6-27-2022

Polychlorinated Organic Contaminants in Baleen from North Pacific Ocean Whales

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Thesis of
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Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science
Marine Science

Nova Southeastern University
Halmos College of Arts and Sciences

June 2022

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NOVA SOUTHEASTERN UNIVERSITY
HALMOS COLLEGE OF ARTS AND SCIENCES

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i. Acknowledgements

I extend my deepest appreciation and gratitude to my committee members, Drs. Dimitrios Giarikos, Amy C. Hirons, Jessica Brown, and Stephen Trumble, for their extensive support and guidance throughout this project. A special thanks to Stephen Trumble at Baylor University for providing all baleen plates and sampling supplies. Funding for this research was provided by Nova Southeastern University's President's Faculty Research and Development Grant. Data will be presented at the 2022 SMM 24th Biennial Conference on the Biology of Marine Mammals. A special thank you goes to my incredible family and friends who have provided me with unconditional support throughout all of the ups and downs this experience has provided.

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iv. Abstract

Persistent organic pollutants (POP) have been detected and analyzed in various baleen whale tissues (blubber, muscles, liver, etc.) This study concentrated on detecting 7 polychlorinated biphenyls (PCB) and 14 organochlorine pesticides from baleen, a baleen whale tissue never before analyzed for POPs. These data were used to investigate temporal and geographic trends by sampling at every 1 cm interval along the length of the baleen plate. Four species of baleen whales stranded in the North Pacific Ocean were included in this study: gray (n=2), humpback (n=2), minke (n=1), and blue (n=1) whales. Organic contaminant concentrations were analyzed with respect to foraging style and habitat differences among the species included. Oscillating periods of high and low contaminant concentrations were found along the length of the baleen in all four whale species indicating these migratory animals are experiencing periods of time with increased POP exposure. While no significant differences were found among POP concentrations tested based on foraging style (benthic vs. lunge), ΣHCH did differ between habitat groups, with the pelagic foragers (minke, blue) having a significantly greater geometric mean concentrations than the neritic (gray, humpback) habitat group. All organic contaminant concentrations were low (ND-77.4 ng/g), likely due to the low trophic position of baleen whales and the keratinous tissue the POPs were extracted from.

Key words: Baleen, Whales, persistent organic pollutants, North Pacific Ocean, SECLER

1. Introduction

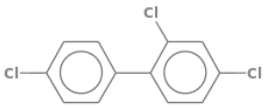
1.1. Persistent Organic Pollutants

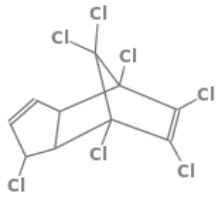
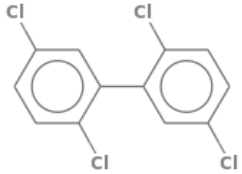
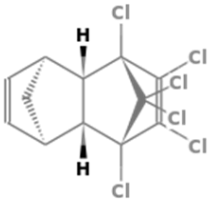
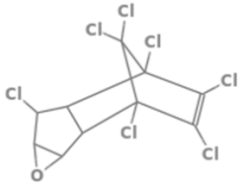
Persistent organic pollutants (POP) consist of a wide variety of toxic carbon-based chemicals that are persistent in the environment for decades after their use (NOAA 2009, UNEP 2003). These pollutants are readily deposited on the ground, in the atmosphere, and ultimately in the planet's water bodies. These have both seen and unforeseen effects on human health, wildlife, and the environment (Jantunen and Bidleman, 1996; Longnecker et al., 1997). Some of the most well-known legacy POP are hexachlorocyclohexanes (HCH), dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCB), and dioxins, more specifically, HCH, DDT, PCB, and other pesticides like heptachlor, aldrin, dieldrin, and endrin are organochlorine compounds. Organochlorine compounds have structures composing of hydrocarbons with more than one chlorine atom present with molecular weights ranging from 290.83- 498.66 g/mol (Table 1). These legacy contaminants have been banned or severely restricted by most developed countries due to their toxicity to wildlife and humans (Beard, 2006; EPA, 2006; Longnecker et al., 1997). Prior to being banned, PCB, HCH and DDT were the most heavily used organic pollutants worldwide and they persist in the environment today.

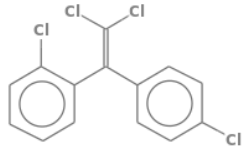
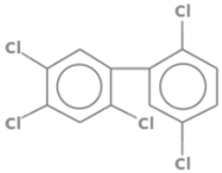
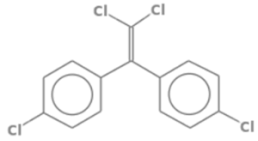
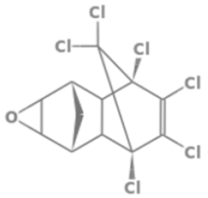
These organochlorine compounds are chemically stable, making them resistant to abiotic and biotic degradation once in the environment (Addison and Ross, 2000; WHO, 1991). POPs are still prevalent today with a worldwide distribution although their major introduction into the environment occurred from the 1940s to the 1970s (UNEP, 2003). High vapor pressure, high lipid solubility and low water solubility are all chemical properties of organochlorine compounds that contribute to their persistence in the environment. High vapor pressures at normal environmental temperatures make POPs volatile compounds, allowing for atmospheric transportation to occur, providing these compounds a worldwide distribution even though most POP release occurred at mid- and low- latitudes (Addison and Ross, 2000; Nisbet and Sarofim, 1972; Simonich and Hites, 1995; Stemmler and Lammel, 2009). Due to their low water solubility and high lipid solubility, once POPs enter the marine environment they are readily stored in the lipid within organisms or are bound to particulate matter and sediments (Addison and Ross, 2000). Since organic contaminants are not easily degraded, they can accumulate in organisms and be transferred throughout food webs and ecosystems (Addison and Ross, 2000; WHO, 1991).

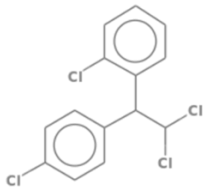
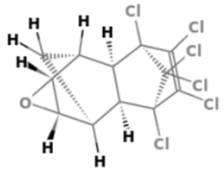
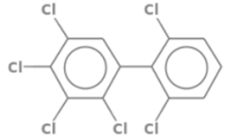
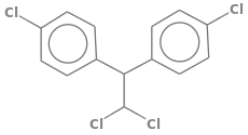
Table 1

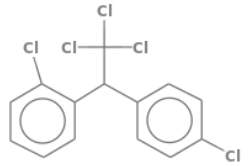
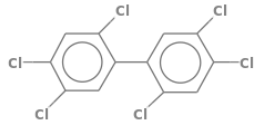
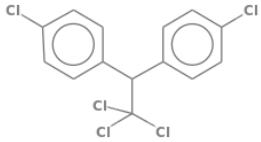
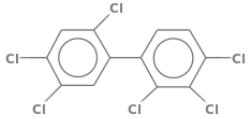
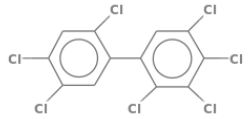
All target organic contaminants analyzed in this study with their IUPAC chemical name, common chemical abbreviation, CAS number, molecular weight, retention time (min) for our GCMS method, chemical formula, and chemical structure.

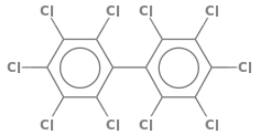
Chemical Name	Chemical Abbreviation	CAS Number	Molecular Weight	Retention Time (min)	Chemical Formula	Chemical Structure
α-1,2,3,4,5,6-hexachlorocyclohexane	α-HCH	319-84-6	290.83	13.830	$C_6H_6Cl_6$	
β-1,2,3,4,5,6-hexachlorocyclohexane	β-HCH	319-85-7	290.83	15.400	$C_6H_6Cl_6$	
γ-1,2,3,4,5,6-hexachlorocyclohexane	γ-HCH	58-89-9	290.83	16.925	$C_6H_6Cl_6$	
2,4,4'-Trichloro-1,1'-biphenyl	PCB 28	7012-37-5	257.543	18.320	$C_{12}H_7Cl_3$	

1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-, 4,7-Methano-1H-indene, 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene	Heptachlor	76-44-8	373.318	18.740	$C_{10}H_5Cl_7$	
1,1'-Biphenyl, 2,2',5,5'-tetrachloro-, 2,2',5,5'-Tetrachloro-1,1'-biphenyl	PCB 52	35693-99-3	291.988	20.040	$C_{12}H_6Cl_4$	
1,4:5,8-Dimethanonaphthalene, 1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-	Aldrin	309-00-2	364.91	20.915	$C_{12}H_8Cl_6$	
2,3,4,5,6,7,7-heptachloro -1a,1b,5,5a,6,6a-hexahydro-	Heptachlor epoxide	1024-57-3	389.317	24.610	$C_{10}H_5Cl_7O$	

1-chloro-2-[2,2-dichloro-1-(4-chlorophenyl)ethenyl]-, 1,1-dichloro-2-(o-chlorophenyl)-2-(p-chlorophenyl)-	o,p'-DDE, 2,4'-DDE	3424-82-6	318.025	26.625	$C_{14}H_8Cl_4$	
1,1'-Biphenyl, 2,2',4,5,5'-pentachloro-, 2,2',4,5,5'-Pentachloro-1,1'-biphenyl, 2,2',4,5,5'-Pentachlorobiphenyl	PCB 101	37680-73-2	326.433	27.605	$C_{12}H_5Cl_5$	
1,1'-(dichloroethenylidene)bis[4-chloro-, 1,1-dichloro-2,2-bis(p-chlorophenyl)-, 1,1-Dichloro-2,2-Bis(p-chlorophenyl)ethylene	p,p'-DDE, 4,4'-DDE	72-55-9	318.025	30.840	$C_{14}H_8Cl_4$	
3,4,5,6,9,9-hexachloro -1a,2,2a,3,6,6a,7,7a-octahydro-	Dieldrin	60-57-1	380.909	21.550	$C_{12}H_8Cl_6O$	

1-chloro-2-[2,2-dichloro-1-(4-chlorophenyl)ethyl]-, 1,1-dichloro-2-(o-chlorophenyl)-2-(p-chlorophenyl)-	o,p'-DDD, 2,4'-DDD	53-19-0	320.041	31.845	$C_{14}H_{10}Cl_4$	
3,4,5,6,9,9-hexachloro -1a,2,2a,3,6,6a,7,7a-octahydro-	Endrin	72-20-8	380.909	34.005	$C_{12}H_8Cl_6O$	
1,1'-Biphenyl, 2,2',3,4,5,6'-Hexachloro-, 2,2',3,4,5,6'-Hexachloro-1,1'-biphenyl, 2,2',3,4,5,6'-Hexachlorobiphenyl	PCB 143	68194-15-0	360.878	34.365	$C_{12}H_4Cl_6$	
1,1-Dichloro-2,2-bis(p-chlorophenyl)ethane, 1,1'-(2,2-dichloroethylidene)bis[4-chloro-, 1,1-dichloro-2,2-bis(p-chlorophenyl)-	p,p'-DDD, 4,4'-DDD	72-54-8	320.041	35.260	$C_{14}H_{10}Cl_4$	

1-chloro-2-[2,2,2-trichloro-1-(4-chlorophenyl)ethyl]-, 1,1,1-trichloro-2-(o-chlorophenyl)-2-(p-chlorophenyl)-	o,p'-DDT, 2,4'-DDT	789-02-6	354.486	36.820	$C_{14}H_9Cl_5$	
1,1'-Biphenyl, 2,2',4,4',5,5'-hexachloro-, 2,2',4,4',5,5'-Hexachloro-1,1'-biphenyl	PCB 153	35065-27-1	360.878	37.195	$C_{12}H_4Cl_6$	
1,1'-(2,2,2-trichloroethylidene)bis[4-chloro-, 1,1,1-Trichloro-2,2-bis(p-chlorophenyl)ethane	p,p'-DDT, 4,4'-DDT	50-29-3	354.486	40.260	$C_{14}H_9Cl_5$	
1,1'-Biphenyl, 2,2',3,4,4',5'-hexachloro-, 2,2',3,4,4',5'-Hexachlorobiphenyl	PCB 138	35065-28-2	360.878	40.350	$C_{12}H_4Cl_6$	
1,1'-Biphenyl, 2,2',3,4,4',5,5'-heptachloro-, 2,2',3,4,4',5,5'-Heptachlorobiphenyl	PCB 180	35065-29-3	395.323	49.585	$C_{12}H_3Cl_7$	

1,1'-Biphenyl, 2,2',3,3',4,4',5,5',6,6'-decachloro-, Decachlorobiphenyl, 2,2',3,3',4,4',5,5',6,6'-Decachloro-1,1'-biphenyl	PCB 209	2051-24-3	498.658	77.545	$C_{12}Cl_{10}$	

1.1.1. Hexachlorocyclohexanes

Hexachlorocyclohexane (HCH) also known as technical HCH is used as an insecticide and was first introduced to the environment in 1942 (Iwata et al., 1993; Janutnen and Bidleman, 1996; Moisey et al., 2001). Technical HCH was used globally until being banned by northern developed countries in the 1970s due to its harmful environmental and health impacts (Barrie et al., 1992; Li and Macdonald, 2005; Moisey et al. 2001). However, Russia and other Asian countries continued to heavily use the insecticide until the 1980s (Janutnen and Bidleman, 1996). Today, technical HCH is still being used for agricultural purposes at tropical latitudes (Li and Macdonald, 2005). It is a mixture of five HCH isomers which include: α-HCH, β-HCH, γ-HCH, δ-HCH, and ε-HCH. It consists of 55-80% α-HCH, 5-14% β-HCH, 8-15% γ-HCH, 2-16% δ-HCH and 3-5% ε-HCH with γ-HCH being the only isomer that provides the insecticidal qualities (Vijgen et al., 2006). It is estimated that 10 million tons of technical HCH were used and ultimately released to the environment from 1948 to 1997 (Li, 1999; Li and Macdonald, 2005). Although technical HCH has been banned in northern developed countries since 1978, countries switched to using pure γ-HCH, also known as lindane, which was used in the United States and other countries until the 2000s (EPA, 2006; Vijgen et al., 2006). However, the production of lindane is highly inefficient and for every ton of lindane that was produced 8-12 tons of HCH isomers were also produced (Bodenstein, 1972; Vijgen et al., 2006; Yu, 2004). It is estimated that an additional 1.6- 4.8 million tons of HCH isomers were released into the environment from lindane production (Vijgen et al., 2006). All HCH isomers are acutely toxic to mammals with exposure found to closely relate with various types of cancer, thyroid disruption, and reproductive system disruptions (Álvarez-Pedrerol, 2008; Ejaz et al., 2004; Kumar et al., 2013; Tomczak et al., 1981; Walker et al., 1999). HCHs enter the terrestrial and marine environment via emissions and runoff. Once in the environment, HCHs are comparatively more volatile organochlorine compounds than DDTs, PCBs, and other organochlorine pesticides and are thus more readily transported via atmospheric currents (Simonich and Hites, 1995). Their high volatility makes them one of the most widely distributed and most detected POPs in the world (Walker et al., 1999). HCH isomers vary by chemical orientation giving them varying properties, with α-HCH, β-HCH, and γ-HCH being the most predominantly detected isomers in the environment (Walker et al., 1999; Vijgen et al., 2006). α-HCH is more readily found in the

atmosphere and water while β-HCH is more resistant to degradation and more lipophilic and is thus found more commonly accumulating in organisms (Walker et al., 1999).

1.1.2. Dichlorodiphenyltrichloroethane and Metabolites

Dichlorodiphenyltrichloroethane (DDT) was originally used as an insecticide during World War II (1939-1945) by the Allied forces (Beard, 2006; Mischke et al., 1985). DDT use expanded commercially in 1945 and was used extensively as a very efficient insecticide, protecting millions of people from malaria, typhus, and starvation (Beard, 2006; Conis, 2010; Mischke et al., 1985). However, negative impacts on wildlife in the environment were discovered, such as increased risk of disease, decreased reproduction rates, increased abnormalities, and nervous system disruption were discovered (Jensen and Jansson, 1976; Vos et al., 2000). Negative impacts were also found among humans, including nervous and reproductive system disruptions, lung damage, decreased efficiency of the immune and endocrine system, birth defects and cancer (Mansour, 2009; Thuy, 2015). When human and environment health implications became evident, the use of DDT was banned or heavily restricted in most developed countries in the 1970s, including the United States (Beard, 2006; UNEP, 2003). However, DDT is still used today in Asian and African countries for malaria control (Stemmler and Lammel, 2009). Although other insecticides were produced, DDT was the most abundantly used. It is estimated that 1.5 million metric tons of DDT was used for agricultural purposes from the 1940s to the 1970s (Beard, 2006; UNEP, 2003). Technical DDT, the most common form of DDT for agriculture purposes, is not pure and contains multiple metabolites (Aguilar, 1984; Walker, 1975). p,p'-DDT is the primary metabolite comprising 75-80% of all DDT, while the remaining 20-25% is o,p'-DDT (Aguilar, 1984; Li and Macdonald, 2005; Walker, 1975). Once in the environment and organisms, DDT is metabolically degraded into dichlorodiphenyldichloroethylene (p,p'-DDE or o,p'-DDE) and dichlorodiphenyldichloroethane (p,p'-DDD or o,p'-DDD) (Aguilar, 1984; Li and Macdonald, 2005; Ramesh et al., 1989). Both DDE and DDD carry the same characteristics as DDT as being difficult to degrade and being persistence in both the environment and organisms. DDT and its metabolites are believed to accumulate in the world's oceans and sediment today with a 2-15 year half-life in soil and a 150 year half-life in the marine environment (Callahan et al., 1979).

1.1.3. Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs) are a group of anthropogenic chemicals that are oily liquids or solids and are resistant to degradation under extreme temperatures and pressures. They were widely used in electrical equipment like capacitors and transformers in addition to hydraulic fluids, heat transfer fluids, lubricants, plasticizers, and as components of surface coatings and inks (Nisbet and Sarofim, 1972; NOAA, 2009). The use of PCBs began in 1929 and they were used extensively until being phased out in the late 1970s by developed countries due to their negative health impacts (Longnecker et al., 1997; NOAA, 2009; Wassermann et al., 1979). PCBs have similar effects on wildlife and humans to that of DDT including the development of cancer, decreased immune and reproductive system function, abnormal liver and thyroid function, and impaired neurological development (Longnecker et al., 1997). There are 209 unique PCB isomers that differ in the number of chlorine atoms and chemical configuration. Due to their unique chemical configuration each PCB isomer has distinctive properties, environmental pathways, and toxicity impacts. Their stability and persistent characteristics increase with increasing number of chlorine atoms in the molecule (Wolska et al., 2012). It is estimated that 1.3 million tons of PCBs were produced globally between 1930 and 1993 (Breivik et al., 2007, Lammel and Stemmler, 2012). Although the Environmental Protection Agency (EPA) banned the manufacturing of PCBs in 1979 in the United States, the residue levels in the environment and in marine organisms are still high enough to produce toxic effects. Some isomers have a half-life up to 70 years (Longenecker et al., 1997; Matthews and Dedrick, 1984; Wassermann et al., 1979). PCBs enter the environment and, ultimately, the oceans through waste, discharge and leaks, river runoff, atmospheric emissions, volatilization of previously deposited PCBs, and petroleum product combustion (Breivik et al., 2002; Jeremiason et al., 1994; Lohmann et al., 2000; Wolska et al., 2012). PCBs are highly toxic and the monitoring of them and their concentrations are crucial for environmental and human health (Longnecker et al., 1997; Wolska et al., 2012).

1.1.4. Heptachlors and Metabolites

Heptachlor is an insecticide that was first used in the United States in 1953 (Rosemund et al., 2007). Heptachlor was used both commercially in buildings and on crops as well as domestically. (Bidleman et al., 1998; Fendick et al., 1990). In the 1970s the United States used

16 kilatons of heptachlor (Bidleman et al., 1998; Fendick et al., 1990). Heptachlor was also released in the environment through chlordane production, another individually produced POP insecticide; approximately 10% of chlordane is heptachlor (Rosemund et al., 2007). In 1988 the use of heptachlor was banned and was only permitted for the controlled use of exterminating fire ants in transformers (Bidleman et al., 1998). Heptachlor and heptachlor epoxide have negative impacts on the central nervous system, reproductive system in both humans and wildlife and is listed as a possible carcinogen for humans (EPA, 2006; Kielhorn et al., 2006). Heptachlor epoxide is an environmental byproduct formed by the oxidation of the insecticide heptachlor (Kerkhoff et al., 1980; Matsumura, 1975). Approximately 20% of heptachlor that enters the environment is oxidized to heptachlor epoxide within hours of input (Rosemund et al., 2007). Both heptachlor and heptachlor epoxide dissolve in water and bind very strongly to soil (Rosemund et al., 2007, Wurl and Obbard, 2005). Heptachlor epoxide is more readily dissolved in water, has a longer residence time in the environment and has more harmful effects than heptachlor (Rosemund et al., 2007). Heptachlor can enter into the environment via groundwater, river runoff, waste dumping, and air transport (Rosemund et al., 2007).

1.1.5. Aldrins and Metabolites

Aldrin was first produced in 1948 for insecticidal purposes primarily in soil and plant root application (Ayres et al., 1988; Jorgenson, 2001; Zitko, 2003). Dieldrin was first produced soon after as a result in attempting to make aldrin less volatile (Zitko, 2003). Due to dieldrin's lower volatility it was primarily used on crops and foliage in addition to soil and root application (Zitko, 2003). Although the chemical properties of dieldrin allowed it to be more versatile those same properties made it much more resistant to degradation than aldrin (Jorgenson, 2001). Furthermore, when released into the environment aldrin readily breaks down into dieldrin with at least 56% of aldrin transforming into dieldrin (Ayres et al., 1988; Jorgenson, 2001). In 1971 the United States limited aldrin and dieldrin use to controlled termite, moth, and plant dipping purposes only, until all use was ceased in 1986 (Zitko, 2003). Both aldrin and dieldrin accumulate in wildlife; once in an organism aldrin rapidly breaks down into dieldrin (Zitko, 2003). Since production has stopped, greater concentrations of dieldrin have been observed in marine mammals and has been reported as having a greater biomagnification factor (Gui et al., 2014, Kannan et al., 1994). Bioaccumulation of endrin is not well reported, likely due to its rapid

biodegradation in organisms (Zitko, 2003). In the environment however, endrin has an estimated half-life of 4300 days (Zitko, 2003). Endrin was first produced in 1951 and was heavily used at low latitudes on cotton crops (Zitko, 2003). Aldrin, dieldrin, and endrin are all cyclodiene compounds consisting of a chlorinated methylene group (Zitko, 2003). These cyclodiene compounds are considered to be nerve poisons, having negative impacts on the nervous and reproductive system as well as carcinogenic properties (Anon, 1986; 1988; 1991; Ztiko, 2003). Endrin was not a pure compound and included amounts of aldrin and dieldrin (Zitko, 2003). Endrin is much more toxic than aldrin and dieldrin which prompted its use to be voluntarily canceled in the United States in 1986 (Zitko, 2003). Aldrin, dieldrin, and endrin are all hydrophobic, but do readily bind to sediments (Jorgenson, 2001). Similarily to the other POP groups, aldrin, dieldrin, and endrin enter the environment through, ground water, river runoff, and atmospheric transport (Jorgenson, 2001; USGS, 1999; Wania and Mackay, 1993).

1.2. Pathways and Environmental Accumulation of POPs

Organochlorine compounds can enter the environment through atmospheric transport, dumping, and runoff. Once in the environment, atmospheric transport is the primary means of movement from POP introduction areas (Aguilar, 1984; Jantunen and Bidleman, 1996; Stemmler and Lammel, 2009). The relative high vapor pressure of these organic contaminants makes them highly volatile at warm, low latitudes causing them to shift into their gas phase and enter the atmosphere (Addison and Ross, 2000; Iwata et al., 1993; Jantunen and Bidleman, 1996; Simonich and Hites, 1995; Takeoka et al., 1991). Once in the atmosphere these organochlorine compounds are transported globally via atmospheric currents and remain there until reaching cooler, higher latitudes where they condense and deposit into the marine and terrestrial environment (Addison and Ross, 2000; Iwata et al., 1993; Jantunen and Bidleman, 1996; Simonich and Hites, 1995; Takeoka et al., 1991). This process of worldwide transport via atmospheric currents is known as global distillation (Simonich and Hites, 1995). Although all organochlorine compounds have similar chemical properties variability occurs among the different POP groups leading to slight differences in movement, persistence, and accumulation throughout ecosystems. For example, HCHs have some of the highest vapor pressures and thus it is predicted that over 90% of HCHs present globally will be transported into the marine environment from the atmosphere via air-water exchange (Jantunen and Bidleman, 1996;

Simonich and Hites, 1995; Strand and Hov, 1994). In comparison, it is estimated that approximately 80% of PCBs present globally will settle in the marine environment primarily through air-water exchange, but not solely (Tanabe, 1988). DDTs have the highest vapor pressure compared to HCHs and PCBs and are thus less volatile and are not readily distilled to colder, higher latitudes (Simonich and Hites, 1995). DDT is so persistent that it has been predicted to continue to circulate in the environment via atmospheric and oceanic currents for decades (Beard, 2006; Li and Macdonald, 2005; Macdonald et al., 2000). Once DDT is deposited into the environment, it can be degraded into its metabolite DDE which is several times more volatile than DDT and is more easily transferred to the marine environment (Aguilar, 1984). Although most of the persistent organic compounds used occurred in the low- to mid - latitude regions, high latitudes have become a sink or a location of POP accumulation because of the efficiency of atmospheric currents (Jantunen and Bidleman, 1996; Lammel and Stemmler, 2012; Li and Macdonald, 2005; Stemmler and Lammel, 2009). Organochlorine contaminant concentrations distribution northward from site of original deposition has been observed for DDTs, PCBs, and HCHs (Lammel and Stemmler, 2012; Li and Macdonald, 2005; Stemmler and Lammel, 2009). Once organic contaminants are deposited into the world's oceans because they typically have low water solubility they primarily bind to particulate organic matter and sediments and become sequestered in the benthos, or become assimilated in marine organisms (Hoffman et al., 2002).

1.3. POP Accumulation in Marine Organisms

These legacy contaminants (POPs) are not only prevalent in the oceans and atmosphere worldwide, but they also can bioaccumulate in organisms (Hoekstra et al., 2002; Thomann, 1989). Bioaccumulation is the process in which contaminants collect and build up in an individual organism. POPs are highly lipophilic and resistant to biodegradation processes causing them to biomagnify in ecosystems (Fisk et al., 2001; Thomann, 1989). Biomagnification is the process in which contaminants are transferred from one trophic level to the next via ingestion, thus having an intensifying effect in higher trophic levels as those organisms ingest prey contaminated with POPs. Organic contaminant concentrations have been recorded in all trophic levels with apex predators typically having the highest concentrations (Corsolini and Sara

2017, Fisk et al., 2001, Hoekstra et al., 2003). Organochlorine compounds primarily enter the aquatic food web through the absorption and uptake by phytoplankton and particulate organic matter. The phytoplankton are then consumed by zooplankton and these POPs accumulate in the next level of the trophic web; this process repeats for all subsequent predator-prey interactions moving throughout the food web (Corsolini and Sara, 2017).

Holden (1972) was the first to monitor POP levels in marine mammals because of their long-life span and high trophic position. These predators are integrators of environmental contaminants throughout the food web rather than point source contaminants (Aguilar, 1984; Holden, 1972). Marine mammals are frequently used to monitor organic contaminant concentrations to monitor ecosystem health and individual health because of the increased health risks due to contaminant biomagnification (Aguilar et al., 2002; Ross et al., 2000). Organic contaminants have been found in odontocetes including toothed whales and dolphins, seals, fur seals, sea lions, and baleen whales (Addison and Ross, 2000; Bolton et al., 2020; Hall et al., 2008; Hoguet et al., 2013; Reiner et al., 2015). POP concentrations in odontocetes, like killer whales (*Orcinus orca*), have been observed near or above toxic levels (Krahn et al., 2007). The high trophic position of odontocetes amplifys the biomagnification impact, increasing POP concentrations that accumulate in their tissues. Comparatively, baleen whales have lower organic contaminant concentrations than their odontocete relatives due to their lower trophic position (Bolton et al., 2020; Hoekstra et al., 2002; Winfield et al., 2020). However, these filter feeders can act as bioconcentrators as they eat abundant amounts of small fauna during their long lives (Beard, 2006).

1.4. Baleen Whales

Fourteen known species of Mysticete whales are divided among four taxonomic families: *Balaenopteridae*, *Balaenidae*, *Neobalaenidae*, and *Eschrichtiidae*. Baleen whales are found in all the world's oceans and are known for their large-scale movements. Most species have consistent migratory patterns where they breed at warmer, low latitudes during winter months, and feed at colder, more productive, high latitudes during summer months. Instead of teeth, mysticetes have baleen plates which allow them to filter small prey from the water column or sediment (Slijper, 1962). Among the four families three different foraging styles exist: lunge, skim, and suction feeding. *Balaenopteridae* forage via lunge feeding; *Balaenidae* and *Neobalaenidae* forage via

skim feeding; and *Eschrichtiidae* forage via suction feeding. Balaenopterid whales have comparatively slender body morphology allowing them to feed vertically in the water column lunging into large aggregations of prey (Goldbogen et al., 2007; Pivorunas, 1977). Balaenid whales have a more robust body morphology with fine baleen allowing them to swim horizontally, mouth continuously open, through the water column to capture some of the smallest invertebrate prey (Werth 2001). Lastly, eschrichtids dive down to the benthos, depress their tongue creating a vacuum to pull prey into their mouth. They also have very coarse baleen that withstands the harsh abrasion from contact with the benthic sediment (Nemoto, 1970; Ray and Schevill, 1974). Baleen whales express adaptive foraging which can be observed in their varying foraging styles, morphology, and baleen structure.

1.4.1. Baleen

Baleen plates are a unique anatomical adaptation only found in mysticete whales. Baleen is comprised of hard α-keratins and continuously grows from the dermis (gingiva) of the maxilla (Fig. 1) (Slijper, 1962; Werth, 2013). The base of the baleen plate attached to the upper jaw, is the location of newest growth. The keratinous structure of baleen is similar to that in hair, fur, claws, vibrissae, and hooves (Fraser et al., 1972; Werth, 2013). Each baleen plate consists of bristles that are cemented together by a keratinous connective tissue (Fig. 1). Functionally, when feeding, baleen plates allow water to exit the mouth but prevent their prey from doing so. The baleen fibers weaken and break as the connective tissue forming the keratinous mat are worn due to friction from water, prey, sediment, and the motion of their tongue along the interior edge of the plates (Werth, 2001). The wear is counteracted by the continuous growth which allows the baleen plates to maintain a near constant length (Lubetkin et al., 2008; Werth, 2013). The tip of the baleen plate, represents the location of oldest baleen growth (Fig. 1). The composition of baleen plates is similar among mysticetes; however, each species has other unique characteristics like the plate abundance, length, growth rate, and fiber diameter; the diameter of the keratinous fibers dictate the prey size and foraging style, with a smaller fringe diameter trapping smaller prey which maximizes their foraging efficiency (Table 2) (Werth, 2001).

1.4.2. Gray Whales

The gray whale (*Eschrichtius robustus*) is in the suborder Mysticeti and is the only member in the Eschrichtiidae family. Two gray whale populations, both migratory, inhabit the North Pacific Ocean, the western (Korean-Okhotsk) and the eastern (California-Chukchi) populations (Fig 3) (Weller et al., 2002). The eastern gray whales spend the winter months off the coast of Baja California, Mexico where the warmer waters serve as their breeding and calving grounds. Beginning in February and lasting through May, they migrate northward along the California, Oregon, and Washington coasts, and spend their summers foraging as far north as the Bering and Chukchi seas and as far south as coastal Oregon (Fig. 1). Their southward migration occurs during December and January (Pike, 1962).

Gray whales were put under protection from commercial whaling in the 1930s (Reeves, 1984; Swartz et al., 2006). Since being protected the eastern population has recovered at an average annual rate of 1.9% to a population size of approximately 20,000 individuals (Rugh et al., 2005; Swartz et al., 2006). The eastern gray whale population is considered stable according to the International Union for Conservation of Nature (IUCN) Red List; however, threats to their population still exist, primarily in the form of fishing and harvesting of aquatic resources and pollution (Cooke, 2018). Gray whales weigh up to 45 metric tons and reach lengths up to 15 m. Among mysticetes, they are the only benthic feeder, giving them unique characteristics to support their benthic foraging style (Nemoto, 1970; Rice, 1998). Gray whales can have 130-180 baleen plates reaching lengths up to 263 mm (Young et al., 2015). Gray whales have the coarsest baleen fibers of all the mysticetes with a fringe diameter typically ranging from 0.6-1.1 mm (Kawamura, 1980; Nemoto, 1959; Young et al., 2015). This is likely due to the larger prey size and harsh conditions to which they subject their plates. Gray whales are suction foragers. When they feed, they dive down to the benthos on the continental shelf, approach at an angle and turn to one side, normally their right (Kasuya and Rice, 1970). They position themselves directly above the substrate, open their mouth and depress their tongue, creating a vacuum to suck in water, sediment and prey, mainly located in the upper 2 cm of the sediment (Nemoto, 1970; Ray and Schevill, 1974). They then close their mouth and push their tongue to the roof of their mouth. The water and fine-grained sediment are forced out through their coarse baleen plates and larger prey become trapped in the baleen fringe (Ray and Schevill, 1974). Although foraging along the benthos is the gray whales' primary feeding strategy, they also can feed via skimming style like the bowhead whales and engulfing. This gives gray whales perhaps the greatest range

Fig. 1. A. Fin whale baleen plate, cleaned, dried and ready for sampling. B. The same fin whale baleen plate post-sampling at 1 cm intervals.

Table 2

Individual baleen whale images and data including, sample ID, baleen plate length, number of sample intervals, species, sex, age class, foraging style, stranding date, and stranding location. Any information that was unknown is signified with a U.

Baleen Images	Sample ID	Baleen Plate Length (cm)	# of Sample Intervals	Species	Sex	Age Class	Foraging Style	Stranding Date	Stranding Location
	G1	47.0	23	*Eschrichtius robustus* (gray)	M	Adult	Benthic	July 2019	Puget Sound, WA
	G2	48.0	31	*Eschrichtius robustus* (gray)	M	Juvenile/ Subadult	Benthic	June 2019	Wrangell, AK
	H1	32.0	14	*Megaptera novaeangliae* (humpback)	U	U	Lunge	2017	AK

	H2	36.1	19	*Megaptera novaeangliae* (humpback)	U	U	Lunge	2016	AK
	M1	29.5	8	*Balaenoptera acutorostrata* (minke)	F	Adult	Lunge	June 2021	Gustavus, AK
	BL1	83.0	53	*Balaenoptera musculus* (blue)	U	U	Lunge	2017	U
	F1	68.5	10	*Balaenoptera physalus* (fin)	U	U	Lunge	2016	AK

of foraging techniques out of any of the mysticetes, thus giving them a wide range in prey types (Nemoto, 1970).

Gray whales are opportunistic foragers and have been observed feeding along their entire migratory route (Nerini, 1984). The coarseness of their baleen is reflective of their larger prey size, in addition to allowing sediment to exit through their baleen plates rather than being trapped and ingested. Benthic amphipods are the predominant prey type of gray whales comprising nearly 90% of their diet, with the species *Ampelisca macrocephala* dominant (Caraveo-Patiño and Hobson, 2007; Nerini, 1984; Zimushko and Lenskaya, 1970). The benthic amphipods are large bodied usually ranging in size 13-27 mm in length (Nerini, 1984). However, because gray whales are opportunistic foragers and their feeding style is not selective, the remaining prey are varied, including polychaetas, mysids, gastropods, bivalves, euphausiids, decapods, and small fin fish (Blokhin and Pavlyuchkov, 1988; Nerini, 1984; Pike, 1962; Rice and Wolman, 1971; Zimushko and Lenskaya, 1970).

1.4.3 Rorquals

The family Balaenopteridae, also known as the rorquals, is the largest group of baleen whales consisting of the blue, fin, sei, Bryde's, humpback, and minke whales. Rorquals are characterized by their streamlined body shape, highly extensible ventral groove blubber, and long, unfused mandibles comprising 25% of their body length (Goldbogen, 2007; Nakamura et al., 2012; Orton and Brodie, 1987; Pivorunas, 1977). These characteristics allow rorquals to successfully forage utilizing their unique intermittent ram suspension feeding technique, better known today as lunge feeding (Goldbogen et al., 2007; Sanderson and Wassersug, 1993). Lunge feeding allows rorquals to engulf large quantities of water and prey at a time via a systematic series of steps (Goldbogen et al., 2007). When foraging, rorquals accelerate towards their prey, when close they open their large jaws so that the floor of their mouth is facing the oncoming flow of water. The pressure created from the water hitting their mouth expands the buccal cavity and the ventral groove blubber expands up to four times their resting size. The whale then closes their mouth around the large volume of water and prey in their mouth, containing more mass than their own body weight. As they close their mouth the water is expelled through the baleen plates while their prey remains (Goldbogen et al., 2007; Pivorunas, 1977).

