic shifts in ocean conditions have magnified this uncertainty, creating highly unpredictable salmon returns. Future climate warming effects will compound this and necessitate extremely precautionary fisheries.

Incidents like the 2010 release of sediment to the Tzoonie River from the upstream Independent Private Power facility highlight the unforeseen threats to salmon habitat.[364]
PHOTO: J. HERTIGER, SUNSHINE COAST CONSERVATION ASSOCIATION

Although human activities are largely responsible for declines in salmon abundance, climate warming may now exacerbate or even supersede these threats, particularly in the southern part of their natural range.– IUCN 2009

Run-of-the-river power projects

Independent Private Power (IPP) projects proposed for watersheds throughout BC threaten freshwater salmon habitat in much the same way that dams have so negatively affected wild salmon in the US Pacific Northwest.[363] Although proponents of these projects state that natural flow regimes will not be altered, IPP water diversions affect the timing of water flow in the diversion reach, as well as sediment transport, ramping rates, and water temperature – all critical aspects of freshwater habitat for salmon. Many of the IPP diversions overlap important spawning and rearing habitat, or are situated immediately upstream of important freshwater salmon habitat.

Ocean carrying capacity

Recent studies suggest that the north Pacific Ocean could be nearing the limit of its rearing capacity for salmon.[365] The annual release of billions of hatchery-reared fry (primarily chum and pink salmon)[366] is likely contributing to competition for food between hatchery and wild populations, and impeding the recovery of wild salmon. These competitive effects might not be limited to salmon. For example, the poor nutrition and impeded recovery of Pacific herring in Prince William Sound following the *Exxon Valdez* oil spill are believed to be the result of interactions with hatchery-reared pink salmon.[367]

Climate change

Temperature and moisture largely determine the distribution of species on Earth. Although the climate has changed throughout the history of our planet, the recent rate of change is of concern. A change in one aspect of either temperature or precipitation can initiate a cascade of responses, which can counteract or magnify the initial change.

Such interactions make it difficult to predict the specific effects that climate change may have, even if the general nature of the change is known. Ordinarily, we rely on the past for evidence to predict the future. But when the context for change is unprecedented, we must rely on our understanding of how temperature affects physical and ecological processes and their interactions.

We are certain that changes to our climate will occur (indeed, shifts in temperature and precipitation are already occurring),[368] but we are uncertain as to the timing and magnitude of changes, or the ecological responses, even at a regional scale.[369]

Stream temperatures

Temperature plays a critical role in the growth, distribution, migration, and survival of salmon. It influences the egg, juvenile, and adult stages of their freshwater residence, and can do so directly on their aquatic environment, or indirectly via influences to their food supply. Any changes to the timing, distribution, abundance, and/or nutritional condition of salmon may have implications for dozens of coastal species that depend on them.

For salmon, minor changes in water temperature of one or two degrees can be significant. The optimal freshwater temperature range for the growth and reproductive success of salmon is generally below 15°C.[370] Salmon streams that experience a weekly temperature above a species' upper tolerance are considered lost habitat.[371] Projections for the Columbia Basin suggest that temperature increases alone will render 40% of existing salmon habitat unsuitable by 2090; this transition is currently underway.[372]

Stream and snow pack changes

A one or two-degree temperature shift is all that is necessary to substantially alter streams that are fed by snow-pack or glaciers. Currently, glacial melt makes its most important contribution

Table 8.1: The optimal stream temperature range and maximum weekly upper tolerance limit for BC's five species of commercially managed salmon.

Species	**Chinook**	**Chum**	**Coho**	**Pink**	**Sockeye**
Optimal Temp	10–15°C	0–12°C	12–14°C	11–13°C	12–15°C
Upper limits[373]	24°C	19.8°C	23.4°C	21°C	~19°C[374]

Coping with climate change: why biological diversity matters

Scientists studying sockeye in the Fraser River watershed found differences in the cardio-respiratory capacity of salmon depending on where they were migrating within the watershed and the historical conditions along their respective routes.[375]

Salmon from populations with more challenging migration routes had greater aerobic scope, larger hearts, and better blood supply to the heart. Further, their optimal temperatures for aerobic, cardiac, and heart rate scopes were consistent with the river's historic temperature ranges.[376] The study underscores the importance of preserving local diversity because populations from one watershed area would not have the physiological adaptations to endure the thermal limits required in other parts of the watershed.

