Received: 2 June 2023 | Revised: 11 September 2023 | Accepted: 15 October 2023
DOI: 10.1111/eth.13419

RESEARCH ARTICLE

ethology WILEY

Non-lunge feeding behaviour of humpback whales associated with fishing boats in Norway

Takashi Iwata[1,2,3] | Kagari Aoki[3] | Patrick J. O. Miller[2] | Martin Biuw[4] | Michael J. Williamson[5] | Katsufumi Sato[3]

[1]Graduate School of Maritime Sciences, Kobe University, Kobe, Hyogo, Japan

[2]Sea Mammal Research Unit, School of Biology, University of St Andrews, Fife, UK

[3]Atmosphere and Ocean Research Institute, The University of Tokyo, Chiba, Japan

[4]Institute of Marine Research, Tromsø, Norway

[5]Institute of Zoology, Zoological Society of London, London, UK

Correspondence
Takashi Iwata, Graduate School of Maritime Sciences, Kobe University, 5-1-1 Fukaeminami-machi, Higashinada-ku, Kobe, Hyogo, 658-0022, Japan.
Email: iwatatakashi@gmail.com

Funding information
Japan Society for the Promotion of Science Postdoctoral Fellowships Research Abroad; Mitsui and Co. Environment Fund; Research Grant against Global Warming of the Ichimura Foundation for New Technology

Editor: Redouan Bshary

Abstract

Top marine predators, such as odontocetes, pinnipeds, and seabirds, are known to forage around fishing boats as fishermen aggregate and/or discard their prey. Recently, incidents of humpback whales interacting with fishing boats have been reported. However, whether humpback whales utilise discard fish as a food source and how they forage around fishing boats is unknown. This study reports, for the first time, the foraging behaviour of a humpback whale around fishing boats. Three whales were tagged using a suction-cup tag containing a video camera, and a behavioural data logger in the coastal area of Tromsø, Norway. Video data from one tagged whale showed that the whale remained in close vicinity of fishing boats for 43 min, and revealed the presence of large numbers of dead fish, fish-eating killer whales, fishing boats, and fishing gear. In waters with large numbers of dead fish, the whale raised its upper jaw, a motion associated with engulfing discard fish from fishing boats, and this feeding behaviour differed markedly from lunge-feeding observed in two other whales in the same area. This behaviour was defined as "pick-up feeding". No lunge feeding was seen on the data logger when the whale foraged around fishing boats. This study highlights a novel humpback whale foraging strategy: low energy gain from scattered prey but also low energy costs as high-energy lunge feeding is not required.

KEYWORDS
biologging, energy cost, feeding behaviour, fisheries interaction, humpback whales

1 | INTRODUCTION

Animals make optimal decisions on how to forage to maximize energy intake rate (Stephens & Krebs, 1986). To increase net energy profitability while feeding, animals perform foraging behaviour to increase gross energy gains and/or to save energy costs. Top marine predators, such as odontocetes, pinnipeds, and seabirds, are known to forage around fishing boats when fishermen aggregate and discard their catch (Bearzi et al., 2019; Hamer & Goldsworthy, 2006; Tasker et al., 2000). This foraging strategy might be associated with low energy costs because it reduces the need for animals to search and chase prey items. Despite interactions with fishing boats being well studied in many species (Bonizzoni et al., 2022; Read, 2008), only recently have incidents of baleen whales interacting with fishing boats been reported (Basran & Rasmussen, 2021), and it is unknown whether they utilise discard fish as a food source. Rorqual whales are known to forage by lunge feeding, an energetically expensive foraging strategy where an individual rapidly accelerates before engulfing a large volume of prey-laden water (Goldbogen et al., 2017). However, it is thought that lunge feeding would be an inappropriate strategy around fishing vessels, since it is inefficient for scattered immobile prey and could increase the risk of collision with vessels.

