Marine Mammal Science

Marine Mammal Science

NOTE OPEN ACCESS

Humpback Whales Blow Poloidal Vortex Bubble Rings

Fred Sharpe[1] | Jodi Frediani[1,2] | Josephine Hubbard[1] | Doug Perrine[3] | Simon Hilbourne[4] | Joy S. Reidenberg[5] | Laurance R. Doyle[6] | Brenda McCowan[1]

[1]Population Health and Reproduction, UC Davis Veterinary Medicine, Davis, California, USA | [2]Jodi Frediani Photography, Santa Cruz, California, USA | [3]Doug Perrine Photography, Kailua-Kona, Hawaii, USA | [4]Marine Research Facility, Jeddah, Saudi Arabia | [5]Center for Anatomy and Functional Morphology, Icahn School of Medicine at Mount Sinai, New York, New York, USA | [6]SETI Institute, Mountain View, California, USA

Correspondence: Jodi Frediani (jodifredi@aol.com)

Received: 13 December 2023 | **Revised:** 15 April 2025 | **Accepted:** 15 April 2025

Funding: This work was supported by the Templeton World Charity Foundation (TWCF0440).

Keywords: bubble net | bubble ring | citizen science | humpback whale | inquisitive | *Megaptera novaeangliae* | play | whale swim | whale watching

Humpback whales (*Megaptera novaeangliae*) have long been known to generate bubbles by physically striking the air–water interface or releasing air through the blowholes or mouth. Melville (1851) was the first to note this propensity by penning "humpbacks churned the water … making more gay foam and whitewater than any of them." In the Norwegian Sea, a whaleship observed a humpback whale that "appeared to dive a short distance below the water's surface and then release air while swimming in a circle. The rising bubble rose to the surface like a thick wall of air bubbles, and these formed a net" (Ingebrigtsen 1929). The first formal studies of humpback whale bubble use commenced in the North Pacific in the late 1960s (Jurasz and Jurasz 1979) followed by a description in the North Atlantic (Hain et al. 1982). Subsequent research across many cetacean species has shown that they produce bubbles in various shapes, sizes, and complexities. A recent review on bubble production (with a focus on odontocetes) classifies this wide diversity of bubble structures into several categories: trails, bursts, clouds, and rings (Moreno and Macgregor 2019).

Bubble production can occur in a variety of behavioral contexts. Male humpback whales use bubbles on the breeding grounds during agonistic displays where they compete for proximity to a female. These blowhole and mouth expulsions of air typically produce bursts or curtains (Baker and Herman 1984) that are thought to serve as "displays of ferocity" and to possibly disorient intruding whales (Baker and Herman 1984; Helweg et al. 1992). Mouth-released bubbles are generated after gulping air at the surface (Baker and Herman 1984) and possibly via a laryngeal–oral connection, which may allow for "oral exhalations" of fine-misted clouds (Reidenberg and Laitman 2007). Blowhole-bubble exhalation has also been observed between humpback mother and calf pairs when passively resting (Ejrnæs and Sprogis 2021). Male humpback whales have been observed releasing bubbles directed at the female genital-mammary area on the breeding grounds (Jones et al. 2022). On the feeding grounds, humpback whales use bubbles to herd, corral, and concentrate prey (Hain et al. 1982; Jurasz and Jurasz 1979; Wiley et al. 2011). Bubbles produce a strong acoustic, visual, and mechanical barrier that schooling prey are reluctant to cross (Sharpe and Dill 1997). These barrier structures may be simple, as in the case of bursts, which are created by a sudden, forceful release of many small bubbles (Baker and Herman 1984; Rountree et al. 2022). Plumes or columns often form a continuous airstream that can be produced as a vertical array when whales are stationary, or a horizontal array when the whale is moving.

Arguably, the most complex bubble structure is the bubble net, whereby a whale or multiple whales swim in a closing spiral while releasing an air curtain (Figure 1a). Bubble net feeding is most often performed cooperatively. The sculpting of intricate spiral nets and other bubble structures utilizes the unique morphological adaptations of humpback whales for maneuverability, including flexible, spindle-shaped bodies, highly elongated flippers, outsized tails, and knobs on leading surfaces (Fish 1994; Fish and Battle 1995; Tomilin 1967; Wiley et al. 2011). The

Fred Sharpe and Jodi Frediani share first authorship.

[Correction added on 7 June, 2025, after first online publication: Supporting information document was updated.]

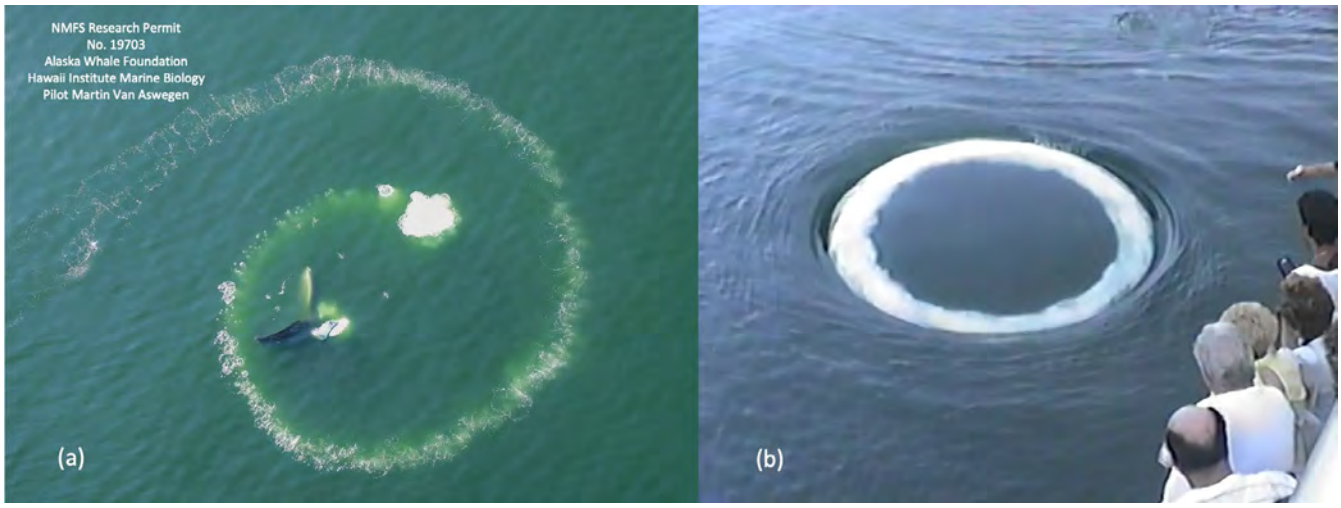

FIGURE 1 | Two distinct bubble structures, including (a) bubble net (Photo: M. Van Aswegen/AWF) and (b) bubble ring (Photo: D. Knaub). Note that they are very different physical structures.

flippers and/or flukes may also be swiped at the surface to inject air below the air–water interface (Weinrich et al. 1992).

