

Harbor Porpoise in the Salish Sea
A Species Profile for the Encyclopedia of Puget Sound
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(Photo: Harbor porpoise surfacing by Erin D'Agnese, Washington Department of Fish and Wildlife)

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Introduction

Harbor porpoise (*Phocoena phocoena*) are the smallest of 22 cetaceans recorded in the Salish Sea and are probably one of the few that are resident year-round (Gaydos and Pearson 2011, Osborne et al. 1988, Scheffer and Slipp 1948). Excluding the Arctic, their distribution extends throughout the Northern Hemisphere. *Phocoena phocoena vomerina* is the subspecies found in the North Pacific, including the Salish Sea. Their subdued coloration is typically dark gray to brown dorsally and shades into white ventrally (Scheffer and Slipp 1948). Weighing less than 100 kg and spanning less than 2 m long, harbor porpoise sit low in the water and barely brush the water’s surface to breathe. Observers rarely glimpse more than their back and small, uniformly colored dorsal fin, which has a longer leading than trailing edge (Allen et al. 2011). They can be confused with Dall’s porpoise (*Phocoenoides dallii*), small, stockier porpoises that are black with white flanks along the belly and white tipped dorsal fins and flukes (Allen et al. 2011). They could also be mistaken for Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), which have similar gray backs but complex white stripes on their sides, a bi-colored and more curved dorsal fin, and more exuberant, social behavior, generally travelling in larger groups and often leaping from the water completely.

Stock Delineation

Phocoena phocoena occupy the sub-Arctic oceans of the Northern Hemisphere, with *P. p. phocoena* in the North Atlantic, *P. p. vomerina* in the North Pacific, and *P. p. relicta* in the Black Sea. Mitochondrial DNA analysis of these subspecies by Rosel et al. (1995a) supports these designations and suggests that genetic divergence is high among them. In the eastern North Pacific, *P. p. vomerina* are found in coastal and inland waters from Point Barrow,

Alaska to Point Conception, California. Rosel et al. (1995a) evaluated the genetic makeup within *P. p. vomerina* and suggest that a significant amount of gene flow occurs continuously from California to Alaska.

However, more recent molecular studies of the harbor porpoises continuously occupying the coastline of the western United States and Canada have identified several genetically distinct subpopulations. Chivers et al. (2002) used maternally inherited mitochondrial DNA and bi-parentally inherited nuclear DNA from harbor porpoises to look for genetic variation among stocks defined a priori. Based on this data, they found that the Central California, Oregon/Washington outer coast, and Washington inland waters populations were all genetically different subunits, meaning that the amount of interbreeding among these areas is low. These stock boundaries are also roughly supported by contaminant concentration ratios obtained from blubber samples along the California, Oregon, and Washington coasts and Puget Sound (Calambokidis and Barlow 1991). This study found geographical patterns in the ratios of PCBs, DDEs, and HCBs in harbor porpoise blubber. These ratios in individuals allowed accurate prediction of 86% of samples to the state-level, which by extension suggests that intermixing among these areas is not extensive.

Chivers et al. (2002) also identified finer population subunits as well, broken down into Monterey Bay, San Francisco, Oregon coast, Columbia River, Washington coast, San Juan Islands, Vancouver Island, Strait of Georgia, and Copper River Delta. All neighboring subunits were significantly different except the 3 neighbor comparisons encompassing the Columbia River, Washington coast, San Juan Islands, and Vancouver Island subunits. This suggests that a significant amount of interbreeding occurs among these Washington and British Columbia geographic neighbors, but not among the other California, Oregon, British Columbia, and Alaska subunits. A follow-up study using roughly the same methodology, however, classifies Northern California harbor porpoises with those along the Oregon coast, and also suggests that one or more stocks might occupy the Strait of Juan de Fuca and the San Juan Islands area (Chivers et al. 2007). However, a study by Crossman (2012) using mitochondrial and nuclear DNA, contrasts slightly with the studies by Chivers et al. (2002, 2007). The data analyzed by Crossman (2012) suggests that a single, interbreeding population of harbor porpoises exists from the southern Juan de Fuca Strait north to the Queen Charlotte Islands in British Columbia. Overall, these studies suggest a single, interbreeding population of harbor porpoises within the Salish Sea.

Stock designations for North Pacific harbor porpoise have evolved with our increasing knowledge of their genetic structure, pollutant loads, and aerial density observations (Calambokidis et al. 2015). Currently, the National Oceanic and Atmospheric Administration (NOAA) recognizes 9 stocks of harbor porpoise in the Northeast Pacific and periodically publishes stock assessments for each stock: Morro Bay, Monterey Bay, San Francisco-Russian River, Northern California-Southern Oregon, Northern Oregon-Washington Coast, Washington Inland Waters, Southeast Alaska, Gulf of Alaska, and Bering Sea (NOAA 2014).

Distribution

In the 1940s, harbor porpoise were considered one of the most frequently sighted cetaceans in Puget Sound proper (South of Admiralty Inlet) and Hood Canal, but by the early 1970s, they had almost completely disappeared from these areas (West 1997, Calambokidis and Baird 1994, Osborne et al. 1988, Scheffer and Slipp 1948). A 1991 aerial survey identified many harbor porpoise off the Oregon and southern Washington coasts, but none were found in Puget Sound proper or Hood Canal (Calambokidis et al. 1992). Reasons for this disappearance are not known but may be related to incidental takes (fishing bycatch), disturbance from vessel traffic and associated noise, or contaminants. Anecdotal reports at the time suggested harbor porpoise decreases in southern British Columbia as well (Baird and Guenther 1994, Calambokidis and Baird 1994). Declines in harbor porpoise have been noted in other developed protected waters in the 20th century, especially in the Baltic and North Seas (Benke et al. 2014, Camphuysen 2004, Lockyer and Kinze 2003). Since 2007 or 2008, harbor porpoise sightings in Central Puget Sound have increased (Cascadia Research Data, unpubl. data). It is not known if this represents an increase in the stock size or an expansion of the area occupied.

Throughout the Salish Sea, current harbor porpoise distribution is thought to be heterogeneous with localized areas of higher density. Satellite tracking of harbor porpoise in the North Sea and western Baltic Sea has similarly shown uneven spatial habitat use by tagged harbor porpoise with clear high-density areas and seasonal variation in distribution (Teilmann et al. 2013, Sveegaard et al. 2011). Aerial and boat surveys suggest that such areas of high porpoise density and seasonal variation in distribution also exist in the Salish Sea. On the Canadian side of the Salish Sea, the BC Cetacean Sightings Network (BCCSN), a long-standing citizen-science project based at the Vancouver Aquarium and operated in collaboration with the Cetacean Research Program of the Canadian Department of Fisheries and Oceans, has received 5,780 harbor porpoise sighting reports since 1986 with most coming in the last 10 years (BCCSN, unpubl. data). Analysis of these data based on sighting effort identified harbor porpoise summer hotspots in Haro Strait, Boundary Pass, south-central Strait of Georgia, and several mainland inlets northwest of Campbell River. Winter hotspots included Port San Juan, Haro Strait, Swanson Channel, the central Strait of Georgia, Burrard Inlet, Howe Sound, and waters in and near Nodales Channel (BCCSN, unpubl. data). Raum-Suryan and Harvey (1998) detected higher density of harbor porpoise sightings in their study area in the Boundary Pass/Northern San Juan Islands region. Hall (2011) also identified a few hot spots in her work and found that while they can be seen year-round in some regions such as the San Juan Islands and the Strait of Juan de Fuca, they seasonally localize in relatively small areas from April to October. A complete list of high-density harbor porpoise areas by season has not been compiled for the Salish Sea.

