

# Underwater components of humpback whale bubble-net feeding behaviour

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## Summary

Humpback whales (*Megaptera novaeangliae*) employ a unique and complex foraging behaviour — bubble-netting — that involves expelling air underwater to form a vertical cylinder-ring of bubbles around prey. We used digital suction cup tags (DTAGs) that concurrently measure pitch, roll, heading, depth and sound (96 kHz sampling rate), to provide the first depiction of the underwater behaviours in which humpback whales engage during bubble-net feeding. Body mechanics and swim paths were analysed using custom visualization software that animates the underwater track of the whale and quantifies tag sensor values. Bubble production was identified aurally and through spectrographic analysis of tag audio records. We identified two classes of behaviour (upward-spiral; 6 animals, 118 events and double-loop; 3 animals, 182 events) that whales used to create bubble nets. Specifically, we show the actual swim path of the whales (e.g., number of revolutions, turning rate, depth interval of spiral), when and where in the process bubbles were expelled and the pattern of bubble expulsion used by the animals. Relative to other baleopterids, bubble-netting humpbacks demonstrate increased manoeuvrability probably aided by a unique hydrodynamically enhanced body form. We identified an approximately 20 m depth or depth interval limit to the use of bubble nets and suggest that this limit is due to the physics of bubble dispersal to which humpback whales have behaviourally adapted. All animals were feeding with at

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least one untagged animal and we use our data to speculate that reciprocity or by-product mutualism best explain coordinated feeding behaviour in humpbacks.

*Keywords:* humpback whale, feeding, bubble net, kinematic, spiral-loop, double-loop.

## 1. Introduction

Humpback whales (*Megaptera novaeangliae*) are large baleen whales (8.5 m at 0.5 years to 14.3 m at 17 years of age; Stevick, 1999) that feed on a variety of relatively small prey species, each of which aggregate in dense concentrations. Common prey include krill (euphausiid spp.), and schooling fish such as herring (*Clupea* spp.), capelin (*Mallotus villosus*) and sand lance (*Ammodytes* spp.) (e.g., Matthews, 1937; Tomilin, 1967; Overholtz & Nicolas, 1979; Ichii & Kato, 1991). In the Gulf of Maine, humpback whales typically target small fish, primarily herring (*Clupea harengus*) and offshore American sand lance (*Ammodytes dubius*; Hain et al., 1982; Kenney et al., 1985; Payne et al., 1986, 1990). American sand lance, the preferred prey for whales in the southern Gulf of Maine and the only prey identified during our study, live in relatively shallow water, school in large aggregations and are relatively weak swimmers (Overholtz & Nichols, 1979; Hain et al., 1982; Weinrich et al., 1997). In particular, their tendency to school near the surface during daylight hours, often in 'chimney-like' vertical columns, enables efficient feeding by predatory humpback whales (Hain et al., 1982; Friedlaender et al., 2009; Hazen et al., 2009).

Like all balaenopterids, humpback whales feed by engulfing a large volume of water containing prey and separating food and water using sieve-like baleen plates (Slijper, 1962; Mackintosh, 1965). However, humpback whales have unique behavioural and morphological adaptations that distinguish them from other baleen whales.

Behaviourally, humpback whales capture prey by engaging in complex feeding manoeuvres that are often accompanied by the apparently directed use of air bubbles. The ability of bubble barriers to corral or herd fish has been reported by a number of authors (e.g., Smith, 1961; Blaxter & Batty, 1985; Sharpe & Dill, 1997). Bubble use by humpback whales has been observed in many of their feeding habitats and is reported to occur in a variety of configurations. These bubble-feeding behaviours appear to vary in nature among both individuals and regions; for example, bubble clouds