This note focuses on bubble rings (Figure 1b), a unique and sparsely documented genre of bubble features produced by baleen whales, although well-described among odontocetes, including Atlantic bottlenose dolphins (*Tursiops truncatus*, McCowan et al. 2000), beluga whales (*Delphinapterus leucas*, Hill et al. 2011), and Orinoco dolphins (*Inia geoffrensis*, Gewalt 1989). Not to be confused with a bubble net (spiral-shaped fish trap; Figure 1a), a ring is a poloidally spinning, air-infused vortex. At Stellwagen Bank in the North Atlantic Ocean, Payne (1995) described them as "madly spinning doughnut-shaped clouds that look like giant smoke rings about three feet in diameter that rise rapidly to the surface." Payne opines on their frequency, noting: "Only one particular whale has been known to engage in this activity, and even she seldom does it. However, once she gets going, the process becomes obvious and is done vigorously. For example, she may blow twenty bubble 'smoke rings' in a row during a bout lasting half an hour … we are still only guessing at how it works and what its real purpose is." Payne's description represents the only published mention of bubble rings in the mysticetes.

Bubble rings in mysticetes may be produced in similar contexts to those in odontocetes; however, the much larger bubble rings of mysticetes differ in their appearance from those produced by odontocetes as the former are filled with a multitude of smaller bubbles giving them a smoky opaque appearance, rather than being a single translucent ring-shaped bubble. Among dolphins, their translucent bubble rings are well-studied and have been linked to play in captivity as well as to foraging and social aggression in the wild (Herzing 1996, 2000; Hill et al. 2011; Marten et al. 1996; McCowan et al. 2000; Moreno and Macgregor 2019; Pace 2000; Paulos et al. 2010; Pryor 1990; Pryor and Kang 1980; Rountree et al. 2022).

Here we report on 12 ring-production episodes involving 39 bubble rings produced by 11 individual humpback whales. The aim of this research is to describe contexts in which humpback whales produce bubble rings and provide insights into their potential functions. We examine evidence for Payne's (1995) hypothesis that bubble rings are associated with foraging as defined by being produced in the presence of prey and feeding activity (vertical lunges, open mouths, extended ventral pleats). Next, we examine the hypothesis that rings are associated with social aggression, as proposed for wild spotted and bottlenose dolphins (Herzing 1996, 2000; Pryor 1990; Pryor and Kang 1980). We use Baker and Herman's (1984) and Pitman et al.'s (2017) definition of aggressive behavior in humpback whales, which includes high levels of arousal, wheezed blows, trumpet blows, slashing of the tail and flippers, and charges directed toward antagonists (e.g., male rivals, killer whales [*Orcinus orca*]). We also examine whether rings are linked to inquisitive behavior in which whales approach boats and swimmers (Mangott et al. 2011; Swartz 2018). Finally, using drone observations collected by several private investigators, we searched for ring production in the absence of boats and close human presence.

Bubble ring events were collected by naturalists, citizen scientists, and researchers with whom we conducted interviews and analyzed their video footage (seven episodes) or photos (five episodes). We gathered bubble ring events through social media and reports from colleagues. We solicited reports through a cetacean-focused Facebook group (Cetal Fauna) and presentations at three scientific conferences (World Marine Mammal Conference [2019], 24th Biennial Conference on the Biology of Marine Mammals [2022], and Humpback Whale World Congress [2023]). These observations were opportunistic, while observers were on the water for a variety of reasons (see "Mission" in Table 2), and were obtained from one private vessel, two research vessels, three commercial whale-watch vessels, two commercial and one private whale-swim vessels, and two light airplanes. All vessels were motorized.

Whenever possible, a still photo or screen capture was obtained of the ventral side of the flukes for comparison with regional fluke photo-identification catalogs. Successful matches were used to help establish each animal's identity, age, sex, and history of human interactions to determine if there were

repeated sightings of the same individual or general demographic patterns to ring production. For events in the North Atlantic Ocean, we compared photographs with the *North Atlantic Humpback Whale Catalog* (NAHWC), Allied Whale (Bar Harbor, Maine), and the *Gulf of Maine Humpback Whale Catalog* (Center for Coastal Studies [CCS], Provincetown, Massachusetts). For North and South Pacific cases, we consulted Happywhale.com. Using the growth curves of Stevick (1999) we categorized individuals of known age into one of three classes (yearling: 1 year; subadult: 4–6 years; adult: 6 or more years). We also documented the type of vessel (whale-watch, research, or private), presence of occupants (or swimmers), and their general demeanor (loud/boisterous or quiet/passive). Video and photos of bubble ring episodes were obtained from various perspectives, including from underwater cameras (held by swimmers or dipped from vessels), filmed above the surface at water level from boats, or obtained from the air (fixed-wing aircraft) (for details see Supporting Information S2). We use several interchangeable and equivalent descriptors to characterize ring creation, including "produce," "release," "blow," and "generate." Estimates of ring diameter were obtained when the ring surfaced adjacent to objects of reference, such as a whale or vessel. We also documented the distance and orientation of the ring blower to the closest object in the water (boats, swimmers, or other whales). We then used behavioral categorizations based on definitions in the literature for humpback whales to help determine the context for bubble ring production (Table 1).

To assess if rings were produced in the absence of humans, we contacted three investigators using semiremote sampling techniques. All unoccupied aerial vehicle (UAV; i.e., drone) flights were conducted at a distance from nearby vessels on breeding grounds (Hawaii), feeding grounds (Antarctica, Alaska), and migratory routes (Bermuda). M. Van Aswegen (personal communication, July 2022)[1] did not observe any bubble structures resembling rings during a five-year study of humpback whales in Hawaii and Southeast Alaska (involving over 3490 UAV flights, totaling > 1090 flight hours, with approximately 300 h in Alaska and 700 h in Hawaii). Similarly, in Antarctica, A. Friedlaender (personal communication, September 2022)[2] made no detection of bubble rings from 100 to 200 UAV flights (20–30 flight hours). In Bermuda, A. Stevenson (personal communication, March 2024)[3] also made no detection of bubble rings during 1200+ UAV flights during an eight-year study of humpback whale behavior. All drone flights were conducted at a distance from nearby vessels.

TABLE 1 | Behavioral categorization for context of bubble ring production.

