ATTACHMENT C
To the Written Evidence of
Raincoast Conservation Foundation

Trans Mountain Expansion Project

Threats to Southern Resident Killer Whales

Prepared for Raincoast Conservation Foundation

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Introduction

In a conventional environmental impact or risk assessment, efforts are made to quantify the probability that something undesirable will happen and the consequences that will arise if that event takes place. These assessments are typically used to consider if the proposed activity adds a plausible risk to species local to the project area and the habitat they are known to use. Proposed project activities, timelines, and suggested mitigation strategies are assessed to identify the level of potential harm that could result from each stage of development through the lifetime of the project.

The Southern Resident killer whale ecotype is listed as endangered under Canada's Species at Risk Act (SARA), and is known to frequent the project area, especially in the summer months (May-August) to feed. The proposed shipping routes for Project related tankers transect the designated critical habitats of the Southern Resident, as well as habitats newly identified as critical. Substantial effort has already been invested to assess the likelihood that anthropogenic threats associated with Trans Mountain Expansion (TMX) would adversely affect or increase the extinction risk of Southern Resident killer whales (*Orcinus orca*) ("Southern Residents").

Considering these assessments and the best available science, we conclude that the Southern Resident population cannot tolerate any additional anthropogenic stressors. Considerable research effort shows that the population is already small, and declining. Southern residents have failed to recover from population removals/live capture for aquaria (1960-1970s) (Colby 2018, Kirby 2013) due to natural and anthropogenic factors. This suggests, with a high degree of certainty, that the Southern Resident population lacks the resilience to buffer additional anthropogenic stressors (Ludwig et al 1993). We concur with the Government of Canada's Imminent Threat Assessment that concluded, "Based on the information reviewed and analysis undertaken as part of this assessment, it is considered that Southern Residents are likely facing imminent threat to survival. Unless alleviated or reduced (i.e. mitigated), the current threats may make survival of the population unlikely or impossible."[1] Population viability analyses (PVA) based on the best available science show that under *status quo* conditions (Lacy et al. 2017) the probability of extinction or quasi-extinction is very high, where the number of reproductive adults is below a threshold that is sufficient to assure persistence of the species.

Status of Southern Residents and state of our knowledge since 2015

Live-capture hunts for aquarium display affected both Northern and Southern Resident killer whales (Williams and Lusseau 2006). The Southern Resident population, however, was affected more severely, with the removals continuing to show lingering, socially disruptive effects on the population and its reproductive potential. Consequently, the Southern Residents have been designated as endangered by SARA since 2003 (DFO 2017). In a now-classic description of a

[1] https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/related-information/southern-resident-killer-whale-imminent-threat-assessment.html#toc5

hypothetical “most endangered animal,” Ehrenfeld (1970) enumerated features of animal species that render populations inherently vulnerable to extinction. These include large body size, long gestation period, small litter size or extended periods of maternal care, formation of large social aggregations for breeding or feeding, and highly restricted distribution or distribution in transboundary waters (Ehrenfeld 1970). The close alignment between this description of a hypothetical most endangered animal and killer whale life histories is a reminder of how inherently vulnerable to extinction the Southern Resident population is, and that recovery from depletion will be slow. Indeed, Ehrenfeld’s (1970) description could be applied to all whales and other long-lived mammals. Highly social odontocetes (toothed whales, dolphins, and porpoises) in particular have been seen to recover more slowly after cessation of whaling than baleen whales, even after accounting for obvious demographic differences (Wade et al. 2012). Home ranges and critical habitats of coastal odontocetes (e.g. resident killer whales) are more limited and local and must support feeding, navigating, communicating, migrating, foraging, mating, calving, and calf rearing simultaneously. This contrasts with baleen whales, which tend to migrate between widely dispersed breeding and feeding grounds. The corollary of this difference in life-history strategies is that degradation of critical habitats for coastal odontocetes affects all aspects of their life histories. As a highly social odontocete population, Southern Residents are facing severe demographic and habitat-related barriers to recovery.

The population viability assessment (PVA) appended to Raincoast’s 2015 submission to the National Energy Board (Lacy et al. 2015) showed that based on status quo conditions, the Southern Resident population was projected to remain at its current size or continue a very slow decline (estimated at a mean annual decline of 0.2%). A 9% chance of quasi-extinction was projected, where the population would fall below 30 whales, and the population would become unviable. The prediction of no population growth or slow decline was robust within plausible ranges of demographic rates. Thus, under status quo conditions the population was not expected to recover from its current endangered status. In addition, analyses showed that the Project would intensify existing threats, accelerating the rate of decline in the Southern Residents and leading to possible extinction.

A more recent PVA confirmed that the population was fragile, with no population growth projected under current (*status quo*) conditions, and decline expected if the population experienced any new or increased threats (Lacy et al. 2017). The adverse contributions of noise and prey decline disturbance were given particular focus. Importantly, the actions required to achieve recovery were shown to be greater if the Project or other development activities add to the existing threats that have prevented recovery to date.

Since Raincoast’s 2015 submission to the National Energy Board (Lacy et al. 2015) and the subsequent published PVA, the Southern Resident killer whale population has suffered major declines. From 2015 to 2018, the population declined from 78 to 74 individuals.[2] During that time, our understanding of the main threats to its recovery has increased. Accordingly, the

[2] Center for Whale Research, unpublished: https://www.whaleresearch.com/

status of Southern Residents and factors hindering population growth now suggest the current risk of extinction in this population is greater than in 2015.

Raincoast's updated "Baseline" population model, estimating the population dynamics under current conditions, projects a mean population growth of r = -0.006, or 0.6% decline per year, with variation across years of SD(r) = 0.047 (Lacy et al. 2018). This compares with projections of mean r = -0.002 (0.2% decline per year), SD(r) = 0.042 in the earlier analysis (Lacy et al. 2015, 2017). The lower revised estimate results from the poor reproduction and calf survival over the last three years, with little sign of population recovery.

Killer whales have a low intrinsic rate of population increase (1). This is particularly true of the heavily depleted Southern Residents population, which also has shown extremely low reproductive potential and success in recent years. Very few births have been noted compared with the number of reproductive females present in the population (Ward et al. 2013,Wasser et al. 2017). Up to 69% of all Southern Residents' pregnancies confirmed between 2008 and 2014 resulted in miscarriage; one-third of these occurred in late gestation or immediately postpartum when metabolic demands on the mother are highest (Wasser et al. 2017). Since 2015, the failure rate in pregnancies has been 100%,[3] with complete failure to produce a single viable calf. When J35 gave birth in summer 2018, her calf survived for half an hour.[4] Reproductive failure can occur through a combination of factors, including failure to find a mate, failure to conceive, reabsorption of the foetus, miscarriage, stillbirth, and failure to a produce viable offspring. Additional threats to the population could result in further population has lost, including of seemingly healthy, reproductive individuals as has been in recent years. Under optimal conditions, killer whale populations are capable of growing at only at 2-3% per year (Taylor et al. 2007), with Southern Residents currently living under far less than optimal conditions. As a result, we express an increased level of concern for Southern Resident Population health when considering trends since the 2015 NEB submission. In addition, we note that the mitigation measures taken by Canada since the SARA listing of Southern Residents have failed to stabilize the population or reverse the decline of the population. Clearly, measures necessary to mitigate threats to the population need to go well beyond any efforts taken to date.

The three main threats to recovery of Southern Residents are lack of Chinook salmon (*Oncorhynchus tshawytscha*), physical and acoustic disturbance of vessels, and toxic effects of contaminants. These threats have been recognized for more than 20 years and are predominantly anthropogenically driven. A 2004 technical workshop of Canada's original Resident Killer Whale Recovery Team identified that Southern Residents were unlikely to recover unless immediate actions were taken to increase abundance and availability of Southern Residents' salmon and other prey; reduce noise and disturbance to improve availability of those salmon to Southern Residents; and to reduce exposure of Southern

[3] Center for Whale Research, unpublished: https://www.whaleresearch.com/
[4] https://www.washingtonpost.com/news/animalia/wp/2018/08/10/the-stunning-devastating-weeks-long-journey-of-an-orca-and-her-dead-calf/?noredirect=on&utm_term=.736f7d37fc74

Residents to persistent organic pollutants (POPs) and other threats that could affect killer whale health and calf survival.[5] An eminent group of scientific and technical advisors helped the Resident Killer Whale Recovery Team formulate a recovery strategy that identified these three main threats, and urged recovery actions. In the intervening 14 years, a growing body of research has greatly improved our understanding of the seriousness of those threats and quantified their relative importance. Management actions taken to date, however, have failed to significantly reduce or abate those threats, resulting in continued decline of the whale numbers.

