OCEANWATCH

SPOTLIGHT

Pollution Hotspots in Killer Whale Habitat Pinpointed by New Conservation Tool

Ocean Wise, Lance Barrett-Lennard | *A southern resident killer whale leaps from the water.*

ocean wise®

AUTHORS Aroha Miller, Stephanie Braig, Kelsey Delisle, Peter Ross **REVIEWERS** Marie Noël, Amber Dearden, Jennifer Chapman, Lance Barrett-Lennard

Overview

Southern resident killer whales (SRKW, *Orcinus orca*) are a treasured sight along the Pacific coast of Canada and the United States (U.S.). Most commonly found off the coast of southern British Columbia (B.C.) and Washington State (W.A.), numbers of these iconic animals are dwindling. The SRKW population dropped to a low of 73 after four individuals were declared missing, presumed dead, in 2019 alone.

In 2001, due to their declining numbers, SRKW were listed as endangered in Canada. Threats to their future survival and recovery continue to mount. The most serious threats are:

- **reduced prey availability;**
- **disturbance and noise pollution from boats; and**
- **environmental contaminants (i.e., harmful chemicals that are accidentally or deliberately released into the environment).**

Many individuals and organizations have been working to bring SRKW back from the brink of population collapse. A key aspect of the SRKW Action Plan[1] involved the protection of critical habitat. Critical habitat includes important feeding grounds for SRKW, where they hunt for their primary prey – Chinook salmon (*Oncorhynchus tshawytscha*). If this critical habitat is destroyed or degraded, SRKW are unlikely to survive.

In 2015, the Ocean Wise Research Institute launched *PollutionTracker*, a conservation tool designed to monitor environmental contaminants in the marine environment along the entire B.C. coast. This novel initiative provides data about the concentration of contaminants in coastal habitats used by SRKW. Sediment samples were collected at over 50 sites along the B.C. coast, with 10 sites located in designated SRKW critical habitat.

Of a long list of potentially harmful contaminants, we describe results for polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and mercury. All are present coast wide. PCBs are highly persistent man-made chemicals that have been banned since the 1970s. There are thousands of different PAHs, which can come from human or natural sources. Mercury is a naturally occurring metal, but can also come from human sources. These three very different contaminant classes have the potential to cause negative health effects in killer whales and their prey – notably Chinook salmon – and their presence may be limiting the recovery of endangered SRKWs.

SRKW are among the world's most PCB-contaminated marine mammals.[2] Within SRKW habitat, significant contaminant hot spots were identified in urban harbours: Vancouver (Burrard Inlet), Prince Rupert and Victoria. Outside of these areas, however, concentrations of PCBs, PAHs and mercury in SRKW critical habitat are much lower. Nonetheless, even low levels of these contaminants in sediment can enter and accumulate in the marine food chain, resulting in high concentrations in SRKW and negative health effects.

While many threats to the survival and recovery of SRKW exist, impacts from environmental contaminants can be mitigated. Actions listed at the end of this report can be implemented to reduce levels of these contaminants in the marine environment and protect SRKW and their prey.

"PollutionTracker, a new Ocean Wise conservation tool, identified urban harbours in B.C. as key pollution hotspots in endangered SRKW habitat."

Ocean Wise | *PollutionTracker measures environmental contaminants in sediment and mussels all along the B.C. coast.*

Southern Resident Killer Whales

A cherished experience for people living along the coast of British Columbia (B.C., Canada) and Washington (W.A., United States [U.S.]) is the sight of tall, black, dorsal fins slicing through the water. Killer whales are highly intelligent, social marine mammals, with distinct vocal dialects, food preferences, and traditions.

Canadian waters are home to three distinct killer whale (*Orcinus orca*) groups: resident killer whales, offshore killer whales, and transient (Biggs) killer whales. Resident killer whales are divided into northern and southern populations, which do not interact or breed with each other.

SRKW live in waters off the Pacific coast of both Canada and the U.S. Their habitat range stretches from California in the south to Alaska in the north. They are most commonly found off the B.C. and W.A. coasts.

SRKW are piscivores, meaning they only eat fish. Their main prey is Chinook salmon (*Oncorhynchus tshawytscha*), which they eat year-round. They occasionally eat other fish species, such as chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), halibut (*Hippoglossus spp.*), and lingcod (*Ophiodon elongates*).[3]

SRKW live in three distinct social units called pods (J, K and L). Historically, each pod was made up of between 40 to 50 members. Individuals in each pod live together but interact with the other pods. The three pods have distinct but overlapping home ranges and dialects.[3]

Since 1976, the total SRKW population has fluctuated between 70 and 99 individuals. As of December 31st, 2019, there were only 73 SRKW remaining in the wild (22 in J pod, 17 in K pod and 34 in L pod), a concerning 30-year low.[4] In 2001, SRKW were listed as endangered under the Canadian Species at Risk Act.[5] In 2005, they were listed under the United States Endangered Species Act (ESA).[6]

Significant efforts are underway in both Canada and the U.S. to recover SRKW. This has involved the identification of SRKW critical habitat, which is legally protected from destruction under the Species at Risk Act. These areas are important feeding grounds, where SRKW seek out their preferred prey, Chinook salmon. Critical habitat is regularly used by all three pods. These areas are found within Haro Strait, Boundary Pass, the Strait of Georgia, and the Strait of Juan de Fuca,[5] spanning southern B.C. and Washington State (Figure 1).

In the mid-1970s, the SRKW population numbered almost 100. By the end of 2019, only 73 SRKW are known to be alive in the wild.