Pilot work using photo-identification and VHF tagging suggests that harbor porpoise might have high geographic fidelity and a small home range. Flaherty and Stark (1982, in Baird 2003) photo-identified 29 harbor porpoise near San Juan Island and re-sighted three individuals, all relatively close (8-30 km) to where they were originally photographed, up to seven months after they were first sighted. Between 1998 and 2005, four harbor porpoise were tagged with VHF tags to begin to understand porpoise movements (Hanson

2007). One porpoise captured and tagged in the northern San Juan Islands remained between Presidents Channel and the southern Strait of Georgia for the several months it was tracked (Hanson 2007). Three more porpoises were tagged in the Strait of Juan de Fuca and remained in the central area of that Strait except for a temporary movement into the La Perouse and Swiftsure Bank areas by two of the porpoises (Hanson 2007). Harbor porpoise movements were not associated with large-scale oceanographic features such as these bank areas; instead, movements were commonly correlated with tidal fronts (Hanson 2007). Satellite transmitters used to track fine scale movements of harbor porpoises to collect data for establishing Marine Protected Areas demonstrated that harbor porpoise are not evenly distributed in the North Sea, the Western Baltic, or the waters between (Svegaard et al. 2011), but such technology has never been employed in the Salish Sea.

Population Trends

Currently, aerial line-transect surveys, flown in a Partenavia twin-engine airplane, are the standard methodology for harbor porpoise stock assessment in the United States. These surveys are stratified for heavy- and low-density areas with most high-density surveys conducted close to shore. Flights are only conducted under the conditions of Beaufort Sea State 1-2 (very calm seas) with a maximum of 50% cloud cover, as most sightings are actually of the porpoise's body in the water (Chandler and Calambokidis 2003). A combination of aerial and boat line-transect surveys are also used to assess abundance. In the Baltic and North Seas, Teilmann et al. (2013) found that harbor porpoise spend 6% of their time at the surface (where they are visible by boat) and 61.5% of their time at a depth between 0 and 2 m (where they are visible aerially). These convert to correction factors of 16.7 and 1.6 for boat and aerial surveys, respectively, to determine total abundance (Teilmann et al. 2013). Passive acoustic data loggers (T-PODs) have recently been used to estimate population density in Danish waters (Kyhn 2010).

The last harbor porpoise aerial surveys published for the Salish Sea were in August of 2002 and 2003 and included the Strait of Juan de Fuca, San Juan Islands, Gulf Islands, and Strait of Georgia (Carretta et al. 2011, Chandler and Calambokidis 2003). They did not cover Puget Sound south of Port Townsend except for one transect that had no harbor porpoise sightings (see the Distribution chapter for the potential significance of this). An average of these estimates of abundance in U.S. waters gave an uncorrected abundance of 3,123 (CV=0.10) harbor porpoise in Washington inland waters (J. Laake, unpubl. data). When corrected for availability and perception bias, using a correction factor of 3.42 ($1/g(0)$; $g(0)=0.292$, CV=0.366) (Laake et al. 1997), the estimated abundance for the Washington Inland Waters stock of harbor porpoise in 2002/2003 was 10,682 (CV=0.38) animals (J. Laake, unpubl. data). Data are not published for the population size for harbor porpoise seen in British Columbian waters.

More recent surveys have been conducted in the Salish Sea but have not yet been published. Increased harbor porpoise strandings over the past decade suggest the population has grown since the 2002/2003 stock assessment (Huggins et al. 2015).

Reproduction

Breeding Seasons

Harbor porpoise reproduce annually during the breeding season when ovulation and mating coincide. In the Gulf of Maine and Bay of Fundy, the breeding season occurs in late June, with fetuses first detectable in early August and parturition in mid-May (Read 1990). Breeding peaks in July in the North Sea and in August in the Baltic Sea (Borjesson and Read 2003). Extensive studies of harbor porpoise breeding have not been conducted in the Salish Sea, but the breeding season is hypothesized to be between April and October due to presence of high numbers of porpoise with calves (Hall 2011). Hall (2011) also identified a likely breeding area for harbor porpoise southeast of Victoria in the Strait of Juan de Fuca. The breeding season of a population can last 1-3 months, the timing of which is likely influenced by seasonal prey availability so that food is readily accessible for lactating females to easily feed while nursing neonatal calves (Borjesson and Read 2003, Read 1990). Crossman (2012) hypothesized that harbor porpoise are polygynandrous, meaning that males and females mate with more than one partner.

Females

Females reach sexual maturity at about 3 years of age and 1.4 m in length (Lockyer and Kinze 2003, Lockyer et al. 2001, Read and Hohn 1995, Read 1990). Population studies report close to or over 90% of mature females conceiving each year, indicating that harbor porpoise have a high rate of reproduction, which is consistent with their relatively short lifespan and duration of lactation (Read and Hohn 1995, Read 1990). However, females along the coast of Greenland may only ovulate every 2 years (Lockyer et al. 2001). Young females frequently fail to conceive in their first year or two of maturity, as reflected in the slight disparity between the average ages of first ovulation (3.15) and first pregnancy (3.76) calculated for the northeast Atlantic populations (Read 1990). Females at least 5 years old tend to conceive every year (Read 1990). In most individuals, only the left ovary is functional (Read 1990). Mating is followed by a 6-7 month preimplantation pregnancy and about a 10.5-month gestation period (Borjesson and Read 2003, Read 1990). Females that fail to conceive must wait until the next breeding season to try again (Read 1990).

Much of harbor porpoise breeding behavior is still unknown, as underwater observations are challenging and a birth has never been directly observed (Read 1990). In addition, few details are known about lactation, although it is believed that lactation may last around a year (Read 1990), meaning that most females spend most of the year both lactating and pregnant (Read and Hohn 1995). There is no evidence of segregation of males and females in breeding or non-breeding seasons (Read and Hohn 1995).

One study (Read 2001) looked for changes in maternal investment based on prey abundance in the Bay of Fundy and Gulf of Maine over 3 decades. Maternal size and condition did not vary over three decades, even though herring abundance based on fishery information decreased in the 1980s and increased dramatically in the 1990s. However, calves were largest and maternal investment was the highest in the 1980s, while prey availability was supposedly at its lowest.

Males

Males reach maturity at the same time as females, at about 3 years (Lockyer et al. 2001, Read and Hohn 1995). Unlike many other cetaceans including Dall's porpoise, which exhibit sexual dimorphism with males being larger than females, harbor porpoise are sexually dimorphic with females being larger than males (Ralls and Mesnick 2002). Whereas females reach maturity at around 1.4 m in length, males are on average slightly smaller at 1.3 m (Lockyer et al. 2001). Males do not exhibit external secondary sexual characteristics, but they do have what Fontaine and Barrette (1997) term "megatestes." Testes size varies with season, with significant hypertrophy (growth) during the breeding season and significant reduction during the non-breeding season (Lockyer et al. 2001, Fontaine and Barrette 1997, Read and Hohn 1995). In the breeding season, testes typically account for more than 5% of total body weight, which is exceptional for mammals (Ralls and Mesnick 2002, Fontaine and Barrette 1997). During the breeding season, mean testes mass is just over 2 kg in males with an average body mass of 51.6 kg (Fontaine and Barrette 1997). Fontaine and Barrette (1997) report a 44.6 kg male with 2.7 kg testes, which account for 6.1% of his total body weight. These authors hypothesize that this unusual characteristic is suggestive of sperm competition in this species, although this has yet to be tested.