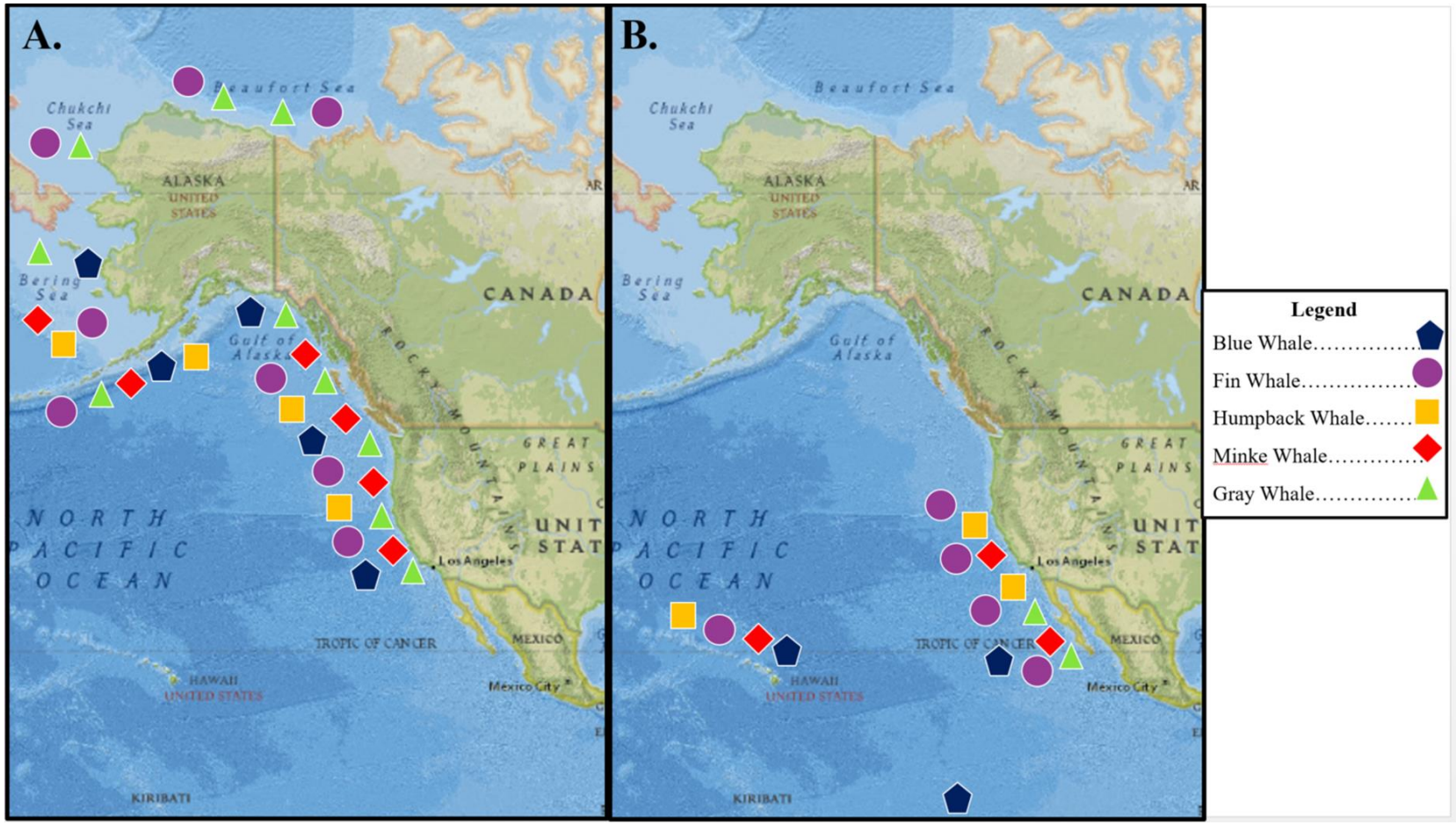


Fig. 2. A. Summer foraging grounds of the five species included in this study: blue, humpback, minke and gray whales. B. Winter breeding grounds of the five species included in this study: blue, humpback, minke and gray whales. Humpback and gray whales typically migrate between these locations in nearshore pelagic waters, while blue, and minke whales typically migrate between these locations in offshore neritic waters.

1.4.4. Blue Whales

The blue whale (*Balaenoptera musculus*) is the largest species in family Balaenopteridae Living up to 90 years, the blue whale is found globally, residing in all of the world's oceans (McDonald et al., 2009; Mizroch et al., 1984). The Society for Marine Mammalogy recognizes five subspecies of blue whales and nine stocks within these subspecies (NMFS, 2020a). Within US waters there are three recognized stocks: Central North Pacific, Eastern North Pacific, and Western North Atlantic. Blue whales in the central North Pacific stock forage in Alaskan waters in the summer and in the winter migrate offshore to lower latitudes within the western and central North Pacific Ocean (NOAA, 2018; Stafford, 2003; Watkins et al., 2000). Some individuals from this stock have been sighted off Hawaii's shoreline in the winter months, while individuals from the eastern North Pacific stock have been sighted here during the summer months (NOAA, 2018; Stafford et al., 2001). The eastern North Pacific stock predominantly feeds along the US west coast during the summer and fall months with their range overlapping with the central North Pacific stock feeding in Alaskan waters southward to southern California (NOAA 2020a, Stafford et al., 2001; Figure 1). However, the California coastline has been identified as the primary, crucial feeding habitat for the eastern North Pacific stock (Calambokidis et al., 2015; NOAA, 2020a) In the winter and spring months individuals from this stock migrate south off the coasts of Baja California, the Gulf of California, and on the Costa Rica Dome (NOAA, 2020a; Stafford et al., 1999). The movements of the western North Atlantic stock are not as well known. The blue whales in the western North Atlantic can be found north into the Arctic Ocean in the summer months but are primarily found feeding in the Gulf of St. Lawrence from spring to fall (NOAA, 2020b). In the winter this population migrates to at least the mid-latitude waters with some individuals having confirmed movements to western Greenland and southern Newfoundland (Mansfield, 1985; NOAA, 2020b; Sears and Larsen, 2002).

Commercial whaling had a large impact on the blue whale population, taking approximately 380,000 whales between the years of 1868 and 1978. The species has been listed as endangered under the Endangered Species Act since its creation in 1973. Today the population is estimated to include 5,000-15,000 mature individuals, which is 3-11% of the size of pre-commercial whaling population size (Cooke et al., 2018; NMFS, 2020a).

Unlike other rorquals, blue whales feed year-round at every location along their migratory route (Busquets-Vass et al., 2017). As the largest species in the world, the blue whale weighs up to 160 metric tons and reaches lengths of 30 m (Mackintosh, 1942; Mizroch et al., 1984). Blue whales have baleen plates up to 3 m in length with a growth rate of approximately 15.5±2.2 cm per year (Busquets-Vass, et al., 2017; Ruud, 1956). Despite their large size, blue whales lunge feed almost exclusively on the invertebrate krill, primarily consisting of two species: *Thysanoessa spinifera* and *Euphausia pacifica*, consuming up to 2 metric tons per day (Fiedler et al., 1998; Rice, 1978).

1.4.6. Humpback Whales

The humpback whale (*Megaptera novaeangliae*) is cosmopolitan, found in all of the world's oceans (Johnson and Wolman, 1984). Three stocks are recognized in the North Pacific Ocean- the California/Oregon/Washington and Mexico stock, the Central North Pacific stock, and the Western North Pacific stock. (Baker et al., 1990; Calambokidis et al., 1989; Muto et al., 2021). The California/Oregon/Washington and Mexico stock forage coastally from California north to British Columbia during the summer and fall months and migrate south to Mexico and parts of South America waters during the winter and spring months (Figure 1) (Calambokidis et al. 1989, 1993; Muto et al., 2021; Steiger et al., 1991. The Central North Pacific stock forage primarily in Alaskan waters during the summer and fall and migrate south to the Hawaiian Islands for the winter and spring (Baker et al., 1990; Calambokidis et al., 1997; Perry et al. 1990). Lastly, the Western North Pacific stock forage along Russia's coastline, occasionally venturing into the Bering Sea and waters around the Aleutian Islands during the summer and fall and then migrating south to Asia to spend the winter and spring months (Calambokidis et al., 1997; NOAA, 2021b).

The crucial feeding grounds of humpback whales are found in high productive waters near shore. Shore-based whaling depleted the North Pacific humpback populations, taking approximately 8,000 individuals from the US West Coast alone between 1919 and 1987 (Rice, 1978; Tonnessen and Johnsen, 1982). It is estimated that commercial whaling took more than 28,000 humpback whales during the 20th century (Muto et al., 2021). The North Pacific stocks are still considered to be endangered and depleted for management purposes while a Marine

Mammal Protection Act (MMPA) stock review is occurring now to determine population status (Muto et al., 2021)

Humpback whales are a medium sized rorqual whale reaching lengths up to 15.5 m and weighing up to 34 metric tons (Johnson and Wolman, 1984). They have a baleen growth rate ranging from 9 cm/yr up to 20 cm/yr (Lowe et al., 2021). Humpback whales are lunge feeders using their baleen to forage opportunistically, consuming multiple prey types including krill and small schooling fish like sardine, anchovy, sand lace and herring (Baker et al., 1985; Clapham et al., 1997; Fleming et al., 2016). Their primary prey source is dependent on prey populations, which vary based on time of year and location. These predators will have periods of time in which they are heavily reliant on a specific species for sustenance (Clapham et al., 1997; Fleming et al., 2016).

1.4.7. Minke Whales

The minke whale (*Balaenoptera acutorostrata*) is the second smallest baleen whale in the world (Rice, 1998; Quintela et al., 2014). The minke whale is cosmopolitan, with a worldwide distribution found in temperate, tropical, and high latitude waters. In addition to their wide latitudinal range, minke whales are also widely distributed within ocean basins being found along the continental shelf as well as offshore (Leatherwood et al., 1982). There are two subspecies of minke whales recognized: *Balaenoptera acutorostrata acutorostrata* found in the North Atlantic Ocean and *Balaenoptera acutorostrata scammoni* found in the North Pacific Ocean (Stewart and Leatherwood 1985).

In the North Pacific Ocean the movements of minke whales are not well known, but general trends have been observed via acoustic monitoring and stock assessment surveys (Clarke et al., 2013; Delarue et al., 2013). In the North Pacific Ocean there are two distinct stocks; the Alaska stock consists of migratory individuals who spend their summers on the foraging grounds around Alaska, migrating to lower latitudes via offshore waters (Figure 1) (Clarke et al., 2013; Delarue et al., 2013; Moore et al., 2000; Muto et al., 2020). The Alaska stock forage the Bering and Chukchi seas as well as in the inshore waters of the Gulf of Alaska (Fig 4) (Clarke et al., 2013; Delarue et al., 2013; Moore et al., 2000; Muto et al., 2020). The second stock recognized is called the California/Washington/Oregon stock and it consists of residential minke whales in the North Pacific Ocean that do not migrate, but rather live year-round in the coastal waters of these

states (Fig 4) (Dorsey et al., 1990). Minke whales have been targeted by commercial whaling since the 1930s and are still hunted today by Japan, Greenland, and Norway for both food and research (NOAA, 2021a). Despite still being targeted today, the minke whale population is considered stable and the most numerous species of rorqual in the world oceans (NOAA, 2021a).

Compared to their large relatives, minke whales are much smaller reaching lengths of 11 m and weighing up to 10 metric tons. Minke whales are more agile forager than their much larger relatives, due to decreased drag when opening their mouth for feeding (Goldbogen et al., 2007; Murase et al., 2007; Nakamura et al., 2012). Minke whales range from having 230-295 baleen plates (Rice, 2009; Young et al., 2015). The baleen plates of minke whales are relatively short, reaching lengths of 0.2 m (Mitani et al., 2006). The baleen plates of minke whales have an approximate growth rate of 129 mm per year (Table 2) (Mitani et al., 2006) Using the baleen growth rate and plate length it has been determined that one minke whale baleen plate can provide up to 1.4 years of continuous data (Mitani et al., 2006). Minke whales primarily feed on pelagic crustaceans and small, schooling fish like juvenile pollock, herring, and capelin (Tomilin, 1967; Zerbini et al., 2016). Small fish ranging from 11.8-17.5 cm make up the majority of their diet with the predominant species varying among location and time of year (Frost and Lowry, 1981; Zerbini et al., 2016).

1.5. Study Relevance and Objectives

It is of crucial importance to monitor POP concentrations in organisms due to the harmful effects they can cause like impairment of the immune system, endocrine disruption, and negative impacts on reproduction (Alonso Farré et al., 2010; Desforges et al., 2016; Hammond et al., 2005; Noel et al., 2017; Robinson et al., 2018). Biomagnifying effects can extend to indigenous peoples of the Eastern Arctic as baleen whales have high nutritional and cultural value to them. Bowhead and gray whales contain large amounts of fat and thereby constitute crucial dietary components; however, there is a risk of POP intake by indigenous individuals who use marine mammals as their main source of fat since these organic contaminants are readily stored in blubber (Chukmasov et al., 2019).

Previous studies have successfully quantified DDT, PCB, HCH, heptachlor, aldrin, and dieldrin concentrations in baleen whales including gray, blue, humpback, and minke whales (Elfes et al., 2010; Metcalfe et al., 2004; Trumble et al., 2013; Varanasi et al., 1994; Yasunaga

and Fujise, 2020). These studies have quantified these organochlorine compounds in blubber, muscle, liver, and earplug cerumen (Elfes et al., 2010; Metcalfe et al., 2004; Trumble et al., 2013; Varanasi et al., 1994; Yasunaga and Fujise, 2020). To our knowledge this study is the first to successfully extract and quantify organic contaminants from keratinous baleen plates. Baleen continuously grows from the maxilla of mysticetes. This continuous growth provides a continuous timeline of data with the base of the plate being the newest growth and the tip of the plate being the oldest growth (Fig. 1). Each baleen plate provides data back in time ranging from 1-4 years depending on species and plate length (Aguilar et al., 2014; Busquets-Vass et al., 2017; Lowe et al., 2021; Mitani et al., 2006). Baleen has been utilized before to observe stable isotope trends through time for these migratory species, as well as hormones and heavy metals (Hunt et al., 2014; Pomerleau et al., 2018; Schell et al., 1989; Shore et al., 2020). Baleen was analyzed for 21 different organic contaminants from five different classes to gain temporal and spatial aspects of POPs in mysticetes. These data are beneficial first steps in understanding how organic contaminants are assimilated in baleen, and how these concentrations change over time in individuals. This enables scientists to determine the effect foraging style, location, and diet has on POP burden in baleen whales; providing insight into the health and recovery of these bioindicator species and the overall health of the ecosystems they inhabit. In this study the baleen of gray, blue, humpback, and minke whales were analyzed representing both benthic and lunge foraging styles.

The objective of this study was to: (i) determine if organic contaminants were present and detectable in keratinous baleen plates of five different whale species, (ii) if organic contaminants concentrations could be quantified at 1 cm intervals along the length of the baleen plate, (iii) determine if organic contaminant concentrations vary with foraging style among baleen whales, (iv) determine if organic contaminant concentrations vary with habitat, and (v) to determine if organic contaminants show any temporal trend along the length of the baleen plate.

Table 3
Ranges of HCH, DDT, PCB, heptachlor, aldrin, and dieldrin concentrations (ng/g) in other tissues previously reported in five baleen whale species: gray, blue, fin, humpback, and minke. * indicates that the sample size was n=1, (avg) indicates the value listed is an average.

Species	Location	Tissue Type	POP type	POP Concentration Range (ng/g)	Year of Collection	Source
Gray Whale	Eastern North Pacific	Muscle	DDTs	121-875	2010-2011	Tsygankov et al., 2015
			DDT	ND-310		
			DDD	ND		
			DDE	121-565		
			ΣHCHs	84-3,693		
			α-HCH	70-1974		
			β-HCH	ND-676		
			γ-HCH	14-1043		
		Liver	ΣDDTs	71-4,924		
			DDT	ND-1552		
			DDD	ND-240		
			DDE	71-3132		
			ΣHCHs	464-11,075		
			α-HCH	72-6160		
			β-HCH	392-2754		
			γ-HCH	ND-2161		
Gray Whale	Alaska	Blubber	ΣPCBs	150-1200	1988-1991	Varanasi et al., 1994
			ΣDDTs	2-88		
			ΣDDEs	9-200		
			ΣDDDs	1-42		
			Dieldrin	4-59		
		Liver	ΣPCBs	79-880		
			ΣDDTs	ND-1		
			ΣDDEs	7-71		

			Dieldrin	3-34		
			ΣDDDs	1-22		
Gray Whale	California	Blubber	ΣPCBs	530-1100	1988-1991	Varanasi et al., 1994
			ΣDDTs	2-41		
			ΣDDEs	63-230		
			ΣDDDs	13-50		
			Dieldrin	17-85		
		Liver	ΣPCBs	140*		
			ΣDDTs	ND*		
			ΣDDEs	12*		
			ΣDDDs	3*		
			Dieldrin	5*		
Gray Whale	Washington	Blubber	ΣPCBs	300-4000	1988-1991	Varanasi et al., 1994
			ΣDDTs	ND-260		
			ΣDDEs	54-730		
			ΣDDDs	10-260		
			Dieldrin	7-1600		
		Liver	ΣPCBs	270-1600		
			ΣDDTs	ND-3		
			ΣDDEs	34-280		
			ΣDDDs	19-52		
			Dieldrin	30-95		
Blue Whale	Santa Barbara	Earplug Cerumen	ΣPCBs	5.9-30	2007	Trumble et al., 2013
			ΣDDTs	120-830		
	Gulf of California	Blubber	ΣPCBs	963-4,535	2010	Fossi et al., 2014
			ΣDDTs	334-3,350		
	Southern Chile	Blubber	ΣPCBs	2.97-975	2011-2013	Munoz-Amanz et al., 2019
			ΣDDTs	3.50-537		

Blue Whale	Gulf of St. Lawrence, Canada	Blubber	Heptachlor	1.0-2.1	1992-1999	Metcalfe et al., 2004
			Heptachlor Epoxide	24.2-216.1		
			Aldrin	0.4-0.8		
			Dieldrin	102.8-353.3		
			Endrin	3.3-12.7		
Fin Whale	Gulf of California	Blubber	ΣPCBs	672-1,745	2010	Fossi et al., 2014
			ΣDDTs	ND-5,087		
			ΣPCBs	245-1,466	2008	Fossi et al., 2010
			ΣDDTs	429-4,294		
Humpback Whale	Southern California	Blubber	ΣPCBs	280-2,800	2004	Elfes et al., 2010
			ΣDDTs	1,300-15,000		
			ΣHCHs	98-160		
	Northern California		ΣPCBs	47-370		
			ΣDDTs	330-1,400		
			ΣHCHs	98-160		
	Washington		ΣPCBs	140-1,200		
			ΣDDTs	390-3,100		
			ΣHCHs	44-89		
	Southeast Alaska		ΣPCBs	<LOQ-1,100		
			ΣDDTs	390-1,600		
			ΣHCHs	<LOQ-480		
	Northern Gulf of Alaska		ΣPCBs	5-570		
			ΣDDTs	27-870		
			ΣHCHs	24-480		
			ΣPCBs	43-1,100		
			ΣDDTs	56-2,200		

	Western Gulf of Alaska		ΣHCHs	190-780		
			ΣPCBs	<LOQ-510		
			ΣDDTs	95-740		
	Eastern Aleutian Islands		ΣHCHs	180-650		
			ΣPCBs	52-250		
	Bering Sea		ΣDDTs	47-300		
			ΣHCHs	65-280		
Humpback Whale	Gulf of St. Lawrence, Canada	Blubber	Heptachlor	ND	1992-1999	Metcalfe et al., 2004
			Heptachlor Epoxide	16.5-33.2		
			Aldrin	ND		
			Dieldrin	169.7-363.4		
			Endrin	ND-12		
Minke Whale	Western North Pacific	Blubber	ΣPCBs	1,400-8,900	2010-2011	Yasunaga and Fujise, 2020
			28	5.6 (avg)		
			52	100 (avg)		
			101	110 (avg)		
			153	640 (avg)		
			138	450 (avg)		
			180	140 (avg)		
			209	3.7 (avg)		
			ΣDDTs	800-5,800		
			p,p'-DDE	1600 (avg)		
			p,p'-DDD	330 (avg)		
			p,p'-DDT	99 (avg)		

Minke Whale	Western North Pacific	Liver	ΣHCHs	410-1,500	2006	Moon et al., 2010
			α-HCH	21 (avg)		
			β-HCH	650 (avg)		
			γ-HCH	7.9 (avg)		
			ΣPCBs	150-4,100		
			ΣDDTs	40-1,300		
		Blubber	ΣHCHs	65-430		
			ΣPCBs	390-6,200		
			ΣDDTs	270-11,000		
Minke Whale	North Atlantic	Blubber	ΣHCHs	40-2,100	1998	Hobbs et al., 2003
			Dieldrin	52-1480		
			Endrin	<1-135		

2. Materials and Methods

2.1. Baleen Sampling

All baleen plates were cleaned, prepped, and sampled in Dr. Stephen Trumble's Laboratory of Ecological and Adaptational Physiology at Baylor University. The baleen plates were stored at -80°C freezer before being cleaned and processed. The baleen was first submerged in a warm deionized water bath with dish detergent overnight to break down detritus and other large particulates on the plate. The gingiva was then stripped away to expose the base of the baleen plate. The plate was left to dry at room temperature for 2-3 days. Once completely dried the plate was wiped three times with 95% ethanol. Length "0" was located at the proximal base, or the attachment point to the upper jaw, the newest baleen growth and from there 1 cm measurements were marked along the midline of the plate to the tip. At each sampling point, baleen was ground into a powder using a Dremel rotary tool fitted with a tungsten carbide bit (Fig 2). The sample interval refers to an individual sample at a specific length (cm) along the baleen plate. Each baleen plate sampled was a different length and therefore each baleen plate had a different number of sample intervals (Fig 2; Table 2). All tools, surfaces, gloved hands, and the baleen plate were wiped with ethanol between each sampling bout to prevent cross-contamination.

2.2. Chemicals and Materials

PCB Standard Solution 7 containing PCB congeners 28, 52, 101, 138, 153, 180, and 209 was acquired from Sigma-Aldrich (Product number: 36989). Chlorinated Pesticides Mix analytical standard containing α-HCH, β-HCH, γ-HCH, heptachlor, Aldrin, heptachlor epoxide isomer B, 4,4'-DDE, 2,4'-DDD, dieldrin, endrin, 4,4'-DDD, 2,4'-DDT, and 4,4'-DDT was acquired from Sigma-Aldrich (Product number: 49151). 2,4'-DDE analytical standard was acquired from Sigma-Aldrich (Product number: 36663). Internal standard PCB 143 analytical standard was acquired from LGC Standards (Product number: DRE-C20014300). Second internal standard ε-HCH analytical standard was also acquired from LGC Standards (Product number: DRE-LA14075000CY). 6 mL SPE tubes packed with 1 g of acidified silica were acquired from Fischer Scientific (Catalog number: NC2036856). Granular anhydrous sodium sulfate was acquired from Sigma-Aldrich (Product number: 798592-500G). *n*-Hexane ≥97%

(Catalog Number: BDH24575.400) and Dichloromethane ≥99.9% (Catalog Number: MK487910) were acquired from VWR.

2.3. Sample Pretreatment

Organic contaminant extraction was performed for hexachlorocyclohexanes (HCHs): α-HCH, β-HCH, γ-HCH; dichlorodiphenyltrichloroethane (DDT) and metabolites: 2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 4,4'-DDD; other chlorinated pesticides: heptachlor, heptachlor epoxide isomer B, Aldrin, dieldrin, endrin; and 7 polychlorinated biphenyl (PCB) congeners: 28, 52, 101, 138, 153, 180, and 209 (Table 1).

Two POP extraction methods were explored to determine the most efficient methodology. The first method tested was by Covaci and Schepens (2001) which was successfully used extracting POPs from hair and fur (Behrooz et al., 2020; Jaspers et al., 2010). Approximately 200 mg of the cleaned, dried and powdered baleen samples from Baylor University were weighed and added to 5 mL of HCl and 5 mL of the *n*-hexane/dichloromethane (4:1) solvent mixture. 50 µL of PCB 143 and ε-HCH, internal spikes were added to the samples. Samples were placed incubated for 24 hours at 40°C in New Brunswick Scientific Excella E24 Incubator Shaker Series. This method was not chosen for baleen plate analysis because the percent recovery was low (9-26%).

A second technique was chosen for baleen plate POP analysis which is a modified method used by Liu et al., (2015). Approximately 200 mg of the cleaned, dried, and powdered baleen samples from Baylor University were weighed. Samples were placed in a ModBlock 70 mL polypropylene, hinged cap digestion tube (item number: 4370-010020) with 2 mL of hydrogen peroxide (H_2O_2) and 2 mL nitric acid (HNO_3) and spiked with 50 µL of PCB 143 and 50 µL ε-HCH internal standards. Samples were then placed on a ModBlock system set to 40°C and were allowed to digest overnight (12 hours). Once the digestion was complete samples were removed from the ModBlock, allowed to cool to room temperature, and diluted with 10 mL of saturated NaCl in 18.2 megohm deionized water.

Samples were then extracted within 24 hours of digestion with 10mL of n-hexane and shaken vigorously for 1 minute, periodically opening the lid to allow gas pressure to escape. Samples were then transferred to 150 mL separatory funnels and the layers were allowed to settle. The bottom solvent layer (water) was placed back in the original digestion tube, and the top *n*-hexane layer was transferred to a clean 600mL beaker. This process was repeated one more

time with an additional 10 mL of *n*-hexane. Next, two liquid-liquid extractions (LLE's) were conducted with 10 mL of dichloromethane. The same method was followed with the bottom layer being the dichloromethane layer which was kept and added to the sample in the 600 mL beaker and the top solvent layer (water) being placed back in the digestion tube.
Solid phase extraction (SPE) cartridges with 1 g of acidified silica were used in the final step to clean samples before GCMS analysis. 250 mg of anhydrous sodium sulfate was added to the SPE cartridges and were prewashed with 4 mL of *n*-hexane/dichloromethane (4:1) solvent mixture. The extracted sample in the 600 mL beaker was then cleaned on the SPE tubes and collected in a new, clean 600 mL beaker. A 4 mL *n*-hexane/dichloromethane (4:1) solvent mixture post wash was conducted on the SPE to full extraction. 2 mL of *n*-hexane/dichloromethane (4:1) solvent mixture was poured in the original sample beaker and swirled for 1 minute and was then poured in the SPE tube. This same process was repeated with an additional 2 mL of *n*-hexane/dichloromethane (4:1) solvent mixture. Once cleaned and collected the sample was evaporated to 1 mL; volume was measured using a 1 mL volumetric vial. If the sample was evaporated to less than 1 mL, *n*-hexane/dichloromethane (4:1) solvent mixture was added. Samples were then loaded into a 1.5 mL amber GCMS vial for analysis. Samples were either analyzed immediately after extraction or stored in a refrigerator at 40℃ until analysis could be completed. The percent recovery for PCB 143 and ε-HCH for all analyzed samples ranged from 14.4- 82.6% and 21.4- 130% respectively.

2.4. Instrumental Analysis

Samples were analyzed on a Shimadzu single quadrupole GCMS-QP2020 NX gas chromatograph-mass spectrometer (GC-MS) in electron ionization (EI) mode. Chromatographic separation was achieved with a 60 m x 0.25 mm i.d. x 0.25 µm film thickness Rxi- XLB fused silica capillary column (Restek Corporation, Bellefonte, CA). Common instrumental parameters for all injections were: ultra-high purity helium as the carrier gas (Airgas), 12.5 min solvent delay, and a MS mass range 35-600. GCMS settings for sample analysis are detailed in Table 4. A solvent wash was conducted between every sample to ensure there was no cross-contamination.

2.5. Statistical Analysis

Descriptive statistics for organic contaminant data, including range, mean, geometric mean, standard deviation, and interquartile range (IQR), were calculated using Microsoft Excel 2013 (15.0.5381.1000). All other statistical analysis was conducted using the statistical package R (v: 4.1.2). Where applicable the geometric mean was used for statistical analysis because it better represented our dataset due to the high variability in among the intervals in the data. For statistical purposes, any value that was not detected (ND) we used half of the limit of detections (LOD) which was a value of 0.000005 ng was used. Normality and homogeneity of data was checked before conducting t-tests using the Shapiro-Wilk test and Bartlett's test respectively. If data was not normal or homogenous it was transformed. If transformations did not meet parametric assumptions a two independent samples Mann-Whitney Wilcoxon test was conducted. Pearson's correlation matrices were used to determine if there were any contaminant correlations within individuals as well as among all contaminants. An independent two-sample t-test was used to observe if there were individual contaminant differences between habitat (neritic and pelagic) and foraging style (benthic and lunge) separately. Principal component analysis (PCA) was conducted to determine if there were any significant groupings of our data based on individual contaminants and sum groups of contaminants. It is important to note that when conducting t-tests the group sample sizes were: neritic (n=4), pelagic (n=2), benthic (n=2), lunge (n=4).

Table 4
GCMS procedures and settings used to analyze samples.

Sampler	
# of Rinses with Solvent (pre-run)	3
# of Rinses with Solvent (post-run)	3
# of Rinses with Sample	1
GC	
Column Temperature	(130.0℃, 0 min) (200.0℃, 10.0℃/min) (220.0℃, 2.00℃/min) (222.0℃, 0.25℃/min, 3 min hold) (243.0℃, 2.00℃/min) (245.0℃, 0.25℃/min, 3 min hold) (249.0℃, 0.25℃/min, 3 min hold) (257.0℃, 2.00℃/min, 3 min hold) (320.0℃, 30.0℃/min, 3 min hold)
Injection Temperature	250℃
Injection Mode	Splitless
Injection Volume	5 µL (sample), 1 µL (washes)
Pressure	65 kPa
Total Flow	22.8 mL/min
Column Flow	1.00 mL/min
Linear Velocity	36.8 cm/sec
Split Ratio	21.9
MS	
Ion Sources Temperature	250℃
Interface Temperature	260℃
Solvent Cut Time	12.5 min
Mass Range	50-600

3. Results and Discussion

3.1. Overview

Persistent organic pollutants are primarily assimilated into body tissues of marine mammals (i.e. blubber, muscle, liver, etc.) via prey consumption. Not only does prey type alter these resultant contaminant concentrations by its diet and foraging location, but tissue type can also affect the binding capacity of various organic contaminants (Aguilar, 1989; Elfes et al., 2010). This study demonstrates that (i) organochlorine compounds are present in the keratinous baleen plates; (ii) POPs are recorded chronologically in baleen plates and reveal episodic patterns along the baleen plate; (iii) POP burden is not significantly different between different foraging styles; and (iv) ΣHCH burden was the only significant difference observed between habitat.

3.2. POPs in Baleen Whales in the North Pacific Ocean

Organic contaminants have been recorded in the air, water, sediment, and organisms of the North Pacific Ocean (Barrie et al., 1992; Hargrave et al., 1988). All five organic contaminant classes analyzed in this study (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, ΣAldrins) have been previously observed in the blubber, muscle, liver, and earplug cerumen tissues of the North Pacific Ocean populations of the five species of baleen whales included in this study gray (G1, G2), humpback (H1, H2), minke, (M1), and blue (BL1) whales (Elfes et al., 2010; Fossi et al., 2014; Trumble et al., 2013; Tsygankov et al., 2015; Yasunaga and Fujise, 2020; Tables 2, 3).

The total contaminant load observed in a single baleen plate for each individual whale consists of the sums of the five organic contaminant classes: ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins at all sample intervals. Every baleen plate has a different number of sample intervals due to varying baleen plate lengths (Table 2). Organic contaminant class percent composition values of total contaminant load were calculated to compare the individuals' contaminant load, not specific locations or time. Total percent composition was also calculated at each sample interval for all individuals (Tables 6, 7, 8, 9, 10, 11). The rank order in contaminant class percent composition from greatest to least for all individuals in this study, except for M1 was: ΣPCBs > ΣHCHs > ΣAldrins > ΣDDTs > ΣHeptachlors (Table 5, Fig. 3). The only change in M1 showed ΣAldrins concentrations greater than ΣHCHs (ΣPCBs > ΣAldrins > ΣHCHs >

ΣDDTs > ΣHeptachlors) (Table 5, Fig. 3). The range of aldrin, dieldrin, and endrin (ΣAldrins) concentrations from previously reported studies show that minke whales have the greatest maximum values recorded among these five species which could explain why ΣAldrins had the second highest percent composition for individual M1 (Hobbs et al., 2003; Table 5).

3.2.1. ΣHCHs

HCHs are insecticides that are acutely toxic to mammals with exposure found to closely relate with various types of cancer, thyroid disruption, and reproductive system disruptions (Álvarez-Pedrerol, 2008; Ejaz et al., 2004; Kumar et al., 2013; Tomczak et al., 1981; Walker et al., 1999).The ΣHCHs contaminant group consists of the sums of: α-HCH, β-HCH, and γ-HCH. β-HCH contributed the most by accounting for 93.5%-98.0% (27.8-399 ng/g) of the total HCH contaminant load for all individuals (Table 12, Fig. 4). This trend was observed at most baleen intervals as well as for the total contaminant load of the entire baleen plate (Tables 12, 13, 14, 15, 16, 18, 18, Fig. 4). α-HCH accounted for 1.31%-6.55% (0.690-5.49 ng/g) and γ-HCH accounted for 0%-0.700% (ND-0.427 ng/g) for all whales (Table 12, Fig. 4).

A similar HCH percent composition trend was also observed in the blubber of baleen whales residing in the North Pacific Ocean with β-HCH accounting for 93.2%-98.4%, α-HCH accounting for 3.2%-4.7%, and γ-HCH accounting for 1.2%-2.2% (Yasunaga and Fujise, 2020). Once in the environment, γ-HCH has the fastest biodegradation rate, followed by α-HCH, and then β-HCH (Bachmann et al., 1988; Tu, 1976). This was also reflected in our data with β-HCH having the greatest percent composition followed by α-HCH, and then γ-HCH (Table 12, Fig. 4).

Considering all individuals, γ-HCH was only detected at 7 sample intervals (Tables 13, 14, 15, 16, 17, 18). This is most likely due to γ-HCH having the fastest biodegradation rate in the environment of all the HCH isomers (Bachmann et al., 1988; Tu, 1976). Furthermore, β-HCH has a Henry's Law Constant value that is a factor of 20 lower than α-HCH which makes β-HCH 20 times more likely to dissolve into the water than α-HCH (Li and Macdonald, 2005; Sahsuvar et al., 2003).