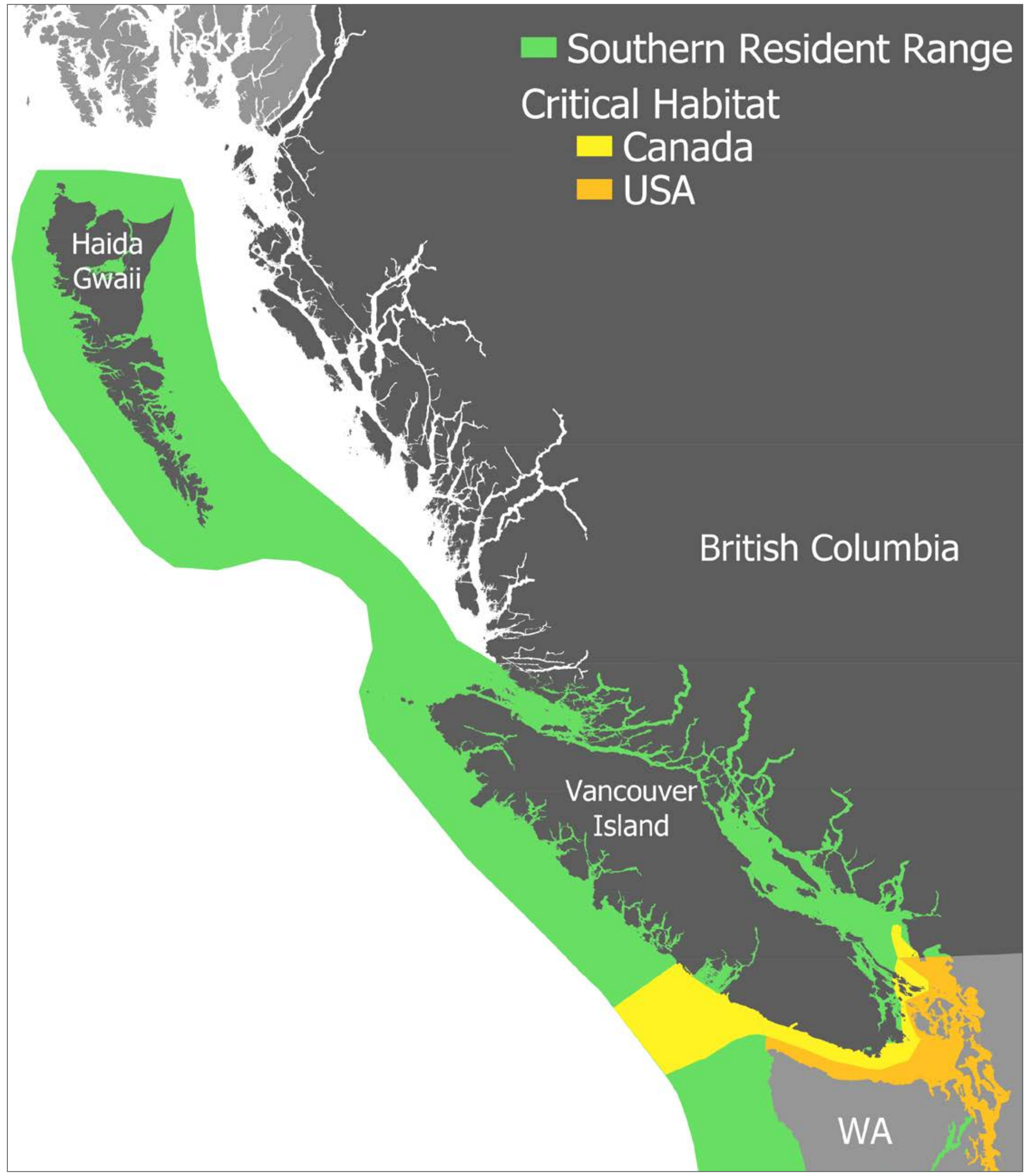


Figure 1. SRKW range (shown in green) with critical habitat shown in Canada (yellow) and the U.S. (orange).

Ocean Wise, Lance Barrett-Lennard | *A pod of southern resident killer whales traveling through British Columbian waters.*

Threat 1

Reduced Prey Availability

SRKW preferred prey is Chinook salmon. A high abundance of Chinook is essential to the survival of SRKW. In recent years, Chinook numbers have been declining because of:

- **habitat destruction**
- **overfishing and**
- **climate change.[7]**

Chinook habitat is negatively impacted by human activities, such as timber harvesting, agriculture, urbanization, and coastal modifications. Overfishing decreases the number and size of Chinook available as prey for SRKW, while climate change reduces salmon numbers.[5] Warming oceans and ocean acidification[i] result in less food being available for Chinook, which in turn means less adult Chinook available for SRKW.

[i] Ocean acidification – a decrease in pH of oceanic waters.

Bob Turner | *An adult chinook salmon navigating the waters of the Squamish River.*

Threat 2

Underwater Noise Pollution

Underwater noise from commercial shipping traffic, marine construction, recreational vessel use, and resource exploration and extraction (i.e., oil and gas) impacts SRKW. These noises interfere with their echolocation[ii] and communication space, a phenomenon known as acoustic masking.[8] Acoustic masking reduces whales' ability to find:

- **prey (Figure 2)**
- **mates and**
- **pod members**

resulting in increased stress and an increased risk of death.