Before considering whether project-related threats can be mitigated, we need management actions that help reverse, not just lessen the threats the whales are facing already. We discuss each of these main threats below in turn, suggesting how each might contribute to the decline of the population observed since the last NEB submission. We note that the best available science shows that the population has no resilience to buffer any increase in existing stressors.

Factors in the decline of the Southern Residents

A number of factors, which are not mutually exclusive, might explain the recent abrupt decline of the Southern Resident population:

- Threats are worsening in number and intensity
- Presence and adverse influence of vessel noise on Southern Resident killer whale behaviour and the ability of the whales to communicate among themselves[6] is more severe than previously characterised
- Stress effects from acoustic disturbance have been underestimated
- The abandonment of foraging behaviours and reduced efficacy in prey capture and prey sharing in increased ambient noise conditions is worse than previously characterised
- Prey availability is lower than estimated because Chinook returns have been affected by warmer oceanic conditions from 2014 to 2016 Hyatt et al. 2017)
- Competition for prey resources from other marine mammals is increasing (Adams et al. 2016)
- The effects of stress, food limitation and malnutrition on Southern Residents were underestimated
- Contribution through bioaccumulation to contaminant load by Chinook salmon and other prey could be higher than accounted for
- The effects of increased contaminant loading due to blubber metabolism was underestimated, particularly on the health and survival of young
- Synergistic effects of threat interactions have not been adequately considered. For example, noise disturbance influences feeding behaviours, which in turn reduces prey intake and may lead to greater release of POPs into the bloodstream through blubber metabolism.

[5] https://www.sararegistry.gc.ca/document/doc1341a/p5_e.cfm#app_d
[6] Communication between or among members of the same species

Existing threats to Southern Residents' recovery: Prey availability

As noted previously, the persistence of the Southern Residents is adversely affected by three primary threats. Of these, prey availability is considered the most problematic and severe. Shipping exacerbates the problem of declining prey availability because the physical and acoustic disturbances associated with vessels: alienate killer whales from using critical habitats where salmon are most abundant; interfere with the killer whale's capacity to detect prey via echolocation; and disrupt communications among individual whales that are essential to successful predation by individuals, matrilines, and pods.

Resident killer whales show extreme dietary preference for salmon (Ford et al. 1998). Among the five species of wild Pacific salmon, resident killer whales show strong selectivity for the largest species, Chinook salmon, and forage preferentially for the oldest and largest Chinook available in their environment (Ford and Ellis 2006). Genetic studies reveal that Southern Residents prefer Fraser River Chinook salmon (up to 90% of fish consumed) (Hanson et al. 2010), which are found seasonally in their core summertime habitat. However, salmon runs from the Fraser River and Puget Sound watersheds, also targeted by Southern Residents, have diminished because of degradation of spawning and rearing habitat, overfishing, and environmental stressors.

Current knowledge of the relationship between Southern Residents and their prey suggest that a healthy killer whale population would begin to demonstrate unacceptable population level responses if average prey abundance was reduced by approximately 10% (Ward et al. 2013). That is, once human activities start to reduce the availability or accessibility of salmon, specifically Chinook, by more than 10% compared with the established long-term average conditions, one would expect a healthy killer whale population to start to experience population reduction. These levels are based on healthy populations, so for endangered populations like the Southern Residents, much lower levels of removal would warrant management intervention (Ford et al. 1998). In addition, best available science suggests human activities are reducing prey available by far more than the 10% reduction a healthy population of killer whales could withstand.

Chinook salmon form more than 90% of the summer diet of Southern Resident killer whales. This obligatory dietary preference manifests itself in a strong correlation between killer whale demography and various indices of interannual variability in Chinook salmon abundance. The ability to predict population-level responses of Southern Residents to future levels of Chinook salmon availability (in the environment) and accessibility (to the whales) hinges on prey-demography relationships (Ford et al. 2010, Ward et al. 2009). Time-series of killer whale demographic data have shown strong correlation to availability of Chinook salmon annually, with salmonid prey availability a limiting factor to the survival of resident killer whale populations (Ford et al. 2010, Ward et al. 2009, Ford et al. 2009, Vélez-Espino et al. 2014, Esteban et al. 2016). However, Northern Residents draw from a wider range of salmon populations than do Southern Residents (Chasco et al. 2017a, Ward et al. 2015, Chasco et al.

2017b), which has afforded them population growth. In a series of bilateral workshops on the importance of Chinook salmon in driving Southern Residents population dynamics, evidence was presented to suggest that Southern Residents have lower survival and reproductive rates than Northern Residents (Ward et al 2013), likely driven by lower prey availability. Indeed, evidence suggests that some threats are worsening since 2007. This suggests that the explanatory powers of statistical models are likely to decrease as the population declines, and stochastic (randomly determined) effects become increasingly influential.

One study modelled prey requirements of Southern Residents at the individual and population levels, based on predictions from typical mammalian metabolic rates (Noren 2011). If the population consumed only Chinook salmon, the daily consumption for the population (calculated in 2008 for 83 individuals and 82 animals ≥1 yr. of age) ranged from 792 to 951 fish/d (289,131–347,000 fish/yr.; assuming an average caloric value of 16,386 kcal/fish). A complementary study used empirical data on body size and prey consumption of captive killer whales to estimate prey intake requirements, then applied this estimate to wild resident populations using data from live-capture fisheries in British Columbia and Washington state (Williams et al. 2011). The model incorporated caloric value of salmon with the body size data from resident killer whales to estimate that the 87 individuals in the southern resident population in 2009 required 468-1088 Chinook per day. The range represents the uncertainty in killer whale body mass at a given length and the caloric value of a typical Chinook salmon. The study noted that to reach a goal of 2.3% annual population growth the energetic requirements of the population would be approximately 75% greater than previously reported. Few studies have compared prey requirements with prey availability, but the number of fish required is large relative to annual returns to the Fraser River and catches in recreational and commercial fisheries combined[20].

Studies have shown that the nutritional requirements of an adult female do not increase dramatically during pregnancy, but does increase by approximately 40% during lactation (Williams and Noren 2009, Ward et al. 2013). Male energy requirements are typically greater due to bigger body size. Killer whales will forage cooperatively, with males in particular dependent on food sharing within the group to meet energetic demands (Baird 2001, Ellis et al. 2017, Matkin et al. 2017).

Current run sizes of Chinook salmon are thought to be approximately 8% in Puget Sound Rivers, and 36% in British Columbia (BC) waters compared with historic run sizes (Lackey et al. 2006).[7] Chinook salmon stocks in BC have been recorded as consistently low since 1998 (39, 40). A recent status review of Chinook salmon stocks in Washington state paints a stark picture: "Of 32 historical populations, 22 are in Washington. Washington's seven spring-run populations are extirpated or at high extinction risk. Of 15 fall-run populations, several are extirpated and most others are at high extinction risk."[8] These declines are attributed to anthropogenic actions

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[7] http://www.govlink.org/watersheds/8/reports/pdf/1709-8207m-wria-8-tenyr-salmon-conservation-plan-9-19-17.pdf

[8] https://wdfw.wa.gov/publications/01742/13_A4_Fish.pdf

(damming access to habitat and historical overfishing (Ruckelshaus et al. 2002), and environmental conditions. In the mid- to late-1990s, and more recently between 2014 and 2016 the Pacific experienced strong El Nino effects (Hyatt et al. 2017), which had large-scale impact in salmon stocks. The warmer conditions resulted in increased disease and mortality rates, and a slower return to natal sites. Conditions were described as particularly unfavourable for Chinook and sockeye returns on the BC coast (Hyatt et al. 2017).

The Chinook that are returning are younger, smaller, and less nutritionally dense than they have been in recent decades.[24] The reason for this significant decline (Jefferey et al. 2017) is unclear, but it increases the demand for the number of individuals Southern Residents need to consume to meet demands (Hanson et al. 2010). Finally, Southern Residents could be experiencing more competition for prey resources, with the occurrence of salmonid species, including Chinook, found to be increasing in pinniped diets (Adams et al. 2016, Chasco et al. 2017a).

