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Novel Bubble-Cloud Feeding Behavior of a Humpback Whale (*Megaptera novaeangliae*) in the Gulf of California

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Humpback whales (*Megaptera novaeangliae*) undergo long migrations between high latitudes where food sources are rich in the summer and low latitudes where calving and breeding occur in the winter. Although monotypic, three separate populations are generally recognized: (1) North Pacific, (2) North Atlantic, and (3) Southern Hemisphere (Shirihai & Jarrett, 2006). The North Pacific humpback whale population's summer feeding range primarily encompasses the Pacific Rim from California in the United States to Kamchatka in Russia, including offshore waters of Alaska, British Columbia, Washington, Oregon, and California (Calambokidis et al., 2000; Urbán et al., 2000; Barlow et al., 2011). México is one of three main wintering areas (others include Japan and Hawaii) used by North Pacific humpback whales. Four subregions are recognized within México: (1) Southern Baja California coast, (2) Northern Gulf of California, (3) mainland coast of México, and (4) the Revillagigedo Archipelago (Urbán & Aguayo, 1987; Calambokidis et al., 2001). Urbán et al. (2000) and Calambokidis et al. (2001) indicate that wintering Mexican Pacific humpback whales preferentially migrate to California, Oregon, and Washington, and, to a lesser extent, to British Columbia summering areas.

Humpback whales employ a variety of feeding techniques, some of which involve the coordination and cooperation of multiple individuals. Lunge-feeding is a whale rushing upward from below, breaking the water surface at a near-vertical angle with mouth agape to capture prey (Hain et al., 1982). Numerous studies have described bubbling behaviors used to confuse, corral, and capture prey—mostly schooling fish (e.g., herring [*Clupea* spp.]; Sharpe & Dill, 1997; Friedlaender et al., 2011) or krill (*Euphausia* sp.; Jurasz & Jurasz, 1979; Hain et al., 1982). During bubble feeding, the whale(s) blow(s) bubbles underwater in varying patterns that form clouds, encircling nets, or curtains as they rise to the surface (Clapham, 2000; Friedlaender et al., 2011). These bubbles manipulate prey behavior by constraining the movement of fish schools (Sharpe & Dill, 1997). An individual or multiple whales will then lunge vertically either through or to the side of the bubbles to gulp down prey that are caught in the bubble structure. Laboratory experiments simulating whale bubble nets showed that Pacific herring (*Clupea harengus pallasi*) are reluctant to swim through a bubble curtain even when frightened (Sharpe & Dill, 1997).

Two general types of bubble-feeding behaviors have been described: (1) bubble-net feeding and (2) bubble-cloud feeding (Jurasz & Jurasz, 1979; Hain et al., 1982). Bubble-net feeding involves the underwater release of multiple columns of random-sized bubbles that rise to the surface forming a net, curtain, or spiral through which the whale(s) lunge(s) to feed (Friedlaender et al., 2011). Bubble-net feeding has been well-documented in Northern Pacific humpback whales on their Southeast Alaska summer feeding ground (Jurasz & Jurasz, 1979), in the Northwestern Atlantic (Hain et al., 1982), and in the Southern Ocean (Mastick, 2016). In bubble-cloud feeding, a single underwater exhalation produces a single relatively large (4 to 7 m in diameter) circular cloud of small, uniform-sized bubbles that rise to the surface (Hain et al., 1982). Clapham (2000) reported a difference in humpback foraging techniques between oceans, with bubble clouds being the most common bubble structure used in the North Atlantic but never observed in the North Pacific.