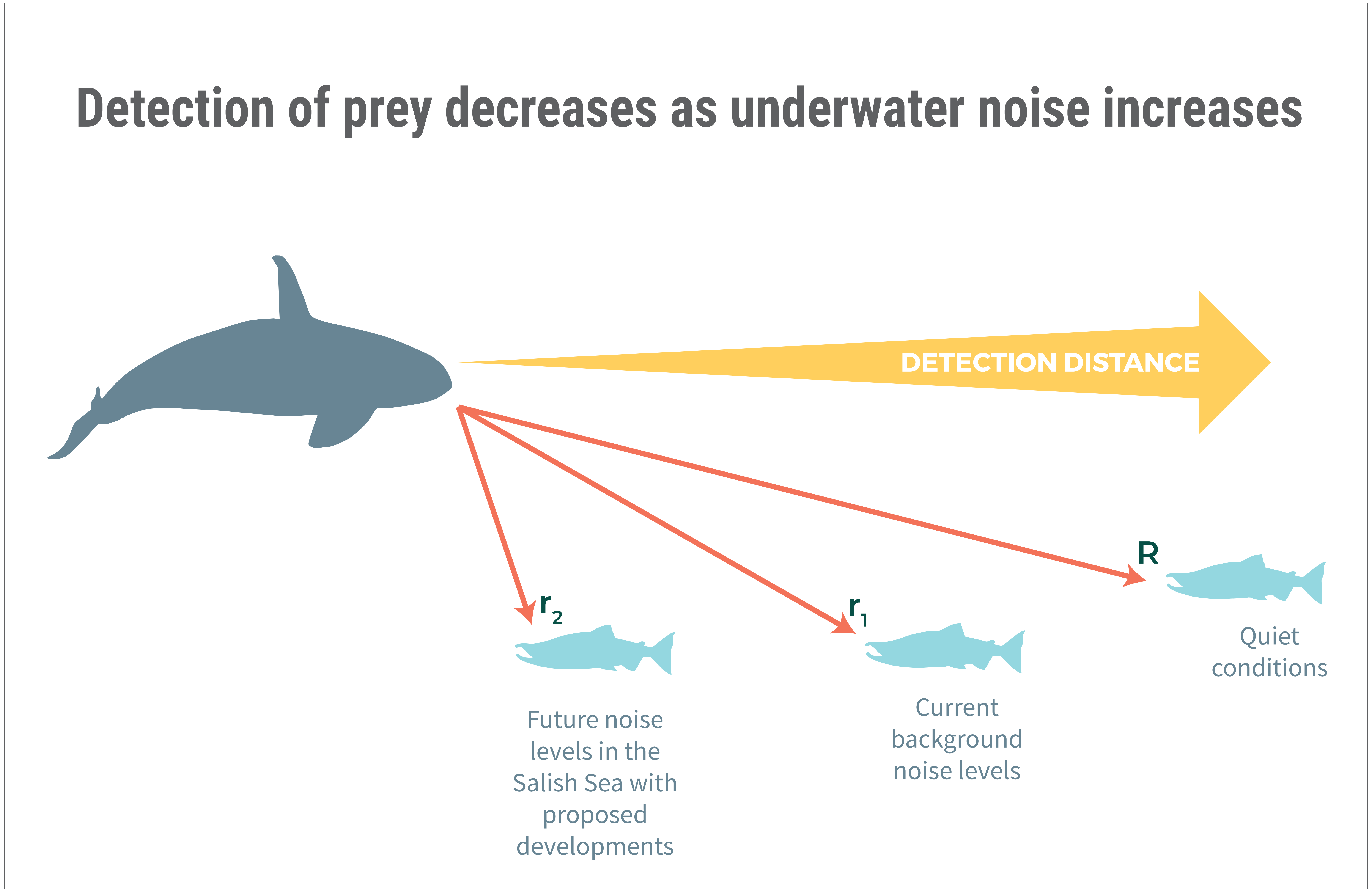


Figure 2. The hypothetical reduction in detection distance of prey for killer whales using echolocation under increasing underwater noise levels. R represents the detection distance under quiet conditions, r_1 represents the detection distance under current background noise levels, and r_2 represents the detection distance predicted to occur if noise levels increase in the future as a result of increased commercial shipping.[9]

[ii] Echolocation – location of objects using reflected sound.

Threat 3

High Levels of Environmental Contaminants

As top predators in the marine food chain, killer whales bioaccumulate,[iii] and in some cases biomagnify,[iv] high concentrations of certain contaminants in their body from their diet (Figure 3). For example Chinook salmon are a source of environmental contaminants to SRKW.[10] Environmental contaminants include the persistent organic pollutants (POPs). POPs are persistent, meaning they stay in the environment for a long time; bioaccumulative, meaning they can build up to high concentrations in body tissues; and toxic, meaning they can have negative health effects. These properties can lead to:

- **increased susceptibility to disease** [11,12]
- **reduced reproductive success**
- **hormonal imbalances and**
- **increased energetic costs** [13,14]

Contaminants are affecting the health of killer whales, and, alongside the other conservation threats noted above, contribute to declining SRKW numbers.[5]

In 2015, the Ocean Wise Research Institute launched *PollutionTracker*, a conservation tool to monitor contaminant levels in coastal sediments and mussels. The first of its kind, this comprehensive coastal monitoring tool was designed to provide insight into the state of killer whale habitats and develop solution-oriented actions. Sediment samples were collected at over 50 sites along the B.C. coast, with 10 sites located in SRKW critical habitat (Table 1). All contaminants discussed below were examined through PollutionTracker.

Sediment can act as both a contaminant sink (i.e., storage) and a source to the food web. PollutionTracker has shown that several contaminants, such as polychlorinated biphenyls (PCBs), are present coast-wide, including within SRKW critical habitat. PCBs, polycyclic aromatic hydrocarbons (PAHs), and mercury are three of the priority contaminants of concern to the recovery of the SKRW population. But how do these contaminants negatively impact SRKW health and survival? A comparison of these three contaminants is shown (Table 1).

"Only methylmercury, the most toxic form of mercury, can bioaccumulate and biomagnify up the food chain – Harding et al. 2018"

Ocean Wise, Lance Barrett-Lennard | *A southern resident killer whale spyhopping.*

[iii] Bioaccumulate – when an organism absorbs a contaminant from its food and/or the environment faster than it can excrete it, and the contaminant subsequently accumulates in its tissues.

[iv] Biomagnification – when the concentration of a contaminant increases as it moves up the food chain. This occurs when the contaminant either cannot be broken down by the organism and excreted, or it is broken down only very slowly. It is subsequently passed up the food chain more quickly than it is broken down or excreted.

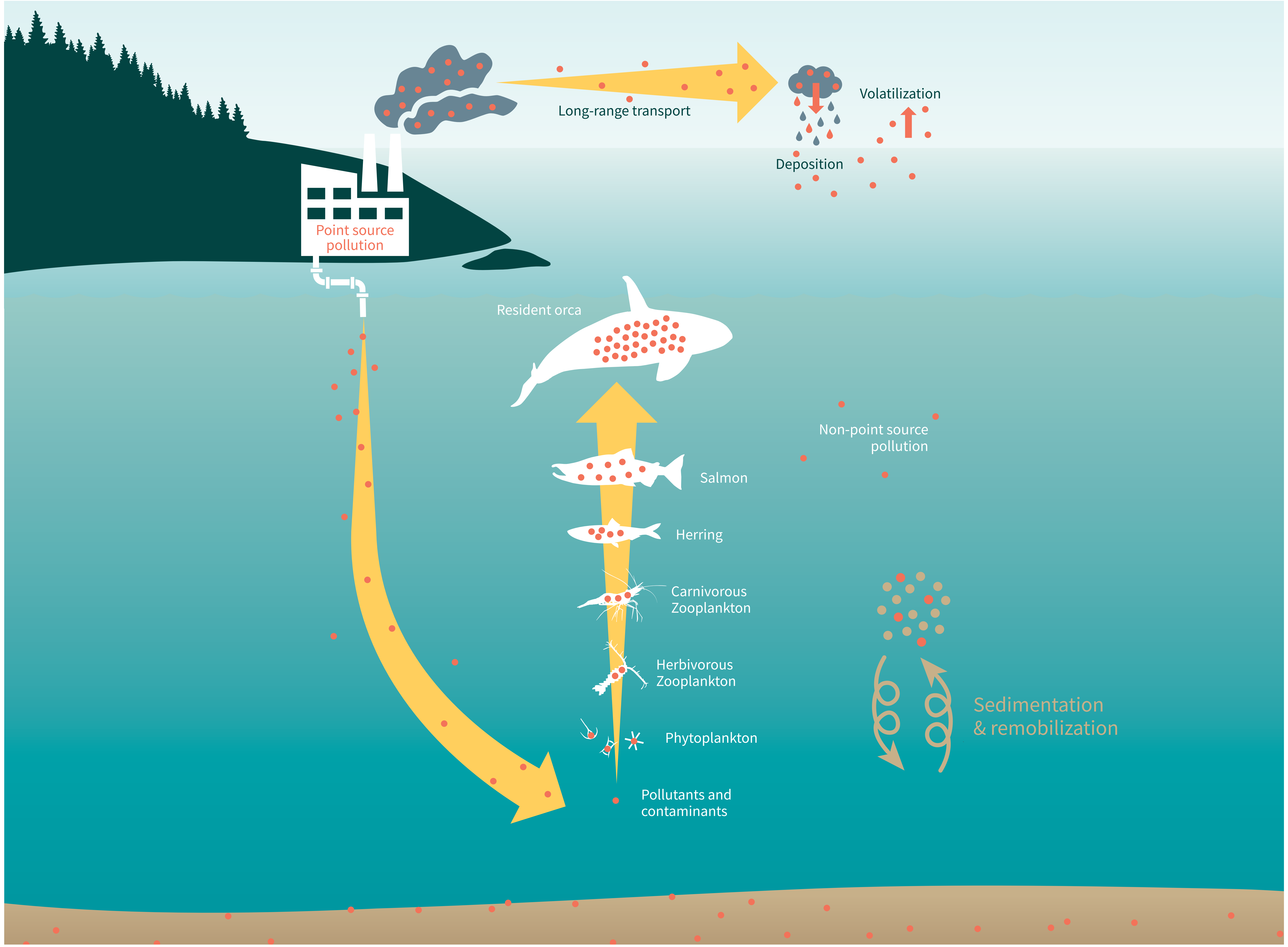
Table 1. A comparison of properties of the three environmental contaminants – polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and mercury (Hg – inorganic and organic forms).