Existing threats to Southern Residents recovery: Effects of acoustic disturbance on prey accessibility and energetic expenditure

The term “acoustic environment” refers to the acoustic characteristics (spatial, temporal and spectral) as a result of all sources of sound (biotic, abiotic, natural and man-made), whereas acoustic habitat refers to that portion of the acoustic environment used by a species for all its various life functions. This section reviews the evidence that acoustic disturbance and elevation of ambient noise conditions in an animal’s acoustic habitat by anthropogenic noise additions represents a major threat to recovery of Southern Residents. Noise additions are either impulsive or continuous. Impulsive noise sources are brief but intense (i.e. acute) additions to the acoustic habitat. These include noise associated with coastal construction (e.g. underwater explosions) and exploration (e.g. airguns and echosounders), and naval operations (e.g. mid-frequency sonar). Vessel noise is an example of a chronic noise source, with more-continuous acoustic additions in areas that Southern Residents inhabit. In this review, we will focus on vessel noise as a dominant source of anthropogenic noise experienced by Southern Residents within their critical habitat. We will also discuss our level of confidence that these effects can be mitigated by management actions.

Research to date on acoustic impacts from ships on marine mammals has quantified two main noise effects: masking (Erbe et al. 2016) of acoustic signals used for communicating and during foraging, and behavioural responses owing to proximity disturbances or noise that disrupt critical life functions (e.g. feeding). Sub-lethal stress responses and avoidance behaviours can also be seen. Acoustic masking and behavioural responses to noise represent different, but not mutually exclusive, potential impacts of anthropogenic noise on endangered whales. Reactions by Southern Residents will differ based on the noise source characteristics and ecological context, with behavioural reactions variable among individual whales depending on the behavioural state of the pod or matriline, as well as the acoustic environment’s influence on sound propagation (Weilgart 2007). In addition, prey response to noise additions can affect the availability of resources for Southern Residents.

Acoustic masking occurs when noise additions (for example vessel noise) impede the detection of a signal (for example a vocalisation from a pod member). Killer whales use acoustic signals (echolocation, whistles, or calls) for prey detection and capture, communication, navigation, orientation. Acoustic masking from noise, either from a single source or from several aggregated noise additions (e.g. vessels, drilling, pile driving, dredging) leads to the loss of opportunities to engage successfully in critical life functions. It can also mask biologically important cues or disrupt vital life functions, primarily feeding. An average of 20 large vessel passages (e.g. bulk carriers, cargo ships, tug boats) per day pass through Haro Strait (approximately one per hour, (Veirs and Veirs 2006), each typically elevating the background noise level by 20 dB re 1 µPa in the frequency range of killer whale vocalisations. Consequently, the spectrum levels in the Southern Residents frequency range are raised in response to the noise pollution from ships (Veirs et al. 2016). This could lead to masking of the signals of killer whales to locate food (echolocation), coordinate foraging tactics (calls), and prey share (whistles and pulsed calls between individuals (Ford et al. 2006). Indeed, the noise levels in Haro Strait, a summer foraging area for Southern Residents, could reduce the range at which Southern Residents can communicate with other killer whales. The acoustic habitat along all shipping lanes is dominated by vessel noise, with communication signalling ability reduced up to 97% in periods of heavy traffic (Williams et al. 2014). This may decrease overall foraging efficiency by 38-100% (Holt et al. 2009).

Ship size, speed, number, and proximity determine the addition to the acoustic environment (Veirs et al. 2016, Holt et al. 2017). Larger vessels generate most noise in the lower frequencies (<1,000 Hz, (Richardson et al. 1995), and are the largest noise contributor in the Southern Resident's foraging area (Lacy et al. 2017, Veirs et al. 2016). In addition, whale-watching vessels are frequently present in the summer months (Holt et al. 2009). The close range passage of these vessels can increase the ambient noise levels in the acoustic habitat up to 30 dB re µPa in the lowest frequencies, (<100 Hz). However, additions of between 5-10 dB re µPa are seen in higher frequencies (> 20,000 Hz, Veirs et al. 2016), encompassing the echolocation range of the Southern Residents. More specifically, when northbound ships transit Haro Strait they raise the spectrum levels of ambient noise in the center of the Southern Resident summertime critical habitat (along the shoreline of Lime Kiln State Park, at a range of ~2 km) by 5-13 dB between 10,000-96,000 Hz (49). This frequency range overlaps with the frequencies at which echolocation clicks of resident killer whales have peak power. The masking of Southern Resident killer whale echolocation clicks by this high-frequency noise from nearby ships was estimated in one specific case to cause a reduction of 85-100% in the range at which a Southern Resident could detect a Chinook salmon in natural background noise (Holt et al. 2008).

The number of vessels present can increase the ambient noise levels (Holt et al. 2009). During the summer months, Southern Residents are never more than 1 km away from at least one vessel during daylight hours (Williams et al. 2014). An increase in approach distances, particularly relevant for whale watching and recreational vessels, was implemented first in the US in 2011 and now in Canadian waters for Southern Residents. However, so far this increase (from 100m to 200m) has not shown the reduction in noise exposure expected (Holt et al. 2017), especially in situations where boats are frequently manoeuvring.

Several behavioural changes have been noted for Southern Residents in the presence of vessel noise. Studies have shown that Northern and Southern Residents reduce foraging time by 18 and 25%, respectively in the presence of boats (Williams and Lusseau 2006, Lusseau et al. 2009). Efforts are underway to identify the acoustic thresholds that trigger disruption of feeding activities, but preliminary results suggest that there is unlikely to be a simple relationship between noise level and the probability of disrupting killer whale foraging. A recent modelling study supported by the Port of Vancouver (Canada) estimated that Southern Residents are exposed to sufficient vessel noise to translate into the daily loss of 20-23% of foraging time (4.9-5.5 hours/day) due to masking and behavioural responses, "with approximately two thirds of this time due to noise from large commercial vessels and one third due to noise from whale watch boats."[9] Cessation of foraging behaviours limits resource acquisition. In addition, transition from both resting and foraging to travelling behaviours frequently noted in the presence of vessels (Lusseau et al. 2009, Ayres et al. 2012), would mean greater energy expenditure. Avoidance of noise sources can also lead to an effective loss of foraging habitat. Together this may represent an unsustainable loss of foraging time. Energetic expenditure may be further heightened by Southern Resident killer whales modifying calling behaviours to overcome the masking effects of vessel noise. In increased noise conditions killer whales have been noted to increase the amplitude (1 dB for every 1 dB in ambient noise increase, (Holt et al. 2009), frequency (pitch, Holt et al. 2009), and length (Foote et al. 2004, Wieland et al. 2010) of calls. Chinook salmon have also shown responses to elevated noise conditions. Pulsed noise in particular has initiated stress and avoidance responses, and even injury or death in fish (Keevin and Hempen 1997, Halvorsen et al. 2012), which could also change foraging efficiency for Southern Residents.

In recent years, considerable investments in measuring and monitoring ocean noise in important Southern Resident habitats have been made. However, monitoring noise and attempting to reduce noise without a clear understanding of the effects of mitigation may not translate into consequential benefits for Killer Whales. Scientists' understanding of how increased global ocean noise generally, and altered ambient conditions in more local site specific settings affect whale behaviour, is limited. Further, how these disturbances affect the biological success of individuals and populations is even less well known. Until the influences of acoustic additions are understood, especially vessel noise, on killer whales and their use of habitat, behaviour, and foraging ecology, proposed mitigation measures remain hypotheses to be tested with empirical data.

A number of approaches exist to reduce ship noise in important whale habitats (Williams et al. 2018), but their efficacy regarding the benefits to Southern Resident killer whales is largely untested. Peak and long-term mean noise levels were reduced by slow-down trial(s), but there were no assessments of whether the Southern Residents responded to the change in noise pollution. For example, the Vancouver Fraser Port Authority initiated a trial in vessel speed

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[9] https://www.portvancouver.com/wp-content/uploads/2017/01/2017-07-ECHO-Program-Estimating-the-effects-of-noise-from-commercial-vessels-and-whale-watch-boats-on-Southern Residents.pdf

reduction through Haro Strait in 2017 by.[10] Vessels were asked to voluntarily comply with an 11-knot speed limit, with a 61% compliance rate noted in the first year. This speed limitation resulted in an average reduction of noise by 5.9 dB re 1 µPa from cargo ships, which demonstrated an average speed reduction of 2.1 knots, and 11.5 dB re 1 µPa from container ships, which are showed to have an average speed reduction of up to 7.7 knots. Whether these reductions in noise were beneficial or biologically relevant for killer whales is unknown. In addition, the potential adverse effects of extended vessel proximity related disturbances were not evaluated.

