Southern Resident Killer Whale: Bioenergetics

Bibliography

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Background & Scope

Endangered Southern Resident killer whales face multiple threats, including reduced prey availability and disturbance from vessels, which can impact foraging behavior. Reduced prey acquisition has the potential to impact individual body condition, reproductive success, and survival. Quantifying how Southern Resident killer whale (SRKW) body energy reserves and condition are affected by food vessel exposure and food deprivation is critical to evaluating impacts to the Southern Resident killer whale population.

We will evaluate the consequences (e.g., reduced body condition, reproduction, and survival) of reduced foraging success for endangered Southern Resident killer whales by developing a stochastic life-stage structured bioenergetic model. This bioenergetic model will be parameterized with values derived from a literature search and will allow us to quantitatively evaluate changes in individual body energy stores and condition as a consequence of prey limitation and anthropogenic disturbance. Impacts of both continuous disruptions and infrequent, minor disruptions will be investigated. We will also provide a flexible bioenergetic framework for conducting similar evaluations for other odontocetes (toothed whales, dolphins, and porpoises).

This literature review is split into the following sections: anthropogenic impact, life history and ecology, bioenergetics, body composition, and management. In order to gather all available data there were no limitations placed on publication date.

Section I – Anthropogenic Impact

This section covers the anthropogenic noise of vessels, whale watching interactions and stressors, along with other human origin impacts on killer whales.

Section II – Life History and Ecology

This section covers the general knowledge of killer whales, social and prey/predator relationships, discussion of ecotypes, and some pieces on pollution impacts.

Section III – Bioenergetics, Growth, Body Size

This section covers bioenergetics information, growth, metabolism, and body size from either photography or capture data.

Section IV – Body Composition

This section covers the body composition pieces such as blubber and muscle properties.

Section V – Management

This section covers management plans, stock assessments, and other discussions of protocol for killer whale strandings.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics Web of Science: Science Citation Index Expanded and Social Science Index; ProQuest's Science and Technology; JSTOR; EBSCO's Academic Search Complete; the NOAA Institutional Repository; ASFA; and BioOne. A review of IWC, NOAA, and other relevant organizations both governmental and NGO was also conducted to identify relevant literature. Only English language materials were included.

Section I: Anthropogenic Impact

Ayres, K. L., Booth, R. K., Hempelmann, J. A., Koski, K. L., Emmons, C. K., Baird, R. W., . . . Wasser, S. K. (2012). Distinguishing the Impacts of Inadequate Prey and Vessel Traffic on an Endangered Killer Whale (Orcinus Orca) Population. *PLoS ONE*, 7(6) https://doi.org/10.1371/journal.pone.0036842

Managing endangered species often involves evaluating the relative impacts of multiple anthropogenic and ecological pressures. This challenge is particularly formidable for cetaceans, which spend the majority of their time underwater. Noninvasive physiological approaches can be especially informative in this regard. We used a combination of fecal thyroid (T3) and glucocorticoid (GC) hormone measures to assess two threats influencing the endangered southern resident killer whales (SRKW; Orcinus orca) that frequent the inland waters of British Columbia, Canada and Washington, U.S.A. Glucocorticoids increase in response to nutritional and psychological stress, whereas thyroid hormone declines in response to nutritional stress but is unaffected by psychological stress. The inadequate prey hypothesis argues that the killer whales have become prey limited due to reductions of their dominant prey, Chinook salmon (Oncorhynchus tshawytscha). The vessel impact hypothesis argues that high numbers of vessels in close proximity to the whales cause disturbance via psychological stress and/or impaired foraging ability. The GC and T3 measures supported the inadequate prey hypothesis. In particular, GC concentrations were negatively correlated with short-term changes in prey availability. Whereas, T3 concentrations varied by date and year in a manner that corresponded with more long-term prey availability. Physiological correlations with prey overshadowed any impacts of vessels since GCs were lowest during the peak in vessel abundance, which also coincided with the peak in salmon availability. Our results suggest that identification and recovery of strategic salmon populations in the SRKW diet are important to effectively promote SRKW recovery.

Bain, D. E. (2002). A Model Linking Energetic Effects of Whale Watching to Killer Whale (Orcinus Orca) Population Dynamics. Friday Harbor Laboratories, University of Washington. Retrieved from http://www.orcarelief.org/docs/bain_paper.pdf

[FROM INTRODUCTION] The Southern Resident population of killer whales (Orcinus orca) has declined from a high of 98 in early 1995 to a low of 78 in 2001 (Bain and Balcomb 1999, Balcomb unpublished data). The causes of the decline are not well understood, but have been reported to be primarily due to a decline in food availability and exposure to toxic chemicals (Dahlheim et al. 2000). Whale watching has been raised as one of the other possible causes.

Barrett-Lennard, L., Smith, T. G., & Ellis, G. M. (1996). A Cetacean Biopsy System Using Lightweight Pneumatic Darts, and Its Effect on the Behavior of Killer Whales. *Marine Mammal Science*, 12(1), 14-27 https://doi.org/10.1111/j.1748-7692.1996.tb00302.x

Lightweight untethered pneumatic darts were used to biopsy killer whales, *Orcinus orca*, for genetic and toxicological analysis. Samples of epidermal, dermal, and hypodermal tissue weighing approximately 0.5 g were obtained by 65% of the 91 darts fired during the study. Sufficient DNA for multiple analyses was extracted from the biopsies, which were also used for fatty acid and toxic contaminant analyses. Reactions such as momentary shakes or accelerations were observed after 81% of the dart hits and 53% of the misses. Aversion to the research vessel was assessed by reapproaching target whales after the sampling attempts. In 6% of the hits and 8% of the misses aversion to the research boat increased immediately following the attempt. No similar increases in aversion were seen when killer whales were reapproached one day to one year after being hit. The darts were also tested successfully on humpback whales, *Megaptera novaeangliae*. In view of the simplicity of the system, its effectiveness in acquiring multipurpose samples, and the apparently short-term disturbance it caused, it is recommended for future cetacean biopsy studies.

Best, P. B., & Ross, G. J. B. (1977). Exploitation of Small Cetaceans off Southern Africa. *Report of the International Whaling Commission*, 27, 494-497. Retrieved from https://archive.iwc.int/?r=31&k=fcd4c84583

The intention in this paper is to describe the forms of exploitation of small cetaceans that occur (or have occurred in the immediate past) off Southern Africa, and the methods of control of this exploitation. Small cetaceans are defined as all odontocetes (apart from the sperm whale) and one mysticetc, the pygmy right whale. Where catch figures exist these are given, and what is known of the composition of the catch is included. Other potential or real hazards to stocks of small cetaceans, such as pollution of their environment or the intensive exploitation by man of some of their food species, are not discussed here, though their potential population impact may be far greater than any of the more direct forms of exploitation mentioned in this paper.

Gordon, C. (2018). Anthropogenic Noise and Cetacean Interactions in the 21st Century: A Contemporary Review of the Impacts of Environmental Noise Pollution on Cetacean Ecologies. *University Honors Theses*. Paper 625 https://doi.org/10.15760/honors.636

Anthropogenic noise has been identified as an environmental pollutant since the early 70s and has since been shown to disrupt biologically significant functions of marine life. Recognizing that the world's oceans are undergoing unprecedented change in the 21st Century, this study reviews the most current research related to the interactions between cetaceans and anthropogenic noise in their environment. Working with literature published after 2008, this review contextualizes the direct and indirect impacts of the greatest sources of anthropogenic noise: vessel traffic, seismic seafloor exploration, and sonar, and their effect on cetacean biology and ecology. This review found that vessel noise interferes with the communication and acoustic functions of cetaceans, as well as elicits behavioral responses that disrupt foraging activity and may contribute to the displacement of individuals and populations. Interactions between cetaceans and seismic surveys are similar to those described for vessel noise, with additional risks of temporary or permanent hearing loss due the intensity of the sounds produced. Sonar activities have greater impacts on the acoustic functions of toothed whales, impacting their ability to echolocate, and has been implicated in multiple mass strandings. In cases of mass strandings of deep-diving species, such as beaked whales, decompression sickness is implicated as a potential cause of death and recent studies of North Atlantic right whales have shown that increased environmental noise correlates with increased glucocorticoid stress hormone levels, suggesting that anthropogenic noise has a potentially injurious impact on cetacean physiology.

Grant, S., & Ross, P. (2002). Southern Resident Killer Whales at Risk: Toxic Chemicals in the British Columbia and Washington Environment. *Canadian Technical Report of Fisheries and Aquatic Sciences* (2412), 123. Retrieved from http://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2412-eng.pdf

Southern resident killer whales (Orcinus orca) have recently been described as “among the most contaminated marine mammals in the world”, with levels of polychlorinated biphenyls (PCBs) exceeding those found in the St. Lawrence Beluga whales (Delphinapterus leucas). Killer whales are exposed to a myriad of anthropogenic contaminants, but those of particular concern include the Persistent Organic Pollutants (POPs). These oily chemicals, which include PCBs, dioxins, furans and dichlorodiphenyltrichloroethane (DDT), are persistent in the environment, bioaccumulate in aquatic food chains, and are toxic to biota. As a result of health risks thought to be associated with exposure to these and other toxic chemicals, as well as declining prey (salmon) abundance and heavy vessel traffic, Canada has listed this small population as “endangered”; a similar listing is pending in the United States. Documenting the sources of these chemicals to killer whales is an important basis for mitigative and regulatory steps for chemical usage, as well as precautionary conservation and management measures for the killer whales. Because of the large habitat requirements and high trophic level of killer whales, contaminants to which they are exposed can be considered of local, regional and international origin. The relative importance of regional sources in the Strait of Georgia and Puget Sound to the contamination of these killer whales is unknown, since contaminants can move great distances through biological, hydrological and atmospheric processes. We conducted a broad-based review of available scientific and technical information in order to characterize sources of contaminants that might accumulate in killer whale food chains. Killer whales are likely to face continued health risks associated with exposure to contaminants in the British Columbia – Washington boundary region as a result of the continued environmental cycling, production, release and transport of both “old” and “new” POPs in the North Pacific ecosystem.

Lachmuth, C. L., Barrett-Lennard, L. G., Steyn, D. Q., & Milsom, W. K. (2011). Estimation of Southern Resident Killer Whale Exposure to Exhaust Emissions from Whale-Watching Vessels and Potential Adverse Health Effects and Toxicity Thresholds. *Marine Pollution Bulletin*, 62(4), 792-805 https://doi.org/10.1016/j.marpolbul.2011.01.002

Southern resident killer whales in British Columbia and Washington are exposed to heavy vessel traffic. This study investigates their exposure to exhaust gases from whale-watching vessels by using a simple dispersion model incorporating data on whale and vessel behavior, atmospheric conditions, and output of airborne pollutants from the whale-watching fleet based on emissions data from regulatory agencies. Our findings suggest that current whale-watching guidelines are usually effective in limiting pollutant exposure to levels at or just below those at which measurable adverse health effects would be expected in killer whales. However, safe pollutant levels are exceeded under worst-case conditions and certain average-case conditions. To reduce killer whale exposure to exhaust we recommend: vessels position on the downwind side of whales, a maximum of 20 whale-watching vessels should be within 800 m at any given time, viewing periods should be limited, and current whale-watch guidelines and laws should be enforced.

Lusseau, D., Bain, D. E., Williams, R., & Smith, J. C. (2009). Vessel Traffic Disrupts the Foraging Behavior of Southern Resident Killer Whales Orcinus Orca. *Endangered Species Research*, 6, 211-221 https://doi.org/10.3354/esr00154

Vessel traffic may have contributed to southern resident killer whales Orcinus orca becoming endangered. To determine the importance of this threat, we measured the behavior of southern residents in the presence and absence of vessels from 2003 to 2005 at 2 different sites along San Juan Island, Washington, USA. We observed activity states of killer whale schools using scan sampling and collected information on the number of vessels present at various distances from those. We use first-order, time-discrete Markov chains to estimate state-transition probability matrices under varying boat exposure conditions. Transition probabilities between activity states were significantly affected by vessel traffic. In addition, there was a reduction in time spent foraging, as estimated from the stationary state budget from the Markov chains, confirming an effect also previously observed in northern resident killer whales. If reduced foraging effort results in reduced prey capture, this would result in decreased energy acquisition. Each school was within 400 m of a vessel most of the time during daylight hours from May through September. The high proportion of time southern resident killer whales spend in proximity to vessels raises the possibility that the short-term behavioral changes reported here can lead to biologically significant consequences.

Mongillo, T. M., Holmes, E. E., Noren, D. P., VanBlaricom, G. R., Punt, A. E., O'Neill, S. M., . . . Ross, P. S. (2012). Predicted Polybrominated Diphenyl Ether (PDBE) and Polychlorinated Biphenyl (PCB) Accumulation in Southern Resident Killer Whales. *Marine Ecology Progress Series*, 453, 263-277 https://doi.org/10.3354/meps09658

Persistent organic pollutants (POPs) are anthropogenic contaminants that bioaccumulate in upper trophic level species. Polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) are POPs of particular concern because they can induce immunotoxicity, neurotoxicity, and reproductive impairment. Killer whales Orcinus orca can accumulate high concentrations of POPs because they are long-lived apex predators. Southern resident killer whales (SRKWs) are an endangered fish-eating population that consists of 3 pods (J, K, and L) with a geographic range from central California, USA, to the Queen Charlotte Islands, Canada. An individual-based modeling approach was used to predict the accumulation of sum PBDEs (ΣPBDEs) and sum PCBs (ΣPCBs) in specific individuals in the SRKW population. Model predictions for the current concentrations corresponded closely to the concentrations measured in biopsies collected from known individuals. The predicted ΣPBDE concentrations over the life-span of individual killer whales were consistent with a doubling time of ~3 to 4 yr, highlighting the rapid emergence of PBDEs as a priority concern in these animals. J pod individuals had the highest predicted ΣPBDE and ΣPCB concentrations, likely due to their increased residence time near industrial centers. Modeled historical ΣPCB concentrations did not increase substantially over time or with age in males born after 1970, whereas the ΣPBDE concentrations increased over time and with age. In general, modeled future projections indicated that the average male and female had similar ΣPBDE trends with age, time, and diet scenario. Future ΣPCBs are predicted to slowly decline; however, SRKWs will continue to be exposed for several generations.

Williams, R., Bain, D. E., Smith, J. C., & Lusseau, D. (2009). Effects of Vessels on Behaviour Patterns of Individual Southern Resident Killer Whales Orcinus Orca. *Endangered Species Research*, 6(3), 199-209 https://doi.org/10.3354/esr00150

Southern resident killer whales numbered only 84 ind. in 2004. Disturbance by vessels may be a factor in the population's endangered status. To determine the importance of this factor, we compared behaviour in the presence and absence of vessels from 2003 to 2005 at 2 different sites along San Juan Island, Washington State, USA. Theodolite tracks were summarised in terms of swimming path directness and deviation indices, travel speed, and rates of respiration and surface active display behaviours. Vessel number and proximity were used in a generalised additive modelling framework as candidate explanatory variables for differences in whale behaviour, along with natural factors. Path directness varied with number of vessels and proximity to vessels. The increased distance that whales travelled in the presence of vessels could have resulted in increased energy expenditure relative to whales that could rest while waiting for affected whales to catch up. The likelihood and rate of surface active behaviour varied with number of vessels. Number and proximity of vessels were also related to variability in respiratory intervals, path deviation index and swimming speed. The high proportion of time that southern resident killer whales spend during summer in proximity to vessels raises the possibility that the short-term behavioural changes reported here may have biologically significant consequences.

Williams, R., Trites, A. W., & Bain, D. E. (2002). Behavioural Responses of Killer Whales (Orcinus Orca) to Whale-Watching Boats: Opportunistic Observations and Experimental Approaches. *Journal of Zoology*, 256(2), 255-270 https://doi.org/10.1017/S0952836902000298

Johnstone Strait provides important summer habitat for the northern resident killer whales Orcinus orca of British Columbia. The site is also an active whale-watching area. A voluntary code of conduct requests that boats do not approach whales closer than 100 m to address perceived, rather than demonstrated, effects of boat traffic on killer whales. The purpose of the study was to test the relevance of this distance guideline. Relationships between boat traffic and whale behaviour were studied in 1995 and 1996 by shore-based theodolite tracking of 25 identifiable focal animals from the Population of 209 whales. Individual killer whales were repeatedly tracked in the absence of boats and during approaches by a 5.2 m motorboat that paralleled each whale at 100 m. In addition, whales were tracked opportunistically, when no effort, was made to manipulate boat traffic. Dive times, swim speeds, and surface-active behaviours such as breaching and spy-hopping were recorded. On average, male killer whales swam significantly faster than females. Whales responded to experimental approaches by adopting a less predictable path than observed during the preceding, no-boat period, although males and females used subtle different avoidance tactics. Females responded by swimming faster and increasing the angle between successive dives, whereas males maintained their speed and chose a smooth, but less direct, path. Canonical correlations between whale behaviour and vessel proximity are consistent with these conclusions, which suggest that weakening whale-watching guidelines, or not enforcing them, would result in higher levels of disturbance. High variability in whale behaviour underscores the importance of large sample size and extensive experimentation when assessing the impacts of human activity on killer whales.

Section II: Life History & Ecology

Allen, S., & Flannery, M. (2014). Orcas of the California Coast: Deciphering the Culture of Killer Whales. *Bay Nature Magazine.* Retrieved from https://baynature.org/article/orcas-california-coast-deciphering-culture-killer-whales/

Magazine article discussing strandings and necropsy of killer whale O319 off Point Reyes, CA.

Baird, R. W. (2000). The Killer Whale: Foraging Specializations and Group Hunting. In Cetacean Societies: Field Studies of Dolphins. Janet Mann, Richard C. Connor, & H. Whitehead (Eds.), (pp. 127-153). Chicago, IL: The University of Chicago Press. Retrieved from http://www.cascadiaresearch.org/staff/robin-baird/robin-w-baird-publications

Among the cetaceans, killer whales (Orcinus orca - Figure 6.1) exhibit several unusual features related to social organization, ecology and behavior. Perhaps the most striking are dispersal patterns. For two so-called "resident" populations in the eastern North Pacific (numbering about 200 and 89 individuals, respectively, as of 1998), neither sex has been recorded dispersing (neither locational nor social dispersal - cf. Isbell and van Vuren 1996) from their natal groups over a 21 year period, nor has immigration into a group been recorded (Bigg et al. 1990a). Natal philopatry by both sexes has not been positively documented for any other population of cetacean, or for that matter, for any other species of mammal. Individuals from "resident" populations feed on fish, and individuals from another, sympatric population, termed "transients," specialize on marine mammal prey. These two forms were termed resident and transient based on research in the 1970s (Bigg et al. 1976; Bigg 1982). These names have been subsequently shown to not be particularly descriptive of the movement patterns and site fidelity of the two forms (Guinet 1990; Baird et al. 1992), but they have been retained as the common names. One apparent consequence of the differences in diet are differences in dispersal patterns. Resident killer whales travel in long-term stable groups comprised of several maternal lineages (Bigg et al. 1990a). However, among transients, all female offspring and all but one male offspring seem to disperse from their maternal groups (social dispersal), but dispersing offspring continue to use their natal range (locational philopatry) (Baird 1994). Besides the difference in diet, resident and transient killer whales also differ in behavior, acoustics, morphology, pigmentation patterns, and genetics (Table 6.1, Figure 6.2). Foraging specializations appear to occur in killer whale populations elsewhere, though research efforts have been generally insufficient to determine whether, similar to the N. Pacific, sympatric forms specialize on different prey types. Individuals of some southern ocean populations feed almost exclusively on marine mammals (Hoelzel 1991; Guinet 1991a; Baird et al. 1992). Predation on marine mammals makes the study of foraging behavior easier than perhaps for any other species of cetacean, because the prey are large, breathe at the surface, and are often captured close to, or even on shore. Several interesting findings have come from these studies, including apparent teaching of hunting skills to offspring (Lopez and Lopez 1985; Guinet 1991b; Hoelzel 1991), and also a strong relationship between group size and foraging success in one population (Baird and Dill 1996). Other studies have demonstrated features for killer whales which appear to be unusual among mammals in general, including the presence of some females who live 20 or more years beyond the birth of their last known offspring (Olesiuk et al. 1990), and the occurrence of group-specific vocal dialects within killer whale populations (Ford and Fisher 1983; Strager 1995). In this paper I review the general biology of killer whales, focusing on several longitudinal studies on free ranging animals. Information on feeding habits, ranging patterns, and social organization and behavior are emphasized.

Barbieri, M. M., Raverty, S., Bradley Hanson, M., Venn-Watson, S., Ford, J. K. B., & Gaydos, J. K. (2013). Spatial and Temporal Analysis of Killer Whale (Orcinus Orca) Strandings in the North Pacific Ocean and the Benefits of a Coordinated Stranding Response Protocol. *Marine Mammal Science*, 29(4), E448-E462 https://doi.org/10.1111/mms.12044

Killer whales (Orcinus orca) are widely distributed throughout the world's oceans, yet little has been documented about their stranding patterns. Knowledge of stranding patterns improves our ability to examine and sample carcasses and provides a foundation for understanding killer whale natural history, diet, reproduction, anthropogenic stressors, emerging diseases, and patterns of unusual mortality. We compiled published and unpublished killer whale stranding data to describe stranding patterns in the North Pacific Ocean. Between 1925 and 2011, 371 stranded killer whales were reported in Japan (20.4%), Russia (3.5%), Alaska (32.0%), British Columbia (27.4%), Washington (4.0%), Oregon (2.7%), California (5.1%), Mexico (3.8%), and Hawaii (0.8%). Strandings occurred at all times of year, but regionally specific seasonal differences were observed. Mortality and annual census data from Northern and Southern Resident populations were extrapolated to estimate that across the North Pacific, an average of 48 killer whales die annually. However, over the last two decades, an average of only 10 killer whale carcasses were recovered annually in this ocean, making each event a rare opportunity for study. Publication of a standardized killer whale necropsy protocol and dedicated funding facilitated the number of complete postmortem necropsies performed on stranded killer whales from 1.6% to 32.2% annually.

Chasco, B., Kaplan, I. C., Thomas, A., Acevedo-Gutiérrez, A., Noren, D., Ford, M. J., . . . Ward, E. J. (2017). Estimates of Chinook Salmon Consumption in Washington State Inland Waters by Four Marine Mammal Predators from 1970 to 2015. *Canadian Journal of Fisheries and Aquatic Sciences*, 74(8), 1173-1194 https://doi.org/10.1139/cjfas-2016-0203

Conflicts can arise when the recovery of one protected species limits the recovery of another through competition or predation. The recovery of many marine mammal populations on the west coast of the United States (U.S.) has been viewed as a success; however, within Puget Sound in Washington State (U.S.) the increased abundance of three protected pinniped species may be adversely affecting the recovery of threatened Chinook salmon (Oncoryhnchus tshawytchsa) and endangered killer whales (Orcinus orca) within the region. Between 1970 and 2015, we estimate the annual biomass of Chinook salmon consumed by pinnipeds has increased from 68 to 625 metric tons. Converting juvenile Chinook salmon into adult equivalents, we found that by 2015 pinnipeds consumed double that of resident killer whales, and six times greater than the combined commercial and recreational catches. We demonstrate the importance of interspecific interactions when evaluating species recovery. As more protected species respond positively to recovery efforts, managers should attempt to evaluate trade-offs between these recovery efforts and the unintended ecosystem consequences of predation and competition on other protected species.

de Bruyn, P. J., Tosh, C. A., & Terauds, A. (2013). Killer Whale Ecotypes: Is There a Global Model? *Biological Reviews of the Cambridge Philosophical Society*, 88(1), 62-80 https://doi.org/10.1111/j.1469-185X.2012.00239.x

Killer whales, Orcinus orca, are top predators occupying key ecological roles in a variety of ecosystems and are one of the most widely distributed mammals on the planet. In consequence, there has been significant interest in understanding their basic biology and ecology. Long-term studies of Northern Hemisphere killer whales, particularly in the eastern North Pacific (ENP), have identified three ecologically distinct communities or ecotypes in that region. The success of these prominent ENP studies has led to similar efforts at clarifying the role of killer whale ecology in other regions, including Antarctica. In the Southern Hemisphere, killer whales present a range of behavioural, social and morphological characteristics to biologists, who often interpret this as evidence to categorize individuals or groups, and draw general ecological conclusions about these super-predators. Morphologically distinct forms (Type A, B, C, and D) occur in the Southern Ocean and studies of these different forms are often presented in conjunction with evidence for specialised ecology and behaviours. Here we review current knowledge of killer whale ecology and ecotyping globally and present a synthesis of existing knowledge. In particular, we highlight the complexity of killer whale ecology in the Southern Hemisphere and examine this in the context of comparatively well-studied Northern Hemisphere populations. We suggest that assigning erroneous or prefatory ecotypic status in the Southern Hemisphere could be detrimental to subsequent killer whale studies, because unsubstantiated characteristics may be assumed as a result of such classification. On this basis, we also recommend that ecotypic status classification for Southern Ocean killer whale morphotypes be reserved until more evidence-based ecological and taxonomic data are obtained.