Context	Behavioral indicators
Foraging[a]	Surface lunges, open mouths, expanded ventral pleats
Agonism[b]	Wheezed blows, trumpet blows, slashing of the tail and flippers, vigorous tail throws, robust bubble trails or clouds, head lunges, charges directed toward antagonists
Inquisitive[c]	Approach to swimmer and/or vessel, prolonged proximity, relaxed/minimally aroused movements (including slow head rises, partial breaches, slow tail lob) slow rolling, spy hopping, object play
Resting[d]	Stationary, minimal movement

[a]Hain et al. (1982); Wiley et al. (2011).
[b]Baker and Herman (1984, 1989).
[c]Sprogis et al. (2020).
[d]Ejrnæs and Sprogis (2021).

A summary of each episode is provided in Table 2 and Figure 2. Details of these episodes can be found in the Supporting Information, including video, when captured (Supporting Information S2–S11).

In two instances (Episodes 1 and 3) we were able to determine the age of ring blowers as a result of repeated observations in fluke databases (Table 2). In a third instance (Episode 10), we felt confident enough to classify the animal as a yearling because of the individual's smaller size and gray fluke coloration. The individual observed to blow rings in Episode 1 had a known birthday obtained from CCS and was determined to be a subadult. The individual observed to blow bubble rings from Episode 3 had a series of sightings in the Happywhale database such that it is clear the individual has a minimum age of 6 and was determined to be an adult.

No direct measurements were made of bubble ring diameters. However, one whale surfaced within or adjacent to several bubble rings (Episode 1). His dorsal hump and/or body girth were visible, providing estimations of ring diameter of 2–3 m for three rings (M. Van Aswegen, personal communication,[4] October 2023, see Supporting Information S12 for calculations). Another ring surfaced next to a skiff, enabling its diameter to be estimated at 2–2.5 m (Episode 11).

All events that permitted direct visual observation revealed that during ring release, whales were motionless or slowly idling forward with blowholes held upright and the body mostly in the horizontal position. All rings were observed to rise vertically with their elliptical plane parallel to the surface. This was visually confirmed for all bubble ring events occurring in the relatively clear waters of the breeding grounds (Episodes 2, 3, 5, 7, 8, 9, 10, 11, 12). On three occasions (Episodes 8, 9, 11), frame-by-frame video inspection revealed that bubble rings emanated from a single right nostril (Episode 8; Supporting Information S13). Most rings appeared radially symmetrical in their incipient stage (as opposed to bilobed), further suggesting a creation from a single aperture.

Two out of twelve documented episodes (Episodes 4 and 6) were associated with foraging, as the rings were produced during active feeding (open mouths, expanded ventral pleats, surface lunging) within a bubble net (Figure 2d,f). Prey items could not be observed from the fixed-wing aircraft that opportunistically observed the bubble net feeding episodes (i.e., foraging context); however, the general configuration of the net suggests the whales were hunting sand lance (*Ammodytidae*, Hain et al. 1982). In neither case were whales observed to feed within an individual ring or engulf portions of the ring itself. Rather, the whales appeared to engulf water adjacent to the rising rings, suggestive of a barrier function, as opposed to prey being entrained or confused within or by the poloidally spinning vortex of the ring structure. Relative to the net's vertical rising columns, rings are disk-shaped, suggesting a more

TABLE 2 | Summary of humpback whale bubble ring episodes including date, location, whale unique identifier, as well as sex and age (M = male, F = female, U = unknown, Y = yearling, S = subadult, A = adult), number of rings produced during the episode, number of whales present during ring production, mission of human observers, names of observers, and context of ring production.

Episode	Date	Location	Whale	Catalog ID	Sex	Age	No. of rings	No. of whales	Mission	Observers	Context
1	August 13, 1988	Stellwagen Bank, MA, USA N. Atlantic	Thorn	NAHWC 0403	M	S	11	1	Whale watch	D. Knaub S. Pittman	Inquisitive
2	2002	Maui, HI, USA N. Pacific	Unk. #1	N/A	U	U	1	2	NMFS Permit #753	F. Nicklin J. Darling J. Sturgis	Inquisitive
3	March 14, 2003	Makalawena, Kona, HI, USA N. Pacific	Caroline	HW-MN0443789	F	A	1	4	NMFS Permit #587	D. Perrine	Inquisitive
4	April 25, 2008	Cape Cod Bay, MA, USA N. Atlantic	Unk. #2	N/A	U	U	3	1	Fish spotting flight[a]	W. Davis	Feeding
5	February 3, 2014	Silver Bank, DR N. Atlantic	Unk. #3	N/A	U	U	2	2	Whale swim	G. Flipse	Resting
6	April 21, 2016	Stellwagen Bank, MA, USA N. Atlantic	Unk. #4	N/A	U	U	3	2	MMPA Permit #17355[a]	A. Henry	Feeding
7	December 29, 2020	Lahaina, Maui, HI, USA N. Pacific	Караул	RCHP-18RUEC1958	F	U	1	1	Whale watch	M. Gaughan	Inquisitive
8	January 23, 2021	Lahaina, Maui, HI, USA N. Pacific	Караул	RCHP-18RUEC1958	F	U	2	1	Whale watch	H. Romanchik	Inquisitive
9	February 22, 2021	Lahaina, Maui, HI, USA N. Pacific	—	HW-MN0442841	F	U	3	1	Whale watch	D. Patton	Inquisitive
10	January 13, 2022	Makalawena, Kona, HI, USA N. Pacific	Inga	HW-MN0443468	F	Y	10	1	Whale watch	D. Perrine	Inquisitive
11	February 27, 2023	Silver Bank, DR N. Atlantic	Unk. #5	N/A	U	U	1	2	Whale swim	S. Istrup	Inquisitive
12	September 7, 2023	Mo'orea, French Polynesia, S. Pacific	Unk. #6	N/A	F	U	1	2	Private whale swim	S. Hilbourne	Inquisitive

[a]An aerial observation.