Photo: C.Cheadle/AllCanadaphotos.com

BC glaciers are retreating at rates unprecedented in the last 8,000 years.[379] The photo shows Garibaldi's Helm glacier in 1928 (above) and 2007 (below). The area of the main glacier has declined by 50% since 1996. However, the retreat to the glacier's current extent likely occurred several times in the past 11,000 years before entering the 'little ice age' of the Middle Ages.[380]
PHOTO ABOVE: GLACIERCHANGE.COM, BELOW, IWONA ERSKINE-KELLIE

to stream flow (in terms of water volume and cool temperatures) mid-summer to early fall when many salmon return to spawn. Climate models predict that precipitation will increasingly fall as rain, rather than snow, a change that shifts the spring/summer run-off timing.[377]

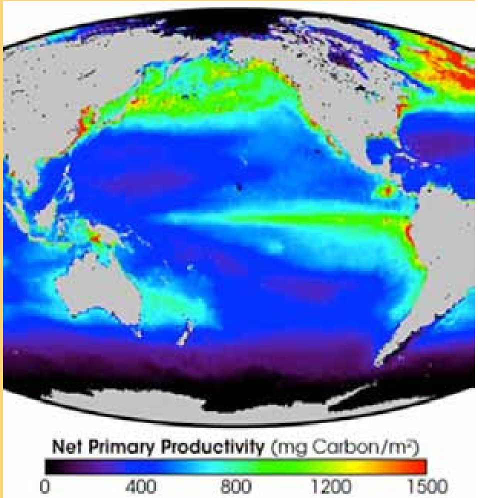
In glacial-driven systems, the snow-pack will diminish and increase peak flows initially (scouring eggs and fry), but decrease flows in the long term. Lower flows and higher temperatures will occur in the summer and fall, effectively reducing salmon habitat. Snowpack changes are evident across the mountain ranges of the west coast, and have been changing over the last 50 years.[378]

Other temperature impacts to salmon survival

Water temperatures above an optimum range stress salmon. Stressed fish have lower survival and are less likely to reach their spawning grounds. Thermal stress in salmon can affect thyroid function, increases the mobilization of stored toxicants[381] and increases their vulnerability to disease.[382] Warmer water temperatures can inhibit upstream spawning migration, or increase mortality en-route to spawning grounds.[383] In streams and lakes, warmer temperatures can trigger algae blooms,[384] reduce food availability, and make salmon habitats vulnerable to invasions by non-native species.[385]

Declining summer flows can also affect the chemical signature of a stream.[386] This has implications for the freshwater homing ability of salmon during their spawning migration.[387] The critical process of imprinting may depend on chemical characteristics of a particular stream remaining stable over time.

Food supply mismatches The Wannock River, draining Owikeno Lake into Rivers Inlet, is predominantly snowmelt driven, but rainfall also contributes to its winter runoff. Significant changes in the spring and summer run-off between the periods 1961-1990 and 1976-2005 are now evident.[388] Snow appears to be melting earlier, increasing flows in the spring, and leaving less run-off by the late summer. This shift, coupled with winds, may be contributing to early spring conditions in Rivers Inlet that influence the timing of plankton blooms and the subsequent food availability for juvenile sockeye after leaving Owikeno Lake.[389] Lack of food in the marine waters, and hence poor survival, has been identified as a probable cause for the impeded recovery of Rivers Inlet sockeye after their collapse in the 1990s.[390]



The importance of primary productivity

Primary production is the creation of energy from the sun, and release of CO_2 to the air and ocean, via photosynthesis. Phytoplankton are the primary producers of the ocean, as vascular plants are on land. All life on earth relies on them for food and CO_2. By far, most of the ocean's productivity occurs along the coasts. Our actions – from removing living creatures for food and altering the shoreline for human spaces, to the inputs of toxins and increases of CO_2 – affect the rate of primary production.