Duffield, D. A., Odell, D. K., McBain, J. F., & Andrews, B. (1995). Killer Whale (Orcinus Orca) Reproduction at Sea World. *Zoo Biology*, 14(5), 417-430 https://doi.org/10.1002/zoo.1430140504

Sea World has maintained killer whales (Orcinus orca) since 1965. The total killer whale inventory (1965-1993) has included 39 whales (25 females, 14 males); 28 were wild-caught and 11 captive-born, including one second-generation calf. As of September, 1993, there were 19 whales in the breeding program. Ten of these whales (53%) were captive-born, either at Sea World or other facilities in North America. The live wild-caught whales ranged in estimated age from 12-27 years (x ± sd = 17.6 ± 4.2 years). The captive-born whales ranged in age from <1 to 8 years. In the Sea World breeding program (through September, 1993), there have been nine live births and one stillbirth, with eight calves part of the current inventory. Births occurred from July to February. Calving intervals ranged from 32-58 months. Female age at birth of first calves ranged from 8 years to an estimated 17 years (x? ± sd = 12.7 ± 3.0 years). Gestation, based on conception estimates from serum progesterone analysis, averaged 17 months (x? ± sd = 517 ± 20 days), but successful pregnancies with viable calves occurred from 15?18 months (468?539 days). Females, in the presence and absence of males, were polyestrus with periods of cycling interspersed with individually variable noncycling (presumed anestrous) periods ranging from 3-16 months. Mean serum progesterone levels (±se) were as follows: noncycling periods = 121 ± 20 pg/ml; peak elevations during nonconceptive ovulatory (estrous) cycles = 3,962 ± 2,280 pg/ml; first pregnancies = 14,592 ± 3,854 pg/ml; second pregnancies = 8,389 ± 395 pg/ml; and third pregnancy = 8,180 ± 4,556.

Durban, J. W., Fearnbach, H., Burrows, D. G., Ylitalo, G. M., & Pitman, R. L. (2017). Morphological and Ecological Evidence for Two Sympatric Forms of Type B Killer Whale around the Antarctic Peninsula. *Polar Biology*, 40(1), 231-236 https://doi.org/10.1007/s00300-016-1942-x

Killer whales (Orcinus orca) are apex marine predators in Antarctica, but uncertainty over their taxonomic and ecological diversity constrains evaluations of their trophic interactions. We describe two distinct, sympatric forms sharing the characteristic pigmentation of Type B, the most common around the Antarctic Peninsula. Laser photogrammetry revealed nonoverlapping size differences among adults: Based on a body length index (BLI: blowhole to dorsal fin) adult females of the larger form ("B1") were 20 % longer than the smaller form ("B2"), and adult males were 24 % longer on average. Dorsal fins of B1 adult females were 19 % taller than B2 females, and adult males 32 % taller. Both types were strongly sexually dimorphic, but B1 more so, including for BLI (B1 males = 1.07× females; B2 = 1.05×) and especially for dorsal fin height (B1 male fins = 2.33× female; B2 = 2.10×). The characteristically large Type B eye patch was more extensive for B1 than B2, comprising 41 and 37 % of BLI, respectively. Average group size was also significantly different, with B1s in smaller groups (mean 7, range 1–14) and B2s more gregarious (mean 36, range 8–75). Stable isotope analysis of skin biopsies indicated dietary differences: a significantly lower nitrogen 15N/14N ratio in B2s supported observations of feeding primarily on krill consumers (e.g., pygoscelid penguins), while B1s prey mainly on predators of krill consumers (e.g., Weddell seals Leptonychotes weddellii). These differences likely represent adaptations to distinct foraging niches, which has led to genetic divergence; their ecology now needs further study.

Ford, J. K., Ellis, G. M., Olesiuk, P. F., & Balcomb, K. C. (2010). Linking Killer Whale Survival and Prey Abundance: Food Limitation in the Oceans' Apex Predator? *Biology Letters*, 6(1), 139-142 https://doi.org/10.1098/rsbl.2009.0468

Killer whales (Orcinus orca) are large predators that occupy the top trophic position in the world's oceans and as such may have important roles in marine ecosystem dynamics. Although the possible top-down effects of killer whale predation on populations of their prey have received much recent attention, little is known of how the abundance of these predators may be limited by bottom-up processes. Here we show, using 25 years of demographic data from two populations of fish-eating killer whales in the northeastern Pacific Ocean, that population trends are driven largely by changes in survival, and that survival rates are strongly correlated with the availability of their principal prey species, Chinook salmon (Oncorhynchus tshawytscha). Our results suggest that, although these killer whales may consume a variety of fish species, they are highly specialized and dependent on this single salmonid species to an extent that it is a limiting factor in their population dynamics. Other ecologically specialized killer whale populations may be similarly constrained to a narrow range of prey species by culturally inherited foraging strategies, and thus are limited in their ability to adapt rapidly to changing prey availability.

Ford, J. K. B., & Ellis, G. M. (2006). Selective Foraging by Fish-Eating Killer Whales Orcinus Orca in British Columbia. *Marine Ecology Progress Series*, 316, 185-199 https://doi.org/10.3354/meps316185

As the apex non-human marine predator, the killer whale Orcinus orca feeds on a wide diversity of marine fauna. Different ecotypic forms of the species, which often exist in sympatry, may have distinct foraging specialisations. One form found in coastal waters of the temperate NE Pacific Ocean, known as the 'resident' ecotype, feeds predominantly on salmonid prey. An earlier study that used opportunistic collection of prey remains from kill sites as an indicator of predation rates suggested that resident killer whales may forage selectively for chinook salmon Oncorhynchus tshawytscha, the largest but one of the least abundant Pacific salmon species. Potential biases in the prey fragment sampling technique, however, made the validity of this finding uncertain. We undertook field studies of foraging behaviour of resident killer whales to resolve this uncertainty and to examine potential variation in prey selection by season, geographical area, group membership and prey availability. Foraging by resident killer whales was found to frequently involve sharing by 2 or more whales. Prey fragments left at kill sites resulted mostly from handling and breaking up of prey for sharing, and all species and sizes of salmonids were shared. Resident killer whale groups in all parts of the study area foraged selectively for chinook salmon, probably because of the species' large size, high lipid content, and year-round availability in the whales' range. Chum salmon Oncorhynchus keta, the second largest salmonid, were also taken when available, but smaller sockeye O. nerka and pink O. gorbuscha salmon were not significant prey despite far greater seasonal abundance. Strong selectivity for chinook salmon by resident killer whales probably has a significant influence on foraging tactics and seasonal movements, and also may have important implications for the conservation and management of both predator and prey.

Ford, M. J., Hanson, M. B., Hempelmann, J. A., Ayres, K. L., Emmons, C. K., Schorr, G. S., . . . Balcomb-Bartok, K. (2011). Inferred Paternity and Male Reproductive Success in a Killer Whale (Orcinus Orca) Population*.* *Journal of Heredity*, 102(5), 537-553 https://doi.org/10.1093/jhered/esr067

We used data from 78 individuals at 26 microsatellite loci to infer parental and sibling relationships within a community of fish-eating ("resident") eastern North Pacific killer whales (Orcinus orca). Paternity analysis involving 15 mother/calf pairs and 8 potential fathers and whole-pedigree analysis of the entire sample produced consistent results. The variance in male reproductive success was greater than expected by chance and similar to that of other aquatic mammals. Although the number of confirmed paternities was small, reproductive success appeared to increase with male age and size. We found no evidence that males from outside this small population sired any of the sampled individuals. In contrast to previous results in a different population, many offspring were the result of matings within the same "pod" (long-term social group). Despite this pattern of breeding within social groups, we found no evidence of offspring produced by matings between close relatives, and the average internal relatedness of individuals was significantly less than expected if mating were random. The population's estimated effective size was <30 or about 1/3 of the current census size. Patterns of allele frequency variation were consistent with a population bottleneck.

Ford, M. J., Hempelmann, J., Hanson, M. B., Ayres, K. L., Baird, R. W., Emmons, C. K., . . . Park, L. K. (2016). Estimation of a Killer Whale (Orcinus Orca) Population's Diet Using Sequencing Analysis of DNA from Feces. *PLoS ONE*, 11(1) https://doi.org/10.1371/journal.pone.0144956

Estimating diet composition is important for understanding interactions between predators and prey and thus illuminating ecosystem function. The diet of many species, however, is difficult to observe directly. Genetic analysis of fecal material collected in the field is therefore a useful tool for gaining insight into wild animal diets. In this study, we used high-throughput DNA sequencing to quantitatively estimate the diet composition of an endangered population of wild killer whales (Orcinus orca) in their summer range in the Salish Sea. We combined 175 fecal samples collected between May and September from five years between 2006 and 2011 into 13 sample groups. Two known DNA composition control groups were also created. Each group was sequenced at a ~330bp segment of the 16s gene in the mitochondrial genome using an Illumina MiSeq sequencing system. After several quality controls steps, 4,987,107 individual sequences were aligned to a custom sequence database containing 19 potential fish prey species and the most likely species of each fecal-derived sequence was determined. Based on these alignments, salmonids made up >98.6% of the total sequences and thus of the inferred diet. Of the six salmonid species, Chinook salmon made up 79.5% of the sequences, followed by coho salmon (15%). Over all years, a clear pattern emerged with Chinook salmon dominating the estimated diet early in the summer, and coho salmon contributing an average of >40% of the diet in late summer. Sockeye salmon appeared to be occasionally important, at >18% in some sample groups. Non-salmonids were rarely observed. Our results are consistent with earlier results based on surface prey remains, and confirm the importance of Chinook salmon in this population's summer diet.

Geptner, V. G., Nasimovich, A. A., Bannikov, A. G. e., Hoffmann, R. S., & Sludskiĭ, A. A. (1996). Mammals of the Soviet Union (Vol. 2, pt. 3, pp.680-695). Smithsonian Institution Libraries and National Science Foundation. Retrieved from https://archive.org/details/mammalsofsov231996gept/page/682

Book section on killer whale biology.

Guinet, C., Domenici, P., de Stephanis, R., Barrett-Lennard, L., Ford, J. K. B., & Verborgh, P. (2007). Killer Whale Predation on Bluefin Tuna: Exploring the Hypothesis of the Endurance-Exhaustion Technique. *Marine Ecology Progress Series*, 347, 111-119 https://doi.org/10.3354/meps07035

Killer whales *Orcinus orca* occur in the area of the Strait of Gibraltar, where they prey on migrating bluefin tuna *Thunnus thynnus*. In the spring, killer whales were observed to chase tuna for up to 30 min at a relatively high sustained speed (3.7 ± 0.2 m s^{-1}) until they captured them. Using simple models based on previous locomotor performance data on killer whales and thunnids, we investigated the hypothesis that killer whales push tuna beyond their aerobic limits to exhaust and capture them. To test this hypothesis, the endurance of bluefin tuna was estimated from data on maximum burst and aerobic swimming available for bluefin and yellowfin tuna *T. albacares*. The endurance performance of killer whales was evaluated on the basis of the maximal rate of oxygen uptake during exercise (V_{O2max}). We modelled the maximum aerobic power output for a killer whale according to swimming speed using a V_{O2max} ranging between 20 and 30 ml O_2 kg^{-1} min^{-1}. The output of this model was compared to the observed sustained swimming speed of killer whales chasing prey over long durations. Our results support the hypothesis that killer whales may use an endurance-exhaustion technique to catch small to medium sized (up to 0.8 to 1.5 m) bluefin tuna, while larger tuna may be inaccessible to killer whales unless they use cooperative hunting techniques or benefit through depredation of fish caught on long lines, drop lines or trap nets.

Hall, A. J., & Williams, R. (2015). The Potential Effect of PCBs on Killer Whales – Using the 'SPOC' Individual Based Pollution Model Approach to Estimate Impacts on Population Growth. Sea Mammal Research Unit Scottish Oceans Institute, University of St. Andrews. SC/66a/E/2. Retrieved from https://archive.iwc.int/?r=5598&k=461acc0203

Preliminary results of simulations, using the IWC Pollution 2020 'SPOC' individual based pollution model to explore the effects of PCBs on Pacific killer whales populations, found that the potential population growth rate of Northern resident killer whales (NRKW) would only be substantially affected, through effects of PCBs on calf survival and immunity, when a high proportion of the population were subsequently exposed to a newly introduced pathogen. An annual accumulation of ~1 mg/kg total PCBs resulted in levels in the adult females comparable to the published empirical data (<10 mg/kg lipid weight total PCBs). However, for the Southern resident killer whale (SRKW) population, the model simulations suggested they were experiencing a substantially higher accumulation of approximately 5 mg/kg total PCBs per year as this level was required to produce concentrations in the adult females that were similar to the published empirical data (~ 50 m/kg lipid weight). At this level, in all scenarios where immune effects were also considered, population growth rates (lambda) estimates fell to <1.0, suggesting that PCB exposure could result in a declining population at various levels of introduced pathogen exposure. However, if the accumulation of PCBs declined by 1% per annum after year 50 of 100 years of simulated populations, this would result in a stationary population with lambda ~ 1.0. This modelling approach has been taken to assist in assessing the risks of PCB exposure to killer whale populations under various exposure conditions. However, not all the drivers of population change have been considered and these simulations are likely to represent worst case scenarios. The concentration (dose) response functions embedded in the model are based on laboratory animal data and are therefore not species specific. In addition, direct effects of PCBs on fecundity are not considered here and density dependence is not taken into account. Thus, the results should be interpreted as impacts on potential rather than realised population growth. Interactions with other stressors, anthropogenic noise, contaminants and disease agents, effects of historical exploitation on the population and prey availability, to give just a few examples, would all need to be considered alongside the PCB contaminants as critical factors affecting vital rates and therefore population dynamics.

Hanson, M. B., Baird, R. W., Ford, J. K., Hempelmann-Halos, J., Van Doornik, D. M., Candy, J. R., . . . Ayres, K. L. (2010). Species and Stock Identification of Prey Consumed by Endangered Southern Resident Killer Whales in Their Summer Range. *Endangered Species Research*, 11(1), 69-82 https://doi.org/10.3354/esr00263

Recovery plans for endangered southern resident killer whales Orcinus orca have identified reduced prey availability as a risk to the population. In order to better assess this risk, we studied prey selection from 2004 to 2008 in 2 regions of the whales' summer range: San Juan Islands, Washington and the western Strait of Juan de Fuca, British Columbia. Following the whales in a small boat, we collected fish scales and tissue remains from predation events, and feces, using a fine mesh net. Visual fish scale analysis and molecular genetic methods were used to identify the species consumed. Chinook salmon, a relatively rare species, was by far the most frequent prey item, confirming previous studies. For Chinook salmon prey, we used genetic identification methods to estimate the spawning region of origin. Of the Chinook salmon sampled, 80 to 90% were inferred to have originated from the Fraser River, and only 6 to 14% were inferred to have originated from Puget Sound area rivers. Within the Fraser River, the Upper Fraser, Middle Fraser, South Thompson River and Lower Fraser stocks were inferred to currently be sequentially important sources of Chinook salmon prey through the summer. This information will be of significant value in guiding management actions to recover the southern resident killer whale population.

Heyning, J. E., & Dahlheim, M. E. (1988). Orcinus Orca. *Mammalian Species* (304), 1-9 https://doi.org/10.2307/3504225

Brief overview of killer whale biology, ecology, behavior, distribution, etc.

Krahn, M. M., Pitman, R. L., Burrows, D. G., Herman, D. P., & Pearce, R. W. (2008). Use of Chemical Tracers to Assess Diet and Persistent Organic Pollutants in Antarctic Type C Killer Whales. *Marine Mammal Science*, 24(3), 643-663 https://doi.org/10.1111/j.1748-7692.2008.00213.x

Measuring chemical tracers in tissues of marine predators provides insight into the prey consumed and the predator's contaminant exposure. In this study, samples from Type C killer whales (Orcinus orca) biopsied in Antarctica were analyzed for chemical tracers (i.e., stable isotopes of carbon and nitrogen, fatty acids, and persistent organic pollutants [POPs]). Profiles of these individual tracers were very different from those of killer whale populations that have been studied in the eastern North and eastern Tropical Pacific. For example, $\delta^{13}C$and $\delta^{15}N$ stable isotope values and most POP concentrations were significantly lower in the Antarctic population. In addition, multivariate statistical analyses of both fatty acid and POP profiles found distinctly different patterns for Antarctic Type C whales compared to those from whales in the other populations. Similar assays were conducted on four species of Antarctic marine fish considered potential prey for Type C killer whales. Results were consistent with a diet of fish for Type C whales, but other species (e.g., low trophic-level marine mammals or penguins) could not be eliminated as supplemental prey.

Luksenburg, J. A. (2012). The Cetaceans of Aruba: A Multidisciplinary Study. Thesis (Ph.D.), George Mason University. Retrieved from https://wrlc-gm.primo.exlibrisgroup.com/discovery/fulldisplay?docid=alma9930549803404105&context=L&vid=01WRLC_GML:01WRLC_GML&search_scope=MyInst_and_CI&tab=Everything&lang=en

The Caribbean region is one of the world's biodiversity hotspots and it supports at least 29 species of marine mammals (cetaceans). However, the marine environment of the Caribbean region is highly impacted by human activities. Knowledge of the marine mammals inhabiting the Caribbean Sea is fragmentary and the distribution and movement patterns of most of those species have not yet been described. Aruba is one of the most densely populated islands in the Caribbean, situated in the southern Caribbean and part of the lesser Antilles. Its cetaceans have never been subject to study. This dissertation describes the marine mammals of Aruba from a number of angles: their occurrence and distribution, their morphology and identification, their external injuries, and human attitudes towards the marine mammals of Aruba. Data were collected in 2010 and 2011 (i) from 19,721 km of boat based surveys, (ii) from tissue samples of stranded whales, and (iii) during questionnaire surveys (n = 402) of resident Arubans and tourists. My studies document 16 species of whales and dolphins in Aruban waters, of which two species occur year-round (Paper I), whereas only three species had been documented previously for the island. One of the species newly documented for Aruba was the killer whale (Orcinus orca), which was very poorly known in the Caribbean. In Paper II, we show that killer whales are found throughout the Caribbean region and in all months of the year. A diversity of prey items was recorded, ranging from fish to sea turtles and marine mammals. A preliminary morphological analysis suggests that some Caribbean killer whales share a combination of characters typical of Type 2 in the North Atlantic, whereas others share those typical of `offshore' killer whales in the northwest Pacific. In Paper III, we document the first records of Bryde's whale (Balaenoptera brydei) for Aruba using molecular identification techniques. In Paper IV, I quantify the external injuries of Atlantic spotted dolphin (Stenella frontalis), bottlenose dolphin (Tursiops truncatus) and false killer whale (Pseudorca crassidens). Multiple types of human-related injuries were observed. This study indicates that fishing gear and propeller hits may pose threats to local populations of these species. Bite wounds of cookiecutter sharks (Isistius sp.) were recorded on all three species, and include the first documented record of a cookiecutter shark bite in Atlantic spotted dolphin. Paper V describes the results of the questionnaire survey. This study shows that there was high overall concern among tourists and resident Arubans regarding threats to local marine mammals. Most participants would support more stringent legislation for protecting marine mammals in Aruba. A large proportion of the participants were interested in and willing to pay for viewing marine mammals. Both groups preferred to see marine mammals in the wild rather than in captivity. This may provide input for ongoing debates about the feasibility and desirability of building a dolphinarium on Aruba.

Lundin, J., Ylitalo, G., Giles, D., Seely, E., Parsons, K., Hempelmann, J., . . . Wasser, S. (2018). The Threat of Toxic Contaminants to Southern Resident Killer Whales: Monitoring POPS and PAHS in Scat Samples. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/39/ [Abstract Only]

The Southern Resident killer whale population (SRKW; Orcinus orca) feed primarily on Chinook salmon, which is currently their primary source of exposure to toxics. We measured lipophilic persistent organic pollutants (POPs: PBDEs, PCBs, and DDTs) in SRKW scat (fecal) samples to quantify variations in toxicant levels by pod, sex, and reproductive class, as well as prey availability. We also measured polycyclic aromatic hydrocarbons (PAHs), which do not generally bioaccumulate and would reflect recent exposure to oil, engine (combustion) exhaust, among other potential exposure sources. Samples were collected using detection dogs that use scent to locate fresh SRKW scat on the water's surface. We collected 267 samples during four 5-month study periods between 2010 and 2013. POP levels in scat had expected trends, such as increasing with age and decreasing by number of calves (for adult females). POPs were also highest when the whales primary prey source was at low seasonal abundance, presumably due to metabolizing endogenous lipid stores. By contrast, overall measures of PAHs were low (<5 ppb, wet weight), as expected. However, PAHs indicative of motor exhaust versus oil exposure were relatively high prior to implementation of guidelines aimed at increasing vessel distances to the whales. Results point to the value of monitoring POPs by age, sex and reproductive class and in relation to changes in prey abundance to help identify what reproductive classes are most at risk to high toxic loads, what season the liability is greatest, and whether prey recovery and clean up efforts are working. The PAH exposure data will be available as baseline in SRKW feces in relation to environmental events over time, such as the circumstance of an oil spill in the Salish Sea. Addressing toxics and other vulnerabilities is important for SRKW recovery.

Miller, P. J. O., Samarra, F. I. P., & Perthuison, A. D. (2007). Caller Sex and Orientation Influence Spectral Characteristics of "Two-Voice" Stereotyped Calls Produced by Free-Ranging Killer Whales. *Journal of the Acoustical Society of America*, 121(6), 3932-3937 https://doi.org/10.1121/1.2722056

This study investigates how particular received spectral characteristics of stereotyped calls of sexually dimorphic adult killer whales may be influenced by caller sex, orientation, and range. Calls were ascribed to individuals during natural behavior using a towed beamforming array. The fundamental frequency of both high-frequency and low-frequency components did not differ consistently by sex. The ratio of peak. energy within the fundamental of the high-frequency component relative to summed peak energy in the first two low-frequency component harmonics, and the number of modulation bands off the high-frequency component, were significantly greater when whales were oriented towards the array, while range and adult sex had little effect. In contrast, the ratio of peak energy in the first versus second harmonics of the low-frequency component was greater in calls produced by adult females than adult males, while orientation and range had little effect. The dispersion of energy across harmonics has been shown to relate to body size or sex in terrestrial species, but pressure effects during diving are thought to make such a signal unreliable in diving animals. The observed spectral differences by signaler sex and orientation suguest that these types of information may be transmitted acoustically by freely diving killer whales.

Morin, P. A., Archer, F. I., Foote, A. D., Vilstrup, J., Allen, E. E., Wade, P., . . . Harkins, T. (2010). Complete Mitochondrial Genome Phylogeographic Analysis of Killer Whales (Orcinus Orca) Indicates Multiple Species. *Genome Research*, 20(7), 908-916 https://doi.org/10.1101/gr.102954.109

Killer whales (Orcinus orca) currently comprise a single, cosmopolitan species with a diverse diet. However, studies over the last 30 yr have revealed populations of sympatric "ecotypes" with discrete prey preferences, morphology, and behaviors. Although these ecotypes avoid social interactions and are not known to interbreed, genetic studies to date have found extremely low levels of diversity in the mitochondrial control region, and few clear phylogeographic patterns worldwide. This low level of diversity is likely due to low mitochondrial mutation rates that are common to cetaceans. Using killer whales as a case study, we have developed a method to readily sequence, assemble, and analyze complete mitochondrial genomes from large numbers of samples to more accurately assess phylogeography and estimate divergence times. This represents an important tool for wildlife management, not only for killer whales but for many marine taxa. We used high-throughput sequencing to survey whole mitochondrial genome variation of 139 samples from the North Pacific, North Atlantic, and southern oceans. Phylogenetic analysis indicated that each of the known ecotypes represents a strongly supported clade with divergence times ranging from approximately 150,000 to 700,000 yr ago. We recommend that three named ecotypes be elevated to full species, and that the remaining types be recognized as subspecies pending additional data. Establishing appropriate taxonomic designations will greatly aid in understanding the ecological impacts and conservation needs of these important marine predators. We predict that phylogeographic mitogenomics will become an important tool for improved statistical phylogeography and more precise estimates of divergence times.

