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Harbor Porpoise Aggregations in the Salish Sea

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Abstract: Harbor porpoises are typically seen in small groups of 1–3 individuals, with aggregations of 20+ individuals treated as rare events. Since the 1990s, the harbor porpoise population in the Salish Sea has seen a significant recovery, and an increased number of observed aggregations that exceed the more usual small group sizes has been observed in recent years. By combining the observational data of United States and Canadian research organizations, community scientists, and whale watch captains or naturalists, we demonstrate that harbor porpoise aggregations appear to be more common than previously known, with 160 aggregations documented in 2022 alone. Behavioral data also indicate that foraging behaviors are common and social behaviors, like mating, are seen more often during these encounters compared to small groups. Other behaviors that are considered to be rare or unknown were also observed during these encounters, including cooperative foraging and vessel approach. These aggregations are likely important foraging and social gatherings for harbor porpoises. This holistic approach integrating data from two countries and multiple sources provides a population level assessment that more effectively reflects the behavior of harbor porpoises in this region, which do not recognize the socio-political boundaries imposed upon the natural world.

Keywords: harbor porpoise; aggregation; social behavior; *Phocoena phocoena*; foraging behavior; large group; transboundary; community science; Salish Sea

Citation: Anderson, D.; Shuster, L.; Elliser, C.R.; MacIver, K.; Gless, E.J.; Krieger, J.; Hall, A. Harbor Porpoise Aggregations in the Salish Sea. *Oceans* **2023**, *4*, 269–285. https://doi.org/10.3390/oceans4030019

Academic Editors: Alexander Werth and Sam Dupont

Received: 27 May 2023
Revised: 21 July 2023
Accepted: 2 August 2023
Published: 8 August 2023

1. Introduction

Harbor porpoises (*Phocoena phocoena vomerina*) were a commonly observed cetacean in the waters of Puget Sound and throughout the greater Salish Sea region during the 1940s [1], but by the 1970s, their numbers were greatly reduced throughout the Salish Sea within Washington State, USA (hereafter, Washington or WA), and were completely absent from Puget Sound [2,3]. Information on harbor porpoise abundance in the Salish Sea within British Columbia, Canada, (hereafter British Columbia, or BC) prior to the mid-1990s is sparse [4,5] (Hall unpublished data). Several systematic studies spanned the late 1990's and early 2000's that included the inland waters of southern British Columbia [6,7]. Within the last 30 years, there has been a marked increase in harbor porpoise presence in both WA and southern BC waters of the Salish Sea. A recent study integrating passive acoustic monitoring and community observation logs (historic and contemporary) has documented the frequent presence of harbor porpoises near the Port of Prince Rupert, BC, including large aggregations during winter months [8]. Aerial surveys documented harbor porpoise numbers increasing in Washington waters through the 1990s and reentering Puget Sound beginning in 2000 [9,10]. The first sighting of a small group in South Puget Sound, the southernmost area within the Salish Sea, was in September 2005 by two of the authors

(Shuster and Anderson), with regular sightings beginning in 2008 (Anderson, unpublished data). Harbor porpoises are once again the most common cetacean found throughout the Salish Sea; however, knowledge is discontinuous about the species in these waters [11].

Harbor porpoises are found in coastal waters throughout the Northern Hemisphere. Population health and conservation status of harbor porpoises vary by subspecies and region. The global population of *Phocoena phocoena* is listed as a species of Least Concern on the International Union for Conservation of Nature (IUCN) Red List [12]. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) list the Pacific harbor porpoise [13] population as Special Concern. They are not listed as a threatened or endangered species in the United States, nor classified as strategic populations in the Washington State Inland Waters [14]. Entanglement in fishing gear is considered to be the greatest threat (though this is not as prevalent in US/BC waters as other populations in their global range), with pollution, anthropogenic noise and prey depletion being additional concerns [12]. While they are not endangered or threatened, as top predators that remain in these waters year round, they are important indicator species for the health of the Salish Sea. Population recovery provides an opportunity to identify and close knowledge gaps, collect baseline data, understand habitat usage and behavior, and inform conservation recommendations for this unique region [11].

Salish Sea harbor porpoises are most often seen singly or in small groups, averaging less than three animals [10,11,15], which is typical throughout their global range [16]. However, harbor porpoises occasionally come together in larger aggregations (Figure 1 and Figure S1), where many smaller groups are in close proximity to each other. These aggregations can be with animals densely packed in a small area, or spread over several kilometers, possibly consisting of distinct subgroups that are close enough to interact with each other [17–19]. In other regions, some aggregations are thought to be related to seasonal migrations, for example, when ice forms in the Bay of Fundy [20], or herring migrate in the Baltic Sea [21]. In areas where harbor porpoise are not known to migrate, these occurrences are considered spurious and rare and it is suspected they are feeding aggregations located in an area with a high concentration of prey [17].

Figure 1. Harbor porpoise group within an aggregation of an estimated 300+ individuals on 24 February 2021. Photo credit Trevor Derie, Pacific Mammal Research.