	PCBs	PAHs	Mercury
Man made or natural?	Man made	Both	Both
Route of exposure	Primarily diet and nursing [5,15]	Diet[16] and inhalation[17]	Primarily diet and nursing, but also inhalation and through the skin[18]
Persistent	✔	✔	✔
Bioaccumulative (B)	✔	✔	B – *when present as methyl-mercury (organic form)*
Toxic	✔	✔	✔
Health impacts	Hormonal disruption, skeletal deformities, immunotoxicity, developmental and reproductive problems.[5]	Strongly suspected to affect growth, the immune system, reproduction and cancer. [19]	Neurotoxicity, liver toxicity and immunotoxicity[v]. It is a carcinogen. Methylmercury exposure can cause anorexia, loss of coordination, and eventually death.[20]
# of B.C. sites analysed by *PollutionTracker*	49	40	49

[v] Immunotoxicity – adverse effects on the functioning of the immune system caused by exposure to chemical substances.

Figure 3. PCBs and other environmental contaminants considered Persistent-Bioaccumulative-Toxic enter sediment and food webs. They can reach very high levels in species at the top of the food chain. These chemicals are highly problematic for killer whales that are at the top of the food chain.[21]

Bioaccumulation In Marine Mammals



SRKW are among the most PCB-contaminated cetaceans in the world. PCBs threaten the recovery of all B.C. killer whale populations (Ross et al. 2000).

Ocean Wise, Lance Barrett-Lennardj | *A pod of southern resident killer whales in British Columbian waters.*

Why Are PCBs An Issue?

PCBs were first produced in 1929. They were used as heat resistant fluids and additives in industrial materials such as:

- **plastics**
- **ink and paint additives**
- **carbonless copy paper and**
- **electrical equipment** [22,23]

It was not until years later that the negative health effects from PCB exposure were recognised.

PCBs are readily transported in the atmosphere from one continent to another. They are found in places where they have never been produced or used. Once PCBs enter the marine environment, they persist for a long time and do not easily breakdown. More than 30 years after PCBs were banned, they are still having negative effects on marine organisms.

PCBs accumulate in fatty tissues such as blubber. Killer whales accumulate high concentrations because they are long-lived and are top predators.

PCBs are found in high concentrations in transient, northern and southern resident killer whales, compared to marine mammals from other parts of the world.[5,13] PCBs in female SRKW are passed to calves during pregnancy and nursing (as much as 60 – 95%),[5,15] exposing calves to high PCB concentrations before they are even born.

Spotlight 1

Where are SRKW being exposed to PCBs?

Because sediments can contaminate food webs, PCB concentrations in sediments can be used to predict concentrations in killer whales. A modeling study showed that PCB concentrations in sediment from SRKW critical habitat could lead to concentrations in these animals that exceed PCB toxicity threshold concentrations reported for other marine mammals.[15]

Total PCB concentrations in sediments were relatively low in SRKW critical habitat compared to urban harbours. Concentrations in Victoria Harbour were especially high (Figure 4; maximum values shown).