Olesiuk, P. F., Ellis, G. M., & Ford, J. K. (2005). Life History and Population Dynamics of Northern Resident Killer Whales (Orcinus Orca) in British Columbia. (Research Document 2005/045). Canadian Science Advisory Secretariat Ottawa, Canada. Retrieved from http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2005/2005_045-eng.htm

Annual photo-identification surveys conducted between 1973-75 and 2004 were used to estimate life history parameters and develop a population model for the northern resident population of killer whales that inhabits coastal waters of British Columbia. During the 1970's, 80's and early 90's, the population grew exponentially ($r^2=0.986$; $F_{1,22}=1,568.5$; $P<0.001$) at an annual rate of 2.6% (95% CI 2.48-2.76%). Although the population almost doubled in size from about 125 to 217 animals, there was no evidence of a slowing of the growth rate ($F_{1,21}=0.25$; $P=0.622$), suggesting the population was unrestrained and increasing at its maximum intrinsic rate. The population peaked abruptly in the mid-1990s, declined by 7-9%, and then exhibited a small increase, resulting in no discernible trend over the last decade ($F_{1,10}=1.36$; $P=0.271$), indicating that something was restraining its growth. Life history and population parameters were thus estimated separately for 1973-96, a period of unrestrained growth; and 1996-2004, a period of no net change. During the period of unrestrained growth, females had a mean life expectancy of 46 years and maximum longevity was on the order of 80 years. Females typically gave birth to their first viable calf at 14.1 years of age (SE=0.050; range 10-21 years) and those that survived produced a total of 4.7 calves at mean intervals of 4.9 years (SE=0.18; range 2-11 years) over a reproductive lifespan typically lasting about 24 years. Older females exhibited reproductive senescence, with about 50% being post-reproductive by 38 years of age, and none reproducing after 46 years of age. Based on development of the dorsal fin – a secondary sexual characteristic – males typically attained sexual maturity at 13.0 years of age (SE=0.046; range 9-18 years) and the fin continued to develop for an average of 5.5 years (SE=0.113; range 3-7 years), such that males had typically attained physical maturity by 18.5 years of age. Males had a mean life expectancy of 31 years and maximum longevity was probably on the order of 60-70 years. Mortality curves were U-shaped for both sexes, indicating most mortality occurred early and late in life, but the right limb was steeper for males, resulting in a sex ratio that was progressively skewed toward females with increasing age (1:1 at age 15, 2:1 by age 34, and 3:1 by age 41 years). A sex- and age-structured model incorporating these parameters predicted that a population would increase at a rate of 2.4% per annum and be comprised of 46% juveniles, 22% reproductive females, 10% post-reproductive females, and 22% adult males. During 1973-96, the study population actually increased at 2.6% and was comprised, on average, of 46% juveniles, 21% reproductive females, 11% post-reproductive females and 22% adult males, indicating a good fit with the model predictions. Surprisingly, there were no major changes in reproductive parameters as the population stabilized during 1996-2004. Mean age at first birth increased slightly but significantly from 14.1 to 15.4 years ($t_{49}=3.23$; $P=0.002$), mean age of onset of post-reproductive senescence increased from 38.4 to 40.6 years ($t_{61}=2.84$; $P=0.006$), and calving intervals were marginally longer (5.5 versus 4.9 years; $t_{97}=2.92$; $P=0.091$). The overall effect was a slight drop in the estimated reproductive potential of females from 4.7 to 4.5 calves. The recent decline in productivity was due almost entirely to increases in mortality, which were evident and statistically significant ($7.63<\chi^2<8.14$; $P<0.01$) across all sex- and age-categories. Survival of viable calves to age 15 (about the age they are recruited to the adult population) dropped from 80% to 61%, and mean life expectancy declined from 46 to 30 years for females and from 31 to 19 years for males. Because the increase in mortality was broadly distributed across all sex- and age-classes, the predicted sex and age structure of the stable population remained almost unchanged at 47% juveniles, 24% reproductive females, 11% post-reproductive females, and 18% adult males. The life history parameters for neighbouring resident killer whale populations in Alaska and Washington appear to fall within the range of our unrestrained and stable models for northern BC residents, suggesting the models represent the general population biology of the resident ecotype of killer whale. We believe such models provide a useful construct for exploring and developing a better understanding of the factors that may regulate or impact killer whale populations.

Parsons, K. M., Balcomb, K. C., Ford, J. K. B., & Durban, J. W. (2009). The Social Dynamics of Southern Resident Killer Whales and Conservation Implications for This Endangered Population. *Animal Behaviour*, 77(4), 963-971 https://doi.org/10.1016/j.anbehav.2009.01.018

Quantitatively characterizing the social structure of a population provides important insight into the forces shaping key population processes. Moreover, long-term social dynamics provide an avenue for understanding population-level responses to changes in socioecological conditions. This is particularly true for species that show natal philopatry and highly stable hierarchically structured social units, such as the piscivorous resident killer whales of the northeast Pacific. The southern resident killer whale population is a small, demographically closed population, comprising three commonly recognized pods (J, K and L pods), that has recently been listed as endangered throughout its range in both Canadian and U.S.A. waters. In this study, we quantitatively assessed social structure in this population from 29 years of photo-identification data to characterize significant temporal changes in sociality. Preferential affiliation among killer whales within both genealogical matrilines and pods was supported by two different analytical methods and, despite interannual variability, these social clusters persisted throughout the study. All three pods experienced fluctuations in social cohesion over time, but the overall rate of intrapod affiliation was consistently lowest within L pod, the largest of the southern resident pods. The most recent increase in fluidity within social units, occurring in the mid to late 1990s, was coincident with a significant decline in population size, suggesting a possible common response to external stressors. Quantifying these trends in social structure is the first step towards understanding the causes and consequences of long-term changes in killer whale social structure.

Perrin, W. F., & Reilly, S. B. (1984). Reproductive Parameters of Dolphins and Small Whales of the Family Deiphinidae. *Report of the International Whaling Commission* (Special Issue 6), 97-133. Retrieved from https://swfsc.noaa.gov/publications/CR/1984/8470.PDF

The purposes of this review are to describe and critique methods used to estimate reproductive parameters, to summarize estimates in the literature and to examine patterns in the estimates and their implications. Reviewed are gestation period, fetal growth rate, size at birth, size and age at attainment of sexual maturity, average size and age of adults, maximum size, asymptotic length, ovulation rate, pregnancy rate, calving interval, length of lactation, weaning age, length of "resting" period, age and sex structure, and birth rates. Also discussed are the effects on the estimates of seasonality, schooling segregation, geographical variation and exploitation and the relationships between parameters.

Pitman, R. L., Totterdell, J. A., Fearnbach, H., Ballance, L. T., Durban, J. W., & Kemps, H. (2015). Whale Killers: Prevalence and Ecological Implications of Killer Whale Predation on Humpback Whale Calves off Western Australia. *Marine Mammal Science*, 31(2), 629-657 https://doi.org/10.1111/mms.12182

Reports of killer whales (Orcinus orca) preying on large whales have been relatively rare, and the ecological significance of these attacks is controversial. Here we report on numerous observations of killer whales preying on neonate humpback whales (Megaptera novaeangliae) off Western Australia

(WA) based on reports we compiled and our own observations. Attacking killer whales included at least 19 individuals from three stable social groupings in a highly connected local population; 22 separate attacks with known outcomes resulted in at least 14 (64%) kills of humpback calves. We satellite-tagged an adult female killer whale and followed her group on the water for 20.3 h over six separate days. During that time, they attacked eight humpback calves, and from the seven known outcomes, at least three calves (43%) were killed. Overall, our observations suggest that humpback calves are a predictable, plentiful, and readily taken prey source for killer whales and scavenging sharks off WA for at least 5 mo/yr. Humpback escorts vigorously assisted mothers in protecting their calves from attacking killer whales (and a white shark, Carcharodon carcharias). This expands the purported role of escorts in humpback whale social interactions, although it is not clear how this behavior is adaptive for the escorts.

Reeves, R. R., & Mitchell, E. (1988). Killer Whale Sightings and Takes by American Pelagic Whalers in the North Atlantic. Journal of the Marine Research Institute, Reykjavik, Skulagoetu 4 Reykjavik, Iceland. Retrieved from https://www.hafogvatn.is/is/midlun/utgafa/rit-fiskideildar/killer-whale-sightings-and-takes-by-american-pelagic-whalers-in-the-north-atlantic

Sightings and takes of killer whales, Orcinus orca, as recorded in logbooks and journals of American pelagic whalers, were compiled and plotted to help elucidate the North Atlantic distribution of the species. Of the 96 killer whale observations documented, about 80 percent were on recognized whaling grounds for sperm whales, Physeter catodon, right whales, Eubalaena glacialis, and humpback whales, Megaptera novaeangliae. American whalers in the North Atlantic rarely lowered their boats to chase killer whales. The records presented here demonstrate the wide distribution of killer whales in the North Atlantic, including areas far from any coastline. A relatively large number of records is from the Western Ground, in the central North Atlantic between Madeira and Bermuda, where mainly sperm whales and blackfish, Globicephala spp., were hunted. The whalemen encountered killer whales in this area from March through September (peak in May-September). Large groups of killer whales also were seen in winter (November-April, peak in January-March) close inshore off West Africa, on the Cintra Bay Ground at about 23 degree N, coincident with the presence of right whale mothers and calves. Other clusters of records of killer whales were on the Cape Farewell Ground, east of Cape Farewell, Greenland (June-July); The Shoals, south and east of Newfoundland (July and September); the Southern Ground, northwest of Bermuda (April-July); the Charleston or Hatteras Ground, south and east of the Carolinas (February-June); The Bahamas (January, May-June); and the Caribbean Sea (March-May, July). The current status of killer whales in some of these areas of past occurrence is unknown due to a lack of observational effort there. However, any attempt at a comprehensive understanding of the stock identity, overall distribution and abundance of killer whales in the North Atlantic must take account of the offshore, widespread observations reported here.

Robeck, T. R., Willis, K., Scarpuzzi, M. R., & O'Brien, J. K. (2015). Comparisons of Life-History Parameters Between Free-Ranging and Captive Killer Whale (Orcinus Orca) Populations for Application toward Species Management. *Journal of Mammalogy*, 96(5), 1055-1070 https://doi.org/10.1093/jmammal/gyv113

Data collected on life-history parameters of known-age animals from the northern (NR) and southern resident (SR) killer whales (Orcinus orca) of the eastern North Pacific were compared with life-history traits of killer whales located at SeaWorld (SEA) facilities. For captive-born SEA animals, mean age and body length at 1st estrus was 7.5 years and 483.7cm, respectively. Estimated mean age at 1st conception was different (P < 0.001) for the combined data from both northern and southern resident (NSR) free-ranging populations (12.1 years) compared to SEA (9.8 years), as was the estimated mean age at 1st observed calf (SEA: 11.1 years, NSR: 14.2 years, P < 0.001). Average calf survival rate to 2 years of age for SEA animals (0.966) was significantly greater (P = 0.04) than that for SR (0.799). Annual survival rate (ASR) for SEA increased over approximately 15-year increments with rates in the most recent period (2000-2015 ASR: 0.976) improved (P < 0.05) over the first 2 periods of captivity (1965-1985: 0.906; 1985-2000: 0.941). The SR (0.966) and NR ASR (0.977) were higher (P </= 0.05) than that of SEA until 2000, after which there were no inter-population differences. Based on ASR, median and average life expectancy were 28.8 and 41.6 years (SEA: 2000-2015), 20.1 and 29.0 years (SR), and 29.3 and 42.3 years (NR), respectively. The ASR for animals born at SEA (0.979) was higher (P = 0.02) than that of wild-caught SEA animals (0.944) with a median and average life expectancy of 33.1 and 47.7 years, respectively. These data present evidence for similar life-history parameters of free-ranging and captive killer whale populations and the reproductive potential and survivorship patterns established herein have application for use in future research concerning the overall health of both populations.

Ruggerone, G. T., Springer, A. M., Shaul, L. D., van Vliet. G.B. (2019). Unprecedented biennial pattern of birth and mortality in an endangered apex predator, the southern resident killer whale, in the eastern North Pacific Ocean. *Marine Ecology Progress Series* 608: 291-296 https://doi.org/10.3354/meps12835

We report on an unprecedented, synchronized biennial pattern of birth and mortality in an apex predator inhabiting the eastern North Pacific Ocean—the critically endangered southern resident killer whale *Orcinus orca*. From 1998-2017, mortality of newborn and older whales was 3.6 times higher (61 versus 17 whales) and successful births 50% lower (16 versus 32 whales) in even years than in odd years as the population decreased from 92 to only 76 whales. Percent mortality was 3.1 times higher in even years during the recent 20 yr period of population decline than during an earlier 22 yr period (1976-1997) of population increase and relative high abundance, whereas mortality in recent odd years was 43% lower. Recognized potential mechanisms of decline (low abundance of a key prey species, Chinook salmon *Oncorhynchus tshawytscha*, toxic contaminants, and ship noise) cannot explain this biennial pattern. We present evidence that the causal mechanism is indirectly linked to pink salmon (*O. gorbuscha*), which exhibit a unique and extreme biennial pattern of abundance and interact strongly with other species in marine ecosystems in the North Pacific. Further investigation of this unique biennial pattern in southern resident killer whales is needed to inform recovery efforts for the population.

Ward, E. J., Holmes, E. E., & Balcomb, K. C. (2009). Quantifying the Effects of Prey Abundance on Killer Whale Reproduction. *Journal of Applied Ecology*, 46(3), 632-640 https://doi.org/10.1111/j.1365-2664.2009.01647.x

1. Management decisions for threatened and endangered species require risks to be identified and prioritized, based on the degree to which they influence population dynamics. The potential for recovery of small populations at risk may be determined by multiple factors, including intrinsic population characteristics (inbreeding, sex ratios) and extrinsic variables (prey availability, disease, human disturbance). Using Bayesian statistical methods, the impact of each of these risk factors on demographic rates can be quantified and assigned probabilities to express uncertainty. 2. We assessed the impact of a wide range of factors on the fecundity of two threatened populations of killer whales

Orcinus orca, specifically whether killer whale production is limited by availability of Chinook salmon *Oncorhynchus tshawytscha* . Additional variables included anthropogenic factors, climate variables, temporal effects, and population variables (population size, number of males, female age). 3. Our results indicate that killer whale fecundity is highly correlated with the abundance of Chinook salmon. For example, the probability of a female calving differed by 50% between years of low salmon abundance and high salmon abundance. Weak evidence exists for linking fecundity to other variables, such as sea surface temperature. 4. There was strong data support for reproductive senescence in female killer whales. This pattern of rapid maturity and gradual decline of fecundity with age commonly seen in terrestrial mammals has been documented in few marine mammal species. Maximum production for this species occurs between ages 20–22, and reproductive performance declines gradually to menopause over a period of 25 years. 5. *Synthesis and applications*. Our results provide strong evidence for reproductive senescence in killer whales, and more importantly, that killer whale fecundity is strongly tied to the abundance of Chinook salmon, a species that is susceptible to environmental variation and has high commercial value to fisheries. This strong predator–prey relationship highlights the importance of understanding which salmon populations overlap with killer whales seasonally and spatially, so that those salmon populations important as prey for killer whales can be identified and targeted for conservation efforts.

Wasser, S. K., Lundin, J. I., Ayres, K., Seely, E., Giles, D., Balcomb, K., . . . Booth, R. (2017). Population Growth is Limited by Nutritional Impacts on Pregnancy Success in Endangered Southern Resident Killer Whales (Orcinus Orca). *PLoS ONE*, 12(6), https://doi.org/10.1371/journal.pone.0179824

The Southern Resident killer whale population (Orcinus orca) was listed as endangered in 2005 and shows little sign of recovery. These fish eating whales feed primarily on endangered Chinook salmon. Population growth is constrained by low offspring production for the number of reproductive females in the population. Lack of prey, increased toxins and vessel disturbance have been listed as potential causes of the whale's decline, but partitioning these pressures has been difficult. We validated and applied temporal measures of progesterone and testosterone metabolites to assess occurrence, stage and health of pregnancy from genotyped killer whale feces collected using detection dogs. Thyroid and glucocorticoid hormone metabolites were measured from these same samples to assess physiological stress. These methods enabled us to assess pregnancy occurrence and failure as well as how pregnancy success was temporally impacted by nutritional and other stressors, between 2008 and 2014. Up to 69% of all detectable pregnancies were unsuccessful; of these, up to 33% failed relatively late in gestation or immediately post-partum, when the cost is especially high. Low availability of Chinook salmon appears to be an important stressor among these fish-eating whales as well as a significant cause of late pregnancy failure, including unobserved perinatal loss. However, release of lipophilic toxicants during fat metabolism in the nutritionally deprived animals may also provide a contributor to these cumulative effects. Results point to the importance of promoting Chinook salmon recovery to enhance population growth of Southern Resident killer whales. The physiological measures used in this study can also be used to monitor the success of actions aimed at promoting adaptive management of this important apex predator to the Pacific Northwest.

Ylitalo, G. M., Matkin, C. O., Buzitis, J., Krahn, M. M., Jones, L. L., Rowles, T., & Stein, J. E. (2001). Influence of Life-History Parameters on Organochlorine Concentrations in Free-Ranging Killer Whales (Orcinus Orca) from Prince William Sound, AK. *Science of the Total Environment*, 281(1), 183-203 https://doi.org/10.1016/S0048-9697(01)00846-4

Certain populations of killer whales (Orcinusorca) have been extensively studied over the past 30 years, including populations that use Puget Sound, WA, the inside waters of British Columbia, Southeastern Alaska and Kenai Fjords/Prince William Sound, Alaska. Two eco-types of killer whales, 'transient' and 'resident', occur in all of these regions. These eco-types are genetically distinct and differ in various aspects of morphology, vocalization patterns, diet and habitat use. Various genetic and photo-identification studies of eastern North Pacific killer whales have provided information on the male–female composition of most of these resident pods and transient groups, as well as the approximate ages, reproductive status and putative recruitment order (birth order) of the individual whales. Biopsy blubber samples of free-ranging resident and transient killer whales from the Kenai Fjords/Prince William Sound, AK region were acquired during the 1994–1999 field seasons and analyzed for selected organochlorines (OCs), including dioxin-like CB congeners and DDTs. Concentrations of OCs in transient killer whales (marine mammal-eating) were much higher than those found in resident animals (fish-eating) apparently due to differences in diets of these two killer whale eco-types. Certain life-history parameters such as sex, age and reproductive status also influenced the concentrations of OCs in the Alaskan killer whales. Reproductive female whales contained much lower levels of OCs than sexually immature whales or mature male animals in the same age class likely due to transfer of OCs from the female to her offspring during gestation and lactation. Recruitment order also influenced the concentrations of OCs in the Alaskan killer whales. In adult male residents, first-recruited whales contained much higher OC concentrations than those measured in non-first-recruited (e.g. second recruited, third recruited) resident animals in the same age group. This study provides baseline OC data for free ranging Alaskan killer whales for which there is little contaminant information.

Section III: Bioenergetics, Growth, Body Size

Abbott, K. (2004). The Decline of the Southern Resident Population of Killer Whales: A Two-Part Analysis. Thesis (Masters), Duke University. Retrieved from http://hdl.handle.net/10161/235.

The southern resident population of killer whales declined dramatically in the late 1990s. The number of animals in the population dropped from 97 in 1996 to 78 in 2001, a 20% decline in just five years. Although the reasons for this decline are unknown, external factors such as contaminant exposure, vessel interference, and low prey availability may contribute to the poor health and eventual mortality of the animals. My analysis examines two trends in southern resident mortality. Part 1 uses the percentage of mature males in a population as a surrogate for adult survival and compares the percentage of mature males in the southern resident population versus that of other populations of killer whales. My results indicate that the proportion of the southern resident population that is adult males is significantly lower than the percentage of adult males in the fourteen other populations sampled. I speculate that the high contaminant levels and increased nutritional stress of southern resident males led to this male-biased mortality. In the second part, I develop a method for visually assessing killer whale body condition using photographs. Through 30 years of study, ten southern residents died as a result of emaciation. Of these, two individuals were characterized as "extremely thin" prior to death and four were described as "very thin." Preliminary results indicate that conditions described as worse than "thin" predict mortality. However, body condition of all members of the population fluctuates over time, suggesting that some population-wide factor such as prey availability may influence body condition. Both of these techniques enable managers to track changes in the population over time, thus advancing our understanding of the fluctuating population dynamics of the southern resident community.

Alava, J. J., Ross, P. S., Lachmuth, C., Ford, J. K., Hickie, B. E., & Gobas, F. A. (2012). Habitat-Based PCB Environmental Quality Criteria for the Protection of Endangered Killer Whales (Orcinus Orca). *Environmental Science & Technology*, 46(22), 12655-12663 https://doi.org/10.1021/es303062q

The development of an area-based polychlorinated biphenyl (PCB) food-web bioaccumulation model enabled a critical evaluation of the efficacy of sediment quality criteria and prey tissue residue guidelines in protecting fish-eating resident killer whales of British Columbia and adjacent waters. Model-predicted and observed PCB concentrations in resident killer whales and Chinook salmon were in good agreement, supporting the model's application for risk assessment and criteria development. Model application shows that PCB concentrations in the sediments from the resident killer whale's Critical Habitats and entire foraging range leads to PCB concentrations in most killer whales that exceed PCB toxicity threshold concentrations reported for marine mammals. Results further indicate that current PCB sediment quality and prey tissue residue criteria for fish-eating wildlife are not protective of killer whales and are not appropriate for assessing risks of PCB-contaminated sediments to high trophic level biota. We present a novel methodology for deriving sediment quality criteria and tissue residue guidelines that protect biota of high trophic levels under various PCB management scenarios. PCB concentrations in sediments and in prey that are deemed protective of resident killer whale health are much lower than current criteria values, underscoring the extreme vulnerability of high trophic level marine mammals to persistent and bioaccumulative contaminants.

Amano, M., Yamada, T. K., Brownell, R. L., & Uni, Y. (2011). Age Determination and Reproductive Traits of Killer Whales Entrapped in Ice off Aidomari, Hokkaido, Japan. *Journal of Mammalogy*, 92(2), 275-282 https://doi.org/10.1644/10-mamm-a-276.1

On 7 February 2005 a group of 9 killer whales (Orcinus orca) were trapped in drifting sea ice and died at Aidomari, Hokkaido, Japan. We carried out age determination based on tooth growth layers and examined the reproductive organs of these whales. Growth layer groups (GLGs) in the dentine and cementum were readable, even in the old specimens, and complementary to each other in decalcified and stained thin sections of lower teeth. Reliable age determination of killer whales is feasible, and GLGs are accumulated annually. The longitudinal growth of the teeth continued until about 20 years of age, which is much longer than for the corresponding age in other delphinids. Counts of corpora lutea and albicantia increased linearly with age from 3 to 7 in whales 13–34 years old, but the oldest female (59 years old) had only 8 corpora albicantia, which could indicate a decline in the ovulation rate in old females. Photographs of the original group trapped in the ice confirmed that at least 2 whales escaped or died and did not strand with the others. Therefore, this group was composed originally of a mature male, 1 possibly postreproductive female, 5 reproductively active females, 3 calves, and 2 or 3 unidentified individuals.

Asper, E., & Cornell, L. (1977). Live Capture Statistics for the Killer Whale (Orcinus Orca) 1961-1976 in California, Washington and British Columbia. *Journal of Aquatic Mammals*, 5(1), 21-26. Retrieved from https://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/1977/Aquatic_Mammals_5_1/20-26.pdf

No abstract.

Backus, R. H. (1961). Stranded Killer Whale in the Bahamas. *Journal of Mammalogy*, 42(3), 418-419 https://doi.org/10.2307/1377061

Because records of the killer whale, Orcinus orca, off the southeastern United States are few, the stranding of one of these animals on Great Abaco Island, Bahamas, is reported. The record is of additional interest since this cetacean only rarely beaches itself. The writer is indebted to Mr. and Mrs. John W. Coolidge, Cambridge, Massachusetts, for the data pertaining to the stranding, including eight good photographs of the skull in various aspects, isolated teeth, the cervical bloc, and ribs (Plate I).