The prevalence and importance of aggregations are often dismissed or treated as rare events in the Salish Sea of Washington and British Columbia. In their seminal work on marine mammals in Washington State, Scheffer and Slipp make no mention of larger aggregations, with the observations, "usually in groups of 2 to 5, occasionally 10 to 12", though they do note that, "rarely are more than 3 of a group in sight at one time, although several groups may gather in favored waters" [1]. A literature review of published reference works that include this region indicates that authors predominantly mentioned smaller group sizes, or did not mention group size at all [22,23], while others mention larger

aggregations, usually referring to them as "rare" or "occasional" [24–27], and some works suggested seasonality as a factor influencing larger aggregations with them occurring in summer and early fall [28,29]. The recent study documenting large aggregations during winter months in the waters near the Port of Prince Rupert is an exception [8].

Several surveys for harbor porpoise have been conducted in the northeast Pacific Ocean, including both the Salish Sea and the outer coast, between 1984 and 2015. Only a few note occasional sightings of groups or aggregations of over 20 animals, with only two publications (and three total sightings of 50, 100 and 195 individuals) noted for Salish Sea waters (labeled Inland WA, Table 1). Full survey data were not available for retrospective analysis for either publication. However, the more recent data from aerial surveys by Evenson [9] were available for review and had only one off-effort sighting of an aggregation of over 20 individuals (Evenson, unpublished data). An exception to these data is on the northern BC coast, where harbor porpoise aggregations have been recorded around Prince Rupert, a busy commercial port, with the largest aggregations between December and April, including one of 200–1000 individuals [8]. It is important to note that during line or strip transect surveys, investigators might only record individual groups, not taking note of how multiple groups within a small geographic area create an aggregation.

Table 1. Summary of survey reports for northeast Pacific Ocean harbor porpoise, and whether large groups or aggregations are mentioned. "W. coast" is "West coast", "WA" is Washington, "BC" is British Columbia, "SJDF" is Strait of Juan de Fuca, "SJI" is San Juan Islands, and "SG" is Strait of Georgia.

Region	Dates	Type	Sightings	Citation
W. coast, USA	1984–1986	Ship	852 groups, 2 groups over 20 (0.23%)	[30]
W. coast, USA	1984–1985	Aerial	366 groups, group size range not mentioned	[31]
Inland WA, USA			Two aggregations (50 and 100)	[32]
San Juan Islands, WA, USA	1991–1992	Boat and shore	Four survey types: 301 groups (random boat) with 1 group of "at least 18 harbor porpoise" 125 (fixed boat), 634 (shore abundance), unknown (shore location) includes sighting of 195 individuals	[33]
OR and WA	1991	Aerial	579 groups of 1–7 individuals	[34]
Inland WA	1994–2014	Aerial	1270 groups, 1 aggregation of 28 individuals (0.08%)	[9], Evenson unpub. data
Coastal OR, WA, BC, SJDF, SJI and SG	2002	Aerial	606 groups of 1–7 individuals	[35]
Coastal OR, WA, BC, and SJDF, SJI and SG	2003	Aerial	499 groups of 1–12 individuals	[36]
Inland WA	2013–2015	Aerial	338 groups, mean group size 1.7 No max group size reported	[10]
Northwest BC, Chatham Sound, Prince Rupert	1993–2022	Shore, including community science	626 groups, including 12 aggregations over 31 individuals Largest group was 200–1000 individuals	[8]

Recent observations, however, suggest that these large aggregations may be much more common in the Salish Sea than previously documented. Harbor porpoise aggregations in these waters are not related to migration or icing up, as harbor porpoises are known to remain year-round [6,19], with long-term photo identification (photo ID) [11], genetic data [37], and tag data [38] suggesting the possibility of high site fidelity among this population. On-going photo ID studies in British Columbia are also noting positive identifications of individuals on an inter-annual basis (Porpoise Conservation Society, unpublished data). Long-term sighting data analyses (1991–2008) from British Columbia determined harbor porpoise high density aggregation data are associated with foraging and reproductive behaviors, specific habitats, and oceanographic variables related to tidal phase and mixing [19].

Harbor porpoises are opportunistic feeders, with the majority of their diet composed of small forage fish, along with some cephalopods, crustaceans and arthropods [39,40] and occasionally larger fish are also consumed [41]. A wide variety of forage fish found in the Salish Sea are known food sources for harbor porpoises including Pacific herring (*Chupea pallasi*), Pacific sand lance (*Ammodytes hexapterus*), and surf smelt (*Hypomesus pretiosus*) [42,43]. Salmon and steelhead runs are common in the many rivers entering the Salish Sea [44]. Though salmonids are not considered to be a significant portion of harbor porpoises' diet, as opportunistic feeders, porpoises may eat salmonoid smolts when available [45], and in some locations, porpoises have been observed taking adult salmon [41]. Eulachon (*Thaleichthys pacificus*), a high-fat-content fish, is found in the northern Salish Sea and could serve as an ideal high-calorie food [46]. Traditionally, Northern anchovy (*Engraulis mordax*) was not abundant in these waters until the 2014–2016 Blob event that increased offshore ocean temperatures [47,48] and led to greater abundance of anchovies, especially in South Puget Sound [46,49]. Market squid (*Doryteuthis opalescens*), another staple of harbor porpoises' diet, are also found in South Puget Sound from December through February [46,50].

Large aggregations of harbor porpoises were independently observed by the co-authors and our combined data serve as a method to investigate the occurrence of aggregations throughout the Salish Sea. We compared data from several sources, including small boat surveys, whale watch vessels, land-based marine mammal monitoring field efforts, and community/citizen scientist observers. We quantified the occurrence of these large aggregations, their relation to seasonal patterns, and the prevalence of social behaviors (including mating, fission/fusion of subgroups, coordinated feeding behavior, and willingness to approach vessels) during these groupings. We document that these aggregations occur more commonly than previously thought and suggest that they provide important feeding and socializing opportunities for Salish Sea harbor porpoises.