The individuals included in this study resided in the North Pacific Ocean basin which is characterized by higher concentrations of β-HCH due to HCH production continuing to occur in China and India (Vijden et al., 2011; Yasunaga and Fujise, 2020). In addition to living in an area with increased β-HCH concentrations, β-HCH also has a much longer half-life in marine

Table 5
Percentages of the five organic contaminant groups analyzed (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	ΣHCHs	ΣPCBs	ΣDDTs	ΣHeptachlors	ΣAldrins
G1	23.1%	62.9%	4.34%	0.606%	9.08%
G2	22.1%	46.8%	7.10%	2.57%	21.5%
H1	14.4%	77.7%	3.31%	0%	4.50%
H2	18.3%	62.9%	7.07%	0.088%	11.7%
M1	7.36%	75.4%	2.54%	0%	14.5%
BL1	33.1%	50.5%	4.16%	1.27%	11.0%

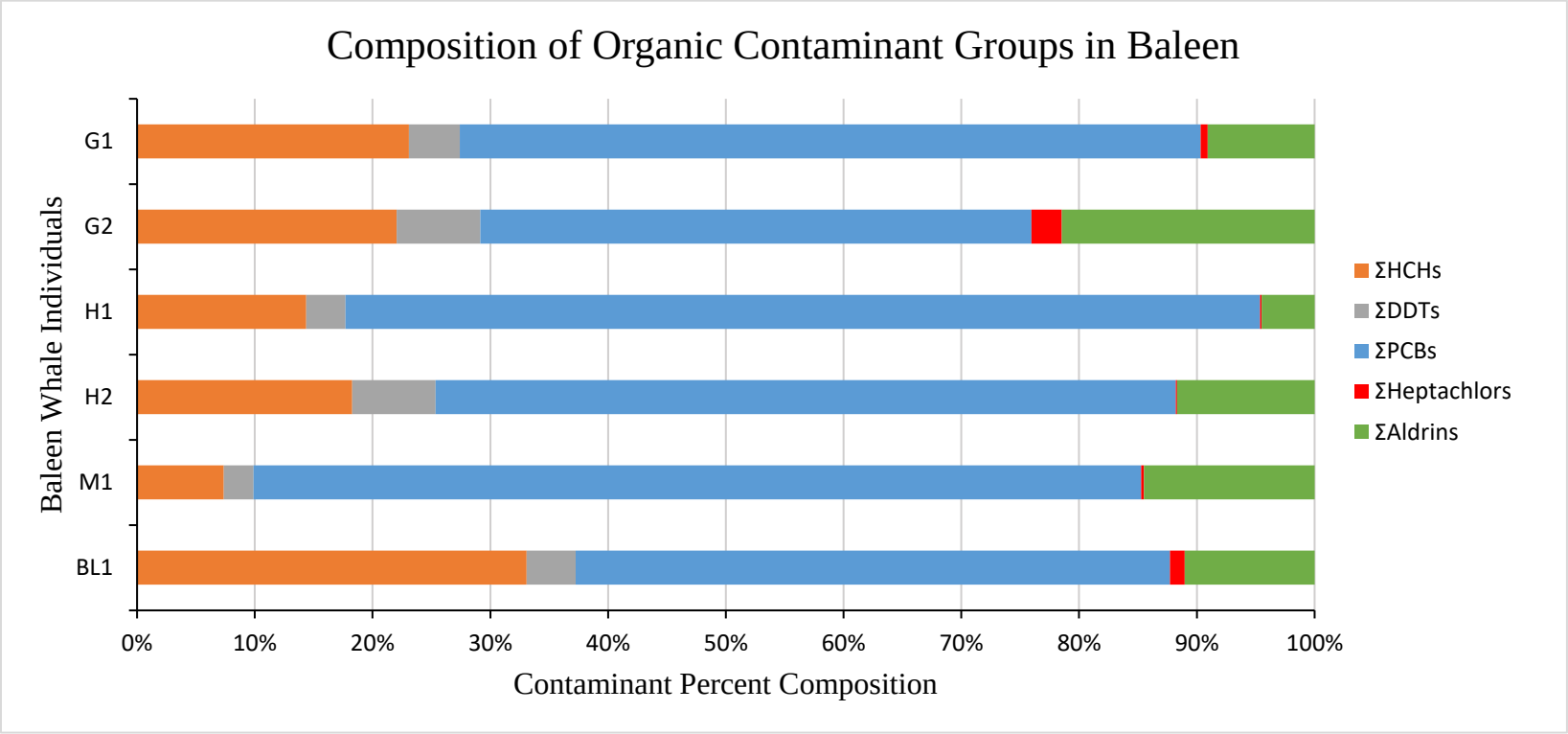


Fig. 3. Percent composition of the five organic contaminant groups analyzed (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 6
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for gray whale G1.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	ΣAll
0	ng/g %	0.517 1.99%	0.466 1.79%	23.0 88.3%	ND	2.08 7.97%	26.1
1	ng/g %	4.50 52.1%	0.473 5.47%	1.65 19.1%	ND	2.02 23.4%	8.65
2	ng/g %	2.16 55.3%	0.281 7.18%	0.498 12.7%	0.633 16.2%	0.335 8.56%	3.91
3	ng/g %	4.26 58.8%	0.521 7.18%	2.47 34.0%	ND	ND	7.25
4	ng/g %	5.09 56.0%	0.807 8.88%	2.43 26.7%	ND	0.761 8.38%	9.09
5	ng/g %	6.40 52.8%	1.46 12.0%	3.06 25.3%	ND	1.19 9.84%	12.1
6	ng/g %	3.35 52.2%	0.288 4.50%	2.78 43.3%	ND	ND	6.41
7	ng/g %	5.00 15.3%	0.774 2.37%	26.2 80.4%	0.113 0.347%	0.522 1.60%	32.6
8	ng/g %	4.58 12.9%	1.02 2.88%	28.2 79.7%	ND	1.60 4.51%	35.4
9	ng/g %	1.23 14.0%	0.386 4.38%	2.55 28.9%	ND	4.65 52.8%	8.81
10	ng/g %	1.38 17.8%	0.557 7.20%	4.71 60.9%	0.094 1.22%	0.991 12.8%	7.73
11	ng/g %	1.68 21.6%	1.42 18.2%	3.67 47.2%	1.01 13.0%	ND	7.78
13	ng/g %	2.49 32.4%	0.356 4.63%	4.84 63.0%	ND	ND	7.68

14	ng/g %	2.90 30.3%	0.505 5.26%	3.56 37.1%	0.081 0.846%	2.54 26.5%	9.59
15	ng/g %	3.09 47.4%	0.365 5.60%	1.61 24.6%	ND	1.46 22.4%	6.52
16	ng/g %	2.44 6.24%	0.462 1.18%	34.4 88.0%	ND	1.80 4.60%	39.1
17	ng/g %	4.94 38.9%	0.205 1.61%	6.00 47.2%	ND	1.56 12.3%	12.7
18	ng/g %	1.58 28.5%	0.449 8.09%	2.92 52.6%	ND	0.598 10.8%	5.54
19	ng/g %	4.62 33.5%	0.830 6.01%	7.99 57.9%	ND	0.364 2.63%	13.8
20	ng/g %	1.55 4.76%	0.194 0.595%	30.1 92.6%	ND	0.669 2.06%	32.5
21	ng/g %	6.36 40.1%	1.40 8.80%	3.46 21.8%	ND	4.66 29.4%	15.9
22	ng/g %	3.44 36.4%	0.604 6.39%	4.30 45.4%	ND	1.12 11.9%	9.46
Total:	ng/g %	73.6 23.1%	13.8 4.34%	200 62.9%	1.93 0.606%	28.9 9.08%	319

Table 7
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for gray whale G2.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	Total
0	ng/g %	4.29 34.8%	1.46 11.8%	3.09 25.0%	1.78 14.4%	1.73 14.0%	12.3
1	ng/g %	5.39 41.8%	1.05 8.12%	6.46 50.1%	ND	ND	12.9
2	ng/g %	3.10 10.5%	1.84 6.24%	23.2 78.4%	1.42 4.83%	ND	29.5
3	ng/g %	12.8 51.6%	1.87 7.54%	4.24 17.1%	0.391 1.58%	5.50 22.2%	24.8
4	ng/g %	ND	0.260 5.66%	3.08 67.1%	0.327 7.13%	0.923 20.1%	4.59
5	ng/g %	15.4 88.2%	1.14 6.54%	0.452 2.58%	0.470 2.69%	ND	17.5
6	ng/g %	7.31 59.8%	0.972 7.95%	1.95 16.0%	ND	1.99 16.3%	98.1
7	ng/g %	19.2 31.7%	2.32 3.84%	37.9 62.7%	0.688 1.14%	0.411 0.679%	60.5
8	ng/g %	3.19 7.35%	1.41 3.26%	36.1 83.2%	0.844 1.95%	1.86 4.28%	43.4
9	ng/g %	2.68 27.5%	0.651 6.69%	1.09 11.2%	ND	5.31 54.6%	9.73
10	ng/g %	1.63 27.8%	0.300 5.13%	2.03 34.7%	ND	1.89 32.3%	5.84
11	ng/g %	2.43 32.6%	0.632 8.46%	4.33 58.0%	0.077 1.03%	ND	7.46
12	ng/g %	3.08 35.6%	2.38 27.6%	0.325 3.76%	0.487 5.64%	2.37 27.4%	8.64

13	ng/g %	3.06 17.8%	2.10 12.2%	7.85 45.6%	ND	4.20 24.4%	17.2
14	ng/g %	3.25 6.30%	1.18 2.28%	ND	4.40 8.52%	42.8 82.9%	51.6
15	ng/g %	3.72 30.8%	0.383 3.17%	2.99 24.8%	1.15 9.50%	3.84 31.8%	12.1
16	ng/g %	8.19 23.6%	1.08 3.12%	22.3 64.3%	0.517 1.49%	2.58 7.45%	34.7
17	ng/g %	3.01 31.7%	0.676 7.13%	5.35 56.5%	ND	0.444 4.69%	9.48
18	ng/g %	3.38 34.2%	0.775 7.84%	4.26 43.1%	0.306 3.10%	1.16 11.8%	9.88
19	ng/g %	ND	0.612 12.0%	3.65 71.4%	ND	0.850 16.6%	5.11
20	ng/g %	2.80 19.8%	1.00 7.08%	4.62 32.6%	1.28 8.99%	4.48 31.6%	14.2
21	ng/g %	1.78 14.9%	1.21 10.1%	5.61 46.7%	0.223 1.86%	3.18 26.5%	12.0
22	ng/g %	4.55 9.31%	1.03 2.10%	8.29 17.0%	0.189 0.387%	34.8 71.2%	48.9
23	ng/g %	3.43 15.9%	9.92 46.1%	7.22 33.5%	0.678 3.15%	0.273 1.27%	21.5
24	ng/g %	1.32 14.1%	0.519 5.53%	4.48 47.7%	0.242 2.58%	2.82 30.1%	9.39
25	ng/g %	4.69 30.1%	0.502 3.23%	8.57 55.1%	ND	1.80 11.6%	15.6
26	ng/g %	3.25 38.2%	0.642 7.56%	4.60 54.2%	ND	ND	8.49
27	ng/g %	1.35 30.2%	0.923 20.7%	1.13 25.5%	0.788 17.7%	0.260 5.83%	4.45
28	ng/g %	4.38 16.8%	0.470 1.80%	18.7 71.5%	0.074 0.282%	2.53 9.66%	26.1

29	ng/g %	4.36 9.93%	4.71 10.7%	30.3 69.0%	0.143 0.325%	4.38 9.98%	43.9
30	ng/g %	4.23 9.13%	1.42 3.07%	35.6 76.7%	ND	5.14 11.1%	46.4
Total:	ng/g %	141 22.1%	45.5 7.10%	300 46.8%	16.5 2.57%	138 21.5%	726

Table 8
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for humpback whale H1.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	Total
(0-2)	ng/g %	0.154 1.49%	0.643 6.25%	8.13 78.9%	ND	1.37 13.3%	10.3
3	ng/g %	5.97 23.4%	1.12 4.39%	15.7 61.5%	0.231 0.905%	2.51 9.82%	25.5
4	ng/g %	3.41 42.6%	0.980 12.2%	2.60 32.5%	ND	1.02 12.7%	8.01
5	ng/g %	10.1 57.5%	0.360 2.05%	6.67 38.0%	ND	0.424 2.42%	17.6
6	ng/g %	1.68 11.2%	0.339 2.27%	12.0 80.7%	ND	0.870 5.82%	14.9
7	ng/g %	13.7 64.9%	1.29 6.12%	5.89 27.9%	ND	0.233 1.10%	21.1
8	ng/g %	2.09 4.27%	1.17 2.38%	43.9 89.4%	0.052 0.106%	1.89 3.84%	49.1
9	ng/g %	1.57 14.4%	1.39 12.7%	6.98 63.8%	ND	1.00 9.14%	10.9
10	ng/g %	3.69 26.0%	0.843 5.93%	8.75 61.6%	ND	0.921 6.49%	14.2
(11-12)	ng/g %	1.28 4.22%	1.33 4.39%	27.0 88.8%	0.051 0.167%	0.754 2.48%	30.4
(13-14)	ng/g %	1.39 18.2%	0.544 7.14%	3.79 49.7%	0.184 2.41%	1.71 22.5%	7.6
(15-16)	ng/g %	2.79 16.2%	0.625 3.63%	12.9 74.8%	ND	0.917 5.32%	17.2
(17-18)	ng/g %	1.97 3.08%	0.969 1.52%	59.1 92.6%	ND	1.77 2.77%	63.9

(19-20)	ng/g %	2.96 3.89%	0.533 0.701%	71.5 94.0%	ND	1.10 1.45%	76.1
Total:	ng/g %	52.7 14.4%	12.1 3.31%	154 77.7%	0.518 0.141%	13.6 4.50%	227

Table 9
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for humpback whale H2.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	Total
0	ng/g %	5.60 36.4%	1.74 11.3%	5.72 45.6%	ND	1.03 6.67%	14.1
1	ng/g %	5.59 33.9%	3.20 19.4%	4.05 32.3%	ND	2.36 14.3%	15.2
3	ng/g %	3.46 21.7%	2.21 13.8%	4.51 42.9%	ND	3.44 21.6%	13.6
4	ng/g %	4.21 33.3%	1.22 9.63%	6.15 48.7%	ND	1.06 8.39%	12.6
5	ng/g %	1.95 44.3%	0.745 16.9%	1.18 26.8%	ND	0.528 12.0%	4.40
6	ng/g %	3.16 5.94%	1.95 3.66%	43.3 83.6%	0.224 0.421%	3.42 6.42%	52.1
7	ng/g %	3.25 37.2%	0.370 4.23%	4.51 28.2%	ND	2.65 30.4%	78.9
8	ng/g %	5.62 71.5%	0.826 10.5%	0.535 6.80%	ND	0.883 11.2%	7.87
9	ng/g %	ND	0.068 1.51%	2.89 63.8%	ND	1.57 34.7%	4.53
10	ng/g %	2.99 20.4%	2.58 17.6%	8.06 54.9%	ND	1.06 7.20%	14.7
11	ng/g %	4.01 25.5%	0.986 6.28%	5.63 40.5%	ND	4.34 27.6%	15.0
12	ng/g %	2.64 31.2%	1.46 17.2%	ND	ND	4.38 51.6%	9.15
13	ng/g %	5.04 45.2%	1.58 14.2%	4.26 38.2%	ND	0.277 2.48%	11.1

14	ng/g %	7.62 41.1%	1.47 7.95%	4.48 32.4%	ND	3.44 18.6%	17.0
15	ng/g %	1.38 12.9%	0.384 3.57%	6.45 65.6%	0.070 0.649%	1.86 17.3%	10.2
(16-17)	ng/g %	0.730 6.03%	0.723 5.97%	8.62 87.7%	ND	0.036 0.301%	10.1
(18-19)	ng/g %	2.71 5.03%	1.21 2.25%	47.9 91.2%	ND	0.841 1.56%	52.7
(20-22)	ng/g %	1.05 2.14%	0.881 1.79%	42.0 84.2%	ND	5.85 11.9%	49.8
Total:	ng/g %	61.0 18.3%	23.6 7.07%	210 62.9%	0.294 0.088%	39.0 11.7%	393

Table 10
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for minke whale M1.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	Total
(0-1)	ng/g %	3.06 4.42%	1.09 1.57%	60.8 87.7%	0.389 0.562%	3.97 5.73%	69.3
2	ng/g %	2.41 14.5%	0.895 5.39%	10.6 63.6%	0.265 1.60%	2.48 14.9%	16.6
3	ng/g %	3.12 3.35%	0.718 0.772%	82.0 88.2%	ND	7.18 7.72%	93.0
4	ng/g %	5.02 31.0%	1.32 8.18%	1.49 9.22%	0.243 1.50%	8.11 50.1%	16.2
(5-6)	ng/g %	3.19 9.90%	1.87 5.79%	3.63 11.3%	ND	23.6 73.0%	32.3
(7-8)	ng/g %	2.07 3.28%	0.551 0.872%	59.4 93.8%	ND	1.28 2.02%	63.3
(9-10)	ng/g %	4.70 5.02%	1.15 1.23%	81.3 86.8%	ND	6.52 6.96%	93.7
(11-12)	ng/g %	6.17 31.1%	2.65 13.3%	5.52 27.8%	ND	5.52 27.8%	19.8
Totals:	ng/g %	29.7 7.36%	10.2 2.54%	305 75.4%	0.898 0.222%	58.6 14.5%	404

Table 11
Organic contaminant class (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) concentrations (ng/g), percent composition and total contaminant load (ΣAll) calculated at each sample interval for blue whale BL1.

Length (cm)		ΣHCHs	ΣDDTs	ΣPCBs	ΣHeptachlors	ΣAldrins	Total
0	ng/g %	8.32 47.1%	1.41 7.99%	5.30 30.0%	ND	2.64 14.9%	17.7
1	ng/g %	6.71 38.5%	0.673 3.86%	4.11 23.6%	ND	5.95 34.1%	87.9
2	ng/g %	8.12 70.5%	1.62 14.0%	0.555 4.81%	0.411 3.57%	0.823 7.14%	11.5
3	ng/g %	6.03 27.5%	1.20 5.46%	5.12 23.4%	ND	9.55 43.6%	21.9
4	ng/g %	16.8 85.3%	1.02 5.19%	ND	ND	1.87 9.50%	19.7
5	ng/g %	4.47 30.7%	1.07 7.37%	5.98 41.1%	ND	3.04 20.9%	14.6
6	ng/g %	5.84 43.4%	1.42 10.6%	2.84 21.1%	ND	3.36 25.0%	13.5
7	ng/g %	25.0 80.2%	2.14 6.87%	1.16 3.71%	0.335 1.07%	2.55 8.16%	31.2
8	ng/g %	15.7 67.0%	0.121 0.519%	5.36 22.9%	ND	2.25 9.62%	23.4
9	ng/g %	17.5 57.5%	0.218 0.714%	9.18 30.1%	ND	3.56 11.7%	89.2
10	ng/g %	28.5 71.1%	1.27 3.16%	6.97 17.4%	0.275 0.687%	3.06 7.62%	40.1
11	ng/g %	4.89 35.6%	0.364 2.65%	1.32 9.59%	ND	7.17 52.2%	13.7
12	ng/g %	16.8 19.8%	1.14 1.34%	65.2 76.7%	ND	1.87 2.20%	85.0

13	ng/g %	13.5 66.1%	0.868 4.24%	1.54 7.51%	ND	4.53 22.1%	20.5
14	ng/g %	24.2 77.4%	1.33 4.30%	4.82 15.4%	ND	0.886 2.84%	31.2
15	ng/g %	11.2 73.3%	0.844 5.53%	0.819 5.36%	0.526 3.44%	1.89 12.4%	15.3
16	ng/g %	5.26 35.2%	0.676 4.53%	9.00 60.3%	ND	ND	14.9
17	ng/g %	1.84 20.6%	0.452 5.05%	4.43 49.6%	ND	2.21 24.7%	8.94
18	ng/g %	0.019 0.174%	1.18 10.9%	4.84 44.6%	0.274 2.52%	4.55 41.9%	10.9
19	ng/g %	6.13 27.4%	1.15 5.12%	11.6 51.8%	2.70 12.0%	0.816 3.64%	22.4
20	ng/g %	2.89 27.4%	0.351 3.33%	5.50 52.1%	0.126 1.19%	1.69 16.0%	10.6
21	ng/g %	1.42 11.6%	1.68 13.7%	7.31 59.3%	1.24 10.1%	0.663 5.39%	12.3
22	ng/g %	14.0 64.4%	0.468 2.15%	5.74 26.4%	ND	1.54 7.09%	21.8
23	ng/g %	13.5 56.7%	0.842 3.55%	3.19 13.4%	ND	6.26 26.4%	23.8
24	ng/g %	7.03 29.3%	0.986 4.11%	14.3 59.8%	0.311 1.29%	1.32 5.52%	24.0
25	ng/g %	12.1 35.0%	0.418 1.21%	4.38 12.7%	0.773 2.24%	16.8 48.8%	34.5
26	ng/g %	5.07 39.1%	1.51 11.7%	4.45 34.3%	ND	1.72 13.2%	91.7
27	ng/g %	60.1 87.4%	1.93 2.81%	2.13 3.10%	ND	4.61 6.70%	68.8
28	ng/g %	ND	0.804 16.8%	1.02 21.3%	2.54 53.2%	0.411 8.61%	4.78

29	ng/g %	0.085 0.785%	1.32 12.1%	8.50 78.3%	ND	0.957 8.81%	10.9
30	ng/g %	5.75 9.45%	1.18 1.94%	48.9 80.4%	3.21 5.29%	1.78 2.92%	60.8
31	ng/g %	1.37 20.4%	0.074 1.11%	3.32 49.5%	ND	1.94 29.0%	6.71
32	ng/g %	2.65 5.41%	0.732 1.49%	45.1 92.0%	0.170 0.346%	0.366 0.747%	49.0
33	ng/g %	4.90 46.3%	0.610 5.77%	3.71 35.1%	ND	1.36 12.9%	10.6
34	ng/g %	0.482 1.15%	1.27 3.03%	39.2 93.7%	ND	0.882 2.11%	41.8
35	ng/g %	4.44 32.1%	0.291 2.11%	6.81 49.2%	ND	2.29 16.6%	13.8
36	ng/g %	0.627 5.77%	1.29 11.9%	7.42 68.3%	ND	1.53 14.1%	10.9
37	ng/g %	3.63 40.8%	0.995 11.2%	2.01 22.6%	0.223 2.51%	2.03 22.8%	8.88
38	ng/g %	3.20 29.7%	1.28 11.8%	3.63 33.7%	0.486 4.51%	2.17 20.2%	10.8
39	ng/g %	2.74 38.3%	0.781 10.9%	2.90 40.5%	ND	0.744 10.4%	7.17
40	ng/g %	3.87 41.0%	0.815 8.64%	2.49 26.4%	0.111 1.18%	2.14 22.8%	9.44
41	ng/g %	0.349 4.21%	0.771 9.30%	6.50 78.5%	ND	0.661 7.97%	8.28
42	ng/g %	3.18 5.32%	2.24 3.74%	53.4 89.5%	ND	0.887 1.49%	59.7
43	ng/g %	3.23 32.6%	1.10 11.1%	4.68 47.2%	ND	0.913 9.20%	9.92
44	ng/g %	3.69 37.0%	1.08 10.9%	3.88 38.9%	ND	1.33 13.3%	9.98

45	ng/g %	4.72 9.92%	0.604 1.27%	38.0 79.8%	0.279 0.597%	4.02 8.44%	47.6
46	ng/g %	2.92 6.20%	1.15 2.44%	41.7 88.5%	ND	1.36 2.88%	47.1
47	ng/g %	2.89 43.0%	0.382 5.68%	2.98 44.3%	ND	0.473 7.03%	6.73
48	ng/g %	0.036 0.092%	1.19 3.02%	34.2 87.2%	0.317 0.807%	3.48 8.88%	39.3
49	ng/g %	2.01 26.9%	0.948 12.7%	4.51 60.4%	ND	ND	7.46
50	ng/g %	1.33 22.4%	1.46 24.7%	2.60 43.8%	ND	0.536 9.04%	5.93
51	ng/g %	3.78 5.64%	ND	55.9 83.4%	1.10 1.64%	6.21 9.28%	67.0
52	ng/g %	2.30 59.1%	0.565 14.5%	1.03 26.4%	ND	ND	3.89
Total:	ng/g %	407 33.1%	51.3 4.16%	621 50.5%	15.4 1.27%	136 11.02%	1439

Table 12
Percentages of HCH isomers in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	α-HCH	β-HCH	γ-HCH
G1	3.97%	95.6%	0%
G2	3.89%	96.1%	0%
H1	1.31%	98.3%	0%
H2	3.91%	95.4%	0.70%
M1	6.55%	93.5%	0%
BL1	1.89%	98.0%	0%

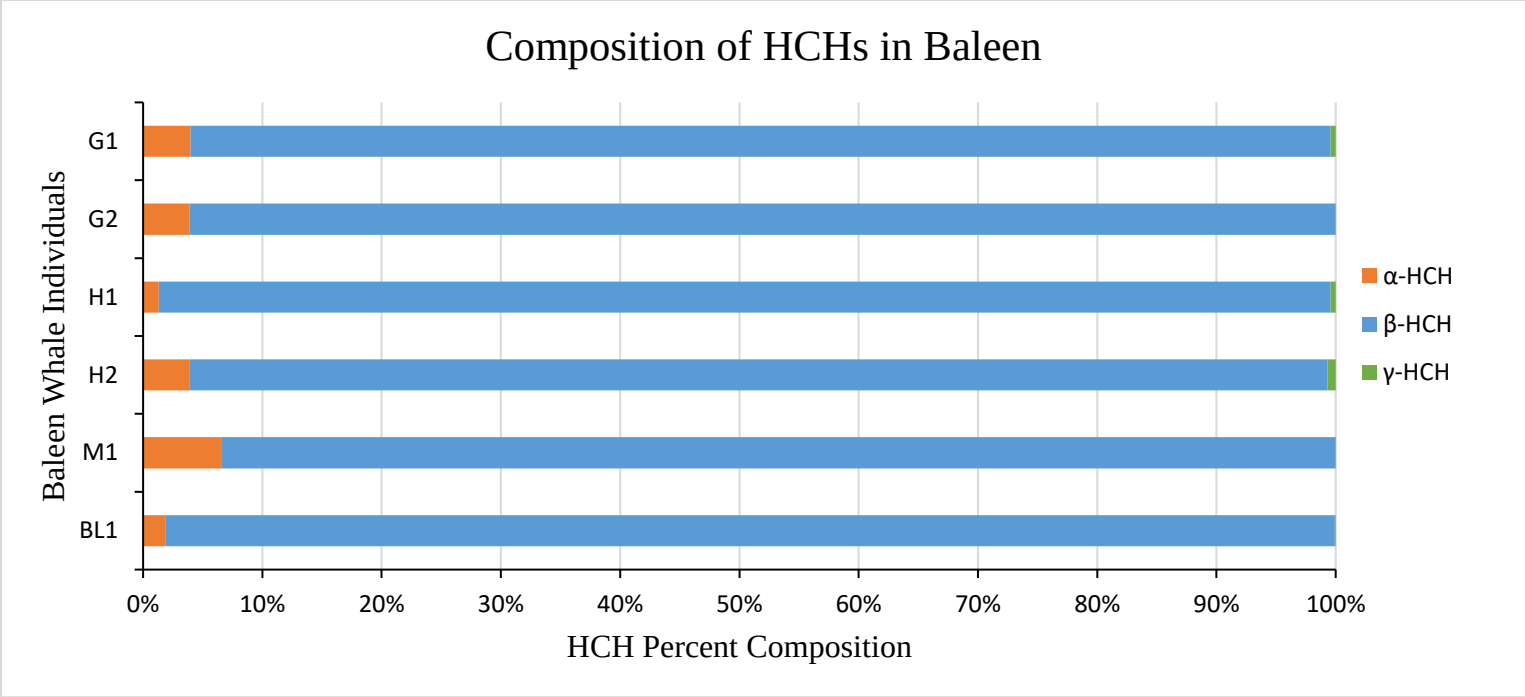


Fig. 4. Percent composition of ΣHCHs (α-HCH, β-HCH, and γ-HCH) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 13
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for gray whale G1. ND=not detected

Length (cm)		α-HCH	β-HCH	γ-HCH	ΣHCHs
0	ng/g %	ND	0.517 100%	ND	0.517
1	ng/g %	0.557 12.4%	3.95 87.6%	ND	4.50
2	ng/g %	ND	2.16 100%	ND	2.16
3	ng/g %	ND	4.26 100%	ND	4.26
4	ng/g %	ND	4.96 97.5%	0.128 2.52%	5.09
5	ng/g %	ND	6.40 100%	ND	6.40
6	ng/g %	ND	3.35 100%	ND	3.35
7	ng/g %	ND	5 100%	ND	5.00
8	ng/g %	ND	4.58 100%	ND	4.58
9	ng/g %	ND	1.23 100%	ND	1.23
10	ng/g %	ND	1.38 100%	ND	1.38
11	ng/g %	ND	1.68 100%	ND	1.68
13	ng/g %	0.378 15.2%	2.11 84.8%	ND	2.49
14	ng/g %	ND	2.90 100%	ND	2.90
15	ng/g %	1.20 38.9%	1.88 61.1%	ND	3.09
16	ng/g %	ND	2.44 100%	ND	2.44
17	ng/g %	ND	4.94 100%	ND	4.94
18	ng/g %	ND	1.58 100%	ND	1.58
19	ng/g %	ND	4.62 100%	ND	4.62

20	ng/g %	0.782 50.5%	0.573 37%	0.194 12.5%	1.55
21	ng/g %	ND	6.36 100%	ND	6.36
22	ng/g %	ND	3.44 100%	ND	3.44
Total:	ng/g %	2.92 3.97%	70.3 95.6%	0.322 0.44%	73.57 100%

Table 14
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for gray whale G2. ND=not detected

Length (cm)		α-HCH	β-HCH	γ-HCH	ΣHCHs
0	ng/g %	ND	4.29 100%	ND	4.29
1	ng/g %	2.42 44.9%	2.97 55.1%	ND	5.39
2	ng/g %	0.288 9.28%	2.81 90.7%	ND	3.10
3	ng/g %	ND	12.8 100%	ND	12.8
4	ng/g %	ND	ND	ND	ND
5	ng/g %	ND	15.4 100%	ND	15.4
6	ng/g %	ND	7.31 100%	ND	7.31
7	ng/g %	ND	19.2 100%	ND	19.2
8	ng/g %	ND	3.19 100%	ND	3.19
9	ng/g %	ND	2.68 100%	ND	2.68
10	ng/g %	ND	1.63 100%	ND	1.63
11	ng/g %	ND	2.43 100%	ND	2.43
12	ng/g %	0.538 17.5%	2.54 82.5%	ND	3.08
13	ng/g %	0.907 29.6%	2.16 70.4%	ND	3.06
14	ng/g %	0.423 13.0%	2.83 87.0%	ND	3.25
15	ng/g %	ND	3.72 100%	ND	3.72
16	ng/g %	ND	8.19 100%	ND	8.19
17	ng/g %	0.306 10.2%	2.70 89.8%	ND	3.01
18	ng/g %	ND	3.38 100%	ND	3.38
19	ng/g %	ND	ND	ND	ND

20	ng/g %	ND	2.80 100%	ND	2.80
21	ng/g %	ND	1.78 100%	ND	1.78
22	ng/g %	ND	4.55 100%	ND	4.55
23	ng/g %	ND	3.43 100%	ND	3.43
24	ng/g %	0.372 28.1%	0.952 71.9%	ND	1.32
25	ng/g %	ND	4.69 100%	ND	4.69
26	ng/g %	ND	3.25 100%	ND	3.25
27	ng/g %	ND	1.35 100%	ND	1.35
28	ng/g %	0.240 5.47%	4.14 94.5%	ND	4.38
29	ng/g %	ND	4.36 100%	ND	4.36
30	ng/g %	ND	4.23 100%	ND	4.23
Total:	ng/g %	5.49 3.89%	135.75 96.1%	ND	141.24 100%

Table 15
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for humpback whale H1. ND=not detected

Length (cm)		α-HCH	β-HCH	γ-HCH	ΣHCHs
(0-2)	ng/g %	ND	0.154 100%	ND	0.154
3	ng/g %	ND	5.97 100%	ND	5.97
4	ng/g %	ND	3.18 93.3%	0.23 6.74%	3.41
5	ng/g %	ND	10.1 100%	ND	10.1
6	ng/g %	0.27 16.1%	1.41 83.9%	ND	1.68
7	ng/g %	0.423 3.09%	13.3 96.9%	ND	13.7
8	ng/g %	ND	2.09 100%	ND	2.09
9	ng/g %	ND	1.57 100%	ND	1.57
10	ng/g %	ND	3.69 100%	ND	3.69
(11-12)	ng/g %	ND	1.28 100%	ND	1.28
(13-14)	ng/g %	ND	1.39 100%	ND	1.39
(15-16)	ng/g %	ND	2.79 100%	ND	2.79
(17-18)	ng/g %	ND	0.02	ND	1.97
(19-20)	ng/g %	ND	2.96 100%	ND	2.96
Total:	ng/g %	0.69 1.31%	51.8 98.3%	0.23 0.29%	52.7

Table 16
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for humpback whale H2. ND=not detected

Length (cm)		α-HCH	β-HCH	γ-HCH	ΣHCHs
0	ng/g %	0.243 4.34%	5.09 90.8%	0.27 4.82%	5.60
1	ng/g %	0.805 14.4%	4.79 85.6%	ND	5.59
3	ng/g %	ND	3.46 100%	ND	3.46
4	ng/g %	ND	4.06 96.3%	0.157 3.72%	4.21
5	ng/g %	ND	1.95 100%	ND	1.95
6	ng/g %	0.310 9.8%	2.85 90.2%	ND	3.16
7	ng/g %	ND	3.25 100%	ND	3.25
8	ng/g %	0.751 13.4%	4.87 86.6%	ND	5.62
9	ng/g %	ND	ND	ND	ND
10	ng/g %	ND	2.99 100%	ND	2.99
11	ng/g %	ND	4.01 100%	ND	4.01
12	ng/g %	ND	2.64 100%	ND	2.64
13	ng/g %	0.277 5.50%	4.76 94.5%	ND	5.04
14	ng/g %	ND	7.62 100%	ND	7.62
15	ng/g %	ND	1.38 100%	ND	1.38
(16-17)	ng/g %	ND	0.73 100%	ND	0.730
(18-19)	ng/g %	ND	2.71 100%	ND	2.71
(20-22)	ng/g %	ND	1.05 100%	ND	1.05
Total:	ng/g %	2.39 3.91%	58.2 95.4%	0.427 0.70%	61.03 100%

Table 17
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for minke whale M1. ND=not detected

Length (cm)		**α-HCH**	**β-HCH**	**γ-HCH**	**ΣHCHs**
(0-1)	ng/g %	ND	3.06 100%	ND	3.06
2	ng/g %	ND	2.41 100%	ND	2.41
3	ng/g %	ND	3.12 100%	ND	3.12
4	ng/g %	1.95 38.8%	3.07 61.2%	ND	5.02
(5-6)	ng/g %	ND	3.19 100%	ND	3.19
(7-8)	ng/g %	ND	2.07 100%	ND	2.07
(9-10)	ng/g %	ND	4.70 100%	ND	4.70
(11-12)	ng/g %	ND	6.17 100%	ND	6.17
Totals:	ng/g %	1.95 6.55%	27.8 93.5%	ND	29.74 100%

Table 18
α-HCH, β-HCH, γ-HCH concentrations (ng/g), percent composition and ΣHCHs contaminant load calculated at each sample interval for blue whale BL1. ND=not detected

Length (cm)		α-HCH	β-HCH	γ-HCH	ΣHCHs
0	ng/g %	1.19 14.3%	7.13 85.7%	ND	8.32
1	ng/g %	1.14 16.9%	5.57 83.1%	ND	6.71
2	ng/g %	ND	8.12 100%	ND	8.12
3	ng/g %	ND	6.03 100%	ND	6.03
4	ng/g %	ND	16.8 100%	ND	16.8
5	ng/g %	ND	4.47 100%	ND	4.47
6	ng/g %	ND	5.84 100%	ND	5.84
7	ng/g %	ND	25.0 100%	ND	25.0
8	ng/g %	ND	15.7 100%	ND	15.7
9	ng/g %	ND	17.5 100%	ND	17.5
10	ng/g %	ND	28.5 100%	ND	28.5
11	ng/g %	ND	4.89 100%	ND	4.89
12	ng/g %	ND	16.8 100%	ND	16.8
13	ng/g %	ND	13.5 100%	ND	13.5
14	ng/g %	ND	24.2 100%	ND	24.2
15	ng/g %	0.388 3.46%	10.8 96.5%	ND	11.2
16	ng/g %	0.533 10.1%	4.72 89.9%	ND	5.26
17	ng/g %	ND	1.84 100%	ND	1.84
18	ng/g %	ND	0.019 100%	ND	0.019
19	ng/g %	ND	6.13 100%	ND	6.13

20	ng/g %	ND	2.89 100%	ND	2.89
21	ng/g %	1.24 87.2%	0.183 12.8%	ND	1.42
22	ng/g %	0.605 4%	13.4 95.7%	ND	14.0
23	ng/g %	ND	13.5 100%	ND	13.5
24	ng/g %	ND	7.03 100%	ND	7.03
25	ng/g %	ND	12.1 100%	ND	12.1
26	ng/g %	ND	5.07 100%	ND	5.07
27	ng/g %	ND	60.1 100%	ND	60.1
28	ng/g %	ND	ND	ND	0
29	ng/g %	ND	ND	0.085 100%	0.085
30	ng/g %	ND	5.75 100%	ND	5.75
31	ng/g %	ND	1.37 100%	ND	1.37
32	ng/g %	0.295 11.1%	2.36 88.9%	ND	2.65
33	ng/g %	ND	4.90 100%	ND	4.90
34	ng/g %	ND	0.482 100%	ND	0.482
35	ng/g %	ND	4.44 100%	ND	4.44
36	ng/g %	ND	0.627 100%	ND	0.627
37	ng/g %	0.679 18.7%	2.95 81.3%	ND	3.63
38	ng/g %	ND	3.20 100%	ND	3.20
39	ng/g %	ND	2.74 100%	ND	2.74
40	ng/g %	ND	3.87 100%	ND	3.87
41	ng/g %	ND	0.101 28.9%	0.248 71.1%	0.349
42	ng/g %	ND	3.18 100%	ND	3.18

43	ng/g %	0.602 18.6%	2.63 81.4%	ND	3.23
44	ng/g %	ND	3.69 100%	ND	3.69
45	ng/g %	ND	4.72 100%	ND	4.72
46	ng/g %	ND	2.92 100%	ND	2.92
47	ng/g %	ND	2.89 100%	ND	2.89
48	ng/g %	ND	0.036 100%	ND	0.036
49	ng/g %	ND	2.01 100%	ND	2.01
50	ng/g %	ND	1.33 100%	ND	1.33
51	ng/g %	1.05 27.7%	2.73 72.3%	ND	3.78
52	ng/g %	ND	2.30 100%	ND	2.30
Total:	ng/g %	7.71 1.89%	399 98.0%	0.333 0.08%	407 100%

mammals than α-HCH does (Li and Macdonald, 2005). Once β-HCH accumulates in the tissues of marine mammals, it is resistant to degradation and remains in the body for a longer duration than that of α-HCH (Li and Macdonald, 2005). All of these factors likely explain why β-HCH is the largest contributor to the sum of HCHs contaminant group.

3.2.2. ΣDDTs

DDT (2,4'-DDT, 4,4'-DDT) is a pollutant that was used as an insecticide that breaks down into four different metabolites (2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 4,4'-DDD) (Beard, 2006). DDT and all of its metabolites have been discovered to have negative impacts on wildlife in the environment, such as increased risk of disease, decreased reproduction rates, increased abnormalities, and nervous system disruption (Jensen and Jansson, 1976; Vos et al., 2000).

The ΣDDTs contaminant group consists of the sums of 2,4'-DDT, 4,4'-DDT and its metabolites 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD. 2,4'-DDE contributed the most, accounting for 30.3%-51.8% (4.18-26.6 ng/g) of the total DDT contaminant load in baleen for all individual whales (Table 19, Fig. 5).

The ΣDDE (2,4'-DDE, 4,4'-DDE) were the metabolites contributing the most to the total DDT contaminant load ranging from 44.2%-67.1% (6.05-30.2 ng/g) (Table 19, Fig. 5). DDT (2,4'-DDT, 4,4'-DDT) were the next greatest contributing pollutants for all whales ranging from 20.1%-38.4% (3.22-13.6 ng/g), except for minke whale M1. M1 had a DDT percent contribution of 20.1% (2.06 ng/g) while ΣDDD for M1 was 20.9% (2.14 ng/g). This same percent composition trend was previously observed in minke whale blubber with DDE (78.5%) having the greatest percent contribution to ΣDDT, followed by DDD (16.1%) and then DDT (4.9%) (Yasunaga and Fujise, 2020). For the remaining whales, ΣDDD had the smallest percent contribution to total DDT contaminant load ranging from 9.59%-19.3% (2.11-7.58 ng/g) (Table 19, Fig. 5).