Hybridization

Cetaceans are unusual among mammals in that they are karyologically quite uniform, meaning that they have the same number of chromosomes of similar shape and size (Árnason 1972). This facilitates hybridization between cetacean species, something that is not possible between karyologically dissimilar species. Harbor and Dall's porpoise (*Phocoenoides dalli*) are sister species that diverged about 2-3 million years ago (Rosel et al. 1995b) and are known to hybridize in the Salish Sea (Crossman 2012, Huggins et al. 2009, Willis et al. 2004, Baird et al. 1998).

Dall's/harbor porpoise hybrids can sometimes be identified based on morphological and behavioral features. Willis et al. (2004) describes these features: hybrids are intermediate between the two species in overall size and shape, dorsal fin size and shape, and overall color. Huggins et al. (2009) add that skeletal structure is also intermediate between the two species in terms of bone counts and shapes of skeletal features. Hybrids may also exhibit more Dall's porpoise - like behaviors such as bow riding, which is not typically seen in do harbor porpoise (Willis et al. 2004). Hybrids have been observed alone or associating with Dall's porpoise or other hybrids, but never with harbor porpoise. Hybrids seem to be reproductively viable (Crossman 2012, Willis et al. 2004) and female hybrids have been seen associating with neonatal calves. Using mitochondrial DNA analysis, Crossman et al. (2014) demonstrated that hybrids are widespread over the study area, reproductively viable, and are able to backcross with either parental species, although usually with Dall's porpoise.

Crossman (2012) discusses possible causes of hybridization. Similarities in body length, sexual dimorphism, vocalization frequency, and other ecological, morphological, and behavioral characteristics exist between the two species, which may encourage hybridization events, perhaps due to poor eyesight. Interestingly, in every case the female

is a Dall's and the male is a harbor porpoise (Crossman et al. 2014, Crossman 2012, Huggins et al. 2009, Willis et al. 2004, Baird et al. 1998). Crossman (2012) suggests coercive mating might be occurring among male harbor porpoises, which would explain this trend. However, behaviors such as this are difficult to observe and more research is necessary to explore this and other hypotheses.

Growth and Longevity

Harbor porpoises have a relatively short life history, and have been said to "live life in the fast lane" (Noren et al 2014, Read and Hohn 1995). Fetuses grow at a rate of about 83 mm/month (Borjesson and Read 2003) and develop vestigial hairs near the snout (Scheffer and Slipp 1948), which are not present after birth. At birth, calves are about 65-75 cm long and weigh 4-7 kg (Lockyer and Kinze 2003, Ólafsdóttir et al. 2002). Males seem to consistently outnumber females at a ratio of 1.1 or 1.2 to 1 (Lockyer and Kinze 2003, Ólafsdóttir et al. 2002). Females grow faster and larger than males, reaching up to 1.7 m in length and about 70 kg, while males are a bit smaller at 1.6 m and 60 kg (Ólafsdóttir et al. 2002, Lockyer et al. 2001, Read and Tolley 1997).

At birth, harbor porpoises have 51% and 69% of adult levels for myoglobin and buffering capacity and achieve adult levels for myoglobin and buffering capacity by 9-10 months and 2-3 years postpartum (Noren et al. 2014). Compared to some dolphins, this muscle maturation occurs at an earlier age, suggesting that the pace of muscle maturation in odontocetes is not solely influenced by exposure to hypoxia and exercise but also has to do with life history patterns for species. Harbor porpoise may live into their early 20s but less than 5% of individuals live past 12 years (Lockyer and Kinze 2003, Ólafsdóttir et al. 2002, Read and Hohn 1995).

Acoustics and Echolocation

Anatomy

Like other toothed whales, harbor porpoise use echolocation (biosonar) to navigate and to detect and capture prey (Wisniewska et al. 2012, DeRuiter et al. 2009, Verfuß et al. 2009, Verfuß et al. 2005). The clicks used to echolocate are produced in the nasal cavity using structures termed phonic lips. Porpoise have two pairs of phonic lips on either side of the nasal septum, each with anterior and posterior labia and phonic fissures running between them (Cranford et al. 2011). The larynx pushes air like a piston through the phonic lips, causing them to vibrate and clicks to be generated along the phonic fissure (Cranford et al. 2011, Huggenberger et al. 2008). The fatty melon serves as a wave-guide, directing clicks with signal energy between 100 and 160 kHz towards targets (Madsen et al. 2010). While dolphins use both the left and right pairs of phonic lips, harbor porpoises likely only use the right pair of phonic lips (Madsen et al. 2010). The phonic lips are specialized to withstand continual mechanical stress and contain many layers of very thin cells that reinforce these tissues while maintaining flexibility (Prahl et al. 2009).

Click Phases

The properties of the produced echolocation clicks dictate the quality of information that the harbor porpoise receives from the echoes. There are trade-offs in click quality regarding range, noise, clutter, and resolution that harbor porpoise can adjust depending on the desired target (Madsen and Wahlberg 2007). Researchers can characterize clicks in a more simplified manner by measuring their two-way transit time (Verfuß et al. 2005), the time it takes for the sound wave to reach its target and for the echo to return to the echolocating porpoise; and the lag time (Verfuß et al. 2005) or inter-click interval (Wisniewska et al. 2012), the lapse of time between the arrival of an echo and the emission of the next click. By pairing this click rate data with information about sound intensity and the porpoise's concurrent movements, researchers can make inferences about how porpoise use echolocation during different activities, such as foraging or navigating. From experiments like these, three general phases of echolocation have been described, analogous to that in bats. First is the range-locking (Verfuß 2009, 2005), search (DeRuiter 2009) or scanning (Wisniewska et al. 2012) phase, in which the porpoise assesses its general surroundings and locates targets. The second is the approach phase (DeRuiter 2009, Verfuß 2009), during which the harbor porpoise advances towards the target. Finally, the buzz phase (Wisniewska et al. 2012, DeRuiter 2009) ensues just before and during target capture.

Click Detectors

In the wild, harbor porpoise echolocation clicks can be classified acoustically using click detectors (PODs) and acoustic data loggers such as C-PODs. Distinct diel patterns have detected higher numbers of echolocating porpoise at night in Scotland (Carlstrom 2005) and in Haro Strait and San Juan Channel (J. Wood unpubl. data). Interestingly, in concert with tracking data seen by Hanson (2007) where porpoise were associated with tidal fronts, the most tidally dynamic sites had the highest detections of echolocating porpoise (J. Wood unpubl. data).

Since 2009, visual observations and acoustic recordings of harbor porpoises also have been collected in the Fidalgo Island and Rosario Strait area to determine porpoise abundance, distribution and behavior (A. Jeffries unpubl. data). Work is underway to determine the sensitivity of C-PODS to detect harbor porpoise.