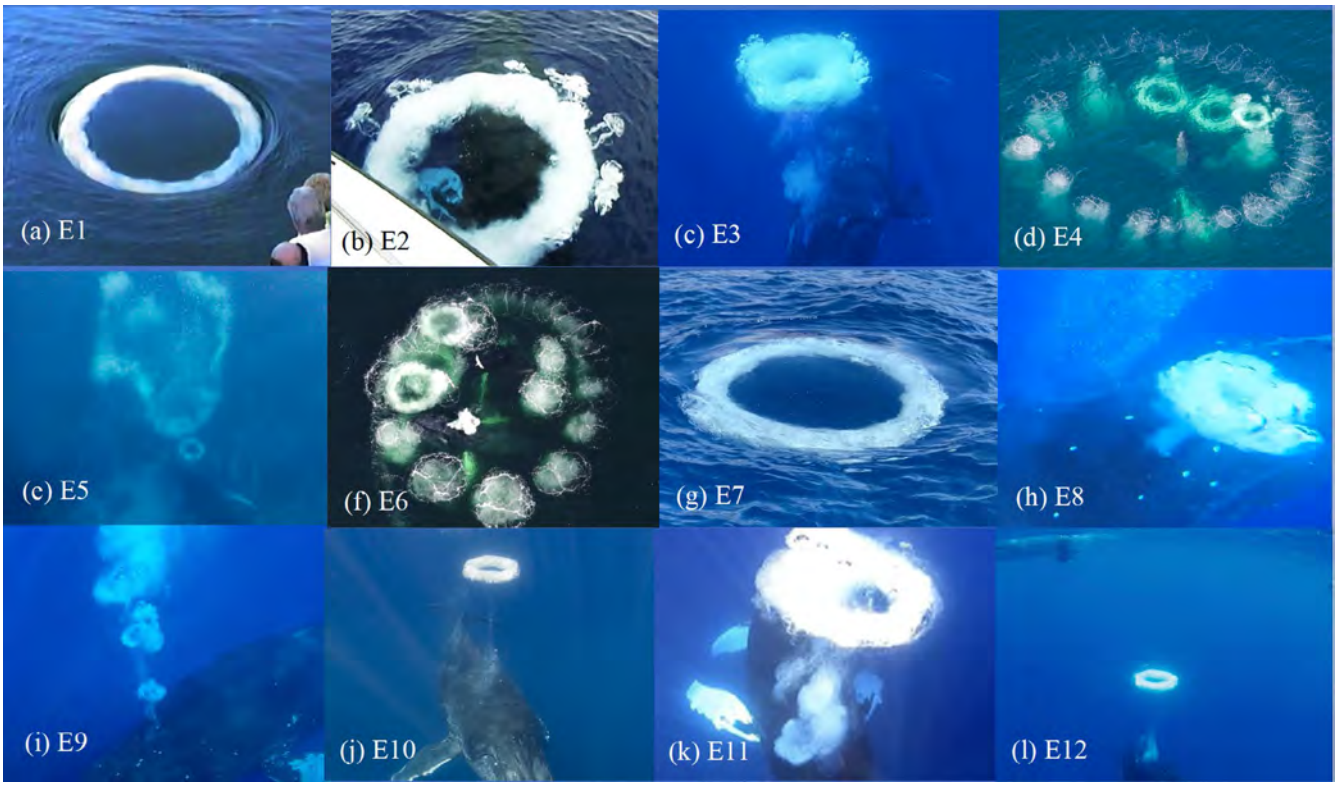

FIGURE 2 | Composite image of at least one bubble ring from each episode. Photo attributions are as follows: (a) D. Knaub, (b) F. Nicklen, (c) D. Perrine, (d) W. Davis, (e) G. Flipse, (f) A. Henry, (g) M. Gaughan, (h) H. Romanchik, (i) D. Patton, (j) D. Perrine, (k) S. Istrup, (l) S. Hilbourne.

localized barrier effect. None of the other ten episodes were associated with feeding behavior, nor were prey organisms (Jurasz and Jurasz 1979) noted within rings. Additionally, no other marine predators (birds, sea lions, other whales) were observed in proximity while the rings were being produced.

Out of the twelve episodes of ring production reported here, ten episodes were collected near a boat or human swimmers, while six episodes had more than one whale present. Despite these ample opportunities for intra- and interspecies aggression, there was no evidence of agonism toward conspecifics or aggression toward boats or swimmers in any of the ring episodes. Aggressive behaviors (Supporting Information S14) include vigorous tail throws and tail slashing, trumpet blows, head lunges, charges toward antagonists (Tyack 1983), and large, robust bubble trails or clouds (Baker and Herman 1984; Tyack and Whitehead 1983). Even mild forms of annoyance and evasion noted elsewhere (Baker and Herman 1989; Scheidat et al. 2004; Sprogis et al. 2020), such as diving away, increased swimming speed, or increased dive times, were not noted in any of the ring blowing events. Individual humpback whales observed blowing bubble rings appeared relaxed and minimally aroused during their ring deployment (see Table 1), as well as during their various inquisitive behaviors (spy hops, tail lobs, pectoral slaps, partial breaches/head raises). Rather than exhibiting avoidance behavior, eight of nine ring blowers (excluding the two episodes during feeding) approached the boat or swimmers. All bubble structures appeared modest and nuanced, as opposed to robust bubble clouds and curtains associated with aggression (Baker and Herman 1984; Supporting Information S14).

In the majority of the nine inquisitive episodes (1, 7, 8, 9, 10) the ring blower was alone, suggesting that the primary recipient was not another whale (Table 2). In all nine inquisitive episodes, the closest object to the blower (at the moment of ring release) was a boat or swimmer, not another whale (Table 3). Seven of eight ring blowers approached a boat or swimmer to one body length (13–15 m) or less. When other whales were present, they hung back as the ring blower approached a boat or swimmer (Episodes 2, 3, 11, 12). On two occasions (Episodes 3 and 11) the blower initially approached in an investigative fashion, including nearly touching a swimmer (Episode 3). One ring was produced partially under a boat (Episode 2), while another was released directly beneath a boat (Episode 8). In one additional episode, a ring partially enveloped a swimmer after its collapse at the surface (Episode 11). All ring blowers lingered in the vicinity of a boat or swimmer, and some animals appeared relaxed in their movements (Episodes 1, 2, 10, 12). Four whales had a history of inquisitive or mugging behavior whereby a whale approaches close to a stationary vessel so that the vessel cannot get safely underway. Whales also often engaged in curious behaviors during these mugging events such as spy hopping (Martinez et al. 2015), where whales temporarily positioned their eyes vertically out of the water or just beneath the surface in proximity to boats (Episodes 1, 3, 7, 8, 10). Aerial vocalizations such as wheezed or trumpet blows, which may indicate arousal or antagonism, were not noted. Some ring blowers were in pairs exhibiting rolling behavior, presumed courting behavior (Episodes 3 and 11), while another pair was engaged in object play with brown algae before ring blowing (Episode 12) (Meynecke and Kela 2023).

TABLE 3 | Summary of the closest object in the water to the ring blower during inquisitive episodes, including the animal's orientation and distance to the object.