Some evidence (Veirs et al. 2016) suggests that for many ships a reduction of ~1 dB can be expected for every 1-knot reduction in speed. As such, efforts to reduce noise levels by reducing speed could lead to straightforward calculations in terms of acoustic masking (i.e., lost communication and foraging space). If the speed limit of 11 knots was enforced it would affect most of the vessels transiting the region and putatively result in reduction of acoustic disturbance to Southern Residents in critical foraging areas (Veirs et al. 2016). In addition to speed limitation, removal of the noisiest vessel in the fleet (Veirs et al. 2018), retrofitting and incentivising higher levels of maintenance, 'lateral displacement' of shipping routes,[11] the use of convoys (staged vessel movements, timed entry to port areas), and restricting vessel numbers in Haro Strait have been suggested as measures. These could, either alone or in concert, provide some acoustic relief to Southern Resident killer whales in the Salish Sea, although it is unknown what levels of reductions in noise would be biologically relevant for the whales.

The adverse affects of noise on Southern Residents are typically described as sublethal. However, for an endangered population like Southern Residents, failure to recover or show population growth is due to cumulative impacts of several sublethal stressors, rather than aggregate impacts, or a single lethal threat such as ship strikes[12] Therefore, assessments of a stressor's impact must consider both the aggregate exposure (e.g. multiple vessels over time) and how each stressor contributes to an overall cumulative risk (e.g. vessel noise and reduced prey availability). In addition, scaling findings from individual exposure to estimate population effects can be complex. So far, there has been limited application of a synergistic framework (PCoD model, NRC 2005) on empirical data successfully.

Two main problems hinder progress on managing and mitigating sublethal stressors. Modeling population consequences of the cumulative impacts of multiple sublethal stressors is difficult

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[10]Vancouver Fraser Port Authority. 2018. ECHO Program, Voluntary vessel slowdown trial summary findings. Available from: https://www.flipsnack.com/portvancouver/echo-haro-strait-slowdown-trial-summary/full-view.html.

[11] "a reduction of > 1–2 dB is unlikely for this management option, no matter where it is applied" in the SRKW critical habitat within the Salish Sea (Williams et al. 2018)

[12] The terms aggregate and cumulative are not synonymous and have taken on specific meanings when it comes to noise and stressors. Aggregate refers to assessing the impact/effect/influence of multiple forms of the same stressor (i.e. noise), whereas cumulative is used to refer to assessing the impact/effect/influence of multiple types of stressor (i.e. no food, nets, pollution, noise).

(Ocean Studies Board and National Academies of Sciences, Engineering, and Medicine, 2017), and the tolerance of killer whales for sublethal impacts has not been quantified. Without quantitative guidance, it is necessary to infer sustainable levels of human impacts on killer whale populations. The use of observations of behavioural response to differing noise sources and levels may aid this process. The well-quantified relationship between salmon abundance and killer whale demography, allows some estimates of how prey reductions might affect killer whale population dynamics. By simulating natural variability in prey availability, and then in that simulation systematically reduce the proportion prey accessible to the whales, for example through habitat avoidance of areas that exceed a noise threshold and/or increased fisheries take, it may be possible to see how cumulative impacts from multiple human activities reduce Southern Resident foraging capacity. How this then manifests into a lowered killer whale population growth rate (i.e., through reduced survival and fecundity) can also be estimated.

Existing threats to Southern Resident's recovery: Effects of persistent organic pollutants (POPs)

The three main threats to Southern Residents; reduced prey availability, acoustic and physical disturbance, and contamination act synergistically on the whales. Among these, contamination is the threat that lends itself least to immediate mitigation measures. If a threat to population success cannot be mitigated, greater measures (i.e. more precautionary recovery targets) should be taken to mitigate the threats that can be addressed by management action; in the case of Southern Residents primarily in reducing acoustic disturbance and then in alleviating prey limitation where possible

Researchers raised concerns about high levels of persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDTs), and polybrominated diphenyl ethers (PBDEs), in resident killer whales almost 20 years ago (Ross et al. 2000) These contaminants are lipophilic, and are stored in the blubber layer of killer whales. Exposure comes from ingestion of contaminated prey, as well as from sediment in the water column (Alava et al 2016). The waters in the Strait of Georgia show high levels water column and sediment bound levels of PBDE in shallow waters (Frouin et al. 2013). In addition, Puget Sound Chinook salmon have the highest level of POP contaminants of all salmon populations (O'Neill an West 2009), with these fat-soluble compounds bioccumulating up the food chain to the apex predator. The POPs can cause health effects in affected individuals directly (Hickie et al. 2007), and cause immunosuppression causing individuals to become more susceptible to disease outbreaks Ross 2002).

On a global scale, POP concentrations are high enough to raise concerns about extinction risk of many killer whale populations (Desforges et al. 2018). Recent efforts have tried to predict the demographic consequences of POP contaminant loads for Southern Residents, specifically impacts on calf survival (Hall et al. 2018). Preliminary modelling studies show that tissue concentrations of PCBs are high enough to cause the Southern Residents population to tip from a stable to a declining trend. The PCB presence in female Southern Residents is high enough to reduce foetal brain growth (Meerts et al. 2000) and cause a 7-50% calf mortality (Lacy et al.

2017). Contaminant load is mobilised through lactation, passing from mother to calf. An estimated 70-90% of accumulated POPs are transferred from a primiparous (i.e. pregnant for the first time) female to their young, with levels in subsequent calves dependent on the time between births (Ylitalo et al. 2001, Mongillo et al. 2012). In a population, the greatest contamination levels are therefore seen in young juveniles and adult males. (Ross et al. 2000, Hickie et al. 2007)

Reduced opportunities to feed and reduced prey intake can lead to the metabolism of blubber stores to meet energy demands. This mobilises POPs in to the blood stream, and increases the likelihood of associated health concerns in Southern Residents such as immune and endocrine disruption, reduced fecundity, and cancer. Ultimately, this can lead to individual death (Reddy et al. 2001,Schwacke et al 2002, Fonnum et al. 2006, Ylitalo 2005, Buckman et al. 2011, Lundin et al. 2016, Mongillo et al. 2016).

As POPs do not lend themselves immediately to any practical mitigation measures, we believe that contaminants should be treated in risk assessments (e.g. the NEB's review of the TMX expansion) as a fixed cost. Empirical data on tissue concentrations of PCBs in Southern Residents killer whales are predicted to cause a 0-2% decline (Ocean Studies Board and National Academies of Sciences, Engineering, and Medicine 2017). The quantification of population-effects depends on whether the interest is in direct effects (calf survival) or indirect effects (immunosuppression, reduced fecundity). If a threat to population success cannot be mitigated, greater measures (i.e., more precautionary recovery targets) should be taken to mitigate the threats that can be addressed by management action; in the case of Southern Residents primarily in reducing acoustic disturbance and then in alleviating prey limitation where possible.

Efficacy of potential mitigation actions to protect Southern Residents and their critical habitat

Critical habitat for Southern Residents includes physical features (e.g. the seabed), ecological features (e.g. Chinook salmon), and acoustic attributes (i.e., acoustic conditions that allow killer whales to communicate, maintain a social network, and find salmon).

The NEB's May 2016 report on the TMX notes "the operation of Project related marine vessels is likely to result in significant adverse effects to the Southern Resident Killer Whales, and that it is likely to result in significant adverse effects on Aboriginal cultural uses associated with these marine mammals." Below, we discuss if the potential mitigation measures that may be discussed in the TMX reconsideration process are likely to be effective. Throughout we also ask whether these measures are effective in mitigating the threats that Southern Residents already face. Major threats present in l Southern Resident critical habitat include: prey limitation, acoustic disturbance, and contaminant loading. Adding additional vessel traffic will increase acoustic additions and possibly contamination risk from vessel exhaust and oil spill (Lundin et al. 2018).

In taking this approach, we find ourselves concurring entirely with the main conclusions of the Government of Canada's Imminent Threats analysis of 24 May 2018, which concluded:[13]

- "The species is currently facing threats that might be impacting survival and/or recovery,"
- "threats to the *recovery* of the Southern Residents population could be considered imminent," and
- "threats to the *surviva*l of the Southern Residents population could be considered imminent, and
- existing anthropogenic threats require intervention:
  - in terms of prey availability, the threat "does require the type of intervention that is proposed" in that document,
  - in terms of acoustic and physical disturbance, "this threat is still considered to be acting on the population and does require immediate intervention," and
  - with respect to environmental contaminants, "this threat is still considered to be acting on the population and does require intervention."