2. Materials and Methods

2.1. Study Location

The Salish Sea is an inland fjord-like body of water composed of many inlets, passages and bays in Washington and British Columbia (Figure 2). The major basins include the Strait of Juan de Fuca (Juan de Fuca Strait in Canada), connecting to the Pacific Ocean; the San Juan Islands, northeast of the Strait of Juan de Fuca in Washington; the Gulf Islands, in Canada north of the San Juan Islands; the Strait of Georgia, between mainland BC and Vancouver Island; and Puget Sound, south of the east end of the Strait of Juan de Fuca.

2.2. Data Collection

Four organizations contributed harbor porpoise sighting data of aggregation sizes $\geq$ 20 animals for this analysis between February 2017 and March 2023. Data were collected through boat and land-based surveys by local researchers, public reports from community scientists (including a public sighting app), and sighting reports from whale-watch captains and naturalists via a private sighting app.

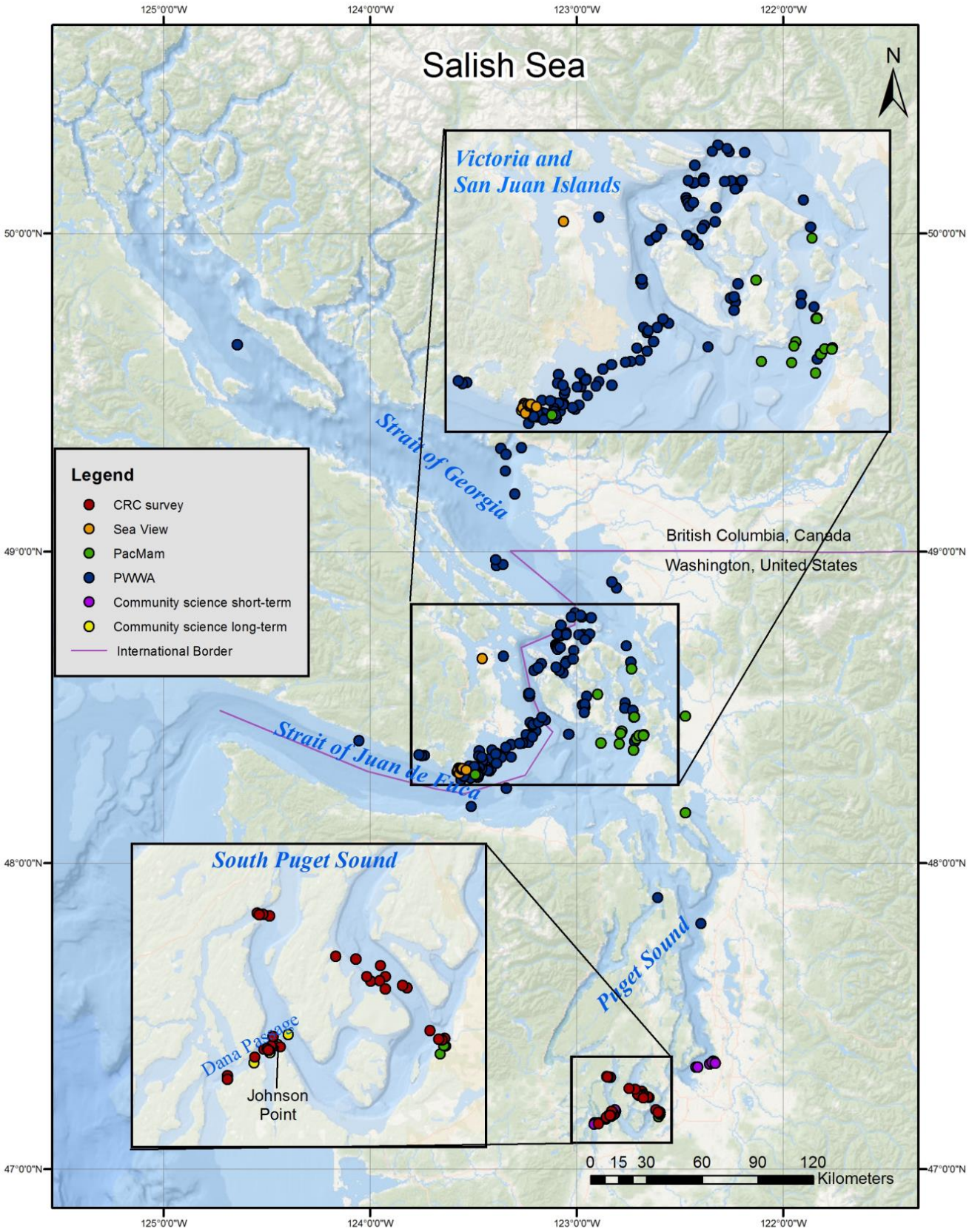

Figure 2. Map of the Salish Sea, including all sighting reports.