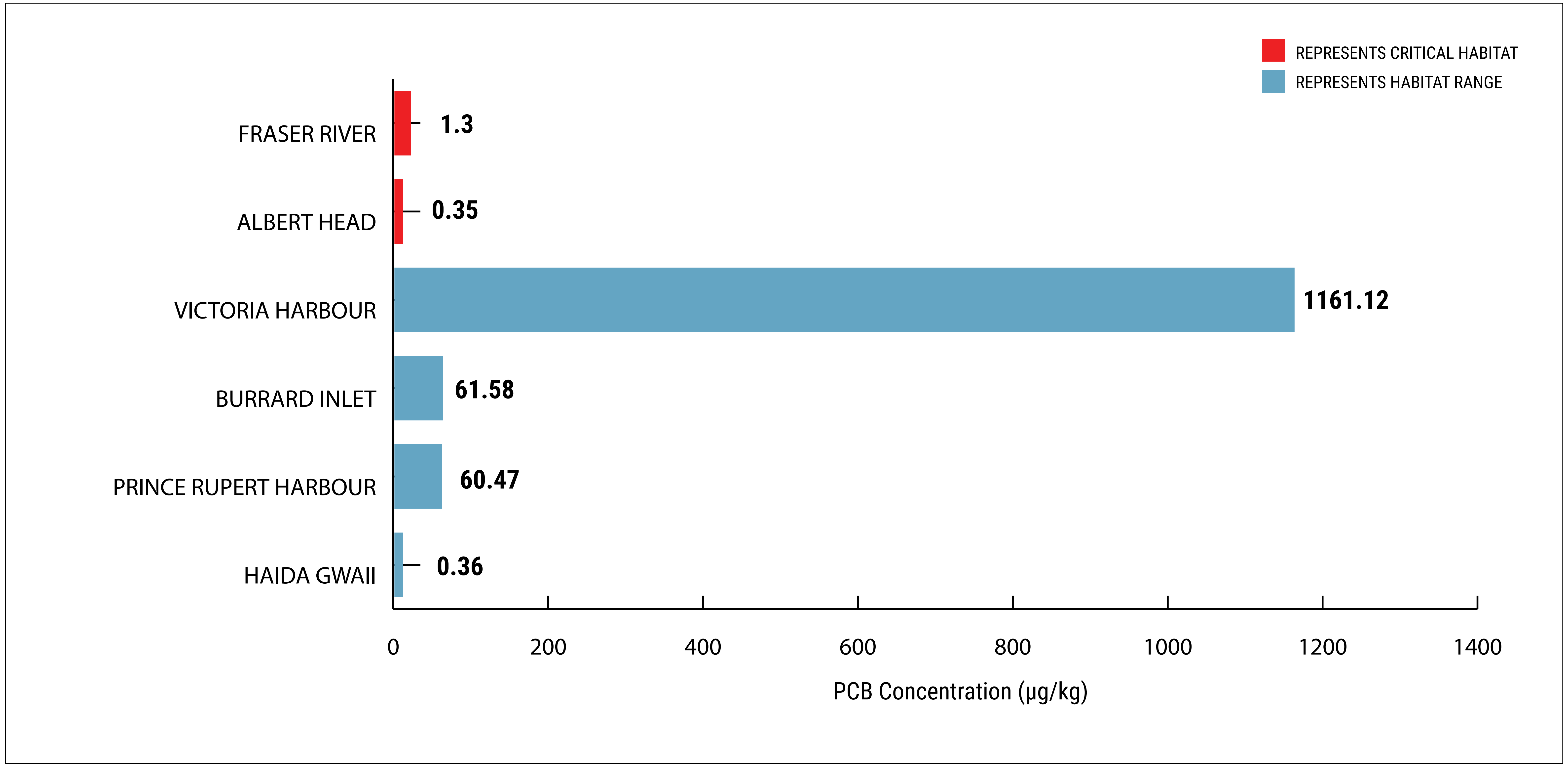


Figure 4. Maximum PCB concentrations detected in sediment from selected sites within critical habitat (red) or habitat range (blue).

Despite being banned in the 1970s, PCBs continue to pose a health risk to SRKW, in particular in or adjacent to urban harbours, where concentrations were high compared to more remote locations.

Ocean Wise, NOAA permit 19091 | *Individuals from a southern resident killer whale pod swim together.*

Why Are PAHs An Issue?

PAHs are a large, diverse group of substances produced naturally by forest fires and volcanoes, but also formed by human activities, such as burning fossil fuels.

PAHs are found virtually everywhere, but are generally highest in urban coastal areas, with high concentrations in sediment and marine organisms.[24] Most PAHs bind (i.e., adsorb[vi]) strongly to particles that are suspended in the water, then settle through the water column and into sediments.[24] They can be re-introduced into marine waters through sediment disturbance, such as from storms, the activities of marine animals or dredging. This presents a continuous source of contamination for marine species.[25]

SRKW are exposed to PAHs through their diet,[16] oil spills and engine fumes.[17] When SRKW surface near vessel traffic, PAHs from engine exhaust are inhaled and remain in their lungs for long periods while they are underwater.[17] Despite rules stipulating minimum approach distances, vessel traffic around cetaceans continues to increase.[26]

Spotlight 2

Where are SRKW being exposed to PAHs?

Walk along the edge of any marina and you will undoubtedly see the sheen of oil around moored vessels. In addition to frequent, small spills, a number of larger spills have occurred along the B.C. coast.

Two high profile spills have occurred in recent years along the B.C. coast.

- In 2015, the MV Marathassa released at least 2,700 litres of fuel oil into English Bay, Vancouver.[27,28]
- In 2016, the Nathan E. Stewart, a tug boat that ran aground near Bella Bella in northern B.C., released more than 110,000 litres of diesel and heavy oils.

PAH concentrations in sediments were highest in harbours, while concentrations from SRKW critical habitat and remote, non-urban areas were typically lower (Figure 5, maximum values shown).

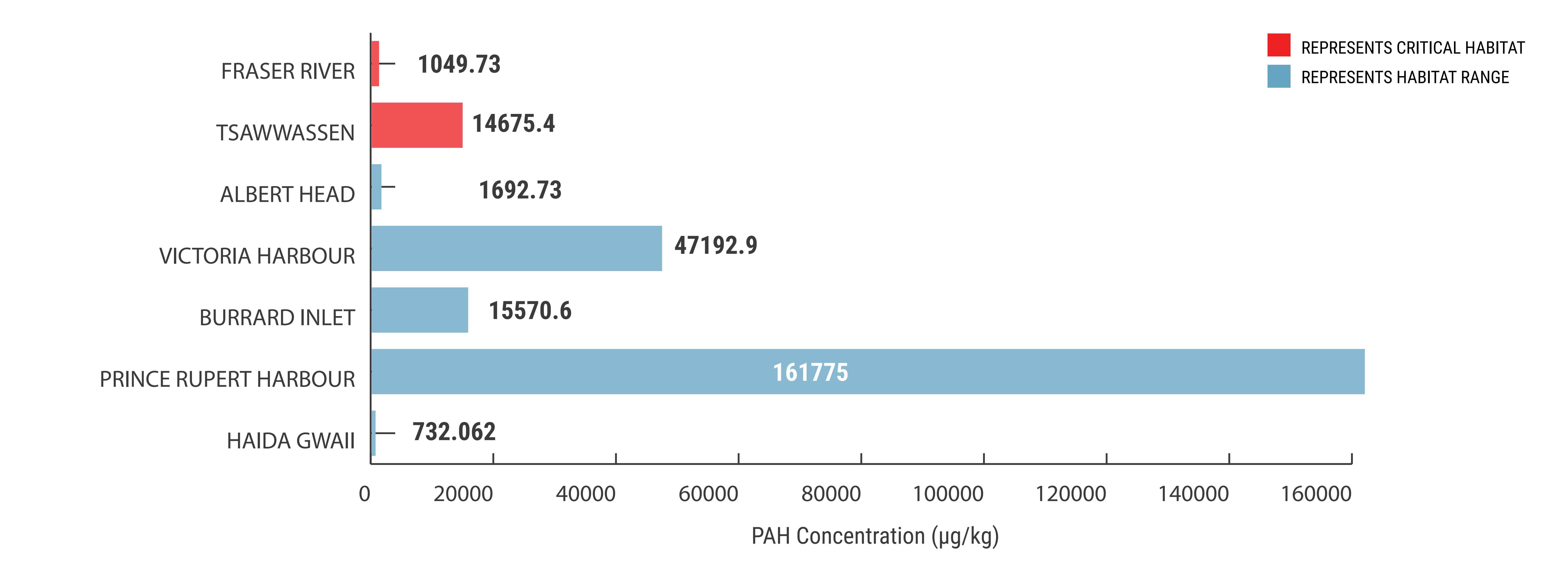


Figure 5. Maximum total PAH concentrations detected in sediment samples from selected sites in critical habitat (red) or within habitat range (blue).

[vi] Adsorb – adhesion of a molecule/liquid or gas to the surface/internal surface of a material.

PAH concentrations were highest in sediments from urban harbours. Fish at these sites have shown high PAH concentrations and can be a dietary source of PAHs for SKRW (Grant and Ross 2000).

Flikr Creative Commons | *Float plane landing in Victoria Harbour B.C.*

Why Is Mercury An Issue?