We suggest that additional threats should not be added before abating those that Southern Residents are known to be already facing. As stated in the 2011 Resident Killer Whale Recovery Strategy (Fisheries and Oceans Canada 2011), we can consider the Southern Resident population to be recovered when the "the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of the species' persistence in the wild. A species will be considered recovered when its long-term persistence in the wild has been secured." We believe none of these conditions has been met to date. We concur entirely with the Imminent Threats Analysis, which concluded, starkly, that"[d]espite ongoing and planned mitigation measures, the key threats affecting the Southern Residents killer whale population are, to date, not being fully abated; further, the effectiveness of these actions has not yet been evaluated, which can take many years. Given the long life-span of the species, recovery is a long-term goal and effects of reducing the threats on the population to ensure survival and advance recovery would not occur over the short-term."[14]

Mitigation efforts needed to protect Southern Residents and their critical habitat from existing threats, before consideration of introducing new threats

We believe, before considering the addition of new threats, the Government of Canada should demonstrate the efficacy of mitigation of the existing threats Southern Residents already face. We see a necessary implementation of the following mitigation options, coupled with objective and independent scientific monitoring to test their effectiveness, before relying on any of these mitigation measures in the context of the TMX expansion.

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[13] https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/related-information/southern-resident-killer-whale-imminent-threat-assessment.html#toc11
[14] http://www.sararegistry.gc.ca/document/doc1341a/ind_e.cfm

Prey availability

The best available science suggests that Southern Residents require access to approximately 30% more Chinook salmon than the average returns observed during the 1979–2008 period.

Physical and acoustic disturbance from vessels

The effects of acoustic disturbance on Southern Residents are multifaceted. Vessel noise can induce stress, reduce effective foraging habitat, hinder foraging efficacy and prey sharing, and increase energetic demands by altering behaviours often to cease feeding. Our understanding of marine physical acoustics and ocean noise budgets in the Salish Sea are increasing rapidly, and there are a number of reasonable ways to reduce the noise levels from ships (Ayres et al. 2012, Veirs et al. 2018). In contrast, our understandings of the behavioural and ecological effects of noise on killer whale acoustic habitat are lacking, and our understanding of the responses of whales within the complexity of their foraging ecology remains insufficient. For example, slowing ships down can reduce the source level of individual ships, but increase duration of exposure. Given the large variability in behavioural responses of killer whales to ship noise level (Williams et al. 2014), it remains to be seen whether Southern Residents foraging efficiency is improved following suggested measures to reduce transit speeds. For example, the best available science (dose response curves) suggests that Southern Residents may respond to a 3 dB drop in peak noise levels from a slowed ship by being more likely to continue foraging than in the higher peak noise levels received from ship going ~3 knots faster. However, in some cases the slowed ships may also reduce the amount of naturally quiet time experienced by the Southern Residents. If the lower-level ship noise masks the faintest signals the Southern Residents need to detect, like the echo of their own echolocation click from a distant Chinook salmon, the resulting behavioural response to the longer-lasting, lower-level ship noise could be a deleterious one -- like not beginning to forage because their prey can not be detected. We encourage efforts to test whether killer whales feed more when ships slow down and reduce their source level. However, until such measure as this and those suggested below, can be assessed by objective and independent scientific monitoring to test their efficacy, we warn against relying on them as viable mitigation measures, especially in the context of the TMX expansion.

Mitigation measures proposed for TMX: unproven hypotheses that could be tested on existing threats

For each of the three main threats described above, the *status quo* is already untenable/ unsustainable. The best available science already demonstrates the Southern Resident population has a negative population growth with the current level of the threats described. The population lacks resilience to buffer against any additional stressors. Therefore, the proposed TMX-related shipping activities are likely to result in significant adverse effects on the southern resident population.

The direct evidence presented by TMX to NEB in the context of the NEB reconsideration identifies means to (a) improve our knowledge base of Southern Residents and the threats they face, and (b) mitigate impacts of shipping and other activities on the population.[15] We encourage the Government of Canada to test *in situ* some of those proposed mitigation measures on existing threats, before introducing new threats whose significant adverse effects may or may not be able to be mitigated.

The discussion of threats above leads us to conclude that we lack clear dose-response characterisations between the threats and the affects they can have on individual survival, both as an individual stressor and cumulatively. In addition, threats are misrepresented when addressed outside of the wider context of Southern Resident killer whale life history. More work is needed to understand how the effects of each stressor can aggregate for an individual, and the interplay between multiple stressors. Cumulative effects studies may find threats to be additive, synergistic, or antagonistic, with these relationships also likely to change through the course of an individual's lifetime. Multiple *in situ* observations would be needed in addition to the PVA and models described above. Finally, results from individuals must then be applied to a population-wide context. Only then can we consider the best steps to take in mitigating current threats, and consider adding a further stress burden. The addition of stressors, beyond their current levels, before this analysis is complete would likely spell disaster for the Southern Resident killer whale population.

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[15] https://apps.neb-one.gc.ca/REGDOCS/Item/Filing/A95280

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Education

Sep 1998 – Jun 2003 **University of Washington Seattle**
PhD, Oceanography
Seattle, USA

Sep 1995 – Jun 1997 **University of Washington Seattle**
MSc, Oceanography
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Sep 1988 – Jun 1992 **Stanford University**
BS, Earth Systems
Palo Alto, USA

Thesis

Scott R Veirs: *Heat flux and hydrography at a submarine volcano: Observations and models of the Main Endeavour vent field in the northeast Pacific*. 06/2003, Degree: PhD, Supervisor: Russel McDuff

Publication Highlights

Scott R. Veirs, Val Veirs, Jason D. Wood: *Ship noise extends to frequencies used for echolocation by endangered killer whales*. PeerJ 02/2016; 4(3)., DOI:10.7717/peerj.1657

Marla M Holt, Dawn P Noren, Val Veirs, Candice K Emmons, Scott Veirs: *Speaking up: Killer whales (Orcinus orca) increase their call amplitude in response to vessel noise*. The Journal of the Acoustical Society of America 02/2009; 125(1):EL27-32., DOI:10.1121/1.3040028

Research Experience

Jun 1995 – Jun 2003 **Research Assistant, Teaching Assistant**
University of Washington Seattle, School of Oceanography

Journal Publications

Scott R. Veirs, Val Veirs, Jason D. Wood: *Ship noise extends to frequencies used for echolocation by endangered killer whales*. PeerJ 02/2016; 4(3)., DOI:10.7717/peerj.1657

Val Veirs, Scott Veirs, Jason Wood: *Shipping noise signatures*. The Journal of the Acoustical Society of America 05/2011; 129(4)., DOI:10.1121/1.3587664

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Scott Veirs, Val Veirs, Jason D Wood: *Spatial confirmation of vocal communication between a killer whale calf and its natal family*. The Journal of the Acoustical Society of America 06/2008; 123(5):3362., DOI:10.1121/1.2933958

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Scott Veirs, Val Veirs: *Vessel noise measurements underwater in the Haro Strait, WA*. The Journal of the Acoustical Society of America 11/2006; 120(5):3382., DOI:10.1121/1.4781642

Scott R. Veirs, Russell E. McDuff, Frederick R. Stahr: *Magnitude and variance of new bottom horizontal heat flux at the Main Endeavour hydrothermal vent field*. Geochemistry Geophysics Geosystems 02/2006; 70(2)., DOI:10.1029/2005GC000952

Val Veirs, Scott Veirs: *One year of background underwater sound levels in Haro Strait, Puget Sound*. The Journal of the Acoustical Society of America 04/2005; 117(4):2577., DOI:10.1121/1.4776892

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S. R. Veirs, F. R. Stahr, R. E. McDuff, R. E. Thomson, D. R. Yoerger, A. M. Bradley: *Measurements and Models of Heat Flux Magnitude and Variance from the Main Endeavour Hydrothermal Vent Field*.

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Alan C. Mix, W. Rugh, Nicklas G. Pisias, S. Veirs, Leg Scientific Party: *Color Reflectance Spectroscopy: A Tool for Rapid Characterization of Deep Sea Sediments*. DOI:10.2973/odp.proc.ir.138.104.1992

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Val Veirs, Scott Veirs: *Average levels and power spectra of ambient sound in the habitat of southern resident orcas*.

Val Veirs, Scott Veirs: *Salish Sea Hydrophone Network 2007-2008 progress report*.

