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Account of a Solitary Humpback Whale (*Megaptera novaeangliae*) Bubble-Net Feeding in the Moray Firth, Northeast Scotland

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Humpback whales (*Megaptera novaeangliae*), like other rorquals, possess ventral pleats that allow them to engulf large volumes of water, dense with prey, through an efficient lunging action (Pyenson et al., 2012). This feeding method is implemented by humpback whales in various ways by different populations that show behavioural plasticity between geographical locations. In Alaska, for example, humpbacks may dive down hundreds of metres to feed upon aggregated krill (Burrows et al., 2016), while in the west Antarctic Peninsula, the whales feed both closer to the surface and at depth (Ware et al., 2010). To maximise the energetic efficiency of lunge feeding, some humpback populations employ a unique behaviour known as bubble-net feeding, involving the simultaneous expulsion of air underwater while swimming to form a vertical, cylindrical ring of bubbles (Wiley et al., 2011; McMillan et al., 2018). Targeted baitfish are subsequently confused and confined at the water's surface into a tightly packed ball by the rising bubbles (Sharpe & Dill, 1997; Leighton et al., 2007; Wiley et al., 2011; Bryngelson & Colonius, 2019). The whales then lunge through this bait ball with their mouths agape, engulfing as many netted prey as possible.

The earliest eyewitness report of bubble-net feeding was recorded in 1905 off the coast of Norway by Ingebrigtsen (1929). Since then, the behaviour has been well-documented in other regions of the world, from the Atlantic Ocean, including North America's eastern seaboard around the Stellwagen Bank National Marine Sanctuary and other regions of the Gulf of Maine (Askin et al., 2017; Mastick et al., 2022), in the northeastern Pacific in Alaska and Canada (Jurasz & Jurasz, 1979; Hain et al., 1982), in the Baja Californian breeding grounds off the coast of Mexico in the eastern Pacific (Gendron & Urban, 1993), in the southeastern Pacific in the Magellan Strait (Acevedo et al., 2011) to the Southern Ocean around the South Shetland Islands (Herr et al., 2016), off the east coast of Australia in the southwestern Pacific (Pirotta et al., 2021), and in the Arabian Sea in the northern Indian Ocean (Baldwin et al., 2011). To date, however, this behaviour has only briefly been reported once within UK waters in the Firth of Clyde on the west coast of Scotland (Zonfrillo, 1996), although only a vague account of observed surface bubbles was provided in this case, with no description of the pathway or mechanics of the feeding whale.

On 8 October 2021, during a dedicated boat survey for minke whales (*Balaenoptera acutorostrata*) in the Moray Firth, northeast Scotland, a solitary adult humpback whale was encountered performing bubble-net feeding manoeuvres. The whale was encountered approximately ~11 km offshore (57° 46.948' N, 2° 14.061' W) in an area with a bottom depth of 143 m as measured with a dual frequency echosounder (Raymarine plc, Fareham, UK). Minke whales were also observed in the immediate area, along with multiple bird species forming active feeding rafts comprising northern gannets (*Morus bassanus*), European herring gulls (*Larus argentatus*), black-legged kittiwakes (*Rissa tridactyla*), guillemots (*Uria aalge*), and razorbills (*Alca torda*). The bubble-netting behaviour was recorded from a DJI Mavic Pro2 Unmanned Aerial Vehicle (UAV) (Da-Jiang Innovations, Shenzhen, China) post-encounter, flown 30 m above the humpback; from this vantage point, the size, body mechanics, and swim path of the whale were fully observed.

The captured video showed the humpback whale releasing bubbles in a corkscrew, "Fibonacci-shaped" spiral as it circled upwards in a clockwise direction (Figure 1), increasing its turn rate towards the end of the spiral (see Supplemental Video File 1; the supplemental video for this paper is available in the "Supplemental Material" section of the *Aquatic Mammals* website: https://www.aquaticmammals-journal.org/index.php?option=com_content&view=article&id=10&Itemid=147). Two separate spiral

Figure 1. Still images of one of the bubble-net feeding sequences as captured from the UAV drone. During each sequence, the humpback whale (*Megaptera novaeangliae*) circled in a clockwise upwards spiral (with an increasing body turn rate) while blowing bubbles in a continuous stream through 1.5 revolutions. Video footage of this sequence is available as Supplemental Video File 1. (*Video footage credit:* Ciarán Dolan)

events were recorded from the UAV, with the duration of bubble release (time from the first to last exhaled bubbles breaking the water's surface) lasting 12 and 14 s, respectively, as bubbles were released as a continuous stream through 1.5 revolutions as tracked from above. The diameter of the bubble net spanned ~13.5 m, proximate to the whale's estimated length at 12.8 m, as calibrated from the footage with respect to the 8-m survey vessel *in situ*. Each of the upward spirals concluded with the whale lunging dorsally through the centre of the surfacing bubble net, the mouth of the whale agape with ventral pleats fully distended (Figure 2). Dense aggregations of prey could be identified on the depth-finder but were too deep to sample. However, during subsequent boat surveys over the following days, minke whales were recorded surface feeding on juvenile sprat (*Sprattus sprattus*) in the very same encounter area.