Mercury is a metal that originates from forest fires, volcanoes and weathering of rocks containing mercury.[30] Human made sources include:

- **coal burning**
- **metal smelting**
- **gold and silver mining and**
- **chlor-alkali production.**[31]

Mercury enters the marine environment mainly through atmospheric transport, which deposits mercury via rainfall, snowfall and dry deposition.[18] Mercury can also be transported through river and stream sediments, and ocean currents.

In the marine environment, mercury adsorbs to particles in the water and sediments. Once in the sediment, it persists for long periods. Under certain conditions, mercury can turn into methylmercury, its most toxic and bioavailable[vii] form.[32] Both mercury and methylmercury are bioavailable to species at the base of the food chain.

Marine mammals can take up mercury through their lungs and skin, contaminated food, across the placenta prior to birth and via milk during nursing. Mercury tends to accumulate in organs, especially the liver and brain.[18,33]

Spotlight 3

Where are SRKW being exposed to mercury?

In the mid-1950s, the horror now known as Minamata disease unfolded before the eyes of the world. People in a Japanese community were afflicted with symptoms ranging from tingling in the hands and feet, to convulsions, paralysis, and sometimes death. The cause was eventually determined to be the consumption of methylmercury-contaminated fish and shellfish from Minamata Bay.[34]

Although not easy to study the effects of mercury on the health of killer whales, it is known to be toxic to all mammals. Put simply, increased mercury concentrations in killer whales and their food webs because of human activities presents a conservation threat.

Mercury concentrations measured in sediment within SRKW critical habitat were low or not detected at some sites (e.g., Albert Head). However, samples from 15 sites within their wider habitat range had much higher concentrations. These were typically located in urban harbours (Figure 6).

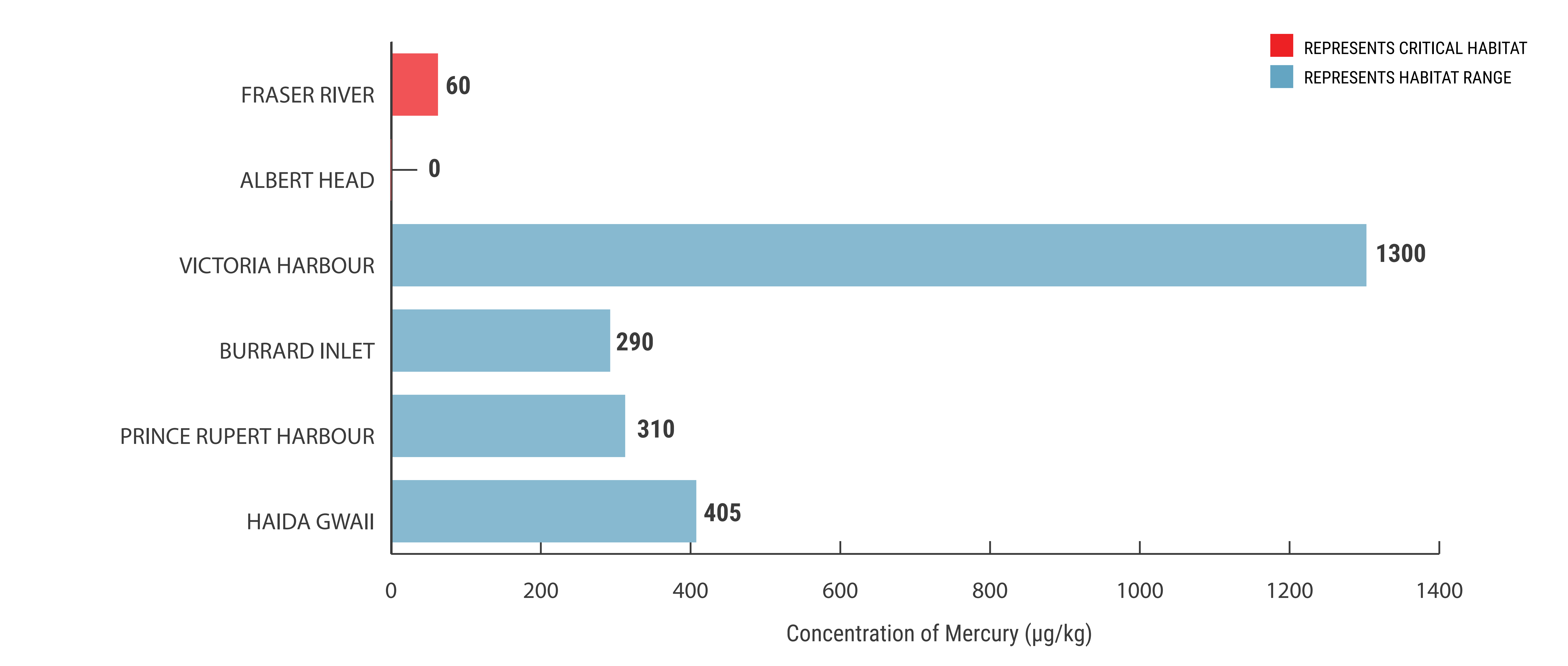


Figure 6. Maximum mercury concentrations in sediment samples from selected sites within critical habitat (red) or within habitat range (blue).

[vii] Bioavailable – the rate at which a substance is absorbed into a living system.

The highest mercury concentration was seen in the urban harbour of Victoria, within SRKW habitat, posing a risk to SRKW health and recovery.

Ocean Wise, NOAA permit 19091 | *A southern resident killer whale chasing a salmon.*

Conclusion

The Northeastern Pacific Ocean is increasingly noisy, busy, and polluted. It is on the receiving end of emissions and waste discharged from millions of coastal inhabitants. And yet it is also home to our iconic and endangered SRKW.

Contaminants impact the health of SRKW, either directly, by increasing their susceptibility to disease and decreasing their reproductive success; or indirectly, by contaminating and affecting Chinook salmon numbers, their primary prey.

However, progress has been made on a number of fronts. Although still problematic, PCBs have been declining in killer whales since regulations were imposed in the mid 1970s. Regulations and best practices have led to declining concentrations in toxic contaminants in B.C., highlighting the value of targeted interventions that recover killer whale habitat quality. For the three environmental contaminants reviewed here, a number of national regulations and international agreements exist to decrease emissions; however, ongoing work is needed to ensure these regulations are working (see Box 1).

Several contaminants appear at concentrations in urban harbours that could compound detrimental effects on SKRW health, including PCBs, mercury, and hydrocarbons. Monitoring allows us to identify priority pollutants, take action, and monitor progress. PollutionTracker occupies an invaluable niche by providing a transparent '*state of coastal pollution*' tool.

Julie Dimitrijevic | *Marine mammal researchers conducting survey work in Burrard Inlet, Vancouver.*

What can you do?

Individual and Organization Actions

❑ Recycle and dispose of all waste responsibly, according to local guidelines.