Foraging

Harbor porpoise echolocate to forage for their principal prey, fish and cephalopods. Some harbor porpoise may echolocate and dive 5 times more frequently at night than during the day, suggesting most foraging occurs at night for some individuals (Linnenschmidt et al. 2013). During probable foraging events, tagged, free-ranging harbor porpoise had click intervals from 30-150 ms during the search phase, 10-80 ms during the approach phase, and only 3 ms during the buzz phase (Linnenschmidt et al. 2013). DeRuiter et al. (2009) and Verfuß et al. (2009) measured similar click intervals in captive harbor porpoises foraging in an enclosure. They observed a search and approach phase click interval of about 30-50 ms and the buzz phase as beginning 2-4 m from the prey and having a shorter click interval of 1.5-3 ms.

Findings by Au et al. (2009) suggest that harbor porpoise may be able to distinguish between different species of fish based on consistent, species-specific characteristics in echo feedback. The researchers simulated Atlantic bottlenose dolphin (*Tursiops truncatus*) and harbor porpoise echolocation signals and found that the echo structure could discern between Atlantic cod (*Gadus morhua*), gray mullet (*Chelon labrosus*), pollack (*Pollachius pollachius*), and sea bass (*Dicentrarchus labrax*).

Navigation

Harbor porpoise also use echolocation for navigation and spatial orientation. Even in clean, clear pools in which landmarks are visible, harbor porpoise have been observed to echolocate continuously (Verfuß et al. 2005). However, Verfuß et al. (2009) compared swimming harbor porpoise with and without eyecups, and while they observed no change in click intervals in blindfolded porpoise, the porpoise swam half the speed as in trials without eyecups, meaning that twice as many clicks were emitted per meter in the blindfolded trials. This suggests that harbor porpoise use some visual cues paired with biosonar cues.

Verfuß et al. (2005) monitored harbor porpoise trained to swim through a pool from one position to another and observed the porpoise clicking continuously throughout every trial and using focal objects as landmarks. Click intervals decreased as the porpoise approached more closely to its destination but increased for more complicated tasks. Wisniewska et al. (2012) trained harbor porpoise to choose between two targets located at the end of a pool. These researchers observed the porpoise directing their biosonar in the direction of either target and adjusting output levels and pulse intervals to change the range of their biosonar. In each trial, they observed the porpoise conduct an average of 4 scans to choose a target, with roughly 8 clicks per scan (for an average of 32 total echoes per trial). The buzz phase began about 0.5 m from the target and also coincided with a reduction in source level, which effectively narrowed the depth of gaze of the biosonar.

Evolution

Harbor porpoises are one of several toothed whales (odontocetes) that produce narrow band high frequency (NBHF) clicks, which are $>125 \mu\text{s}$ long and relatively weak signals typically above 100 kHz (Madsen et al. 2010, Morisaka and Connor 2007). Other NBHF odontocetes include members of *Phocoenidae*, such as Dall's porpoise (*Phocoenoides dalli*); members of the Delphinid genus *Cephalorhynchus*; the Pygmy sperm whale *Kogia breviceps*; and *Pontoporia blainvillei*, the single member of the family Pontoporiidae (Morisaka and Conner 2007). Interestingly, 100 kHz happens to be the upper effective hearing range of killer whales (*Orcinus orca*) that prey upon these small odontocetes (Morisaka and Connor 2007). It has been hypothesized that these NBHF species have convergently evolved to meet the dual requirements for operating an effective sonar system while minimizing the risk of killer whale predation from passive listening (Kyhn et al. 2013, Morisaka and Conner 2007).

As a side note, killer whales seem to have adapted their echolocation behavior in a different way. To avoid alerting their marine mammal prey, transient killer whales communicate about 27 times less than the fish-eating residents (Barrett-Lennard et al. 1996). Resident

killer whales produce long click trains, which are not a problem during foraging, as fish have poor hearing (Deecke et al. 2005). In contrast, transients produce short, infrequent clicks that are less noticeable to marine mammals such as harbor porpoise (Deecke et al. 2005, Barrett-Lennard et al. 1996).

While harbor porpoise and sympatric Dall's porpoise have remarkably similar clicks, Kyhn et al. (2013) detected a small but consistent 4 kHz click frequency difference between the two species in British Columbia. Although small, they hypothesized that the difference was large enough to be exploited for acoustically differentiating species.

Diving

Harbor porpoises dive almost continuously, on average over 40 times per hour (Linnenschmidt et al. 2013, Otani et al. 1998). Dive information is collected on free-ranging harbor porpoise tagged with time-depth recorders. Studies of this kind have been conducted on a small number of individuals in the Kattegat Sea, Denmark (Linnenschmidt et al. 2013); Funka Bay, Hokkaido, Japan (Otani et al. 1998); and in the Bay of Fundy, Canada, and the Gulf of Maine, USA (Read and Westgate 1997, Westgate et al. 1995). Collectively, most dives recorded in these studies were less than 40 m deep and lasted less than 2 min. The maximum dive depth and length recorded were 226 m and 321 s, respectively (Westgate et al. 1995). These longer, deeper dives seem to be more common at night (Westgate et al. 1995). Work conducted in the San Juan Islands and just to the north with the border of Canada (Raum-Suryan and Harvey 1998) detected harbor porpoise at depths of 20 to 235 m, with a mean depth of 142 m.

Due to this frequent diving behavior, scientists carrying out stock assessments must determine correction values to account for harbor porpoise not seen at the surface of the water. Through extensive aerial and land-based observations of the waters northwest of Orcas Island, WA, researchers determined that porpoises in this area spend about 23% of their time at the water's surface (Laake et al. 1997). In contrast, harbor porpoise in the Baltic and North Seas spend 6% of their time at the surface and 61.5% of their time just below the surface at depths between 0 and 2 m (Teilmann et al. 2013).

Time-depth recording tags that radio or satellite transmit may not accurately capture wild harbor porpoise diving behavior due to their considerable size and bulk. This poses a research concern regarding the reliability of collected data as well as an animal welfare concern (Solsona Berga et al. 2015). Solsona Berga et al. (2015) attached single and double tags to harbor porpoises to determine what effect the second tag had on dive behavior. The second tag weighed about 230 g in air, was slightly buoyant, and had a frontal surface area of 19-25 cm². The second tag resulted in a small but not statistically significant reduction in dive duration and increase in time spent at the surface. However, the effect of the second tag on dive depth was statistically significant, reducing depth by 61% compared to the single tag.

Diet and Foraging Behavior

In the Strait of Juan de Fuca, harbor porpoise foraging is affected by tidal and lunar cycles with increased relative densities of porpoise associated with the ebb current, the occurrence of new or full moons, and from April through October (Hall 2011). Stomach samples collected from 26 harbor porpoise stranded in the Salish Sea between 1990 and 1997 contained 12 fish species and 3 cephalopod species, with fishes from 10 families comprising 52% of the total prey and cephalopods slightly more than 46.5% (Walker et al. 1998). Interestingly mandibles from the polychaete worm *Nereis vexillosa* were a common finding and juvenile blackbelly eelpout (*Lycodopsis pacifica*) was the dominant fish found with a frequency of occurrence of 26.9% (Walker et al. 1998). It was not clear if *N. vexillosa* (which can grow to a length of 30 cm) was consumed directly by the porpoise or secondarily as ingesta of larger prey consumed by the porpoise. The authors felt that the high frequency of blackbelly eelpout was due to a high seasonal availability of juvenile fish and biased the results against the importance of other fishes, including five fish species commonly ingested: Pacific herring (*Clupea harengus pallasii*), walleye pollock (*Theragra chalcogramma*), Pacific hake (*Merluccius productus*), eulachon (*Thaleichthys pacificus*) and Pacific sanddab (*Citharichthys sordidus*). Harbor porpoise ingested prey ranging from 58 mm to 371 mm (Walker et al. 1998).