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EDUCATION

Case Institute of Technology
Cleveland, Ohio, June 1964, BS (Physics)
Illinois Institute of Technology
Chicago, Illinois, June 1969, Ph.D.
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PUBLICATIONS

Proposed metrics for the management of underwater noise for southern resident killer whales. Coastal Ocean Report Series, Heise et. al., Technical Report · August 2017 DOI: 10.25317/CORI20172

A key to quieter seas: half of ship noise comes from 15% of the fleet, Scott Veirs, Val Veirs, Rob Williams, Michael Jasny, Jason Wood, Authorea preprint 03/24/2017 DOI: 10.22541/au.149039726.69540798

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Killer whale scouting: Listen live for troops J, K, and L. Scott R. Veirs, Val R. Veirs, and Jason D. Wood, J. Acoust. Soc. Am. 129, 2538 (2011), DOI:10.1121/1.3588433

Orca hearing weighted decibels: Underwater sound measurements appropriate to studies of Orcinus (killer whales). David Bain, Scott Veirs, and Val Veirs, J. Acoust. Soc. Am. 129, 2607 (2011), DOI:10.1121/1.3588648

Are click rates in killer whales an indicator of group behavior and foraging hotspots? Erica L. Beneze, Jason Wood, Scott Veirs, and Val Veirs, J. Acoust. Soc. Am. 129, 2607 (2011), DOI:10.1121/1.3588650

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Killer whale habitat use and prey fields from remote hydrophones and echosounders. Scott Veirs, Val Veirs, Jason Wood, Brian Moore, Bob McClure, and Bob Otis, J. Acoust. Soc. Am. 125, 2647 (2009), DOI:

Frequency quantiles and dual harmonic tracking for detection and classification of killer whale calls. Val Veirs, J. Acoust. Soc. Am. 125, 2588 (2009), DOI:

Speaking up: Killer whales (Orcinus orca) increase their call amplitude in response to vessel noise Marla M. Holt, Dawn P. Noren, Val Veirs, Candice K. Emmons, and Scott Veirs, J. Acoust. Soc. Am. 125, EL27 (2009), DOI:10.1121/1.3040028

Spatial confirmation of vocal communication between a killer whale calf and its natal family Scott Veirs, Val Veirs, and Jason D. Wood, J. Acoust. Soc. Am. 123, 3362 (2008), DOI:10.1121/1.2933958

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Vessel noise measurements underwater in the Haro Strait, WA Scott Veirs and Val Veirs, J. Acoust. Soc. Am. 120, 3382 (2006), DOI:

One year of background underwater sound levels in Haro Strait, Puget Sound Val Veirs and Scott Veirs, J. Acoust. Soc. Am. 117, 2577 (2005), DOI:

Source levels of free-ranging killer whale (orcinus orca) social vocalizations Val Veirs, J. Acoust. Soc. Am. 116, 2615 (2004), DOI:

POSITIONS – (Last 25 years)

2005-2012	Faculty Member, Beam Reach Marine Science and Sustainability School
2003-2010	Member of Board of Directors of the Whale Museum (President 2005--2010) - Friday Harbor, WA
2008-2016	Member of Board of Directors of the San Juan Nature Institute (Vice President 2005-2010, President 2010-2016) Friday Harbor, WA
1995-1998	Director of Environmental Science at Colorado College
1992-1993	Professor of Physics, University of Indiana - in Malaysia
1988-1992	Chair, Department of Physics, Colorado College
1987-Present	Professor of Physics, Colorado College (currently Emeritus)
1985 (Spring)	Lectures in Artificial Intelligence, Guadalajara and Mexico City, Mexico
1984 (Fall)	Visiting Faculty in Artificial Intelligence, Yale University

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PRESENT POSITION
Imogene P. Johnson Senior Scientist, Bioacoustics Research Program, Cornell Lab,
Senior Scientist Department of Neurobiology and Behavior, Cornell University.

EDUCATION and EMPLOYMENT

Stony Brook University, Stony Brook, NY	B.Sc.	1972	Biology
Stony Brook University, Stony Brook, NY	B.E.	1972	Engineering
Stony Brook University, Stony Brook, NY	M.S.	1974	Electrical Engr.
Stony Brook University, Stony Brook, NY	Ph.D.	1980	Biology
The Rockefeller University, NY, NY	Post. Doc.	1981-83	Bio/Anim. Comm.
The Rockefeller University, NY, NY	Asst. Prof.	1983-87	Bio/Anim. Comm.
Cornell University, Ithaca, NY	Senior Sci.	1987-2017	CLO and NB&B

PROFESSIONAL SOCIETIES
Acoustic Society of America Fellow
Animal Behavior Society
AAAS, IEEE
Explorers Club (FN85)
Society for Marine Mammalogy
Sigma Xi,
Tau Beta Pi

HONORS AND AWARDS
Member, Tau Beta Pi, 1969
President, Tau Beta Pi, Stony Brook Chapter, 1971-1972
National Fellow, Tau Beta Pi, 1972-1973
Biomedical Research Fellowship, 1978, 1979
NIMH Postdoctoral Fellow, 1981-1983
Fellow, Acoustic Society of America, 2000

PROFESSIONAL APPOINTMENTS
1983 - 1987 Assistant Professor, The Rockefeller University, New York, NY
1985 – 2010 U.S. Delegate to the International Whaling Commission Scientific Committee
1987 - 2013 Director Bioacoustics Research Program, The Cornell Lab of Ornithology 2013 - 2017 Senior Scientist, Cornell Lab and Dept. of Neurobiology and Behavior, Cornell University

RECENT AND ONGOING RELEVANT RESEARCH

1996 – present-ongoing: Acoustic monitoring of large whale distributions, behaviors, and movements relative to environmental factors and man-made activities using Navy IUSS assets in the North Atlantic. DoD.

1999 – present-ongoing: Raven: Design, implementation, and distribution of bioacoustics software instrument. NSF and Cornell.

2007 – present-ongoing: Application of near-real-time auto-detection system for large whale acoustic monitoring and mitigation of Northeast Gateway Deepwater Port. Excelerate Energy North America.

2010 – 2015: Portable and persistent autonomous real-time marine mammal acoustic monitoring. NOPP-NSF.

2011 – 2016: DCL System Research Using Advanced Approaches for Land-based or Ship-based Real-Time Recognition and Localization of Marine Mammals. NOPP-ONR.

2011 – 2016: CHAOZ-X - An Ocean Observing System for Monitoring and Mapping Marine Mammals and Noise in the Chukchi Sea Ecosystem. BOEM -NOAA-WHOI.

2013 – 2016: Acoustic ecology of predator-prey interactions: encoding and decoding alarm calls in multispecies communication networks. Collaborative research with Erick Greene, NSF.

PUBLICATIONS

Malige, F., Julie Patris, J., Buchan, S.J., Stafford, K.S., Rendell, L.E., Shabangu, F.W., Findlay, K.P., Hucke-Gaete, R., Neira, S., Clark, C.W., and Herv´e Glotin. 2018. Annual decrease in pulse rate and peak frequency of Southeast Pacific blue whale song type using a new mathematical model of pulsed sound. J. Acoust. Soc. Am.

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Muirhead, C.A., Warde, A.M., Biedron, I.S., Mihnovets, N., Clark, C.W., and Rice, A.R. 2018. Seasonal Acoustic Occurrence of Blue, Fin, and North Atlantic Right Whales in the New York Bight. Aquatic Conservation 1-10.

Cholewiak, D.M., Cerchio, S., Jacobsen, J.K, Urbán J.R., W. Clark, C.W. 2017. Songbird dynamics under the sea: Acoustic interactions between humpback whales suggest song mediates male interactions. R. Soc. Open Sci., 5: 171298. DOI:10.1098.

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Thomisch, K., Boebel, O., Clark, C. W., Spiesecke, S., Zitterbart, D. P., and Van Opzeeland, I. 2016. Spatio-temporal patterns in acoustic presence and distribution of Antarctic blue whales in the Weddell Sea. Endangered Species Research, 30:239-253. doi: 10.3354/esr00739.

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Charif, R. A., Rahaman, A., Muirhead, C. A., Pitzrick, M. S., Warde, A. M., Hall, J. Pyc, C., and Clark, C. W. 2013. Bowhead whale acoustic activity in the southeast Beaufort Sea during late summer 2008-2010. J. Acoust. Soc. Am. 134:4323-4334.

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Morano, J. L., Salisbury, D. P. Rice, A. N., Conklin, K. L., Falk, K. L., and Clark, C. W. 2012b. Seasonal changes in fin whale (Balaenoptera physalus) 20-Hz song in the Western North Atlantic Ocean. J. Acoust. Soc. Am. 132:1207-1212.

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Submitted Papers

Cholewiak, D., Clark, C.W., Frankel, A, Hatch, L., Ponirakis, D., Risch, D., Stanistreet, J., Thompson, M., Vu, E., and Van Parijs S. M. 2017. In Review. Communicating amidst the noise: modeling the aggregate effect of ambient noise and multiple vessel types on the communication space of baleen whales in the Stellwagen Bank National Marine Sanctuary. Endangered Species Research.

Clark, C.W., and Gagnon, G.C. 2017. In Review. Fin Whale Song Decreases with Increased Swimming Speed. R. Soc. Open Sci.