This paper reports our observation of an individual humpback whale bubble-cloud feeding on small schooling fish in the Gulf of California offshore of Loreto, Baja California Sur, México. Our observation is rare in several respects. Except for one report in northern California (Kieckhefer, 1992), we found no documentation of bubble-cloud feeding in the North Pacific population despite it being a common technique used by North Atlantic humpback whales (Hain et al.,

1982). Second, the behavior we observed occurred on the winter range. Humpback whales typically do not feed in their tropical breeding areas (Clapham, 2000); however, there are a few documented occurrences of humpbacks feeding in Mexican waters (Urbán & Aguayo, 1987; Frisch-Jordán et al., 2019). Only one (Gendron & Urbán, 1993) described a solo humpback creating a bubble net (not a cloud) to feed on krill in the southern Gulf of California, México.

The individual we are reporting is a previously identified humpback whale, cataloged CRC-18680 in the Cascadia Research Collective database and as HW-MN0502142 in the Happy Whale database. It was photographed and positively identified in the Santa Barbara Channel, California (June 2019 and September 2020), and in the Gulf of California, Baja California Sur, México (February 2020) (Figure 1).

The authors made this sighting while aboard the 7.62-m panga *Concha* during a whale-watching trip organized by the Oceanic Society (Ross, CA, USA) and Vive Loreto Tours (Loreto, Baja California Sur) on 26 March 2021. Visibility was good (~4.5 km), and sea conditions were calm (Beaufort Sea State 1). The observation, which began at 1200 h and lasted for ~1 h, occurred in nearshore waters just north of Isla Coronado, Baja California Sur, México (26° 9' 51.942" N, 111° 17' 32.898" W).

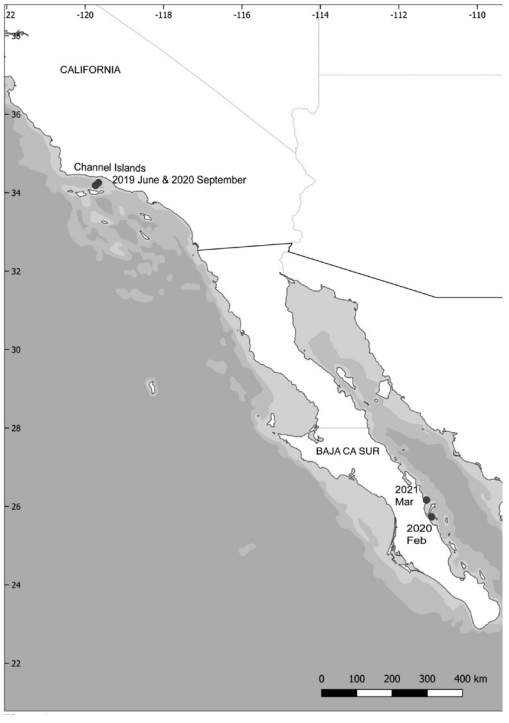

Figure 1. Sightings of humpback whale (*Megaptera novaeangliae*) CRC-18680/HW-MN0502142 in coastal waters of the Gulf of California, Baja California Sur, México, and in Santa Barbara Channel north of Channel Islands (Map courtesy of S. A. Thompson, Farallon Institute, Petaluma, California)

On the morning of 26 March, our group was snorkeling on the east side of Isla Coronado, where, among the many species of tropical fish, we noted a large bait ball of sardines. At ~1135 h, our captain received a marine radio call from another skipper reporting a large whale off the northern tip of Isla Coronado. We motored north along the Isla's eastern side and located the humpback whale. The behavior we describe below was ongoing as we approached the area where the other vessel was already present.

A solitary humpback whale was actively feeding. After swimming back and forth several times at the surface, it dove, fluke exposed, as it sounded. Photos of the ventral fluke were collected for identification and to document behavior (Figure 2). Several minutes later, a 12- to 16-m diameter circle (as estimated by its size in relation to the length of the whale) of small uniform bubbles rose to the surface (a bubble cloud). Less than 5 min following bubble-cloud formation, the whale explosively lunged vertically through the center of the bubble cloud it had created, mouth agape. As it rose one-quarter to one-third the length of its body above the water's surface, it closed its mouth and, with the throat and lateral pleats very distended, expelled water (Figure 3). Small fish could be seen jumping at the surface of the bubble cloud.