Bell, E. (2017). Annual Report of the Southern Ocean Research Partnership (IWC-SORP) 2016/17. International Whaling Commission-Southern Ocean Research Partnership, SC/67a/SH04Rev1. Retrieved from https://archive.iwc.int/pages/download.php?ref=6760&size=&ext=pdf&k=&alternative=3474&usage=-1&usagecomment=

The Southern Ocean Research Partnership (IWC-SORP) was established in 2009 with the aim of developing a multi-lateral, non-lethal scientific research programme that would improve the coordinated and cooperative delivery of science to the IWC. There are now 12 member countries in the Partnership: Argentina, Australia, Brazil, Chile, France, Germany, Italy, New Zealand, Norway, South Africa, the United States and Belgium joined the Partnership in October 2016. This paper reports on the continued progress of IWC-SORP and its five ongoing research themes since the Scientific Committee meeting in 2016. This progress includes the production of 30 peer-reviewed scientific papers in 2016/17, bringing the total number of peer-reviewed publications related to IWC-SORP produced since the start of the initiative to ca. 93. Moreover, 103 IWC-SORP related papers have been submitted to the Scientific Committee, 16 of them this year. Fieldtrips to the western Antarctic Peninsula, Marion Island, the Chesterfield-Bellona Reef in the Coral Sea and East Australia have taken place in the past year, and four IWC-SORP researchers participate in the Antarctic Circumpolar Expedition voyage. Thousands of images for photo-identification have been collected, satellite tags have been deployed on killer whales, Antarctic minke whales and humpback whales. As well as video suction cup tags on humpback whales; biopsy samples have been collected from killer whales and humpback whales; and hundreds of hours of acoustic recordings have been made. More information can be found at: http://www.marinemammals.gov.au/sorp

Best, P., Meÿer, M., & Lockyer, C. (2010). Killer Whales in South African Waters—A Review of Their Biology. *African Journal of Marine Science*, 32(2), 171-186 https://doi.org/10.2989/1814232X.2010.501544

The distribution, seasonality and schooling behaviour of killer whales Orcinus orca in South African waters have been investigated from 785 records compiled between 1963 and 2009, and their size, morphometrics, growth, reproduction, food and feeding behaviour described from the examination of 54 individuals, 36 of which were landed at the Durban whaling station between 1971 and 1975. Qualitatively, the species appears to be more frequently encountered offshore, where it forms small schools of generally less than six animals. Seasonality of occurrence is not marked, although circumstantial evidence indicates that some individuals migrate from higher latitudes. Males reach 8.81 m and females 7.9 m, with 16.2% of males exceeding the size of the largest female. Stomach content and observational data suggest that the species can be characterised locally as an opportunistic predator of megavertebrates, rather than as the fish-feeding ecotype previously described. A stranded adult male with extreme tooth wear that was 1.5–2 m shorter than other males of equivalent age may be representative of a separate 'offshore' ecotype. Apparent differences between features of the popu lation's life history and those of resident killer whales in the north-eastern Pacific might be attributed to either uncertainties in age determination using dentinal growth layer groups or sampling bias. The basis for the suggestion that killer whales in South African waters should be reclassified as Vulnerable (rather than Data Deficient) is challenged.

Bigg, M. (1982). An Assessment of Killer Whale (Orcinus Orca) Stocks off Vancouver Island, British Columbia. *Report of the International Whaling Commission*, 32. SC/Jn81/KW4. Retrieved from https://archive.iwc.int/?r=36

A study of photographically identifiable individual killer whales was undertaken during 1973-81. In all. 30 pods were found, containing about 260 whales. A pod is a long term family or kinship group which periodically joins with ochers to form communities. Around Vancouver Island there are two resident communities and one transient community. The three communities do not associate with one another. Resident and transient killer whales differ in pod size and behaviour. The coastal range of movements for most resident pods is probably about 300 nm. Transient pods appear to range further. Births occur mainly during fall and winter. At birth, lengths average about 8 ft. First pregnancies generally occur al 16 Ft, or at an age of at least 6.7 years. Sexual maturity occurs in males at I 9 ft. or at an age of at least 12 yrs. A long term stability in pod composition permits direct measurement of vital statistics. The rate of calf production to an average age of six months is 10.30% per cow. The minimum interval between calving is three years. Many cows apparently rarely give birth. Annual natural mortality rates average 2.80% for bulls. 0.70% for cows and 2.30% for juveniles. Pods increase at an average net rate of 2.52% per year. Exploited pods have a slightly higher productivity than unexploited pods.

Bradford, A. L., Weller, D. W., Punt, A. E., Ivashchenko, Y. V., Burdin, A. M., VanBlaricom, G. R., & Brownell, R. L. (2012). Leaner Leviathans: Body Condition Variation in a Critically Endangered Whale Population. *Journal of Mammalogy*, 93(1), 251-266 https://doi.org/10.1644/11-mamm-a-091.1

The role of environmental limitation and density-dependent regulation in shaping populations is debated in ecology. Populations at low densities may offer an unobstructed view of basic environmental and physiological interactions that impact individual fitness and thus population productivity. The energy reserves of an organism are reflected in its body condition, a measure linking individual fitness and the environment. From 1997 to 2007, we monitored the critically endangered western gray whale (*Eschrichtius robustus*) population on its primary summer feeding ground off the northeastern coast of

Sakhalin Island, Russia. This effort resulted in a large data set of photo-identification images from 5,007 sightings of 168 individual whales that we used to visually assess western gray whale body condition. We quantified temporal variation in the resulting 1,539 monthly body condition determinations with respect to observations of reproductive status and sex. Western gray whale body condition varied annually, and we identified years of significantly better (2004) and worse (1999, 2006, and 2007) body condition. This study is the 1st to track the within-season body condition of individual whales. Body condition improved significantly as the summer progressed, although results suggest that not all whales replenish their energy stores by the end of the season. The body condition of lactating females was significantly worse than that of other whales at all times and was most often determined to be compromised. The body condition of their weaning calves exhibited no temporal variation and was consistently good. It is possible lactating females provide an energetic buffer to their offspring at the expense of their own body condition and future reproductive success. Findings from the analysis establish a foundation for quantifying links between western gray whale body condition, demographic parameters, and environmental conditions; and provide a baseline for monitoring individual and population condition of an ecosystem sentinel species in a changing environment. Overall, this study highlights the presence of density-independent environmental and physiological mechanisms that affect the abundance and growth of populations.

Christensen, I. (1984). Growth and Reproduction of Killer Whales, Orcinus Orca, in Norwegian Coastal Waters. *Reports of the International Whaling Commission* Special Issue 6, 253-258. Retrieved from https://archive.iwc.int/?r=466&k=09362c372e

Length data and reproductive material collected by coastal whalers during the period 1938-67 and 1978-81 are analysed, female killer whales attain sexual maturity at a length of 15-16 ft (4.6-4.9 m) and an age of about 8 years, and males at about 19 ft (5.8m) and 15-years. Mating occurs throughout the year, with a maximum in October-December. The birth rate seems to be one calf every three years. Preliminary age determinations indicate that physical maturity is attained at 20-25 years, with a life span of at least 35 years.

Dahlheim, M. E. (1997). A Photographic Catalog of Killer Whales, Orcinus Orca, from the Central Gulf of Alaska to the Southeastern Bering Sea. National Marine Fisheries Service, NOAA Technical Report NMFS 131, 58 p. Retrieved from https://repository.library.noaa.gov/view/noaa/3024

In 1992 and 1993, researchers from the National Marine Mammal Laboratory initiated photo-identification studies on Alaskan killer whales, Orcinus orca. Waters from Kodiak Island west to the central and eastern Aleutian Islands and southeastern Bering Sea were surveyed. A total of 289 individual whales were identified. A photographic record of the whales encountered during these surveys is presented. When photographs of the 289 individual whales were compared among various regions in Alaska (Prince William Sound and Southeast Alaska) and areas outside Alaska (British Columbia, Washington, and California), II matches were found. The count is conservative because the 1992 and 1993 surveys were limited in geographical range, restricted to summer periods, and whales may have been missed along the survey track line. Future research incorporating both photo identification studies and line transect surveys will provide reliable abundance estimates of Alaskan killer whales.

Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Perryman, W. L., & Leroi, D. J. (2015). Photogrammetry of Killer Whales Using a Small Hexacopter Launched at Sea. *Journal of Unmanned Vehicle Systems*, 3(3), 131-135 https://doi.org/10.1139/juvs-2015-0020

Conventional aircraft have been used for photogrammetry studies of free-ranging whales, but are often not practical in remote regions or not affordable. Here we report on the use of a small, unmanned hexacopter (APH-22; Aerial Imaging Solutions) as an alternative method for collecting photographs to measure killer whales (*Orcinus orca*) at sea. We deployed and retrieved the hexacopter by hand during 60 flights (average duration 13.2 min, max 15.7 min) from the upper deck of an 8.2 m boat, utilizing the aircraft's vertical takeoff and landing (VTOL) capability. The hexacopter was quiet and stable in flight, and therefore could be flown at relatively low altitudes without disturbing whales. The payload was a Micro Four-Thirds system camera that was used to obtain 18920 still images from an altitude of 35–40 m above the whales. Tests indicated a ground-resolved distance of <1.4 cm across the full extent of a flat and undistorted field of view, and an onboard pressure altimeter enabled measurements in pixels to be scaled to true size with an average accuracy of 5 cm. As a result, the images were sharp enough to differentiate individual whales using natural markings (77 whales in total) and preliminary estimates resolved differences in whale lengths ranging from 2.6 to 5.8 m. This first application at sea demonstrated the APH-22 hexacopter to be a safe and cost-effective platform for collecting photogrammetry images to fill key scientific data gaps about whales, and we anticipate this utility will extend to studies of other wildlife species.

Durban, J. W., & Parsons, K. M. (2006). Laser-Metrics of Free-Ranging Killer Whales. *Marine Mammal Science*, 22(3), 735-743. https://doi.org/10.1111/j.1748-7692.2006.00068.x

No abstract.

Evans, W., Yablokov, A. V., & Bowles, A. E. (1982). Geographic Variation in the Color Pattern of Killer Whales (Orcinus Orca). *Report of the International Whaling Commission*, 32, 687-694. SC/Jn81/KW11. Retrieved from https://archive.iwc.int/?r=36&k=e3a85bd029

Evans and Yablokov (1978) proposed a method for analyzing differences in the color pattern of killer whales (Orcinus area). This species' rather complex pattern was divided into several distinct components. Using schemes similar to those proposed by Yablokov (1969), Mitchell (1970), Perrin (1972) and Evans (1975), each component was identified by a descriptive name associated with its anatomical location, e.g. post-dorsal fin saddle, flank field, post-ocular, etc. The observed variants of each component were compiled from illustrations in the literature, photographs taken in the field during various research cruises, and by examination of live specimens at Sea World, San Diego, California, Orlando, Florida and at several other oceanaria in the United States and Canada. These components and the observed variations are presented in Fig. 1. In our original paper (Evans and Yablokov, 1978) it was hypothesized that the pigmentation pattern of Orcinus is geographically variable. If this assumption is valid it should then be possible to characterize different regional populations, based on analysis and quantification of color pattern types. To test this hypothesis we collected samples of Orcinus color patterns from as many geographic areas as possible.

Farmer, N. A., Noren, D. P., Fougeres, E. M., Machernis, A., & Baker, K. (2018). Resilience of the

Endangered Sperm Whale Physeter Macrocephalus to Foraging Disturbance in the Gulf of Mexico, USA: A Bioenergetic Approach. *Marine Ecology Progress Series*, 589, 241-261. http://dx.doi.org/10.3354/meps12457

The endangered sperm whale Physeter macrocephalus spends the majority of its time foraging, relying upon echolocation to locate and consume several 100 kg of prey per day. In the northern Gulf of Mexico, sperm whales are exposed to a variety of anthropogenic stressors, including ship strikes, fisheries interactions, habitat loss and degradation due to oil and gas development, and chemical and noise pollution. In particular, they are exposed to high levels of anthropogenic noises related to geological and geophysical surveys for hydrocarbon deposits. The sounds produced by these surveys could reduce sensory volume, increase search effort required to locate resources, and interfere with auditory signal processing critical to foraging success. We developed a stochastic life-stage structured bioenergetic model to evaluate the consequences of reduced foraging efficiency on carbohydrate, lipid, and protein reserves in the blubber, muscle, and viscera. The model indicates that individual resilience to foraging disruptions is primarily a function of size (i.e. reserve capacity) and daily energetic demands. Mothers are the most vulnerable life stage due to the high energy demands associated with pregnancy and lactation. Continuous disruption has a greater impact than intermittent disruption; even minor foraging disruptions may lead to terminal starvation if the whales have no opportunity to replenish reduced reserves. Infrequent, minor disruptions in foraging are unlikely to be fatal, but may result in reduced body reserves that may be associated with reduced reproductive success. Our model provides a bioenergetic framework for evaluating the level, frequency, and consequences of foraging disruptions associated with anthropogenic stressors.

Fearnbach, H., Durban, J. W., Ellifrit, D. K., & Balcomb III, K. C. (2011). Size and Long-Term Growth Trends of Endangered Fish-Eating Killer Whales. *Endangered Species Research*, 13(3), 173-180 https://doi.org/10.3354/esr00330

The Endangered southern resident population of killer whales Orcinus orca has been shown to be food-limited, and the availability of their primary prey, Chinook salmon Oncorhynchus tshawytscha, has been identified as a key covariate for the whales' individual survival and reproduction. We collected aerial photogrammetry data on individual whale size, which will help to better inform energetic calculations of food requirements, and we compared size-at-age data to make inferences about long-term growth trends. A helicopter was used to conduct 10 flights in September 2008, resulting in 2803 images from which useable measurements were possible for 66 individually identifiable whales, representing more than three-quarters of the population. Estimated whale lengths ranged from 2.7 m for a neonate whale in its first year of life, to a maximum of 7.2 m for a 31 yr old adult male. Adult males reached an average (asymptotic) size estimate (±SE) of 6.9 ± 0.2 m, with growth slowing notably after the age of 18 yr; this was significantly larger than the asymptotic size of 6.0 ± 0.1 m for females, which was reached after the earlier age of 15 yr. Notably, there was no overlap between the ranges of estimated sizes of adult males (6.5 to 7.2 m) and females (5.5 to 6.4 m). On average, older adults (>30 yr) were 0.3 m (n = 14, p = 0.03) and 0.3 m (n = 5, p = 0.23) longer than the younger whales of adult age, for females and males, respectively; we hypothesize that a long-term reduction in food availability may have reduced early growth rates and subsequent adult size in recent decades.

Fearnbach, H., Durban, J. W., Ellifrit, D. K., & Balcomb, K. C. (2018). Using Aerial Photogrammetry to

Detect Changes in Body Condition of Endangered Southern Resident Killer Whales. *Endangered Species Research*, 35, 175-180 https://doi.org/10.3354/esr00883

The endangered population of southern resident killer whales *Orcinus orca* is hypothesized to be food-limited, but uncertainty remains over if and when the availability of their primary prey, Chinook salmon *Oncorhynchus tshawytscha*, is low enough to cause nutritional stress. To measure changes in body condition, we collected 1635 measurable images from a helicopter hovering 230-460 m above whales, and linked these to individuals with distinctive natural markings. Head width (HW), measured at 15% of the distance between the blowhole and the dorsal fin (BHDF), was measured from images of 59 individuals in 2008 (from a population of 84) and 66/81 individuals in 2013, enabling assessment of between-year changes for 44 individuals (26 females, 18 males). Of these, 11 had significant declines in the ratio of HW/BHDF compared to 5 with significant increases. Two whales with declines died shortly after being photographed, suggesting a link between body condition and mortality. Most (8/11) of the significant declines in condition were from 1 social pod (J-pod), and all the whales that increased in condition were from one of the other 2 pods, K-pod (n = 3) and L-pod (n = 2). Notably, 11/16 whales that changed condition were reproductive-aged females and there were no adult males with significant changes. This likely reflects the increased energetic costs of lactation to reproductive females, and the nutritional help provided to adult males through prey sharing. These data demonstrate the utility of aerial photogrammetry as a non-invasive approach for providing quantitative data on body condition, and support monitoring the condition of reproductive females as key indicators of nutritional stress.

Foote, A. D., Newton, J., Piertney, S. B., Willerslev, E., & Gilbert, M. T. (2009). Ecological, Morphological and Genetic Divergence of Sympatric North Atlantic Killer Whale Populations. *Molecular Ecology*, 18(24), 5207-5217 https://doi.org/10.1111/j.1365-294X.2009.04407.x

Ecological divergence has a central role in speciation and is therefore an important source of biodiversity. Studying the micro-evolutionary processes of ecological diversification at its early stages provides an opportunity for investigating the causative mechanisms and ecological conditions promoting divergence. Here we use morphological traits, nitrogen stable isotope ratios and tooth wear to characterize two disparate types of North Atlantic killer whale. We find a highly specialist type, which reaches up to 8.5 m in length and a generalist type which reaches up to 6.6 m in length. There is a single fixed genetic difference in the mtDNA control region between these types, indicating integrity of groupings and a shallow divergence. Phylogenetic analysis indicates this divergence is independent of similar ecological divergences in the Pacific and Antarctic. Niche-width in the generalist type is more strongly influenced by between-individual variation rather than within-individual variation in the composition of the diet. This first step to divergent specialization on different ecological resources provides a rare example of the ecological conditions at the early stages of adaptive radiation.

Forrester, D. J., Odell, D. K., Thompson, N. P., & White, J. R. (1980). Morphometrics, Parasites, and Chlorinated-Hydrocarbon Residues of Pygmy Killer Whales from Florida. *Journal of Mammalogy*, 61(2), 356-360 https://doi.org/10.2307/1380067

The pygmy killer whale (Feresa attenuata Gray 1874) is one of the rarest and least known of the small, toothed whales. Caldwell and Caldwell (1971) summarized the world records of Feresa through about 1970. Since that time, records of several additional individuals from different locations have been published, including one from the Texas coast (James et al., 1970); one from the East Coast of Florida

(Caldwell and Caldwell, 1973, 1975; White, 1976); and one from Australia (Bryden, 1976). The purpose of the present paper is to report three new records of Feresa from Florida with various associated data.

Gaydos, J. K., Balcomb, K. C., Osborne, R. W., & Dierauf, L. (2004). Evaluating Potential Infectious Disease Threats for Southern Resident Killer Whales, Orcinus Orca: A Model for Endangered Species. *Biological Conservation*, 117(3), 253-262 https://doi.org/10.1016/biocon.2003.07.004

Infectious diseases have the potential to play a role in the decline of threatened wildlife populations, as well as negatively affect their long-term viability, but determining which infectious agents present risks can be difficult. The southern resident killer whale, Orcinus orca, population is endangered and little is known about infectious diseases in this species. Using available reference literature, we identified 15 infectious agents (bacteria, viruses, and fungi) reported in free-ranging and captive killer whales, as well as 28 additional infectious agents reported in free-ranging and captive odontocete species sympatric to southern resident killer whales. Infectious agents were scored as having a high, medium, or low ability to affect fecundity or reproductive success, to cause disease in individual animals, and to cause epizootics. Marine Brucella spp., cetacean poxvirus, cetacean morbilliviruses, and herpesviruses were identified as high priority pathogens that warrant further study. Using identified pathogens to develop a standardized necropsy and disease testing protocol for southern resident killer whales and sympatric odontocetes will improve future efforts to better understand the impacts of priority and non-priority infectious agents on southern resident killer whales. This model can be used to evaluate potential infectious disease risks in other threatened wildlife populations. (C) 2003 Elsevier Ltd. All rights reserved.

Griffin, E. I., & Goldsberry, D. G. (1968). Notes on the Capture, Care and Feeding of the Killer Whale Orcinus Orca at Seattle Aquarium. *International Zoo Yearbook*, 8(1), 206-208 https://doi.org/10.1111/j.1748-1090.1968.tb00485.x

No abstract.

Guerrero-Ruiz, M., Pérez-Cortés M, H., Mario Salinas, Z., & Jorge Urbán, R. (2006). First Mass Stranding of Killer Whales (Orcinus Orca) in the Gulf of California, Mexico. *Aquatic Mammals*, 32(3), 265-272 http://dx.doi.org/10.1578/AM.32.3.2006.265

We present the first report of a mass stranding of killer whales (Orcinus orca) in Mexican waters. This species is a temporal inhabitant of the region. On 31 July 2000, eight killer whales stranded alive at the southern tip of Isla San José in Bahía de La Paz (24° 54' N, 110° 35' W). All the individuals died despite the attempts performed by local fishermen to return them to sea. The group consisted of an undetermined number of females, immature males, and two calves. Skin and blubber samples were collected, as well as a skull on 2 August from a 4.6-m immature male. A second skull was collected on 19 August, which belonged to an individual of undetermined sex that measured 5 m in length. The teeth from both individuals were completely worn down. A couple of months later, two other skulls were collected. Individual strandings of killer whales are rare, and six records have been documented in the Mexican Pacific and Gulf of California. This report represents the first mass stranding of killer whales in Mexico. Since 1972, more than 160 killer whale sightings have been collected in the Gulf of California, with more than 90 photo-identified killer whales; nevertheless, no matches with the stranded individuals were found. There are few cases of killer whales found stranded live, probably as a result of whales chasing or following prey, or as a result of an outgoing tide. Causes of this stranding remain unknown.

Hall, A. J., McConnell, B. J., Schwacke, L. H., Ylitalo, G. M., Williams, R., & Rowles, T. K. (2018). Predicting the Effects of Polychlorinated Biphenyls on Cetacean Populations through Impacts on Immunity and Calf Survival. *Environmental Pollution*, 233, 407-418 https://doi.org/10.1016/j.envpol.2017.10.074

The potential impact of exposure to polychlorinated biphenyls (PCBs) on the health and survival of cetaceans continues to be an issue for conservation and management, yet few quantitative approaches for estimating population level effects have been developed. An individual based model (IBM) for assessing effects on both calf survival and immunity was developed and tested. Three case study species (bottlenose dolphin, humpback whale and killer whale) in four populations were taken as examples and the impact of varying levels of PCB uptake on achievable population growth was assessed. The unique aspect of the model is its ability to evaluate likely effects of immunosuppression in addition to calf survival, enabling consequences of PCB exposure on immune function on all age-classes to be explored. By incorporating quantitative tissue concentration-response functions from laboratory animal model species into an IBM framework, population trajectories were generated. Model outputs included estimated concentrations of PCBs in the blubber of females by age, which were then compared to published empirical data. Achievable population growth rates were more affected by the inclusion of effects of PCBs on immunity than on calf survival, but the magnitude depended on the virulence of any subsequent encounter with a pathogen and the proportion of the population exposed. Since the starting population parameters were from historic studies, which may already be impacted by PCBs, the results should be interpreted on, a relative rather than an absolute basis. The framework will assist in providing quantitative risk assessments for populations of concern.

Jonsgård, Å., & Lyshoel, P. B. (1969). A Contribution to the Knowledge of the Biology of the Killer Whale (Orcinus Orca). The University of Oslo M. M. Committee.ICES6. Retrieved from http://hdl.handle.net/11250/101530

Modern whaling for small whales in Norway has lasted for about 40 years. In addition to minke whales (Balaenoptera acutorostrats) which have been the main prey, bottlenose whales (Byperdoon ampullatus), killer whales (Orcinus orca) and pilot whales (Globicephala melaena) have also been caught. The meat of the minke whale is used both for human and animal consumption, while all meat from toothed whales is used for animal c6nsumption only. As the price offered for animal food has changed rather considerably from time to time, a corresponding change has taken place regarding the whaler's interest in catching such whales.

From 1938, the whalers were compelled to apply for a licence. The licensees have to fill in a form for each whale taken, containing both biological and technical information. Jonsgard and ~ynes (1952) briefly analyzed the data concerning killer whales caught up to and including the season 1950. Since then, several hundred forms concerning killer whales have been recieved. In the following 1413 forms concerning biological data on killer whales received in the period 1938-1967 have been examined, the aim of which has been to see if they might give any further information on the biology of this species of whale.

Jonsgård, Å., & Lyshoel, P. B. (1970). A Contribution to the Knowledge of the Biology of the Killer Whale Orcinus Orca (L.). *Nytt Magasin for Zoologi*, 18, 41-48. [Scanned from Library copy]

Biological data from 1413 killer whales caught by Norwegian whalers in northeastern North Atlantic waters in the period 1938-1967 are examined. Four more killer whales were examined by two Norwegian biologists in 1967. The distribution and migration of killer whales in these waters seem to be dependent upon the distribution and migration of the herring. Mammals are eaten by larger killer whales. Females and males seem to attain sexual maturity when about 16 and 19 feet long respectively. The young are very close to 7 feet in length at birth. The breeding season may stretch over several months, although there is some evidence that relatively more calves are born in late autumn and winter. In length, adult females and males seldom exceed 26 and 30 feet respectively.

Jourdain, E. M., Samarra, F. I. P., Tavares, S. B., & Karoliussen, R. E. (2017). Incidence of Probable Vertebral Column Deformities in Norwegian and Icelandic Killer Whales (Orcinus Orca). *Aquatic Mammals*, 43(6), 682-690 https://doi.org/10.1578/am.43.6.2017.682

No abstract.

Kastelein, R., Kershaw, J., Berghout, E., & Wiepkema, P. (1998). *Food Consumption and Growth of Marine Mammals.* Drukkerij Zuidam & Zonen B.V., Woerden. Retrieved from http://edepot.wur.nl/196196

No abstract.