2.2.1. Cascadia Research Collective

Cascadia Research Collective (CRC) has conducted year-round, regular, small-boat-based (4.2 m Zodiac) surveys in South Puget Sound since summer 2016. Sightings of all marine mammals are recorded in Google Sheets. Porpoise counts are estimates of the number of animals within good sighting distance from the boat, usually around 300 m, with a Beaufort Sea State of under three. For larger aggregations, several sightings are recorded while passing through the area. Additionally, reports are collected from fishers and community scientist residents living on banks overlooking various locations of Puget Sound. Only reports from experienced observers, or those that supplied photographs or video, were included. Sightings of 31 groups $\geq$ 20 included in this analysis were reported between 9 January 2019 and 11 May 2023.

2.2.2. Pacific Mammal Research

Pacific Mammal Research (PacMam), based in Anacortes, Washington, is a research organization studying harbor porpoises and harbor seals (*Phoca vitulina*) through land-based, long-term photo ID and behavioral surveys. In March of 2021, a custom opportunistic sighting form (PacMam harbor porpoise project) was created using the Epicollect5 app platform through a collaboration with Kwiáht (Center for the Historical Ecology of the Salish Sea). This app allows the public to easily document opportunistic harbor porpoise sightings throughout the Salish Sea. Community science participants were recruited through public presentations and through social media. The majority of sightings are from the general public, though there are some from local researchers. Information on total group size, number of calves, Global Positioning System (GPS) location, weather, tidal phase, boat presence, gull presence, behavior, length of time watching the porpoises, expertise of the observer, and any extra notes can be documented. Data entry is not required for every field and observer expertise varies; therefore, some sighting records do not contain information about each of these factors. To date, users of this app have documented over 300 harbor porpoise sightings throughout the Salish Sea, from South Puget Sound, north to the San Juan Islands, and out the Strait of Juan de Fuca. These sightings are not restricted to large aggregations and range from 1–100+ harbor porpoises. Thus, for this study a subset of the data was used (group sizes $\geq$ 20, and observer expertise level of experienced or expert). Twenty-nine sightings occurring between January and November 2022 were included in this analysis.

2.2.3. Pacific Whale Watch Association

The Pacific Whale Watch Association (PWWA) is a professional association of ecotourism operators in Washington and British Columbia. Whale watching season is primarily March through November, with only a few companies operating year-round. Tours focus on finding large whales, including killer whales (*Orcinus orca*), humpback whales (*Megaptera novaeangliae*), and gray whales (*Eschrichtius robustus*), limiting their operations to areas where the larger whales are likely to be located. As of 2023, the PWWA comprises 30 member companies departing from 23 ports ranging as far south as Seattle, WA, as far north as Telegraph Cove, BC, and as far west as Port Renfrew, BC. PWWA members utilize the private PWWA App, developed by Johannes Krieger in 2018, to record wildlife sightings throughout the Salish Sea. Sightings of harbor porpoises in the region are fairly common and not routinely reported by whale watchers, but for this study, PWWA captains and naturalists were asked to document "large aggregations" of harbor porpoises, groups of 10 or more individuals, beginning in April 2021. Included in this analysis were 146 sightings of groups $\geq$ 20 occurring between February 2021 and December 2022. Sightings records in the PWWA App include species, group size, travel direction (if known), time, date, and GPS location of the sighting.

2.2.4. Sea View

Sea View Marine Sciences (Sea View) specializes in marine mammal research, monitoring, and mitigation. Sea View is on Vancouver Island near Victoria, British Columbia and has worked extensively in southern BC waters conducting numerous field assessments and research projects with professional biologists and observers. From 2017 to 2023, harbor porpoise group size and behavioral data were collected by Sea View as part of a larger Marine Mammal Monitoring Program of the Canadian Department of National Defence (DND) training operations in the Salish Sea. Field efforts and data collection were conducted entirely in Canadian waters and were conducted according to the DND schedule. Sightings of 14 groups $\geq$ 20 between August 2018 and September 2022 were included in this analysis.

2.2.5. All Data

Duplication of sightings across platforms was possible; therefore, care was taken to remove these from the data. Sighting reports from PWWA vessels, which were duplicated in the PacMam data, using criteria of same day, location and reporting party, were deleted from the PacMam data. Reports to CRC that matched PacMam data were deleted from CRC data. Potential duplicates in PacMam and PWWA data were removed by checking for reports on the same day with locations within 2 km (20–49 individuals), 4 km (50–99 individuals), or 8 km (>100 individuals), without islands between reported locations, where only one of the two or more sightings were kept for analysis. The encounter with the highest estimate of individuals was kept, as the aggregations could grow over time. No duplications were found in the PacMam data, and 20 sightings were removed from the PWWA data.

Large aggregations can cover several square kilometers, so even accurate GPS locations taken within the aggregation do not represent the extent of the entire aggregation. Map of sightings was generated using ArcMAP 10.8.2. (Figure 2).

The timing of these aggregations can vary, and we differentiate between long- and short-term events. Long-term aggregations are defined as harbor porpoises remaining in the same area, in large numbers (20+), lasting at least one week, as documented by observers recording the presence of the aggregation on multiple days with good sighting conditions, with few gaps of more than a few days. Short-term aggregations are defined as large numbers of harbor porpoises (20+), usually lasting for a few hours, or up to a few days at most.

To determine the temporal occurrence of these events, results from each dataset were analyzed to determine if aggregations occurred throughout the year. Additional analysis of possible variation in occurrence relating to seasonality was not conducted, as much variability is due to bias in observer effort. (For example, opportunistic data are highly biased toward summer and early fall, when weather is best and more boats are on the water).