In the coastal area of Tromsø, north Norway, local fishermen operate set net fishing for herring *Clupea harengus* which attracts killer whales *Orcinus orca* around fishing boats for opportunistic feeding events (Mul et al., 2020). Humpback whales *Megaptera novaeangliae*, a rorqual baleen whale species, also feed on herring in this region (Jourdain and Vongraven 2017) and have recently been reported to conduct similar interactions with these fishing boats (Basran & Rasmussen, 2021). Discard fish are a potential low-cost food source for humpback whales. However, it is unknown whether humpback whales forage on discard fish during these interactions. Here, we report the first case of a humpback whale foraging on discard fish from herring fisheries, and the low-energy cost-feeding strategy used to obtain this prey.

2 | MATERIALS AND METHODS

2.1 | Fieldwork

Field surveys were conducted in January 2017, off the island of Vengsoya, Tromsø (69° 51′N, 18° 31′E), Norway. Underwater behaviour of humpback whales was collected using biologging tags. Tags included a behavioural data logger (W1000-3MPD3GT; diameter × length: 26×175 mm; 140 g mass in air; Little Leonardo, Tokyo, Japan), a video camera (DVL400M130-2R; length × width × height: 68×21×22 mm; 47 g mass in air; Little Leonardo Ltd.), a Very High Frequency (VHF) transmitter (Advanced Telemetry Systems, USA), and a satellite transmitter (SPOT6; Wildlife Computers), and a single suction cup for attachment. The behavioural data logger records diving depth, temperature, conductivity, and swim speed and 3-axis magnetic field strength at 1 Hz as well as dorso-ventral, lateral, and longitudinal accelerations at 32 Hz. The video camera recorded 30 frames per second with a 43° field-of view on land and 31° field-of-view underwater. Humpback whales were slowly approached from a 6 m boat and tags were attached using a 6 m carbon fibre pole (Aoki et al., 2015; Johnson & Tyack, 2003). Tags did not have programmable pop-off mechanisms but naturally detached after several hours. The data loggers were retrieved using ARGOS satellite telemetry to locate the general area of the floating tag along with VHF transmitter signals to determine the precise location for tag recovery. The study was carried out under a permit issued by the Norwegian Animal Research Authority (FOTS ID 8165).

2.2 | Analysis of video and behavioural data

Video footage was first analysed to determine whether foraging events had occurred. Data of behavioural data logger was then assessed to identify the foraging strategy, and whether humpback whales used lunge feeding around fishing boats.

We analysed depth, speed, and acceleration data using IGOR Pro version 8.0 (WaveMetrics). As measured by power spectral density, the fluke stroke of the tagged whale was detected as the dominant cycle frequency of the longitudinal acceleration data (for method details, see Iwata et al., 2021). Swim speed was recorded as the number of rotations per second of an external propeller and was converted to swim speed ($m\,s^{-1}$) as previously described (Sato et al., 2003). Swim speeds slower than the stall speed of $0.2\,m\,s^{-1}$ that tag cannot measure speed due to too slow were not included in the analysis. Diving was defined as spending longer than 10 s continuously at a depth greater than 3 m. Feeding events in humpback whales are commonly detected by identifying lunge events from biologging tags (Goldbogen et al., 2008; Simon et al., 2012). In previous studies, lunge feeding of humpback whales has been detected by tri-axis accelerations and swim speed calculated by flow noise (Simon et al., 2012). In this study, lunge feeding events were detected by the following protocol. (1) "Jerk", the rate of change in acceleration, was calculated from tri-axis accelerations (Ydesen et al., 2014), (2) coefficient of variation which is one of variation and a standard deviation divided by mean, of jerk and swim speed were calculated from moving average values of every 5 s, (3) one peak of maximum value of the coefficient of variation were detected within a time window of 30 s, (4) when the peak of the coefficient of variation in jerk and swim speed were detected simultaneously within a time window of 5 s, the events were defined as lunge feeding. The histograms of the peak coefficient of variation in jerk and swim speed demonstrate an unimodal distribution, and values exceeding the right edge of the peak were attributed to intense or high-speed movements. Therefore, the value at the rightmost edge of the peak was set as the threshold for lunge event detection. Fluke stroke rate, maximum swim speed, and events of lunge feeding during diving were calculated. Statistical analyses were performed in R (R Development Core Team, 2022). Fluke stroke rate and maximum swim speed during feeding of each whale were compared using Dunnett's multiple comparison test (Rolland et al., 2005) which is used for making multiple comparison between a single control and several treatments using the *multcomp* package in R.