Kastelein, R. A., Kershaw, J., Berghout, E., & Wiepkema, P. R. (2003). Food Consumption and Suckling in Killer Whales. *International Zoo Yearbook*, 38(1), 204-218 https://doi.org/10.1111/j.1748-1090.2003.tb02081.x

Between 1976 and 1996 food consumption and suckling in Killer whales Oscines orca maintained at Marineland Antibes, France, were studied. The food intake of the whales was still increasing at 20 years of age, when they were consuming c. 19 000 kg of fish per year. Wild Killer whales will expend more energy foraging than captive animals and probably eat more than 19 000 kg/year. A seasonal pattern of food consumption was observed in all the whales, although this may have been caused by seasonal changes in the feeding schedule. Data on the number of suckling bouts per 24 hours in the first 5-10 days after birth of 1.1 calves are presented, together with the body measurements of a 13 year-old.

Kriete, B. (1995). Bioenergetics in the Killer Whale, Orcinus Orca. Thesis (Ph.D), University of British Columbia. Retrieved from https://open.library.ubc.ca/collections/831/items/1.0088104

A series of three papers is presented, each one related to the bioenergetics of killer whales, Orcinus orca. The first chapter describes how standard and realized metabolic rates were determined in captive killer whales by collecting respirations at different apneas and different activity states by training the animals to exhale into a funnel onto which a meteorological balloon was attached. These exhalations were analyzed for tidal volumes and respiratory gases; estimates of realized metabolic rates were based on activity budgets observed in the individual animals. Tidal volumes at rest were 2.7 to 4.2 times higher than those predicted by allometric equations, while estimated vital capacities are estimated to lie between 68% and 94% of the values predicted by allometric equations. Standard metabolic rates for the adult animals were similar to Kleiber's estimates (1.2 to 1.3 times Kleiber). Realized metabolic rates were between 2.7 and 2.9 times those of the whales' SMR, which are values similar to those of terrestrial mammals. In the second chapter, food consumption and the influence of other factors such as pregnancy, lactation and water temperature on the food intake of captive killer whales, were examined. Food data were collected from the aquaria at which the animals were held and analyzed for caloric values on a daily basis. While food intake increased with age, differences in water temperature ranging between 7 and 23 °C had little or no effect on food intake. Pregnancy caused an increase in food consumption of 25% only during the last month of gestation, but food intake increased up to 100% with lactation. The best fit for feeding rate as a function of body weight was determined as: food intake (kg/d) = 0.277 M^{0663}, where M = body mass in kg. A mean net assimilation efficiency of 0.73 was calculated by comparing food intake to energy expenditure measured by respiration analysis. In the third chapter, realized metabolic rates were estimated in free-ranging killer whales along the Pacific West Coast of British Columbia and Washington. Swimming velocities and respiration rates were determined by tracking movements of whales using a theodolite and a loran. The relationship between swimming velocities and respiration rates showed an increase in respiration rate with increasing swimming speed for different age and sex classes of killer whales. These data were combined with metabolic rates determined by respiration analysis in captive killer whales during different activity states to estimate metabolic rates of wild killer whales during swimming (males: metabolic rate (kcal/kg/d) = 29.32 + 1.11V^{25} females: metabolic rate (kcal/kg/d) = 32.29 + 1.26V^{25}). The minimum cost of transport for male and female killer whales occurred at 3.1 rn/sec which corresponded to 0.18 and 0.20 kcal/kg/km. The drag that killer whales experience at different swimming velocities was calculated based on theoretical assumptions and suggests that drag is mainly laminar (males: 88% of the flow was laminar and 12% were turbulent; females: 89% of the flow was laminar and 11% turbulent).

Mikhalev, Y. A., Ivashin, M. V., Savusin, V. P., & Zelenaya, F. E. (1981). The Distribution and Biology of Killer Whales in the Southern Hemisphere. *Report of the International Whaling Commission*, 31, 551-566. SC/32/SM12. Retrieved from https://archive.iwc.int/?r=35&k=263a102d8b

Biological and distributional data for Southern Hemisphere killer whales, collected between 1961/62 and 1978/79 arc analysed. It appears that killer whales are found in warm waters in winter and migrate into high latitudes in the summer. From the available data six populations of killer whales are proposed (classified by their winter distribution): Western American; Eastern American; Western African; Eastern African; Western Australian; Eastern Australian; although it is believed that further populations will be determined in the future for the open waters of the Atlantic, Indian and Pacific Oceans. The migration appears to be linked with that of its prey species, in particular the minke whale. Morphological and reproductive data are presented and discussed. A new species or killer whale, the dwarf killer whale Orcinus nanus, is proposed.

Noren, D. P. (2011). Estimated Field Metabolic Rates and Prey Requirements of Resident Killer Whales. *Marine Mammal Science*, 27(1), 60-77 https://doi.org/10.1111/j.1748-7692.2010.00386.x

Killer whales are large animals that often feed in groups and thus have the potential to deplete prey populations. Determining predator energy requirements is essential to assessing whether prey availability is sufficient. This is important because one risk factor facing the endangered Southern Resident killer whale distinct population segment is limited prey availability. Body mass, field metabolic rate (FMR), and daily prey energy requirements (DPERs) were estimated for each individual in the population. FMRs were calculated from body mass, assuming they range from five to six times Kleiber-predicted basal metabolic rates. FMRs of adults were also calculated from resident killer whale activity budgets and the metabolic cost of swimming at speeds associated with daily activities. These two methods yielded similar results. Total FMRs varied by age and sex, which is partly due to the long developmental period and sexual dimorphism in killer whales. FMRs for males (465–4,434 kg) ranged from 35,048 to 228,216 kcal/d while FMRs for females (465–3,338 kg) ranged from 35,048 to 184,444 kcal/d. DPERs were calculated from FMRs assuming a standard digestive efficiency. Corresponding DPERs ranged from 41,376 to 269,458 kcal/d and 41,376 to 217,775 kcal/d, respectively.

Noren, D. P., Dunkin, R. C., Williams, T. M., & Holt, M. M. (2012). Energetic Cost of Behaviors Performed in Response to Vessel Disturbance: One Link in the Population Consequences of Acoustic Disturbance Model. In: Popper A.N., Hawkins A. (eds) The Effects of Noise on Aquatic Life. Advances in Experimental Medicine and Biology, vol 730. Springer, New York, NY https://doi.org/10.1007/978-1-4419-7311-5_97

Several studies have shown that cetaceans respond to the physical presence and/or acoustic emissions from marine vessels. For example, cetaceans perform surface-active behaviors (SABs) in response to an increase in the number of and/or close approaches by vessels (Lusseau 2006; Noren et al. 2009; Williams et al. 2002, 2009). SABs are often performed in bouts of one or more behaviors performed sequentially, and the majority of SABs provide both visual and acoustic signals that are important to social marine mammals. Indeed, the use of sound is essential to the survival and reproduction of cetaceans (National Research Council 2003), and because of this, anthropogenic sound exposure in marine mammals is a concern. Individuals may compensate for increased vessel noise by changing the amplitude (Holt et al. 2009; Scheifele et al. 2005), duration (Foote et al. 2004), repetition rate, and/or frequency of the sounds they produce.

Noren, D. P., Holt, M. M., Dunkin, R. C., & Williams, T. M. (2013). The Metabolic Cost of Communicative Sound Production in Bottlenose Dolphins (Tursiops Truncatus). *Journal of Experimental Biology*, 216(Pt 9), 1624-1629 https://doi.org/10.1242/jeb.083212

Bottlenose dolphins (Tursiops truncatus) produce various communicative sounds that are important for social behavior, maintaining group cohesion and coordinating foraging. For example, whistle production increases during disturbances, such as separations of mother-calf pairs and vessel approaches. It is clear that acoustic communication is important to the survival of these marine mammals, yet the metabolic cost of producing whistles and other socials sounds and the energetic consequences of modifying these sounds in response to both natural and anthropogenic disturbance are unknown. We used flow-through respirometry to determine whether the metabolic cost of sound production could be quantified in two captive dolphins producing social sounds (whistles and squawks). On average, we found that metabolic rates measured during 2 min periods of sound production were 1.2 times resting values. Up to 7 min were required for metabolism to return to resting values following vocal periods. The total metabolic cost (over resting values) of the 2 min vocal period plus the required recovery period (163.3 to 2995.9

ml O2 or 3279.6 to 60,166.7 J) varied by individual as well as by mean duration of sounds produced within the vocal period. Observed variation in received cumulative sound energy levels of vocalizations was not related to total metabolic costs. Furthermore, our empirical findings did not agree with previous theoretical estimates of the metabolic cost of whistles. This study provides the first empirical data on the metabolic cost of sound production in dolphins, which can be used to estimate metabolic costs of vocal responses to environmental perturbations in wild dolphins.

Noren, D. P., & Mocklin, J. A. (2012). Review of Cetacean Biopsy Techniques: Factors Contributing to Successful Sample Collection and Physiological and Behavioral Impacts. *Marine Mammal Science*, 28(1), 154-199 https://doi.org/10.1111/j.1748-7692.2011.00469.x

Biopsy techniques have been developed to collect skin and blubber samples through non-lethal methods. One sample can provide data on genetics, prey preferences, foraging ecology, contaminant loads, and physiological processes. The limited data available suggest that biopsy wounds heal quickly and that there are usually no discernable adverse health effects. Published accounts on factors contributing to the success of collecting biopsy samples and the behavioral impacts to cetaceans following biopsy sampling were standardized to permit statistical analysis. Several factors contribute to the success of acquiring samples; however, sampling rates do not differ significantly between delivery devices. Behavioral responses to biopsy sampling vary by species and other factors. The most predominant response for odontocetes is low, while low and moderate responses are equally prevalent for mysticetes. The use of retrieval lines may increase the occurrence of moderate and strong responses by mysticetes. These findings suggest that biopsy sampling is relatively benign, causing only minor and short-lived responses. However, most researchers do not report sufficient data to assess short- and long-term physiological and behavioral impacts. Finally, limited data suggest that biopsy sampling does not impact cetacean habitat use or distribution patterns. Yet these impacts are rarely investigated, so additional data are needed.

O'Neill, S. M., Ylitalo, G. M., & West, J. E. (2014). Energy Content of Pacific Salmon as Prey of Northern and Southern Resident Killer Whales. *Endangered Species Research*, 25(3), 265-281 https://doi.org/10.3354/esr00631

Recovery of depleted species is difficult, but it can be especially complex when the target species interacts strongly with other depleted species. Such is the case for northern and southern resident killer whales Orcinus orca which are listed as 'endangered' under the US Endangered Species Act (ESA) and Canada's Species at Risk Act. These resident killer whales prey heavily on Pacific salmon Oncorhynchus spp., including several 'evolutionarily significant units' also listed under the ESA. In response to concerns that a depleted prey base may affect killer whale recovery, we analyzed proximate composition and calculated caloric content of Pacific salmon to evaluate the importance of salmon species, population, body size, and lipid levels in determining their energy content as prey for killer whales. We sampled all 5 species of Pacific salmon, but emphasized Chinook salmon, a predominant prey of killer whales. Energy density ($kcal\ kg^{-1}$) was highly correlated with lipid content, whereas total energy value ($kcal\ fish^{-1}$) was determined primarily by fish mass and secondarily by lipid content. These salmon energetics data can be used to provide better precision and estimates on the caloric value of prey to killer whales. To facilitate application of these results to the co-management of salmon and killer whales, we produced a simple relationship that uses fish length to predict total energy of Chinook salmon as prey where population-specific energy densities and fish masses are lacking. Benefits to killer whales from possible salmon fishery closures, or other activities that affect prey availability, will depend on the salmon species and populations involved.

Reckendorf, A., Ludes-Wehrmeister, E., Wohlsein, P., Tiedemann, R., Siebert, U., & Lehnert, K. (2018). First Record of Halocercus Sp (Pseudaliidae) Lungworm Infections in Two Stranded Neonatal Orcas (Orcinus Orca). *Parasitology*, 145(12), 1553-1557 https://doi.org/10.1017/s0031182018000586

Orca (Orcinus orca) strandings are rare and post-mortem examinations on fresh individuals are scarce. Thus, little is known about their parasitological fauna, prevalence of infections, associated pathology and the impact on their health. During post-mortem examinations of two male neonatal orcas stranded in Germany and Norway, lungworm infections were found within the bronchi of both individuals. The nematodes were identified as Halocercus sp. (Pseudaliidae), which have been described in the respiratory tract of multiple odontocete species, but not yet in orcas. The life cycle and transmission pathways of some pseudaliid nematodes are incompletely understood. Lungworm infections in neonatal cetaceans are an unusual finding and thus seem to be an indicator for direct mother-to-calf transmission (transplacental or transmammary) of Halocercus sp. nematodes in orcas.

Robeck, T. R., Blum, J. L., Steinman, K. J., Ratner, J. R., Bergfelt, D. R., & O'Brien, J. K. (2018). Longitudinal Profiles of Relaxin and Progestagens During Pregnancy, Pregnancy Loss and False Pregnancy in the Killer Whale (Orcinus Orca). *General and Comparative Endocrinology*, 267, 98-108 https://doi.org/10.1016/j.ygcen.2018.06.008

The circulating pattern of immunoreactive relaxin and progestagens based on monthly and gestational stage (early, mid, late) profiles were determined during pregnancies that resulted in live calves (LIVE, n=30), stillbirths (STILLB, n=3), abortions (ABORT, n=5) and presumptive false pregnancies (FALSE, n=8), and during the follicular (n=34) and luteal phase (n=58). Monthly LIVE relaxin concentrations steadily increased during gestation, but values did not significantly exceed those of the luteal phase until 9months prior to parturition, peaking during the final month at 2356ng/ml. Relaxin surged (P<0.05) during the final week of gestation (36,397ng/ml), undergoing a 3 and 9-fold increase compared with concentrations in the preceding two weeks, respectively. Monthly relaxin production did not differ among each reproductive state with the exception of months-13-16 where concentrations were higher (P<0.001) for STILLB than LIVE. Relaxin concentration was reduced (P<0.0001) by 849% in placental versus maternal serum collected within 1day of labor. Mid- and late-pregnancy progestagen concentrations were lower for FALSE (P<0.001) compared with STILLB and LIVE. Late pregnancy progestagen concentrations were reduced for FALSE (P<0.05) and ABORT (P<0.02) compared with LIVE and STILLB. Monthly progestagen production in ABORT tended to be lower than LIVE across a range of gestational months (Months 2, 7, 8, 11) but this difference only became significant during months 14 and 15. Results indicate that relaxin is primarily produced by the CL during pregnancy, and that concentrations could not be used to differentiate from non-pregnant females until the final 6months of gestation. In addition, as would be expected from a primarily CL product, relaxin cannot be used to detect abnormal pregnancies. Conversely, progestagens, which are produced by both the placenta and CL can be used to differentiate FALSE from normal pregnancy and may be useful indicators of fetal health in the killer whale.

Robeck, T. R., & Monfort, S. L. (2006). Characterization of Male Killer Whale (Orcinus Orca) Sexual Maturation and Reproductive Seasonality. *Theriogenology*, 66(2), 242-250 https://doi.org/10.1016/j.theriogenology.2005.11.007

Longitudinal serum testosterone concentrations (n=10 males) and semen production (n=2 males) in killer whales were evaluated to: (1) characterize fluctuations in serum testosterone concentrations with respect to reproductive maturity and season; (2) compare morphologic changes to estimated age of sexual maturity, based on changes in serum testosterone concentrations; and (3) evaluate seasonal changes in sperm production. Classification of reproductive status and age class was based on differences (P<0.05) in serum testosterone concentrations according to age; juvenile males ranged from 1 to 7 years (mean±S.D. testosterone, 0.13±0.20ng/mL), pubertal males from 8 to 12 years (2.88±3.20ng/mL), and sexually mature animals were 13 years and older (5.57±2.90ng/mL). For captive-born males, serum testosterone concentrations, total body length and height to width ratio of the dorsal fin were 0.7±0.7ng/mL, 495.6±17.5cm and 1.14±0.13cm, respectively, at puberty; at sexual maturity, these end points were 6.0±3.3ng/mL, 548±20cm and 1.36±0.1cm. Serum testosterone concentrations were higher (P<0.05) from March to June than from December to February in pubertal animals (4.2±3.4ng/mL versus 1.4±2.6ng/mL) and than from September to December in sexually mature animals (7.2±3.3ng/mL versus 4.0±2.0ng/mL). Ejaculates (n=90) collected from two males had similar (P>0.05) sperm concentrations across all months. These data represent the first comprehensive study on male testosterone concentrations during and after sexual maturation, and on reproductive seasonality in the killer whale.

Roos, M. M. (2015). Respiration Timing and Underwater Activity in Killer Whales (Orcinus Orca). (Master of Philosophy Doctoral), University of St Andrews, Retrieved from http://hdl.handle.net/10023/6958

Accurate estimates of energetic requirements of top predators in-situ are essential to improve sustainable marine ecosystems' management. Yet, obtaining direct energetic measurements of free-ranging cetaceans is unfeasible. Breathing rate has been used as indicator of cetacean metabolic rates, though rate alone does not account for breath-by-breath variation in gas exchange. This study's aim was to investigate 1) the strength of correlations between respiration rates and underwater activity levels; and 2) the potential influence of including respiratory timing (besides rate) and oxygen uptake dynamics on in-situ cetacean energetic studies. Kinematic data from 12 adult wild Norwegian herring-feeding killer whales (Orcinus orca) were recorded with high-resolution tags (DTAGs) to reveal individual breathing events. Three-axis accelerometer and flow noise data were used to derive stroking rate and speed as underwater activity level metrics. An oxygen exchange model, including an oxygen uptake curve as key feature, and oxygen consumption from swimming speed or stroke number, was established to estimate oxygen extraction dynamically per individual breath, based upon modelled oxygen store at the time of each breath. Correlations between predicted oxygen uptake and activity level over 15 min periods were relatively weak when using constant uptake per breath (for both speed and stroking r2 < 0.1). Including fluctuating oxygen uptake per breath significantly improved the correlation between modelled oxygen uptake and activity (for both speed and stroking r2 > 0.9). Model outcomes found that cost of transport kept decreasing when assuming fixed oxygen uptake, whereas applying fluctuating uptake revealed a clear minimum cost of transport speed of 2.0-2.5 m·s-1. With on-going development and effort concerning bio-logging, together with gain of accurate information on energetic costs relating to kinematics, the proposed model could become a useful tool to improve our knowledge of free-ranging cetaceans’ energetic requirements in relation to more advanced sustainable marine ecosystem management.

Roos, M. M., Wu, G. M., & Miller, P. J. (2016). The Significance of Respiration Timing in the Energetics Estimates of Free-Ranging Killer Whales (Orcinus Orca). *Journal of Experimental Biology*, 219(Pt 13), 2066-2077 https://doi.org/10.1242/jeb.137513

Respiration rate has been used as an indicator of metabolic rate and associated cost of transport (COT) of free-ranging cetaceans, discounting potential respiration-by-respiration variation in O2 uptake. To investigate the influence of respiration timing on O2 uptake, we developed a dynamic model of O2 exchange and storage. Individual respiration events were revealed from kinematic data from 10 adult Norwegian herring-feeding killer whales (Orcinus orca) recorded with high-resolution tags (DTAGs). We compared fixed O2 uptake per respiration models with O2 uptake per respiration estimated through a simple 'broken-stick' O2-uptake function, in which O2 uptake was assumed to be the maximum possible O2 uptake when stores are depleted or maximum total body O2 store minus existing O2 store when stores are close to saturated. In contrast to findings assuming fixed O2 uptake per respiration, uptake from the broken-stick model yielded a high correlation (r(2)>0.9) between O2 uptake and activity level. Moreover, we found that respiration intervals increased and became less variable at higher swimming speeds, possibly to increase O2 uptake efficiency per respiration. As found in previous studies, COT decreased monotonically versus speed using the fixed O2 uptake per respiration models. However, the broken-stick uptake model yielded a curvilinear COT curve with a clear minimum at typical swimming speeds of 1.7-2.4 m s(-1) Our results showed that respiration-by-respiration variation in O2 uptake is expected to be significant. And though O2 consumption measurements of COT for free-ranging cetaceans remain impractical, accounting for the influence of respiration timing on O2 uptake will lead to more consistent predictions of field metabolic rates than using respiration rate alone.

Tang, K. N., Nollens, H. H., Robeck, T. R., & Schmitt, T. L. (2018). Serum Cobalamin and Folate Concentrations as Indicators of Gastrointerstinal Disease in Killer Whales (Orcinus Orca). *Journal of Zoo and Wildlife Medicine*, 49(3), 564-572 https://doi.org/10.1638/2017-0102.1

Cobalamin and folate are water-soluble vitamins that are useful indicators of chronic gastrointestinal (GI) function in humans and some animal species. Serum cobalamin and folate concentrations in an ex situ population of killer whales (Orcinus orca) were measured and factors that may affect their serum concentrations were identified. Serum samples (n¼104) were analyzed from killer whales (n¼10) both while clinically healthy and during periods of clinical GI disease as defined by clinical signs and fecal cytology. To characterize serum cobalamin and folate concentrations in clinically healthy animals, a mixed-model regression was used, with cobalamin and folate both significantly affected by weight (cobalamin: P , 0.0001, folate: P¼ 0.006) and season (cobalamin: P , 0.0001, folate: P , 0.0001). The marginal mean concentrations for cobalamin and folate across weight and season were 742 6 53.6 ng/L and 30.2 6 2.6 lg/L, respectively. The predicted 95% confidence intervals (CI) for these analytes were then compared with samples collected during periods of GI disease. Across individuals, 22% (2/9) ofthe folate and 80% (8/10) ofthe cobalamin samples from the animals with GI disease fell outside the 95%CI for the population. When comparing samples within an individual, a similar pattern presented, with 100% of cobalamin of the observed abnormal samples reduced compared to healthy animal concentration variability. The same was not true for folate. These results suggest that serum concentrations of cobalamin and folate may be useful minimally invasive markers to identify GI disease in killer whales, especially when values are compared within an individual.

Tennessen, J., Holt, M. M., Hanson, B., Emmons, C. K., Giles, D. A., & Hogan, J. (2018). Multi-Sensor Archival Tags on Southern Resident Killer Whales Reveal Patterns in Kinematic Behavior During Subsurface Foraging in the Salish Sea. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/478/ [Abstract Only]

Accumulating evidence suggests that endangered southern resident killer whales may not be meeting their energetic requirements for body maintenance and growth, which can negatively affect survival and reproduction. A variety of factors are likely contributing to the decline in body condition and population size of southern residents, including disturbance from vessels and noise, which is known to interfere with foraging behavior. Between 2010-2014 we deployed 28 suction cup-attached digital acoustic recording tags ("DTAGs") equipped with hydrophones, pressure sensors, and tri-axial accelerometers and magnetometers on southern residents as part of a study to investigate how underwater vessel noise impacts foraging behavior. Here, we present a fine-scale analysis of the kinematic behavior associated with subsurface foraging, which is a necessary precursor to understanding how vessel noise may be impairing successful foraging. First, we describe a method to identify subsurface prey capture events using kinematic data, and characterize the kinematic behavior associated with prey capture dives. Next, we show how foraging behavior differs between sexes. Finally, we discuss next steps to relate these findings to vessel noise impacts and implications for population recovery.

Trites, A. W., & Pauly, D. (1998). Estimating Mean Body Masses of Marine Mammals from Maximum Body Lengths. *Canadian Journal of Zoology*, 76 (5), 886-896 https://doi.org/10.1139/z97-252

Generalized survival models were applied to growth curves published for 17 species of cetaceans (5 mysticetes, 12 odontocetes) and 13 species of pinnipeds (1 odobenid, 4 otariids, 8 phocids). The mean mass of all individuals in the population was calculated and plotted against the maximum body length reported for each species. The data showed strong linearity (on logarithmic scales), with three distinct clusters of points corresponding to the mysticetes (baleen whales), odontocetes (toothed whales), and pinnipeds (seals, sea lions, and walruses). Exceptions to this pattern were the sperm whales, which appeared to be more closely related to the mysticetes than to the odontocetes. Regression equations were applied to the maximum lengths reported for 76 species of marine mammals without published growth curves. Estimates of mean body mass were thus derived for 106 living species of marine mammals.

Whittow, G. C., Hampton, I. F. G., Matsuura, D. T., Ohata, C. A., Smith, R. M., & Allen, J. F. (1974). Body Temperature of Three Species of Whales. *Journal of Mammalogy*, 55(3), 653-656 https://doi.org/10.2307/1379555

The available information on the body temperature of whales has been ta Morrison (1962), Ridgway (1972), and Irving (1973). The data were obtained from either dead whales or animals subjected to some degree of restraint necessary for the insertion of a rectal probe. Nothing is known about the body temperature of free-swimming whales. The present investigation was prompted by the opportunity to obtain data from three species of odontocete whales, and by the availability of a technique for measuring the body temperature, in the unrestrained animal, by telemetry. The study was performed on animals in tropical waters, and interest in it was enhanced by the possibility that whales, with a high level of heat production and a thick layer of insulating blubber (Irving, 1973), might encounter problems of heat dissipation in warm water, especially during acivity.