All contributing groups recorded porpoise behavior, paying particular attention to those rarely seen outside of these aggregations, especially social and unique foraging behaviors not possible in smaller groups. CRC and PacMam data were analyzed for the frequency of occurrence of behaviors in large versus small groups. CRC data were from dedicated boat surveys and have more detailed descriptions of behavior. Frequencies of probable foraging, traveling, probable mating, vessel approach, vessel avoidance, fission–fusion, logging, side surface feeding, and general splashing (non-mating breaching, tail slaps, chases, porpoising) were compared between large and small groups. For PacMam app data, the options for behavior are more general, as the app is for public use. Frequencies of "traveling in one direction" (travel), "play, socializing, leaping" (social), and dives/surface chases, probable feeding (foraging) were compared between large and small groups. In both datasets, some sightings had more than one behavior documented. In these cases the sighting was scored for each of those behaviors, so a sighting with both foraging and travel behaviors would be scored as a foraging sighting and a traveling sighting to accurately analyze the frequency of behaviors. Because of this, the total number of sightings used in

the frequency analysis is more than the actual total number of sightings. Analysis of this type could not be conducted for the PWWA App data because those users were specifically asked to document larger groups (10 or more individuals); thus, the data are biased to larger groups and does not include enough smaller groups for comparison. Sea View's research occurred during DND training operations. Data presented in this publication were used with DND authorization and approval for analysis of harbor porpoise high-density aggregations observed during the Marine Mammal Monitoring Program. DND approval was granted for analysis for large aggregations only, so comparison with smaller groups was not possible with these data.

3. Results

3.1. CRC Data

CRC has conducted 97 surveys since 2016, covering 8790 km in the South and Central basins of the Puget Sound. During this period, harbor porpoises were encountered 450 times. Aggregations of 20 or more individuals were encountered 31 times (6.9% of encounters) from January 2017 through March 2023, all within South Puget Sound (Table S1). Six of the included sightings were in long-term aggregations, to verify reports by community scientists. Due to the visibility limitations experienced by observers in a small boat, obtaining a count that fully represents the extent or number of animals present in the larger aggregations is not possible because of the difficulty in viewing the entire extent of the aggregation.

There have been 16 community science reports of short-term aggregations of 20 or more animals, including two reports of aggregations of 100 or more, submitted to CRC and included in this analysis (Table S3). The first report of a large aggregation in South Puget Sound was submitted in 2012 by a marina employee. Fishers in Case Inlet encountered an estimated 200 individuals and observed breaching, chasing, and wake riding.

Of particular note are large, long-term aggregations around Johnson Point in 2019, 2020, and 2021. Community scientists used high-power binoculars from their hilltop home overlooking Dana Passage and observed porpoises when winds were light and the Beaufort Sea State was less than 3. Aggregations formed in early winter and persisted through March or April, with an additional aggregation in October and November 2021. Animals were sighted daily when winds were light and the aggregation frequently shifted position within the observation area of approximately 12 square km. A wide variety of behaviors were reported, including many foraging dives, cooperative feeding in bait balls, following slow-moving vessels, and breaches (Table S2).

3.2. PacMam Data

Reports to PacMam included 22 unique reports from January through November 2022 of short-term aggregations of groups of 20 or more individuals, including three groups of 100 or more in 2022 (Table S3). These data were extracted from a dataset of 286 reports, representing 7.7% of sightings. Travel, foraging, and social behavior states were observed. Specific behaviors observed included directional surfacing (travel), surface chases (foraging), and mating attempts (social).

3.3. PWWA Data

After accounting for potential duplicates, PWWA naturalists and captains logged 33 unique, short-term aggregations of 20 or more individuals, including five groups of 100 or more individuals in 2021. There were short term aggregations of 93 groups of 20 or more individuals, including 15 aggregations of 100 or more individuals in 2022 (Table S4). Only aggregations 10+ animals were recorded; therefore, it is unknown what percentage these aggregations represent of PWWA operations.

3.4. Sea View Data

Sea View documented 14 porpoise aggregation sightings occurring between August 2018 and September 2022 representing 13.3% of the observational dataset for this time period. These data were extracted from a larger dataset of 105 sightings of individuals and groups of harbor porpoise with a minimum total of 1542 porpoise observed across all sightings and years. Thirteen were short-term aggregations with 12 in Strait of Juan de Fuca, and one in Saanich Inlet, BC. Two events (10 August 2018 and 6 June 2019) were observed with the number of animals in the aggregation increasing throughout the day, to 20+ and 100+ animals, respectively. Foraging behaviors were observed during both events.

Site fidelity for aggregations was noted for a nearshore habitat in Strait of Juan de Fuca on 28 April 2021, 19 May 2021 and 8 June 2021 with a consistent group size of ~15–20 animals. Behaviors noted during these three events included foraging and socializing.

A three-day aggregation occurred in June 2022, during which foraging and reproductive behaviors were documented by Sea View. During this event, less commonly observed harbor porpoise behaviors occurred, including wake-riding and multiple aerial behaviors. These observations in Strait of Juan de Fuca are spatially consistent with the high-density aggregations reported by Hall [19], suggesting long-term habitat use that spans decades in this part of British Columbia.