The configuration of the recorded bubble net, described above, was comparable to existing descriptions of this complex feeding behaviour from other accounts. For example, Wiley et al. (2011) described individual humpbacks from the Stellwagen Bank National Marine Sanctuary, Gulf of Maine, northwestern Atlantic, performing similar upwards spiral manoeuvres (in both clockwise and anti-clockwise directions) as well as more complex double-loop strategies and coordinated methods involving multiple animals. In our present observations, the whale released a continuous stream of surfacing bubbles, creating a discrete annular bubble curtain as opposed to the multiple bubble bursts also described for the species (e.g., Jurasz & Jurasz, 1979; Hain et al., 1982). Wiley et al. (2011) proposed a 20-m depth limit for bubble-net feeding whales due to the physics of bubble dispersal to which humpback whales have behaviourally adapted. In the present Moray Firth encounter, the turbidity of the water restricted visibility from the UAV as the whale circled below the surface; however, the duration of the rising bubble trail was consistent with a dive depth within this projected 20 m interval.

While records of humpback whales remain low in northeast Scotland (Reid et al., 2003; Robinson et al., 2007), an increasing trend in the number of sightings of the species is evident in recent years (Ryan et al., 2016; O'Neil et al., 2019). Since 2001, 17 individuals have been documented in the Moray Firth by the CRRU research team between

Figure 2. The humpback whale surfacing vertically through the centre of the bubble trap in a dorsal lunge, with mouth fully agape and ventral pleats distended (*Still from phone video footage:* Tom Dolan)

July and October (K. P. Robinson, unpub. data), for which all identifying fluke photographs were submitted to the *North Atlantic Humpback Whale Catalogue* (NAHWC), which contains over 10,500 individuals collated over four decades. Humpbacks are a migratory species, undertaking long journeys from their low latitude breeding grounds to higher latitude areas to feed (Rizzo & Schulte, 2009), and previous studies have managed to map these routes from the mark-recapture of individually recognisable animals (e.g., Stevick et al., 2003; Robbins et al., 2011). Accordingly, one of the Moray Firth individuals captured by the CRRU in August 2013 (NA06642) was subsequently observed in 2015 off Cape Verde in the east Atlantic by Strava Tours, and then more recently in April 2018 in the Azores in the northeast Atlantic by Whale Watch Azores. Lindsey Jones, who maintains the NAHWC and discovered these matches, confirmed this is the first humpback from Scotland that has been recaptured in both the migratory stopover area of the Azores *and* the Cape Verde Islands breeding ground, and the second known resighting between Cape Verde and Scotland (Lindsay Jones, pers. comm., April 2020).

It has been proposed that humpbacks in the Southern Hemisphere supplement their energy stores on Antarctic migrations by feeding off of the east coast of Tasmania (Andrews-Goff et al., 2018). The Moray Firth may subsequently provide a short-term replenishing area for these whales on their passage to known destinations further north in Iceland and the Barents Sea (Stevick et al., 2006) or when making the return journey southwards (e.g., O'Neil et al., 2019). The regional and temporal availability and predictability of prey quintessentially influence the foraging responses of baleen whales (Robinson et al., in press), and the highly productive waters of the Moray Firth may provide important food reserves for these migrating whales (Robinson et al., 2009; Paxton et al., 2014).

A better knowledge of the movements and behaviour of humpback whales in inshore Scottish waters is also valuable from a conservation perspective. Entanglement in static fishing gear (e.g., pots, creels), for example, has been identified as the largest anthropogenic threat to baleen whales in these waters (Northridge et al., 2010), with estimates of at least six humpbacks being entangled in Scotland each year (Leaper et al., in press). The species is highly susceptible to entanglement due to its elongated pectoral fins that are easily caught up in ground lines (Ryan et al., 2016). Despite the low densities of humpback whales recorded in Scottish waters, entanglements of the species nevertheless show an increasing trend (Leaper et al., in press). Encouragingly, Scottish creel fishermen have shown willingness to engage in entanglement mitigation (MacLennan et al., 2019) and have suggested measures such as the introduction of sinking lines, which should be pursued with some urgency.

The use of UAVs in cetacean research provides a non-invasive, cost-effective, and highly

versatile tool for collecting data from free-ranging marine mammal populations (e.g., Christiansen et al., 2016; Aniceto et al., 2018; Raoult et al., 2020). Indeed, the present report underscores the value of UAVs for documenting anecdotal behaviours that might otherwise have been missed using traditional boat-based monitoring methods alone. Based on the former recapture of individual NA06642 between Scotland and the Cape Verde Islands, the migratory route of the bubble-netting humpback whale reported herein could conceivably be the same. The most recent study of the Cape Verde breeding population reported just 267 individuals (Wenzel et al., 2020), and genetic analyses have established clear population separation between this east Atlantic population and the larger, western Atlantic breeding population in the Dominican Republic (e.g., Palsbøll et al., 1997; Constantine et al., 2012). Thus, future studies focusing on the collection of skin samples from Scottish humpbacks for microsatellite genotyping would provide a more thorough understanding of the large-scale movements and migratory origin of these intermittent seasonal visitors.

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