All DDT metabolite concentrations and percent compositions were also calculated at each sample interval for all individual whales (Tables 20, 21, 22, 23, 24, 25). Similar percent composition trends have been previously reported in gray whale muscle and liver samples and blue whale earplug cerumen and blubber with DDE having the largest concentrations followed by DDT and then DDD (Metcalfe et al., 2004; Trumble et al., 2013; Tsygankov et al., 2015). DDT is primarily broken down into DDE with a much smaller portion being degraded into DDD

which can explain the percent compositions observed for the individuals included in this study (Okonkwo et al., 2008). Minke whale M1 could have been potentially exposed to an older source of DDT allowing for more degradation to occur, contributing to the higher DDD percent composition.

DDE is known to have a higher body retention time than DDT because it is more difficult to excrete due to nonpolar nature (Borrell and Aguilar, 1987; Morgan and Roan, 1972). The more time that elapses after an exposure to DDT allows for DDT to break down into DDE, causing DDT concentrations in the body to decrease while DDE concentrations increase. This known relationship between DDT and DDE allows for scientists to approximate DDT exposure times.

The relationship between DDE percentage (%DDE) and ΣDDT burden (2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 4,4'-DDD. 2,4'-DDE 2,4'-DDT, 4,4'-DDT) can provide insight into how old or new the exposure to a DDT source in the environment is for an individual (Borrell and Aguilar, 1987). A positive correlation between %DDE and ΣDDT burden indicates an individual was exposed to an old source of DDT because as ΣDDT burden increases the %DDE also increases; as time elapses DDT is breaking down into DDE causing DDE to dominate the ΣDDT burden. All individuals included in this study did show a positive correlation between %DDE and ΣDDT burden with slopes ranging from 0.0122-0.2895 indicating an older exposure to DDT (Borrell and Aguilar, 1987; Fig 6). This trend has been observed in other biota, including other baleen whales (Borrell and Aguilar, 1987). Individuals G1 and BL1 showed a slight positive correlation with slopes less than 0.07 and R2 values less than 0.02 (Fig 6) which indicates that they were most likely exposed to DDT more recently than G2, H1, H2 and M1. Since DDT readily breaks down into DDE, a DDE:DDT ratio is also often calculated to provide insight into the type of exposure the individual experienced (Aguilar, 1984; Bolton et al., 2020; Borrell and Aguilar, 1987; Yasunaga and Fujise et al., 2020). Organisms that have a high DDE:DDT ratio value are considered to have an older organochlorine contaminant exposure from their environment because the DDT has had time to breakdown into DDE. Whereas a low value (<1) is considered to have exposure to a newer source of DDT with less time for the DDT to breakdown into DDE (Borrell and Aguilar, 1987; Gaskin 1982). The DDE:DDT ratio was calculated by taking the 4,4'-DDE concentration at each sample interval to the 4,4'-DDT

Table 19
Percentages of DDT isomers in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT
G1	30.3%	13.9%	7.42%	10.0%	17.5%	20.9%
G2	34.1%	33.0%	4.32%	5.27%	11.7%	11.6%
H1	47.0%	9.10%	4.80%	12.6%	8.90%	17.6%
H2	39.1%	21.4%	10.8%	8.50%	5.41%	14.7%
M1	49.4%	9.6%	4.31%	16.6%	14.7%	5.38%
BL1	51.8%	6.96%	6.79%	7.99%	12.2%	14.2%

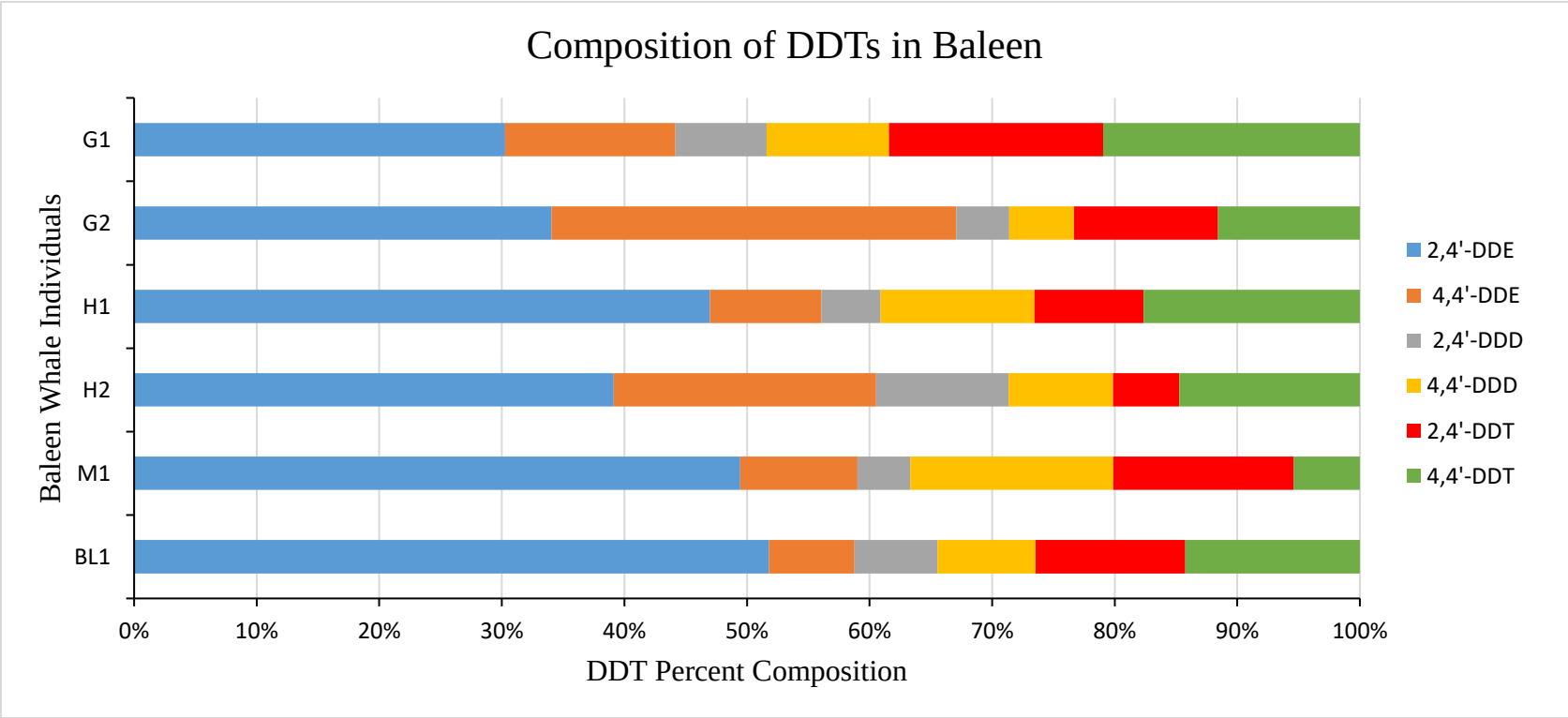


Fig. 5. Percent composition of ΣDDTs (2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 20
2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for gray whale G1. ND=not detected

Length (cm)		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
0	ng/g %	0.267 57.4%	ND	0.043 9.26%	ND	0.095 20.4%	0.060 13.0%	0.466
1	ng/g %	0.183 38.7%	0.053 11.3%	0.076 16.1%	ND	0.038 8.06%	0.122 25.8%	0.473
2	ng/g %	ND	0.090 32.3%	ND	ND	0.081 29.0%	0.109 38.7%	0.281
3	ng/g %	0.260 50.0%	0.048 9.21%	0.055 10.5%	ND	0.158 30.3%	ND	0.521
4	ng/g %	0.523 64.8%	0.220 27.3%	ND	ND	0.064 7.95%	ND	0.807
5	ng/g %	0.532 36.5%	0.211 14.5%	0.147 10.1%	0.266 18.2%	0.028 1.89%	0.275 18.9%	1.46
6	ng/g %	ND	0.067 23.3%	ND	0.125 43.3%	ND	0.096 33.3%	0.288
7	ng/g %	0.409 52.8%	ND	0.052 6.74%	0.096 12.4%	ND	0.217 28.1%	0.774
8	ng/g %	0.604 59.1%	0.196 19.1%	ND	0.098 9.57%	0.124 12.2%	ND	1.02
9	ng/g %	ND	0.05 14.0%	0.152 39.5%	ND	0.063 16.3%	0.117 30.2%	0.386
10	ng/g %	ND	ND	ND	0.113 20.3%	0.160 28.8%	0.283 50.8%	0.557
11	ng/g %	0.155 10.9%	0.037 2.6%	ND	0.140 9.9%	0.827 58.3%	0.258 18.2%	1.42
13	ng/g %	ND	0.119 33.3%	0.089 25.0%	0.074 20.8%	0.074 20.8%	ND	0.356
14	ng/g %	0.153 30.4%	0.081 16.1%	0.135 26.8%	ND	0.135 26.8%	ND	0.505

15	ng/g %	0.337 92.1%	0.029 7.89%	ND	ND	ND	ND	0.365
16	ng/g %	0.245 53.1%	ND	0.075 16.3%	ND	ND	0.142 30.6%	0.462
17	ng/g %	ND	0.093 45.5%	ND	0.047 22.7%	0.065 31.8%	ND	0.205
18	ng/g %	ND	0.187 41.7%	0.037 8.33%	0.103 22.9%	0.121 27.1%	ND	0.449
19	ng/g %	0.285 34.3%	ND	ND	0.071 8.57%	ND	0.474 57.1%	0.830
20	ng/g %	ND	0.065 33.3%	0.024 12.5%	0.105 54.2%	ND	ND	0.194
21	ng/g %	0.229 16.4%	0.229 16.4%	0.051 3.64%	ND	0.381 27.3%	0.508 36.4%	1.40
22	ng/g %	ND	0.143 23.6%	0.088 14.5%	0.143 23.6%	ND	0.231 38.2%	0.604
Total:	ng/g %	4.18 30.3%	1.92 13.9%	1.03 7.42%	1.38 10.0%	2.42 17.5%	2.89 20.9%	13.82 100%

Table 21
2,4’-DDT, 4,4’-DDT, 2,4’-DDE, 4,4’-DDE, 2,4’-DDD, and 4,4’-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for gray whale G2. ND=not detected

Length (cm)		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
0	ng/g %	0.398 27.3%	0.078 5.33%	0.117 8.00%	ND	0.165 11.3%	0.699 48.0%	1.46
1	ng/g %	0.848 80.9%	ND	ND	0.20 19.1%	ND	ND	1.05
2	ng/g %	0.676 36.7%	0.151 8.2%	0.281 15.2%	0.187 10.2%	0.417 22.7%	0.129 7.03%	1.84
3	ng/g %	0.267 14.3%	0.093 4.98%	0.081 4.32%	ND	1.429 76.4%	ND	1.87
4	ng/g %	ND	0.048 18.5%	0.038 14.8%	0.038 14.8%	0.135 51.9%	ND	0.260
5	ng/g %	0.498 43.5%	0.138 12.1%	ND	0.092 8.06%	0.304 26.6%	0.111 9.68%	1.14
6	ng/g %	0.283 29.1%	ND	ND	0.151 15.5%	0.340 35.0%	0.198 20.4%	0.972
7	ng/g %	1.77 76.2%	ND	0.166 7.14%	ND	0.095 4.08%	0.292 12.6%	2.32
8	ng/g %	0.756 53.5%	0.071 5.03%	0.124 8.81%	ND	0.089 6.29%	0.373 26.4%	1.41
9	ng/g %	0.440 67.6%	0.138 21.1%	0.073 11.3%	ND	ND	ND	0.651
10	ng/g %	0.210 70.0%	0.052 17.5%	0.037 12.5%	ND	ND	ND	0.300
11	ng/g %	0.411 65.2%	0.124 19.7%	ND	0.096 15.2%	ND	ND	0.632
12	ng/g %	1.64 68.8%	0.205 8.6%	0.179 7.53%	0.068 2.87%	ND	0.291 12.2%	2.38
13	ng/g %	1.16 55.3%	ND	0.254 12.1%	0.224 10.7%	ND	0.459 21.9%	2.10

14	ng/g %	0.654 55.6%	0.131 11.1%	ND	0.131 11.1%	0.261 22.2%	ND	1.18
15	ng/g %	ND	ND	0.026 6.82%	ND	ND	0.357 93.2%	0.383
16	ng/g %	0.660 61.1%	0.258 23.9%	ND	0.077 7.08%	0.086 7.96%	ND	1.08
17	ng/g %	0.417 61.6%	ND	ND	ND	0.083 12.0%	0.176 26.0%	0.676
18	ng/g %	ND	0.054 6.98%	0.108 14.0%	0.171 22.1%	ND	0.441 57.0%	0.775
19	ng/g %	ND	0.073 11.9%	ND	0.146 23.9%	ND	0.393 64.2%	0.612
20	ng/g %	0.367 36.5%	0.184 18.3%	0.019 1.92%	0.126 12.5%	0.309 30.8%	ND	1.00
21	ng/g %	0.438 36.3%	0.115 9.55%	0.023 1.91%	0.115 9.55%	0.354 29.3%	0.162 13.4%	1.21
22	ng/g %	ND	0.090 8.77%	0.108 10.5%	0.171 16.7%	0.252 24.6%	0.405 39.5%	1.03
23	ng/g %	0.626 6.31%	8.82 88.9%	ND	0.097 0.98%	0.079 0.799%	0.30 3.0%	9.92
24	ng/g %	0.242 46.7%	ND	0.095 18.3%	0.078 15.0%	0.104 20.0%	ND	0.519
25	ng/g %	0.206 41.1%	ND	0.081 16.1%	0.054 10.7%	0.161 32.1%	ND	0.502
26	ng/g %	0.279 43.5%	0.056 8.70%	ND	ND	0.279 43.5%	0.028 4.0%	0.642
27	ng/g %	0.308 33.3%	0.163 17.7%	0.087 9.38%	0.173 18.8%	ND	0.192 20.8%	0.923
28	ng/g %	ND	0.046 9.8%	0.065 13.7%	ND	0.101 21.6%	0.258 54.9%	0.470
29	ng/g %	0.867 18.4%	3.85 81.6%	ND	ND	ND	ND	4.71

30	ng/g %	1.05 74.0%	0.078 5.48%	ND	ND	0.293 20.5%	ND	1.42
Total:	ng/g %	15.5 34.1%	15.0 33.0%	1.96 4.32%	2.40 5.27%	5.34 11.7%	5.26 11.6%	45.5 100%

Table 22
2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for humpback whale H1. ND=not detected

Length (cm)		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
(0-2)	ng/g %	0.398 62.0%	0.035 5.43%	0.035 5.0%	ND	ND	0.175 27.2%	0.643
3	ng/g %	0.624 55.7%	0.081 7.22%	ND	0.208 18.6%	ND	0.208 18.6%	1.121
4	ng/g %	0.490 50.0%	0.040 4.08%	0.040 4.0%	0.110 11.2%	ND	0.300 30.6%	0.980
5	ng/g %	ND	0.248 68.9%	ND	ND	ND	0.112 31.1%	0.360
6	ng/g %	ND	ND	0.026 8.0%	0.235 69.2%	0.078 23.1%	ND	0.339
7	ng/g %	0.910 70.5%	ND	0.095 7.0%	ND	0.286 22.1%	ND	1.291
8	ng/g %	0.427 36.6%	0.458 39.3%	ND	0.188 16.1%	0.094 8.04%	ND	1.167
9	ng/g %	0.770 55.4%	0.126 9.0%	ND	0.149 10.7%	0.092 6.61%	0.253 18.2%	1.391
10	ng/g %	0.551 65.3%	ND	0.101 12.0%	ND	0.191 22.7%	ND	0.843
(11-12)	ng/g %	0.514 38.6%	0.072 5.43%	0.196 14.7%	ND	0.094 7.07%	0.457 34.2%	1.333
(13-14)	ng/g %	0.257 47.3%	0.044 8.11%	0.074 13.5%	0.169 31.1%	ND	ND	0.544
(15-16)	ng/g %	0.333 53.3%	ND	0.017 2.67%	0.175 28.0%	0.10 16.0%	ND	0.625
(17-18)	ng/g %	0.427 44.1%	ND	ND	0.292 30.1%	ND	0.250 25.8%	0.969
(19-20)	ng/g %	ND	ND	ND	ND	0.145 27.3%	0.388 72.7%	0.533

Total:	ng/g %	5.70 47.0%	1.11 9.10%	0.583 4.80%	1.525 12.6%	1.08 8.90%	2.14 17.6%	12.1 100%

Table 23
2,4’-DDT, 4,4’-DDT, 2,4’-DDE, 4,4’-DDE, 2,4’-DDD, and 4,4’-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for humpback whale H2. ND=not detected

Length (cm)		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
0	ng/g %	0.360 20.7%	0.054 3.11%	0.793 45.6%	0.324 18.7%	0.207 11.9%	ND	1.74
1	ng/g %	0.390 12.2%	2.061 64.3%	0.511 15.9%	0.069 2.16%	0.043 1.35%	0.130 4.05%	3.20
3	ng/g %	0.416 18.8%	1.024 46.4%	0.288 13.0%	0.192 8.70%	ND	0.288 13.0%	2.208
4	ng/g %	0.774 63.6%	ND	0.332 27.3%	0.111 9.09%	ND	ND	1.22
5	ng/g %	0.320 43.0%	0.035 4.65%	ND	0.078 10.5%	ND	0.312 41.9%	0.745
6	ng/g %	0.905 46.5%	0.405 20.8%	ND	0.172 8.85%	0.164 8.0%	0.302 15.0%	1.95
7	ng/g %	ND	0.171 46.2%	ND	0.199 53.8%	ND	ND	0.370
8	ng/g %	0.667 80.7%	ND	ND	ND	ND	0.160 19.3%	0.826
9	ng/g %	ND	ND	0.068 100%	ND	ND	ND	0.068
10	ng/g %	1.32 51.1%	0.107 4.14%	0.107 4.14%	0.427 16.5%	0.204 8.0%	0.417 16.2%	2.58
11	ng/g %	0.356 36.1%	0.146 14.8%	ND	0.082 8.33%	ND	0.402 40.7%	0.986
12	ng/g %	0.851 58.5%	0.168 11.6%	0.050 3.40%	ND	0.228 15.6%	0.158 10.9%	1.46
13	ng/g %	0.821 51.9%	0.267 16.9%	0.082 5.19%	0.103 6.49%	0.164 10.4%	0.144 9.09%	1.58
14	ng/g %	0.704 47.7%	0.089 6.0%	0.067 4.55%	ND	0.045 3.03%	0.57 38.6%	1.47

15	ng/g %	0.140 36.4%	ND	ND	ND	ND	0.244 63.6%	0.384
(16-17)	ng/g %	0.314 43.4%	0.058 8.08%	0.051 7.07%	0.066 9.09%	0.073 10.1%	0.161 22.2%	0.723
(18-19)	ng/g %	0.551 45.6%	0.078 6.43%	0.057 4.68%	0.184 15.2%	0.148 12.3%	0.191 15.8%	1.21
(20-22)	ng/g %	0.341 38.7%	0.392 44.5%	0.148 16.8%	ND	ND	ND	0.881
Total:	ng/g %	9.23 39.1%	5.05 21.4%	2.55 10.8%	2.01 8.50%	1.28 5.41%	3.48 14.7%	23.6 100%

Table 24
2,4’-DDT, 4,4’-DDT, 2,4’-DDE, 4,4’-DDE, 2,4’-DDD, and 4,4’-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for minke whale M1. ND=not detected

Length (cm)		**2,4'-DDE**	**4,4'-DDE**	**2,4'-DDD**	**4,4'-DDD**	**2,4'-DDT**	**4,4'-DDT**	**ΣDDTs**
(0-1)	ng/g %	0.771 70.6%	0.168 15.4%	0.061 5.59%	ND	0.092 8.39%	ND	1.09
2	ng/g %	ND	0.099 11.1%	ND	0.276 30.9%	0.343 38.3%	0.177 19.8%	0.895
3	ng/g %	ND	0.110 15.4%	ND	0.398 55.4%	ND	0.210 29.2%	0.718
4	ng/g %	0.868 65.6%	0.243 18.4%	0.032 2.40%	0.190 13.6%	ND	ND	1.32
(5-6)	ng/g %	0.718 38.4%	0.066 3.53%	0.044 2.35%	0.168 9.02%	0.872 46.7%	ND	1.87
(7-8)	ng/g %	ND	0.107 19.4%	0.173 31.3%	0.165 29.9%	0.107 19.4%	ND	0.551
(9-10)	ng/g %	0.780 67.6%	0.077 6.67%	0.132 11.4%	ND	ND	0.165 14.3%	1.15
(11-12)	ng/g %	1.93 72.9%	0.110 4.17%	ND	0.510 19.3%	0.097 3.65%	ND	2.65
Total:	ng/g %	5.07 49.4%	0.981 9.6%	0.441 4.31%	1.70 16.6%	1.51 14.7%	0.552 5.38%	10.2 100%

Table 25
2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 4,4'-DDE, 2,4'-DDD, and 4,4'-DDD concentrations (ng/g), percent composition and ΣDDTs contaminant load calculated at each sample interval for blue whale BL1. ND=not detected

Length (cm)		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
0	ng/g %	0.738 52.3%	0.047 3.31%	0.121 8.61%	0.327 23.2%	ND	0.178 12.6%	1.41
1	ng/g %	ND	0.20 29.7%	0.018 2.70%	ND	0.309 45.9%	0.145 21.6%	0.673
2	ng/g %	0.593 36.7%	0.105 6.51%	0.105 6.51%	0.211 13.0%	0.201 12.4%	0.402 24.9%	1.62
3	ng/g %	0.437 36.5%	0.070 5.84%	0.114 9.49%	0.306 25.5%	0.271 22.6%	ND	1.20
4	ng/g %	0.384 37.5%	0.210 20.5%	0.055 5.36%	0.374 36.6%	ND	ND	1.02
5	ng/g %	0.506 47.2%	0.043 4.00%	0.060 5.60%	ND	0.189 17.6%	0.275 25.6%	1.07
6	ng/g %	0.502 35.4%	0.116 8.16%	0.251 17.7%	0.116 8.16%	0.155 10.9%	0.280 19.7%	1.42
7	ng/g %	0.603 28.1%	0.163 7.59%	0.086 4.02%	0.316 14.7%	0.708 33.0%	0.268 12.5%	2.14
8	ng/g %	ND	ND	ND	0.084 69.2%	0.037 30.8%	ND	0.121
9	ng/g %	ND	ND	ND	0.089 40.7%	0.073 33.3%	0.056 25.9%	0.218
10	ng/g %	0.615 48.6%	0.147 11.6%	0.083 6.52%	0.073 5.80%	0.193 15.2%	0.156 12.3%	1.27
11	ng/g %	ND	ND	0.112 30.8%	ND	0.252 69.2%	ND	0.364
12	ng/g %	0.881 77.4%	0.110 9.68%	0.046 4.03%	0.101 8.87%	ND	ND	1.14
13	ng/g %	0.566 65.2%	ND	ND	0.132 15.2%	0.170 19.6%	ND	0.868

14	ng/g %	0.419 31.2%	0.267 19.9%	ND	ND	0.114 8.51%	0.543 40.4%	1.34
15	ng/g %	0.586 69.4%	ND	0.095 11.2%	0.086 10.2%	0.078 9.18%	ND	0.845
16	ng/g %	0.324 47.9%	ND	ND	ND	ND	0.352 52.1%	0.676
17	ng/g %	0.230 51.0%	ND	ND	ND	0.221 49.0%	ND	0.452
18	ng/g %	0.547 46.4%	ND	0.170 14.4%	0.104 8.80%	ND	0.358 30.4%	1.18
19	ng/g %	0.350 30.5%	ND	0.090 7.81%	ND	0.511 44.5%	0.197 17.2%	1.15
20	ng/g %	0.117 33.3%	0.144 41.0%	ND	ND	0.090 25.6%	ND	0.351
21	ng/g %	0.779 46.3%	0.077 4.57%	0.163 9.71%	ND	0.663 39.4%	ND	1.68
22	ng/g %	0.263 56.3%	0.078 16.7%	0.127 27.1%	ND	ND	ND	0.468
23	ng/g %	0.354 42.0%	ND	0.086 10.2%	ND	0.230 27.3%	0.172 20.5%	0.842
24	ng/g %	0.712 72.2%	ND	0.10 10.2%	ND	ND	0.174 17.6%	0.986
25	ng/g %	ND	0.309 73.9%	ND	0.109 26.1%	ND	ND	0.418
26	ng/g %	0.880 58.2%	ND	ND	ND	ND	0.631 41.8%	1.51
27	ng/g %	1.27 65.7%	0.133 6.86%	ND	0.114 5.88%	0.114 5.88%	0.303 15.7%	1.93
28	ng/g %	0.636 79.1%	0.168 20.9%	ND	ND	ND	ND	0.804
29	ng/g %	0.711 54.0%	0.104 7.91%	0.085 6.47%	ND	0.303 23.0%	0.114 8.63%	1.32

30	ng/g %	0.832 70.6%	0.084 7.14%	0.112 9.52%	ND	ND	0.150 12.7%	1.18
31	ng/g %	ND	0.047 62.5%	ND	ND	0.028 37.5%	ND	0.074
32	ng/g %	0.536 73.2%	0.089 12.2%	ND	0.107 14.6%	ND	ND	0.732
33	ng/g %	0.291 47.7%	0.047 7.69%	ND	0.188 30.8%	0.085 13.8%	ND	0.610
34	ng/g %	0.661 52.3%	0.073 5.81%	0.057 4.52%	0.147 11.6%	0.163 12.9%	0.163 12.9%	1.27
35	ng/g %	0.272 93.3%	ND	ND	ND	0.019 6.67%	ND	0.291
36	ng/g %	0.944 73.3%	ND	0.086 6.67%	0.137 10.7%	ND	0.120 9.33%	1.29
37	ng/g %	0.335 33.6%	0.102 10.3%	0.102 10.3%	ND	ND	0.456 45.8%	0.995
38	ng/g %	0.780 61.2%	ND	ND	0.211 16.5%	0.119 9.35%	0.165 12.9%	1.28
39	ng/g %	0.316 40.5%	0.084 10.7%	0.074 9.52%	ND	ND	0.307 39.3%	0.781
40	ng/g %	0.648 79.5%	0.093 11.4%	0.074 9.09%	ND	ND	ND	0.815
41	ng/g %	0.422 54.8%	0.055 7.14%	ND	0.101 13.1%	0.083 10.7%	0.110 14.3%	0.771
42	ng/g %	1.78 79.7%	0.104 4.64%	0.123 5.49%	ND	ND	0.226 10.1%	2.24
43	ng/g %	0.243 22.1%	0.039 3.54%	0.126 11.5%	ND	0.524 47.8%	0.165 15.0%	1.10
44	ng/g %	0.672 62.1%	0.131 12.1%	0.070 6.45%	0.096 8.87%	0.114 10.5%	ND	1.08
45	ng/g %	0.324 53.7%	ND	0.072 11.9%	0.171 28.4%	0.036 5.97%	ND	0.604

46	ng/g %	0.597 52.1%	0.038 3.31%	0.047 4.13%	0.161 14.0%	ND	0.303 26.4%	1.15
47	ng/g %	0.309 81.0%	ND	0.073 19.0%	ND	ND	ND	0.382
48	ng/g %	0.679 57.3%	0.090 7.63%	0.217 18.3%	0.081 6.87%	0.118 9.92%	ND	1.19
49	ng/g %	0.563 59.4%	ND	0.085 8.91%	0.103 10.9%	ND	0.197 20.8%	0.948
50	ng/g %	0.920 62.8%	ND	0.161 11.0%	0.054 3.66%	ND	0.330 22.6%	1.46
51	ng/g %	ND	ND	ND	ND	ND	ND	ND
52	ng/g %	0.435 76.9%	ND	0.035 6.15%	ND	0.096 16.9%	ND	0.565
Total:	ng/g %	26.6 51.8%	3.57 6.96%	3.48 6.79%	4.10 7.99%	6.27 12.2%	7.30 14.2%	51.28 100%

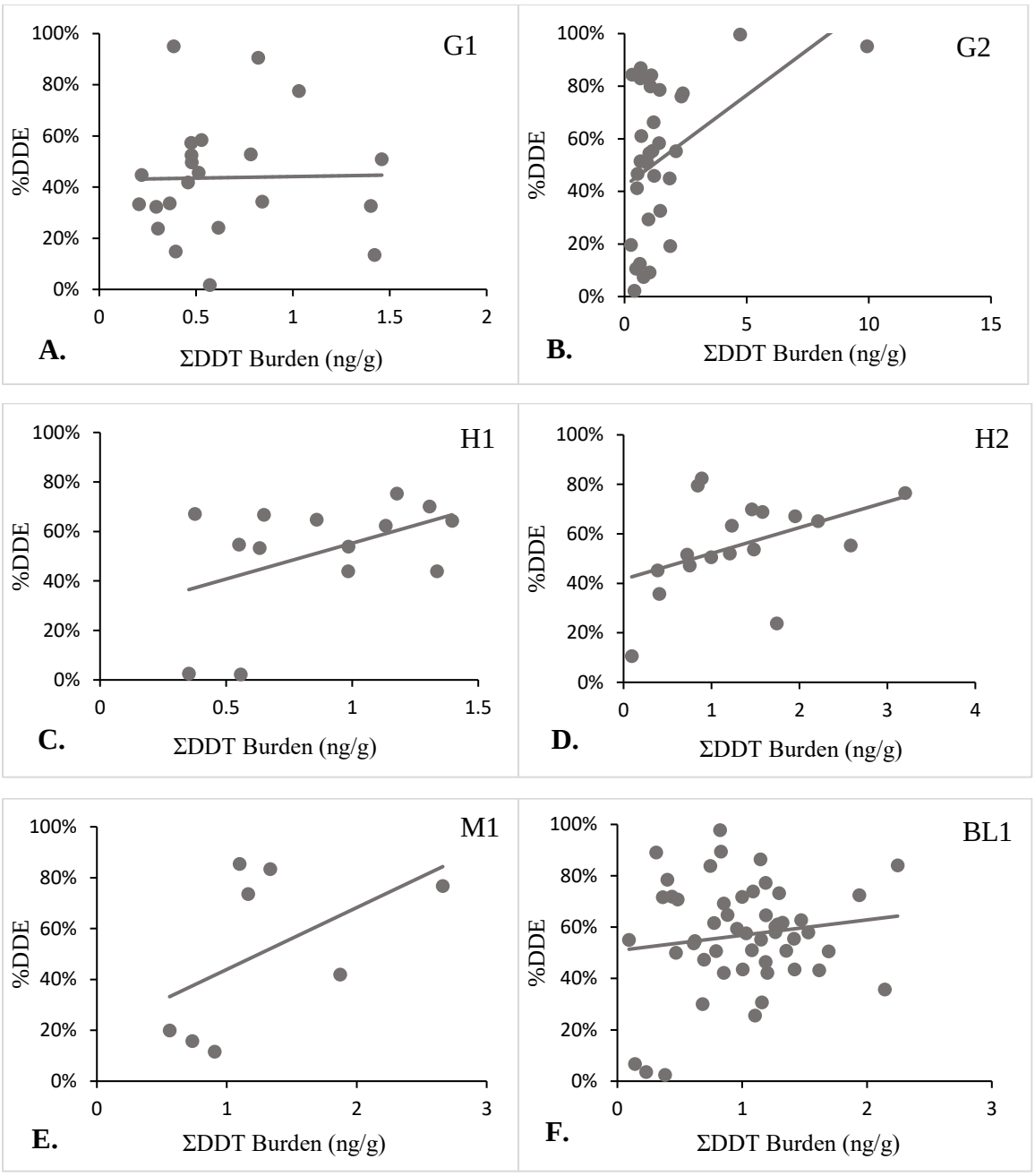


Fig. 6. Relationship between DDE percentage (%DDE) and ΣDDT burden (2,4'-DDE, 4,4'-DDE, 2,4'-DDD, 4,4'-DDD. 2,4'-DDE 2,4'-DDT, 4,4'-DDT). All ΣDDT burden concentrations are presented in ng/g. (**A**) Gray whale G1, $y=0.0122x + 0.429$, $R^2=0.0004$. (**B**) Gray whale G2, $y=0.0691x + 0.4205$, $R^2=0.1897$. (**C**) Humpback whale H1, $y=0.2895x + 0.263$, $R^2=0.2085$. (**D**) Humpback whale H2, $y=0.1044x + 0.4164$, $R^2=0.1988$. (**E**) Minke whale M1, $y=0.2432x + 0.1961$, $R^2=0.2663$. (**F**) Blue whale BL1, $y=0.06x + 0.5083$, $R^2=0.0194$.

concentration at the same sample interval providing a ratio value per interval (Trumble et al., 2013; Yasunaga and Fujise et al., 2020; Tables 26, 27, 28, 29, 30, 31). Gray whale G1 had a mean DDE:DDT ratio value among sample intervals of 11.0±16.0 with a range of 0.008-48.0. Among all individuals, gray whale G2 had the highest mean DDE:DDT ratio value among sample intervals of 35.5±144 and a range of 0.011-808 (Table 32). Humpback whale H1 had a mean DDE:DDT ratio value among sample intervals of 7.69±23.3 with a range of 0.016-88.0 (Table 32). Humpback whale H2 had a mean DDE:DDT ratio value among sample intervals of 11.0±29.1 with a range of 0.024-122 (Table 32). Minke whale M1 had a mean DDE:DDT ratio value among sample intervals of 18.9±18.7 and a range of 0.467-46.0 (Table 32). Among all individuals blue whale BL1 had the lowest mean DDE:DDT ratio value among sample intervals of 7.23±13.8 and a range of 0.007-68.0 (Table 32). All whales had a relatively high mean DDE:DDT ratio (>1) reaffirming the %DDE and ΣDDT burden positive correlations indicating an older exposure to DDT (Ahlborg et al., 1995; Borrell and Aguilar, 1987). However, all individuals had a large range in DDE:DDT ratio along the length of the baleen plate indicating that these migratory species are interacting with both new and old DDT sources (Aguilar, 1984; Borrell and Aguilar, 1987; Gaskin 1982; Tables 26, 27, 28, 29, 30, 31). Trumble et al. (2013) sampled a blue whale earplug from 2007 and reported a mean ratio of 24±10 with a maximum ratio value of 54. DDE:DDT ratios have been shown to increase through time however, gray whale G2 was the only individual that had a higher mean DDE:DDT ratio value than the previously reported 2007 blue whale despite all stranding later in time (Bolton et al., 2020; Trumble et al., 2013). The DDE:DDT ratios calculated in the previously reported blue whale were observed in earplug cerumen and not baleen plates (Trumble et al., 2013). It has been shown that DDE:DDT ratios can vary among different tissues which could explain why the mean DDE:DDT ratio values reported in this study are lower than those previously reported (Aguilar, 1984; Trumble et al., 2013).

3.2.3. ΣPCBs

PCBs were widely used in electrical equipment, surface coatings, and inks from 1929 to the late 1970s (Nisbet and Sarofim, 1972; NOAA, 2009). Exposure to PCBs can lead to cancer, decreased immune and reproductive system function, abnormal liver and thyroid function, and impaired neurological development (Longnecker et al., 1997). The ΣPCBs contaminant group

Table 26
DDE:DDT ratio at every sample interval for gray whale G1 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample intervals).

Length (cm)	DDE:DDT
0	0.071
1	0.438
2	0.833
3	14.0
4	48.0
5	0.767
6	0.700
7	0.020
8	44.0
9	0.462
10	0.017
11	0.143
13	32.0
14	18.0
15	6.00
16	0.033
17	20.0
18	40.0
19	0.008
20	16.0
21	0.450
22	0.619
Total	0.664

Table 27
DDE:DDT ratio at every sample interval for gray whale G2 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample intervals).

Length (cm)	DDE:DDT
0	0.111
1	1.00
2	1.17
3	30.0
4	10.0
5	1.25
6	0.024
7	0.014
8	0.190
9	30.0
10	14.0
11	26.0
12	0.706
13	0.011
14	34.0
15	0.012
16	54.0
17	0.026
18	0.122
19	0.186
20	38.0
21	0.714
22	0.222
23	29.4
24	1.00
25	1.00
26	2.00
27	0.850
28	0.179
29	808
30	16.0
Total	2.85

Table 28
DDE:DDT ratio at every sample interval for humpback whale H1 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample

Length (cm)	DDE:DDT
(0-2)	0.200
3	0.389
4	0.133
5	2.21
6	1.00
7	1.00
8	88.0
9	0.500
10	1.00
(11-12)	0.159
(13-14)	12.0
(15-16)	1.00
(17-18)	0.021
(19-20)	0.016
Total	0.516

Table 29
DDE:DDT ratio at every sample interval for humpback whale H2 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample

Length (cm)	DDE:DDT
0	12.0
1	15.9
3	3.56
4	1.00
5	0.111
6	1.34
7	36.0
8	0.029
9	1.00
10	0.256
11	0.364
12	1.06
13	1.86
14	0.157
15	0.024
(16-17)	0.364
(18-19)	0.407
(20-22)	122
Total	1.45

Table 30
DDE:DDT ratio at every sample interval for minke whale M1 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample intervals).

Length (cm)	DDE:DDT
(0-1)	44.0
2	0.563
3	0.526
4	46.0
(5-6)	18.0
(7-8)	26.0
(9-10)	0.467
(11-12)	16.0
Total	1.78

Table 31
DDE:DDT ratio at every sample interval for blue whale BL1 calculated by taking 4,4'-DDE divided by 4,4'-DDT. Total represents the DDE:DDT ratio for the entire baleen plate, total 4,4'-DDE (sum of all sample intervals) divided by total 4,4'-DDT (sum of all sample intervals).