❑ Do not burn wood that has been treated or painted as it may contain contaminants and can create highly toxic dioxins and furans (another class of contaminants similar to PCBs).

❑ Reduce/eliminate the use of gasoline and diesel-powered engines which contain PAHs.

❑ Create 'killer whale' or 'salmon' friendly gardens, lawns and households by eliminating harmful pesticides and cleaning agents.

❑ Learn more about contaminants in the marine environment, for example from Health Canada:
canada.ca/en/health-canada/services/chemical-substances/fact-sheets.html
canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants.html

❑ A list of common consumer products that contain mercury can be found at canada.ca/en/environment-climate-change/services/pollutants/mercury-environment/products-that-contain.html

Government Actions and Policy

❑ Continue to fund research on killer whales, Chinook salmon and their habitat.

❑ Continue to fund monitoring and research of contaminants in the marine environment.

❑ Review current contaminant regulations and update as needed.

❑ Develop contaminant guidelines relevant to marine mammals, including SRKW.

❑ Support companies to switch to electric vessels where feasible.

❑ Enforce regulations stating boats must stay 400 m away from SRKW in critical habitat, and 200 m away in other B.C. waters.

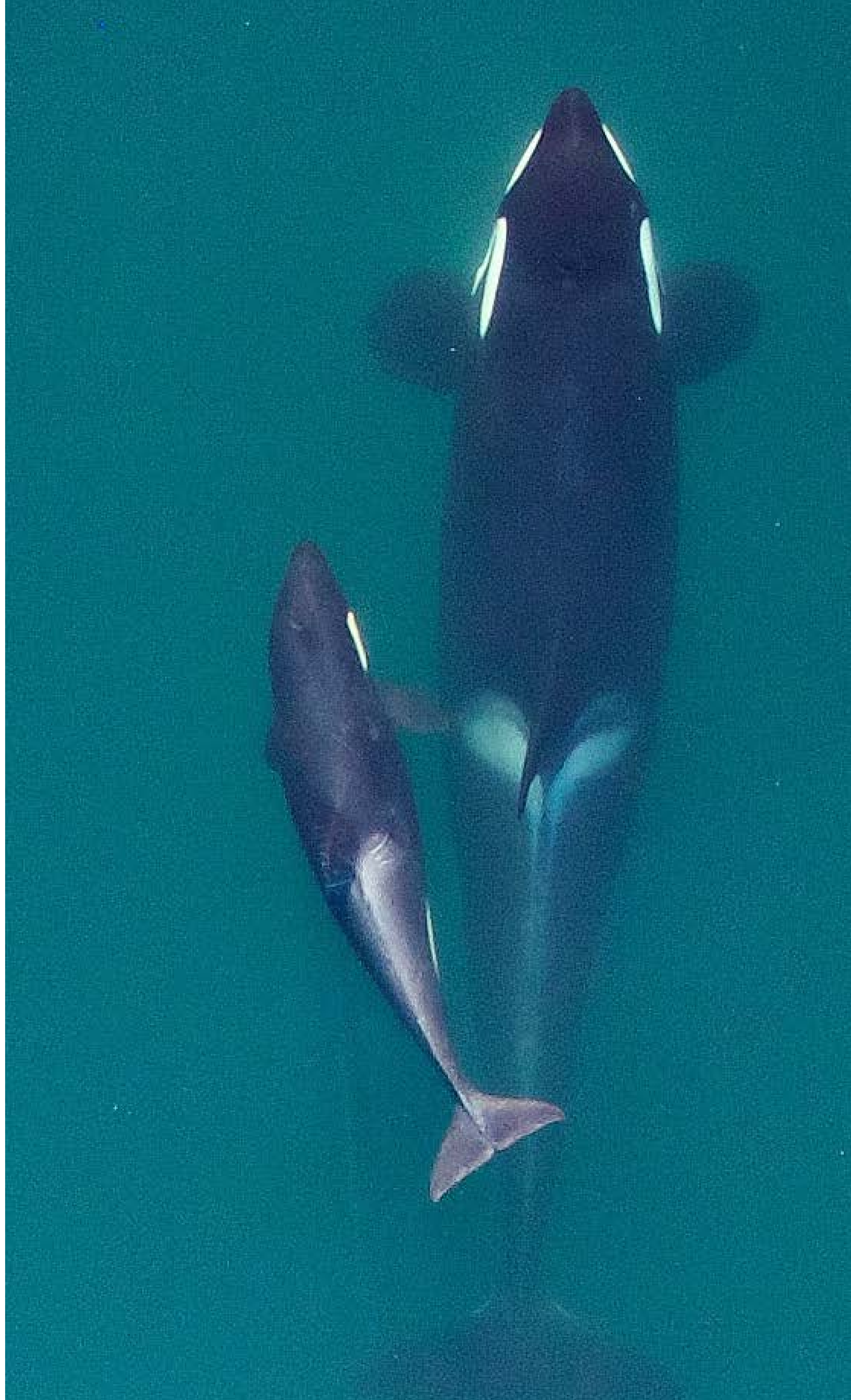
Box 1. Examples of regulations in existence.

Examples of International and National Government Regulations in Existence

PCBs | The Stockholm Convention on POPs, an international treaty that came into force in 2004; in Canada, the import, manufacture and sale of PCBs is banned.

PAHs | Sixteen PAHs are on the US EPA's Priority Pollutant List; in Canada, the government has the authority to regulate and authorize prevention and control of the release of PAH

Mercury | The Minamata Convention on Mercury is an international treaty that came into force in 2017; in Canada, the manufacture and import of products containing mercury is not allowed.



Ocean Wise, NOAA permit 19091 | *A southern resident killer whale swimming with her calf.*

References

1. Fisheries and Oceans Canada. Action plan for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada [Internet]. Ottawa; 2017. Available from: https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/Ap-ResidentKillerWhale-v00-2017Mar-Eng.pdf

2. Ross P, Ellis G, Ikonomou M, Barrett-Lennard L, Addison R. High PCB concentrations in free ranging pacific killer whales, Orcinus orca: effect of age, sex and dietary preference. Mar Pollut Bull. 2000;40:504–15.