Williams, R., Lusseau, D., & Hammond, P. S. (2006). Estimating Relative Energetic Costs of Human Disturbance to Killer Whales (Orcinus Orca*). Biological Conservation*, 133(3), 301-311 https://doi.org/10.1016/j.biocon.2006.06.010

This study examined the activities of "northern resident" killer whales (Orcinus orca) in Johnstone Strait, British Columbia, Canada, in July and August, from 1995 to 2002. Disturbance from boat traffic has been identified as a conservation concern for this population. The primary aims of the study were to test whether boat presence altered whales' activities, and if so, to estimate whether behavioural responses were likely to have carried energetic costs. A land-based observation site near a vessel-exclusion marine protected area allowed us to conduct a natural experiment to monitor whale activities in the presence and absence of boats. Using Time-Discrete Markov Chain models, boat presence was linked to significant changes in the probability that focal whales would switch from one activity state to another, which led to significantly different activity budgets in the presence and absence of boats. We estimated that the energetic cost of meeting these budgets differed by only 3-4%. In the presence of boats, however, whales reduced their time spent feeding and the time spent rubbing their bodies on smooth pebble beaches. These lost feeding opportunities could have resulted in a substantial (18%) estimated decrease in energy intake. Our sensitivity analysis provides preliminary evidence that disturbance could carry higher costs to killer whales in terms of reducing energy acquisition than increasing energetic demand, and future research should address this directly. Meanwhile, our observations suggest that protected areas would confer greatest conservation benefit to endangered killer whale populations if they were designed to protect important foraging areas. (c) 2006 Elsevier Ltd. All rights reserved.

Williams, R., & Noren, D. P. (2009). Swimming Speed, Respiration Rate, and Estimated Cost of Transport in Adult Killer Whales. *Marine Mammal Science*, 25(2), 327-350 https://doi.org/10.1111/j.1748-7692.2008.00255.x

The physiology of free-ranging cetaceans is difficult to study and as a consequence, data on the energetics of these animals are limited. To better understand the energetic cost of swimming in killer whales, total cost of transport (COT) was estimated from swimming speeds and respiration rates from wild adult northern resident killer whales (Orcinus orca) and reported values of oxygen consumption in captive whales. Respiration rate (breaths per minute) was positively correlated with swimming speed (meters per second), while mass-specific COT (Joules per kilogram per meter) decreased with speed. Lack of data on very fast-swimming animals hindered assessment of the exact speed at which COT was minimal. However, minimum mass-specific COT for killer whales in the present study approached those predicted by a previously published allometric equation for marine mammals, and corresponded to "optimal" swimming speeds of 2.6-3 m/s. Interestingly, the observed average swimming speed (1.6 m/s) was lower than predicted optimal swimming speed. Finally, females with dependent calves had higher respiration rates than females without calves. These findings could be due to synchronous breathing with calves or could result from increased costs of lactation and swimming with a calf in echelon formation. Consequently, females with calves may have much greater COT at optimal swimming speeds than females without calves.

Williams, T. M. (1999). The Evolution of Cost Efficient Swimming in Marine Mammals: Limits to Energetic Optimization. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 354(1380), 193-201 https://doi.org/10.1098/rstb.1999.0371

Mammals re-entered the oceans less than 60 million years ago. The transition from a terrestrial to an aquatic lifestyle required extreme morphological and behavioural modifications concomitant with fundamentally different locomotor mechanisms for moving on land and through water. Energetic transport costs typically reflect such different locomotor modes, but can not be discerned from the fossil record. In this study the energetic challenges associated with changing from terrestrial to aquatic locomotion in primitive marine mammals are examined by comparing the transport, maintenance and locomotor costs of extant mammals varying in degree of aquatic specialization. The results indicate that running and swimming specialists have converged on an energetic optimum for locomotion An allometric expression, COTTOT=7.79 mass (-0.29) (r(2)=0.83, n=6 species), describes the total cost of transport in J kg(-1) m(-1) for swimming marine mammals ranging in size from 21 kg to 15 000 kg. This relation is indistinguishable from that describing total transport costs in running mammals. In contrast, the transitional lifestyle of semi-aquatic mammals, similar to that of ancestral marine mammals, incurs costs that are 2.4-5.1 times higher than locomotor specialists. These patterns suggest that primitive marine mammals confronted an energetic hurdle before returning to costs reminiscent of their terrestrial ancestry, and may have reached an evolutionary limit for energetic optimization during swimming.

Williams, T. M., Dunkin, R., Yochem, P., McBain, J., Fox-Dobbs, K., Mostman-Liwanag, H., & Maresh, J. (2008). Assessing Stable Isotope Signature Variation in Cetaceans: An Evaluation of Skin Sampling Techniques and Correlations with Diet for Bottlenose Dolphins and Killer Whales. Northwest Fisheries Science Center (NWFSC). Retrieved from https://www.nwfsc.noaa.gov/research/divisions/cb/ecosystem/marinemammal/documents/twilliams_final_contract_report.pdf

We evaluated methods for assessing carbon and nitrogen isotope compositions in the epidermis of two species of odontocetes, the bottlenose dolphin (Tursiops trucatus, n = 2) and killer whale (Orcinus orca, n = 9). Diet profiles including composition and food intake rates of captive animals were monitored for 5 - 7 months and matched to stable isotope values determined from skin samples obtained immediately after the diet monitoring period. An investigation of four different epidermal sampling sites for dolphins demonstrated that anatomical site (including peripheral fins and body flank) had no effect on isotopic values (mean for all sites = –18.39 ± 0.29 SD for δ13C and 18.82 ± 0.25 SD for δ15N). Values for killer whales differed from the dolphins and averaged –17.69 ± 0.34 for δ13C and 14.51 ± 0.15 for δ15N. These ranges reflected differences in diet between the species, which consisted of an approximate 50/50 mix of Atlantic herring and Icelandic capelin for the dolphins and a mixed fish diet including these species as well as mackerel, salmon, sardine and smelt for the killer whales. The magnitude of the observed effect depended on the difference in isotopic profiles of the fish species comprising routine and new diets, and may be especially evident for some species of salmon.

Williams, T. M., Estes, J. A., Doak, D. F., & Springer, A. M. (2004). Killer Appetites: Assessing the Role of Predators in Ecological Communities. *Ecology*, 85(12), 3373-3384 https://doi.org/10.1890/03-0696

Large body size, carnivory, and endothermic costs lead to exceptionally high caloric demands in many mammalian predators. The potential impact on prey resources may be marked but is difficult to demonstrate because of the mobility, sparseness, and cryptic nature of these animals. In this study, we developed a method based on comparative bioenergetics and demographic modeling to evaluate predator effects and then used this approach to assess the potential impact of killer whales on sea otter and Steller sea lion populations in the Aleutian Islands. Daily caloric requirements of killer whales determined from allometric regressions for field metabolic rate show that an adult killer whale requires 51–59 kcal·kg⩾1·d⩾1 (2.5–2.9 W/kg). Caloric values of prey items determined by bomb calorimetry ranged from 41 630 kcal for an adult female sea otter to sequentially higher values for male otters, sea lion pups, and adult Steller sea lions. Integrating these results with demographic changes in marine mammal populations show that fewer than 40 killer whales could have caused the recent Steller sea lion decline in the Aleutian archipelago; a pod of five individuals could account for the decline in sea otters and the continued suppression of sea lions. The collapse of the historical prey base of killer whales due to human whaling may have contributed to a sequential dietary switch from high to low caloric value prey, thereby initiating these declines. This study demonstrates that a combined physiological–demographic approach increases our ability to critically evaluate the potential impact ofa predator on community structure and enables us to define underlying mechanisms that drive or constrain top-down forcing in dynamic ecosystems.

Williams, T. M., Fuiman, L. A., Horning, M., & Davis, R. W. (2004). The Cost of Foraging by a Marine Predator, the Weddell Seal, Leptonychotes Weddellii: Pricing by the Stroke. *The Journal of Experimental Biology*, 207(6), 973-982 https://doi.org/10.1242/jeb.00822

Foraging by mammals is a complex suite of behaviors that can entail high energetic costs associated with supporting basal metabolism, locomotion and the digestion of prey. To determine the contribution of these various costs in a free-ranging marine mammal, we measured the post-dive oxygen consumption of adult Weddell seals (N=9) performing foraging and non-foraging dives from an isolated ice hole in McMurdo Sound, Antarctica. Dives were classified according to behavior as monitored by an attached video-data logging system (recording activity, time, depth, velocity and stroking). We found that recovery oxygen consumption showed a biphasic relationship with dive duration that corresponded to the onset of plasma lactate accumulation at approximately 23 min. Locomotor costs for diving Weddell seals increased linearly with the number of strokes taken according to the relationship: locomotor cost =– 3.78+0.04 × stroke number (r2=0.74, N=90 dives), where locomotor cost is in ml O2 kg–1. Foraging dives in which seals ingested Pleuragramma antarcticum resulted in a 44.7% increase in recovery oxygen consumption compared to non-foraging dives, which we attributed to the digestion and warming of prey. The results show that the energy expended in digestion for a free-ranging marine mammal are additive to locomotor and basal costs. By accounting for each of these costs and monitoring stroking mechanics, it is possible to estimate the aerobic cost of diving in free-ranging seals where cryptic behavior and remote locations prevent direct energetic measurements.

Section IV: Body Composition

Alava, J. J., Jiménez, P. J., Fair, P. A., & Barrett-Lennard, L. (2019). First Record of a Live-Stranded Killer Whale (Orcinus Orca) in Coastal Ecuador and Insights on Killer Whale Occurrence in Ecuadorian Waters. *Aquatic Mammals*, 45(1), 106-115 http://dx.doi.org/10.1578/AM.45.1.2019.106

[...]the aim of this note is to describe the first live-stranding of a killer whale calf along the mainland coast of Ecuador and its rescue by the local community. Based on a recent study assessing the size and long-term growth trends in southern resident killer whales of known age from the Northeastern Pacific (Fearnbach et al., 2011), the plausible estimated age for this calf was <1 y (i.e., inferred from the relationship of maximum estimate of lengths vs observed/ estimated ages of southern resident killer whales using Figure 4 in Fearnbach et al., 2011). Since the physical examination of body condition (i.e., body mass index) is the most fundamental parameter to assess health in cetaceans (Moore et al., 2018), an initial assessment of calf body condition from its appearance in photos suggests that the animal did not exhibit signs of external injuries or wounds, but it had a depression on both the melon and at the back of the skull (Figure 2), which are indications of emaciation (Read & Murray, 2000; Fearnbach et al., 2018). The presence of an unusually thin blubber layer and epaxial musculature (i.e., external depression posterior to the nuchal crest of the skull) indicates poor body condition and may indicate the incidence of chronic disease (Read & Murray, 2000). [...]an impairment of the melon structure in this animal could have influenced the production of sounds for echolocation, possibly contributing to the stranding. [...]cetacean viruses such as morbilliviruses and papillomaviruses, as well as bacteria Brucella spp. and the parasite Toxoplasma gondii, are considered to interfere with population abundance by inducing high mortalities, lowering reproductive success, or by synergistically increasing the virulence of other diseases (Van Bressem et al., 2009). [...]the recent mass mortality of small-toothed cetaceans, including long-beaked common dolphins (Delphinus capensis), and Burmeister's porpoises (Phocoena spinipinnis) that were stranded along the northern coast of Peru was associated with cumulative multi-stressors and anthropogenic impacts (e.g., pollution, underwater noise, and pathogens) exacerbated by the El Niño event (Alava, 2012).

Bourque, J., Dietz, R., Sonne, C., St Leger, J., Iverson, S., Rosing-Asvid, A., . . . McKinney, M. A. (2018). Feeding Habits of a New Arctic Predator: Insight from Full-Depth Blubber Fatty Acid Signatures of Greenland, Faroe Islands, Denmark, and Managed-Care Killer Whales Orcinus Orca. *Marine Ecology Progress Series*, 603, 1-12 https://doi.org/10.3354/meps12723

An increasing number of North Atlantic killer whales Orcinus orca have recently been observed in sub-Arctic and Arctic seas. Within these regions, marine mammal consumption appears frequent relative to the more fish-based diet within traditional habitats. To provide insight into feeding habits of northward range-expanding killer whales, full-depth blubber fatty acid signatures from 21 free-ranging killer whales from southeast Greenland, Faroe Islands, and Denmark were compared to those of 4 managed-care killer whales, which were fed a constant, long-term fish diet. We analyzed the entire blubber layer in 10 equal-length subsections to evaluate how fatty acid stratification throughout blubber depth may influence fatty acid-based feeding evaluations. Specific fatty acid markers previously linked to marine mammal feeding in other killer whale populations were significantly higher in free-ranging killer whales relative to managed-care individuals, suggesting that marine mammals represent a time-integrated component of free-ranging killer whales' diet. Unlike the managed-care whales, fatty acid signatures were highly variable among the free-ranging killer whales, suggesting that either they are generalists or exhibit inter-individual feeding variation. All samples, regardless of origin, showed stratification of fatty acid signatures through blubber layers. Dietary fatty acids generally occurred in higher proportions and were more variable in the inner-most layers for the free-ranging whales. These data suggest that superficial blubber sampling through biopsy darting may not capture fine-scale and/or short-term variation in diet, and therefore the sampling approach should be carefully considered in research using fatty acids to evaluate feeding ecology of killer whales and other cetaceans.

Christensen, I. (1982). Killer Whales in Norwegian Coastal Waters. *Report of the International Whaling Commission*, 32, 633-672. SC/Jn81/KW1. Retrieved from https://archive.iwc.int/?r=36&k=e3a85bd029

Observations reported by whalers and fishermen indicate that killer whales are present in all areas of the Norwegian coast throughout the year. No migration pattern has been discovered, but killer whales occur in greatest numbers in the Lofoten and More areas and off the southern west coast. A mean catch of 57 killer whales per year over the period 1938--1980 has not changed the length distribution in the catch. Decreasing fatness from 1951 to 19M may have been caused by a decreasing availability of food. Reported weights indicate that meat constitutes 40% of total body weight, blubber 29%, bones 22%-, and viscera 9%. Feeding behaviour and pod organization is described from recorded observation. Female killer whales seem to reach sexual maturity at a length of 15 feet, and an age of about 6 years. Matings occur throughout the year, with a maximum in October-December. A gestation period of 12 months and one birth every second year is indicated. Preliminary age determinations indicate continued growth in groups of body length up to 20-25 year, and a life span of at least 35 years.

Colegrove, K. M., St. Leger, J. A., Raverty, S., Jang, S., Berman-Kowalewski, M., & Gaydos, J. K. (2010). Salmonella Newport Omphaloarteritis in a Stranded Killer Whale (Orcinus Orca) Neonate. *Journal of Wildlife Diseases*, 46(4), 1300-1304 https://doi.org/10.7589/0090-3558-46.4.1300

Salmonella enterica serovar Newport (*Salmonella* Newport) was isolated from multiple tissues in a neonate killer whale (Orcinus orca) that stranded dead in 2005 along the central coast of California, USA. Necrotizing omphaloarteritis and omphalophlebitis was observed on histologic examination suggesting umbilical infection was the route of entry. Genetic analysis of skin samples indicated that the neonate had an offshore haplotype. Salmonellosis has rarely been identified in free-ranging marine mammals and the significance of *Salmonella* Newport infection to the health of free-ranging killer whales is currently unknown.

Endo, T., Kimura, O., Hisamichi, Y., Minoshima, Y., & Haraguchi, K. (2007). Age-Dependent Accumulation of Heavy Metals in a Pod of Killer Whales (Orcinus Orca) Stranded in the Northern Area of Japan. *Chemosphere*, 67(1), 51-59 https://doi.org/10.1016/j.chemosphere.2006.09.086

Mercury (Hg), cadmium (Cd), iron (Fe) manganese (Mn), zinc (Zn) and copper (Cu) concentrations in the liver, kidney and muscle of nine killer whales (including three calves) that stranded together in the northern area of Japan were determined. The Hg and Cd concentrations were found at trace levels in the calf organs, and increased with age. The Fe concentration in the muscle was significantly lower in the calves than in the mature whales and also increased with age. In contrast, Mn and Cu concentrations in the muscle were significantly higher in the calves than in the mature whales, and changes in the Zn concentration relative to age were unclear. These results suggest minimal mother-to-calf transfer of the

toxic metals Hg and Cd and accumulation of these metals in the organs with age, while the essential metals Mn and Cu were found at higher concentrations in the muscle of calves than in mature whales.

Endo, T., Kimura, O., Sato, R., Kobayashi, M., Matsuda, A., Matsuishi, T., & Haraguchi, K. (2014). Stable Isotope Ratios of Carbon, Nitrogen and Oxygen in Killer Whales (Orcinus Orca) Stranded on the Coast of Hokkaido, Japan. *Marine Pollution Bulletin*, 86(1-2), 238-243 https://doi.org/10.1016/j.marpolbul.2014.07.012

We analyzed delta(13)C, delta(15)N and delta(18)O in the muscle and liver from killer whales stranded on the coast of Japan. The delta(15)N values in the muscle samples from calves were apparently higher than those in their lactating mothers, suggesting that nursing may result in the higher delta(15)N values in the muscle samples of calves. The delta(15)N value in the muscle samples of male and female whales, except for the calves, were positively correlated with the delta(13)C values and body length, suggesting that the increases in delta(15)N were due to the growth of the whales and increase in their trophic level. In contrast, the delta(18)O values in the muscle samples of female whales except for the calves were negatively correlated with the delta(13)C and delta(15)N values. The delta(18)O may be lower in whales occupying higher trophic positions (delta(15)N), although it might also be affected by geographic and climatic conditions.

Herman, D. P., Burrows, D. G., Wade, P. R., Durban, J. W., Matkin, C. O., LeDuc, R. G., . . . Krahn, M. M. (2005). Feeding Ecology of Eastern North Pacific Killer Whales Orcinus Orca from Fatty Acid, Stable Isotope, and Organochlorine Analyses of Blubber Biopsies. *Marine Ecology Progress Series*, 302, 275-291 https://doi.org/10.3354/meps302275

Blubber biopsy samples from eastern North Pacific killer whales Orcinus orca were analyzed for fatty acids, carbon and nitrogen stable isotopes and organochlorine contaminants. Fatty acid profiles were sufficiently distinct among the 3 reported ecotypes ('resident,' 'transient' or 'offshore') to enable individual animals to be correctly classified by ecotype and also by mitochondrial DNA (mtDNA) haplotype. Profiles of PCBs also enabled unambiguous classification of all 3 killer whale ecotypes, but stable isotope values lacked sufficient resolution. Fatty acid, stable isotope and PCB profiles of the resident and transient ecotypes were consistent with those expected for these whales based on their reported dietary preferences (fish for resident whales, marine mammals for transients). In addition, these ecotype profiles exhibited broad similarity across geographical regions, suggesting that the dietary specialization reported for resident and transient whales in the well-studied eastern North Pacific populations also extends to the less-studied killer whales in the western Gulf of Alaska and Aleutian Islands. Killer whales of the same ecotype were also grouped by region of sample collection. The mean stable isotope ratios of various regional groups differed considerably, suggesting that the prey preferences of these North Pacific killer whales may be both region and ecotype specific. Furthermore, 3 specific ecotypes of killer whales were found to have measured stable isotope values that were consistent with dietary preferences reported in the literature. Finally, although the offshore population had blubber fatty acid profiles implicating fish as its primary prey, contaminant and stable isotope results were equally congruent with predation on marine mammals.

Herman, D. P., Matkin, C. O., Ylitalo, G. M., Durban, J. W., Hanson, M. B., Dahlheim, M. E., . . . Krahn, M.

M. (2008). Assessing Age Distributions of Killer Whale Orcinus Orca Populations from the Composition of Endogenous Fatty Acids in Their Outer Blubber Layers. *Marine Ecology Progress Series*, 372, 289-302 https://doi.org/10.3354/meps07709

Knowledge of the age distributions of killer whale Orcinus orca populations is critical to assess their status and long-term viability. Except for accessible, well-studied populations for which historical sighting data have been collected, currently there is no reliable benign method to determine the specific age of live animals for remote populations. To fill this gap in our knowledge of age structure, we describe new methods by which age can be deduced from measurements of specific lipids, endogenous fatty acids (FAs) and FA ratios present in their outer blubber layers. Whereas correlation of wax and sterol esters with age was reasonable for female ‘resident’ killer whales, it was less well-defined for males and ‘transients.’ Individual short-, branched-, and odd-chain FAs correlated better with age for transients and residents of both sexes, but these single parameter relationships were population specific and seemingly varied with long-term diet. Alternatively, a simple, empirical multi-linear model derived from the combination of 2 specific FA ratios enabled the ages of individual eastern North Pacific killer whales to be predicted with good precision ($\sigma = \pm 3.8$ yr), appeared to be independent of individual diet and was applicable to both genders and ecotypes. The model was applied to several less well-studied killer whale populations to predict their age distributions from their blubber FA compositions, and these distributions were compared with a population of known age structure. Most interestingly, these results provide evidence for the first time that adult male transient killer whales appear to have lower life expectancies than do their resident counterparts in Alaska.

Jepson, P. D., Deaville, R., Barber, J. L., Aguilar, A., Borrell, A., Murphy, S., . . . Law, R. J. (2016). PCB Pollution Continues to Impact Populations of Orcas and Other Dolphins in European Waters. *Scientific Reports*, 6, 17 https://doi.org/10.1038/srep18573

Organochlorine (OC) pesticides and the more persistent polychlorinated biphenyls (PCBs) have well-established dose-dependent toxicities to birds, fish and mammals in experimental studies, but the actual impact of OC pollutants on European marine top predators remains unknown. Here we show that several cetacean species have very high mean blubber PCB concentrations likely to cause population declines and suppress population recovery. In a large pan-European meta-analysis of stranded ($n = 929$) or biopsied ($n = 152$) cetaceans, three out of four species:-striped dolphins (SDs), bottlenose dolphins (BNDs) and killer whales (KWs) had mean PCB levels that markedly exceeded all known marine mammal PCB toxicity thresholds. Some locations (e.g. western Mediterranean Sea, south-west Iberian Peninsula) are global PCB "hotspots" for marine mammals. Blubber PCB concentrations initially declined following a mid-1980s EU ban, but have since stabilised in UK harbour porpoises and SDs in the western Mediterranean Sea. Some small or declining populations of BNDs and KWs in the NE Atlantic were associated with low recruitment, consistent with PCB-induced reproductive toxicity. Despite regulations and mitigation measures to reduce PCB pollution, their biomagnification in marine food webs continues to cause severe impacts among cetacean top predators in European seas.

Jourdain, E., Karoliussen, R., Curé, C., Massenet, M., Barrett-Lennard, L., & Ellis, G. M. (2019). A Case of Natural Killer Whale (Orcinus Orca) Entrapment in Northern Norway: From Assessment to Rescue. *Aquatic Mammals*, 45(1), 14-20 https://doi.org/10.1578/am.45.1.2019.14

No abstract.

Kajiwara, N., Kunisue, T., Kamikawa, S., Ochi, Y., Yano, S., & Tanabe, S. (2006). Organohalogen and Organotin Compounds in Killer Whales Mass-Stranded in the Shiretoko Peninsula, Hokkaido, Japan. *Marine Pollution Bulletin*, 52(9), 1066-1076 https://doi.org/10.1016/j.marpolbul.2006.01.011

Blubber and liver samples were obtained for analysis of wide ranges of contaminants from killer whales (Orcinus orca) which were locked away in drifting sea ice on the coast of Rausu, the Shiretoko Peninsula in Eastern Hokkaido, Japan in February 2005. Among the organohalogen compounds analyzed, DDTs were the predominant contaminants with concentrations ranging from 28 to 220 lg/g on a lipid-weight basis followed by PCBs and other organochlorine pesticides. PBDEs levels were two or three orders of magnitude lower than those of PCBs and DDTs. 2,3,7,8-Tetrachlorodibenzo-p-dioxin toxic equivalents (TEQs) derived by WHO mammal-TEF in killer whales were in the range of 110–440 pgTEQ/g. Mono-ortho coplanar PCBs contributed to 75–98% of total TEQs, indicating coplanar PCBs are significant contaminants for risk assessment in this species. The fact that hepatic residue levels of butyltins (from 13 to 770 ng/g wet weight) were much higher than those of phenyltins may be reflecting extensive use of tributyltin as antifouling paint.