Ocean productivity

Winds, and their role in upwelling, downwelling, and the cycling of nutrients, drive primary production and influence salmon abundance.[391] BC's coast is dominated in winter by southerly winds that bring warm waters towards the coast and create downwelling (sinking of cold surface waters). In summer, weather is driven by northerly winds that bring cooler waters, which create up-welling (nutrient-rich deep waters are pulled to the surface).[392] Broadly, climate change is expected to decrease upwelling circulation.[393] Although no trends in upwelling or downwelling in the Queen Charlotte Basin are yet evident, more frequent shifts between El Niño (warmer) and La Niña (cooler) waters are now evident,[394] and downwelling winds have generally been stronger since the mid-1990s compared with the last 50 years.[395]

Stratification and acidification

Future climate warming scenarios, especially at high latitudes, predict increased temperature and reduced salinity in the upper ocean. They also predict increasing ocean acidity because of increased absorption of CO_2. The corresponding decline in density of surface waters due to increased temperatures and declines in salinity could decrease nutrients and oxygen concentrations at deeper depths, and ultimately reduce ocean productivity. These conditions have already been observed in the north Pacific Ocean.[396]

By the mid-1990s, the pH of the ocean's surface had declined from 8.2 to 8.1 (a 30% increase in acidity) from CO_2 emissions emitted over the previous 200 years.[397] Future predictions suggest that pH will decline another 0.3-0.4 units by the end of this century, which translates to a 100–150% increase in acidity.[398] An increase in acidity will likely reduce the availability of calcium carbonates, which marine organisms use to construct their hard shells and carbonate skeletons. This may adversely affect salmon by decreasing their food supply, or by increasing the number of predators that prey on juvenile salmon.[399]

The projection that warmer temperatures will cause more precipitation to fall as winter rain rather than snow (which is typically stored until the summer melt) is one of the most confident predictions of regional climate models, and is already evident in the Owikeeno and the Skeena watersheds.[410] Consequently, these rivers flow faster in the spring and slower in the summer. Coho, sockeye, and Chinook that spend extended time rearing in freshwater are expected to experience a large increase in stress from diminishing summer stream flows and higher temperatures.

Unknowns: sound and impacts from low frequency shipping noise

Water is an excellent medium for sound transmission because of its high molecular density. As such, sound travels about five times faster in water than through air, with wavelengths that are roughly five times longer.[400] Sound also attenuates less over the same distance. Consequently, sound travels much greater distances at higher amplitudes in water. In addition, sound will likely be affected by climate warming, travelling farther with less absorption (thus, louder), as oceans absorb more CO_2.[401]

Little is known about the effects of human generated sounds on fish. Even less is known about the impacts to developing eggs and embryos.[402] It is becoming clear however, that artificial underwater noise may not be benign.[403] Sub-lethal effects from underwater noise generated by shipping include: increased heart rate, metabolism, motility, and the secretion of stress hormones.[404]

Although the harm caused by short-term intense sounds like sonar, pile-driving, and explosions have attracted the most attention, research suggest that perhaps a larger impact on fish will be from less intense sounds, of longer duration, that have the potential to affect much larger areas.[405]

Most fish are able to detect sound within a hearing range between 100 and 500 Hz.[406] Sound produced by vessel traffic is more intense at low frequencies.[407] Enbridge's tankers will be emitting low frequency (100-200 Hz) at levels in the range of 175-180 dB.[408] According to Enbridge, this sound will be detectable by salmon and likely other marine fish up to 7-8 km (4-5 mi) from the marine terminal, and 4-6 km (2-2.7 mi) from the tanker route.[409]

Unfortunately, most of the Kitimat River salmon populations (Chinook, chum, coho, steelhead and cutthroat) are now enhanced by a hatchery, owing to declines in the 1970s of wild salmon. Given the recent reductions in funding from Fisheries and Oceans Canada, the hatchery's future is uncertain. Strong, wild salmon populations are the region's best investment in their salmon economy. A protected Kitimat estuary would be a vital step toward recovery of wild salmon, salmon habitat, and the salmon food web.

Photo: Issaquah Salmon Hatchery.

Kitimat Arm – salmon at the cross roads

Construction of an oil storage tank farm and marine shipping terminal in Kitimat Arm will likely have a significant impact on local salmon populations and their habitat in the short and long term. These negative influences represent steady cumulative stressors to the Kitimat River's salmon populations already degraded by extensive logging, urbanization, chemical contamination, structural and physical changes in the estuary, hatchery enhancement activities, and fishing pressure.[411]

Habitat conditions in the estuary will likely be further eroded by the construction and operation of the single approved, and numerous proposed, Liquefied Natural Gas terminals. At minimum, chronic oiling, remobilization of contaminated sediments, and increased suspended solids will accompany the proposed petrochemical activities, adding more stress to the ecological processes and structures that support rearing habitat for salmon, eulachon, and other forage fish.