Length (cm)	DDE:DDT
0	0.263
1	1.38
2	0.262
3	16.0
4	46.0
5	0.156
6	0.414
7	0.607
8	1.00
9	0.071
10	0.941
11	1.00
12	24.0
13	1.00
14	0.491
15	1.00
16	0.014
17	1.00
18	0.013
19	0.023
20	32.0
21	16.0
22	16.0
23	0.028
24	0.026
25	68.0
26	0.007
27	0.438
28	36.0
29	0.917
30	0.563
31	10.0
32	20.0
33	10.0
34	0.450
35	1.00
36	0.036
37	0.224

38	0.028
39	0.273
40	20.0
41	0.500
42	0.458
43	0.235
44	30.0
45	1.00
46	0.125
47	1.00
48	20.0
49	0.024
50	0.014
51	1.00
52	1.00
Total (ng/g):	0.489

Table 32

Geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and ranges (ng/g) in DDE:DDT ratio values of all individuals of IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

		G1	G2	H1	H2	M1	BL1
DDE:DDT	Geometric Mean (IQR)	1.17 (17.3)	1.28 (20.8)	0.590 (0.831)	1.02 (2.85)	6.17 (29.9)	0.753 (9.78)
	Mean ± SD	11.0 ± 16.0	35.5 ± 144	7.69 ± 23.3	11.0 ± 29.1	18.9 ± 18.7	7.23 ± 13.8
	Range	0.008-48.0	0.011-808	0.016-88.0	0.024-122	0.467-46.0	0.007-68.0

consists of the sums of congeners 28, 52, 101, 138, 153, 180, and 209. PCB 52 contributed the most by accounting for 53%-86.1% (127-329 ng/g) of the total PCB contaminant load for all individuals (Table 33, Fig. 6). The percent composition for the remaining six congeners (PCBs 28, 101, 138, 153, 180, and 209) showed the greatest variability among all individuals compared to the other contaminant groups (Table 33, Fig. 6). Total PCB congener percent composition to ΣPCB from greatest to least among the individuals were: G1 (52>209>180>101>138>153>28), G2 (52>209>101>138>28>180>153), H1 (52>209>28>138>101>153>180), H2 (52>101>209>138>28>180>153), M1 (52>209>138>101>153>180>28), and BL1 (52>28>101>209>153>138>180) (Table 33, Fig. 6). PCB congener percent composition among the sample intervals also varied greatly, however typically PCB 209 and PCB 101 were the next greatest congeners after PCB 52 (Tables 34, 35, 36, 37, 38, 39). PCBs are readily transported to the marine environment where they have the greatest direct impact on wildlife (Rice et al., 2002). Once in the marine environment these organochlorine compounds are either assimilated into organisms or sediments (Rice et al., 2002). Once in the sediments, PCBs can remobilize into the water column making them a continued source for contamination (Rice et al., 2002).

PCB congeners have varying numbers of chlorine atoms (Table 1) which gives them varying levels of resistance to degradation. Typically, PCB congeners with fewer attached chlorine atoms (1-4) can be degraded by organisms and abiotic processes in the environment (Rice et al. 2002). These chemical properties allow for lower chlorinated PCBs to move more efficiently throughout the environment, which is then strongly influenced by environmental factors and proximity to anthropogenic sources (Beyer et al., 2000; Yasunaga and Fujise, 2020). PCB 52 has four chlorine atoms so it can biodegrade rapidly once introduced into the environment (Table 1). Total PCB 52 concentrations were dominated by large concentrations (18.0-77.4 ng/g) observed at few sample intervals for each whale, which could be representing exposure to recently introduced concentrations of PCB 52 into the environment (Tables 34, 35, 36, 37, 38, 39). The large PCB 52 concentrations contributed to PCB 52 having the greatest percent composition for all individuals. However, between periods of large PCB 52 concentrations were sample intervals where PCB 52 was not detected or concentrations were much lower (nd-3.07 ng/g) (Tables 34, 35, 36, 37, 38, 39). Although the use of PCBs was banned in the 1970s they are still being detected in the pigments of products being produced today including: inks, paper products, packaging, and plastics (Gui et al., 2014; Stone, 2014). In

Table 33
Percentages of PCB congeners in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	PCB 28	PCB 52	PCB 101	PCB 153	PCB 180	PCB 209	PCB 138
G1	0%	66.6%	5.36%	2.68%	7.03%	13.4%	4.63%
G2	5.44%	60.8%	8.69%	3.09%	4.05%	12.2%	5.79%
H1	6.25%	63.9%	2.59%	2.07%	0%	21.3%	3.70%
H2	4.73%	60.5%	12.3%	2.68%	2.76%	8.51%	8.51%
M1	0.68%	86.1%	2.18%	1.29%	0.97%	5.63%	3.11%
BL1	12.9%	53.0%	11.1%	4.96%	3.20%	10.3%	4.61%

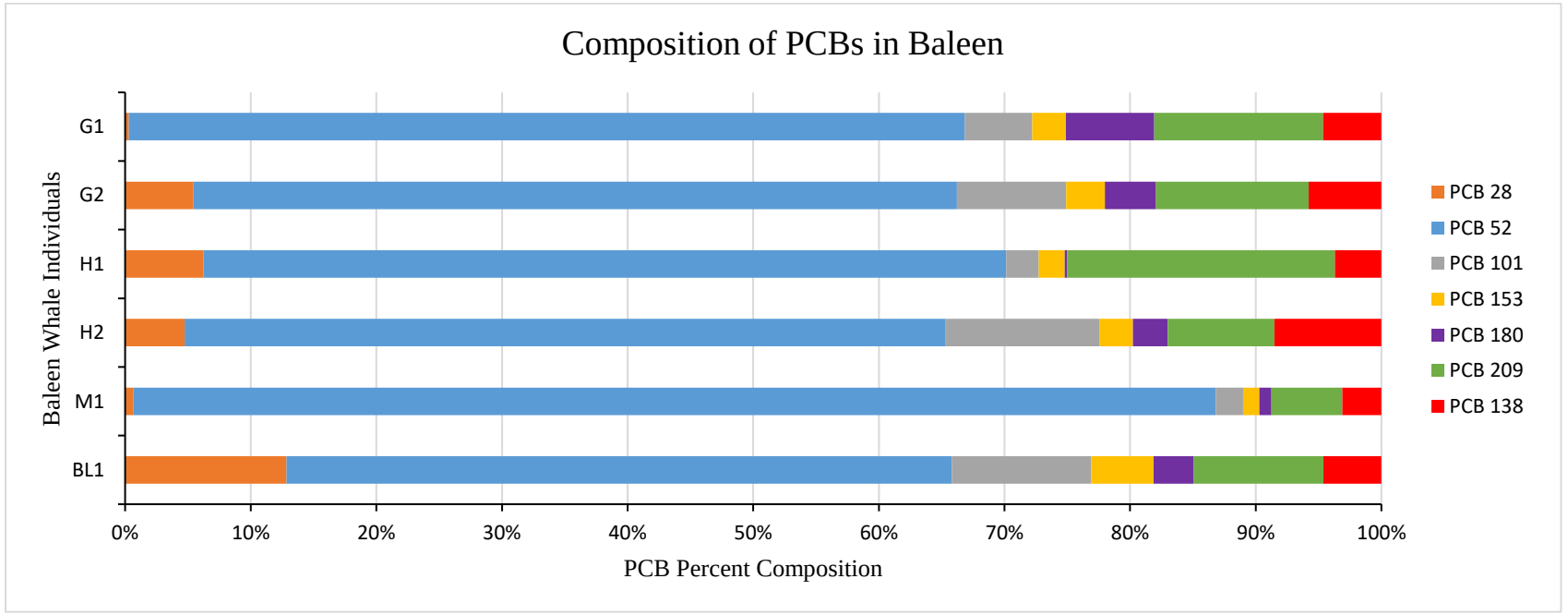


Fig. 6. Percent composition of ΣPCBs (28, 52, 101, 138, 153, 180, and 209) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 34
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for gray whale G1. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
0	ng/g %	ND	23.0 100%	ND	ND	ND	ND	ND	23.0
1	ng/g %	ND	0.565 34.3%	0.336 20.4%	ND	0.748 45.4%	ND	ND	1.65
2	ng/g %	ND	ND	ND	ND	ND	0.498 100%	ND	0.498
3	ng/g %	0.589 23.9%	ND	0.452 18.3%	0.774 31.4%	ND	0.240 9.72%	0.411 16.7%	2.47
4	ng/g %	ND	0.798 32.8%	0.798 32.8%	0.835 34.3%	ND	ND	ND	2.43
5	ng/g %	ND	ND	1.93 62.9%	1.14 37.1%	ND	ND	ND	3.06
6	ng/g %	ND	ND	1.59 57.1%	0.683 24.6%	0.510 18.3%	ND	ND	2.78
7	ng/g %	ND	24.1 91.8%	ND	ND	1.06 4.05%	1.08 4.11%	ND	26.2
8	ng/g %	ND	27.1 96.1%	0.480 1.70%	0.631 2%	ND	ND	ND	28.2
9	ng/g %	ND	ND	1.72 67.6%	ND	0.825 32.4%	ND	ND	2.55
10	ng/g %	ND	ND	ND	ND	ND	4.71 100%	ND	4.71
11	ng/g %	ND	ND	0.354 9.7%	ND	ND	ND	3.31 90.3%	3.67
13	ng/g %	ND	0.926 19.1%	ND	ND	0.33 6.89%	1.24 25.6%	2.34 48.4%	4.84

14	ng/g %	ND	0.396 11.1%	0.514 14.4%	0.604 17.0%	ND	ND	2.05 57.5%	3.56
15	ng/g %	ND	0.750 46.7%	ND	0.856 53.3%	ND	ND	ND	1.61
16	ng/g %	ND	29.9 86.9%	ND	ND	ND	ND	4.52 13.1%	34.4
17	ng/g %	ND	ND	ND	0.679 11.3%	ND	ND	5.32 88.7%	6.00
18	ng/g %	ND	ND	1.58 54.2%	ND	ND	1.34 45.8%	ND	2.92
19	ng/g %	ND	ND	ND	1.55 19.4%	ND	2.37 29.7%	4.07 50.9%	7.99
20	ng/g %	ND	25.3 84.0%	0.145 0.482%	0.508 1.69%	0.427 1.42%	0.597 1.98%	3.15 10.5%	30.1
21	ng/g %	ND	ND	0.517 15.0%	ND	0.907 26.2%	2.03 58.8%	ND	3.46
22	ng/g %	ND	0.593 13.8%	0.341 7.93%	1.02 23.8%	0.560 13.0%	ND	1.78 41.4%	4.30
Total:	ng/g %	0.589 0.294%	133 66.6%	10.8 5.36%	9.28 4.63%	5.37 2.68%	14.1 7.03%	27.0 13.4%	200 100%

Table 35
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for gray whale G2. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
0	ng/g %	ND	ND	1.15 37.1%	ND	0.981 31.8%	0.961 31.1%	ND	3.09
1	ng/g %	0.276 4.3%	ND	0.657 10.2%	1.61 24.9%	1.28 19.8%	ND	2.64 40.9%	6.46
2	ng/g %	ND	21.2 91.7%	0.446 1.90%	0.475 2.10%	0.993 4.30%	ND	ND	23.2
3	ng/g %	1.78 42.1%	1.14 26.8%	0.168 4.0%	0.534 12.6%	0.615 14.5%	ND	ND	4.24
4	ng/g %	ND	0.231 7.50%	0.529 17.2%	ND	ND	ND	2.32 75.3%	3.08
5	ng/g %	ND	ND	ND	ND	0.452 100%	ND	ND	0.452
6	ng/g %	ND	ND	0.613 31.4%	1.34 68.6%	ND	ND	ND	1.95
7	ng/g %	0.893 2.4%	33.4 88.1%	ND	1.26 3.30%	ND	ND	2.36 6.20%	37.9
8	ng/g %	ND	29.7 82.2%	1.07 3.0%	0.862 2.40%	ND	0.578 1.6%	3.93 10.9%	36.1
9	ng/g %	ND	ND	0.569 52.1%	ND	ND	0.523 47.9%	ND	1.09
10	ng/g %	ND	ND	1.30 63.8%	0.494 24.4%	ND	0.240 11.8%	ND	2.03
11	ng/g %	ND	1.20 27.7%	2.33 54.0%	ND	ND	0.794 18.4%	ND	4.33
12	ng/g %	ND	ND	0.325 100%	ND	ND	ND	ND	0.325

13	ng/g %	ND	3.07 39.1%	1.46 18.6%	1.02 13.0%	0.810 10.3%	1.48 18.9%	ND	7.85
14	ng/g %	ND	ND	ND	ND	ND	ND	ND	0
15	ng/g %	ND	0.522 17.4%	ND	ND	ND	ND	2.47 82.6%	2.99
16	ng/g %	ND	18.0 80.6%	1.44 6.50%	ND	0.967 4.30%	ND	1.90 8.50%	22.3
17	ng/g %	ND	1.99 37.2%	0.806 15.1%	ND	ND	0.815 15.2%	1.74 32.5%	5.35
18	ng/g %	ND	ND	1.16 27.3%	0.432 10.1%	0.775 18.2%	1.89 44.4%	ND	4.26
19	ng/g %	0.895 24.5%	ND	1.37 37.5%	1.39 38.0%	ND	ND	ND	3.65
20	ng/g %	2.75 59.6%	ND	0.174 3.8%	ND	0.406 8.8%	1.29 27.8%	ND	4.62
21	ng/g %	ND	0.692 12.3%	1.22 21.7%	0.931 16.6%	ND	ND	2.77 49.4%	5.61
22	ng/g %	ND	ND	4.76 57.4%	ND	ND	1.36 16.4%	2.17 26.2%	8.29
23	ng/g %	0.714 9.90%	ND	1.34 18.6%	2.47 34.2%	0.969 13.4%	ND	1.73 23.9%	7.22
24	ng/g %	ND	ND	0.450 10.0%	1.14 25.5%	ND	ND	2.89 64.5%	4.48
25	ng/g %	8.35 97.4%	ND	0.224 2.60%	ND	ND	ND	ND	8.57
26	ng/g %	0.651 14.1%	0.912 19.8%	0.512 11.1%	0.437 9.50%	1.03 22.4%	1.06 23.0%	ND	4.60
27	ng/g %	ND	ND	ND	1.13 100%	ND	ND	ND	1.13
28	ng/g %	ND	9.75 52.2%	0.470 2.50%	ND	ND	ND	8.46 45.3%	18.7

29	ng/g %	ND	26.7 88.2%	0.514 1.70%	1.16 3.80%	ND	0.829 2.70%	1.07 3.50%	30.3
30	ng/g %	ND	33.6 94.5%	0.985 2.80%	0.654 1.80%	ND	0.322 0.90%	ND	35.6
Total:	ng/g %	16.3 5.44%	182 60.8%	26.0 8.69%	17.3 5.79%	9.27 3.09%	12.1 4.05%	36.4 12.16%	300 100%

Table 36
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for humpback whale H1. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
(0-2)	ng/g %	ND	1.10 13.5%	0.315 3.87%	ND	ND	ND	6.71 82.6%	8.13
3	ng/g %	ND	1.85 11.8%	0.520 3.31%	1.53 9.70%	ND	ND	11.8 75.2%	15.7
4	ng/g %	ND	ND	ND	ND	0.440 16.9%	ND	2.16 83.1%	2.60
5	ng/g %	ND	0.840 12.6%	2.70 40.4%	0.672 10.1%	ND	0.312 4.68%	2.15 32.3%	6.67
6	ng/g %	5.78 48.0%	0.400 3.32%	ND	ND	0.870 7.22%	ND	4.99 41.4%	12.0
7	ng/g %	ND	1.37 23.2%	0.688 11.7%	ND	0.370 6.28%	ND	3.47 58.9%	5.89
8	ng/g %	ND	35.9 81.8%	1.06 2.42%	0.875 1.99%	0.719 1.64%	ND	5.34 12.2%	43.9
9	ng/g %	ND	ND	ND	0.483 6.92%	1.07 15.3%	ND	5.43 77.8%	6.98
10	ng/g %	ND	ND	1.46 16.7%	0.910 10.4%	ND	ND	6.38 72.9%	8.75
(11-12)	ng/g %	ND	25.7 95.2%	0.630 2.34%	ND	0.659 2.44%	ND	ND	27.0
(13-14)	ng/g %	0.809 21.4%	ND	ND	1.49 39.4%	0.478 12.6%	ND	1.01 26.6%	3.79
(15-16)	ng/g %	5.90 45.8%	ND	ND	0.575 4.46%	0.733 5.7%	0.192 1.49%	5.48 42.6%	12.9
(17-18)	ng/g %	ND	54.9 92.9%	ND	4.00 6.76%	0.219 0.370%	ND	ND	59.1
(19-20)	ng/g %	5.32 7.45%	60.0 84.0%	ND	ND	0.339 0.475%	ND	5.79 8.11%	71.5

Total:	ng/g %	17.8 6.25%	182 63.9%	7.37 2.59%	10.5 3.70%	5.90 2.07%	0.504 0.177%	60.7 21.3%	154 100%

Table 37
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for humpback whale H2. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
0	ng/g %	ND	ND	3.15 55.1%	ND	ND	1.26 22.0%	1.31 22.8%	5.72
1	ng/g %	ND	1.03 25.4%	1.74 42.9%	ND	ND	ND	1.28 31.6%	4.05
3	ng/g %	ND	ND	0.40 8.9%	0.784 17.4%	ND	0.216 4.8%	3.11 69.0%	4.51
4	ng/g %	2.20 35.8%	ND	1.36 22.2%	ND	ND	2.58 42.0%	ND	6.15
5	ng/g %	ND	ND	ND	ND	1.18 100%	ND	ND	1.18
6	ng/g %	ND	38.5 89.0%	1.28 2.90%	0.509 1.20%	1.27 2.90%	ND	1.72 4.0%	43.3
7	ng/g %	ND	ND	1.26 27.9%	2.05 45.4%	0.730 16.2%	0.474 10.5%	ND	4.51
8	ng/g %	ND	ND	ND	ND	0.535 100%	ND	ND	0.535
9	ng/g %	ND	1.97 68.2%	ND	ND	ND	0.917 31.8%	ND	2.89
10	ng/g %	0.990 12.3%	ND	7.07 87.7%	ND	ND	ND	ND	8.06
11	ng/g %	ND	ND	0.868 15.4%	2.01 35.7%	ND	ND	2.75 48.9%	5.63
12	ng/g %	ND	ND	ND	0.673 100%	ND	ND	ND	0.673
13	ng/g %	ND	2.79 65.5%	0.451 10.6%	ND	1.02 23.9%	ND	ND	4.26
14	ng/g %	ND	ND	2.95 65.8%	ND	ND	ND	1.53 34.2%	4.48

15	ng/g %	1.05 16.2%	0.570 8.8%	1.33 20.5%	1.45 22.5%	ND	ND	2.06 31.9%	6.45
(16-17)	ng/g %	5.69 66.0%	ND	ND	0.467 5.4%	ND	ND	2.47 28.6%	8.62
(18-19)	ng/g %	ND	41.6 86.9%	3.92 8.2%	ND	0.905 1.9%	0.339 0.70%	1.13 2.4%	47.9
(20-22)	ng/g %	ND	40.6 96.6%	ND	0.926 2.20%	ND	ND	0.495 1.20%	42.0
Total:	ng/g %	9.93 4.94%	127 63.25%	25.8 12.83%	8.87 4.41%	5.63 2.80%	5.79 2.88%	17.9 8.89%	201 100%

Table 38
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for minke whale M1. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
(0-1)	ng/g %	ND	55.2 90.8%	1.17 1.92%	0.763 1.26%	ND	ND	3.66 6.01%	60.8
2	ng/g %	ND	ND	3.36 31.8%	ND	1.73 16.4%	ND	5.46 51.7%	10.6
3	ng/g %	ND	77.4 94.4%	0.586 0.714%	3.16 3.85%	ND	0.873 1.06%	ND	82.0
4	ng/g %	ND	ND	ND	ND	0.815 54.6%	0.677 45.4%	ND	1.49
(5-6)	ng/g %	ND	ND	ND	ND	ND	ND	3.63 100%	3.63
(7-8)	ng/g %	2.06 3.47%	54.8 92.3%	ND	1.19 2.00%	0.527 0.89%	0.798 1.34%	ND	59.4
(9-10)	ng/g %	ND	72.9 89.7%	1.52 1.87%	1.86 2.28%	ND	0.615 0.757%	4.40 5.41%	81.3
(11-12)	ng/g %	ND	2.15 39.0%	ND	2.51 45.5%	0.855 15.5%	ND	ND	5.52
Total:	ng/g %	2.06 0.675%	262 86.1%	6.63 2.18%	9.48 3.11%	3.93 1.29%	2.96 0.973%	17.1 5.63%	305 100%

Table 39
PCB 28, 52, 101, 138, 153, 180, 209 concentrations (ng/g), percent composition and ΣPCBs contaminant load calculated at each sample interval for blue whale BL1. ND=not detected

Length (cm)		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
0	ng/g %	ND	ND	0.617 11.6%	ND	ND	ND	4.68 88.4%	5.30
1	ng/g %	ND	ND	1.37 33.4%	1.70 41.4%	ND	1.04 25.2%	ND	4.11
2	ng/g %	ND	ND	0.555 100%	ND	ND	ND	ND	0.555
3	ng/g %	ND	ND	1.00 19.6%	ND	0.515 10.1%	0.908 17.7%	2.69 52.6%	5.12
4	ng/g %	ND	ND	ND	ND	ND	ND	ND	ND
5	ng/g %	1.17 19.5%	ND	ND	1.58 26.4%	2.03 33.9%	0.567 9.47%	0.644 10.8%	5.98
6	ng/g %	0.493 17.3%	ND	0.773 27.2%	ND	1.57 55.4%	ND	ND	2.84
7	ng/g %	ND	ND	ND	1.16 100%	ND	ND	ND	1.16
8	ng/g %	1.56 29.1%	1.37 25.6%	2.43 45.3%	ND	ND	ND	ND	5.36
9	ng/g %	1.85 20.2%	0.919 10.0%	3.52 38.3%	1.19 12.9%	ND	ND	1.70 18.5%	9.18
10	ng/g %	ND	ND	ND	ND	1.61 23.0%	1.20 17.2%	4.17 59.7%	6.97
11	ng/g %	ND	ND	ND	ND	1.32 100%	ND	ND	1.32
12	ng/g %	60.2 92.4%	ND	0.853 1.31%	ND	1.39 2.13%	0.651 1.00%	2.05 3.14%	65.2

13	ng/g %	ND	ND	ND	ND	1.54 100%	ND	ND	1.54
14	ng/g %	0.686 14.2%	ND	ND	ND	1.58 32.8%	0.714 14.8%	1.84 38.1%	4.82
15	ng/g %	ND	0.293 35.8%	ND	0.526 64.2%	ND	ND	ND	0.819
16	ng/g %	ND	1.34 14.9%	0.695 7.72%	ND	ND	2.15 23.9%	4.81 53.4%	9.00
17	ng/g %	ND	ND	ND	1.07 24.1%	ND	0.341 7.69%	3.02 68.2%	4.43
18	ng/g %	1.47 30.4%	ND	2.51 51.9%	0.443 9.16%	ND	0.415 8.58%	ND	4.84
19	ng/g %	ND	ND	2.83 24.3%	1.78 15.4%	1.70 14.6%	0.951 8.19%	4.36 37.5%	11.6
20	ng/g %	ND	ND	1.39 25.2%	1.32 24.1%	0.874 15.9%	1.15 21.0%	0.757 13.8%	5.50
21	ng/g %	ND	1.39 19.1%	1.46 20.0%	ND	0.423 5.79%	0.913 12.5%	3.12 42.6%	7.31
22	ng/g %	ND	ND	1.54 26.9%	0.898 15.6%	0.712 12.4%	0.224 3.91%	2.36 41.2%	5.74
23	ng/g %	1.49 46.8%	ND	1.08 33.9%	0.612 19.2%	ND	ND	ND	3.19
24	ng/g %	4.26 29.7%	ND	6.78 47.3%	0.658 4.59%	ND	1.20 8.34%	1.44 10.1%	14.3
25	ng/g %	ND	ND	1.55 35.3%	ND	ND	0.482 11.0%	2.35 53.7%	4.38
26	ng/g %	ND	ND	ND	3.27 73.5%	1.18 26.5%	ND	ND	4.45
27	ng/g %	ND	ND	1.26 59.1%	ND	ND	0.872 40.9%	ND	2.13
28	ng/g %	ND	ND	1.02 100%	ND	ND	ND	ND	1.02

29	ng/g %	3.20 37.7%	1.87 22.0%	1.84 21.6%	0.673 7.92%	0.919 10.8%	ND	ND	8.50
30	ng/g %	0.636 1%	42.1 86.1%	2.98 6.10%	0.907 1.85%	1.24 2.54%	ND	1.05 2.14%	48.9
31	ng/g %	ND	ND	1.50 45.1%	1.11 33.3%	0.716 21.6%	ND	ND	3.32
32	ng/g %	ND	40.2 89.1%	2.85 6.32%	1.71 3.80%	ND	0.339 0.75%	ND	45.1
33	ng/g %	ND	ND	0.845 22.8%	1.06 28.6%	1.22 32.9%	0.582 15.7%	ND	3.71
34	ng/g %	ND	34.8 88.7%	ND	0.514 1.31%	1.06 2.71%	0.045 0.11%	2.79 7.12%	39.2
35	ng/g %	ND	ND	4.49 65.9%	ND	0.689 10.1%	0.282 4.14%	1.35 19.8%	6.81
36	ng/g %	ND	ND	7.42 100%	ND	ND	ND	ND	7.42
37	ng/g %	ND	ND	0.921 45.8%	0.400 19.9%	0.409 20.4%	0.279 13.9%	ND	2.01
38	ng/g %	ND	ND	0.826 22.7%	0.596 16.4%	ND	0.376 10.4%	1.83 50.5%	3.63
39	ng/g %	ND	2.36 81.4%	ND	ND	0.326 11.2%	0.214 7.37%	ND	2.90
40	ng/g %	0.667 26.8%	ND	0.611 24.5%	0.685 27.5%	0.528 21.2%	ND	ND	2.49
41	ng/g %	ND	1.68 25.8%	0.550 8.46%	ND	1.41 21.7%	0.872 13.4%	1.99 30.6%	6.50
42	ng/g %	ND	48.1 90.1%	0.708 1.32%	0.811 1.52%	0.613 1.15%	ND	3.18 5.95%	53.4
43	ng/g %	ND	ND	1.17 24.9%	0.874 18.7%	0.689 14.7%	1.00 21.4%	0.951 20.3%	4.68
44	ng/g %	1.07 27.5%	ND	0.900 23.2%	0.550 14.2%	0.734 18.9%	0.629 16.2%	ND	3.88

45	ng/g %	ND	35.4 93.4%	0.550 1.45%	1.50 3.96%	ND	0.468 1.23%	ND	38.0
46	ng/g %	ND	39.5 94.9%	ND	ND	ND	ND	2.12 5.10%	41.7
47	ng/g %	1.10 36.9%	ND	1.88 63.1%	ND	ND	ND	ND	2.98
48	ng/g %	ND	30.0 87.6%	ND	ND	0.896 3%	ND	3.35 9.78%	34.2
49	ng/g %	ND	ND	2.74 60.8%	ND	1.31 29.2%	ND	0.451 10.0%	4.51
50	ng/g %	ND	ND	0.911 35.1%	ND	0.688 26.5%	1.00 38.5%	ND	2.60
51	ng/g %	ND	47.7 85.5%	1.06 1.90%	1.03 1.84%	0.945 1.69%	ND	5.09 9.11%	55.9
52	ng/g %	ND	ND	1.03 100%	ND	ND	ND	ND	1.03
Total (ng/g):	ng/g %	79.9 12.9%	329 53.0%	69.0 11.1%	28.6 4.61%	30.8 4.96%	19.9 3.20%	64.1 10.3%	621 100%

commercially produced pigments, PCB 52 is the primary congener found in yellow pigments with concentrations higher than other PCBs also found in pigments (Anezaki and Nakano, 2014; Vorkamp, 2016). Furthermore, all congeners analyzed in this study are also present in pigments, but at a lesser magnitude than PCB 52 (Anezaki and Nakano, 2014; Vorkamp, 2016). The PCBs from these pigments can enter into the environment via atmospheric currents, air-water exchange, and wastewater dumping with manufacturing plants located in China and California, US (Anezaki and Nakano, 2014; Vorkamp, 2016). It can be hypothesized that the large range and high variability in PCB 52 concentrations could represent times of exposure to anthropogenic sources followed by abiotic and biotic degradation or it could be due to their migratory movements (Rice et al., 2002). On the contrary, PCB congeners that have greater than 5 chlorine atoms typically resist degradation processes (Rice et al., 2002). PCB 101, 138, 153, 180, and 209 all have 5 or more chlorine atoms and together contributed 13.2%-34.8% towards the total ΣPCBs contaminant load among all individuals (Table 33, Fig. 6). Previously conducted studies have found PCB congeners 138 and 153 to have the greatest percent composition in the blubber and earplug cerumen of baleen whales in the North Pacific Ocean (Metcalfe et al., 2004; Trumble et al., 2013; Yasunaga and Fujise, 2020). This same trend was not observed in the baleen of the whales in this study. This could be due to the varying assimilation of POPs among different tissue types (Aguilar, 1984; Varanasi et al., 1994).

3.2.4. ΣHeptachlors

Heptachlor is an insecticide that once in the environment rapidly breaks down into heptachlor epoxide (Rosemund et al., 2007). Heptachlor and heptachlor epoxide have negative impacts on the central nervous system, reproductive system in both humans and wildlife and is listed as a possible carcinogen for humans (EPA, 2006). The ΣHeptachlors contaminant group consists of the sums of heptachlor and heptachlor epoxide. Heptachlor contributed the most by accounting for 85.1%-98.4% (1.64-12.1 ng/g) in gray whales G1, G2 and blue whale BL1 (Tables 40, 41, 42, 46). Heptachlor epoxide contributed the most by accounting for 70.5%-100% (0.224-0.633 ng/g) in humpback whales H1, H2, and minke whale M1 (Tables 40, 43, 44, 45 Fig. 9). Both gray whales showed a similar percent composition with heptachlor dominating the contribution to the ΣHeptachlors. Across all whales heptachlor and heptachlor epoxide were only detected in 36.7% of sample intervals (Tables 41, 42, 43, 44, 45, 46). Both humpback whales also had a similar percent composition, but with heptachlor epoxide dominating the contribution

to the ΣHeptachlors. Heptachlor epoxide is an environmental byproduct formed by the oxidation of the insecticide heptachlor (Kerkhoff et al., 1980; Matsumura, 1975). Approximately 20% of heptachlor that enters the environment is oxidized to heptachlor epoxide within hours of distribution (Rosemund et al., 2007). Both heptachlor and heptachlor epoxide dissolve in water and bind strongly to soil but heptachlor epoxide more readily dissolves in water, has a longer residence time in the environment and has more harmful effects than heptachlor (Rosemund et al., 2007, Wurl and Obbard, 2005). Heptachlor binds more strongly to sediments than heptachlor epoxide (Wurl and Obbard, 2005). It can be hypothesized that the heptachlor dominated individuals (G1, G2, BL1) were either exposed to a more recent input of heptachlor or in the case of the gray whales were coming into contact with heptachlor in the sediments since it readily binds to coastal marine sediments (Rosemund et al., 2007, Wurl and Obbard, 2005). It can also be hypothesized that the remaining individuals (H1, H2, M1) were exposed to a more chronologically distant heptachlor environmental input since the environmentally degraded from, heptachlor epoxide was the primary contributor to ΣHeptachlors.

3.2.5. ΣAldrins

Aldrin, dieldrin, and endrin are all cyclodiene compounds produced and used for their insecticidal purposes (Ayres et al., 1988; Jorgenson, 2001; Zitko, 2003) These cyclodiene compounds are considered to be nerve poisons, having negative impacts on the nervous and reproductive system as well as carcinogenic properties (Anon, 1986; 1988; 1991; Ztiko, 2003). The ΣAldrins contaminant group consists of the sums of: aldrin, dieldrin, and endrin. Dieldrin contributed the most by accounting for 50.6%-88.1% (10.4-88.8 ng/g) of the ΣAldrins contaminant load for all individuals (Table 47, 48, 49, 50, 51, 52, 53 Fig 8). Aldrin was the second greatest contributor accounting for 11.9%-45.3% (6.12-61.4 ng/g) for all individuals except gray whale G2. Gray whale G2 was the only one that had endrin as the second greatest contributor with 22.9% (31.6 ng/g) (Table 49). For all whales except gray whale G2, endrin contributed the least accounting for 0%-4.14% (ND-5.62 ng/g) (Table 47, Fig 8). Both aldrin and dieldrin were produced directly for insecticidal purposes (Ayres et al., 1988; Jorgenson, 2001). However, dieldrin is much more resistant to degradation than aldrin. When released into the

Table 9
Percentages of heptachlor and heptachlor epoxide in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	Heptachlor	Heptachlor Epoxide
G1	85.1%	14.9%
G2	70.2%	29.8%
H1	0%	100%
H2	23.7%	76.3%
M1	29.5%	70.5%
BL1	77.5%	22.5%

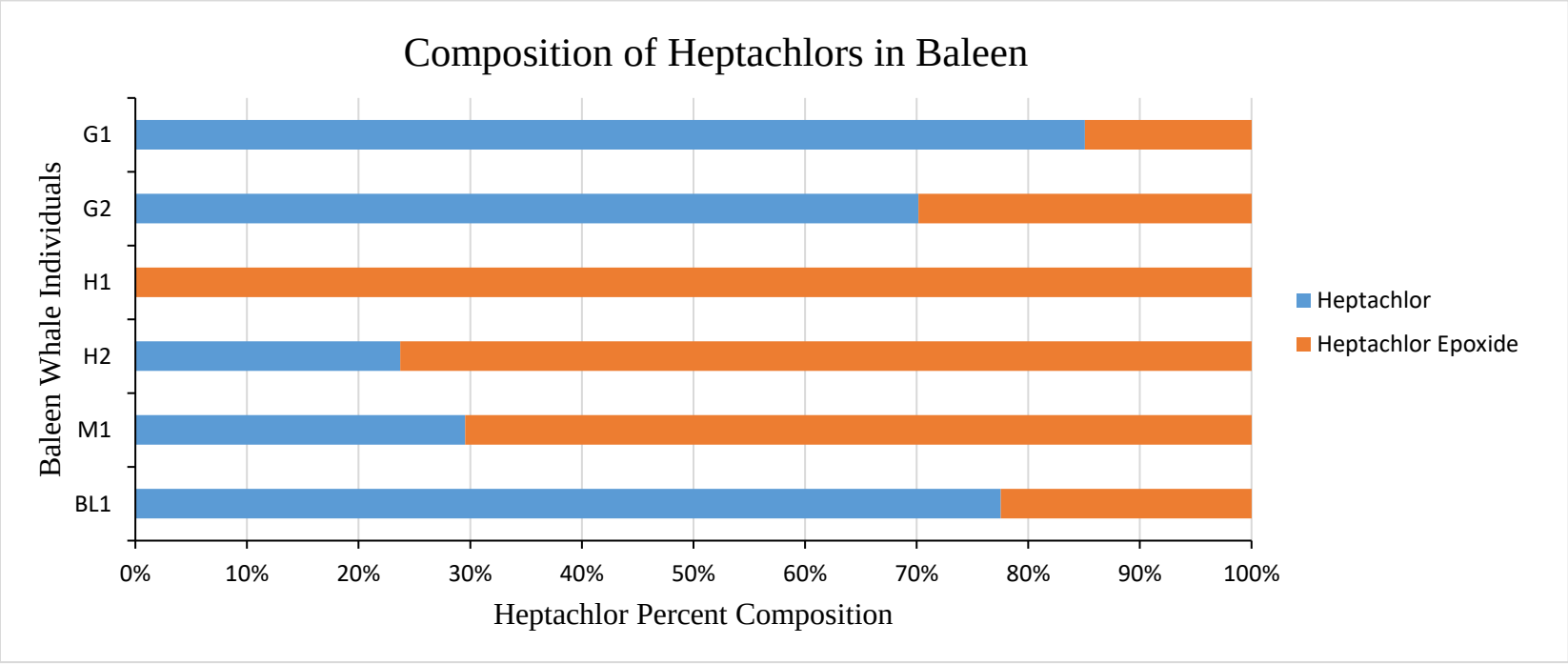


Fig. 7. Percent composition of ΣHeptachlors (Heptachlor, Heptachlor Epoxide) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 41
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for gray whale G1. ND=not detected

Length (cm)		Heptachlor	Heptachlor Epoxide	ΣHeptachlors
0	ng/g %	ND	ND	ND
1	ng/g %	ND	ND	ND
2	ng/g %	0.633 100%	ND	0.633
3	ng/g %	ND	ND	ND
4	ng/g %	ND	ND	ND
5	ng/g %	ND	ND	ND
6	ng/g %	ND	ND	ND
7	ng/g %	ND	0.113 100%	0.113
8	ng/g %	ND	ND	ND
9	ng/g %	ND	ND	ND
10	ng/g %	ND	0.094 100%	0.094
11	ng/g %	1.01 100%	ND	1.01
13	ng/g %	ND	ND	0.00
14	ng/g %	ND	0.081 100%	0.081
15	ng/g %	ND	ND	ND
16	ng/g %	ND	ND	ND
17	ng/g %	ND	ND	ND
18	ng/g %	ND	ND	ND
19	ng/g %	ND	ND	ND
20	ng/g %	ND	ND	ND

21	ng/g %	ND	ND	ND
22	ng/g %	ND	ND	ND
Total:	ng/g %	1.64 85.1%	0.288 14.9%	1.93 100%

Table 42
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for gray whale G2. ND=not detected