Episode	Closest object	Orientation at ring release	Distance—body length—±13 m	Duration of episode (min)	Human behavior
1	Vessel	Variable	1	10	Loud/boisterous
2	Vessel	Direct oblique	<1	30	Quiet/passive
3	Swimmer	Facing forward	1	60	Quiet/passive
7	Vessel	Facing forward	1	10	Loud/boisterous
8	Vessel	Oblique	<1	Unk.	Loud/boisterous
9	Vessel	Oblique	1[a]	7	Loud/boisterous
10	Vessel	Facing forward	1	180	Loud/boisterous
11	Swimmer	Facing forward	<1	10	Loud/boisterous
12	Vessel	Facing forward	<1	45	Quiet/passive

Note: Human behavior is also noted as either loud/boisterous (joyful vocalizations and/or percussive behavior) or quiet/passive (lack of loud vocalizations and/or percussion).
[a]Indicates that the whale was positioned more than one body length away from the object at the time of ring release, although at other times during the episode the whale approached within one body length of the vessel.

In only one episode was the ring blower stationary and not engaged in other behaviors indicative of foraging, agonism/aggression, or being inquisitive (Episode 5; see Table 2). In this episode, two whales were stationary ±20 m below the surface and were slowly approached by several swimmers on the surface, after which one of the two whales produced a bubble ring (Figure 2e).

We found that humpback whales use rings in non–mutually exclusive contexts including feeding (within bubble nets), during inquisitive behavior, and while passively resting. Most episodes showed evidence of inquisitive behavior with a notable lack of other behaviors indicative of feeding or agonism/aggression. Although there was little evidence of feeding during bubble ring production, this may be limited by the majority of collected sightings occurring on breeding grounds where feeding is scarce. Additionally, there was no evidence of agonism or aggression in any of the bubble production episodes. Agonism in humpback whales is most commonly observed in competitive groups on the breeding grounds whereby males challenge one another to become the primary escort of a female. Other observations of agonism in humpback whales include indicators of annoyance from mothers toward calves that stray too far on the breeding grounds (G. Flipse, personal communication, November 2023),[5] or when defending against predators such as killer whales (Ford and Reeves 2008; Pitman et al. 2017). More research is needed to systematically study bubble ring production and ascertain under what conditions bubble rings are consistently produced.

It is not uncommon for inquisitive humpback whales and curious (popularly called "friendly") gray whales (*Eschrichtius robustus*) to release air while interacting with boats (Jones 1985). It is not understood why some whales go beyond typical inquisitive encounters with volitional approaches (Frediani et al. 2011; Supporting Information S15) to initiate bubble ring production. There are several populations of baleen whales in which individuals commonly approach and interact with boats; however, bubbling in these contexts has received little study. "Curious and friendly" gray whales were first noted in San Ignacio Lagoon in the early 1960s where they gave "every indication of inviting attention and even physical, friendly contact" (Gilmore 1976; Swartz 2018). In Hervey Bay, Australia, humpback whales often show inquisitive or "friendly" behavior toward vessels (Martinez et al. 2015). Friendly gray whales are known to release bubbles "around and under boats," yet the specific meaning of these releases remains unexplored (Gilmore 1976; Swartz 2018). Hain et al. (1982) noted that "some swimming and bubbling behavior [by humpback whales] may be 'play' behavior, particularly when displayed in the presence of closely associated dolphins." Burghardt (2010) defines play as spontaneous behavior lacking in immediate utilitarian function. The ancillary behaviors exhibited during the majority of inquisitive ring episodes suggest play as described by Zoidis et al. (2014) and include "continuously rolling, arching, or twirling on the longitudinal axis combined with stalling or no forward movement" under the water and usually within 5 m of the surface. Play activities visible above the surface may include pectoral fin slaps, tail swishes, relaxed tail lobs, and chin, half or full body breaches, many of which were also observed during inquisitive bubble production events. Swim-through behavior exhibited by Thorn in Episode 1 conforms with playful ring/object manipulation described by McCowan et al. (2000).

To assess to what degree bubble ring production coincided with human presence, we contacted three expert investigators using semiremote sampling techniques for observing humpback whales. Across all three expert consultations, there was no occurrence of bubble ring production in humpback whales observed during nearly 5000 UAV flights. Although these data are preliminary, they suggest that bubble ring production may be selective to when human observers or boats are present. However, the degree to which the presence of human observers influences humpback whale bubble ring production remains uncertain. Presumably, other events have occurred but were not recognized as notable nor designated as a separate class of behavior in field study ethograms. Other events may have simply occurred too long ago to be remembered in detail. Rings may go undetected

if they dissipate prior to reaching the surface (Episodes 5, 7, 11, 12), or are obscured by waves, reflectance, or darkness.

Bubbles are widely interpreted as communicative in many cetacean species (Jones et al. 2022; Moreno and Macgregor 2019). Some acoustic studies suggest it is more efficient to create new vocal signals for use during interspecies interactions (Herzing 2023). For example, zoo-housed western gorillas (*Gorilla gorilla*) utter species-atypical vocalizations to attract the attention of human caregivers (Salmi et al. 2022). Similarly, the greater honeyguide (*Indicator indicator*), a wild, free-living bird, gives a loud, specialized, chattering call to elicit interaction with humans (Spottiswoode et al. 2016). In some cases (Episodes 1, 7, 8, 9, 11), whales may be responding to the loud and boisterous behaviors of humans onboard, which may create a mutually gratifying loop between participants. However, other episodes (Episodes 2, 3, 5, 10, 12) were characterized by smaller vessels engaged in research or recreational whale watching (or swimming) *without* boisterous human participants, suggesting other internal motivations by ring blowers that remain to be explored.

Patterns of bubble production in cetaceans constitute a mode of communication not available to terrestrial mammals (Pryor 1990). Careful study of ring generation in dolphins has provided insight into dolphin intent, mood, and technical ability (McCowan et al. 2000). Unlike dolphins, which generate bubble rings using a variety of means (Moreno and Macgregor 2019), we found that the blowhole was the sole means of ring production in the humpback whale. Furthermore, the blowhole is well established as the site of production for bubble nets in other studies (Hain et al. 1982; Wiley et al. 2011). Other than the whale approaching and positioning its head near a boat or swimmer, there was no outward evidence that a bubble ring release was imminent, no vestibule inflation, no O-shape to the nare opening, nor any nodding or jerking of the head. This differs from dolphins, who often s-posture the body and nod the head prior to ring release (McCowan et al. 2000; Moreno and Macgregor 2019). In humpback whales, the blowholes are opened by muscular contractions of the superficial nasal muscles (Buono et al. 2015) and are closed when the muscles relax (Maust-Mohl et al. 2019). Social play requires that interactants be attuned to the rapidly changing nature of the play via mirroring and innovation (Graham et al. 2010). Interactive bubble ring "playbacks" (via mechanical generation of bubble rings using a bubble ring generator) in the manner of acoustic playback studies could be useful for further understanding of this volitional, nonverbal phenomenon. Such studies could uncover the scale at which humpback whales can adjust their bubble rings in response to human prompts.