3. Marine Mammal Commission. Southern resident killer whale [Internet]. 2019 [cited 2019 Oct 22]. Available from: https://www.mmc.gov/priority-topics/species-of-concern/southern-resident-killer-whale/

4. Centre for Whale Research. Media release [Internet]. 2019 [cited 2019 Nov 13]. Available from: https://www.whaleresearch.com/july2019population

5 SARA. Northern and southern resident killer whales (Orcinus orca): recovery strategy 2018. Species At Risk Act [Internet]. 2018. 2018 [cited 2019 Oct 23]. Available from: https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry recovery-strategies/northern-southern-killer-whales-2018.html#toc8

6. NOAA. Endangered and threatened wildlife and plants: endangered status for southern resident killer whales. Final Rule. Fed Regist [Internet]. 2005;70. Available from: https://archive.fisheries.noaa.gov/wcr/publications/frn/2005/70fr69903.pdf

7. DFO. Fisheries management measures to protect Fraser River Chinook [Internet]. 2019. Available from: https://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/salmon-saumon/2019-chinook-quinnat-eng.html

8. Heise K. Underwater noise. In: Ocean Watch: Howe Sound Edition. Vancouver; 2017.

9. Heise K. Underwater noise interferes with marine animal communication. In: Bodtker K, editor. Ocean Watch BC Coast Edition (2018). 2017. p. 218.

10. Cullon D, Yunker M, Alleyne C, Dangerfield N, O'Neill S, Whiticar M, et al. Persistent organic pollutants in Chinook salmon (Oncorhynchus tshawytscha): Implications for resident killer whales of British Columbia and adjacent waters. Environ Toxicol Chem. 2009;28:148–61.

11. Ross P, De Swart R, Addison R, Van Loveren H, Vos J, Osterhaus A. Contaminant-induced immunotoxicity in harbour seals: Wildlife at risk? Toxicology. 1996;112:157–69.

12. Ross PS, DeSwart R, VanLoveren H, Osterhaus A, Vos J. The immunotoxicity of environmental contaminants to marine wildlife: a review. Annu Rev Fish Dis. 1996;112:157–65.

13. Ross P. Marine mammals as sentinels in ecological risk assessment. Hum Ecol Risk Assess. 2000;6:29–46.

14. Ross P. Fireproof killer whales (Orcinus orca): flame-retardant chemicals and the conservation imperative in the charismatic icon of British Columbia, Canada. Can J Fish Aquat Sci. 2006;63:224–34.

15. Alava JJ, Ross PS, Lachmuth C, Ford JKB, Hickie BE, Gobas FAPC. Habitat-based PCB environmental quality criteria for the protection of endangered killer whales (Orcinus orca). Environ Sci Technol. 2012;46:12655–63.

16. Ball A, Truskewycz A. Polyaromatic hydrocarbon exposure: An ecological impact ambiguity. Environ Sci Pollut Res. 2013;20:4311–26.

17. Lachmuth CL, Barrett-Lennard LG, Steyn DQ, Milsom WK. Estimation of southern resident killer whale exposure to exhaust emissions from whale-watching vessels and potential adverse health effects and toxicity thresholds. Mar Pollut Bull [Internet]. 2011 [cited 2019 Dec 11];62:792–805. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0025326X11000038

18. Das K, Debacker V, Pillet S, Bouquegneau J. Heavy metals in marine mammals. In: Vos J, Bossart G, Fournier M, O'Shea T, editors. Toxicology of Marine Mammals. London: CRC Press; 2002. p. 33.

19. Harris KA, Yunker MB, Dangerfield N, Ross PS. Sediment-associated aliphatic and aromatic hydrocarbons in coastal British Columbia, Canada: Concentrations, composition, and associated risks to protected sea otters. Environ Pollut. 2011;159:2665–74.

20. Scheuhammer A, Braune B, Chan HM, Frouin H, Krey A, Letcher R, et al. Recent progress on our understanding of the biological effects of mercury in fish and wildlife in the Canadian Arctic. Sci Total Environ [Internet]. 2015;509–510:91–103. Available from: http://dx.doi.org/10.1016/j.scitotenv.2014.05.142

21. Noël M, Ross P. Persistent organic pollutants in marine mammals. In: Bodtker K, editor. Ocean Watch BC Coast Edition. 2018. p. 117.

22. ATSDR. Toxicological Profile for Polychlorinated Biphenyls (PCBs). U.S. Department of Health and Human Services. Public Health Service. 2000.

23. US EPA. Polychlorinated Biphenyls (PCBs). 2019.

24. Meador JP, Stein JE, Reichert WL, Varanasi U. Bioaccumulation of polycyclic aromatic hydrocarbons by marine organisms. Rev Environ Contam Toxicol. 1995;143:79–165.

25. Burd B, Lowe C, Morales-„Caselles C, Noel M, Ross P, Macdonald T. Uptake and trophic changes in polybrominated diphenyl ethers in the benthic marine food chain in southwestern British Columbia, Canada. Facets. 2019;4:20–51.

26. Lundin JI, Ylitalo GM, Booth RK, Anulacion B, Hempelmann JA, Parsons KM, et al. Modulation in persistent organic pollutant concentration and profile by prey availability and reproductive status in southern resident killer whale scat samples. Environ Sci Technol. 2016;50:6506–16.

27. Azpiri J. MV Marathassa acquitted of all charges in 2015 English Bay oil spill. Global News [Internet]. 2019; Available from: https://globalnews.ca/news/4936311/mv-marathassa-english-bay-oil-spill-acquittal/

28. Ross P, Yunker M, Morales-Caselles C. Multi-agency environmental monitoring following the MV Marathassa oil spill in Vancouver in April 2015: are we ready for the big one? In Vancouver BC: Salish Sea Ecosystem Conference; 2016.

29. CBC News. U.S company fined nearly $3M for 2016 fuel spill in B.C. First Nation's fishing territory. CBC News [Internet]. 2019; Available from: https://www.cbc.ca/news/canada/british-columbia/nathan-e-stewart-spill-2016-heiltsuk-nation-sentencing-1.5213264

30. Government of Canada. Natural sources of mercury. 2010.

31. Environment Climate Change Canada. Canadian Mercury Science Assessment: Summary of Key Results. Gatineau; 2016.

32. Harding G, Dalziel J, Vass P. Bioaccumulation of methylmercury within the marine food web of the outer Bay of Fundy, Gulf of Maine. Hu Y, editor. PLoS One [Internet]. 2018 [cited 2019 Dec 11];13:e0197220. Available from: https://dx.plos.org/10.1371/journal.pone.0197220

33. Harding G, Dalziel J, Vass P. Bioaccumulation of methylmercury within the marine food web of the outer Bay of Fundy, Gulf of Maine. Hu Y, editor. PLoS One. 2018;13:e0197220.

34. Nabi S. Methylmercury and Minamata disease. In: Toxic Effects of Mercury. Springer; 2014. p. 187–99.

This project was undertaken with financial support from

sitka foundation

North Family Foundation

Cite this report as: Miller A, Braig S, Delisle K, Ross PS. 2020. Pollution hotspots in killer whale habitat pinpointed by new conservation tool. Ocean Watch Spotlight. Ocean Wise Conservation Association, Vancouver, Canada. 22 pg. ISBN: 978-1-7772408-3-7

OCEANWATCH

Ocean Wise, Lance Barrett-Lennard | *A southern resident killer whale leaps from the water.*