3 | RESULTS

Three humpback whales were tagged, IDs mn17_022LLa, mn17_022LLb, and mn17_026LLa, recording a total of 32 hours of behavioural data and 17 hours of video data. Several humpback whales were observed visually around fishing boats and whale mn17_026LLa was tagged around fishing boats. Video data from animal mn17_026LLa around fishing boats showed that the whale remained in close vicinity of fishing boats for around 43 minutes after tagging, and revealed the presence of large numbers of dead/almost dead fish (herring and cod species), fish-eating killer whales, fishing boats, and fishing gear such as ropes (Figure 1, Video S1). In waters with large numbers of dead/almost dead fish, the whale raised its upper jaw in 10 times, a motion associated with engulfing the fish (Figure 1, Video S1). We defined this behaviour as "pick-up feeding" since whales caught discarded fish from fishermen. There was no lunge feeding signal in behavioural data of whale mn17_026LLa throughout tag period. However, several lunge feeding signals in behavioural data of whales mn17 _022LLa and mn17_022LLb were detected with values of jerk and swim speed changing abruptly and largely (Figure 2). Fluke stroke rates during a diving of whale mn17_026LLa during pick-up feeding and whales mn17 _022LLa and mn17_022LLb during lunge feeding were 8.4 ± 2.5 (SD) (n = 22 dives), 13.3 ± 1.6 (n = 5 dives), and 10.4 ± 1.7 (n = 9 dives) per minutes respectively. Fluke stroke rates during pick-up feeding were significantly lower than fluke stroke rates during lunge feeding (mn17_026LLa < mn17_022LLa (p < .001), mn17_026LLa < mn17_022LLb (p < .05), Dunnett Contrasts). Maximum swim speed during a diving of whale mn17_026LLa during pick-up feeding and whale mn17 _022LLa and mn17_022LLb during lunge feeding were 2.4 ± 0.7 ms^{-1}, 4.8 ± 0.1 ms^{-1}, and 4.7 ± 0.4 ms^{-1} respectively. Maximum swim speed during pick-up feeding were