Bubble rings were often interspersed with other bubble structures (plumes, bursts). These structures merit further consideration, as they occur along a structural and perhaps behavioral continuum (plumes-bursts-rings; for a review see Moreno and Macgregor 2019). Such structures may also be produced as failed attempts at creating a ring. "All bubble 'types' are constructed from variations in air release parameters and have a continuum of possible features rather than the clearly distinct categories with which we treat them" (K. Moreno, personal communication, December 2022).[6]

Whatever the reason for their creation, maintaining vigilance in the field will help elucidate the frequency and function of bubble rings. We encourage whale watchers and researchers alike to watch for and report on ring production. Bubble ring production reports should include photo and/or video evidence and include details such as location, date and time, number of whales present, behavior of whale(s) present, and data collection method such as UAV monitoring or boatside mission. Expanded use of semiremote tools will help confirm the extent to which human presence contributes to bubble ring production in humpback whales. Ring generation during inquisitive encounters adds to the humpback whale's diverse interspecies behaviors, including playful lifting of dolphins (Deakos et al. 2010) and human swimmers (T. Cheeseman, personal communication, August 2022),[7] intervention on behalf of the depredated (Pitman et al. 2017), and postmortem attentive behavior, or inspection of the dead (Frediani et al. 2020). Both playful and communicative overtures of bubble rings may hold deeper meaning (Graham et al. 2010) for humpback whales and their potential for interspecies communication (McCowan et al. 2023). As noted by Bearzi et al. (2018) concerning cetacean sentience and intentions, "we must acknowledge our present ignorance and keep a door open to the unexpected."

Author Contributions

Jodi Frediani: conceptualization, data curation, formal analysis, investigation, methodology, project administration, validation, visualization, writing – original draft, writing – review and editing. **Fred Sharpe:** conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, validation, visualization, writing – original draft, writing – review and editing. **Josephine Hubbard:** visualization, writing – original draft, writing – review and editing. **Doug Perrine:** data curation, investigation, resources, writing – review and editing. **Simon Hilbourne:** data curation, investigation, resources, writing – review and editing. **Joy S. Reidenberg:** investigation, visualization, writing – review and editing. **Laurance R. Doyle:** funding acquisition, project administration, supervision, writing – review and editing. **Brenda McCowan:** funding acquisition, project administration, visualization, writing – review and editing.

Acknowledgments

We give our thanks to the following individuals and organizations. For bubble ring media and insightful interviews: Dan Knaub (The Whale Video Company), Sharon Pittman, Jim Darling, Wayne Davis, Gene Flipse, Molly Gaughan, Allison Henry, Simon Istrup, Captain Steve Lawless, Don McLeish, Flip Nicklin, Debbie Patton, Hannah Pittore, Hollis Romanchik, and Chere Tamura. For providing drone observations: Martin Van Aswegen, Ari Friedlaender, Lars Bjeder, Andrew Stevenson, Liah McPherson, and Fabien Vivier. For recollections of bubble rings from the Gulf of Maine during the 1980s: Mason Weinrich. For providing their reviews and invaluable comments on versions of the manuscript: Jim Crutchfield, Jooke Robbins (Center for Coastal Studies), Kelsey Moreno, Lisa Walker, Andy Szabo (Alaska Whale Foundation), and Pat Sharpe. For providing visual media and data: the Hawaii Whale Research Foundation (NMFS Research Permit No. 587) and the Whale Trust (NMFS Research Permit No. 753). For use of their data: the Russian Cetacean Habitat Project (RCHP). Our deep gratitude to the Templeton World Charity Foundation for a Diverse Intelligences Grant (TWCF0440) awarded to the SETI Institute (Laurance R. Doyle, PI), to Pranab Das (TWCF) for funding facilitation and to Debbie Kohler (SETI) for superb administrative support. For her assistance with copy editing and reformatting: Ellen Blue. And finally, our gratitude to the

whales (Thorn, Караул, Caroline, Inga and their ring-blowing kind) for sharing their poloidal creations.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] Martin Van Aswegen, Alaska Whale Foundation, PO Box 1927, Petersburg, AK 99833, July 2022.

[2] Ari Friedlaender, Institute of Marine Sciences, University of California at Santa Cruz, 115 McAllister Way, Santa Cruz, CA 95060, September 2022.

[3] Andrew Stevenson, Whales Bermuda, Flamingo Cliff, 8 St. Patrick's Road, Flatts HM 05, Bermuda, March 2024.

[4] Martin Van Aswegen, Alaska Whale Foundation, PO Box 1927, Petersburg, AK 99833, October 2023.

[5] Gene Flipse, Conscious Breath Adventures, PO Box 1263, Archer, FL 32618, November 2023.

[6] Kelsey Moreno, Department of Psychology, Office: G-307D, Saint Xavier University, 3700 W. 103rd Street, Chicago, IL 60655, December 2022.

[7] Ted Cheeseman, Happywhale, Santa Cruz, CA 95060, August 2022.

[Correction added on 7 June, 2025, after first online publication: Kelly was updated as Kelsey in Footnote 6.]

References

Baker, C. S., and L. M. Herman. 1984. "Aggressive Behavior Between Humpback Whales (*Megaptera novaeangliae*) Wintering in Hawaiian Waters." *Canadian Journal of Zoology* 62, no. 10: 1922–1937. https://doi.org/10.1139/z84-282.

Baker, C. S., and L. M. Herman. 1989. "Behavioral Responses of Summering Humpback Whales to Vessel Traffic. Experimental and Opportunistic Observations." NPS-NR-TRS-89-01. Final Report to the National Park Service, Alaska Regional Office, Anchorage, Alaska from Kewalo Basin Marine Mammal Laboratory.

Bearzi, G., D. Kerem, N. B. Furey, R. L. Pitman, L. Rendell, and R. R. Reeves. 2018. "Whale and Dolphin Behavioural Responses to Dead Conspecifics." *Zoology* 128: 1–15. https://doi.org/10.1016/j.zool.2018.05.003.

Buono, M. R., M. S. Fernández, R. Ewan Fordyce, and J. S. Reidenberg. 2015. "Anatomy of Nasal Complex in the Southern Right Whale, *Eubalaena australis* (Cetacea, Mysticeti)." *Journal of Anatomy* 226, no. 1: 81–92. https://doi.org.10.1111/joa.12250.

Burghardt, G. M. 2010. "Defining and Recognizing Play." In *The Oxford Handbook of the Development of Play*, edited by P. Nathan and A. D. Pellegrini, 9–18. Oxford University Press.

Deakos, M. H., B. K. Branstetter, L. Mazzuca, D. Fertl, and J. R. Mobley Jr. 2010. "Two Unusual Interactions Between a Bottlenose Dolphin (*Tursiops truncatus*) and a Humpback Whale (*Megaptera novaeangliae*) in Hawaiian Waters." *Aquatic Mammals* 36, no. 2: 121–128. https://doi.org/10.1578/AM.36.2.2010.121.