Length (cm)		Heptachlor	Heptachlor Epoxide	ΣHeptachlors
0	ng/g %	1.78 100%	ND	1.78
1	ng/g %	ND	ND	ND
2	ng/g %	1.05 73.7%	0.374 26.3%	1.42
3	ng/g %	ND	0.391 100%	0.391
4	ng/g %	0.077 23.5%	0.250 76.5%	0.327
5	ng/g %	0.470 100%	ND	0.470
6	ng/g %	ND	ND	ND
7	ng/g %	0.427 62.1%	0.261 37.9%	0.688
8	ng/g %	0.489 57.9%	0.356 42.1%	0.844
9	ng/g %	ND	ND	ND
10	ng/g %	ND	ND	ND
11	ng/g %	ND	0.077 100%	0.077
12	ng/g %	0.487 100%	ND	0.487
13	ng/g %	ND	ND	ND
14	ng/g %	4.40 100%	ND	4.4
15	ng/g %	0.443 38.6%	0.704 61.4%	1.15
16	ng/g %	ND	0.517 100%	0.517
17	ng/g %	ND	ND	ND
18	ng/g %	ND	0.306 100%	0.306
19	ng/g %	ND	ND	ND

20	ng/g %	1.28 100%	ND	1.28
21	ng/g %	ND	0.223 100%	0.223
22	ng/g %	ND	0.189 100%	0.189
23	ng/g %	ND	0.678 100%	0.678
24	ng/g %	ND	0.242 100%	0.242
25	ng/g %	ND	ND	ND
26	ng/g %	ND	ND	ND
27	ng/g %	0.788 100%	ND	0.788
28	ng/g %	ND	0.074 100%	0.074
29	ng/g %	ND	0.143 100%	0.143
30	ng/g %	ND	ND	ND
Total:	ng/g %	11.3 70.2%	4.79 29.8%	16.0 100%

Table 43
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for humpback whale H1. ND=not detected

Length (cm)		Heptachlor	Heptachlor epoxide	ΣHeptachlors
(0-2)	ng/g %	ND	ND	ND
3	ng/g %	ND	0.231 100%	0.231
4	ng/g %	ND	ND	ND
5	ng/g %	ND	ND	ND
6	ng/g %	ND	ND	ND
7	ng/g %	ND	ND	ND
8	ng/g %	ND	0.052 100%	0.052
9	ng/g %	ND	ND	ND
10	ng/g %	ND	ND	ND
(11-12)	ng/g %	ND	0.051 100%	0.051
(13-14)	ng/g %	ND	0.184 100%	0.184
(15-16)	ng/g %	ND	ND	ND
(17-18)	ng/g %	ND	ND	ND
(19-20)	ng/g %	ND	ND	ND
Total:	ng/g %	ND	0.518 100%	0.518

Table 44
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for humpback whale H2. ND=not detected

Length (cm)		Heptachlor	Heptachlor Epoxide	ΣHeptachlors
0	ng/g %	ND	ND	ND
1	ng/g %	ND	ND	ND
3	ng/g %	ND	ND	ND
4	ng/g %	ND	ND	ND
5	ng/g %	ND	ND	ND
6	ng/g %	ND	0.224 100%	0.224
7	ng/g %	ND	ND	ND
8	ng/g %	ND	ND	ND
9	ng/g %	ND	ND	ND
10	ng/g %	ND	ND	ND
11	ng/g %	ND	ND	ND
12	ng/g %	ND	ND	ND
13	ng/g %	ND	ND	ND
14	ng/g %	ND	ND	ND
15	ng/g %	0.070 100%	ND	0.070
(16-17)	ng/g %	ND	ND	ND
(18-19)	ng/g %	ND	ND	ND
(20-22)	ng/g %	ND	ND	ND
Total:	ng/g %	0.070 23.7%	0.224 76.3%	0.294 100%

Table 45
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for minke whale M1. ND=not detected

Length (cm)		Heptachlor	Heptachlor epoxide	ΣHeptachlors
(0-1)	ng/g %	ND	0.389 100%	0.389
2	ng/g %	0.265 100%	ND	0.265
3	ng/g %	ND	ND	ND
4	ng/g %	ND	0.243 100%	0.243
(5-6)	ng/g %	ND	ND	ND
(7-8)	ng/g %	ND	ND	ND
(9-10)	ng/g %	ND	ND	ND
(11-12)	ng/g %	ND	ND	ND
Total:	ng/g %	0.265 29.5%	0.633 70.5%	0.898 100%

Table 46
Heptachlor and heptachlor epoxide concentrations (ng/g), percent composition and ΣHeptachlors contaminant load calculated at each sample interval for blue whale BL1. ND=not detected

Length (cm)		Heptachlor	Heptachlor Epoxide	ΣHeptachlors
0	ng/g %	ND	ND	ND
1	ng/g %	ND	ND	ND
2	ng/g %	ND	0.411 100%	0.411
3	ng/g %	ND	ND	ND
4	ng/g %	ND	ND	ND
5	ng/g %	ND	ND	ND
6	ng/g %	ND	ND	ND
7	ng/g %	0.335 100%	ND	0.335
8	ng/g %	ND	ND	ND
9	ng/g %	ND	ND	ND
10	ng/g %	ND	0.275 100%	0.275
11	ng/g %	ND	ND	ND
12	ng/g %	ND	ND	ND
13	ng/g %	ND	ND	ND
14	ng/g %	ND	ND	ND
15	ng/g %	0.526 100%	ND	0.526
16	ng/g %	ND	ND	ND
17	ng/g %	ND	ND	ND
18	ng/g %	ND	0.274 100%	0.274
19	ng/g %	2.70 100%	ND	2.70

20	ng/g %	0.126 100%	ND	0.126
21	ng/g %	0.894	0.346	1.24
22	ng/g %	ND	ND	ND
23	ng/g %	ND	ND	ND
24	ng/g %	ND	0.311 100%	0.311
25	ng/g %	0.527 68.2%	0.245 31.8%	0.773
26	ng/g %	ND	0.222 100%	0.222
27	ng/g %	ND	ND	ND
28	ng/g %	2.54 100%	ND	2.54
29	ng/g %	ND	ND	ND
30	ng/g %	3.04 94.5%	0.178 5.52%	3.21
31	ng/g %	ND	ND	ND
32	ng/g %	ND	0.170 100%	0.170
33	ng/g %	ND	ND	ND
34	ng/g %	ND	ND	ND
35	ng/g %	ND	ND	ND
36	ng/g %	ND	ND	ND
37	ng/g %	0.223 100%	ND	0.223
38	ng/g %	ND	0.486 100%	0.486
39	ng/g %	ND	ND	ND
40	ng/g %	0.111 100%	ND	0.111
41	ng/g %	ND	ND	ND
42	ng/g %	ND	ND	ND

43	ng/g %	ND	ND	ND
44	ng/g %	ND	ND	ND
45	ng/g %	ND	0.279 100%	0.279
46	ng/g %	ND	ND	ND
47	ng/g %	ND	ND	ND
48	ng/g %	ND	0.317 100%	0.317
49	ng/g %	ND	ND	ND
50	ng/g %	ND	ND	ND
51	ng/g %	1.10 100%	ND	1.10
52	ng/g %	ND	ND	ND
Total:	ng/g %	12.1 77.5%	3.51 22.5%	15.6 100%

environment aldrin readily breaks down into dieldrin with at least 56% of aldrin transforming into dieldrin (Ayres et al., 1988; Jorgenson, 2001). Aldrin and dieldrin production were stopped in 1998; since production has stopped, greater concentrations of dieldrin have been observed in other marine mammals and has been reported as having a greater biomagnification factor (Gui et al., 2014, Kannan et al., 1994). Dieldrin was also the predominate insecticide used in California, Oregon, and Washington of the United States (Jorgenson, 2001). The increased dieldrin use along the west coast of the United States, tendency of aldrin to degrade into dieldrin, and the persistence of dieldrin in the environment can all allude to the increased percent composition of dieldrin in all individuals for the ΣAldrins class (Tables 48, 49, 50, 51, 52, 53). Bioaccumulation of endrin is not well reported, likely due to its rapid biodegradation in organisms (Zitko, 2003). In the environment however, endrin has an estimated half-life of 4300 days (>11 years) (Zitko, 2003). It is likely, that endrin was rarely detected, only found in 2 samples, due to the rapid biodegradation and excretion processes occurring in the bodies of these baleen whales (Zitko, 2003).

3.3. Temporal Patterns Along the Length of Baleen Plates Within Individual Whales

Baleen is a keratinous tissue that continuously grows, and it can provide a snapshot of information of what is occurring in the myticete's body at the time of growth (Slijper, 1962; Werth, 2013). A benefit to baleen sampling is the increased, continuous timeline of data it can provide. Using baleen, previously conducted studies have successfully created continuous timelines of heavy metal and hormone concentrations recording temporal patterns and oscillations (Hunt et al., 2014; 2018; Pomerleau et al., 2018; Schell et al., 1989; Shore et al., 2020). It can be hypothesized that the organic contaminants quantified in this study are being recorded in the baleen plate in a similar manner to hormones and heavy metals. Baleen plate organic contaminant profiles were created to show the organic contaminant concentrations at each sample interval (every 1 cm) for all individuals (Table 2). Each species has a different average baleen growth rate: gray whales 24.44 cm/yr, humpback whales 17-20 cm/yr, minke whales 12.9 cm/yr, and blue whales 15.5 cm/yr. Therefore, depending on species, 1 cm represents a different period of time (Busquets-Vass et al., 2017; Caraveo-Patiño et al., 2007; Lowe et al., 2021 Mitani et al., 2006). Upon analysis of the baleen POP profiles, patterns were observed temporally.

The baleen plate of gray whale G1 had a sample length of 22 cm (Table 2). In absence of stable isotope data, we used previously calculated average gray whale baleen growth rate of 24.44 cm/yr and approximated that the baleen plate of gray whale G1 represented 0.9 years of information with each cm representing ~18.25 days (Caraveo-Patiño et al., 2007).

0 cm is the base of the baleen plate and is the location of the newest growth. In G1 the last sample interval is located at 22 cm and is the location of oldest baleen growth, growing approximately 0.9 years before sample interval 0 cm. In gray whale G1, increased total organic contaminant loads occur at 0 cm (26.1 ng/g), 7-8 cm (32.6 ng/g, 35.4 ng/g), 16 cm (39.1 ng/g), and 20 cm (32.5 ng/g) (Fig. 9a). At these sample intervals in G1 (0cm, 7-8cm, 16cm, 20-21cm) the total organic pollutant load is the greatest creating a "peak" in the data (Fig 9). These periods of increased POP concentrations range in duration from 0.5-1 month long. In between these sample intervals are periods of lower total organic pollutant concentrations creating a "trough" in the data (Fig 9a). These periods of decreased POP concentrations range in duration from 1.5-3.5 months long. Gray whale G1 was found stranded on 06 July 2019; applying this date to the base of the baleen plate (0 cm) we can approximate that the peaks in organic contaminant load occurred in July 2019 (0 cm), March 2019 (7-8 cm), November 2018 (16 cm), and September 2018 (20 cm).

The baleen plate of gray whale G2 had a sample length of 30 cm (Table 2). In the absence of stable isotope data we approximated that the baleen plate of gray whale G2 represented 1.2 years of information with each cm representing ~18.25 days (Caraveo-Patiño et al., 2007). In G2, peaks of total contaminant load occur at 7-8 cm (60.5 ng/g, 43.4 ng/g), 14-16 cm (51.6 ng/g, 12.1 ng/g, 34.7 ng/g), 22 cm (48.9 ng/g), and 29-30 cm (43.9 ng/g, 46.4 ng/g) (Fig 9b). The peaks in total contaminant load in G2 range in duration from 0.5-1.5 months long. All peaks in G2 are separated by troughs spanning 2.5 months. Gray whale G2 was found stranded on 17 June 2019; applying this date to the base of the baleen plate (0 cm) we can approximate that the peaks in organic contaminant load occurred in February-March 2019 (7-8 cm), October-November 2018 (14-16 cm), July 2018 (22 cm), and March-April 2018 (29-30 cm).

The peaks in total contaminant load concentrations within these two gray whales occur at similar intervals along the length of the baleen plate, corresponding to similar times of the year.

Table 10
Percentages of aldrin, dieldrin, and endrin in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Individual	Aldrin	Dieldrin	Endrin
G1	34.3%	65.7%	0%
G2	12.5%	64.6%	22.9%
H1	37.1%	62.9%	0%
H2	26.2%	73.8%	0%
M1	11.9%	88.1%	0%
BL1	45.3%	50.6%	4.14%

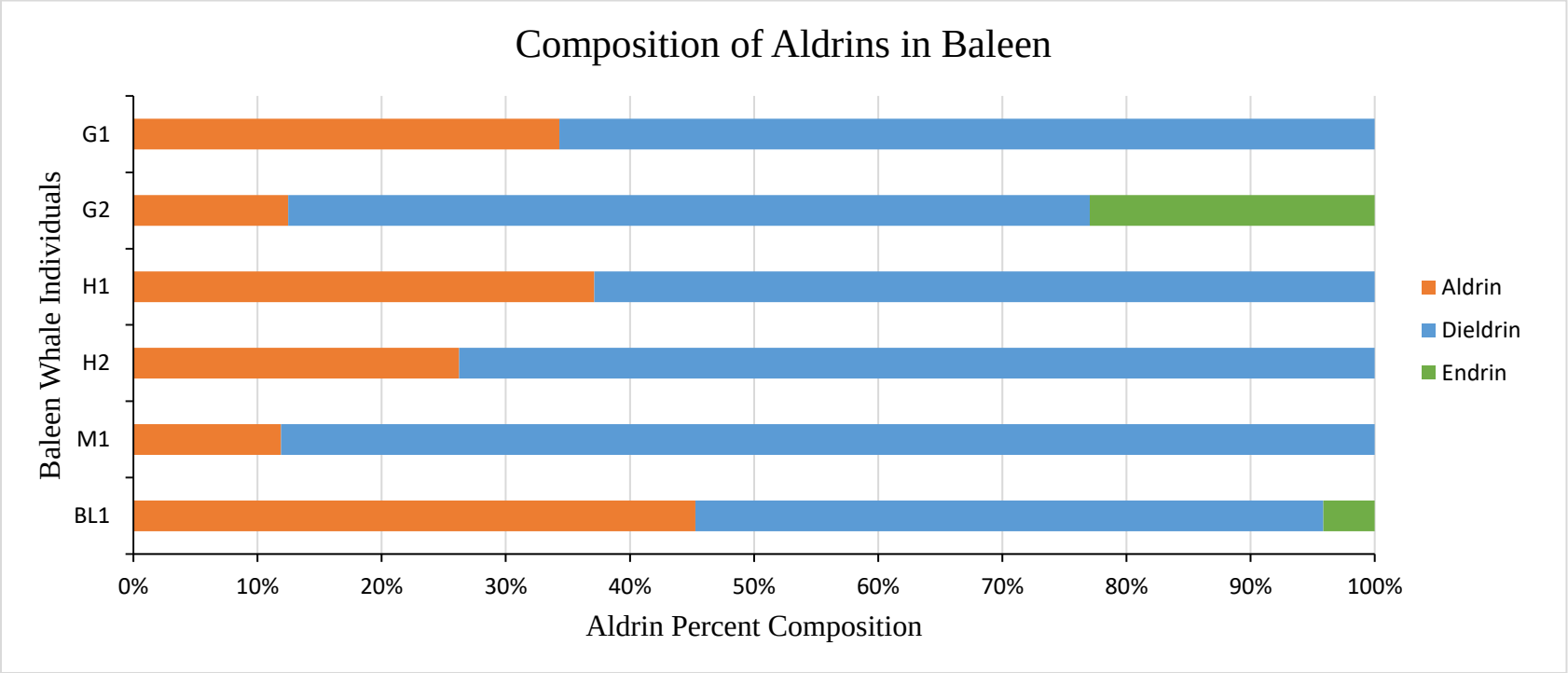


Fig. 8. Percent composition of ΣAldrins (Aldrin, Dieldrin, and Endrin) in the total baleen plate analyzed in the baleen of gray, humpback, minke, and blue whales from the eastern North Pacific Ocean.

Table 48
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for gray whale G1. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
0	ng/g %	ND	2.08 100%	ND	2.08
1	ng/g %	ND	2.02 100%	ND	2.02
2	ng/g %	ND	0.335 100%	ND	0.335
3	ng/g %	ND	ND	ND	ND
4	ng/g %	0.761 100%	ND	ND	0.761
5	ng/g %	0.67 56.2%	0.523 43.8%	ND	1.19
6	ng/g %	ND	ND	ND	ND
7	ng/g %	0.191 36.7%	0.330 63.3%	ND	0.522
8	ng/g %	0.204 12.8%	1.40 87.2%	ND	1.60
9	ng/g %	ND	4.65 100%	ND	4.646
10	ng/g %	0.991 100%	ND	ND	0.991
11	ng/g %	ND	ND	ND	ND
13	ng/g %	ND	ND	ND	ND
14	ng/g %	0.721 28.4%	1.82 71.6%	ND	2.54
15	ng/g %	ND	1.46 100%	ND	1.46
16	ng/g %	0.801 44.5%	1.00 55.5%	ND	1.80
17	ng/g %	ND	1.56 100%	ND	1.56
18	ng/g %	0.598 100%	ND	ND	0.598
19	ng/g %	ND	0.364 100%	ND	0.364
20	ng/g %	ND	0.669 100%	ND	0.669

21	ng/g %	3.86 82.9%	0.797 17.1%	ND	4.66
22	ng/g %	1.12 100%	ND	ND	1.12
Total:	ng/g %	9.92 34.3%	19.0 65.7%	ND	28.9 100%

Table 49
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for gray whale G2. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
0	ng/g %	ND	1.73 100%	ND	1.73
1	ng/g %	ND	ND	ND	ND
2	ng/g %	ND	ND	ND	ND
3	ng/g %	3.61 65.6%	1.89 34.4%	ND	5.50
4	ng/g %	0.288 31.3%	0.635 68.8%	ND	0.923
5	ng/g %	ND	ND	ND	ND
6	ng/g %	1.99 100%	ND	ND	1.99
7	ng/g %	ND	0.411 100%	ND	0.411
8	ng/g %	0.471 25.4%	1.39 74.6%	ND	1.86
9	ng/g %	0.450 8.46%	4.86 91.5%	ND	5.31
10	ng/g %	0.584 31.0%	1.30 69.0%	ND	1.89
11	ng/g %	ND	ND	ND	ND
12	ng/g %	0.889 37.5%	1.48 62.5%	ND	2.37
13	ng/g %	0.80 19.1%	3.40 80.9%	ND	4.20
14	ng/g %	ND	42.8 100%	ND	42.8
15	ng/g %	ND	3.84 100%	ND	3.84
16	ng/g %	1.36 52.6%	1.22 47.4%	ND	2.58
17	ng/g %	ND	0.444 100%	ND	0.444
18	ng/g %	ND	1.16 100%	ND	1.16
19	ng/g %	0.511 60.2%	0.338 39.8%	ND	0.849

20	ng/g %	0.725 16.2%	3.76 83.8%	ND	4.48
21	ng/g %	0.515 16.2%	2.67 83.8%	ND	3.18
22	ng/g %	0.423 1.22%	2.82 8.10%	31.6 90.7%	34.8
23	ng/g %	ND	0.273 100%	ND	0.273
24	ng/g %	ND	2.82 100%	ND	2.82
25	ng/g %	0.215 11.9%	1.59 88.1%	ND	1.80
26	ng/g %	ND	ND	ND	ND
27	ng/g %	0.260 100%	ND	ND	0.260
28	ng/g %	0.507 20.1%	2.02 79.9%	ND	2.53
29	ng/g %	0.286 6.52%	4.10 93.5%	ND	4.38
30	ng/g %	3.27 63.6%	1.87 36.4%	ND	5.14
Total:	ng/g %	17.2 12.5%	88.8 64.6%	31.6 22.9%	137 100%

Table 50
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for humpback whale H1. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
(0-2)	ng/g %	0.175 12.8%	1.20 87.2%	ND	1.37
3	ng/g %	0.532 21.2%	1.98 78.8%	ND	2.51
4	ng/g %	0.580 56.9%	0.440 43.1%	ND	1.02
5	ng/g %	0.224 52.8%	0.200 47.2%	ND	0.424
6	ng/g %	0.400 46.0%	0.470 54.0%	ND	0.870
7	ng/g %	0.233 100%	ND	ND	0.233
8	ng/g %	1.33 70.7%	0.552 29.3%	ND	1.89
9	ng/g %	0.218 21.8%	0.782 78.2%	ND	1.00
10	ng/g %	ND	0.921 100%	ND	0.921
(11-12)	ng/g %	0.420 55.8%	0.333 44.2%	ND	0.754
(13-14)	ng/g %	0.412 24.0%	1.30 76.0%	ND	1.71
(15-16)	ng/g %	0.183 20.0%	0.733 80.0%	ND	0.917
(17-18)	ng/g %	0.938 52.9%	0.833 47.1%	ND	1.77
(19-20)	ng/g %	0.473 42.9%	0.630 57.1%	ND	1.10
Total:	ng/g %	6.12 45.0%	10.4 76.2%	ND	13.6 100%

Table 51
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for humpback whale H2. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
0	ng/g %	ND	1.03 100%	ND	1.03
1	ng/g %	0.649 27.5%	1.71 72.5%	ND	2.36
3	ng/g %	0.096 2.8%	3.34 97.2%	ND	3.44
4	ng/g %	0.442 41.7%	0.618 58.3%	ND	1.06
5	ng/g %	ND	0.528 100%	ND	0.528
6	ng/g %	1.78 51.9%	1.65 48.1%	ND	3.42
7	ng/g %	1.73 65.4%	0.919 34.6%	ND	2.65
8	ng/g %	ND	0.883 100%	ND	0.883
9	ng/g %	0.332 21.1%	1.24 78.9%	ND	1.57
10	ng/g %	0.136 12.8%	0.922 87.2%	ND	1.06
11	ng/g %	2.74 63.2%	1.60 36.8%	ND	4.34
12	ng/g %	0.287 6.6%	4.09 91.4%	ND	4.38
13	ng/g %	0.277 100%	ND	ND	0.277
14	ng/g %	ND	3.44 100%	ND	3.44
15	ng/g %	0.407 21.9%	1.45 78.1%	ND	1.86
(16-17)	ng/g %	0.036 100%	ND	ND	0.036
(18-19)	ng/g %	0.70 83.2%	0.141 16.8%	ND	0.841
(20-22)	ng/g %	0.63 10.8%	5.22 89.2%	ND	5.85
Total:	ng/g %	10.2 26.2%	28.8 73.8%	ND	39.0 100%

Table 52
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for minke whale M1. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
(0-1)	ng/g %	0.695 17.5%	3.28 82.5%	ND	3.97
2	ng/g %	ND	2.48 100%	ND	2.48
3	ng/g %	ND	7.18 100%	ND	7.18
4	ng/g %	2.25 27.8%	5.85 72.2%	ND	8.11
(5-6)	ng/g %	ND	23.6 100%	ND	23.6
(7-8)	ng/g %	ND	1.28 100%	ND	1.28
(9-10)	ng/g %	0.286 4.40%	6.23 95.6%	ND	6.52
(11-12)	ng/g %	3.74 67.8%	1.78 32.3%	ND	5.52
Total:	ng/g %	6.97 11.9%	51.6 88.1%	ND	58.6 100%

Table 53
Aldrin, dieldrin, and endrin concentrations (ng/g), percent composition and ΣAldrins contaminant load calculated at each sample interval for blue whale BL1. ND=not detected

Length (cm)		Aldrin	Dieldrin	Endrin	ΣAldrins
0	ng/g %	0.701 26.6%	1.93 73.4%	ND	2.64
1	ng/g %	0.582 9.80%	5.36 90.2%	ND	5.95
2	ng/g %	0.316 38.4%	0.507 61.6%	ND	0.823
3	ng/g %	9.55 100%	ND	ND	9.55
4	ng/g %	1.87 100%	ND	ND	1.87
5	ng/g %	1.79 59.0%	1.24 41.0%	ND	3.04
6	ng/g %	0.715 21.3%	2.65 78.7%	ND	3.36
7	ng/g %	1.61 63.2%	0.938 36.8%	ND	2.55
8	ng/g %	1.40 62.2%	0.850 37.8%	ND	2.25
9	ng/g %	2.27 63.6%	1.30 36.4%	ND	3.56
10	ng/g %	2.02 66.1%	1.04 33.9%	ND	3.06
11	ng/g %	0.841 11.7%	0.710 9.9%	5.62 78.4%	7.17
12	ng/g %	0.229 12.3%	1.64 87.7%	ND	1.87
13	ng/g %	1.72 37.9%	2.81 62.1%	ND	4.53
14	ng/g %	ND	0.886 100%	ND	0.886
15	ng/g %	1.39 73.5%	0.500 26.5%	ND	1.89
16	ng/g %	ND	ND	ND	ND
17	ng/g %	1.35 60.8%	0.866 39.2%	ND	2.21
18	ng/g %	ND	4.55 100%	ND	4.55
19	ng/g %	ND	0.816 100%	ND	0.816

20	ng/g %	0.640 37.8%	1.05 62.2%	ND	1.69
21	ng/g %	ND	0.663 100%	ND	0.663
22	ng/g %	1.04 67.7%	0.498 32.3%	ND	1.54
23	ng/g %	1.68 26.9%	4.57 73.1%	ND	6.26
24	ng/g %	ND	1.32 100%	ND	1.32
25	ng/g %	15.3 90.8%	1.55 9.2%	ND	16.8
26	ng/g %	0.782 45.6%	0.933 54.4%	ND	1.72
27	ng/g %	0.967 21.0%	3.64 79.0%	ND	4.61
28	ng/g %	ND	0.411 100%	ND	0.411
29	ng/g %	0.227 23.8%	0.730 76.2%	ND	0.957
30	ng/g %	0.626 35.3%	1.15 64.7%	ND	1.78
31	ng/g %	0.670 34.4%	1.27 65.6%	ND	1.94
32	ng/g %	ND	0.366 100%	ND	0.366
33	ng/g %	0.263 19.3%	1.10 80.7%	ND	1.36
34	ng/g %	0.057 6.5%	0.824 93.5%	ND	0.882
35	ng/g %	0.524 22.9%	1.77 77.1%	ND	2.29
36	ng/g %	ND	1.53 100%	ND	1.53
37	ng/g %	0.940 46.3%	1.09 53.7%	ND	2.03
38	ng/g %	0.826 38.0%	1.35 62.0%	ND	2.17
39	ng/g %	0.335 45.0%	0.409 55.0%	ND	0.744
40	ng/g %	0.796 37.1%	1.35 62.9%	ND	2.15
41	ng/g %	0.661 100%	ND	ND	0.661
42	ng/g %	ND	0.887 100%	ND	0.887

43	ng/g %	0.282 30.9%	0.631 69.1%	ND	0.913
44	ng/g %	0.777 58.6%	0.550 41.4%	ND	1.33
45	ng/g %	0.721 17.9%	3.30 82.1%	ND	4.02
46	ng/g %	0.521 38.5%	0.834 61.5%	ND	1.36
47	ng/g %	0.109 23.1%	0.364 76.9%	ND	0.473
48	ng/g %	2.30 66.0%	1.19 34.0%	ND	3.48
49	ng/g %	ND	ND	ND	ND
50	ng/g %	0.536 100%	ND	ND	0.536
51	ng/g %	1.49 23.9%	4.72 76.1%	ND	6.21
52	ng/g %	ND	ND	ND	ND
Total:	ng/g %	61.4 45.3%	68.7 50.6%	5.62 4.10%	136 100%

In both gray whales a temporal trend of peaks and troughs in POP contaminant concentrations is observed. Gray whales have a well-known migration route with individuals traveling through the same geographic areas during predictable times of the year, every year (Pike, 1962, Urbán et al., 2021). The observed temporal patterns in POP peaks within both gray whales are potentially highlighting the predictable and repetitive migratory movements of this species. These data is a possible indication that some location(s) midway along the northward and southward gray whale migratory route are characterized by increased POP concentrations.

Humpback whales have variable baleen growth rates, with average growth rates ranging from 17-20 cm/yr (Lowe et al., 2021). Humpback whale H1 had a sample length of 20 cm (Table 2). Using the average baleen growth rate range of 17-20 cm/yr we estimated that the baleen plate of humpback whale H1 represents 1-1.2 years of information with each cm representing ~15.5-18.25 days (Lowe et al., 2021). In humpback whale H1 the greatest total organic contaminant loads occur at sample intervals 8 cm (49.1 ng/g), (17-18) cm (63.9 ng/g), and (19-20) cm (76.1 ng/g) creating two peaks in POP burden (Fig. 10a). The approximate time elapsed between the two peaks for whale H1 is 4-5 months.

Humpback whale H2 had a sample length of 22 cm (Table 2). Using the average baleen growth rate range of 17-20 cm/yr we approximated that the baleen plate of H2 represents 1.1-1.2 years of information with each cm representing ~15.5-18.25 days (Lowe et al., 2021). Humpback whale H2 has the greatest concentrations of total contaminant load occurring at sample intervals 6 cm (52.1 ng/g), 18-19 cm (52.7 ng/g), and 20-22 cm (49.8 ng/g) creating two peaks in POP burden (Fig. 10b). The approximate time elapsed between the two peaks for humpback whale H2 is 5-6 months.

Although the exact stranding location for humpback whales H1 and H2 is unknown, we do know that both animals stranded in coastal Alaskan waters. It is likely that both animals were part of the Central North Pacific stock, foraging in Alaskan waters in the summer and migrating south to Hawaii for the winter (NOAA 2021b). Without knowing the month or season of death we are unable to draw conclusions about the peak concentrations periods observed. However, similarities in the temporal patterns of POP burden were observed between humpback whales, with both animals having a peak at the tip of baleen growth, approximately one year prior to stranding. Both humpback whales also had an isolated peak of total organic contaminant load occurring at similar locations along the length of the baleen plate,

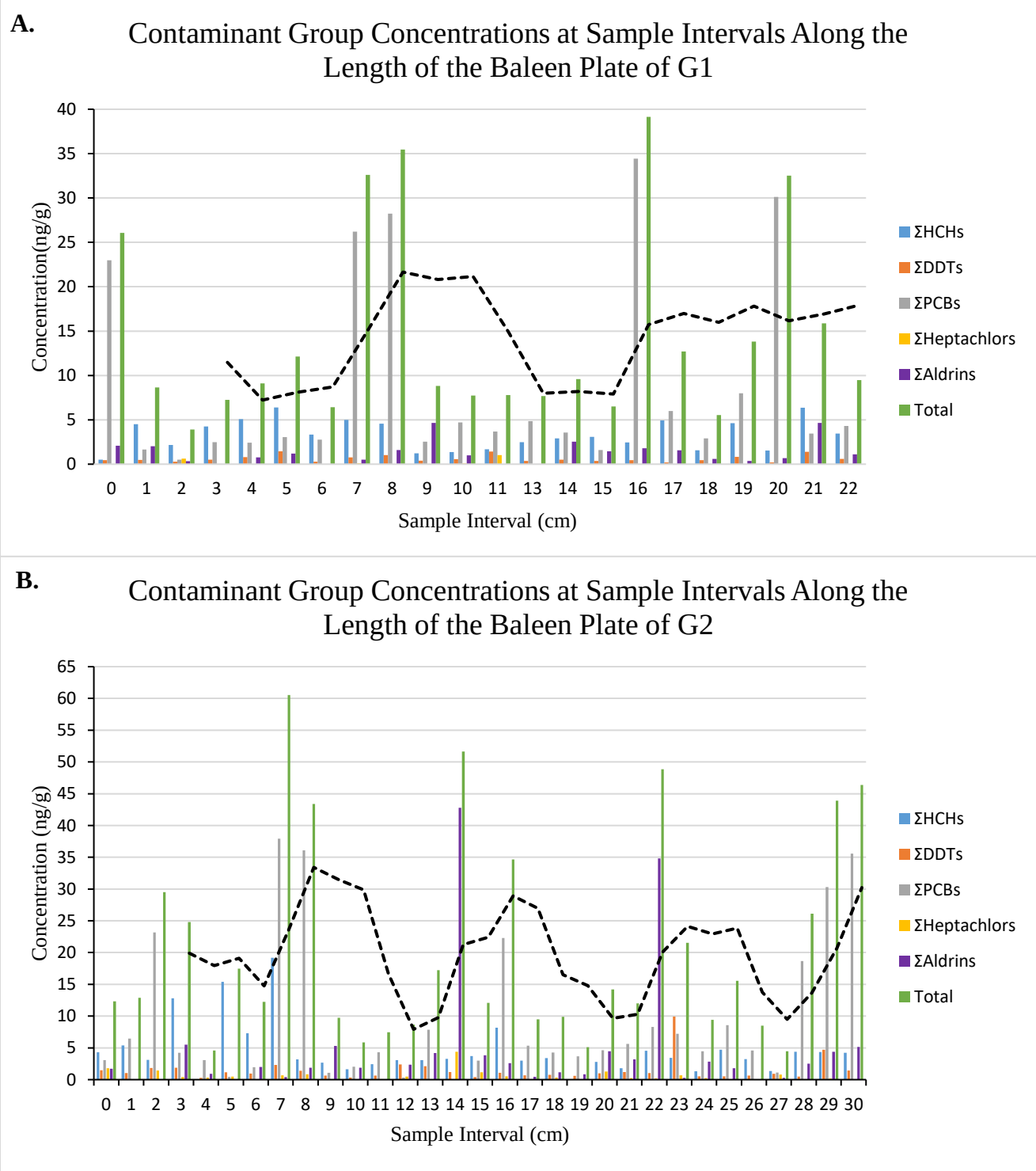
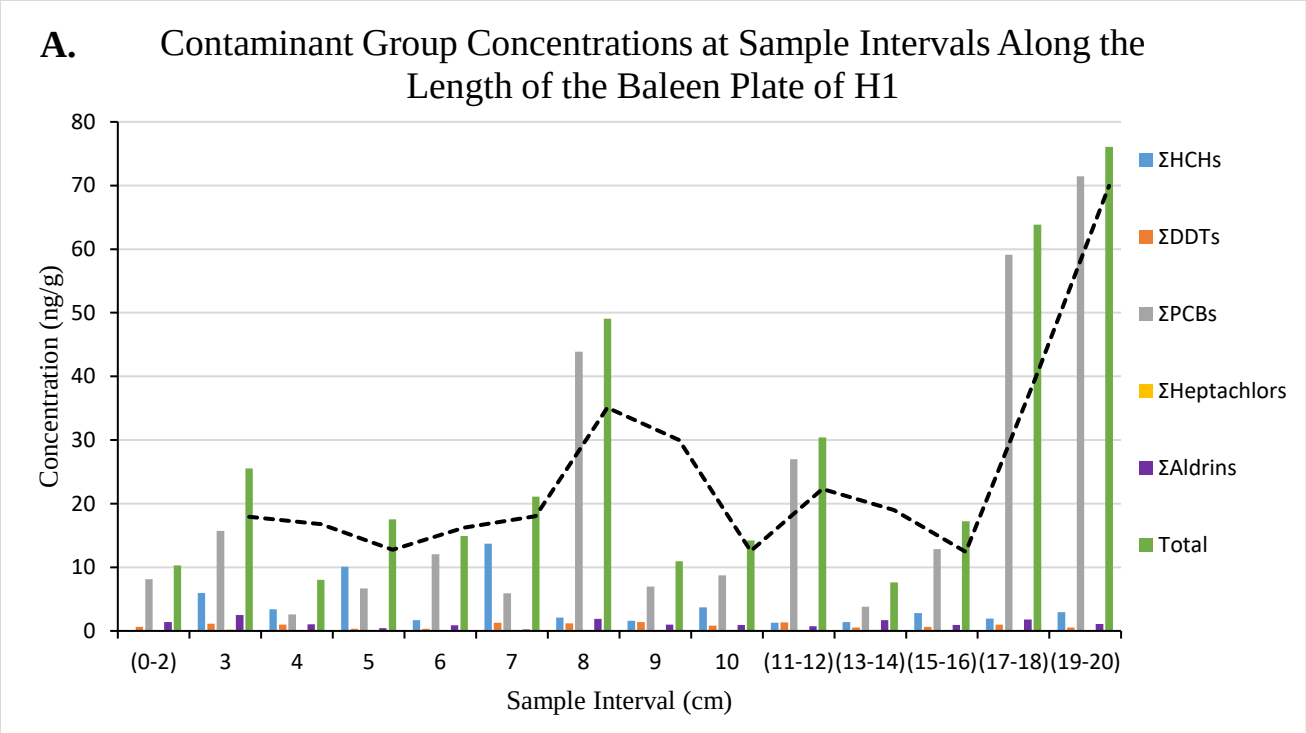


Fig. 9. A. Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for gray whale G1, with the moving average of total contaminant load plotted. **B.** Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for gray whale G2, with the moving average of total contaminant load plotted.