Because the Kitimat estuary is critical for the recovery of these species, further declines in its health and ability to support young salmon might conspire in the near complete loss of wild salmon from this area. Given the impaired state of the estuary, activities that accompany construction and operation of an oil-shipping terminal impose additional stress on all these fish populations and their associated food webs. We believe that these considerations should weigh heavily on the decision to construct such a terminal.

9. Conclusion

Canada's Pacific salmon weave a connecting thread between land and sea, First Nation and western cultures, the past, and the future. Wild salmon are the economic and cultural underpinning to coastal people, and an ecological foundation species for wildlife and ecosystems. PHOTO: JEREMYKORESKI.COM

Priceless and irreplaceable

Salmon and the interconnected life forms that weave these fish through open ocean, nearshore waters, and into watersheds are the very soul of British Columbia. The prospect of losing our 'natural' identity compels us to think imaginatively and long term. We must radically embrace a different way of living with our planet while the opportunity to protect salmon and their coastal ecosystem still exists.

At what price?

Attaching a dollar value to the damage that spilled oil has on salmon ecosystems is impossible. The monetary cost of the *Exxon Valdez* spill is estimated at US $9.5 billion of which Exxon has paid $3.5 billion; taxpayers paid the remainder. British Petroleum claims to have spent US $14 billion on clean-up and restoration in the first two years following the Deep Water Horizon oil spill, but the true costs are unknown. Scientists have speculated that the full environmental consequences will not be understood for at least 40 years,[414] because the toxic effects from the huge volumes of dispersed oil, and the use of dispersants in deep water, are presently unknown.

A 2011 Angus Reid Public Opinion poll reported that salmon are as culturally significant to British Columbians as the French language is to Quebecers.[412] The poll further reported that British Columbians value salmon so highly that 86% of respondents agreed that: "Economic growth and development should not come at the expense of wild salmon habitat." This ranged from a low of 84% of voters who had voted Conservative in the last federal election, to a high of 92% of citizens who had voted Green – an astounding level of agreement.[413] PHOTO: G. KEHRIG

According to the Wilderness Tourism Association, salmon are the provider species for nearly one-half of BC's $1.5 billion in direct annual spending on nature tourism. Without them, viewing tours for whales, eagles, bears, and wolves, sport fishing and coastal cruises would vastly diminish, as would commercial fishing, fish processing, and our province's egotistic Super Natural BC brand. The self-sufficiency of, and social resilience by, numerous coastal communities are directly linked to wild salmon vitality.[416] Peter Ladner, Business in Vancouver Magazine.

Photo: T. Irvin

The question remains: can money truly replace the functional or total loss of a marine species, a productive ecosystem, or the demise of a coastal community's way of life?

From Raincoast's perspective, species and wild places warrant protection in their own right, regardless of the utilitarian value that healthy environments provide for people. Nonetheless, values compel us to safeguard species, including humans; all of which depend upon a healthy and ecologically rich environment.[415]

Failure to reconcile ecology and commerce has been a hallmark of international and domestic policy for decades. This is because a fundamental conflict exists between economic growth and conservation.[417] As the economy grows, natural capital (such as forest lands, soil, and water) is reallocated from wildlife to the human economy. Many believe technological progress may reconcile this conflict, but technological progress expands the breadth of the human niche and, when primarily in the service of economic growth, only exacerbates the conflict.[418]

A future of past abundance

Reconstruction of past catch and harvest records suggest that salmon abundance during the early 1900s was much higher than it is today. Roughly one-half million chum salmon are estimated to have returned to rivers of the north coast's Skeena watershed during 1916-1919, which is up to 50 times higher than the number of chum that return today.[419] A similar situation likely existed with Chinook salmon returning to the Fraser River, where between one-half and one million Chinook were caught annually in the early 20th century.[420] Implementing needed changes to fisheries management and securing protection of habitat would begin the rebuilding process for the Queen Charlotte Basin's more than 2,600 salmon runs.