3.5. All Data

Harbor porpoise aggregations were encountered in every month of the year (Table 2). Higher sightings during March-October are likely attributed to greater observation efforts for all datasets due to increased day length, better weather, and good sighting conditions during these months. This is especially true for the PWWA data as these are the primary months whale-watching vessels are on the water (only a few are active November–February).

Table 2. Distribution of sightings by month. Sightings of large aggregations occurred every month of the year. The seasonal variation documented is likely due to increased observer efforts during warmer months, that have longer days, and more days with good sighting conditions. Community scientist reports of long-term aggregations were recorded one time per aggregation per month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CRC survey	3	4	4	1	6	0	4	5	2	0	2	0
Community science long-term (CRC)	2	3	3	1	1	0	0	0	0	1	2	1
Community science short-term (CRC)	1	2	1	4	4	4	0	0	0	0	0	0
PacMam app	0	3	17	1	2	12	5	6	2	1	1	0
PWWA	0	4	16	5	8	27	20	13	14	16	2	1
Sea View	0	0	0	1	3	6	1	2	1	0	0	0

Across all these data collection platforms, behaviors recorded during these encounters could include synchronized group foraging, traveling, mating (which often occurs with males breaching as they attempt to mate—this is a consistent behavior seen in harbor porpoise populations world-wide) (Figure 3) [51], surface chases (Figure 4), spyhops, non-mating breaches, porpoising, fusion–fission of groups, and logging. Due to inconsistent recording between platforms, non-mating social behaviors were grouped into "Social behavior/splashing" (Table 3) (Figure 5). Sub-groups often experience fusion/fission during foraging, coming together for a series of dives, before splitting up again, not always in the same groups. Wake riding was also observed in several cases, with one short-duration bow ride recorded in Dana Passage. Porpoises will often approach slow-moving or stopped vessels during these aggregations. In the short- and long-term aggregations of 100+ individuals, mating attempts can be common, sometimes numbering in the dozens over

a relatively short direct observation period (1–2 h). One aggregation had over 40 mating attempts, recorded by an experienced observer with PacMam.

Figure 3. Behavior typical of a mating practice or attempt. Photographed during an aggregation of approximately 20 individuals on 31 August 2018. Photo credit: Laurie Shuster and David Anderson, Cascadia Research Collective, taken under National Marine Fisheries Service (NMFS) permit number 20605.

Figure 4. Activity typical of a chase. Photographed during aggregation of over 100 individuals on 21 January 2019. Photo credit: Laurie Shuster and David Anderson, Cascadia Research Collective, taken under National Marine Fisheries Service (NMFS) permit number 20605.

Table 3. Behaviors recorded during encounters. Not all encounters had recorded behavior, as encounters can be short in duration and/or at a distance where it is difficult to determine. Multiple behaviors can occur during a single encounter, especially with larger groups. * One aggregation had over 40 mating attempts, recorded by an experienced observer.

	CRC		**PacMam**	
	Aggregations (Total 31)	**Small Group (Total 398)**	**Aggregation (Total 56)**	**Small Group (Total 274)**
Foraging	29 (93.5%)	202 (50.8%)	22 (39.3%)	91 (33.2%)
Traveling	2 (6.5%)	80 (20.1%)	6 (10.7%)	107 (39.1%)
Mating	5 (16.1%)	11 (2.8%)	2 (3.6%) *	3 (1.2%)
Social behavior/splashing	13 (41.9%)	23 (5.8%)	4 (7.1%)	10 (3.6%)
Vessel approach	5 (16.1%)	25 (6.3%)	--	--
Fission–fusion	4 (12.9%)	16 (4.0%)	--	--

Figure 5. Splash during aggregation with four porpoises in foreground. Photographed during aggregation of approximately 200 individuals on 2 June 2022. Photo credit: Anna Hall, Sea View Marine Sciences.

Based on the prevalence of foraging activities during most, if not all, of these aggregations, it is likely that they are primarily foraging opportunities. However, social activities are also quite common, and it is equally likely that these aggregations provide opportunities for increased social interactions.

4. Discussion

Reports of harbor porpoise aggregations in the Salish Sea are considered rare events; however, these transboundary data demonstrate that aggregations are more common than previously documented and occur year-round (Table 2) in the Salish Sea. This conflicts with previous studies that suggest the aggregations were seasonal and limited to summer and early fall [28,29]. In other locations, harbor porpoise populations are known to migrate seasonally [20,21] and it is possible that previous Salish Sea researchers assumed a similar seasonal pattern. However, historical knowledge of Salish Sea harbor porpoises is sparse [52], due to the limited amount and breadth of research studies conducted. Therefore, it is unlikely those limited studies had the ability to accurately document these grouping patterns. In addition, when the harbor porpoise numbers were depleted, there may not have been enough animals or aggregations to be able to accurately determine seasonality.

The recovery of the Salish Sea harbor porpoise population [9] has likely been a driver behind increased occurrence of aggregations. At the same time, Dall's porpoise (*Phocoenoides dalli*) populations have substantially decreased and are seen infrequently in the Salish Sea [9]. Dall's may avoid areas with harbor porpoise presence [4] and their departure could also provide increased opportunities for resources such as prey and preferred habitat.