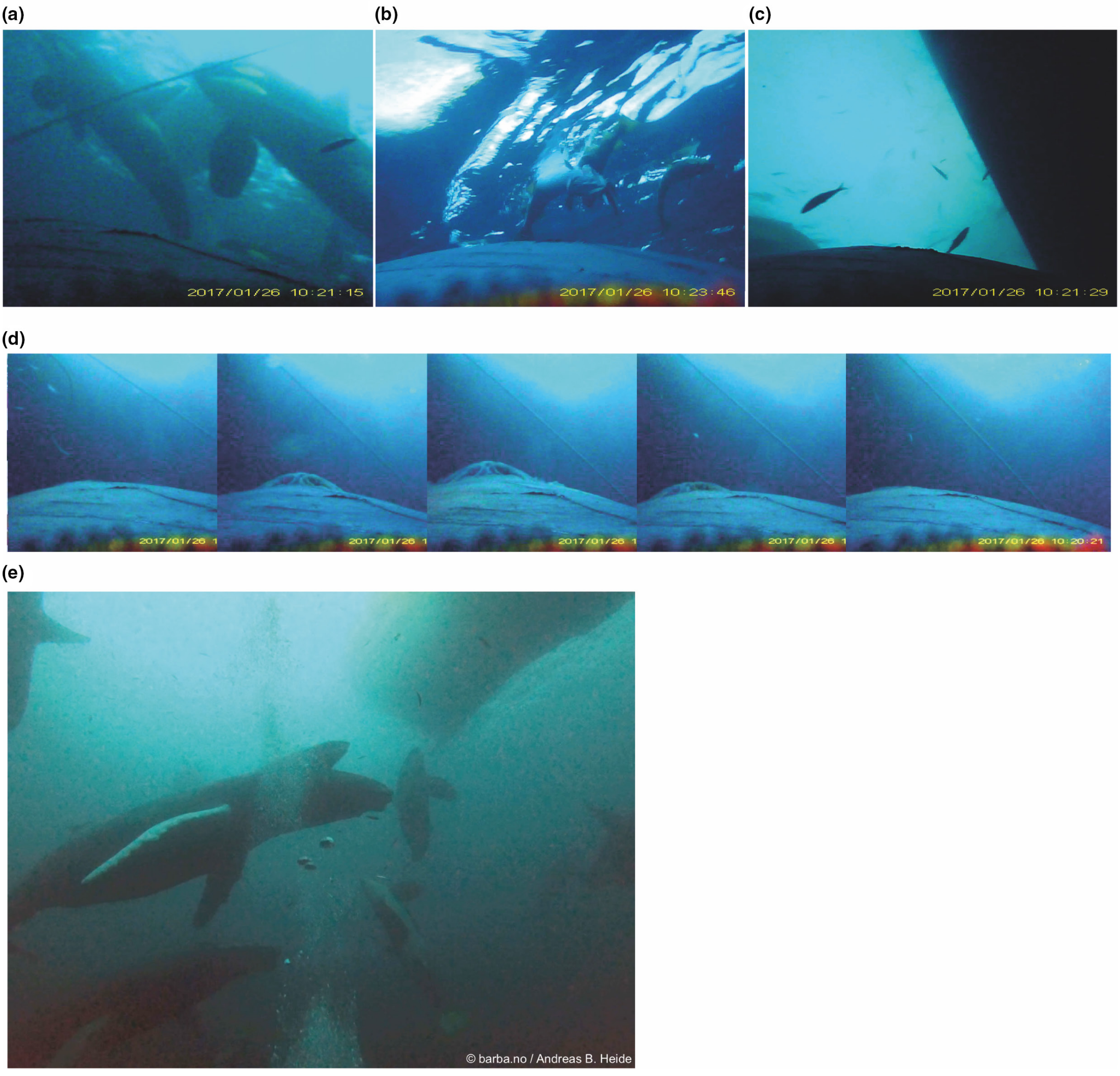

FIGURE 1 Underwater video footage from a whale mn17_026LLa. Images of (a), (b), (c), and (d) were recorded by animal-borne video camera and an image of (e) was taken by an underwater camera of documentary program industry staff (taken by Andreas B. Heide from the sailing vessel Barba). (a) killer whales and fishing ropes. (b) dead cod. (c) dead herring. (d) a tagged whale raised its upper jaw, presumably a motion associated with engulfing the fish. (e) a humpback whale and killer whales feed fish together around fishing boats (photo by Andreas B. Heide).