Photo: BC Archives

The last hours of ancient sunlight. Photo: C. Tatu

Acute and chronic condition

As dreary as it is to contemplate, we must be candid about the status of BC's salmon populations. Analysis performed by Raincoast in 2013, which relied on national and global criteria for classifying *threatened* or *endangered* populations, reported that more than one-third of BC's 450 Conservation Units are either *threatened* or *endangered*. Most of BC's commercial and recreational fisheries now target hatchery or enhanced salmon populations, because wild runs are generally depleted. The depressed state of wild salmon has concurrent effects on wildlife, especially on iconic species like the spirit bear, grizzly bear and killer whale.[421]

Wild salmon experience a gauntlet of obstacles on the path to rebuilding their former abundance; habitat degradation, reduced prey availability, overfishing, disease, and a warming planet, top the list. The cumulative effects of these stressors are undoubtedly reducing salmon productivity and diminishing their inherent resilience. With the exception of unfolding climate change, these stressors are within our ability to mitigate. The choice to extract, ship and burn tar sands oil, will affect salmon years from now. This is also within our ability to decide. To continue on the current trajectory will worsen climate warming,

As natural capital is converted to monetary capital, the world economy grows at the expense and exclusion of all other species and habitats. Photo G.Lenz and diminish our future ability to recover already depressed wild salmon populations in BC.

The concerns we have are not new, nor are the problems that precipitated them. They are, however, a powerful argument in favour of a radically different course of action. Solutions to our energy and growth problems are everywhere if we make the collective, individual, and political choices to implement them. Opening the door to these solutions begins with saying 'no' to converting our coast to an energy corridor and being the catalyst for the unbridled exploitation of our land, oceans, freshwater, and climate that accompanies tar sands extraction. From here, other protective and restorative actions can be taken, so the priceless and irreplaceable BC coast can continue its unparalleled evolutionary journey.