The availability of food is likely a dominant influence in the formation of these aggregations. Foraging behaviors were frequently documented, with most individuals in the aggregations exhibiting regular foraging dives or surface-level chases. The lower percentages documented in the PacMam data are likely due to observer bias. These data were generally collected by the public, and for behavior, "unknown" was an option for entry. For example, about 21% for both large and small groups included unknown behavior. Thus, the lower documented foraging behavior in the PacMam data is likely an underrepresentation. Fusion/fission behavior was observed, with subgroups of 10 or more animals synchronizing their dives then splitting up again after a series of dives. Synchronized feeding on surface bait balls, including where individual porpoises were seen on their sides at the surface, swimming in a circle were observed. This could be a way to condense a bait ball before making a feeding pass, as has been documented in other cetacean species [53–55]. This foraging behavior is rarely seen outside large groups, [19] (Anderson and Shuster, unpublished data Cooperative feeding during high-density aggregations was noted by Hall [19] in southern British Columbia.

The large number of harbor porpoise aggregations documented in this study indicate prey abundance sufficient to support both short- and long-term events. The high metabolic rate of harbor porpoises [56–58] would require substantial food resources to support aggregations of over 100 porpoises that inhabit an area for several months. Porpoises have been documented foraging in the presence of other marine mammals and birds in

many locations. During winter months in 2019 and 2020, sufficient prey were present in nearby Case Inlet in South Puget Sound to feed several hundred California sea lions (*Zalophus californianus*) (Jefferies, pers. com.) along with a large aggregation of harbor porpoises and other marine species such as harbor seals, three long-beaked common dolphins (*Delphinus capensis*), and large flocks of marine birds that were frequently seen in the area. Regional oceanographic elements, such as shoals, fronts, and high tidal flows can concentrate plankton and forage fish. Numerous spawning events in these waters create a potential plentiful food source for harbor porpoises. Five species of fish that are key components of harbor porpoise diet are present in the Salish Sea: Pacific herring, Pacific sand lance, surf smelt, eulachon, northern anchovy [6,39]. Thus, there are a variety of prey species that may concentrate in large enough numbers to support short- and longer-term harbor porpoise aggregations, along with other species. More research is needed to understand which forage species are more important for driving these events.

Social behaviors and interactions appear to be important components of harbor porpoise aggregations (Table 3). While social interactions are occasionally observed in smaller groups, they were over twice as likely to occur in larger groups. Mating attempts are seen year-round in small groups [59] (Elliser unpublished data, Anderson unpublished data, Hall unpublished data), but typically only one or two attempts are observed, whereas dozens of attempts have been observed in some aggregations.

During aggregation events, porpoises are also more likely to interact with slow-moving or stopped vessels, are less likely to substantially relocate to avoid fast moving vessels and have been observed wake riding or following the prop wash of boats. Porpoises' proximity and interaction with boats was documented in 16.1% of CRC survey observations and noted in some community science reports. In several South Puget Sound aggregation encounters, harbor porpoises have approached the research vessel in a small sub-group, diving under the boat, and then reemerging on the other side while porpoising away at high speed (Shuster and Anderson, unpublished data.). Whale watch personnel have documented porpoises approaching their vessels during encounters with larger aggregations and noted an increased likelihood of porpoises wake riding or following the prop wash of slow-moving vessels. However, vessel-approach behaviors are not limited to larger aggregations. Land-based observers at Burrows Pass in northern Washington have also documented animals in smaller groups approaching vessels (Table S4), wake riding, and interacting with prop wash (Elliser, unpublished data), as have boat-based observers in South Puget Sound (Shuster and Anderson, unpublished data).

While harbor porpoises are generally considered relatively solitary, formation into larger groups provides numerous opportunities to interact and may promote a diverse repertoire of social interactions. Abundance of food is a potential impetus for aggregation formation; therefore, porpoises may spend less time and energy foraging, enabling a shift of resources toward social behaviors.

The social structure of harbor porpoises has not been well investigated and is unknown at this time. Due to their vocalization patterns (e.g., lack of whistles normally attributed to communicative calls) and tendency towards very small groups (1–3 individuals), it has been thought that they do not have very strong social ties. However, indications of sociality are present in the literature. Breaching and splashing in wild harbor porpoises have been attributed as social behaviors. A previous review of harbor porpoise social behaviors, from wild and captive settings, noted these to be well developed and set within a context of individual and group relationships [19].

Harbor porpoises have been observed using complex, cooperative foraging behaviors with role specialization that is rarely seen in animals [60,61]. In the Firth of Clyde (Scotland), a common dolphin was found to change its vocalizations to match local harbor porpoises [62], and harbor porpoise clicks have been shown to be used in communicative contexts, not just foraging [63,64]. Although little is known about their associations, there is early evidence through photo ID that shows at least some individuals are often sighted together over weeks to months at a time (Elliser, unpublished data). It is likely that social

interactions are more important to this species than what is observed in the limited social encounters observed at the surface [63]. These large aggregations may be important aspects of their social structure. The importance of larger groups is seen in other species, such as the Southern Resident killer whales (SRKW). In the Salish Sea, SRKW are usually found in tight, matrilineal pods but periodically join to form superpods where the individuals mix and socialize with members of other pods [65]. Large aggregations may provide similar opportunities for individual harbor porpoises to socialize with others in their community or population, and facilitate genetic diversity. Further research is needed to determine the role of these aggregations in harbor porpoise society.