Ejrnæs, D. D., and K. R. Sprogis. 2021. "Ontogenetic Changes in Energy Expenditure and Resting Behaviour of Humpback Whale Mother-Calf Pairs Examined Using Unmanned Aerial Vehicles." *Wildlife Research* 49, no. 1: 34–45. https://doi.org/10.1071/WR20186.

Fish, F. E. 1994. "Influence of Hydrodynamic Design and Propulsive Mode on Mammalian Swimming Energetics." *Australian Journal of Zoology* 42, no. 1: 79–101. https://doi.org/10.1071/ZO9940079.

Fish, F. E., and J. M. Battle. 1995. "Hydrodynamic Design of the Humpback Whale Flipper." *Journal of Morphology* 225, no. 1: 51–60. https://doi.org/10.1002/jmor.1052250105.

Ford, J. K. B., and R. R. Reeves. 2008. "Fight or Flight: Antipredator Strategies of Baleen Whales." *Mammal Review* 38, no. 1: 50–86. https://doi.org/10.1111/j.1365-2907.2008.00118.

Frediani, J. G., N. A. Black, and F. Sharpe. 2020. "Postmortem Attractions: Humpback Whales Investigate the Carcass of a Killer Whale–Depredated Gray Whale Calf." *Aquatic Mammals* 46, no. 4: 402–410. https://doi.org/10.1578/AM.46.4.2020.402.

Gewalt, W. 1989. "Orinoco Freshwater Dolphins (*Inia geoffrensis*) Using Self-Produced Air Bubble 'Rings' as Toys." *Aquatic Mammals*15, no. 2: 73–79.

Gilmore, R. M. 1976. "The Friendly Whales of Laguna San Ignacio." *Terra* 15, no. 1: 24–28.

Graham, K. L., G. M. Burghardt, and J. J. Wiens. 2010. "Current Perspectives on the Biological Study of Play: Signs of Progress." *Quarterly Review of Biology* 85, no. 4: 393–418. https://doi.org/10.1086/656903.

Hain, J. H. W., G. R. Carter, S. D. Kraus, C. A. Mayo, and H. E. Winn. 1982. "Feeding Behavior of the Humpback Whale *Megaptera novaeangliae* in the Western North Atlantic." *Fishery Bulletin* 80, no. 2: 259–268.

Helweg, D. A., G. B. Bauer, and L. M. Herman. 1992. "Observations of an S-Shaped Posture in Humpback Whales (*Megaptera novaeangliae*)." *Aquatic Mammals* 18, no. 3: 74–78.

Herzing, D. L. 1996. "Vocalizations and Associated Underwater Behavior of Free-Ranging Atlantic Spotted Dolphins, *Stenella frontalis* and Bottlenose Dolphins, *Tursiops truncatus*." *Aquatic Mammals* 22, no. 2: 61–79.

Herzing, D. L. 2000. "Acoustics and Social Behavior of Wild Dolphins: Implications for a Sound Society." In *Hearing by Whales and Dolphins*, edited by W. Au and R. R. Fay, vol. 12, 225–272. Springer-Verlag.

Herzing, D. L. 2023. "Getting Out of Our Skin: What Decoding Interspecies Communication and Nonhuman Intelligence Can Tell Us About Deciphering Alien Languages." In *Xenolinguistics: Towards a Science of Extraterrestrial Language*, edited by Douglas A. Vakoch and Jeffrey Punske. Routledge, Taylor & Francis Group.

Hill, H. M., M. S. Kahn, L. J. Brilliott, B. M. Roberts, C. Gutierrez, and S. Artz. 2011. "Beluga (*Delphinapterus leucas*) Bubble Bursts: Surprise, Protection, or Play?" *International Journal of Comparative Psychology* 24, no. 2: 235–243.

Ingebrigtsen, A. 1929. "Whales Caught in the North Atlantic and Other Seas." *Rapports et Procès-verbaux des réunions, Conseil Permanent International pour l'Exploration de la Mer* 56, no. 2: 126.

Jones, M. L. 1985. *Evaluation of the Potential Impact of Whale-Watching Activities on Gray Whales in Laguna San Ignacio, Baja California Sur, Mexico, 1978 to 1982*. San Jose State University Research Repository. https://scholarworks.calstate.edu/downloads/b27741398.

Jones, M. L., C. P. Nicklin, and J. D. Darling. 2022. "Female Humpback Whale (*Megaptera novaeangliae*) Positions Genital-Mammary Area to Intercept Bubbles Emitted by Males on the Hawaiian Breeding Grounds." *Aquatic Mammals* 48, no. 6: 617–620. https://doi.org/10.1578/AM.48.6.2022.617.

Jurasz, C. M., and V. P. Jurasz. 1979. "Feeding Modes of the Humpback Whale Megaptera novaeangliae in Southeast Alaska." *Scientific Reports of the Whales Research Institute*. 31: 69–83.

Mangott, A. H., R. A. Birtles, and H. Marsh. 2011. "Attraction of Dwarf Minke Whales *Balaenoptera acutorostrata* to Vessels and Swimmers in the Great Barrier Reef World Heritage Area—The Management Challenges of an Inquisitive Whale." *Journal of Ecotourism* 10, no. 1: 64–76. https://doi.org/10.1080/14724041003690468.

Marten, K., K. Shariff, S. Psarakos, and D. J. White. 1996. "Ring Bubbles of Dolphins." *Scientific American* 275, no. 2: 82–87. https://doi.org/10.1038/scientificamerican0896-82.

Martinez, E., J. J. Currie, S. H. Stack, S. K. Easterly, and G. D. Kaufman. 2015. "Note on Patterns of Area Use by Humpback Whales (*Megaptera novaeangliae*) in 2013 in Hervey Bay, Australia, With an Emphasis on Mother-Calf Dyads." Working Paper SC/66a/SH/2, submitted to the Scientific Committee of the International Whaling Commission.

Maust-Mohl, M., D. Reiss, and J. S. Reidenberg. 2019. "A Comparison of Common Hippopotamus (Artiodactyla) and Mysticete (Cetacea) Nostrils: An Open and Shut Case." *Anatomical Record* 302, no. 5: 693–702.

McCowan, B., J. Hubbard, L. Walker, F. Sharpe, J. Frediani, and L. Doyle. 2023. "Interactive Bioacoustic Playback as a Tool for Detecting and Exploring Nonhuman Intelligence: 'Conversing' With an Alaskan Humpback Whale." *PeerJ* 11: e16349. https://doi.org/10.7717/peerj.16349.