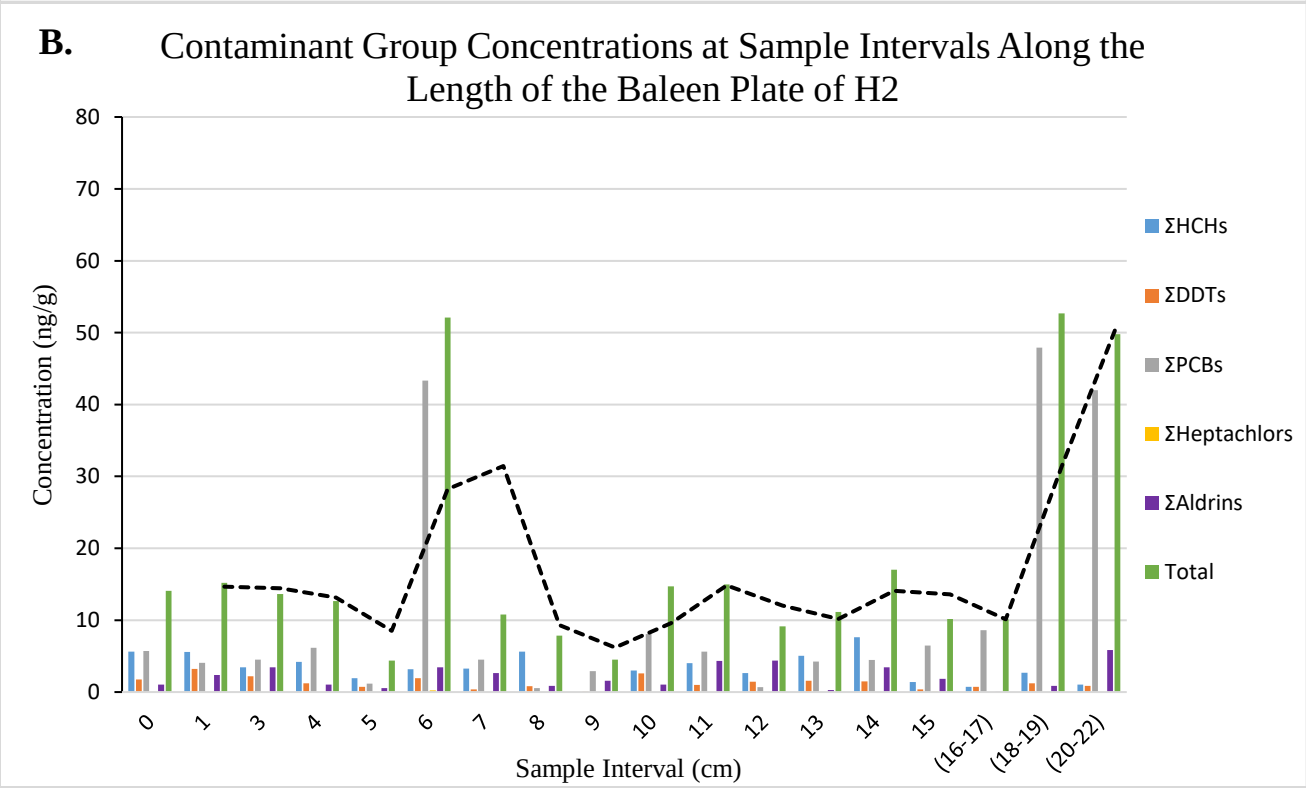


Fig. 10. A. Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for humpback whale H1, with the moving average of total contaminant load plotted. **B.** Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for humpback whale H2, with the moving average of total contaminant load plotted.

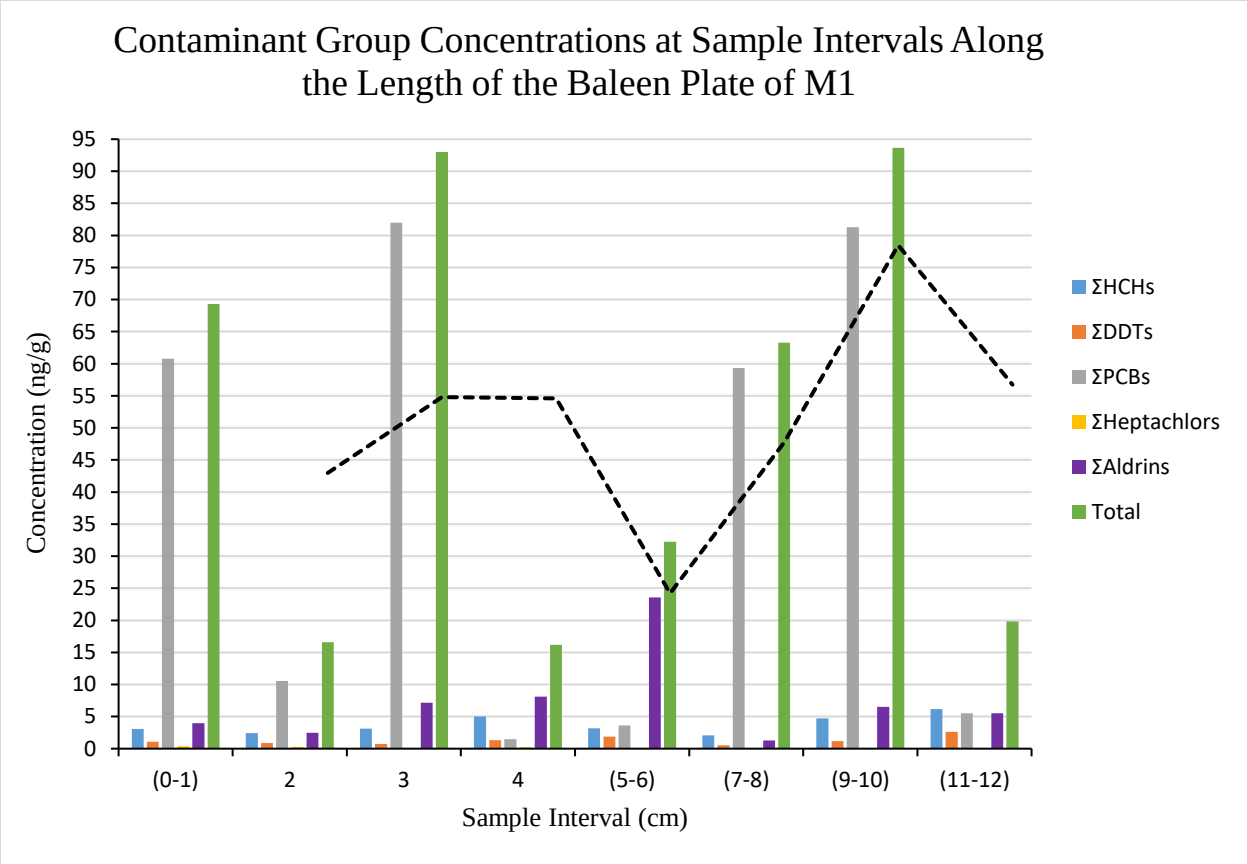


Fig. 11. Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for minke whale M1, with the moving average of total contaminant load plotted.

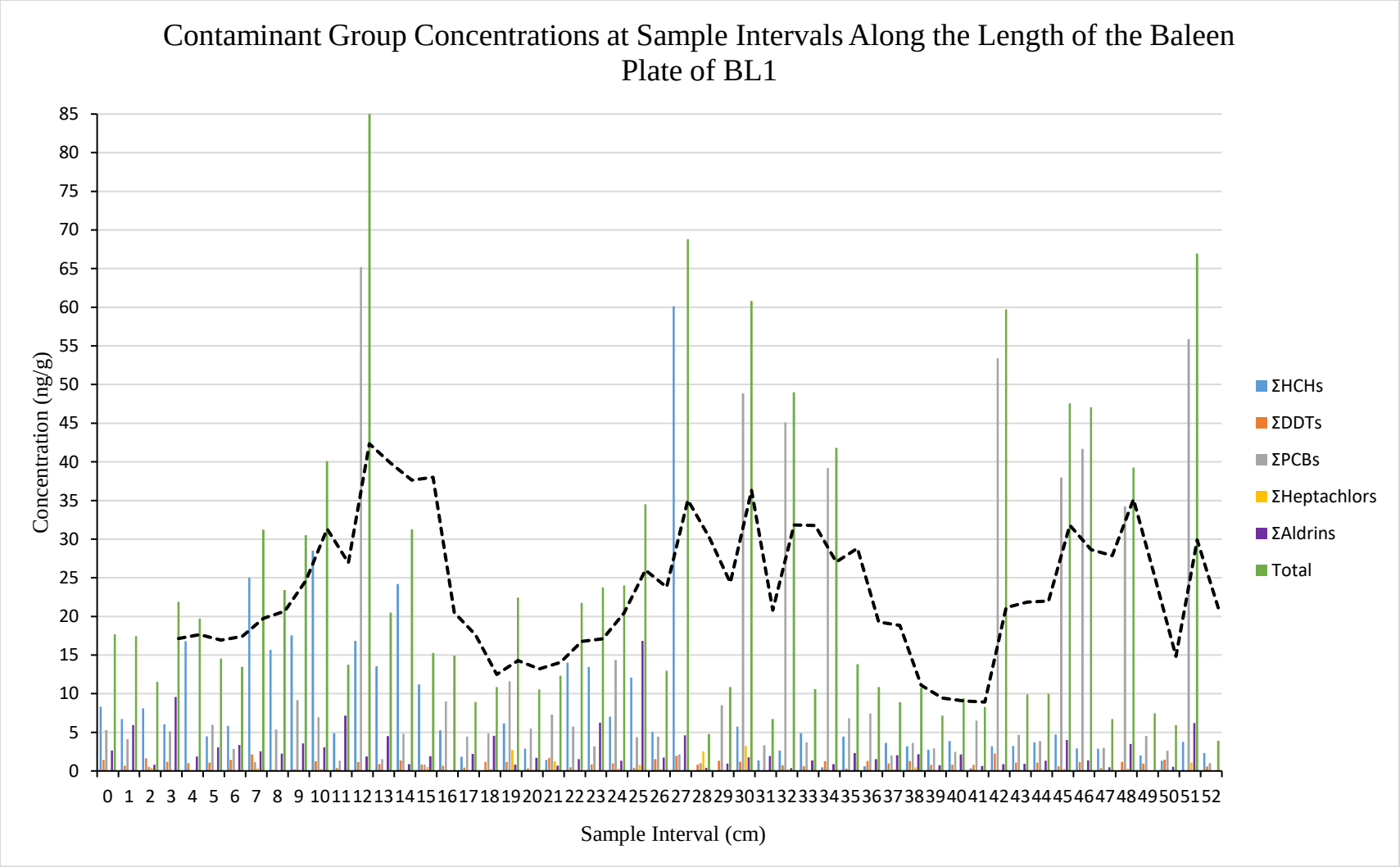


Fig 12. Organic contaminant group concentrations (ng/g) at each sample interval (cm) along the entire length of the baleen plate for blue whale BL1, with the moving average of total contaminant load plotted.

8 cm for H1 and 6 cm for H2. (Fig 10). Both individuals seem to experience a short period of time (0.5 months) of increased POP exposure along their migratory route

Comparatively, minke whale baleen plates are very short, with M1 having a baleen sample length of 12 cm. Using the minke whale average baleen growth rate of 12.9 cm/yr we estimated that the baleen plate of M1 represents 0.930 years of information with each cm representing ~28.29 days (Mitani et al., 2006). In minke whale M1 the greatest total organic contaminant loads occurred at sample intervals 0-1 cm (69.3 ng/g), 3 cm (93.0 ng/g), 7-8 cm (83.3 ng/g), and 9-10 cm (93.7 ng/g) creating three peaks in POP burden (Fig 11). Minke whale M1 stranded in Alaska on 2 June 2021; applying this date to the base of the baleen plate (0 cm) we can approximate that the peaks in organic contaminant load occurred in May-June 2021 (0-1 cm), March 2021 (3 cm), and September-November 2020 (7-8 cm, 9-10 cm). The stranding location of M1 is in the middle of the identified foraging ground for two different stocks. The AK stock is migratory, feeding in Alaskan waters in the summer and migrating offshore to lower latitudes in the winter. The WA/OR/CA stock is residential and does not migrate. Considering these data, the short time period represented, few sample intervals, and unknown movements, it is inconclusive if there is any movement or foraging periodicity in the POP concentrations of this minke whale.

On the contrary, the blue whale baleen plate had the longest baleen plate with individual BL1 having a baleen sample length of 52 cm. Using average blue whale baleen plate growth rate of 15.5 cm/yr it was approximated that the baleen plate of BL1 represents 3.4 years of information with each cm representing ~23.55 days (Busquets-Vass et al., 2017). Throughout the baleen plate of blue whale BL1 there are three general areas that peak in contaminant concentrations and those are from: 8-14 cm (40.1 ng/g, 13.7 ng/g, 85.0 ng/g, 20.5 ng/g), 25-34 cm (13.0 ng/g, 68.8 ng/g, 4.78 ng/g, 10.9 ng/g, 60.8 ng/g, 6.71 ng/g, 49.0 ng/g, 10.6 ng/g, 41.8 ng/g), and 42-51 cm (59.7 ng/g, 9.92 ng/g, 9.98 ng/g, 47.6 ng/g, 47.1 ng/g, 6.73 ng/g, 39.3 ng/g, 7.46 ng/g, 5.93 ng/g, 67.0 ng/g) (Fig 12). The first POP peak in BL1 ranging from sample intervals 8-14 cm represents an approximate duration of 4 months of increased POP exposure. The second POP peak in BL1 ranging from 25-34 cm represents an approximate duration of 7 months. The third POP peak in BL1 ranging from sample intervals 42-51 cm represents an approximate duration of 7 months of increased POP exposure. Between these peaks are clear troughs composed of lower total contaminant concentrations. The approximate duration of time

between POP peak 1 and 2 is 6.5 months, and 6 months between POP peak 2 and 3. The stranding location and exact date are unknown for BL1. However, we do know that this animal stranded along the U.S. West Coast, likely indicating BL1 was in the Eastern North Pacific Stock. Blue whales in this stock migrate north to Alaskan waters to forage and migrate south off the coasts of Mexico. The timeline provided by the baleen plate of blue whale BL1 shows three periods of increased POP exposure. The approximate duration of the peaks of increased POP exposure and duration in between these peaks suggest that the POP peaks could represent annual foraging in the same geographic location. Blue whales do feed exclusively on krill year-round throughout all locations along their migration route (Busquets-Vass et al., 2017). However, it has been determined that POP concentrations in herbivorous zooplankton, like krill, likely reflect the POP concentrations in the water they inhabit (Fisk et al., 2001). The temporal patterns in total organic pollutant peaks and troughs observed along the length of the baleen plate in BL1 could reflect the variation in POP concentrations of their prey depending on location in their migratory route (Busquets-Vass et al., 2017; Fisk et al., 2001).

The distinct highs (peaks) and lows (troughs) observed in the total POP concentrations along the full length of the baleen plate shows that these migratory animals experience times of increased POP exposure as well as times of decreased POP exposure. This could be due to many factors such as location, time of year, and prey. The time of year impacts where these migratory species are located with the summer months being spent in the productive waters at high-latitudes and the winter months being spent at less productive low latitude waters. Similar, repeating temporal trends were discovered in both species where we had more than one representative whale, humpback and gray. It has been reported that higher POP concentrations are found near anthropogenic sources as well as higher latitudes due to atmospheric transport (Beyer et al., 2000; Jantunen and Bidleman, 1996; Lammel and Stemmler, 2012; Li and Macdonald, 2005; Stemmler and Lammel, 2009; Yasunaga and Fujise, 2020). It has also been reported that baleen whales feed year-round with the time of year impacting where these animals are feeding, the type of prey being consumed, as well as the abundance of prey available (Blokhin and Pavlyuchkov, 1988; Busquets-Vass et al., 2017; Fleming et al., 2016; Nerini, 1984). Regional differences in POP concentrations have been observed in the blubber tissues of baleen whales in the North Pacific Ocean (Elfes et al., 2010). Elfes et al., (2010) reported significantly greater POP concentrations in baleen whales feeding in California compared to

other regions along the US West Coast. Elfes et al., (2010) also reported increased HCH concentrations in the blubber of baleen whales located at higher latitudes. These migratory species are moving through waters and ecosystems with varying POP input and concentrations. The baleen plates of these individuals have recorded peaks and troughs of POP concentrations most likely reflecting their migratory movements acting as bioindicators of the locations and ecosystems they inhabit.

3.3. Variation in POP Burden Among Habitat and Foraging Style

Baleen whales are adaptive foragers with each family having a unique primary foraging style, targeting different species of prey (Goldbogen et al., 2007; Pivorunas, 1977). In this study we had representatives from family Balaenopteridae (blue, humpback, and minke) who lunge feed to capture their prey. We also had gray whales who are benthic, suction foragers from family Eschrichtiidae. Geometric means of organic contaminant concentrations were used in the t-tests to look for significant differences in POP concentrations among foraging style (Table 2). The ΣHCHs range of geometric means for benthic foragers (G1, G2) was 2.70-2.86 ng/g and 2.28-3.50 ng/g for lunge foragers (H1, H2, M1, BL1) (Table 58). The ΣDDTs geometric means ranged from 0.546-1.05 ng/g and 0.798-1.16 ng/g for benthic and lunge foraging groups respectively (Table 59).The benthic foraging group ΣPCBs geometric means ranged from 4.98-4.53 ng/g while the lunge foraging group ΣPCBs geometric mean ranged from 5.26-17.3 ng/g (Table 60). The ΣHeptachlors geometric means ranged from 0.018-0.181 ng/g and 0.019-0.063 ng/g for benthic and lunge foraging groups respectively (Table 61). The ΣAldrins range of geometric means was 1.04-11.6 ng/g for the benthic foragers and 1.02-5.31 ng/g for the lunge foragers (Table 62). The geometric mean ranges of the benthic and lunge foraging style groups overlapped for organic contaminant classes ΣHCHs, ΣDDTs, ΣHeptachlors, and ΣAldrins indicating that the POP concentrations for these classes were not significantly different among foraging style ($p>0.05$). The ΣPCBs organic contaminant class did not have an overlapping range in geometric means among foraging groups however, the difference was not statistically significant ($p=0.1105$). T-tests were run for all individual contaminants as well among foraging style with no significant differences ($p>0.05$).

Although the species in this study represent two different foraging styles, all species are generalist and opportunistic foragers which could explain why there were no significant

differences in POP burden found between foraging style (Dehn et al., 2006; Gendron et al., 2001; Mitani et al., 2006; Witteveen et al., 2011). In previously conducted studies it has been observed that these baleen whales in the North Pacific Ocean are located at a similar trophic position with δ15N values ranging from 11.5-13.2 ‰ (Dehn et al., 2006; Gendron et al., 2001; Mitani et al., 2006; Witteveen et al., 2011; Table 54). Nitrogen isotope ratios (δ15N) reflect the prey ingested by the consumer, with a slight enrichment occurring at each trophic level (DeNiro and Epstein, 1978; 1981; Kelly, 2000). δ15N values are frequently used to measure predator-prey interactions and trophic positions (Boecklen et al., 2011). A difference of 3 in δ15N values indicates a difference in trophic levels between organisms (Boecklen et al., 2011; DeNiro and Epstein, 1978; 1981; Kelly, 2000).

All whales included in this study were located in the North Pacific Ocean, however each species has varying migration patterns and movements within this ocean basin (Fig 1). (Baker, 1990; Calambokidis et al., 1989; 2015; Clarke et al., 2013; Dorsey et al., 1990; Pike, 1962; Watkins et al., 2000). Minke and blue whales primarily migrate in offshore, pelagic waters (Calambokidis et al., 2015; Clarke et al., 2013; Dorsey et al., 1990; Watkins et al., 2000). Meanwhile, gray and humpback whales mainly migrate along the U.S. West Coast in neritic waters (Baker, 1990; Calambokidis et al., 1989; Pike, 1962). Individuals were grouped into pelagic (M1 and BL1), and neritic (G1, G2, H1, and H2). The pelagic geometric mean values for ΣHCHs were 3.50 ng/g and 3.45 ng/g for M1 and BL1 respectively (Table 58). The neritic geometric mean values for ΣHCHs were 2.86 ng/g, 2.70 ng/g, 2.45 ng/g, and 2.28 ng/g for G1, G2, H1, and H2 respectively (Table 58). The pelagic group had ΣHCHs concentrations that ranged from nd-60.1 ng/g while the neritic group had ΣHCHs concentrations that ranged from nd-19.2 ng/g (Table 58). There was a significant difference ($p<0.05$) in the ΣHCHs (α-HCH, β-HCH, and γ-HCH) between habitat groups (Fig. 13). The pelagic group had a significantly higher geometric mean of ΣHCHs than the neritic group (Fig. 13). HCH isomers vary by chemical orientation giving them varying properties which cause them to move throughout the environment and ecosystem differently (Walker et al., 1999; Vijgen et al., 2006). Latitude has also shown to influence HCH concentrations with greater HCH concentrations found in the blubber of whales located in higher latitudes (Elfes et al., 2010). Because there were no significant differences in ΣHCHs contaminant load between foraging style, we can hypothesize that the various environmental pathways of HCH isomers are increasing the ΣHCHs contaminant

load in the offshore, pelagic species. Pelagic geometric means of ΣDDTs ranged from 0.798-1.16 ng/g while neritic geometric means of ΣDDTS ranged from 0.546-1.04 ng/g (Table 59). The geometric means for ΣPCBs ranged from 5.26-17.3 ng/g and 4.53-12.6 ng/g for pelagic and neritic habitat groups respectively (Table 60). ΣHeptachlors geometric means ranged from 0.036-0.063 ng/g for the pelagic habitat group and 0.018-0.181 ng/g for the neritic habitat group (Table 61). The geometric means for ΣAldrins ranged from 1.44-5.31 ng/g and 1.02-11.6 ng/g for pelagic and neritic habitat groups respectively (Tabl3 62). The remaining organic contaminant classes had geometric mean ranges that overlapped between habitat groups indicating no significant difference ($p>0.05$). T-tests were ran for all individual contaminants as well among habitat group with no significant differences ($p>0.05$).

A principal component analysis (PCA) was conducted, that included all sample intervals for each individual to increase the sample size. An increased sample size was desirable to provide a more inclusive and accurate understating of the data by incorporating the variability in POP concentrations instead of the simplification of the dataset through a geometric mean. The PCA was used to provide a clearer understanding on determining if habitat and foraging style had an impact on contaminant load. A PCA conducted included all values for each individual contaminant (Fig. 14). The results showed that 11 principal components (PCs) were needed to explain a total of 69.3% of the variance, with each PC explaining less than 8.5% of the data (Table 55). There are no significant groupings among the individuals, indicating that the organic contaminant load is similar among all individuals included in this study. The contaminants were independent factors in contributing to the organic contaminant load in each individual which was also confirmed in a correlation matrix (Fig. 15, Table 56). Few contaminant interactions had an absolute value correlation coefficient greater than 0.200, with the vast majority being very close to 0 (Fig. 15, Table 56). This indicates that the organic contaminants analyzed in this study are acting independently of each other.

A second PCA was ran that included the five contaminant groups used (ΣHCHs, ΣDDTs, ΣPCBs, ΣHeptachlors, and ΣAldrins) instead of the 21 individual contaminants. The results showed that 3 PCs explained a total of 70.5% of the variance in the data (Table 57). Out of the five contaminant groups each PC explained approximately 20% of the variance in the data, implying that each contaminant group had a similar impact on variance in this dataset. PC1 is inversely correlated to ΣHeptachlors and ΣAldrins. PC2 is directly correlated to ΣHCHs and PC3

is inversely correlated to ΣPCBs. Three possible plots were created using the three principal components identified by the PCA results: PC1 vs PC2 (Fig. 16), PC1 vs. PC3 (Fig 17), and PC2 vs PC3 (Fig 18). All three plots showed no significant groupings among the individuals, indicating that the organic contaminant class load is similar among all individuals in the study. In Winfield et al., (2020) a similar result was found where ocean basin had a significant impact on POP burden, but species did not. Although a range of baleen whale species are included in this study, all of them were located in the eastern North Pacific Ocean and are expressing a statistically similar organic contaminant load.

3.5. Baleen POP Burden Compared to Other Tissues

3.5.1. ΣHCHs

HCHs were first introduced into the environment in 1942, despite being banned by most countries for their toxic impacts to the environment and humans in the 1980s they are still used in the tropics today (Iwata et al., 1993; Janutnen and Bidleman, 1996; Li and Macdonald, 2005). At least one HCH isomer was detected at 100% of sample intervals for individuals G1, H1, and M1 (Tables 13, 15, 17). At least one HCH isomer was detected at 93.5%, 94.4%, and 98.1% of sample intervals for individuals G2, H2, and BL1 (Tables 14, 16, 18). The means for the ΣHCHs among the sample intervals in gray whales G1 and G2 were 3.35±1.70 ng/g and 4.56±4.20 ng/g respectively (Table 58). The ΣHCHs in the gray whales ranged from nd-19.2 n/g per sample interval. Tsyankov et al., (2015) reported a ΣHCHs range of 84-3,693 ng/g in muscle tissues and 464-11,075 ng/g in liver tissues of gray whales. The ΣHCHs mean values among the sample intervals for the humpback whales H1 and H2 were 3.78±3.77ng/g and 3.40±2.00 ng/g respectively (Table 58). The ΣHCHs in the humpback whales ranged from nd-13.7 ng/g per sample interval. In the minke whale the ΣHCHs mean among the sample intervals was 3.73±1.42ng/g with a range of 2.07-6.17 ng/g per sample interval (Table 58). Previously reported ΣHCH values for minke whales ranged from 410-1,500 ng/g in blubber samples collected in 2010-2011 (Yasunaga and Fujise, 2020). Minke whale samples collected in 2006 reported a ΣHCH range of 65-430 ng/g in liver samples and 40-2,100 ng/g in blubber samples (Moon et al., 2010). The blue whale mean for ΣHCH was 7.69±9.95 ng/g among the sample intervals with an observed range of nd-60.1 ng/g (Table 58). All of the HCH values either fall within or below the range of previously reported values. Since baleen is made of keratin, a proteinaceous tissue, and

Table 54
$\delta^{15}N$ values for gray, humpback, minke and blue whales.

Species	$\delta^{15}N$ Values	Study
Gray	12.0	Dehn et al., 2005
Humpback	13.2	Witteveen et al., 2011
Minke	11.5	Mitani et al., 2006
Blue	12.9	Gendron et al., 2001

Fig. 13. The geometric means of the pelagic (M1, BL1) baleen whales was significantly higher than that of the neritic (G1, G2, H1, H2) 3.48 ng/g and 2.57 ng/g respectively (p-value= 0.004979).

Table 55
Principal components (PCs) and their % of variance values for the PCA of individual contaminants.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
% of Variance	8.48%	7.96%	7.55%	7.07%	6.67%	5.92%	5.72%	5.25%	5.10%	4.84%	4.77%
Cumulative % of Variance	8.48%	16.4%	24.0%	31.1%	37.7%	43.6%	49.4%	54.6%	59.7%	64.5%	69.3%

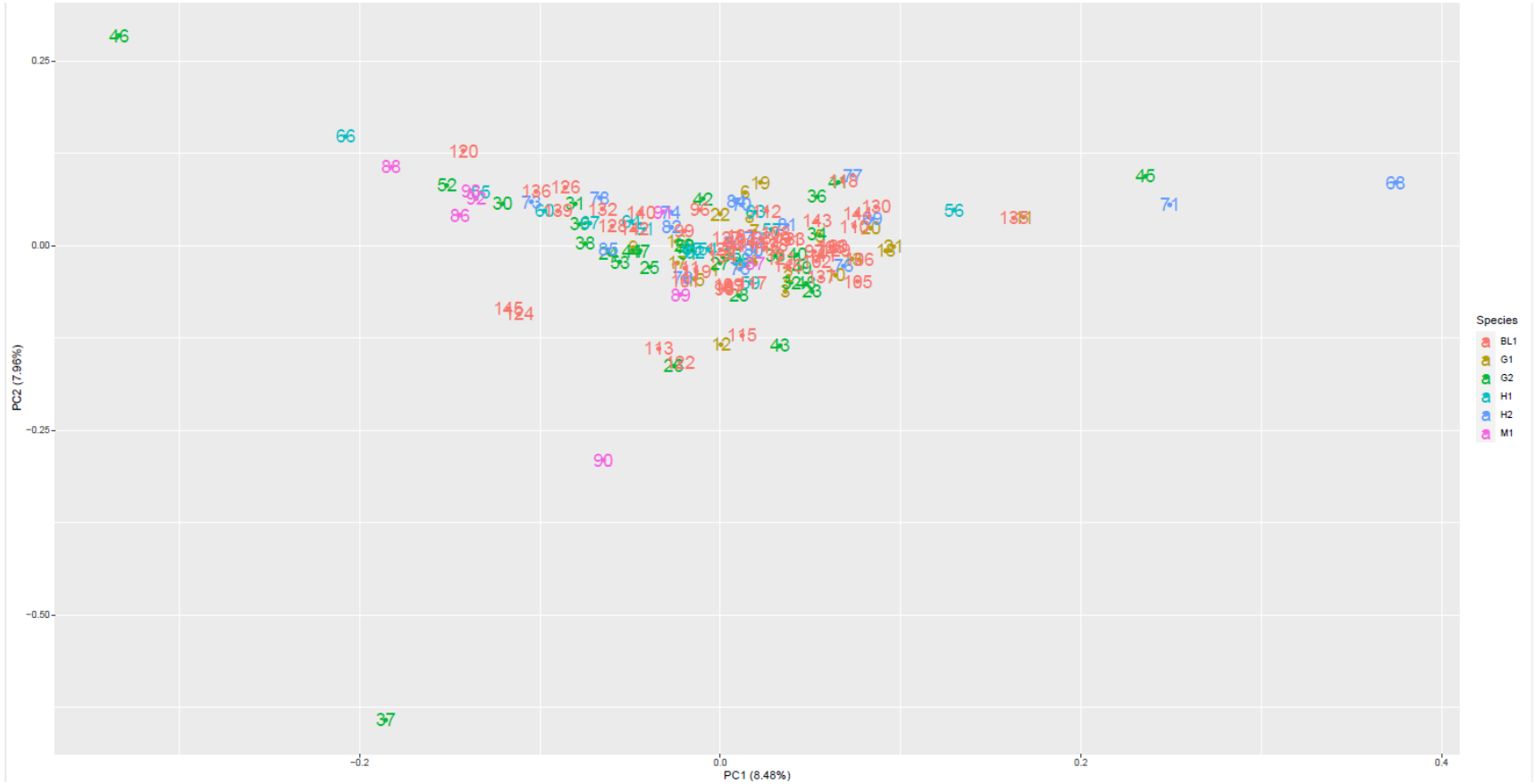


Fig. 14. Distribution of baleen interval samples against the PC1 and PC2 in the PCA analysis for all 21 organochlorine compounds in the baleen plates of blue, gray, humpback, and minke whales from the eastern North Pacific Ocean.

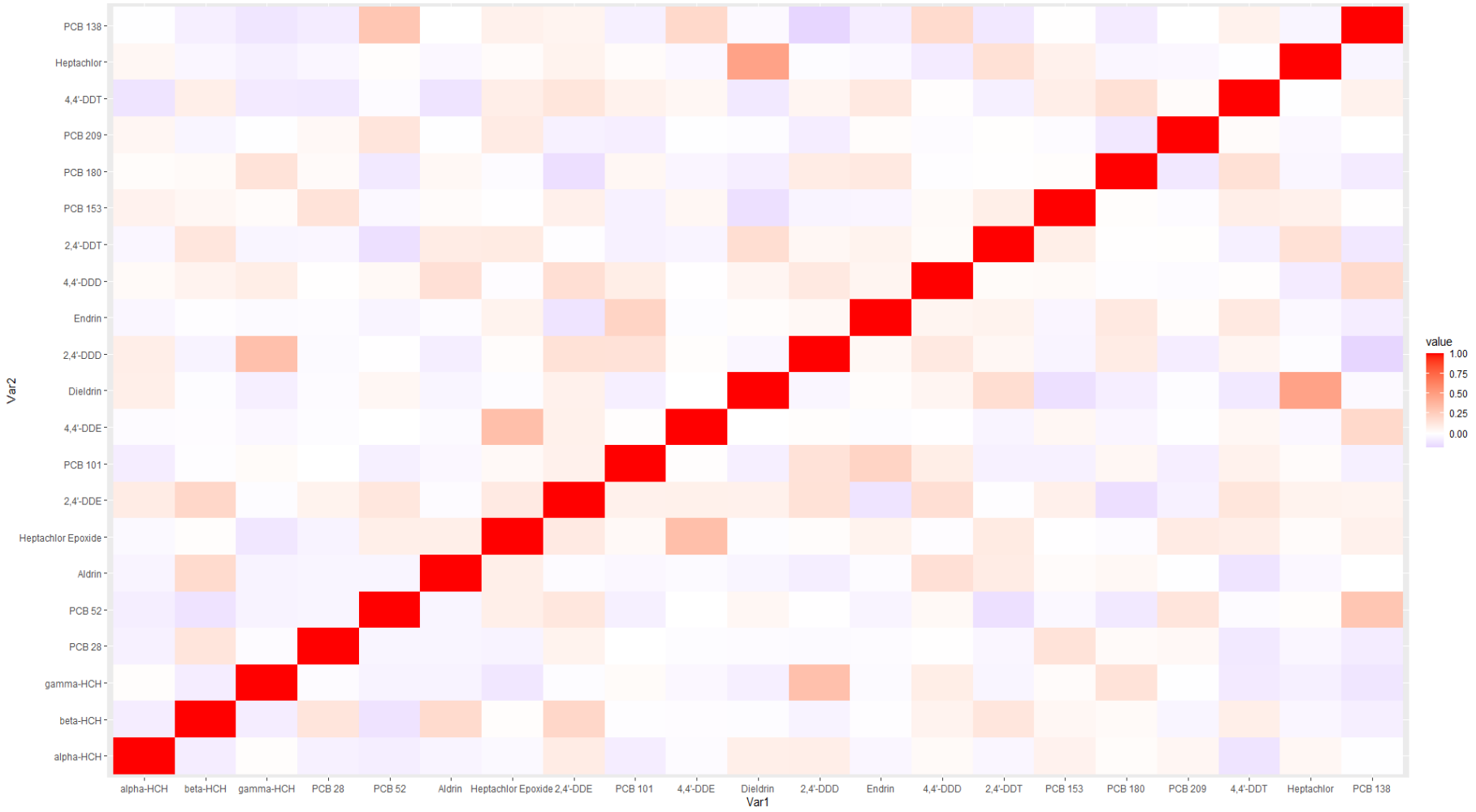


Fig. 15. Individual contaminant correlation matrix across all individuals. White blocks represent a correlation value at or close to 0. Blue boxes represent negative correlations and red boxes represent positive correlations. The bolder and brighter the color of the box is the stronger the correlation. The diagonal of bright red indicates a correlation value of 1, and can provide an example of what a strong correlation would look like. However, these boxes can be ignored because they are indicating that each contaminant is strongly correlated with itself. All correlations between contaminants are consider weak with no value exceeding 0.478.

Dieldrin	2,4'-DDD	Endrin	4,4'-DDD	2,4'-DDT	PCB 153	PCB 180	PCB 209	4,4'-DDT	Heptachlor	PCB 138
0.084	0.088	-0.038	0.029	-0.037	0.067	0.018	0.046	-0.116	0.042	-0.004
-0.014	-0.049	-0.007	0.060	0.132	0.042	0.026	-0.044	0.083	-0.036	-0.068
-0.068	0.326	-0.020	0.091	-0.042	0.020	0.145	-0.004	-0.088	-0.064	-0.108
-0.018	-0.021	-0.016	0.004	-0.040	0.146	0.024	0.036	-0.093	-0.038	-0.079
0.041	-0.002	-0.048	0.033	-0.132	-0.028	-0.094	0.135	-0.016	0.013	0.296
-0.044	-0.073	-0.017	0.160	0.098	0.019	0.038	-0.006	-0.116	-0.034	-0.002
-0.013	0.017	0.064	-0.011	0.107	-0.003	-0.015	0.103	0.090	0.019	0.072
0.072	0.154	-0.116	0.166	-0.008	0.078	-0.134	-0.060	0.134	0.065	0.059
-0.067	0.150	0.223	0.092	-0.060	-0.061	0.041	-0.071	0.067	0.019	-0.065
-0.001	0.013	-0.014	-0.003	-0.045	0.041	-0.041	-0.005	0.040	-0.034	0.202
1	-0.036	0.016	0.051	0.173	-0.130	-0.071	-0.015	-0.093	0.478	-0.024
-0.036	1	0.039	0.116	0.042	-0.045	0.099	-0.078	0.050	-0.013	-0.175
0.016	0.039	1	0.052	0.065	-0.041	0.115	0.015	0.116	-0.029	-0.075
0.051	0.116	0.052	1	0.022	0.026	-0.008	-0.018	0.009	-0.085	0.188
0.173	0.042	0.065	0.022	1	0.086	0.003	0.008	-0.064	0.159	-0.098
-0.130	-0.045	-0.041	0.026	0.086	1	0.010	-0.017	0.090	0.074	0.004
-0.071	0.099	0.115	-0.008	0.003	0.010	1	-0.096	0.159	-0.036	-0.085
-0.015	-0.078	0.015	-0.018	0.008	-0.017	-0.096	1	0.019	-0.032	0.000
-0.093	0.050	0.116	0.009	-0.064	0.090	0.159	0.019	1	-0.004	0.068
0.478	-0.013	-0.029	-0.085	0.159	0.074	-0.036	-0.032	-0.004	1	-0.043
-0.024	-0.175	-0.075	0.188	-0.098	0.004	-0.085	0.000	0.068	-0.043	1

Table 56
Individual contaminant correlation coefficients from the Pearson's correlation matrix.