In addition to the prey species identified by Walker et al. (1998), more recent investigation using stomach contents from animals stranded in the Salish Sea from 1991-2010 reveal that harbor porpoise also consume Pacific sandlance (*Ammodytes hexapterus*), Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), shiner perch (*Cymatogaster aggregata*), a species of Stichaeidae (likely high cockscomb *Anoplarchus purpureus*), and lantern fish (*Myctophidae*) (Nichol et al. 2013). Nichol et al. (2013) did not observe eulachon in stomach contents. These researchers also analyzed Dall's porpoise stranded in the Salish Sea during the same time period revealing significant dietary overlap in the two species including Pacific herring, walleye pollock, Pacific hake, and an unidentified psychrolutid (likely blackfin sculpin, *Malacocottus kincaidii*).

Table 1: Prey consumed by harbor porpoise in the Salish Sea (adapted from Nichol et al. 2013)

Prey	Citation
Clupeidae	
Pacific herring, <i>Clupea pallasii</i>	Nichol et al. 2013, Walker et al. 1998
Pacific sardine, <i>Sardinops sagax</i>	Nichol et al. 2013
Gadidae	
Walleye pollock, <i>Theragra chalcogramma</i>	Nichol et al. 2013, Walker et al. 1998
Pacific hake, <i>Merluccius productus</i>	Nichol et al. 2013, Walker et al. 1998
Psychrolutidae	
Blackfin sculpin, <i>Malacocottus kincaidii</i> *	Nichol et al. 2013
Engraulidae	
Northern anchovy, <i>Engraulis mordax</i>	Nichol et al. 2013
Embiotocidae	
Shiner perch, <i>Cymatogaster aggregata</i>	Nichol et al. 2013
Myctophidae (lantern fish)	Nichol et al. 2013
Osmeridae	
Eulachon, <i>Thaleichthys pacificus</i>	Walker et al. 1998

Batrachoididae Plainfin midshipmen, <i>Porichthys notatus</i>	Walker et al. 1998
Zoarcidae Black belly eelpout, <i>Lycodopsis pacifica</i>	Walker et al. 1998
Ammodytidae Pacific sandlance, <i>Ammodyte hexapterus</i>	Nichol et al. 2013, Walker et al. 1998
Scorpaenidae Rockfish, <i>Sebastes</i> sp.	Walker et al. 1998
Cottidae Northern sculpin, <i>Icelinus borealis</i>	Walker et al. 1998
Bothidae Pacific sanddab, <i>Citharichthys sordidus</i>	Walker et al. 1998
Stichaedae (high cockscomb)	Nichol et al. 2013
Polycaeta Mussell worm, <i>Nereis vexillosa</i>	Nichol et al. 2013, Walker et al. 1998
Cephalopoda	
Loliginidae Opalescent squid, <i>Loligo opalescens</i>	Walker et al. 1998
Onychoteuthidae Boreal clubhook squid, <i>Onychoteuthis borealijaponica</i>	Walker et al. 1998
Gonatidae Berry armhook squid, <i>Gonatus berryi</i>	Walker et al. 1998
Crustacea	
Penaeidae	Walker et al. 1998

*Prey is identified to family and species is suspected.

Diseases

Stranding investigations have identified a subset of harbor porpoise mortality factors. However, a comprehensive review of harbor porpoise mortality still needs to be conducted for the Salish Sea. Briefly, pathogens that have been detected in harbor porpoise in the Salish Sea and worldwide include those listed in Table 2.

Table 2: Infectious agents and parasites detected in harbor porpoise

Pathogen	Salish Sea	Elsewhere
Bacteria		
<i>Aeromonas</i> sp.		North and Baltic Seas, Wunschmann et al. 2001
<i>Aeromonas hydrophyla</i>		North Sea, Jauniaux et al. 2002
<i>Brucella</i> spp.		North Sea, Siebert et al. 2009
<i>Clostridium perfringens</i>		North and Baltic Seas, Siebert et al. 2009, Wunschmann et al. 2001
<i>Escherichia coli</i>	Huggins et al. 2015*	North Atlantic, Siebert et al. 2009; North Sea, Jauniaux et al. 2002; Greenland, North and Baltic Seas, Wunschmann et al. 2001
<i>Erysipelothrix rhusiopathiae</i>		North and Baltic Seas, Siebert et al. 2009, Wunschmann et al. 2001
<i>α-haemolytic streptococci</i>		North Atlantic, Siebert et al. 2009; Greenland, North and Baltic Seas, Wunschmann et al. 2001

<i>β-haemolytic streptococci</i>		North and Baltic Seas, Siebert et al. 2009, Wunschmann et al. 2001
<i>Proteus vulgaris</i>		North Sea, Jauniaux et al. 2002
<i>Pseudomonas fluorescens</i>		WA/OR outer coast, Huggins et al. 2015
<i>Pseudomonas</i> sp.		North Sea, Jauniaux et al. 2002
<i>Pseudomonas aeruginosa</i>		North and Baltic Seas, Wunschmann et al. 2001
<i>Salmonella</i> sp.		England and Wales, Jepson et al. 1999; Baltic Sea, Siebert et al. 2009; Scotland, Foster et al. 1999
<i>Salmonella Newport</i> Group C2	Norman et al. 2004b	
<i>Salmonella typhimurium</i>		WA/OR outer coast, Huggins et al. 2015
<i>Staphylococcus aureus</i>	Huggins et al. 2015*	WA/OR outer coast, Huggins et al. 2015; North Sea, Siebert et al. 2009; North and Baltic Seas, Wunschmann et al. 2001
<i>Staphylococcus</i> sp.		North Sea, Jauniaux et al. 2002
<i>Staphylococcus intermedius</i>		North and Baltic Seas, Wunschmann et al. 2001
<i>Streptococcus canis</i>		England and Wales, Jepson et al. 1999
<i>γ-streptococci</i>		North and Baltic Seas, Wunschmann et al. 2001
<i>Streptococcus</i> sp.		Including <i>S. equisimilis</i> , North Sea, Jauniaux et al. 2002;
<i>Streptococcus zooepidemicus</i>		Baltic Sea, Siebert et al. 2009
<i>Vibrio alginolyticus</i>	Huggins et al. 2015	
<i>Vibrio anguillarum</i>		North and Baltic Seas, Wunschmann et al. 2001
<i>Vibrio cholerae</i>	Huggins et al. 2015	
<i>Vibrio parahaemolyticus</i>		WA/OR outer coast, Huggins et al. 2015
<i>Yersinia pseudotuberculosis</i>	Huggins et al. 2015	
Viruses		
<i>γ-herpesvirus</i>	Gaydos unpubl. data	
Herpesvirus, likely Alphaherpesvirinae		Sweden, Kennedy et al. 1992
Morbillivirus		Ireland, Kennedy et al. 1991
Papillomavirus		Germany, Van Bresse et al. 1999
Fungi		