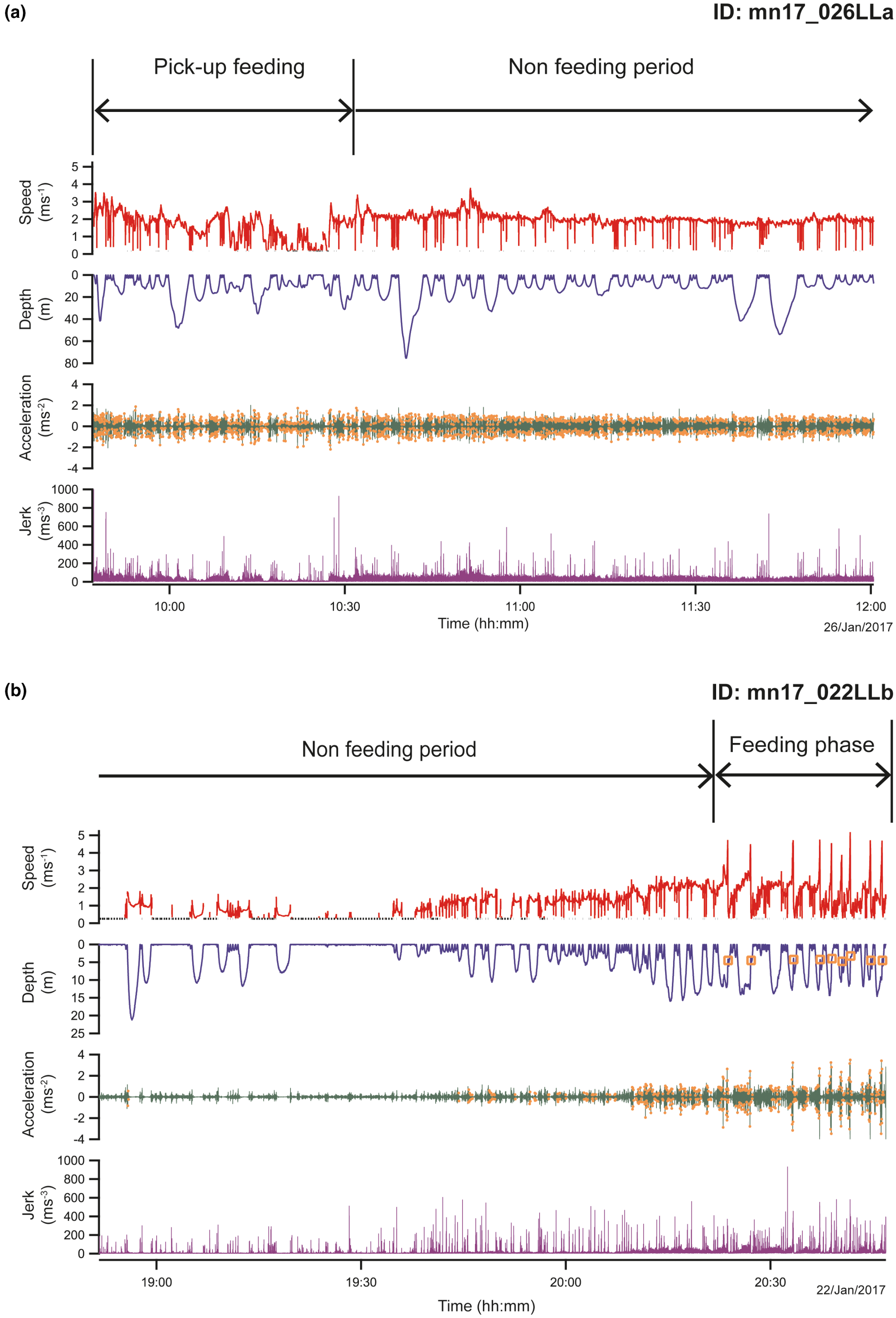

FIGURE 2 Time series records of behavioural data which are swim speed, diving depth, dynamic acceleration, and jerk, of humpback whales. The orange dots on the dynamic acceleration and the orange squares on the diving depth indicate fluke strokes and lunge feedings respectively. (a) a part of record of a whale (ID mn17_026LLa) which performed pick-up feeding. Video data showed that pick-up feeding of the whale for 43 min immediately after tagging then changed behaviour to not related feeding until tag detached. Video cameras worked for this period. (b) a part of the record of a whale (ID mn17_022LLb) which performed lunge feeding. Values of jerk and swim speed changed abruptly and largely during the feeding phase. Video camera worked for this period but all the footages were too dark for analysing.

significantly slower than maximum swim speed during lunge feeding (mn17_026LLa < mn17_022LLa ($p < .001$), mn17_026LLa < mn17_022LLb ($p < .001$), Dunnett Contrasts).

Video data for 8 hours from whale mn17_026LLa following pick-up feeding and video data from whales mn17_022LLa and mn17_022LLb did not show any scenes related to feeding behaviour.