	α-HCH	β-HCH	γ-HCH	PCB 28	PCB 52	Aldrin	Heptachlor Epoxide	2,4'-DDE	PCB 101	4,4'-DDE
α-HCH	1	-0.076	0.012	-0.059	-0.071	-0.048	-0.027	0.100	-0.077	-0.017
β-HCH	-0.076	1	-0.076	0.135	-0.120	0.190	0.011	0.208	-0.007	-0.011
γ-HCH	0.012	-0.076	1	-0.017	-0.051	-0.052	-0.103	-0.013	0.022	-0.032
PCB 28	-0.059	0.135	-0.017	1	-0.044	-0.042	-0.050	0.065	-0.002	-0.014
PCB 52	-0.071	-0.120	-0.051	-0.044	1	-0.044	0.086	0.128	-0.065	-0.001
Aldrin	-0.048	0.190	-0.052	-0.042	-0.044	1	0.083	-0.018	-0.034	-0.021
Heptachlor Epoxide	-0.027	0.011	-0.103	-0.050	0.086	0.083	1	0.108	0.032	0.334
2,4'-DDE	0.100	0.208	-0.013	0.065	0.128	-0.018	0.108	1	0.073	0.076
PCB 101	-0.077	-0.007	0.022	-0.002	-0.065	-0.034	0.032	0.073	1	0.008
4,4'-DDE	-0.017	-0.011	-0.032	-0.014	-0.001	-0.021	0.334	0.076	0.008	1
Dieldrin	0.084	-0.014	-0.068	-0.018	0.041	-0.044	-0.013	0.072	-0.067	-0.001
2,4'-DDD	0.088	-0.049	0.326	-0.021	-0.002	-0.073	0.017	0.154	0.150	0.013
Endrin	-0.038	-0.007	-0.020	-0.016	-0.048	-0.017	0.064	-0.116	0.223	-0.014
4,4'-DDD	0.029	0.060	0.091	0.004	0.033	0.160	-0.011	0.166	0.092	-0.003
2,4'-DDT	-0.037	0.132	-0.042	-0.040	-0.132	0.098	0.107	-0.008	-0.060	-0.045
PCB 153	0.067	0.042	0.020	0.146	-0.028	0.019	-0.003	0.078	-0.061	0.041
PCB 180	0.018	0.026	0.145	0.024	-0.094	0.038	-0.015	-0.134	0.041	-0.041
PCB 209	0.046	-0.044	-0.004	0.036	0.135	-0.006	0.103	-0.060	-0.071	-0.005
4,4'-DDT	-0.116	0.083	-0.088	-0.093	-0.016	-0.116	0.090	0.134	0.067	0.040
Heptachlor	0.042	-0.036	-0.064	-0.038	0.013	-0.034	0.019	0.065	0.019	-0.034
PCB 138	-0.004	-0.068	-0.108	-0.079	0.296	-0.002	0.072	0.059	-0.065	0.202

Table 57
Principal components (PCs) and their % of variance values for the PCA of individual contaminants.

	PC1	**PC2**	**PC3**
% of Variance	27.7%	22.4%	20.5%
Cumulative % of Variance	27.7%	50.1%	70.5%

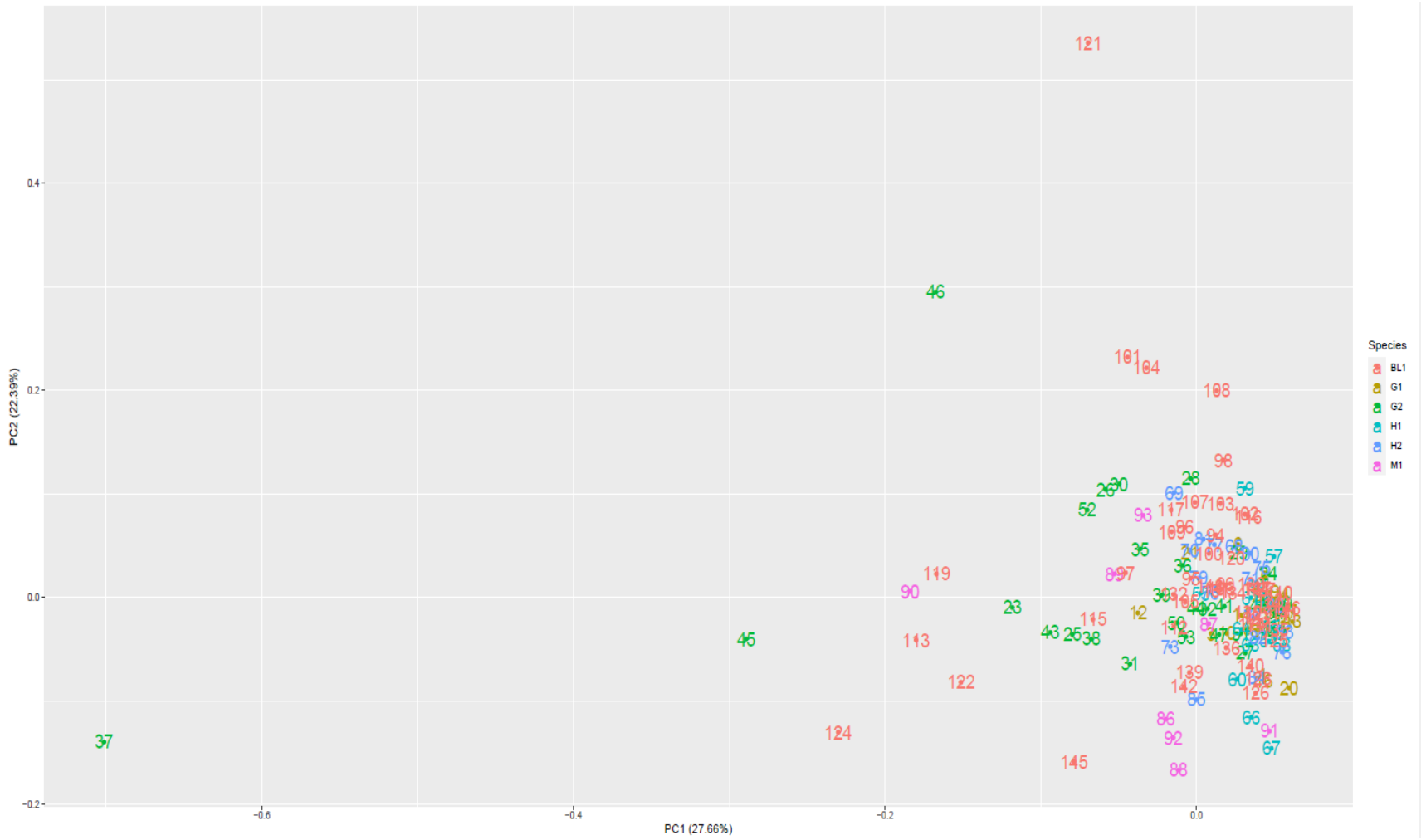


Fig. 16. Distribution of baleen interval samples against the PC1 and PC2 in the PCA analysis for the five organochlorine classes in the baleen plates of blue, gray, humpback, and minke whales from the eastern North Pacific Ocean.

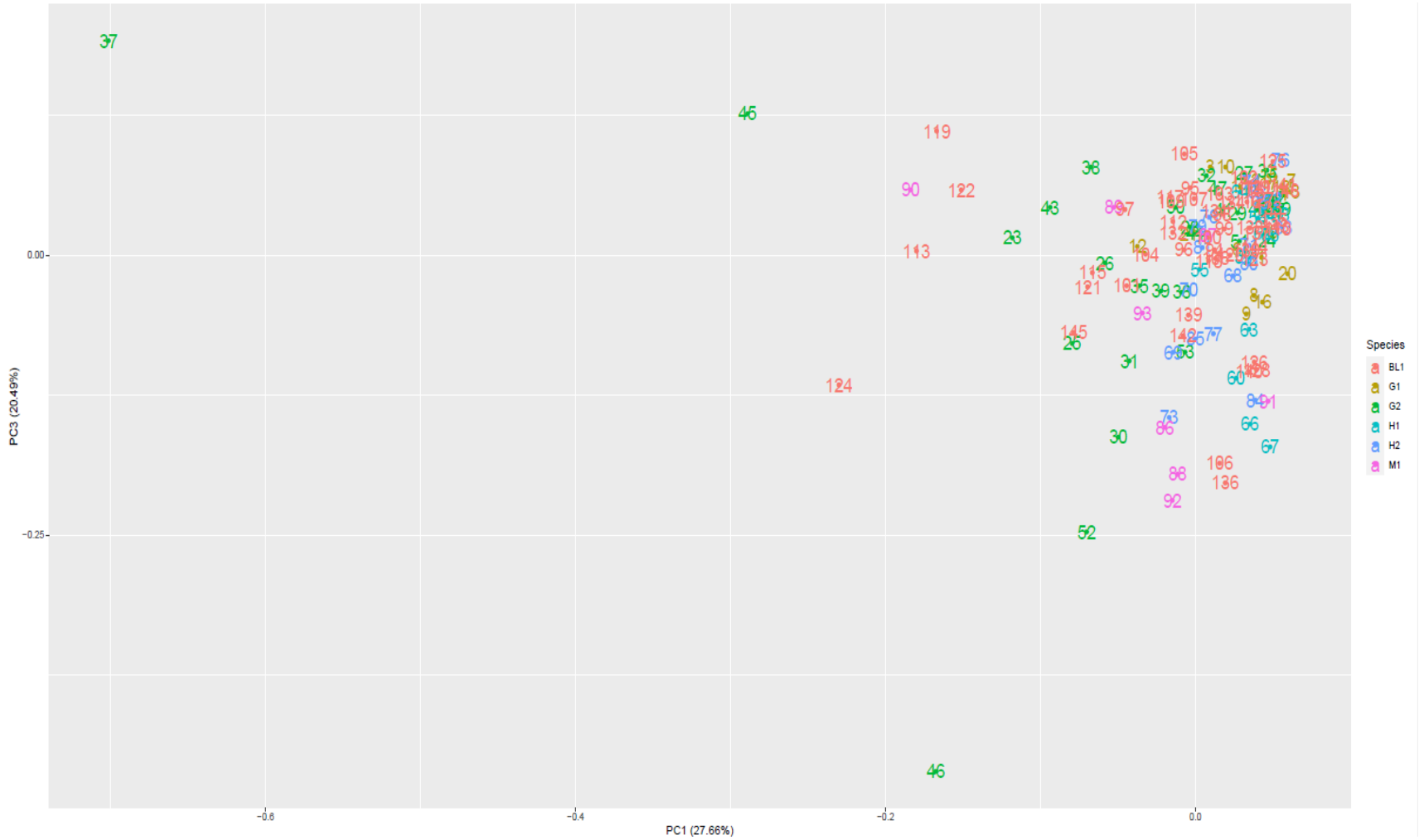


Fig. 17. Distribution of baleen interval samples against the PC1 and PC3 in the PCA analysis for the five organochlorine classes in the baleen plates of blue, gray, humpback, and minke whales from the eastern North Pacific Ocean.

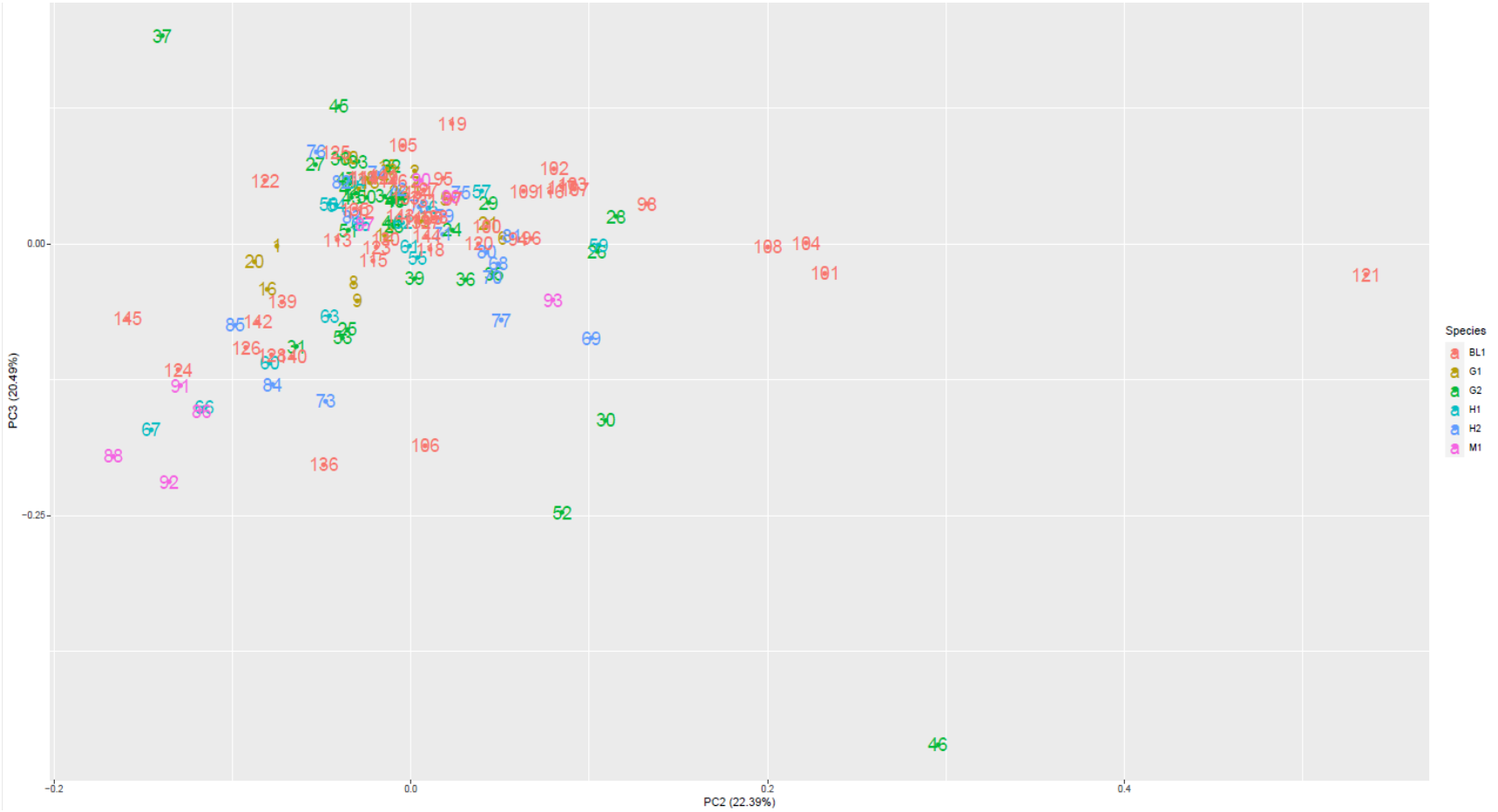


Fig. 18. Distribution of baleen interval samples against the PC2 and PC3 in the PCA analysis for the five organochlorine classes in the baleen plates of blue, gray, humpback, and minke whales from the eastern North Pacific Ocean.

these organochlorine compounds are highly lipophilic it is not surprising that the values are lower than those found in blubber and other tissues throughout the organism.

3.5.2. ΣDDTs

DDT was first commercially produced in 1945 and was used extensively before being banned my most developed countries in the 1970s (Beard, 2006; Mischke et al., 1985). Even so, DDT is still used today in Asian and African countries for malaria control (Stemmler and Lammel, 2009). At least one DDT isomer was detected at 100% of sample intervals for all individuals except BL1, which had at least one DDT isomer detected at 98.1% sample intervals (Tables 20, 21, 22, 23, 24, 25). The means among the sample intervals for the ΣDDTs contaminant class in gray whales G1 and G2 were 0.638±0.382ng/g and 1.48±1.79ng/g (Table 59). The ΣDDTs in the gray whales ranged from 0.196-9.92 ng/g (Table 59). Tsyankov et al., (2015) sampled gray whales in 2010-2011 from the North Pacific Ocean and reported ΣDDTs ranges of 121-875 ng/g in muscle tissue and 71-4,924 in liver tissue. ΣDDTs mean values among the sample intervals for humpback whales H1 and H2 were 0.879±0.361ng/g and 1.32±0.806ng/g respectively (Table 59). The humpback whales had a ΣDDTs range of 0.339-3.20 ng/g (Table 59). Blubber samples from humpback whales sampled along the entirety of the US west coast in 2004 reported a ΣDDTs range of 27-15,000 ng/g (Elfes et al., 2010). The minke whale had a ΣDDTs mean value of 1.29±0.683 ng/g among the sample intervals and ranged from 0.551-2.65 ng/g (Table 59). Minke whale blubber samples have a previously reported ΣDDTs range of 800-5,800 ng/g and 270-11,000 ng/g (Moon et al., 2010; Yasunaga and Fujise, 2020). Minke whale liver samples have a reported ΣDDTs range of 40-1,300 ng/g (Moon et al., 2010). In the blue whale the ΣDDTs mean among the sample intervals was 0.978±0.495 ng/g with values ranging from ND-2.24 ng/g (Table 59). ΣDDTs values in blue whale blubber have been observed ranging from 334-3,350 ng/g in the North Pacific Ocean and 3.50-537 ng/g in the South Pacific Ocean (Fossi et al., 2014; Munoz-Amanz et al., 2019). In earplug cerumen ΣDDTs ranged from 120-830 ng/g (Trumble et al., 2013). ΣDDTs followed a similar trend to ΣHCHs where all values observed in the baleen plates fell below or within the range previously reported in other tissues.

Table 58

Individual specific HCH concentrations (geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and range (ng/g)) in baleen of gray whale, humpback, minke, and blue whales from the eastern North Pacific Ocean. IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

Individual		α-HCH	β-HCH	γ-HCH	ΣHCHs
G1	Geometric Mean (IQR)	0.011 (0)	2.63 (2.88)	0.006 (0)	2.86 (2.87)
	Mean ± SD	0.136 ± 0.316	3.20 ± 1.78	0.019 ± 0.047	3.35 ± 1.70
	Range	ND - 1.20	ND - 6.40	ND - 0.194	0.517 - 6.40
G2	Geometric Mean (IQR)	0.015 (0)	2.36 (0.707)		2.70 (0.508)
	Mean ± SD	0.181 ± 0.466	4.38 ± 4.24	ND	4.56 ± 4.20
	Range	ND - 2.42	ND - 19.2		ND - 19.2
H1	Geometric Mean (IQR)	0.009 (0.002)	2.39 (2.11)	0.006 (0.002)	2.45 (2.02)
	Mean ± SD	0.054 ± 0.128	3.70 ± 3.70	0.021 ± 0.060	3.78 ± 3.77
	Range	ND - 0.423	ND - 13.3	ND - 0.230	0.154 - 13.7
H2	Geometric Mean (IQR)	0.016 (0.179)	2.07 (2.46)	0.007 (0.001)	2.28 (2.70)
	Mean ± SD	0.136 ± 0.256	3.24 ± 1.86	0.028 ± 0.070	3.40 ± 2.00
	Range	ND - 0.805	ND - 7.62	ND - 5.69	ND - 7.62
M1	Geometric Mean (IQR)	0.010 (0.002)	3.29 (0.673)		3.50 (1.89)
	Mean ± SD	0.248 ± 0.687	3.47 ± 1.33	ND	3.73 ± 1.42
	Range	ND - 1.95	2.07 - 6.17		2.07 - 6.17
BL1	Geometric Mean (IQR)	0.012 (0)	2.89 (5.77)	0.005 (0)	3.45 (5.67)
	Mean ± SD	0.149 ± 0.336	7.53 ± 9.98	0.011 ± 0.035	7.69 ± 9.95
	Range	ND - 1.24	ND - 60.1	ND - 0.248	ND - 60.1

Table 59

Individual specific DDT concentrations (geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and range (ng/g)) in baleen of gray whale, humpback, minke, and blue whales from the eastern North Pacific Ocean. IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

Individual		2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD	2,4'-DDT	4,4'-DDT	ΣDDTs
	Geometric Mean (IQR)	0.053 (0.267)	0.046 (0.106)	0.022 (0.071)	0.025 (0.100)	0.039 (0.119)	0.040 (0.223)	0.546 (0.424)
G1	Mean ± SD	0.192 ± 0.196	0.088 ± 0.077	0.048 ± 0.049	0.065 ± 0.069	0.111 ± 0.181	0.133 ± 0.153	0.638 ± 0.382
	Range	ND - 6.04	ND - 0.229	ND - 0.152	ND - 0.266	ND - 0.827	ND - 0.508	0.194 - 1.46
	Geometric Mean (IQR)	0.206 (0.185)	0.058 (0.052)	0.027 (0.033)	0.032 (0.072)	0.051 (0.090)	0.045 (0.125)	1.05 (0.383)
G2	Mean ± SD	0.500 ± 0.448	0.486 ± 1.69	0.065 ± 0.075	0.079 ± 0.073	0.174 ± 0.267	0.172 ± 0.188	1.48 ± 1.79
	Range	ND - 1.77	ND - 8.82	ND - 0.281	ND - 0.224	ND - 1.43	ND - 0.699	0.260 - 9.92
	Geometric Mean (IQR)	0.181 (0.265)	0.027 (0.073)	0.020 (0.059)	0.038 (0.179)	0.030 (0.093)	0.045 (0.247)	0.802 (0.590)
H1	Mean ± SD	0.408 ± 0.275	0.081 ± 1.28	0.044 ± 0.055	0.111 ± 0.104	0.079 ± 0.085	0.155 ± 0.081	0.879 ± 0.361
	Range	ND - 0.910	ND - 0.458	ND - 0.196	ND - 0.922	ND - 0.286	ND - 0.456	0.339 - 1.39
	Geometric Mean (IQR)	0.300 (0.431)	0.080 (0.203)	0.044 (0.133)	0.045 (0.175)	0.023 (0.155)	0.079 (0.262)	1.04 (0.926)
H2	Mean ± SD	0.513 ± 0.341	0.282 ± 0.507	0.143 ± 0.213	0.113 ± 0.119	0.073 ± 0.086	0.194 ± 0.165	1.32 ± 0.806
	Range	ND - 1.32	ND - 2.06	ND - 0.792	ND - 0.427	ND - 0.228	ND - 0.570	0.680 - 3.20
	Geometric Mean (IQR)	0.132 (0.797)	0.113 (0.031)	0.028 (0.072)	0.094 (0.182)	0.051 (0.160)	0.018 (0.164)	1.16 (0.605)
M1	Mean ± SD	0.635 ± 0.651	0.123 ± 0.057	0.057 ± 0.063	0.213 ± 0.177	0.191 ± 0.297	0.072 ± 0.094	1.29 ± 0.683
	Range	ND - 1.93	0.066 - 0.243	ND - 0.173	ND - 0.510	ND - 0.872	ND - 0.210	0.551 - 2.65
	Geometric Mean (IQR)	0.275 (0.363)	0.029 (0.100)	0.032 (0.098)	0.026 (0.109)	0.034 (0.165)	0.038 (0.22)	0.798 (0.646)
BL1	Mean ± SD	0.502 ± 0.337	0.069 ± 0.073	0.067 ± 0.060	0.080 ± 0.096	0.120 ± 0.167	0.140 ± 0.158	0.978 ± 0.495
	Range	ND - 1.78	ND - 0.309	ND - 0.251	ND - 0.374	ND - 0.708	ND - 0.631	ND - 2.24

3.5.3. ΣPCBs

PCB use began in 1929, with an estimated 1.3 million tons being produced globally until the year of 1993 (Breivik et al., 2007, Lammel and Stemmler, 2012). The majority of PCB production occurred up until the 1970s when most developed countries banned its production due to its harmful effects (Longnecker et al., 1997; NOAA, 2009; Wassermann et al., 1979). At least one PCB congener was detected at 100% of sample intervals for all individuals except G2 and BL1 (Tables 34, 36 37, 38). At least one PCB congener detected at 96.8% and 98.1% of sample intervals for individuals G2 and BL1 respectively (Tables 35, 39).The means among the sample intervals for the ΣPCBs contaminant class in gray whales G1 and G2 were 9.13±11.0 ng/g and 9.69±11.5 ng/g respectively with concentrations ranging from nd-37.9 ng/g (Table 60). ΣPCBs values ranged from 79-1600 ng/g in gray whale liver samples and 150-4000 ng/g in blubber samples (Varanasi et al., 1994). The means among the sample intervals for ΣPCBs in humpback whales H1 and H2 were 20.4±22.0 ng/g and 11.2±15.5ng/g respectively with concentrations ranging from 0.535-71.5 ng/g (Table 60). Humpback whale previously reported ΣPCBs concentrations ranged from below the limit of detection to 2,800 ng/g in blubber samples (Elfes et al., 2010). The minke whale had a ΣPCBs mean value of 38.1±36.1 ng/g among the sample intervals with values ranging from 1.49-82.0 ng/g (Table 60). Previously reported ΣPCBs values in minke whale blubber ranged from 1,400- 8,900 ng/g and 390- 6,200 ng/g (Moon et al., 2010; Yasunaga and Fujise, 2020). Minke whale ΣPCBs values in liver samples ranged from 150-4,100 ng/g (Moon et al., 2010). In the blue whale the ΣPCBs mean was 11.7±16.7 ng/g among the sample intervals with values ranging from nd-65.2 ng/g (Table 60). ΣDDTs values in blue whale blubber have been observed ranging from 963-4,535 ng/g in the North Pacific Ocean and 2.97-975 ng/g in the South Pacific Ocean (Fossi et al., 2014; Munoz-Amanz et al., 2019). In earplug cerumen ΣPCBs ranged from 5.9-30 ng/g. ΣPCBs followed a similar trend to ΣHCHs and ΣDDTs where all values observed in the baleen plates fell below or within the range previously reported in other tissues except for the blue whale earplug cerumen.

3.5.4. ΣHeptachlors

Heptachlor use began in the United States in 1953 being used both commercially and domestically until 1988 when it was banned because of its negative health impacts on humans

and the environment (Bidleman et al., 1998). At least one contaminant from the ΣHeptachlors contaminant class, heptachlor or its metabolite heptachlor epoxide, were detected at 21.7% (G1), 67.7% (G2), 28.6% (H1), 11.1% (H2), 37.5% (M1), and 35.8% (BL1) of sample intervals (Tables 41, 42, 43, 44, 45, 46). The means among the sample intervals for the ΣHeptachlors contaminant class in gray whales G1 and G2 were 0.096±0.246 ng/g and 0.537±0.860 ng/g respectively with concentrations ranging from nd-1.78 ng/g (Table 61). The means among the sample intervals for ΣHeptachlors in humpback whales H1 and H2 were 0.045±0.073 ng/g and 0.025±0.053 ng/g respectively with concentrations ranging from nd-0.231 ng/g (Table 61). In a previously conducted study heptachlor was not detected in humpback blubber samples, but heptachlor epoxide was ranging from 16.5-33.2 ng/g (Metcalfe et al., 2004). The minke whale had a ΣHeptachlors mean value of 0.120±0.158 ng/g among the sample intervals with values ranging from nd-0.389 ng/g (Table 61). In the blue whale the ΣHeptachlors mean was 0.302±0.680 ng/g among the sample intervals with values ranging from nd-3.04 ng/g (Table 61).

Metcalfe et al., (2004) also analyzed blue whale blubber and found heptachlor values ranging from 1.0-2.1 ng/g and heptachlor epoxide values ranging from 24.2-216.1 ng/g. More detailed heptachlor concentration information for all individuals from this study can be found in Table 18.

3.5.5. ΣAldrins

Aldrin and dieldrin were both first produced in 1948 followed shortly by endrin in 1951. Aldrin, dieldrin, and endrin are all cyclodiene compounds having similar negative impacts on the environment and humans which ceased their production in the United States in 1986 (Ayres et al., 1988; Jorgenson, 2001; Zitko, 2003). At least one contaminant from the ΣAldrins contaminant class, aldrin, dieldrin, or endrin, was detected at 100% of sample intervals for individuals H1, H2, and M1 (Tables 50, 51, 52). At least one contaminant from the ΣAldrins contaminant class was detected at 82.6%, 83.9% and 94.3% of sample intervals for individuals G1, G2, and BL1 respectively (48, 49, 53). The means among the sample intervals for the ΣAldrins contaminant class in gray whales G1 and G2 were 1.32±1.31 ng/g and 4.76±9.58 ng/g respectively with concentrations ranging from nd-42.8 ng/g (Table 62). Varanasi et al., (1994) analyzed blubber and liver tissue of gray whales for dieldrin and endrin. Dieldrin concentrations

Table 60

Individual specific PCB concentrations (geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and range (ng/g)) in baleen of gray whale, humpback, minke, and blue whales from the eastern North Pacific Ocean. IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

Individual		PCB 28	PCB 52	PCB 101	PCB 138	PCB 153	PCB 180	PCB 209	ΣPCBs
	Geometric Mean (IQR)	0.006 (0)	0.112 (0.889)	0.082 (0.511)	0.059 (0.747)	0.027 (0.485)	0.043 (0.953)	0.059 (2.26)	4.98 (4.89)
G1	Mean ± SD	0.031 ± 0.125	6.07 ± 11.1	0.490 ± 0.631	0.424 ± 0.476	0.247 ± 0.360	0.644 ± 1.15	1.23 ± 1.77	9.13 ± 11.0
	Range	ND - 0.589	ND - 29.9	ND - 1.93	ND - 1.55	ND - 1.06	ND - 4.71	ND - 5.32	0.498 - 34.4
	Geometric Mean (IQR)	0.019 (0)	0.123 (0)	0.325 (0.294)	0.083 (0.433)	0.028 (0)	0.039 (0)	0.063 (0)	4.53 (1.55)
G2	Mean ± SD	0.530 ± 1.58	5.88 ± 11.0	0.841 ± 0.921	0.562 ± 0.642	0.302 ± 0.436	0.394 ± 0.556	1.18 ± 1.82	9.69 ± 11.5
	Range	ND - 8.35	ND - 33.6	ND - 4.76	ND - 2.47	ND - 1.28	ND - 1.89	ND - 8.46	ND - 37.9
	Geometric Mean (IQR)	0.032 (0.603)	0.428 (19.7)	0.064 (0.668)	0.101 (0.896)	0.137 (0.645)	0.008 (0.001)	1.60 (3.56)	12.6 (17.4)
H1	Mean ± SD	1.28 ± 2.39	13.0 ± 21.8	0.529 ± 0.777	0.754 ± 1.08	0.423 ± 0.352	0.040 ± 0.093	4.34 ± 3.17	20.4 ± 22.0
	Range	ND - 5.78	ND - 60.0	ND - 2.70	ND - 1.53	ND - 1.07	ND - 0.312	ND - 11.8	2.60 - 71.5
	Geometric Mean (IQR)	0.017 (0.001)	0.073 (1.73)	0.217 (1.64)	0.049 (0.752)	0.026 (0.677)	0.024 (0.304)	0.120 (1.67)	5.44 (3.56)
H2	Mean ± SD	0.555 ± 1.41	7.06 ± 15.3	1.43 ± 1.85	0.495 ± 0.700	0.316 ± 0.477	0.325 ± 0.668	0.994 ± 1.08	11.2 ± 15.5
	Range	ND - 5.69	ND - 41.6	ND - 7.07	ND - 2.05	ND - 1.27	ND - 2.58	ND - 3.11	0.535 - 47.9
	Geometric Mean (IQR)	0.011 (0.001)	1.19 (59.6)	0.081 (1.25)	0.186 (2.02)	0.064 (0.820)	0.059 (0.702)	0.151 (3.84)	17.3 (60.9)
M1	Mean ± SD	0.262 ± 0.726	32.8 ± 35.3	0.831 ± 1.18	1.19 ± 1.22	0.494 ± 0.625	0.373 ± 0.401	2.15 ± 2.36	38.1 ± 36.1
	Range	ND - 2.06	ND - 77.4	ND - 3.36	ND - 3.16	ND - 1.73	ND - 0.873	ND - 5.46	1.49 - 82.0
	Geometric Mean (IQR)	0.022 (0.488)	0.042 (1.34)	0.303 (1.54)	0.069 (0.902)	0.093 (1.06)	0.059 (0.647)	0.092 (2.12)	5.26 (5.59)
BL1	Mean ± SD	1.51 ± 8.27	6.21 ± 8.27	1.30 ± 1.55	0.543 ± 0.683	0.584 ± 0.611	0.377 ± 0.474	1.21 ± 1.55	11.7 ± 16.7
	Range	ND - 60.25	ND - 48.1	ND - 7.42	ND - 3.27	ND - 2.03	ND - 2.15	ND - 5.09	ND - 65.2

in gray whale blubber ranged from 7-1600 ng/g from animals collected in WA, 4-59 ng/g from animals collected in AK, and 17-85 ng/g from animals collected in CA (Varanasi et al., 1994). Dieldrin concentrations in gray whale liver ranged from 30-95 ng/g from animals collected in WA, 3-34 ng/g from animals collected in AK, and a value of 5 ng/g was recorded in one liver collected from an animal located in CA (Varanasi et al., 1994). The means among the sample intervals for ΣAldrins in humpback whales H1 and H2 were 1.18±1.02 ng/g and 2.17±1.66 ng/g respectively with concentrations ranging from 0.036-5.85 ng/g (Table 62). In a previously conducted study by Metcalfe et al., (2004) humpback blubber tissues were analyzed for aldrin, dieldrin and endrin. Aldrin was not detected in the humpback blubber samples, but dieldrin ranged from 169.7-363.4 ng/g, and endrin ranged from ND- 12 ng/g (Metcalfe et al., 2004). The minke whale had a ΣAldrins mean value of 7.33±6.96 ng/g among the sample intervals with values ranging from 1.28-23.6 ng/g (Table 62). Minke blubber samples were analyzed in 2003 and dieldrin concentrations were reported ranging from 52- 1480 ng/g; endrin concentrations were reported ranging from <1-135 ng/g (Hobbs et al., 2003). In the blue whale the ΣAldrins mean was 2.57±2.87 ng/g among the sample intervals with values ranging from nd-16.8 ng/g (Table 62). Metcalfe et al., (2004) previously reported values from blue whale blubber samples ranged from 0.4-0.8 ng/g for aldrin, 102.8-353.7 ng/g for dieldrin, and 3.3-12.7 ng/g for endrin.

4. Conclusions

This study was the first to quantify organic contaminant concentrations in baleen plates. It provides the first baseline information of polychlorinated organic contaminant concentrations for five different species of baleen whales located in the North Pacific Ocean. Baleen providing a continuous timeline of data showed episodic, temporal trends in POP concentrations along the length of the baleen plate for all whales indicating that these migratory species reflect POP burden differences through time. All lipophilic POP concentrations quantified in the baleen tissue were lower than previously recorded concentrations in other lipophilic tissues (liver, blubber) of the same species, which is likely due to baleen being a proteinaceous tissue. Further research should be done analyzing and comparing organic contaminant concentrations from baleen and other tissues in the same individual to determine how readily contaminant concentrations are being stored in different tissues. In order to also greatly improve our understanding on the episodic, temporal trends in the baleen plates, stable isotope analysis should be done in coordination with organic contaminant data.

Table 61
Individual specific heptachlor and heptachlor epoxide concentrations (geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and range (ng/g)) in baleen of gray whale, humpback, minke, and blue whales from the eastern North Pacific Ocean. IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

Individual		Heptachlor	Heptachlor Epoxide	ΣHeptachlors
G1	Geometric Mean (IQR)	0.007 (0)	0.007 (0.001)	0.018 (0.002)
	Mean ± SD	0.079 ± 0.248	0.017 ± 0.033	0.096 ± 0.246
	Range	ND - 1.01	ND - 0.113	ND - 1.01
G2	Geometric Mean (IQR)	0.026 (0)	0.032 (0)	0.135 (0.237)
	Mean ± SD	0.380 ± 0.866	0.157 ± 0.207	0.537 ± 0.860
	Range	ND - 1.78	ND - 0.704	ND - 1.78
H1	Geometric Mean (IQR)		0.012 (0.035)	0.019 (0.035)
	Mean ± SD	ND	0.040 ± 0.073	0.045 ± 0.073
	Range		ND - 0.231	ND - 0.231
H2	Geometric Mean (IQR)	0.005 (0.001)	0.006 (0.001)	0.012 (0.001)
	Mean ± SD	0.008 ± 0.015	0.017 ± 0.052	0.025 ± 0.053
	Range	ND - 0.070	ND - 0.224	ND - 0.070
M1	Geometric Mean (IQR)	0.008 (0.002)	0.014 (0.061)	0.036 (0.244)
	Mean ± SD	0.037 ± 0.092	0.083 ± 0.149	0.120 ± 0.158
	Range	ND - 0.265	ND - 0.389	ND - 0.389
BL1	Geometric Mean (IQR)	0.013 (0)	0.012 (0)	0.041 (0.271)
	Mean ± SD	0.232 ± 0.663	0.070 ± 0.129	0.302 ± 0.680
	Range	ND - 3.04	ND - 0.486	ND - 3.04

Table 62
Individual specific aldrin, dieldrin, and endrin concentrations (geometric mean (IQR) (ng/g), mean ± standard deviation (ng/g), and range (ng/g)) in baleen of gray whale, humpback, minke, and blue whales from the eastern North Pacific Ocean. IQR = interquartile range, ND = values were less than the limit of detection, SD = standard deviation.

Individual		Aldrin	Dieldrin	Endrin	ΣAldrins
G1	Geometric Mean (IQR) Mean ± SD Range	0.043 (0.704) 0.453 ± 0.853 ND - 3.86	0.140 (1.44) 0.865 ± 1.11 ND - 4.65	ND	0.529 (1.35) 1.32 ± 1.31 ND - 4.66
G2	Geometric Mean (IQR) Mean ± SD Range	0.080 (0.281) 0.555 ± 0.893 ND - 3.61	0.457 (1.09) 2.87 ± 7.55 ND - 42.8	0.008 (0) 1.34 ± 5.87 ND - 31.6	1.04 (1.46) 4.76 ± 9.58 ND - 42.8
H1	Geometric Mean (IQR) Mean ± SD Range	0.287 (0.297) 0.438 ± 0.344 ND - 1.33	0.480 (0.452) 0.741 ± 0.504 ND - 1.98	ND	1.02 (0.746) 1.18 ± 1.02 0.232 - 2.51
H2	Geometric Mean (IQR) Mean ± SD Range	0.155 (0.593) 0.570 ± 0.759 ND - 2.74	0.692 (1.01) 1.60 ± 1.48 ND - 5.22	ND	1.41 (2.51) 2.17 ± 1.66 0.036 - 5.85
M1	Geometric Mean (IQR) Mean ± SD Range	0.073 (1.08) 0.874 ± 1.39 ND - 3.74	4.28 (4.17) 6.45 ± 7.25 1.28 - 23.6	ND	5.31 (3.82) 7.33 ± 6.96 1.28 - 23.6
BL1	Geometric Mean (IQR) Mean ± SD Range	0.255 (1.24) 1.16 ± 2.41 ND - 15.3	0.552 (0.845) 1.30 ± 1.28 ND - 5.36	0.005 (0) 0.110 ± 0.771 ND - 5.62	1.44 (2.16) 2.57 ± 2.87 ND - 16.8

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