<i>Candida lipolytica</i>		North Sea, Jauniaux et al. 2002
<i>Cryptococcus gattii</i>	Stephen et al. 2002, Norman et al. 2011, Huggins et al. 2015	
<i>Rhizopus</i> sp.		Germany, Wünschmann et al. 2002
Parasites		
Cestodes		
<i>Diphyllobothrium stemmacephalum</i>		Belgium and Germany, Brosens et al. 1996
Nematodes		
<i>Anasakis</i> spp.	Norman et al. 2004b J. Gaydos unpubl. data	
<i>Anasakis simplex</i>		North Sea, Jauniaux et al. 2002; Germany, Wünschmann et al. 2002; North Atlantic, Wunschmann et al. 2001; Belgium and Germany, Brosens et al. 1996
<i>Crassicauda</i> sp.	Norman et al. 2004b, J. Gaydos unpubl. data, Cascadia Research unpubl. data	Greenland, Wunschmann et al. 2001
<i>Halocercus</i> sp.	Norman et al. 2004b, J. Gaydos unpubl. data	North Sea, Jauniaux et al. 2002; Greenland, Wunschmann et al. 2001
<i>Halocercus incaginatus</i>		Oregon, Stroud and Roffe 1979; Netherlands, Slob et al. 1966
<i>Halocercus ponticus</i>	Cascadia Research unpubl. data	
<i>Halocercus tauricus</i>		Netherlands, Slob et al. 1966
<i>Pseudoterranova decipiens</i>	Gaydos unpubl. data	
<i>Pseudalius inflexus</i>		North Sea, Jauniaux et al. 2002; England and Wales, Jepson et al. 1999; Germany, Wünschmann et al. 2002; North Atlantic, Wunschmann et al. 2001; Belgium and Germany, Brosens et al. 1996; Netherlands, Slob et al. 1966
<i>Stenurus</i> sp.	Gaydos unpubl. data	
<i>Stenurus minor</i>	Cascadia Research unpubl. data	Germany, Wünschmann et al. 2002; Greenland and North Atlantic, Wunschmann et al. 2001;

		Belgium and Germany, Brosens et al. 1996; Netherlands, Slob et al. 1966
<i>Torynus convoluta</i>	Cascadia Research, unpubl. data, Gaydos unpubl. data	North Sea, Jauniaux et al. 2002; North Atlantic, Wunschmann et al. 2001; England and Wales, Jepson et al. 1999; Germany, Wunschmann et al. 2002; Belgium and Germany, Brosens et al. 1996; Netherlands, Slob et al. 1966
Protozoa		
<i>Sarcocystis neurona</i>	Barbosa et al. 2015, Gibson et al. 2011, Huggins et al. 2015	
<i>Sarcocystis</i> sp.		Greenland, Wunschmann et al. 2001
<i>Toxoplasma gondii</i>	Gibson et al. 2011, Huggins et al. 2015	
Trematodes		
<i>Campula oblonga</i>		Belgium and Germany, Brosens et al. 1996
<i>Campula oblongata</i>	Norman et al. 2004b, Gaydos unpubl. data	North Sea, Jauniaux et al. 2002; Germany, Wunschmann et al. 2002; North Atlantic, Wunschmann et al. 2001
<i>Hedwenius mironovi</i>	Gaydos unpubl. data	
<i>Orthospianchus mironovi</i>		Greenland, Wunschmann et al. 2001
<i>Pholeter gastrophilus</i>		North Sea, Jauniaux et al. 2002
<i>Synthesium nipponicus</i>	Gaydos unpubl. data	

*Pathogen has been detected in the Salish Sea and/or the outer coast of Washington and Oregon

In the 2006-2007 UME affecting harbor porpoises in the Washington inland waters as well as the Washington and Oregon coasts, infectious disease was found to be the primary cause of death in 33% of cases and secondary in 25% of cases (Huggins et al. 2015). Respiratory disease was the result of nearly half of these infections, stemming from parasitic, bacterial, and viral infections (Huggins et al. 2015). A significant portion of these occurred in the Salish Sea in the eastern Strait of Juan de Fuca and San Juan Island (Huggins et al. 2015). Other infections were protozoal, most frequently associated with meningoencephalitis and myocarditis; and fungal, including *Cryptococcus gattii* (Huggins et al. 2015). A variety of other non-pathological infections were detected, including *Neospora* spp., *Coxiella burnetti*, and 26 bacterial isolates, the bacteria mostly considered normal flora or post mortem invaders (Huggins et al. 2015). Huggins et al. (2015) did not detect *Brucella* spp. or morbilliviruses by PCR, but serology did detect exposure to *Brucella* spp.

Predators

In the Salish Sea, the only recorded predators of harbor porpoise are transient killer whales (Ford et al. 1998, Baird and Dill 1995, Jefferson et al. 1991) Transient killer whales off the

coast of Washington and British Columbia subsist on a diet of pinnipeds, cetaceans, and sometimes even marine birds. While more than half of their caloric intake comes from harbor seals (*Phoca vitulina*), about 11% of kills observed by Baird and Guenther (1995) were harbor porpoise. In fact, these researchers noted a 100% chase-to-kill ratio for transient killer whales preying on harbor porpoise.

Shark attacks on marine mammals are less common in the eastern North Pacific than in other locales, but a few instances of white shark predation on harbor porpoise have been recorded off the outer coast of British Columbia (Baird and Guenther 1995) and Washington State (Long and Jones 1996). Additionally, a sevengill shark attack was confirmed for a harbor porpoise stranded on the outer Washington coast (Cascadia Research unpubl. data).

In other regions, additional threats to harbor porpoises include bottlenose dolphins (*Tursiops truncatus*) and grey seals (*Halichoerus grypus*). Harbor porpoise and bottlenose dolphin overlap in California between Point Conception and San Francisco Bay. Jacobson et al. (2015) report 28 stranded porpoise likely killed by bottlenose dolphin attacks between 2005 and 2011, possibly due to prey competition or infanticidal behavior. This study also documented reductions in harbor porpoise vocalization in the presence of bottlenose dolphins. Gray seal attacks on harbor porpoises have also been documented in Belgium and the Netherlands. In Belgium, two harbor porpoise washed ashore with traumatic lesions that were likely inflicted by grey seals based on mouth and tooth structure (Haelters et al. 2012). Wound and DNA analysis have confirmed grey seal attacks on harbor porpoises stranded along the Dutch coast (Leopold et al. 2015). These stranded animals were typically healthy juveniles with thick blubber stores.

Non-predatory interactions result in harbor porpoise injury and mortality in the Salish Sea as well. Piscivorous southern resident killer whales have been documented on numerous occasions chasing and harassing harbor porpoises (Cascadia Research and The Whale Museum, unpubl. data). Baird (1998) also observed two Pacific white-sided dolphins interacting with a harbor porpoise neonate off of San Juan Island in eastern Haro Strait. Although the harbor porpoise was dragged by the flipper by the two dolphins and incurred several bite wounds, it is more likely that the dolphins were exhibiting play rather than predatory behavior. It is unknown if this type of interspecific interaction is common or if this was an aberrant case.

Stranding Information

Washington State

Harbor porpoise are the most commonly stranded cetacean in Washington State (Norman et al., 2004a). Until the mid-2000s, statewide annual harbor porpoise strandings remained fairly consistent at an average of 6 animals. Between 2 May and 2 June 2003, 15 harbor porpoise stranded in eastern Strait of Juan de Fuca and Haro Strait. These strandings were thought to be related to mid-frequency active tactical sonar use by the naval vessel *USS SHOUP* operating in that area on 5 May 2003. Necropsies and CT scans did not identify any

lesions characteristic of acoustic trauma, but due to poor condition of the carcasses, acoustic trauma could not be ruled out. Causes of death for some individuals included blunt force trauma, fibrinous peritonitis, salmonellosis, and necrotizing pneumonia (Norman et al. 2004b).