4 | DISCUSSION

This study reveals that humpback whales utilise discard fish near fishing boats for foraging. Whale mn17_026LLa did not perform lunge feeding around fishing boat but instead used a potentially lower energetic cost 'pick-up feeding' where the whale opened its upper to engulf fish. Number of strokes and swim speed in marine mammals is used an index of energy consumption (Davis et al., 1985; Williams et al., 2000). Whale mn17_026LLa around fishing boats did not conduct lunge behaviours, fluke stroke actively, and swimming without high speed indicating that pick-up feeding may be foraging strategy associated with low energy costs. Additional underwater, high-resolution documentary footage of this behaviour from this region, supports our findings, indicating that whales caught dead fish while travelling at low almost drifting speeds (Figure 1, Video S2 and S3). Although footages from animal-borne video did not give an accurate number of fish eaten, pick-up feeding was only conducted 10 times for 43 minutes, and, as such, relatively few fish, compared to lunge feeding events, would have been eaten (Goldbogen & Madsen, 2018). Despite, this pick-up feeding was still likely of net benefit to the whale due to the low energy costs of this behaviour. Moreover, it is plausible that whales may benefit from the ready detectability of fishing boats, potentially leading to a reduction in prey searching duration (Mul et al., 2020).

Rorqual whales primarily employ lunge feeding as a foraging strategy but several other strategies have been reported. They include trap-feeding (McMillan et al., 2019) and bottom feeding (Parks et al., 2014) in humpback whales, tread-water feeding (Iwata et al., 2017) and head slap feeding (Izadi et al., 2022) of Bryde's whales *Balaenoptera edeni edeni* and *B. e. brydei*, and skim feeding of sei whales *B. borealis* (Segre et al., 2021). This study documents an alternate, novel, humpback whale foraging strategy, called pick-up feeding, that is low energy gain from scattered prey but also low energy costs. A previous study reviewing foraging behaviour in rorqual whales has suggested that recent recovery of whale populations may driving the increase in novel foraging strategies (McCarthy et al., 2023). The new pick-up feeding strategy of humpback whales seen here could be a result of competition between whales for prey.

Pick-up feeding includes risks of entanglement with net, which is a common and significant threat to baleen whales (Berrow & Whooley, 2022; Clapham et al., 1999). In addition, bycatch of large animals, such as baleen whales, also pose an issue for fishermen's safety and may cause costly damage to equipment. As such this behaviour could pose a threat to humpback whales and, should it become more common, avoidance sounds, such as pingers (Guidino et al., 2022) to deter whales from feeding close to fishing boats should be utilised to potentially minimise this behaviour. This study showed a novel feeding behaviour in humpback whales, which provides information on the ecology and behaviour of this species which could help inform conservation and management of humpback whales around fisheries in this region.

AUTHOR CONTRIBUTIONS

Takashi Iwata: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; visualization; writing – original draft; writing – review and editing. **Kagari Aoki:** Writing – review and editing; funding acquisition; methodology. **Patrick J.O. Miller:** Data curation; investigation; project administration; supervision; writing – review and editing. **Martin Biuw:** Data curation; investigation; writing – review and editing. **Michael J. Williamson:** Data curation; investigation; writing – review and editing. **Katsufumi Sato:** Supervision; writing – review and editing.

ACKNOWLEDGEMENTS

We thank L. Kleivane for assisting with fieldwork. We also thank Andreas B. Heide from the sailing vessel Barba to provide underwater video footages.

FUNDING INFORMATION

This study was supported by program Bio-Logging Science of the University of Tokyo (UTBLS), the Japan Society for the Promotion of Science Postdoctoral Fellowships Research Abroad, the Mitsui and Co. Environment Fund, and The Research Grant against Global Warming of the Ichimura Foundation for New Technology.

CONFLICT OF INTEREST STATEMENT

We declare we have no competing interests.

DATA AVAILABILITY STATEMENT

https://zenodo.org/record/7299386#.Y4hOELJBwqs.