Photo: C. Cheadle/ allcanadaphotos.com

Endnotes

1 Hyatt et al. 2007 including: 131 pink, 94 coho, 67 chum, 55 sockeye, and 36 Chinook populations.
2 2600 salmon runs were identified in Areas 3-10 by Price et al. 2008; Thomson and MacDuffee 2002.
3 Cederholm et al. 2000, Piccolo et al. 2009, Darimont et al. 2010, Hocking and Reynolds 2011.
4 Hyatt et al. 2007.
5 IBM Business Consulting Services 2006.
6 5,573 spawning populations in Fisheries Management Areas 1-12 and 27 in DFO SEDS database 1952-2008; Hyatt et al. 2007.
7 Hyatt et al. 2007.
8 8 Simenstad and Cordell 2000, Healey 1982a, Simenstad 1982.
9 Peterson et al. 2003, Rice et al. 2001, Carls et al. 2001.
10 Rice 1985.
11 Koski 2004.
12 Poly-aromatic hydrocarbons are potent pollutants that consist of fused aromatic rings. PAHs occur in oil, coal, and tar deposits. Some are known carcinogenic, mutagenic, and teratogenic compounds. See Ch. 4 & 5 this report.
13 Carls and Meador 2009.
14 Peterson et al. 2003.
15 Short and Neckles 1999.
16 Pearson and Skalski 2011.
17 Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Polycyclic Aromatic Hydrocarbons.
18 Savoie et al. 2006.
19 This is not an endorsement of their validity.
20 Wood 2001.
21 Hyatt et al. 2007, Riddell 1993.
22 Holtby and Ciruna 2007.
23 Welch et al. 2011.
24 SCSA 2007 Economic Report http://www.leg.bc.ca/cmt/38thparl/session-3/aquaculture/reports/Rpt-AQUACULTURE-38-3-Volume2-2007-MAY-16.pdf (Dec.03 2013)
25 Hyatt et al. 2007.
26 Simenstad and Cordell 2000, Healey 1982, Simenstad et al. 1982.
27 Levings et al. 1986.
28 5,573 spawning populations in Fisheries Management Areas 1-12 and 27 in DFO's SEDS database. See also Hyatt et al. 2007.
29 Aro and Shepard 1967.
30 i.e. > 5,000 sockeye, > 20,000 pinks, > 10,000 chums, > 2,000 coho, and > 500 Chinook salmon
31 Hyatt et al. 2007.
32 These are salmon spawning populations within DFO's NuSEDS Areas 1-12; also see MacDuffee & Thomson 2002.
33 Garabaldi and Turner 2004.
34 Hilborn et al. 2003.
35 This number is somewhat arbitrary depending on where boundaries are drawn on Northern Vancouver Island and in Queen Charlotte Strait. Our boundary includes DFO Fisheries Mgmt Areas 1-12 & 27
36 Holtby and Ciruna 2007.
37 Holtby and Ciruna 2007.
38 Withler 1982, Lichatowich 1999, Wood 2001.
39 Schindler et al. 2010.
40 SEDS database for Areas 1-12 and 27 holds 1192 records of pink presence. Work by RCF (Temple 2007) has identified additional (uncatalogued) streams on BC's north and central coast;
41 Holtby and Ciruna 2007.
42 Darimont et al. 2010.
43 NOAA Fisheries Service 2005. http://alaskafisheries.noaa.gov/habitat/seis/final/Volume_II/Appendix_F.5.pdf. Last Accessed Dec. 06 2013.
44 NOAA Fisheries Service 2005.
45 Darimont et al. 2010.
46 Hanson et al. 2005, Ford and Ellis 2006.
47 Holtby and Ciruna 2007.
48 Holtby and Ciruna 2007.
49 Langer et al. 2010.
50 Pers. Comm. M. MacDuffee, RCF 2012.
51 Gresh et al. 2000.
52 Raincoast surveyed 218 small streams in Fisheries Management Areas 6, 7 and 8, 2004-2006 and found coho presence in 30 percent (n=65) of previously undocumented streams. See Temple 2007.
53 Holtby and Ciruna 2007.
54 Hyatt et al. 2007.
55 Ferguson, 2009.
56 Holtby and Ciruna 2007.
57 Ford et al. 2010.
58 Ford et al. 2011.
59 NOAA Fisheries Service 2005.
60 Koski 2009, Langer 2010. Also see WA Dept of Ecology. http://www.ecy.wa.gov/programs/sea/pugetsound/species/salmon_est.html#chinook. Accessed October 27, 2013
61 Greene et al. 2005.
62 Ben-David 1997, Crait et al. 2006
63 Darimont et al. 2008
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76 Ibid.
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79 NRC 1996, Hyatt et al. 2007, Krkosek et al. 2007. Also see technical reports/discussion papers of the Cohen Commission that address habitat, salmon ecology and salmon survival issues.
80 According to Wikipedia as cited in Syncrude's *The land we borrow*, Syncrude is the world's largest mine (by area) at 191 km^2.
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119 Wolfe et al. 2008.
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172 Larry Pynn, Vancouver Sun, November 23, 2012. Second B.C. shipping incident in two days heightens concerns over Enbridge Northern Gateway project.
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217 Carls and Thedinga 2010, Heintz et al. 1999, Heintz et al. 2000, Carls et al. 2005.
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219 Rice et al. in Spies 2007.
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221 organ deformities, delayed development, etc.
222 Harwell and Gentile 2006.
223 Heintz et al. 2007.
224 Heintz et al. 2011.
225 Hicken et al. 2011.
226 Marty et al. 1997a.
227 Rice et al. in Spies 2007.
228 Wertheimer et al. 1994.
229 Carls et al. 2005.
230 The cytochrome P450 enzyme system is a group of enzymes found in high

levels in the liver. These enzymes change many drugs and fat soluble substances into less toxic forms that are easier for the body to excrete.

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262 Marty 2008.

263 Hose et al. 1996, McGurk and Brown 1996.

264 Acoustic observations suggest that Pacific herring migrate to the surface at night to gulp air; Thorne and Thomas 1990, Thomas et al. 2007, Thorne and Thomas 2008.

265 Disease assessments (1993-2002) indicate viral hemorrhagic septicemia virus (VHSV) and associated ulcers were related to population declines in 1993/1994 and 1998; and *Ichthyophonus hoferi* was related to a population decline in 2001. Source: Marty et al. 2004.