Strandings throughout the region increased in 2006, with 64 porpoise (49 in Washington, 15 in Oregon), and an Unusual Mortality Event (UME) was declared for both states (Huggins et al. 2015, Norman et al. 2012). Huggins et al. (2015) evaluated the stranding and necropsy data on 114 porpoise stranded 2006-2007 and identified a range of causes of mortality. Disease and trauma were the two most common causes of death, followed by malnutrition (Huggins et al. 2015). The lack of a single cause of mortality, along with the relatively even distribution geographically, temporally, and among age classes and between genders suggest that the increases in strandings probably stem from a growing population and more robust stranding network coverage (Huggins et al. 2015, Norman et al. 2012). The continuing high numbers of strandings supports this conclusion, with 50 in 2008, 66 in 2009, 56 in 2010, and 91 in 2011 (Huggins et al. 2015). However, the more frequent documentation of stranded animals with evidence of fishery interaction since the beginning of the UME, primarily in central and southern Puget Sound and Hood Canal, is of particular concern, especially given the likely small number of porpoise in these areas.

British Columbia

Between 1934 and 1991, there were 81 strandings of harbor porpoise recorded in British Columbia. Strandings were observed more often near cities, in water 10-100 m deep, likely due to increased effort in these areas (Baird and Guenther 1995). Between 2008-2011, the British Columbia Marine Mammal Response Network (BCMMRN) recorded 114 harbor porpoise strandings (BCMMRN unpubl. data). This dramatic increase in the number of strandings probably reflects increased response effort. The BCMMRN reports seasonal peaks in harbor porpoise strandings, with most adult strandings occurring in May and most juvenile and calf strandings happening in August.

Since 2006, 5 live-stranded harbor porpoises have been recovered and presented to the Vancouver Aquarium's Marine Mammal Rescue Centre for rehabilitation (Vancouver Aquarium, unpubl. data). Estimated age at stranding ranged from 6 weeks to 3 years, with younger animals stranding more frequently in the summer and early fall. Animals ranged in weight from 12.1 to 42 kg at admission. Each animal received 24-hour care by trained veterinary staff and rescue volunteers. Length of stay ranged from 2 to 71 days for animals that died during rehabilitation. Animals that strand as dependent calves are considered non-releasable and two perinatal animals that were successfully rehabilitated are permanently housed in a habitat at the Vancouver Aquarium (Vancouver Aquarium unpubl. data). The causes of death in the other three animals include severe metabolic compromise, hydrocephalus, and encephalomyelitis associated with *Cryptococcus* sp. Medical challenges with stranded porpoises include diagnosis of the underlying cause of stranding, very high metabolic rate and nutritional demands particularly with neonates, and the effect of stranding on muscles and pulmonary function resulting in a requirement for intensive and prolonged supportive care (Vancouver Aquarium, unpubl. data).

Europe

A larger study of stranded harbor porpoise in the German North and Baltic Seas covered 1990-2000 and included 1,015 stranded and porpoises incidentally caught in fishing gear, with an average of 100 per year in both seas. Strandings occurred year round, but summer peaks in strandings were observed similar to those in BC, with peaks in June and July in the North Sea and in July and August in the Baltic Sea. Variations in the annual number of stranded porpoise are hypothesized to be due to varying weather and water conditions affecting whether animals wash ashore (Hasselmeier et al. 2004).

Peltier et al. (2013) used harbor porpoise stranding data covering the North Sea and the Channel and Bay of Biscay over the years 1990-2009 to develop a population indicator. The indicator is based on a geographic null hypothesis (H_0) of harbor porpoise stranding, which assumes a uniform population distribution throughout the study area corrected for drift based on wind and tidal conditions. The difference (positive or negative) between actual strandings and H_0 is defined as the stranding anomaly, an indicator of harbor porpoise mortality. The authors point out that this is a relatively low-cost means of tracking cetacean distribution, abundance, and mortality, as it is based on stranding data that is already being collected in many areas globally.

Legal Status

Harbor porpoise populations are recognized as being at risk by Canadian agencies at the federal and provincial levels, classified under the Blue List in British Columbia and as a Special Concern under Committee on the Status of Endangered Wildlife in Canada and the Species at Risk Act (Gaydos and Zier 2014). In the United States, harbor porpoise are Candidates for listing in Washington State but have no federal classification (Gaydos and Zier 2014).

Anthropogenic Threats

Preferring shallow, coastal waters within 200 m of land, harbor porpoise live in close proximity to human development and thus its negative environmental impacts, especially in the Salish Sea. The primary threats to harbor porpoise are entanglement in fishing nets, habitat degradation, decline in prey species, pollution, and noise, which harm harbor porpoise directly and indirectly by placing stressors on habitat, prey availability, reproduction, and other factors (Jeffries 2011, Fisheries and Oceans Canada 2009). These anthropogenic threats are implicated in the decline in harbor porpoise abundance in the Salish Sea (West 1997). In contrast, natural threats, such as predation or disease, are considered less harmful for harbor porpoise population health (Fisheries and Oceans Canada 2009).

Fisheries Bycatch

Harbor porpoise are among the 82% of recognized odontocete species in the world that have been accidentally caught in fishing gear since 1990 (Reeves et al. 2013). Harbor porpoise are threatened by entanglement throughout their distribution and fisheries bycatch could be an important mortality factor for the species within the Salish Sea.

Reports on harbor porpoise bycatch in the Salish Sea have been incomplete, making an accurate assessment of the impact of fisheries difficult. Gearin et al. (1994) observed 138 harbor porpoise taken in a Makah Indian Tribe salmon gillnet fishery around Cape Flattery, Washington State from 1988-1990. A 1997 report indicates that an average of 16 harbor porpoise were killed as fisheries bycatch in Washington inland waters annually (West 1997). Hall et al. (2002) estimate a salmon gillnet fishery bycatch mortality of fewer than 100 harbor porpoise per year in British Columbian waters, based on 1997-2001 bycatch data.

A list of fisheries known to have incidental takes of harbor porpoise is available (NOAA), but the actual takes still need to be quantified. We need an accurate assessment of fisheries takes on harbor porpoise in both Washington and British Columbia to better understand the current impact of fisheries on the conservation status of the species. This assessment should include Tribal and Non-Tribal Fisheries.

Harbor porpoise bycatch throughout the North Atlantic Ocean is extensive, estimated to be greater than 15,000 animals annually in the 1990s (Stenson 2003, cited in Reeves et al. 2013). Reeves et al. (2013) hypothesize that fisheries bycatch in the Baltic could have dire consequences to the threatened population in those waters, while the impacts on other populations is unknown. Along the Danish coastline, fishery bycatch was implicated as a primary cause in a mass stranding of 85 harbor porpoises from 7-15 April 2005 (Wright et al. 2013). The average stranding rate for all of Denmark for that time period was 0.65 animals/week (Wright et al. 2013).