ORCID

Takashi Iwata https://orcid.org/0000-0001-5492-9411
Kagari Aoki https://orcid.org/0000-0002-5986-9849
Patrick J. O. Miller https://orcid.org/0000-0001-8028-9673
Martin Biuw https://orcid.org/0000-0001-8051-3399
Michael J. Williamson https://orcid.org/0000-0001-9681-8920
Katsufumi Sato https://orcid.org/0000-0002-7557-4784

REFERENCES

Aoki, K., Amano, M., Kubodera, T., Mori, K., Okamoto, R., & Sato, K. (2015). Visual and behavioral evidence indicates active hunting by sperm whales. *Marine Ecology Progress Series*, *523*, 233–241.

Basran, C. J., & Rasmussen, M. H. (2021). Fishers and whales in Iceland: Details of whale interactions with fishing gear from the fishers' perspective, with focus on humpback whales (*Megaptera novaeangliae*). *IWC Journal of Cetacean Research and Management*, *22*(1), 111–128.

Bearzi, G., Piwetz, S., & Reeves, R. R. (2019). Odontocete adaptations to human impact and vice versa. In *Ethology and behavioral ecology of odontocetes* (pp. 211–235). Springer.

Berrow, S., & Whooley, P. (2022). Managing a dynamic North Sea in the light of its ecological dynamics: Increasing occurrence of large baleen whales in the southern North Sea. *Journal of Sea Research*, *182*, 102186.

Bonizzoni, S., Hamilton, S., Reeves, R. R., Genov, T., & Bearzi, G. (2022). Odontocete cetaceans foraging behind trawlers, worldwide. *Reviews in Fish Biology and Fisheries*, *32*, 1–51.

Clapham, P. J., Young, S. B., & Brownell, R. L., Jr. (1999). Baleen whales: Conservation issues and the status of the most endangered populations. *Mammal Review*, *29*(1), 37–62.

Davis, R. W., Williams, T. M., & Kooyman, G. L. (1985). Swimming metabolism of yearling and adult harbor seals Phoca vitulina. *Physiological Zoology*, *58*(5), 590–596.

Goldbogen, J. A., Cade, D. E., Calambokidis, J., Friedlaender, A. S., Potvin, J., Segre, P. S., & Werth, A. J. (2017). How baleen whales feed: The biomechanics of engulfment and filtration. *Annual Review of Marine Science*, *9*(1), 367–386.

Goldbogen, J. A., Calambokidis, J., Croll, D. A., Harvey, J. T., Newton, K. M., Oleson, E. M., & Shadwick, R. E. (2008). Foraging behavior of humpback whales: Kinematic and respiratory patterns suggest a high cost for a lunge. *Journal of Experimental Biology*, *211*(23), 3712–3719.

Goldbogen, J. A., & Madsen, P. T. (2018). The evolution of foraging capacity and gigantism in cetaceans. *Journal of Experimental Biology*, *221*(11), jeb166033.

Guidino, C., Campbell, E., Bielli, A., Pasara-Polack, A., Alfaro-Shigueto, J., & Mangel, J. C. (2022). Pingers reduce small cetacean bycatch in a Peruvian small-scale driftnet fishery, but humpback whale (Megaptera novaeangliae) interactions abound. *Aquatic Mammals*, *48*(2), 117–125.

Hamer, D. J., & Goldsworthy, S. D. (2006). Seal–fishery operational interactions: Identifying the environmental and operational aspects of a trawl fishery that contribute to by-catch and mortality of Australian fur seals (Arctocephalus pusillus doriferus). *Biological Conservation*, *130*(4), 517–529.

Iwata, T., Akamatsu, T., Thongsukdee, S., Cherdsukjai, P., Adulyanukosol, K., & Sato, K. (2017). Tread-water feeding of Bryde's whales. *Current Biology*, *27*(21), R1154–R1155.

Iwata, T., Biuw, M., Aoki, K., Miller, P. J. O. M., & Sato, K. (2021). Using an omnidirectional video logger to observe the underwater life of marine animals: Humpback whale resting behaviour. *Behavioural Processes*, *186*, 104369.