McCowan, B., L. Marino, E. Vance, L. Walke, and D. Reiss. 2000. "Bubble Ring Play of Bottlenose Dolphins (*Tursiops truncatus*): Implications for Cognition." *Journal of Comparative Psychology* 114, no. 1: 98–106. https://doi.org/10.1037/0735-7036.114.1.98.

Melville, H. 1851. *Moby-Dick; or, the Whale*. Richard Bentley; Harper & Brothers.

Meynecke, J.-O., and H. Kela. 2023. "What's at Play: Humpback Whale Interaction With Seaweed Is a Global Phenomenon." *Journal of Marine Science and Engineering* 11, no. 9: 1802. https://doi.org/10.3390/jmse11091802.

Moreno, K. R., and R. P. Macgregor. 2019. "Bubble Trails, Bursts, Rings, and More: A Review of Multiple Bubble Types Produced by Cetaceans." *Animal Behavior and Cognition* 6, no. 2: 105–126. https://doi.org/10.26451/abc.06.02.03.2019.

Pace, D. S. 2000. "Fluke-Made Bubble Rings as Toys in Bottlenose Dolphin Calves (*Tursiops truncatus*)." *Aquatic Mammals* 26, no. 1: 57–64.

Paulos, R. D., M. Trone, and S. A. Kuczaj II. 2010. "Play in Wild and Captive Cetaceans." *International Journal of Comparative Psychology* 23, no. 4: 701–722. https://doi.org/10.46867/ijcp.2010.23.04.06.

Payne, R. 1995. *Among Whales*. Scribner.

Pitman, R. L., V. B. Deecke, C. M. Gabriele, et al. 2017. "Humpback Whales Interfering When Mammal-Eating Killer Whales Attack Other Species: Mobbing Behavior and Interspecific Altruism?" *Marine Mammal Science* 33, no. 1: 7–58. https://doi.org/10.1111/mms.12343.

Pryor, K., and I. Kang. 1980. *Social Behavior and School Structure in Pelagic Porpoises (*Stenella attenuata and S. longirostris*) During Purse Seining for Tuna*. Southwest Fisheries Center Administrative Report LJ-80-11C. Southwest Fisheries Science Center.

Pryor, K. W. 1990. "Non-Acoustic Communication in Small Cetaceans: Glance, Touch, Position, Gesture, and Bubbles." In *Sensory Abilities of Cetaceans*. NATO ASI Series, edited by J. A. Thomas and R. A. Kastelein, vol. 196. Springer.

Reidenberg, J. S., and J. T. Laitman. 2007. "Blowing Bubbles: An Aquatic Adaptation That Risks Protection of the Respiratory Tract in Humpback Whales (*Megaptera novaeangliae*)." *Anatomical Record* 290, no. 6: 569–580. https://doi.org/10.1002/ar.20537.

Rountree, R. A., K. R. Moreno, and F. Juanes. 2022. "Hunting, Fighting, or Playing With Bubbles: Possible Usage and Acoustic Characteristics of Bubble Burst Sounds Produced by the Amazon River Dolphin (*Inia geoffrensis*)." *Aquatic Mammals* 48, no. 4: 324–340.

Salmi, R., M. Szczupider, and J. Carrigan. 2022. "A Novel Attention-Getting Vocalization in Zoo-Housed Western Gorillas." *PLoS One* 17, no. 8: e0271871. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0271871.

Scheidat, M., C. Castro, J. Gonzalez, and R. Williams. 2004. "Behavioural Responses of Humpback Whales (*Megaptera novaeangliae*) to Whalewatching Boats Near Isla de la Plata, Machalilla National Park, Ecuador." *Journal of Cetacean Research and Management* 6, no. 1: 63–68. https://doi.org/10.47536/jcrm.v6i1.791.

Sharpe, F. A., and L. M. Dill. 1997. "The Behavior of Pacific Herring Schools in Response to Artificial Humpback Whale Bubbles." *Canadian Journal of Zoology* 75, no. 5: 725–730. https://doi.org/10.1139/z97-093.

Spottiswoode, C. N., K. S. Begg, and C. M. Begg. 2016. "Reciprocal Signaling in Honeyguide-Human Mutualism." *Science* 353, no. 6297: 387–389. https://doi.org/10.1126/science.aaf4885.

Sprogis, K. R., L. Bejder, D. Hanf, and F. Christiansen. 2020. "Behavioural Responses of Migrating Humpback Whales to Swim-With-Whale Activities in the Ningaloo Marine Park, Western Australia." *Journal of Experimental Marine Biology and Ecology* 522: 151254. https://doi.org/10.1016/j.jembe.2019.151254.

Stevick, P. T. 1999. "Age-Length Relationships in Humpback Whales: A Comparison of Strandings in the Western North Atlantic With Commercial Catches." *Marine Mammal Science* 15, no. 3: 725–737. https://doi.org/10.1111/j.1748-7692.1999.tb00839.x.

Swartz, S. L. 2018. "Gray Whale: *Eschrichtius robustus*." In *Encyclopedia of Marine Mammals*, 3rd ed., 422–428. Academic Press. https://doi.org/10.1016/B978-0-12-804327-1.00140-0.

Ognev, S. I. 1967. "Cetacea." In *Mammals of the U.S.S.R. and Adjacent Countries*, vol. 9, 717. Israel Program for Scientific Translation (IPST).

Tyack, P. 1983. "Differential Response of Humpback Whales, *Megaptera novaeangliae*, to Playback of Song or Social Sounds." *Behavioral Ecology and Sociobiology* 13: 49–55.

Tyack, P., and H. Whitehead. 1983. "Male Competition in Large Groups of Wintering Humpback Whales." *Behaviour* 83: 132–154. https://doi.org/10.1163/156853982X00067.

Weinrich, M. T., M. R. Schilling, and C. R. Belt. 1992. "Evidence for Acquisition of a Novel Feeding Behaviour: Lobtail Feeding in Humpback Whales, *Megaptera novaeangliae*." *Animal Behaviour* 44, no. 6: 1059–1072. https://doi.org/10.1016/S0003-3472(05)80318-5.

Wiley, D., C. Ware, A. Bocconcelli, et al. 2011. "Underwater Components of Humpback Whale Bubble-Net Feeding Behaviour." *Behaviour* 148, no. 5/6: 575–602. https:/doi.org/10.1163/000579511X570893.

Zoidis, A. M., K. S. Lomac-MacNair, A. E. Chomos-Betz, A. J. Day, and A. S. McFarland. 2014. "Effects of Sex, Seasonal Period, and Sea State on Calf Behavior in Hawaiian Humpback Whales (*Megaptera novaeangliae*)." *Aquatic Mammals* 40, no. 1: 44–58. https://doi.org/10.1578/AM.40.1.2014.44.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.