Krahn, M. M., Hanson, M. B., Baird, R. W., Boyer, R. H., Burrows, D. G., Emmons, C. K., . . . Collier, T. K. (2007). Persistent Organic Pollutants and Stable Isotopes in Biopsy Samples (2004/2006) from Southern Resident Killer Whales. *Marine Pollution Bulletin*, 54(12), 1903-1911 https://doi.org/10.1016/j.marpolbul.2007.08.015

"Southern Resident" killer whales include three "pods" (J, K and L) that reside primarily in Puget Sound/Georgia Basin during the spring, summer and fall. This population was listed as "endangered" in the US and Canada following a 20% decline between 1996 and 2001. The current study, using blubber/epidermis biopsy samples, contributes contemporary information about potential factors (i.e., levels of pollutants or changes in diet) that could adversely affect Southern Residents. Carbon and nitrogen stable isotopes indicated J- and L-pod consumed prey from similar trophic levels in 2004/2006 and also showed no evidence for a large shift in the trophic level of prey consumed by L-pod between 1996 and 2004/2006. Sigma PCBs decreased for Southern Residents biopsied in 2004/2006 compared to 1993-1995. Surprisingly, however, a three-year-old male whale (J39) had the highest concentrations of Sigma PBDEs, Sigma HCHs and HCB. POP ratio differences between J- and L-pod suggested that they occupy different ranges in winter.

Krahn, M. M., Hanson, M. B., Schorr, G. S., Emmons, C. K., Burrows, D. G., Bolton, J. L., . . . Ylitalo, G. M. (2009). Effects of Age, Sex and Reproductive Status on Persistent Organic Pollutant Concentrations in “Southern Resident” Killer Whales*. Marine Pollution Bulletin*, 58(10), 1522-1529 https://doi.org/10.1016/j.marpolbul.2009.05.014

“Southern Resident” killer whales (Orcinus orca) that comprise three fish-eating “pods” (J, K and L) were listed as “endangered” in the US and Canada following a 20% population decline between 1996 and 2001. Blubber biopsy samples from Southern Resident juveniles had statistically higher concentrations of certain persistent organic pollutants than were found for adults. Most Southern Resident killer whales, including the four juveniles, exceeded the health-effects threshold for total PCBs in marine mammal blubber. Maternal transfer of contaminants to the juveniles during rapid development of their biological systems may put these young whales at greater risk than adults for adverse health effects (e.g., immune and endocrine system dysfunction). Pollutant ratios and field observations established that two of the pods (K- and L-pod) travel to California to forage. Nitrogen stable isotope values, supported by field observations, indicated possible changes in the diet of L-pod over the last decade.

Krahn, M. M., Herman, D. P., Matkin, C. O., Durban, J. W., Barrett-Lennard, L., Burrows, D. G., . . . Wade, P. R. (2007). Use of Chemical Tracers in Assessing the Diet and Foraging Regions of Eastern North Pacific Killer Whales. *Marine Environmental Research*, 63(2), 91-114 https://doi.org/10.1016/j.marenvres.2006.07.002

Top predators in the marine environment integrate chemical signals acquired from their prey that reflect both the species consumed and the regions from which the prey were taken. These chemical tracers-stable isotope ratios of carbon and nitrogen; persistent organic pollutant (POP) concentrations, patterns and ratios; and fatty acid profiles-were measured in blubber biopsy samples from North Pacific killer whales (Orcinus orca) (n=84) and were used to provide further insight into their diet, particularly for the offshore group, about which little dietary information is available. The offshore killer whales were shown to consume prey species that were distinctly different from those of sympatric resident and transient killer whales. In addition, it was confirmed that the offshores forage as far south as California. Thus, these results provide evidence that the offshores belong to a third killer whale ecotype. Resident killer whale populations showed a gradient in stable isotope profiles from west (central Aleutians) to east (Gulf of Alaska) that, in part, can be attributed to a shift from off-shelf to continental shelf-based prey. Finally, stable isotope ratio results, supported by field observations, showed that the diet in spring and summer of eastern Aleutian Island transient killer whales is apparently not composed exclusively of Steller sea lions.

Krahn, M. M., Herman, D. P., Ylitalo, G. M., Sloan, C. A., Burrows, D. G., Hobbs, R. C., . . . Moore, S. E. (2004). Stratification of Lipids, Fatty Acids and Organochlorine Contaminants in Blubber of White Whales and Killer Whales*. Journal of Cetacean Research Management*, 6(2), 175-189. Retrieved from http://www.cascadiaresearch.org/publications/stratification-lipids-fatty-acids-and-organochlorine-contaminants-blubber-white-whales

The biopsy 2 via dart, trocar or surgery 2 is becoming the preferred protocol for sampling skin and blubber of many cetacean species, because a small sample from a healthy animal may provide better information than a larger sample collected via necropsy from an ill or emaciated animal. Furthermore, the biopsy is often the only means of obtaining samples (e.g. for threatened or endangered species). Because biopsy darts collect only a small sample of tissue 2 and blubber can be heterogeneous in structure and composition 2 it is essential to compare the results obtained from biopsies to those found by analysing full-thickness blubber samples obtained via necropsy. This manuscript compares blubber stratification in two odontocete species, white whales (Delphinapterus leucas) and killer whales (Orcinus orca). Five parameters (i.e. lipid percent and classes, contaminant concentrations and profiles, fatty acid profiles) were measured by blubber depth. Results of these comparisons strongly suggest that biopsy results must be interpreted with caution and in conjunction with results from species-specific blubber depth profiling. For example, lipid classes measured in biopsy samples of white whales and killer whales were similar to those for equivalent-depth samples obtained by necropsy. In addition, lipid-adjusted contaminant concentrations measured in dart or trocar samples adequately represented those obtained by necropsy of both species. Conversely, the lipid content in biopsy samples was lower than that found in same-depth necropsied samples due to loss of lipid during sampling. Also, because of the high level of fatty acid stratification observed, fatty acid profiles from the outer blubber layer collected via biopsy from both species are less likely than the metabolically active inner layer to be useful in determining the prey species consumed by these odontocetes. This study demonstrates, for white and killer whales, that properly interpreted results from blubber biopsies can provide valuable information about the body condition, health and life history of individual animals.

Law, R. J., Allchin, C. R., Jones, B. R., Jepson, P. D., Baker, J. R., & Spurrier, C. J. H. (1997). Metals and Organochlorines in Tissues of a Blainville's Beaked Whale (Mesoplodon Densirostris) and a Killer Whale (Orcinus Orca) Stranded in the United Kingdom. *Marine Pollution Bulletin*, 34(3), 208-212 https://doi.org/10.1016/S0025-326x(96)00148-8

No abstract.

Noël, M., Barrett-Lennard, L., Guinet, C., Dangerfield, N., & Ross, P. S. (2009). Persistent Organic Pollutants (POPS) in Killer Whales (Orcinus Orca) from the Crozet Archipelago, Southern Indian Ocean. *Marine Environmental Research*, 68(4), 196-202 https://doi.org/10.1016/j.marenvres.2009.06.009

Persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and dibenzofurans (PCDFs), are ubiquitous environmental contaminants of which significant concentrations are reported in upper trophic level animals. In 1998, we collected blubber biopsy samples (n = 11) from killer whales (Orcinus orca) inhabiting the coastal waters around Possession Island, Crozet Archipelago, southern Indian Ocean, for contaminant analyses. Despite inhabiting an isolated region far removed from industrial activities, these killer whales can presently be considered among the most PCB-contaminated cetaceans in the southern hemisphere, with concentrations ranging from 4.4 to 20.5 mg/kg lipid weight (lw). PCDD levels ranged from below the detection limit (5 ng/kg) to 77.1 ng/kg lw and PCDF levels from below the detection limit (7 ng/kg) to 36.1 ng/kg lw. Over 70% of our study animals had PCB concentrations which exceeded a 1.3 mg/kg PCB threshold established for endocrine disruption and immunotoxicity in free-ranging harbour seals, suggesting that organic contaminants cannot be ruled out as an additional threat to this declining population.

Noël, M., Ylitalo, G., Hanson, B., Towers, J., & Ross, P. (2018). PCB and PBDE Levels in Southern and Northern Resident Killer Whales: Update on Contaminant Levels and Related Health Effects. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/30/

Salish Sea's killer whale populations are among the most contaminated marine mammals in the world and face risks related to the effects of polychlorinated biphenyls (PCBs) and related contaminants such as polybrominated diphenylethers (PBDEs). While PCBs have long been banned, they continue to present toxic risks to marine mammals, along with a number of other, emerging persistent, bioaccumulative and toxic (PBT) contaminants. Since PBTs have been identified as a threat to the recovery of resident killer whale populations under the auspices of the US Endangered Species Act and the Canadian Species at Risk Act (SARA), documenting the presence, trends and health effects of emerging PBT contaminants represents an important line of research. In the summer of 2016 and 2017, we collected blubber biopsies from 10 southern resident and nine northern resident killer whales. PCB and PBDE analyses were conducted using high resolution gas chromatography/high resolution mass spectrometry. Given the likelihood of significant temporal changes in the concentrations of these contaminants, this study will provide updated contaminant concentration data and strengthen our ability to prioritize contaminants of concern in resident killer whales. In addition, stable isotope and fatty acid analyses will provide important information on diet and nutritional status. Together with analyses of the expression of essential genes involved in immune response, hormone regulation and lipid metabolism, this study provides new essential information on the health status of resident killer whales as it relates to contaminant exposure and will help inform the development and application of recovery action plans.

Noren, D. P., Ylitalo, G. M., Burtis, K. F., Boyd, D., McCoy, A., Schmitt, T. L., . . . St Leger, J. A. (2018). Assessing Persistent Organic Pollutant (POP) Transfer from Female Killer Whales (Orcinus Orca) to Calves During Gestation and Lactation. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/47/ [Abstract Only]

Persistent organic pollutants (POPs) pose a health risk for southern resident killer whales (SRKWs). Data on maternal contaminant transfer to calves are needed to inform models that estimate future contaminant loads as well as assess risk to newborn killer whale calves exposed to POPs. We conducted a study on trained female killer whales and their calves to fill these data gaps. POPs and lipid content were quantified in blood serum (POP levels in serum and blubber are highly correlated) collected during gestation and in milk and serum collected post-partum from female killer whales. Serum samples were also collected from calves during the lactation period. POP concentrations in milk collected over 15 months post-partum from the primiparous female decreased by 47-65%, depending on the contaminant class. The highest influx of contaminants to calves tended to occur soon after birth. Greater contaminant transfer rates during early lactation were also reflected in maternal serum POP levels. POP levels in maternal serum decreased significantly during the first 144-158 days post-partum, depending on contaminant class, and then leveled off through the remaining lactation period. This resulted in 67-81% reductions in POP levels in maternal serum over 15 months. By 15 months post-partum, serum POP levels from the primiparous female had dropped to levels measured in the multiparous female during pregnancy. Dissimilar to the multiparous female, body mass and blubber thickness in the primiparous female also declined significantly during the first 3-5 months post-partum, demonstrating linkages between lipid and POP transfer from blubber stores to milk in early lactation. By the end of lactation, lipid-corrected POP concentrations in serum from the first-born calf were 5-8 times greater than the corresponding POP levels from her primiparous mother. These results demonstrate that very young neonatal SRKW calves, particularly first-born calves, are at high risk from contaminant exposure.

Omata, Y., Umeshita, Y., Watarai, M., Tachibana, M., Sasaki, M., Murata, K., & Yamada, T. K. (2006).

Investigation for Presence of Neospora Caninum, Toxoplasma Gondii and Brucella Species Infection in Killer Whales (Orcinus Orca) Mass-Stranded on the Coast of Shiretoko, Hokkaido, Japan. *Journal of Veterinary Medical Science*, 68(5), 523-526 https://doi.org/10.1292/jvms.68.523

Twelve killer whale (Orcinus orca) were hemmed in by ice floes, and nine died on the Aidomari coast in the Nemuro Strait in Rausu, Shiretoko, Hokkaido, Japan on 8 February 2005. Tissue samples collected from 8 whales were tested for Neospora caninum, Toxoplasma gondii, and Brucella species DNA by polymerase chain reaction (PCR) assay. Gamma-globulin isolated from blood samples by ammonium sulfate precipitation was tested for antibodies to these pathogens by means of agglutination tests and immunoblotting. None of the 8 tissue samples had antibodies to the pathogens, when subjected to agglutination tests. In immunoblotting, one sample (sample No.5) showed antibody binding to N. caninum antigens. In the PCR assay, none of the samples was positive. Further study is necessary to examine the prevalence of the pathogens in marine mammals inhabiting this area. KEY WORDS: infection, killer whale, mass-stranding.

Ono, M., Kannan, N., Wakimoto, T., & Tatsukawa, R. J. M. P. B. (1987). Dibenzofurans a Greater Global Pollutant Than Dioxins?: Evidence from Analyses of Open Ocean Killer Whale. *Marine Pollution Bulletin*, 18(12), 640-643. https://doi.org/10.1016/0025-326X(87)90396-1

Three specimens of killer whales (Orcinus orca), an open ocean carnivore, were analysed for extremely toxic polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) to understand their long-range distribution patterns. Several PCDF congeners, including the highly toxic 2,3,7,8-tetra- and 2,3,4,7,8-penta-CDFs were identified in the blubber of those specimens. The PCDF isomeric pattern in killer whale is more complex than the reported patterns in humans and birds, indicating the weaker metabolic potency of killer whales for these toxic compounds. High levels of PCBs (about 400 mg kg -I) have also been detected in those specimens. The 2,3,7,8-substituted PCDF congeners identified in commercial PCBs were also found in killer whale, indicating PCBs as the possible source. Isomer-specific and trace level determinations of PCDD in killer whale, revealed no detectable quantities. The detection of comparatively high levels (>300 ng kg -I) of PCDFs and undetection of PCDDs in open ocean killer whales suggest that PCDFs are more ubiquitous than PCDDs.

Pedro, S., Boba, C., Dietz, R., Sonne, C., Rosing-Asvid, A., Hansen, M., . . . McKinney, M. A. (2017). Blubber-Depth Distribution and Bioaccumulation of PCBs and Organochlorine Pesticides in Arctic-Invading Killer Whales. *Science of the Total Environment*, 601, 237-246 https://doi.org/10.1016/j.scitotenv.2017.05.193

Sightings of killerwhales (Orcinus orca) in Greenland have increased in recent years, coincidentwith sea ice loss. These killerwhales are likely from fish-feeding North Atlantic populations, but may have access tomarinemammal prey in Greenlandic waters, which could lead to increased exposures to biomagnifying contaminants. Most studies on polychlorinated biphenyl (Sigma PCB) and organochlorine (OC)

contaminants in killerwhales have used biopsies which may not be representative of contaminant concentrations through the entire blubber depth. Here, we measured PCB and OC concentrations in 10 equal-length blubber sections of 18 killer whales harvested in southeast Greenland (2012-2014), and 3 stranded in the Faroe Islands (2008) and Denmark (2005). Overall, very high concentrations of Sigma PCB, Schlordanes (Sigma CHL), and Sdichlorodiphenyltrichloroethane (Sigma DDT) were found in the southeast Greenland and Denmark individuals (means of similar to 40 to 70 mg kg(-1) lipid weight). These concentrations were higher than in the Faroe Island individuals (means of similar to 2 to 5 mg kg(-1) lipid weight) and above those previously reported for other fish-feeding killerwhales in the North Atlantic, likely in part due to additional feeding onmarinemammals. On a wetweight basis, concentrations of all contaminants were significantly lower in the outermost blubber layer (0.15-0.65 cm) compared to all other layers ($p < 0.01$), except for Sigma hexachlorocyclohexanes. However, after lipid correction, no variationwas found for Sigma CHL and Sigma chlorobenzene concentrations, while the outermost layer(s) still showed significantly lower SPCB, SDDT, Smirex, Sendosulfan, and dieldrin concentrations than one or more of the inner layers. Yet, the magnitude of these differenceswas low (up to 2-fold) suggesting that a typical biopsy may be a reasonable representation of the PCB and OC concentrations reported in killer whales, at least on a lipid weight basis. (C) 2017 Elsevier B.V. All rights reserved.

Pitman, R. L., Fearnbach, H., LeDuc, R., Gilpatrick, J., Ford, J., & Ballance, L. (2007). Killer Whales Preying on a Blue Whale Calf on the Costa Rica Dome: Genetics, Morphometrics, Vocalisations and Composition of the Group. *Journal of Cetacean Research Management*, 9(2), 151-158 Retrieved from http://scrippsscholars.ucsd.edu/lballance/content/killer-whales-preying-blue-whale-calf-costa-rica-dome-genetics-morphometrics-vocalizations-a

Killer whale (Orcinus orca) populations in high latitude, nearshore areas appear to regularly exhibit prey specialisation among two or more sympatric ecotypes, but nearly nothing is known about populations that inhabit open ocean areas or tropical latitudes. On 26 September 2003, during a cetacean survey in the eastern tropical Pacific Ocean, a group of an estimated 19 killer whales was encountered feeding on a calf of a blue whale (Balaenoptera musculus); the location was 10°58’N, 88°40’W, 230km west of Nicaragua. The whales were studied for 2.5 hours and during this time skin biopsy samples were collected, acoustic recordings made, aerial and lateral photographs taken and behavioural observations recorded. The 19 individuals identified included 4 males (3 adults, 1 subadult), 5 cow-calf pairs and 5 other females/subadult males. Using aerial photogrammetry, body lengths of 17 different animals were measured: the largest male (who carried the carcass most of the time) was 8.0m long; and the largest female (with a calf) was 6.1m. From10 biopsy samples, two distinct haplotypes were identified that differed from resident (i.e. fish-eating ecotype) killer whales in the northeastern Pacific by one and two base pairs, respectively. The single discrete call recorded was a typical killer whale call but it had a two-part pitch contour that was structurally distinct from calls recorded to date in the North Pacific. These observations reaffirm that calves of even the largest whale species are vulnerable to predation, although by migrating to calving areas in the tropics, where killer whale densities are lower, baleen whales should be able to increase their overall reproductive fitness, as suggested by Corkeron and Connor (1999).

Ross, P. S., Ellis, G. M., Ikonomou, M. G., Barrett-Lennard, L. G., & Addison, R. F. (2000). High PCB

Concentrations in Free-Ranging Pacific Killer Whales, Orcinus Orca: Effects of Age, Sex and Dietary Preference. *Marine Pollution Bulletin*, 40(6), 504-515 https://doi.org/10.1016/S0025-326X(99)00233-7

Blubber biopsy samples were obtained for contaminant analysis from two discrete populations of killer whales (Orcinus orca) which frequent the coastal waters of British Columbia, Canada. Detailed life history information for the fish-eating `resident' population, comprising two distinct communities, and the marine mammal-eating `transient' killer whale population, provided an invaluable reference for the interpretation of contaminant concentrations. Total PCB concentrations (sum of 136 congeners detected) were surprisingly high in all three communities, but transient killer whales were particularly contaminated. PCB concentrations increased with age in males, but were greatly reduced in reproductively active females. The absence of age, sex and inter-community differences in concentrations of polychlorinated- dibenzo-p-dioxins (PCDDs) and- dibenzofurans (PCDFs) may have partly reflected low dietary levels, but more importantly, metabolic removal of dioxin-like compounds in killer whales. While information on toxic thresholds does not exist for PCBs in cetaceans, total 2,3,7,8-TCDD Toxic Equivalents (TEQ) in most killer whales sampled easily surpassed adverse effects levels established for harbour seals, suggesting that the majority of free-ranging killer whales in this region are at risk for toxic effects. The southern resident and transient killer whales of British Columbia can now be considered among the most contaminated cetaceans in the world.

Ryan, C., & Pierini, A. (2013). Stranded Pregnant Killer Whale (Orcinus Orca (L.)) in Co. Mayo, Ireland *The Irish Naturalists' Journal*, 32(1), 78-79. Retrieved from https://www.jstor.org/stable/24393889

On 4 October 2010 a dead Killer Whale (Orcinus orca (Linnaeus, 1758)) was reported stranded at Kinvrovar, Doohoma, Co. Mayo (F712149). The authors visited the stranding on 10 October and although the carcass was not in an advanced state of decomposition, it was discoloured and most of the skin had flayed off. Species identification was confirmed by the presence of large rounded pectoral fins, the position of the dorsal fin half-way along the back, and large teeth that were rounded in cross-section. The total body length was measured as 5.12 m. The rostrum and lower jaws had been cut with an electric saw before the authors' visit, so an absolute tooth count was not possible. However, there were c.20 teeth or tooth sockets in the upper jaw and the largest tooth remaining measured 27 mm in diameter which is typical for Killer Whales and is diagnostic. Significant apical tooth-wear indicated that the animal was old and probably a 'type 1' ecotype which are believed to be generalist predators (Foote et al. 2009). Determination of gender was impossible by external examination because the genitals were heavily scavenged and the dorsal fin was badly decomposed. A gross post mortem examination was carried out to look for signs of any obvious traumas that may have contributed to, or caused the animal's death, and to determine the gender. Only the left side of the carcass could be examined, but it exhibited no visible external traumas and no haemorrhaging was found in the blubber, indicating that live-stranding was unlikely. The lack of obvious blunt trauma made a ship-strike as an improbable cause of death, and nothing was found to indicate fisheries bycatch. When an incision was made on the left flank from above the pectoral fin to the anus a 2.09 m foetus was found in an amniotic sac. The presence of two mammary slits indicated that the foetus was female. It was also almost fully developed because length at birth for this species is between 2.08 m and 2.20 m in the North Atlantic (Perrin and Reilly 1984). In addition, 19 hollow teeth or tooth sockets in the upper and 22 in the lower jaws indicate an advanced degree of development. The eyes appeared to be decomposed and the skull was unfused in several places. The flexible dorsal fin and tail fluke were both folded to the left. An unusual observation was that the foetus was in cranial presentation in uteri, which is extremely rare in odontocetes (Slijper 1949). Caudal presentation of the foetus in cetaceans is important for successful delivery, as it prevents a calf from drowning during protracted deliveries (given that the breathing stimulus is believed to be the coldness of the water) (Slijper 1956). This indicates that survival of this calf during delivery would have been compromised. It is possible that the atypical orientation of the foetus may have been a factor in the cause of death of the mother. Records of stranded killer whales are rare but evenly distributed along the Irish coast (Berrow and Rogan 1997). This record brings to 15 the number of stranded killer whales, and of the seven records since 1983, three have been of neonates and one a pregnant female. Moreover, no calves have been observed alive in Irish waters in recent times (IWDG, unpublished data). Pregnancy abnormalities will have an adverse effect on the reproductive viability a species. In Irish waters the reproductive and recruitment rates of killer whales is low (Evans 1988). We suggest that the prevalence of such reproductive abnormalities merits particular attention in the future.

Schnitzler, J. G., Reckendorf, A., Pinzone, M., Autenrieth, M., Tiedemann, R., Covaci, A., . . . Siebert, U. (2019). Supporting Evidence for PCB Pollution Threatening Global Killer Whale Population. *Aquatic Toxicology*, 206, 102-104 https://doi.org/10.1016/j.aquatox.2018.11.008

A recent Science report predicted the global killer whale population to collapse due to PCB pollution. Here we present empirical evidence, which supports and extends the reports' statement. In 2016, a neonate male killer whale stranded on the German island of Sylt. Neonatal attributes indicated an age of at least 3 days. The stomach contained ~20 mL milk residue and no pathologies explaining the cause of death could be detected. Blubber samples presenting low lipid concentrations were analysed for persistent organic pollutants. Skin samples were collected for genotyping of the mitochondrial control region. The blubber PCB concentrations were very high [SPCBs, 225 mg/kg lipid weight (lw)], largely exceeding the PCB toxicity thresholds reported for the onset of immunosuppression [9 mg/kg lw ∑PCB] and for severe reproductive impairment [41 mg/kg lw ∑PCB] reported for marine mammals. Additionally, this individual showed equally high concentrations in p,p'-DDE [226 mg/kg lw], PBDEs [5 mg/kg lw] and liver mercury levels [1.1 μg/g dry weight dw]. These results suggest a high placental transfer of pollutants from mother to foetus. Consequently, blubber and plasma PCB concentrations and calf mortality rates are both high in primiparous females. With such high pollutant levels, this neonate had poor prerequisites for survival. The neonate belonged to Ecotype I (generalist feeder) and carried the mitochondrial haplotype 35 present in about 16% of the North Atlantic killer whale from or close to the North Sea. The relevance of this data becomes apparent in the UK West Coast Community, the UK's only residentorca population, which is currently composed of only eight individuals (each four males and females) and no calves have been reported over the last 19 years.Despite worldwide regulations, PCBs persist in the environment and remain a severe concern for killer whale populations, placing calves at high risk due to the mother-offspring PCB-transfer resulting in a high toxicological burden of the neonates.