Izadi, S., Aguilar de Soto, N., Constantine, R., & Johnson, M. (2022). Feeding tactics of resident Bryde's whales in New Zealand. *Marine Mammal Science*, *38*(3), 1104–1117.

Johnson, M. P., & Tyack, P. L. (2003). A digital acoustic recording tag for measuring the response of wild marine mammals to sound. *IEEE Journal of Oceanic Engineering*, *28*(1), 3–12.

McCarthy, J., Sebo, E., & Firth, M. (2023). Parallels for cetacean trap feeding and tread-water feeding in the historical record across two millennia. *Marine Mammal Science*, *39*(3), 830–841.

McMillan, C. J., Towers, J. R., & Hildering, J. (2019). The innovation and diffusion of "trap-feeding," a novel humpback whale foraging strategy. *Marine Mammal Science*, *35*(3), 779–796.

Mul, E., Blanchet, M. A., McClintock, B. T., Grecian, W. J., Biuw, M., & Rikardsen, A. (2020). Killer whales are attracted to herring fishing vessels. *Marine Ecology Progress Series*, *652*, 1–13.

Parks, S. E., Cusano, D. A., Stimpert, A. K., Weinrich, M. T., Friedlaender, A. S., & Wiley, D. N. (2014). Evidence for acoustic communication among bottom foraging humpback whales. *Scientific Reports*, *4*(1), 1–7.

R Development Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Read, A. J. (2008). The looming crisis: Interactions between marine mammals and fisheries. *Journal of Mammalogy*, *89*(3), 541–548.

Rolland, R. M., Hunt, K. E., Kraus, S. D., & Wasser, S. K. (2005). Assessing reproductive status of right whales (*Eubalaena glacialis*) using fecal hormone metabolites. *General and Comparative Endocrinology*, *142*(3), 308–317.

Sato, K., Mitani, Y., Cameron, M. F., Siniff, D. B., & Naito, Y. (2003). Factors affecting stroking patterns and body angle in diving Weddell seals under natural conditions. *Journal of Experimental Biology*, *206*(9), 1461–1470.

Segre, P. S., Weir, C. R., Stanworth, A., Cartwright, S., Friedlaender, A. S., & Goldbogen, J. A. (2021). Biomechanically distinct filter-feeding behaviors distinguish sei whales as a functional intermediate and ecologically flexible species. *Journal of Experimental Biology*, *224*(9), jeb238873.

Simon, M., Johnson, M., & Madsen, P. T. (2012). Keeping momentum with a mouthful of water: Behavior and kinematics of humpback whale lunge feeding. *Journal of Experimental Biology*, *215*(21), 3786–3798.

Stephens, D. W., & Krebs, J. R. (1986). *Foraging theory*. Princeton University Press.

Tasker, M. L., Camphuysen, C. J., Cooper, J., Garthe, S., Montevecchi, W. A., & Blaber, S. J. (2000). The impacts of fishing on marine birds. *ICES Journal of Marine Science*, *57*(3), 531–547.

Williams, T. M., Davis, R. W., Fuiman, L. A., Francis, J., Le Boeuf, B. J., Horning, M., Calambokidis, J., & Croll, D. A. (2000). Sink or swim: Strategies for cost-efficient diving by marine mammals. *Science*, *288*(5463), 133–136.

Ydesen, K. S., Wisniewska, D. M., Hansen, J. D., Beedholm, K., Johnson, M., & Madsen, P. T. (2014). What a jerk: Prey engulfment revealed by high-rate, super-cranial accelerometry on a harbour seal (Phoca vitulina). *Journal of Experimental Biology*, *217*(13), 2239–2243.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Iwata, T., Aoki, K., Miller, P. J. O., Biuw, M., Williamson, M. J., & Sato, K. (2023). Non-lunge feeding behaviour of humpback whales associated with fishing boats in Norway. *Ethology*, *00*, 1–6. https://doi.org/10.1111/eth.13419