To reduce this number, acoustic alarms, or pingers, are attached to gillnets to deter harbor porpoise. Harbor porpoise studied in Clayoquot Sound, BC did not approach within 130 m of a gillnet equipped with pingers, compared to their behavior with non-alarmed nets, which they approached within 4 m (Culik et al. 2001). Focusing on salmon gillnet fisheries in northern Washington waters, Gearin et al. (2000) found that between 1996-1996, 2 harbor porpoise were killed in nets with pingers while 47 were killed in nets without pingers. In 1997 when all nets were equipped with pingers, 12 porpoise were killed, which represents an 85% reduction from the expected take of 79 porpoises without pingers (Gearin et al. 2000). The pingers did not affect salmon, sturgeon, or harbor seal catches (Gearin et al. 2000). In the US Northeast gillnet fishery, mesh gillnets equipped with pingers reduced harbor porpoise bycatch by 92% compared to those without pingers in a controlled scientific study (Palka et al. 2008). Although pingers have been required since 1999, actual pinger usage in this fishery varied between 36% and 87% and annual harbor porpoise bycatch was only reduced 50-70% from 1999-2007 compared to pre-1999 levels (Palka et al. 2008).

Contaminants

As relatively long-lived piscivores, harbor porpoise are particularly vulnerable to contaminant accumulation (West 1997). Calambokidis and Barlow (1991) analyzed PCB, DDE, and HCB levels in 45 harbor porpoises sampled 1971-1986 along the coasts of Washington, Oregon, and California. Mean concentrations of blubber samples were

comparable to those measured in other areas, at 14 ppm for PCBs, 31 ppm for DDEs, and 0.51 ppm for HCBs (mg/kg wet weight, Calambokidis and Barlow 1991). Ratios of PCB/DDE and HCB/DDE varied significantly with latitude and could be used to predict latitude (Calambokidis and Barlow 1991). Other contaminant analyses have been previously conducted on harbor porpoise tissues but have not been published. Although some contaminants such as PCBs and DDT have decreased in the region, newly emerging contaminants such as PBDEs are of concern. Monitoring contaminant ratios could be an ancillary technique for evaluating population structure within the Inland Waters Salish Sea stock. Central Puget Sound might be an ideal area to investigate the relationship between contaminant levels and infectious diseases.

Exposure to contaminants may predispose marine mammals to infectious disease. Higher PCB and PBDE levels in the Norwegian North Atlantic and German North and Baltic Seas are implicated in increased bacterial infections of harbor porpoise distributed in those areas versus their Greenlandic and Icelandic counterparts (Siebert et al. 2009). Siebert et al. (2009) found that harbor porpoises in Norwegian and German waters had higher levels of potentially pathogenic bacteria including *Brucella* sp., *Clostridium perfringens*, *Escherichia coli*, *Erysipelothrix rhusiopathiae*, β -haemolytic streptococci and *Staphylococcus aureus* compared to Greenlandic and Icelandic harbor porpoises. Similarly, along the coasts of England and Wales, harbor porpoise that died due to infectious disease (mainly pneumonia) had significantly greater PCB concentrations in blubber samples than harbor porpoise that died due to physical trauma (Jepson et al. 1999). Further evaluation in another study demonstrated that a 1 mg/kg increase in blubber PCBs increases the risk of infectious disease mortality by 2%, with a doubling of risk occurring at 45 mg/kg (Hall et al. 2006). A similar study in England and Wales comparing harbor porpoises that died of infectious disease versus physical trauma also found that the former group was associated with significantly higher levels of mercury, selenium, and zinc in the liver (Bennett et al. 2001).

Marine debris is another threat to harbor porpoise populations. Williams et al. (2011) conducted line-transect surveys to map marine debris and estimated that 36,000 pieces exist in British Columbian waters, most commonly Styrofoam, plastic bottles, and plastic bags. Debris was concentrated around the Queen Charlotte Basin, Victoria, Prince Rupert, Langara Island, and Cape Scott. Those areas around the southern half of Vancouver Island and the northern mainland fjords overlap with harbor porpoise distribution, posing a high risk for entanglement and ingestion (Williams et al. 2011). Baird and Hooker (2000) report a harbor porpoise stranded in Nova Scotia having a balled up piece of plastic lodged in its esophagus. The stomach was empty, but fish remnants were located cranial to the plastic. With no other signs of injury or pathology, ingestion of plastic debris was apparently the cause of death (Baird and Hooker 2000).

Noise

Noise is hypothesized to be a major contributor to early harbor porpoise population decline in Puget Sound proper (West 1997). High levels of ambient noise in the coastal environment may be making otherwise ideal habitat unusable to harbor porpoise (Fisheries and Oceans Canada 2009). Loud noise can induce hearing loss and temporary or

permanent threshold shifts in hearing sensitivity, affecting communication and foraging ability (Kastelein et al. 2013).

Acoustic harassment devices (AHDs) in use around fisheries are designed to repel marine mammal predators such as seals. However, AHDs also affect non-target species, especially harbor porpoise. In Retreat Passage, BC, AHD usage was monitored from an observation area 80 m away in a study area bounded by coastline and 2.5-3.5 km observation ability, depending on visibility (Olesiuk et al. 2002). AHD activation reduced mean harbor porpoise sightings in the study area by 96-98%. AHDs also decreased resightings by 86-91% (Olesiuk et al. 2002). Conducted over an 18-week period, this study showed no signs of short-term habituation to AHD presence (Olesiuk et al. 2002). In the German North Sea, AHDs used to deter seals from fisheries and marine construction also reduced harbor porpoise abundance by 52-95% within a 7.5-km radius (Brandt et al. 2013).

Harbor porpoises are a concern in the installation of offshore wind and tidal energy infrastructure. A pilot tidal turbine project was planned for Admiralty Inlet, WA. In preparation, Tollit et al. (2010) assessed marine mammal usage of the location and detected harbor porpoise during more than half of their observations. Additionally, acoustic evaluation of the area suggested that harbor porpoises frequenting Admiralty Inlet were accustomed to high levels of ambient noise (Collar et al. 2012). Although this project is not moving forward to completion, it represents an important awareness of its potential impacts on marine mammals. Teilmann and Carstensen (2012) evaluated the impacts of a 72-turbine windfarm offshore of the Danish coast that began operating in 2003. Comparing baseline harbor porpoise echolocation activity from 2001-2002 to the 2002-2003 construction period and the 2003-2012 operation period, the authors have demonstrated a marked decrease since construction began. Although echolocation activity has increased after the construction period, suggestive of gradual habituation, harbor porpoise activity has not fully recovered. It is unknown if it is the noise, vessel traffic, presence of turbines, or prey availability changes that are responsible for harbor porpoise decline in this area (Teilmann and Carstensen 2012).

Sonar use by naval vessels is sometimes implicated in mass marine mammal stranding events. Most notably, US Navy ships operating mid-range frequency sonar are considered responsible for the mass stranding of 17 cetaceans in the Bahamas (NOAA 2001). Necropsies of these animals found evidence of acoustic trauma including hemorrhages around the ears (NOAA 2001). In the eastern Strait of Juan de Fuca and Haro Strait in early May 2003, the *USS SHOUP* operated mid-frequency sonar, which may have been linked to an unusually high number of harbor porpoise strandings (Norman et al. 2004b). The average stranding rate for this area was 6 porpoises per year, while 15 animals stranded from 2 May to 2 June 2003. Necropsies conducted on 11 of those animals showed no definitive signs of acoustic trauma, but due to poor post mortem condition, the possibility could not be ruled out (Norman et al. 2004b).

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