GRADUATE FIELD MEMBERSHIPS

Neurobiology and Behavior
Zoology

GRADUATE MAJORS (serve as chair)

Total Completed

John Bower (NB&B, Ph.D.2000)
Bernard Brennan (NB&B, Ph.D., 2005)
Renata de Sousa Lima Mobley (Zool. - DNR, Ph.D., 2007)
Danielle Cholewiak (NB&B, Ph.D., 2008)
Mya Thompson (NB&B, Ph.D., 2008)

GRADUATE Ph.D. MINORS (member of graduate committee)

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Erin Meyer-Gutbrod (2016)
Peter Marchetto (2015)
Ingrid Biedron (2014)
Dan Pendleton (2009)
Lynn Fletcher (2008)
Yianna Samuel (2007)
Damian Elias (2007)
Andrew Farnsworth (2006)
Leila Hatch (2005)
Karen Fisher (2002)
Hamilton Farris (2000)
Matt Weeg (2001)
Paul Faure (1999)
David Haskell (1998)
Jessica McKibben (1998)
Andrea Lee (1997)
Beth Weisburn (1996)
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Education

2015-2018	University of Victoria Ph.D Department of Geography *Listening to whales: acoustics to ecology*
2010-2012	University of Victoria M.Sc. Department of Geography: *Feeding ecology of Gray whales, Defining the 'Prey-Scape' in Clayoquot Sound on a variety of temporal and spatial scales.*
2005-2009	University of Bath B.Sc. (Hons) Natural Science Honours Thesis: *The environmental influence of scuba diving*

Qualifications

June 2016	Registered Professional Designation (RPBio) gained
August 2014	Aircraft Ditching, Underwater Egress and Sea Survival Course
June 2014	ENFORM Electronic General Safety Orientation
April 2014	BC Forestry Safety Council: Basic Forest Supervisor Training
July 2013	H_2S Alive training
July 2013	Ground Disturbance for Supervisors training
May 2013	Work Safe BC Transportation Endorsement
April 2013	Canada Safety Council Green Defensive Driver training
March 2013	Marine Emergency Duties – A1
March 2013	Wildlife Awareness and Safety training
February 2013	Work Safe BC Occupational First Aid, Level 1
November 2012	AED plus Automated Defibrillator Training
October 2012, May 2014	WHMIS training
March 2011, 2012	Wilderness First Aid
July 2010	CAUS Scientific Diver
April 2010	Small Vessel Operators Permit (SVOP)(Medical Emergency Duties – A3, Radio Operators Certification Marine Commercial, Marine Basic First Aid)
September 2009	Small Pleasure Craft Operators Licence (PCOC)
March 2008	BSAC Open Water Scuba Instructor
February 2008	PADI Master Scuba Diver PADI Open Water Scuba Instructor Emergency First Response Instructor Oxygen Administrator Speciality Instructor
November 2006	BSAC Assistant Instructor (completion of Instructor Foundation Course)
August 2006	PADI Divemaster BSAC Diveleader
September 2004	Duke of Edinburgh Gold Award

Employment

October 2018 onwards	Expert witness for the British Columbia Provincial Government. Collating and evaluating research on the effects of proposed coastal development projects for submission by the Province to the National Energy Board.
Sept. 2015 onwards	Sessional Instructor, Geography Department, University of Victoria. Weekly three-hour sessions discussing the Conservation and Ecology of whales for three-hundred level class. Field course instructor for four-hundred level class in biogeographical field methods, and 'Whale Geography'.
May 2015 onwards	MEOPAR Whale Habitat and Listening Experiment (WHaLE) Research Fellow, and November 2018 onwards as a post-doctoral fellow.
July 2015, July 2016	Lead Instructor, Wildlands Studies Vancouver Island field program. Teaching a two-week field course on marine, intertidal and terrestrial components of Clayoquot Sound, Vancouver Island, Canada.
Jan. 2015 onwards	Continuing Education Instructor, University of Victoria. Teaching a two-part course, each of 5 two-hour evening sessions, on the biology, ecology and physiology, of the marine mammals of British Columbia. Also examined is the history of human-whales interactions and conservation and management techniques. Open to the general public. Also a course on Whale Acoustics, and one-off guest speaker sessions.
Sept. 2012-Sept. 2014	Environmental Scientist, Stantec Consulting Ltd, Victoria, BC. Worked on Projects around Vancouver Island, in northern British Columbia, and Quebec, including collection and analysis of data using subtidal (ROV) and foreshore habitat surveys and assessments, marine environmental monitoring, marine sediment and water sampling, marine mammal surveys and observations, and marine bird surveys. Crew led field programs as well as writing several technical data reports and marine sections for environmental assessments. Also participated in marine mammal observer training sessions for Stantec staff and First Nations participants.

Sept. 2010- May 2012 Jan. 2015 – Present	Teaching Assistant, University of Victoria for Biophysical Systems and the Human Environment, Introduction to Biogeography, Conservation and Ecology of Whales, Coastal Resource management field course, Marine Protected Areas field course, Field Method field course, Geomorphology field course, Hydrology field course, Climatology field course.
Sept. 2010- Present	Science Projects Director and Field Station Coordinator, Society of Ecological and Coastal Research, Ahousaht BC. Manage a year round field research base in a remote site, direct research and intern projects and organise and teach Marine Naturalist training programmes. Acted as liaison between the local community as well as overseeing the day-to-day work of several concurrent projects.
May 2009 – May 2011	Research Assistant, Ocean Technologies Lab University of Bath. Completed analysis of field data, research proposal writing and funding applications. Also was actively involved in several other lab projects, as well as organising a workshop for delegates from Europe and the United States.
Summer 2009, 2010	Volunteer Coordinator and Field Team Leader EarthWatch. Research team lead on field projects in British Columbia, Canada and Baja California, Mexico, and liaison between the volunteers and Principle Investigators. Preparation of field handbooks, briefs, end reports, and funding applications..
June 2007-July 2008	Research Intern Industrial Placement, Sanofi-Aventis, Alnwick. Undertaken as part of Natural Science degree course – conducted research development work within the Molecular and Cellular Toxicology Department of the Alnwick research site. Completed a personal project as well as further study work. Included work in cell culture and proteomics and pathology.

Workshops

Panellist, Public Forum, University of Victoria, ‘The Vancouver Aquarium Uncovered’ hosted by the Faculty of Law, 2018.

Invited Participant/presenter, Workshop on marine mammals as apex predators and ecosystem architects, Society for Marine Mammalogy Biennial Conference, San Francisco, 2015.

Focus Group for the Prevention of Marine Mammal Ship Strikes, Society for Marine Mammalogy Biennial Conference, Dec 5, 2013, Dunedin New Zealand. Can the Cloud Save the Whales?

Invited Participant, Focus Group on Science and Management of Whale-Watching. Society for Marine Mammalogy Biennial Conference, Dec 6, 2013, Dunedin New Zealand

Invited Participant, Gray Whale Scientific Workshop, convened by the California Gray Whale Coalition: Presenter 'Food for Thought: Influence of 'Preyscape' on gray whales of Clayoquot Sound'.

Organiser and Presenter, Marine Naturalist Training. A 3-day training course for whale-watching operators and onboard naturalists, 2010, 2011, 2012, 2014, 2016, 2017 University of Victoria.

Teaching Experience

Sessional Instructor:
Geography 303 – Conservation and ecology of whales: Fall 2015
Geography 474 – Field Studies in Biogeography: Summer 2016
Geography 491 – 'Whale Geography': Summer 2017, 2018
Geography 304 – Coastal Conservation, Spring 2019

Community engagement/Continuing Studies Instructor:
Marine Mammals of British Columbia – Part I– Spring 2015
Marine Mammals of British Columbia – Part II – Fall 2015, 2016
Evolution, Biology, and Ecology of Marine Mammals – Spring 2016, 2018, 2019
Conservation and management issues of marine mammals in British Columbia – Fall 2016
Whale Acoustics: Seeing in the Dark – Spring 2017
Whales, A world of sound – Spring 2018
Wildlands Field Studies – Marine Wildlife and Canadian Coastal Ecosystems – Instructor 2015, 2016
Marine Naturalist Course – Instructor 2010, 2011, 2012, 2014, 2016, 2017
It's not just black and white: the southern resident killer whale story – March 2019

Guest lecturer/instructor:
Geography 101A – Environment, Society and Sustainability: Spring 2016
Geography 103 – Introduction to Physical Geography: Spring 2016, 2017, 2018
Geography 274 – Introduction to Biogeography: Spring 2011, 2012, 2013, 2014, 2015, 2016, 2017
Geography 474 – Field Studies in Biogeography: Summer 2014, 2015, 2016, 2017, 2018
Biology 329 – Biology of the Vertebrates of British Columbia: Spring 2016, 2017, 2018