During our observation period, the humpback repeated the pattern of swimming, diving, bubble-cloud creation, and lunge-feeding on small schooling fish associated with the bubble structures in a large arc around our vantage point. Each of the four to five bubble clouds that we observed appeared on the water surface as a whitish or aqua-colored oval or circle that contrasted with the surrounding undisturbed deep blue surface (Figure 4). Most of the bubble clouds were widely spaced, at least 200 m or more apart, and 5 to 10 min elapsed between each bubble cloud's creation. However, in one instance, the whale created two bubble clouds less than a whale length apart and lunge-fed vertically up through the undisturbed water between the two bubble structures. We last saw this humpback whale swimming in a northeasterly direction, away from Isla Coronado.

The third author (MN) leads regular marine ecology boat trips in the area and had observed this humpback whale in the same general area over the previous 3 mo. It was always observed alone, but bubble-feeding behavior had not been noted in those previous encounters.

Figure 2. Tail fluke ID photo of humpback whale CRC-18680/MN0502142 taken 26 March 2021 (*Photo credit:* Chris Biertuempfel)

Figure 3. Humpback whale CRC-18680/HW-MN0502142 lunge-feeding through bubble cloud on water surface, 26 March 2021 (*Photo credit:* Chris Biertuempfel)

Figure 4. Bubble cloud rising to water surface prior to humpback whale lunge-feeding, 26 March 2021 (Photo courtesy of Clyde Morris)

Allen et al. (2013) traced the cultural spread of a novel foraging technique related to bubble feeding through a North Atlantic population of humpback whales over a 27-y period. In 1980, one whale in the Gulf of Maine was observed using an innovation, now called lobtail feeding, followed by a bubble-feeding sequence. Analyzing legacy data collected by observers on commercial whale-watching boats, the percentage of whales using this behavior accelerated through time until the end of the study (2007) when 37% of the population was sighted lobtail feeding. Other studies (Cerchio et al., 2001; Helweg et al., 2005) indicate that year-to-year changes of humpback whales' complex breeding songs in the North Pacific and Southern Hemisphere are culturally spread. This suggests that humpbacks learn by watching or listening to their neighbors.

Humpbacks have strong fidelity to specific summer feeding areas and winter breeding/calving regions (Urbán et al., 2000; Calambokidis et al., 2001). Genetic and resighting evidence suggests two groups of humpback whales in the eastern North Pacific: (1) a central stock that feeds in Alaskan waters and migrates predominantly to Hawaii and (2) a southern stock that feeds along the coast of California and winters off México (Baker et al., 1998; Urbán et al., 2000). Two consecutive winter sightings of humpback whale CRC-18680/HW-MN0502142 in México combined with two consecutive summer sightings in California indicate it belongs to the southern stock. Since bubble foraging has rarely been reported for this stock, our observation raises some intriguing questions about the origin, adoption, and spread of novel feeding behaviors.

One hypothesis is that this humpback had an encounter with a member of the central stock, which utilizes bubble-feeding behaviors more commonly on the summer range and adopted the feeding method. Although solo when we observed it, humpback CRC-18680/HW-MN0502142 was in a group of five whales when first documented on 29 June 2019. An alternative hypothesis is that this individual devised and began using bubble-cloud feeding independently. In either case, it would be valuable to track whether the bubble-feeding behavior is transmitted and spreads through the southern stock of the eastern North Pacific.

Photo-identification of individual whales is important in describing movements between

wintering habitat and summer feeding areas (Calambokidis et al., 2001) and has been used to trace the origin, adoption, and spread of novel feeding behaviors (Allen et al., 2013). Cooperative or "crowd sourced" databases, such as Happy Whale, would be particularly helpful in tracking socially transmitted behaviors that take place over large distances and take longer to manifest than the time span of many research projects. An understanding of culturally transmitted feeding behaviors would be furthered by researchers and other observers logging whale encounters in photographic databases and documenting anecdotal observations.

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