Siebert, U., Wünschmann, A., Weiss, R., Frank, H., Benke, H., & Frese, K. (2001). Post-Mortem Findings in Harbour Porpoises (Phocoena Phocoena) from the German North and Baltic Seas. *Journal of Comparative Pathology*, 124(2), 102-114 https://doi.org/10.1053/jcpa.2000.0436

Between 1991 and 1996, necropsies were performed on 445 harbour porpoises (Phocoena phocoena), in various states of preservation, stranded on German coasts or accidentally caught by German fishermen. The animals originated from the North and Baltic Seas, and 133 were considered suitable for histopathological, immunohistochemical and microbiological examination. Most of the lesions in these 133 porpoises were caused by parasites, in particular in the respiratory tract, two-thirds of the animals exhibiting pneumonia associated with the parasites. Pneumonia was considered to be the cause of death in 46% of the stranded subadult and adult animals. The findings gave no evidence of any epidemic due to bacterial or viral infection. Bacteriological examination suggested that pneumonia was mainly caused by secondary bacterial infection and not by parasitic infestation alone. Beta-haemolytic streptococci were considered to be the main infectious agents. Morbillivirus antigen was not detected immunohistochemically.

Wolkers, H., Corkeron, P. J., van Parijs, S. M., Similä, T., & van Bavel, B. (2007). Accumulation and Transfer of Contaminants in Killer Whales (Orcinus Orca) from Norway: Indications for Contaminant Metabolism. *Environmental Toxicology and Chemistry*, 26(8), 1582-1590 https://doi.org/10.1897/06-455R1.1

Blubber tissue of one subadult and eight male adult killer whales was sampled in Northern Norway in order to assess the degree and type of contaminant exposure and transfer in the herring?killer whale link of the marine food web. A comprehensive selection of contaminants was targeted, with special attention to toxaphenes and polybrominated diphenyl ethers (PBDEs). In addition to assessing exposure and food chain transfer, selective accumulation and metabolism issues also were addressed. Average total polychlorinated biphenyl (PCB) and pesticide levels were similar, approximately 25 ?g/g lipid, and PBDEs were approximately 0.5 ?g/g. This makes killer whales one of the most polluted arctic animals, with levels exceeding those in polar bears. Comparing the contamination of the killer whale's diet with the diet of high-arctic species such as white whales reveals six to more than 20 times higher levels in the killer whale diet. The difference in contaminant pattern between killer whales and their prey and the metabolic index calculated suggested that these cetaceans have a relatively high capacity to metabolize contaminants. Polychlorinated biphenyls, chlordanes, and dichlorodiphenyldichloro-ethylene (DDE) accumulate to some degree in killer whales, although toxaphenes and PBDEs might be partly broken down.

Worthy, G. (2008). An Investigation into the Possible Relationship Between Killer Whale (Orcinus Orca) Predation and the Continuing Decline of the Steller Sea Lion (Eumetopias Jubatus) Population. Final Report to the Pollock Conservation Cooperative Research Center. Retrieved from https://www.uaf.edu/cfos/research/major-research-programs/pccrc/final_report.pdf

Foraging ecology of marine mammals is often poorly understood because of the inherent difficulties in studying them in their natural environment. Increasingly, fatty acid signature analysis of blubber is being used to evaluate dietary preferences; therefore it is important to fully understand the biochemical composition of this tissue. The purpose of the present study was to describe the characteristics of killer whale blubber and skin, with the goal of ultimately applying this information to explore the feeding ecology of this species, and in particular how killer whales might be impacting Steller sea lions.

Yamada, T., Uni, Y., Amano, M., Brownell, J., & Ishikawa, E. J. (2007). Biological Indices Obtained from a Pod of Killer Whales Entrapped by Sea Ice Off Northern Japan. Scientific Committee Meeting Document SC/59/SM12. Retrieved from https://iwc.int/index.php?cID=1772&cType=document [Abstract Only]

In February 2005, we experienced a tragic event of mass entrapment of killer whales by sea ice and their subsequent deaths in Rausu, Hokkaido northern Japan. There are killer whales in the seas around Japan. Ancient people left a variety of icons and figures representing killer whale figures. There were direct catches of killer whales during the mid-20th Century (Matsuura, 1938; Nishiwaki and Handa, 1958). Our knowledge of the killer whales in Japanese waters, however, is very limited. Only recently, Sato, et al, 2006 listed sighting records of killer whales in the coastal waters of Hokkaido. Few samples have been collected in the past for various reasons so the AKW tragedy turned out to be valuable opportunity to collect samples for various analyses that increased our understanding of these whales. Although we tried to undertake the investigation quickly, unfavourable climate conditions, financial difficulties, and other conditions prevented prompt action and we were not able to initiate the actual necropsies until about one week after the event. Although the temperature was between -5 to -15°C, most individuals were severely decomposed and detailed investigations such as analyses on pathology, reproductive biology, etc. were not as successful as we had hoped. Stomach contents, tissue samples for molecular biology and contaminant analyses, teeth for age determination, and skeletons for exhibit were successfully collected with less influences of decomposition. Together with previously collected data and samples from sporadic fishery catches and stranding events, the AKW stranding was a very important event. The specimens and data collected will serve as a significant resource for future scientists.

Section V: Management

Baird, R. W. (2001). Status of Killer Whales, Orcinus Orca, in Canada. *Canadian Field-Naturalist*, 115(4), 676-701. Retrieved from https://biodiversitylibrary.org/page/35014843

Killer Whales can be found in all three of Canada's oceans, as well as occasionally in Hudson Bay and in the Gulf of St. Lawrence. Little is known about their occurrence or biology in the Atlantic or Arctic, but Killer Whales appear to be uncommon in most parts of these areas. In the Canadian Arctic and western Atlantic small numbers were killed historically in commercial whaling operations (or shot incidentally to such operations), and small numbers have been documented taken by natives. Predictable concentrations of killer whales are found in British Columbia, and populations in British Columbia's nearshore waters are among the most well-known populations of cetaceans world-wide. Killer whales of the Pacific coast can be classified into two distinct "types" or "forms" (termed resident and transients) which differ in diet (residents feed on fish, transients feed on marine mammals), morphology, genetics and behaviour. The exact taxonomic relationship between these two types is unclear, though some authors have termed them "races", others consider them separate species. Regardless, from both a scientific and management perspective these populations should be treated as distinct. Within British Columbia waters residents appears to be sub-divided into three geographic communities or populations (termed the "northern" and "southern" residents, and "offshore" killer whales), based on association patterns, genetics and morphology. Relatively little is known of the "offshore" population of Killer Whales All Populations (including transients and the three resident populations) are small (in the low hundreds), and have low potential rates of increase. No trend information is available for "offshore" or transient killer whales. The "northern" resident population has been growing steadily in size since the 1970s (when live-capture fisheries stopped and shooting declined), while the "southern" resident population has been growing only sporadically, and is currently smaller than the pre-live-capture population estimate from the 1960s. Given the small population sizes and their low potential rates of growth, Killer Whales are potentially at risk from anthropogenic influences in two primary ways: due to immunotoxic affects of persistent toxic chemicals (levels in "Southem" residents are three times higher than levels known to cause immunotoxicity in harbour seals), and due to a reduction in prey availability. It is also possible that the large and growing commercial and recreational whale watching industry on the west coast may be having an impact, though such impacts are as yet unclear. In terms of natural factors, periodic events such as mass strandings or entrapments in narrow inlets or ice have the potential to drastically reduce local Populations. Since virtually all of these factors should impact Killer Whales throughout Canadian waters, all populations, at the least, should be considered vulnerable, that is, as "species of special concern because of characteristics which make them especially sensitive to human activities or natural events". As the "southern" resident population is extremely small (89 individuals in 1998), has declined by 10% in the last three years due to air increase in mortality rates (primarily of adult females), is more subject to anthropogenic influences than other populations, and these influences are not expected to decrease in the foreseeable future, it should be listed as threatened by COSEWIC. Further research, particularly on Arctic, Atlantic and "offshore" populations, is clearly needed.

Bigg, M. A., & Wolman, A. A. (1975). Live-Capture Killer Whale (Orcinus Orca) Fishery, British Columbia and Washington, 1962–73. *Journal of the Fisheries Research Board of Canada*, 32(7), 1213-1221 https://doi.org/10.1139/f75-140

In British Columbia and Washington 263 killer whales (Orcinus orca) were caught during 1962–73 of which 50 were kept for oceanaria, 12 died during capture operations, and the remainder escaped or were released. Peak cropping years were 1967–70 when 77% of all whales removed from the water were taken. Lengths of cropped males were 2.49–6.98 m and females, 2.80–6.25 m. Of 28 females taken an estimated 43% were mature and of 30 males, 20% were adult. The equation relating body length in centimeters and weight in kilograms is W = 0.000208 L2.577. Revenue to netters from the sale of 48 killer whales is estimated to be about $1,000,000. Of 48 whales held in captivity 48% were still alive on April 1, 1974. Survival to the end of 2 yr in captivity is 75% in whales thought to be immature and 13% in adults. The history, capture localities and techniques, and management regulations of the killer whale fishery are also described.

Brownell Jr, R. L., Nowacek, D. P., & Ralls, K. (2008). Hunting Cetaceans with Sound: A Worldwide Review. *Journal of Cetacean Research Management*, 10(1), 81-88. Retrieved from https://repository.si.edu/bitstream/handle/10088/8052/nzp_Brownell_et_al._2008_HWS.pdf?sequence=1&isAllowed=y

Cetaceans are sensitive to a variety of anthropogenic sounds because they normally use sound to navigate, communicate and capture prey. This paper reviews some fisheries that have taken advantage of this sensitivity by using sound to help capture numerous species of dolphins and whales. Fishermen in many parts of the world have independently developed methods that use sounds to drive (herd) various species of small cetaceans so that they can be killed and used for food, culled (i.e. to offset competition for fish), help capture fish (e.g. in the Eastern Tropical Pacific) or be taken into captivity. It is well documented that drive fisheries for small cetaceans have occurred for at least 650 years in Japan and Europe. With respect to large whales, the use of sound became widespread after World War II, with the advent of an early form of sonar (ASDIC) which was used for hunting both baleen and sperm whales. Baleen whales displayed a strong avoidance reaction to ASDIC by swimming rapidly away from the sound while remaining near the surface of the water. In contrast, sperm whales made longer dives in response to ASDIC. During the 20th Century, fishermen using these two acoustical methods killed millions of cetaceans (including those caught in the Eastern Tropical Pacific tuna fisheries), both small and large. The effectiveness of acoustic capture methods shows that a wide range of cetacean species have strong avoidance reactions to a variety of anthropogenic sounds. Research to better document the characteristics of these sounds, including those used in existing drive fisheries and those produced by ASDIC devices, would improve understanding of the types of anthropogenic sounds that could contribute to mass-stranding events and should be minimised in protected habitats for cetaceans.

Dahlheim, M. E. (1981). A Review of the Biology and Exploitation of the Killer Whale, Orcinus Orca, with Comments on Recent Sighting from Antarctica. *Report of the International Whaling Commission*. SC/32/SM9. Retrieved from https://archive.iwc.int/?r=35&k=df5e7a8289

Killer whales, Orcinus area, are cosmopolitan in distribution. At present, a single species is recognized; however, various geographical races may exist. Population estimates are not available on a worldwide basis. Killer whales are usually found in pods and most activities appear to be group orientated. A population birth rate of A-5% is suggested. Various other life history parameters on 0. orca are discussed. Killer whales appear to be opportunistic feeders. Distribution of this species seems to be dependent upon the distribution and· migration of prey items. A worldwide summary of the exploitation and utilization of this species is given for the years 1948-80.

Esteban, R., Verborgh, P., Gauffier, P., Giménez, J., Guinet, C., & de Stephanis, R. (2016). Dynamics of Killer Whale, Bluefin Tuna and Human Fisheries in the Strait of Gibraltar. *Biological Conservation*, 194, 31-38 https://doi.org/10.1016/j.biocon.2015.11.031

A complex balance has arisen between the bluefin tuna, killer whales, and human activities in the Strait of Gibraltar. Recent changes in fishing effort have dramatically decreased tuna stocks, breaking this balance. Killer whales exhibit two strategies for feeding on tuna: active hunting and depredation on a drop-line fishery. From 1999 to 2011, a small community of39 individuals was observed in the Strait in spring and summer. All individuals displayed active hunting and 18 of them also depredated on the fishery. These differences in foraging behaviour influenced life-history parameters. Adult survival for interacting and non-interacting individuals was estimated at 0.991 (SE = 0.011) and 0.901 (SE = 0.050), respectively. Juvenile survival could only be estimated for interacting individuals as 0.966 (SE = 0.024), because only one juvenile and one calf were observed among non-interacting individuals. None of the interacting calves survived after 2005, following the decrease in drop-line fishery catches. Calving rate was estimated at 0.22 (SE = 0. 02) for interacting individuals and 0.02 (SE = 0. 01) for non-interacting. Calving interval, which could only be calculated for interacting groups, was 7 years. The population growth rate was positive at 4% for interacting individuals, and no growth was observed for non-interacting individuals. These differences in demographic parameters could be explained by access to larger tuna through depredation. Consequently, we found that whales would need more tuna to cover their daily energy requirements while actively hunting. Therefore, our findings suggest an effect of artificial food provisioning on their survival and reproductive output. Urgent actions are needed to ensure the conservation of this, already small, community of killer whales. These include its declaration as Endangered, the implementation of a conservation plan, the creation of a seasonal management area where activities producing underwater noise (i.e. military exercise, seismic surveys or even whale watching activities) are forbidden from March to August, and the promotion of bluefin tuna conservation. Additionally, energetic requirements of this whale community should be taken into account when undertaking ecosystem-based fishery management for the Atlantic bluefin tuna stock. In the meantime, as marine predators are most sensitive to changes in fish abundance when prey abundance is low, we suggest an urgent short-term action. Artisanal fisheries, such as drop-lines, should be promoted instead of purse seiners in the Mediterranean Sea. This will help to maintain the survival and reproductive output of the whale community until showing clear signs of recovery and stability, and/or their prey stock recovers.

Filatova, O. A., Shpak, O. V., Ivkovich, T. V., Borisova, E. A., Burdin, A. M., & Hoyt, E. (2014). Killer Whale Status and Live-Captures in the Waters of the Russian Far East. Scientific Committee Meeting Slovenia 2014. SC/65b/SM07. Retrieved from https://archive.iwc.int/?r=4864&k=fb242409c4

Killer whale ecology and population structure have been studied in detail in the eastern North Pacific, but much less information is available from the western North Pacific, where live-capturing have started in recent years. In this paper we summarize the current information about killer whales and the live-capture procedures in the western North Pacific. We have described two killer whale ecotypes in the Russian Far East: fish-eating and mammal-eating ecotypes similar to resident and transient killer whales found in the Northeastern Pacific. Resident killer whales were encountered much more frequently than transients off eastern Kamchatka, near the Commander Islands and Kuril Islands. Transient killer whales prevailed in the western and northern Okhotsk Sea and off Sakhalin Island. Mitochondrial control region haplotypes were different for resident and transient killer whales. Genetic analysis of microsatellite DNA showed that resident and transient killer whales belong to reproductively isolated populations. Values of stable isotope $\delta 15N$ were significantly higher in transients, indicating their higher trophic level. Using the photo-identification method, we have identified 688 resident killer whales in Avacha Gulf, Kamchatka, and more than 800 around the Commander Islands. Some mixing occurs between Avacha Gulf, Commander Islands and the other regions of eastern Kamchatka, but the extent of the mixing varies. We also identified 26 transient killer whales in Avacha Gulf and 18 transient killer whales near the Commander Islands. Recapture rate of transient killer whales in that area was low. In the western Okhotsk Sea no dedicated study has been conducted. We identified 55 transient killer whales through the opportunistic studies. There were multiple resightings within and between seasons in the same area and in adjacent areas. Only transient killer whales have been observed so far in this region. During the period of 2002-2011, six killer whales were captured in different areas of the Russian Far East. In 2012-2013, seven killer whales were captured in the western Okhotsk Sea: one young female in 2012, and six whales of unknown sex and age in 2013. The live-capture of killer whales raises concerns because it targets the same local stock of transient killer whales in the western Okhotsk Sea. Russian officials deny the existence of killer whale ecotypes in the Russian Far East, and consequently do not manage fish-eating and mammal-eating killer whales as different management units. No reliable abundance estimates of either killer whale ecotype in the Okhotsk Sea is available.

Goldsberry, D. G. (1976). Live Capture Techniques for the Killer Whale (Orcinus Orca) and Live Capture Fishery Statistics 1961-76. Paper presented at the 1976 Small Cetaceans Sub-Committee Meeting, London. Retrieved from https://archive.iwc.int/?r=1474&k=d1c3e4247f

Paper is unpublished, may not be findable. No abstract.

Hilborn, R., S.P. Cox, F.M.D. Gulland, D.G. Hankin, N.T. Hobscbs, D.E. Schindler, a., & Trites, A. W. (2012). The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for National Marine Fisheries Service (Seattle. WA) and Fisheries and Oceans Canada. Retrieved from https://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/killer_whale/effects_fisheries.html

No Abstract.

Krahn, M. M., M.J. Ford, W.F. Perrin, P.R. Wade, R.P. Angliss, M.B. Hanson, . . . Waples, R. S. (2004). 2004 Status Review of Southern Resident Killer Whales (Orcinus Orca) under the Endangered Species Act. NOAA NMFS-NWFSC-62. Retrieved from https://www.nwfsc.noaa.gov/assets/25/6377_02102005_172234_krahnstatusrevtm62final.pdf

On 18 December 2002, the Center for Biological Diversity and other plaintiffs initiated a motion for summary judgment in U.S. District Court, Western District of Washington, challenging the National Marine Fisheries Service (NMFS) 2002 decision indicating that listing of Southern Resident killer whales (Orcinus orca) as threatened or endangered under the Endangered Species Act (ESA) was not warranted at that time. The plaintiffs asserted that NMFS's policy that considers the population=s "significance" in determining whether a population should be considered a distinct population segment (DPS) is not permitted by the ESA. In addition, the plaintiffs stated that NMFS's reliance on the "outdated and discredited" species O. orca as the taxon violated the best available science standard. On 17 December 2003, U.S. District Court Judge Robert Lasnik found that the DPS policy is not contrary to congressional intent regarding the ESA and that including an assessment of a population's "significance" is one component of a reasonable interpretation of the term DPS. Judge Lasnik also held that NMFS erred by using the "inaccurate" global species O. orca when considering whether the Southern Resident killer whales are a DPS. The court set aside NMFS's "not warranted" finding and remanded the matter back to NMFS for determining whether the Southern Resident killer whales should be listed under the ESA. NMFS was required to issue a new finding consistent with Judge Lasnik's order by 17 December 2004. NMFS decided that, in order to address the court order in a timely manner, the Biological Review Team (BRT) should be reconvened (referred to as the 2004 BRT). [BACKGROUND]

Krahn, M. M., Wade, P. R., Kalinowski, S. T., Dahlheim, M. E., Taylor, B. L., Hanson, M. B., . . . Waples, R. S. (2002). Status Review of Southern Resident Killer Whales (Orcinus Orca) under the Endangered Species Act. NOAA NMFS-NWFSC-54. Retrieved from https://www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/killer_whales/esa_status/krahn2002tm.pdf

On 2 May 2001, the National Marine Fisheries Service (NMFS) received a petition from the Center for Biological Diversity and 10 co-petitioners requesting that, in light of the recent population decline, Southern Resident killer whales (Orcinus orca) be listed as threatened or endangered under the Endangered Species Act (ESA). In addition, the petitioners requested that NMFS designate critical habitat for the Southern Resident killer whale. The petitioned population consists of three pods (J, K, and L) that reside primarily in Puget Sound (Washington State), the Strait of Juan de Fuca (between the United States and Canada), and the Strait of Georgia (British Columbia) during the spring, summer, and fall (Figure 1). Little is known about their winter distribution. These whales overlap in range to some extent with Northern Resident killer whales that reside in British Columbia (Figure 1), as well as with two nonresident forms— offshores and transients. The petitioners state that the Southern Resident whales have undergone a recent decline that is expected to continue.

National Marine Fisheries Service Northwest Region. (2006). Designation of Critical Habitat for Southern Resident Killer Whales: Biological Report. NOAA. Retrieved from https://www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/killer_whales/esa_status/srkw-ch-bio-rpt.pdf

No abstract.

National Marine Fisheries Service. (2016). Southern Resident Killer Whales (Orcinus Orca) 5-Year Review: Summary and Evaluation. Seattle, WA. Retrieved from https://repository.library.noaa.gov/view/noaa/17031

The Southern Resident killer whale Distinct Population Segment (DPS) was listed as endangered under the Endangered Species Act (ESA) in 2005. In the listing, the National Marine Fisheries Service (NMFS) identified three main threats to their survival: 1) scarcity of prey, 2) high levels of contaminants from pollution, and 3) disturbance from vessels and sound. As of 1 July 2016 after the summer census, there were only 83 individuals left in the population (CWR 2016). Their small population size and social structure also puts them at risk for a catastrophic event, such as an oil spill, that could impact the entire population. Updates regarding research and management actions for the primary threats (prey, pollution and vessels) are included below and in discussions of whether the recovery criteria related to each of the threats have been met. This review fulfills our requirement under section 4(c)(2) of the ESA to conduct, at least once every five years, a review of listed species to ensure that the listing of these species remains accurate.

Perrin, W. F. (1982). Report of the Workshop on Identity, Structure and Vital Rates of Killer Whale Populations, Cambridge, England, June 23-25, 1981. Report of the International Whaling Commission, 32, 617-631. SC/33/Rep4. Retrieved from https://archive.iwc.int/?r=36&k=e3a85bd029

During attempts at the 1980 meeting of the IWC Scientific Committee to assess the status of recently exploited stocks of killer whales, it became apparent that information available to the meeting was not adequate to allow delineation of management units with confidence. For this reason it was decided to convene a meeting of experts on killer whales for the purposes of reviewing all relevant information and making recommendations for definition of management units. A brief review of recent developments in the major killer whale fisheries follows.

R. R. Reeves, W. F. Perrin, B. L. Taylor, Baker, C. S., & Mesnick, S. L. (2004). Report of the Workshop on Shortcomings of Cetacean Taxonomy in Relation to Needs of Conservation and Management. (363). NOAA. Retrieved from https://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-363.PDF

No abstract.

Raverty, S., Gaydos, J. K., & St. Leger, J. A. (2014). Killer Whale Necropsy and Disease Testing Protocol. Retrieved from https://cdn.ymaws.com/www.aazv.org/resource/resmgr/Protocols/orca_necropsy_protocol_2014.pdf

No abstract.

Wiles, G. J. (2016). Periodic Status Review for the Killer Whale in Washington. Washington Department of Fish and Wildlife, Olympia, WA. Retrieved from https://wdfw.wa.gov/publications/01773/

This periodic status review summarizes the biology, population status, threats, and recent management actions directed at the three main populations of killer whales (Orcinus orca) occurring in Washington's marine waters. It also assesses whether the species should retain its current endangered status under state law or be reclassified to another status. Substantial new information has been published on killer whales since the state's last status review (Wiles 2004) and has greatly expanded the knowledge of these populations.

Williams, R., Krkošek, M., Ashe, E., Branch, T. A., Clark, S., Hammond, P. S., . . . Winship, A. (2011). Competing Conservation Objectives for Predators and Prey: Estimating Killer Whale Prey Requirements for Chinook Salmon. *PLoS ONE*, 6(11), e26738 https://doi.org/10.1371/journal.pone.0026738

Ecosystem-based management (EBM) of marine resources attempts to conserve interacting species. In contrast to single-species fisheries management, EBM aims to identify and resolve conflicting objectives for different species. Such a conflict may be emerging in the northeastern Pacific for southern resident killer whales (Orcinus orca) and their primary prey, Chinook salmon (Oncorhynchus tshawytscha). Both species have at-risk conservation status and transboundary (Canada-US) ranges. We modeled individual killer whale prey requirements from feeding and growth records of captive killer whales and morphometric data from historic live-capture fishery and whaling records worldwide. The models, combined with caloric value of salmon, and demographic and diet data for wild killer whales, allow us to predict salmon quantities needed to maintain and recover this killer whale population, which numbered 87 individuals in 2009. Our analyses provide new information on cost of lactation and new parameter estimates for other killer whale populations globally. Prey requirements of southern resident killer whales are difficult to reconcile with fisheries and conservation objectives for Chinook salmon, because the number of fish required is large relative to annual returns and fishery catches. For instance, a U.S. recovery goal (2.3% annual population growth of killer whales over 28 years) implies a 75% increase in energetic requirements. Reducing salmon fisheries may serve as a temporary mitigation measure to allow time for management actions to improve salmon productivity to take effect. As ecosystem-based fishery management becomes more prevalent, trade-offs between conservation objectives for predators and prey will become increasingly necessary. Our approach offers scenarios to compare relative influence of various sources of uncertainty on the resulting consumption estimates to prioritise future research efforts, and a general approach for assessing the extent of conflict between conservation objectives for threatened or protected wildlife where the interaction between affected species can be quantified.