266 Deriso et al. 2008.

267 Peterson et al. 2003.

268 Peterson et al. 2003.

269 A bibliography of the Exxon-Mobil funded research on EVOS is found at valdezsciences.com or http://www.raincoast.org/wp-content/uploads/ExxonMobil-Sponsored-Publications-Bibliography-for-www.valdezsciences.com_.pdf

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271 Dean and Jewett 2001.

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273 Over 45 fish species rely on eelgrass habitats with chum, pink and coho salmon and Pacific herring foremost among them. Johnson and Thedinga 2005.

274 Michael et al. 2003, Heck et al. 2003.

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279 Gomez-Gesteira and Dauvin 2005.

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282 Low sea otter abundance does not always have this effect, as was documented after EVOS.

283 Kitimat River, Kitimat Arm and Douglas Channel are all in DFO Fisheries Management Area 6.

284 This includes an Area 6 targeted chum gill net fishery in Kitimat Arm and a lucrative odd-year pink fishery near Gil Island. Commercial sock-eye are also retained in these fisheries. Chinook and coho returning to the Kitimat River are the target of the sport fishery.

285 Unpublished analysis by Rosernberger & MacDuffee, RCF, 2013.

286 *Essential fish habitat*, as defined under the US Magnuson- Stevens Act, means those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.

287 Including Alcan, Eurocan and the adjacent sawmill, Ocelot, Methanex, and the Kitimat sewage treatment plant.

288 Gottesfield (1985) *in* Karanka, E.J. 1993; Enbridge Northern Gateway Pipelines. 2010. Vol 6B; DFO, http://www.pac.dfo-mpo.gc.ca/sep-pmvs/projects-projets/kitimat/bg-rb-eng.htm, Accessed Dec 2 2011.

289 i.e., copper, lead, zinc, cadmium, mercury, aluminum and iron; see Enbridge 2010 6B.

290 Including pollutants associated with treated municipal sewage, potentially forestry related pesticides and chlorophenols, ocean dumping of dredged materials, and alteration to runoff characteristics (water quality and quantity) from logging, land clearing and development. Also see Macdonald 1983.

291 Johnson, et al. 2009.

292 Karanka 1993, Manzon and Marshall 1981.

293 Altered bedload and excessive sediment has been delivered to the estuary from upstream logging. Between 1953 and 1985, the delta of the Kitimat River advanced 300 metres further into the estuary. Estuary dyking has also affected the deposition of fine sediments that are important as substrate for incubation of several fish species, especially eulachon. The Kitimat sewage treatment plant, Alcan, Eurocan, and Methanex have also contributed to TSS loading in Kitimat Arm. The Kitimat hatchery has also armoured the eastern bank and built a weir that is impassable to eulachon; John Kelson, Personal Communication, Dec 2011.

294 Based on surveys conducted with underwater camera in Kitimat Arm between 2002 and 2008.

295 Kitimat Valley Naturalists. 2011. Marine Birds, Mammals and Kitimat Estuary. Submission to the NEB's Joint Review Panel on the Northern Gateway Hearings. December 2011.

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299 Particularly chum, ocean-type Chinook, ocean-type coho and river-type sock-eye.

300 Enbridge ESA Volume 6B, Page 8-12.

301 Including soft brown kelps, bull kelp and red algae. These biobands are identified by the ShoreZone Coastal Habitat Assessment and discussed in the Mapping Data Summary Report 2004-2008, Survey Area,

Southeast Alaska. Report prepared for NOAA. Data and information available at http://alaskafisheries.noaa.gov/shorezone/default.htm Accessed Dec 03 2013

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304 This was a partnership between the Gitga'at Lands and Resources Stewardship Society, SeaChange Marine Conservation Society and Raincoast Conservation Foundation to survey and map eelgrass habitats within Gitga'at Traditional Territory.

305 The length of time discharged oil persists on various substrates. Soft sediments such as mud, sand and gravels (vs rock) generally have the longest residence time. It is theses habitats where oil has lingered and persisted in Prince William Sound.

306 SHOREZONE is a BC government mapping assessment that classifies the physical character of the shore zone.

307 Enbridge. 2010. Volume 6A. Page 2-21 Sec. 52.

308 Source: MoE fish habitat database; DFO stream summary catalogue.

309 Volume 6A, Part1, Page 44.

310 Johannessen et al. 2007. Pollutants include heavy metals and organochlorines from the Alcan aluminum smelter, Eurocan Pulp and Paper, Methanex plant, and substances coming from sewage and storm water outflows.