Documentation of the occurrence and behavior patterns of large harbor porpoise aggregations was achievable via the coordinated efforts of researchers, community scientists, and whale-watching crews. Diverse participants of this transboundary project provided valuable scientific data, irrespective of the socio-political boundaries, and created an observation network that surpassed the scope of resources available to one small research organization.

Community engagement conversations and the use of mobile apps expanded data collection considerably in 2021 and 2022 (67% of aggregation reports). The creation and promotion of a quick and easy sighting app expanded opportunities for the public to submit sightings and encouraged people to observe animal behavior in an intentional and systematic way while completing the entry form. The PWWA request for whale-watching crews to record sightings of large harbor porpoise aggregations yielded 146 entries submitted by 21 boats. Sightings of harbor porpoises are not usually entered in the PWWA private app, yet crews regularly contributed data once they were aware of the research request. During 2021–2022, most of the sighting entries (56%) were submitted via PWWA. These examples of community interest, engagement, and promotion illustrate a potential road map for future collaborative projects that expand the reach of small research organizations.

5. Conclusions

It is clear from the results presented here that large harbor porpoise aggregations are more common in the Salish Sea than previously realized. It is likely that the aggregations documented here are a small portion of the ones actually occurring throughout these waters. Due to the behaviors observed, these aggregations are likely both important foraging and socialization opportunities for harbor porpoises. Aggregation events may also play a vital role in the reproduction of the species, as noted by the long-term habitat selection and occurrence of mating behavior commonly observed in southern BC [19]. Understanding when and why these aggregations are occurring can help us better understand the foraging ecology, behavioral ecology, and social structure of this enigmatic species.

Moreover, this may also assist in the identification of important habitats that are vital for the long-term survival of Salish Sea harbor porpoise population(s), and potential conflict with net fisheries and associated bycatch risks. However, there is a distinct knowledge gap about harbor porpoise habitat use and behavior in this region [52] that could hamper conservation efforts. The repatriation of a species inspires a wealth of research questions that could illuminate ecosystem factors relevant to numerous species; allocating additional resources to this research could have widespread impacts. Monitoring their populations can provide critical data on ecosystem health. The decline and recovery of harbor porpoises in the Salish Sea is not isolated, and is mirrored in the population in San Francisco Bay [66] around the same time. This highlights the importance of harbor porpoises as a sentinel species for the health of local ecosystems and the importance of understanding their behavioral and foraging ecology for their conservation and that of their ecosystem.

Community collaboration has become an essential component of environmental research like this and fostering additional community partnerships will be important to expanding these aggregation data. Transboundary collaborations of researchers, industry, and community are essential to examining, understanding, and protecting harbor porpoises and the Salish Sea as a habitat region. Environmental and human-influenced factors such

as prey availability, water temperature, and pollution, defy international boundaries in our shared waters and collaboration is critical for the conservation of harbor porpoises and the numerous species of the Salish Sea.

To understand the function and frequency of these large harbor porpoise aggregations, the authors recommend further transboundary studies focused on identifying specific food sources that may be involved in attracting these aggregations, detailed behavioral analyses, bathymetric and environmental factors that may be conducive to aggregations, and determining any trends or patterns that may affect the location and timing of repeated aggregations. This information is critical to fully understanding and conserving this important indicator species in the Salish Sea.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/oceans4030019/s1, Table S1: Cascadia Research Collective South Puget Sound survey results; Table S2: Cascadia Research Collective long-term aggregation reports; Table S3: Cascadia Research Collective short-term aggregation reports; Table S4: Pacific Mammal Research (PacMam) aggregation reports; Table S5: Pacific Whale Watch Association (PWWA) aggregation reports; Table S6: Sea View survey results; Figure S1: Harbor porpoise in foreground, with multiple other groups in the background within large aggregation of 200+ individuals; Figure S2: Additional image of a mating attempt during an aggregation of 100+ individuals; Video S1: Compilation of videos from Cascadia Research Collective encounters.

Author Contributions: Conceptualization, D.A. and C.R.E.; software, J.K.; investigation, D.A., L.S. and A.H.; resources, D.A. and L.S.; data curation, D.A., L.S., C.R.E., K.M., E.J.G., J.K. and A.H.; writing—original draft preparation, D.A.; writing—review and editing, L.S., C.R.E., K.M., E.J.G. and A.H. All authors have read and agreed to the published version of the manuscript.

Funding: CRC research was funded by the authors. PacMam research was funded by Marathon Petroleum Foundation, Inc. and public donations. PWWA research was funded by PWWA member companies. Sea View monitoring data was funded by the Canadian Department of National Defence during training operations that required the Marine Mammal Monitoring Program to be implemented.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The substantial aggregation data used in the preparation of this paper are available in the Supplemental Materials. Data on small groups are being retained by their respective owners, who should be contacted to negotiate availability of that data.

Acknowledgments: CRC vessel surveys were conducted under NOAA-NMFS permit #20605. We would like to thank all the owners of the whale watch companies for supporting this effort, and all the captains and naturalists for submitting harbor porpoise reports. Our thanks also go out to all the community scientists who have submitted reports, with special thanks to Pam and Charlie Rhubart, Michelle Roy and Kim Merriman, who have monitored marine mammal activity from their homes overlooking South Puget Sound waters for several years. Gratitude is also extended to the Canadian Department of National Defence for supporting data sharing for this study.

Conflicts of Interest: The authors declare no conflict of interest.

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