Teaching Assistant:
Geography 101A – Environment, Society and Sustainability: Fall 2010, 2011
Geography 274 – Introduction to Biogeography: Spring 2011, 2012, 2015
Geography 453 – Field Studies in Coastal and Marine Resources: Summer 2010
Geography 457 – Marine Protected Areas: Summer 2010, 2011, 2012, 2015
Geography 474 – Field Studies in Biogeography: Summer 2010, 2011, 2012, 2015, 2017, 2018
Geography 476 – Advanced Studies in Geomorphology: Summer 2011, 2012, 2015
Geography 491 – Advanced Topics in Geography: Microclimate to Climate Change: Summer 2016

Geography 491 – Advanced Topics in Geography: Exploring Hydrological Processes from Theory to Practice: Summer 2016, 2017

Guest Speaker:
Radio Interview for Whale Research – WDR Cologne - March 2016
Victoria Natural History Society – April 2017
Cowichan Valley Naturalists – September 2017
The Hidden World of Whales – 'A Day at UVic' hosted by Continuing Studies, 2017
Geography Department Colloquim, University of Victoria – December 2017
Invited Panellist – Vancouver Aquarium Uncovered – February 2018
Guest speaker, Grade 7-9, Landmark Elementary, Manitoba, September 2018

Awards

Student Travel Grant – October 2011
UVic Graduate Award – May 2015
UVic Graduate Award – July 2015
Student Travel Grant – October 2015
UVic Graduate Award – Summer 2016
UVic Graduate Award – September 2016
Commander Peter Chance MASC Graduate Fellowship – November 2016
UVic Graduate Award – January 2017
UVic Graduate Award – May 2017
UVic Graduate Award – September 2017
Student Travel Grant – December 2017
UVic Graduate Award – W.R. Derrick Sewell Scholarship
UVic Graduate Award – January 2018
Melva J. Hanson Graduate Award – September 2018
M.A. & D.E. Breckenridge Graduate Award – September 2018

Publications and Presentations

Burnham, R.E, Duffus, D.A., and Mouy, X. 2018. Gray whale (*Eschrichtius robustus*) call types recorded during migration off the west coast of Vancouver Island. Front. Mar. Sci. 5:329 doi: 10.3389/fmars.2018.00329.

Burnham, R.E. 2017. Whale Geography: Biogeography, Acoustics and Whales. Progress in Physical Geography, 41(5): 676-685

Burnham, R.E., K. Meland, and D.A. Duffus. 2017. First record of the marine mysid *Hippacanthomysis platypoda* Murano & Chess, 1987 in coastal waters of British Columbia, Canada. Journal of Crustacean Biology, 37(4): 496–498

Burnham, R.E., R. Palm, D. Duffus, X. Mouy, and A. Riera. 2016. The combined use of visual and acoustic data collection techniques for winter killer whale (*Orcinus orca*) observations. Global Ecology and Conservation, 8:24-30.

Burnham, R.E. and D.A. Duffus. 2016. Gray Whale (*Eschrichtius robustus*) Predation and the Demise of Amphipod Prey Reserves in Clayoquot Sound, British Columbia. Aquatic Mammals, 42 (2) 123-126

Burnham, R.E. 2015. Reproductive strategies conferring species dominance in marinemysid (Mysida, Mysidacea) species in coastal waters off Vancouver Island, B.C. Crustaceana, 88 (12-14) 1421-1438

Burnham, R.E. Using ocean gliders to define whale habitat use of offshore waters o west coast Vancouver Island. Canadian Ocean Science Newsletter, March 2017

Rannakari L., R.E. Burnham, and D.A. Duffus 2018. Diurnal and seasonal acoustic trends in northward migrating eastern Pacific gray whales (*Eschrictius robustus).* Aquatic Mammals, 44(1): 1-6

Duffus D.A, R.E. Burnham, L.J. Feyrer. 2013 Ecology, Scales and Gray whales. Whalewatcher Journal of the American Cetacean Society 42(1): 24-28 Fall 2013.

Burnham, R.E. and D.A. Duffus. Patterns of Predator-Prey Dynamics Between Gray Whales (*Eschrichtius robustus*) and Mysid Species in Clayoquot Sound. *Accepted, International Journal of Cetacean Research and Management, September 2015*

Burnham, R.E. Temporal variation in fin whale calling in Clayoquot Sound and its offshore waters. *Accepted, Northwest Science October 2018*

Burnham, R.E. and Duffus, D.A. Acoustic predator-prey reaction: gray whales (*Eschrichtius robustus*). *Accepted, Aquatic Mammals October 2018.*

Burnham, R.E, Duffus, D.A., Mouy, X. The presence of large whale species in Clayoquot Sound and its offshore waters. *Accepted to Continental Shelf Research November 2018.*

Burnham, R.E. Following the leader? Acoustic cues in gray whale (*Eschrichtius robustus)* migration. *Submitted to Animal Behaviour June 2018*

Burnham, R.E. and D.A. Duffus, Gray whale (*Eschrichtius robustus*) acoustics use in a foraging and weaning area. *Submitted to Journal of Mammalogy August 2018*

Burnham, R.E. The acoustic behaviours of gray whales in increased ambient noise conditions during migration and summer foraging. *Submitted Conservation Science and Practise July 2018*

Burnham, R.E., Duffus, D.A., and Malcom, C.D., Towards an enhanced management scheme for recreational whale watching. *Submitted to Tourism in the Marine Environment July 2018*

Burnham, R.E. Temporal separation in call types found for large baleen whale species in offshore waters of the Canadian Pacific. Presentation at 176th Meeting of the Acoustical Society of America, Victoria, Canada, November 2018.

Howatt T., R.E. Burnham, T. Ross, S. Waterman. Characterizing turbulence and zooplankton distribution in Clayoquot Canyon, a whale habitat. Presented at the Ocean Science Meeting, Portland February 2018

Burnham, R.E and D.A. Duffus. Quiet-no more: The consistent and pervasive use of acoustics by gray whales during migration. Poster presented at the 22nd Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, Halifax Canada, October 2017.

Duffus, D.A. and R.E. Burnham. The canary in a coal mine sings. Poster presented at the 22nd Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, Halifax Canada, October 2017.

Burnham, R.E. and D.A.Duffus. Playing hide and seek with a gray whale. Poster presented at the 21 st Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, San Francisco, December 2015.

Duffus, D.A. and R.E. Burnham. The new face of marine mammal conservation. Poster presented at the 21st Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, San Francisco, December 2015

Burnham, R.E. and D.A. Duffus. Ecological Structures Constructed from Predator-Prey Interplay: Lessons from Gray Whale Residency on a Small, Discrete, Foraging Site on the British Columbia Coast. Invited Presenter at a workshop on the role of apex predators. San Francisco December 2015

Participant ‘Can the Cloud Save the Whales?’, Focus Group for the Prevention of Marine Mammal Ship Strikes, Society for Marine Mammalogy Biennial Conference, Dec 5, 2013, Dunedin New Zealand.

Invited Participant, Focus Group on Science and Management of Whale-Watching. Society for Marine Mammalogy Biennial Conference, Dec 6, 2013, Dunedin New Zealand.

Burnham R.E. and D.A. Duffus 2011. Whale foraging ecology on the west coast of Vancouver Island: Mysid-e of the story. Poster presented at the 19 th Biennial Conference on the Biology of Marine Mammals, Society for Marine Mammalogy, Tampa, Florida. International conference.

Burnham R.E. and C. Tombach-Wright. 2012 *Food for Thought: Influence of ‘Preyscape’ on gray whales of Clayoquot Sound*. Invited speaker at the gray whale workshop hosted by California Gray Whale Coalition, San Francisco March 2012

Burnham R.E. *Whale foraging ecology in Clayoquot Sound, west coast of Vancouver Island*. Plenary Speaker at the Pacific Rim Whale Festival, March 2014,Tofino BC.

Burnham R.E. and C. Tombach-Wright. 2012 *Food for Thought: Influence of ‘Preyscape’ on gray whales of Clayoquot Sound*. Presentation at the gray whale workshop hosted by California Gray Whale Coalition, San Francisco March 2012

Burnham R.E. and W.M. Megill 2010. *Surveys for grey whales on the southern central coast of British Columbia and west coast of Vancouver Island, Summer 2009*. Report prepared for the National Marine Fisheries Service, Seattle, WA.

Burnham R.E., Williamson B.J., and W.M. Megill 2010. *Whales of British Columbia project report - Clayoquot Sound and Cape Caution field research in 2009*. Report prepared for Earthwatch Institute, Oxford.