311 Johnson et al. 2009.

312 Concentrations in bile and stomach contents of juvenile salmon from Alcan Harbour and the Hospital Beach sites had concentrations comparable to juvenile salmon from Puget Sound. See Johnson et al. 2009.

313 NOAA 2009.

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315 Dredging can reverse the normal oxidation/reduction potential of the sediments of an eelgrass system, which can reverse the entire nutrient-flow mechanics of the ecosystem.

316 Enbridge Volume 6B, page 271-272.

317 ITOPF 2011.

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319 Marty et al. 1997. Carls and Meador 2009; Heintz et al. 1999, Heintz et al. 2011.

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321 Enbridge ESA Volume 6B, Page 172.

322 Hastings and Popper 2005.

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324 NOAA 2005. Also see Watershed Watch review of groundwater-salmon interactions at http://www.sfu.ca/grow/science/resources/1273696130.pdf

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326 Enbridge Volume 6B, Page 3.

327 For a critique of Enbridge's salmon assessment see Raincoast's submission to the CEAA/ JRP processes. This document can be downloaded at http://www.raincoast.org/wp-content/uploads/Part-4-salmon.pdf.

328 See http://www.enbridge.com/AboutEnbridge/CorporateSocialResponsibility/~/media/www/Site%20Documents/About%20Enbridge/Corporate%20Social%20Responsibility/Reports/2010_Enbridge_CSR_Report.ashx Accessed Dec 10, 2013

329 US National Transportation Safety Board Review of Enbridge Inc pipeline spill in Michigan http://www.ntsb.gov/news/events/2012/marshall_mi/index.html Accessed July 29, 2012.

333 Essential fish habitat is defined by the US Magnuson-Stevens Act as "those waters [fresh and marine] and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity."

330 Internet source Accessed 25th October, 2011, http://www.wisconsinwetlands.org/Enbridge/EnbridgeListofViolations.pdf.; also see endnote source 328.

331 US National Transportation Safety Board Review of Enbridge Inc pipeline spill in Michigan http://www.ntsb.gov/news/events/2012/marshall_mi/index.html. Accessed July 29, 2012.

332 i.e. GENIVAR, who undertook Transport Canada's Risk Assessment for Marine Spills (2013), and SL Ross Env. Research who undertook Enbridge's tank test on the specific gravity of dilbit (2012). See www.slross.com/riskandplan/riskmain.htm (Dec 03, 2013) and www.tc.gc.ca/eng/marinesafety/menu-4100.htm#abs. Accessed Dec 09, 2013.

333 Peterson et al. 2003.

334 Peterson et al. 2003.

335 Semmens 2008, Bravender et al. 1999.

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337 Peterson et al. 2003.

338 Hyatt et al. 2007.

339 Hyatt et al. 2007.

340 General oil spill Response Plan, Enbridge Northern Gateway Pipeline Project. March 2011.

341 DFO website, online at <http://www.pac.dfo-mpo.gc.ca/gis-sig/maps-cartes-eng.htm>, Accessed December 10, 2011.

342 Internet source http://www.businessweek.com/news/2013-11-24/sinopec-s-qingdao-refinery-disrupted-as-blast-death-toll-rises. Accessed Dec 03 2013.

343 Enbridge Northern Gateway Pipelines. 2010. Exhibit B3-37 to B3-42 – Vol 8C - Gateway Application – Risk Assessment and Management of Spills – Marine Transportation - pg.3-3.

344 Enbridge Northern Gateway Pipelines. 2010. Exhibit B23-34 - Gateway Application – TERMPOL TDR Marine Shipping QRA - pg.8-122.

345 French-McCay 2011.

346 Enbridge Northern Gateway Pipelines. 2010. Exhibit B23–B34 - Gateway Application – TERMPOL TDR Marine Shipping Quantitative Risk Analysis – A1Z6L8, pg. 8-122.

347 US Council on Environmental Quality Guidelines, 1971.

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349 Carmichael et al. 2012.

350 Spaling and Smit 1993.

351 Lackey 2008, Wood 2001, NRC 1996, Slaney et al. 1996.

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363 Gower et al. 2012.

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386 Stahl et al. 2008.

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