



ISSN: 1744-7349



## Bryde's whale (*Balaenoptera edeni*) occurrence and foraging behaviour along the east coast of Australia

Vanessa Pirotta, Daniele Cagnazzi, Brett Dixon, Simon Millar, Jessica Millar, Greg Pickering, Paul A. Butcher, Karen A. Stockin & Katharina J. Peters

To cite this article: Vanessa Pirotta, Daniele Cagnazzi, Brett Dixon, Simon Millar, Jessica Millar, Greg Pickering, Paul A. Butcher, Karen A. Stockin & Katharina J. Peters (09 Oct 2024): Bryde's whale (*Balaenoptera edeni*) occurrence and foraging behaviour along the east coast of Australia, New Zealand Journal of Marine and Freshwater Research, DOI: [10.1080/00288330.2024.2409681](https://doi.org/10.1080/00288330.2024.2409681)

To link to this article: <https://doi.org/10.1080/00288330.2024.2409681>



© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



[View supplementary material](#)



Published online: 09 Oct 2024.



[Submit your article to this journal](#)



Article views: 485



[View related articles](#)



[View Crossmark data](#)

## Bryde's whale (*Balaenoptera edeni*) occurrence and foraging behaviour along the east coast of Australia

Vanessa Pirota <sup>a</sup>, Daniele Cagnazzi <sup>b</sup>, Brett Dixon<sup>c</sup>, Simon Millar<sup>d</sup>, Jessica Millar<sup>d</sup>, Greg Pickering<sup>e</sup>, Paul A. Butcher <sup>f,g</sup>, Karen A. Stockin <sup>h</sup> and Katharina J. Peters <sup>i</sup>

<sup>a</sup>Marine Predator Research Group, School of Natural Sciences, Macquarie University, Sydney, Australia; <sup>b</sup>Faculty of Science and Engineering, Southern Cross University, Lismore, Australia; <sup>c</sup>Tura Beach, New South Wales, Australia; <sup>d</sup>Sapphire Coastal Adventures, Merimbula, Australia; <sup>e</sup>Coffs Coast Wildlife Sanctuary, Coffs Harbour, Australia; <sup>f</sup>NSW Department of Primary Industries, National Marine Science Centre, Coffs Harbour, Australia; <sup>g</sup>School of Environment, Science and Engineering, Southern Cross University, National Marine Science Centre, Coffs Harbour, Australia; <sup>h</sup>Cetacean Ecology Research Group, School of Natural Sciences, Massey University, Auckland, New Zealand; <sup>i</sup>Marine Vertebrate Ecology Lab, Environmental Futures, School of Earth, Atmospheric and Life Sciences, University of Wollongong, Wollongong, Australia

### ABSTRACT

Despite their global occurrence in warm-temperate waters and their suspected non-migratory lifestyle, Bryde's whales (*Balaenoptera edeni* spp.) are considered the least-known large baleen whale species. In Australian waters, information on their distribution, ecology and behaviour is scarce. This study documents Bryde's whale occurrence and foraging behaviours along the Australian East Coast using opportunistic citizen science sightings via drone aerial photography, vessel and land-based observations. We observed foraging in both shallow (seafloor visible, beach and breaking waves present) and deep waters. We observed a range of foraging behaviours including lunge feeding (exhibited by individual whales and in pairs), sub-surface and surface skim feeding (shallow waters only) and described multispecies associations. We describe a potentially novel feeding behaviour in shallow waters, where Bryde's whales are feeding directly within or behind the surf break (*shallow water surf feeding*). We quantify the presence of mother-calf pairs in Australian waters, highlighting the use of these waters for potential calving. This study provides insights into Bryde's whale occurrence and foraging behaviour in both shallow and deep waters of eastern Australia.

### ARTICLE HISTORY

Received 22 December 2023  
Accepted 24 September 2024

### HANDLING EDITOR

Natali Delorme


### KEYWORDS

Bryde's whale; *Balaenoptera edeni*; citizen science; cetacean; SDG14 Life Below Water; feeding; drone; New South Wales; Social media; Australia

## Introduction

Cetaceans provide important ecosystem services such as nutrient cycling and maintain a key position in marine food webs. However, information on the foraging behaviour of many species such as large baleen whales is still lacking. Bryde's whales (*Balaenoptera edeni* spp.), a medium-sized (up to 16.5 m) species of baleen whale, are considered the

**CONTACT** Vanessa Pirota  vanessa.pirota@hdr.mq.edu.au

 Supplemental data for this article can be accessed online at <https://doi.org/10.1080/00288330.2024.2409681>

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

least known of the large whales (Kato and Perrin 2018). The taxonomic status of the species remains subject to debate, with two provisional subspecies currently recognised. This includes the small, coastal form, Eden's whale (*B. e. edeni*, Anderson, 1879), and the larger, oceanic form, the Bryde's whale (*B. e. brydei*, Olsen, 1913) (Rice 1998; Committee on Taxonomy 2024).

Distributed within warm temperate and tropical waters of greater than 16°C year-round, Bryde's whales are considered the only 'tropical' baleen whale (Kato and Perrin 2018). Their species range includes coastal and offshore waters between 40°N and 40°S in the North and South Pacific (including parts of the Tasman Sea), Indian Ocean and South and North Atlantic (Kato and Perrin 2018). Overall, little is known about the ecology and behaviour of Bryde's whales (Jefferson et al. 2008). While generally observed alone or travelling in pairs, Bryde's whales have also been documented in aggregations of two or more e.g. South Africa and Gulf of California (Tershy 1992; Penry et al. 2011). Unlike other baleen whales (e.g. humpback whales, *Megaptera novaeangliae*, who are strongly migratory and generally classify as capital breeders – acquire energy resources ahead of time to be stored and used for reproduction (Jönsson 1997)), Bryde's whales are suspected to not undertake distinct annual migratory movements into polar waters to feed. Instead, Bryde's whales may be income breeders (i.e. feed year-round in less productive waters), using adaptable foraging capabilities to exploit abundant and time-sensitive resources such as schooling fish, krill and zooplankton (Wiseman et al. 2011; Izadi et al. 2022). As such, the reproductive behaviour of Bryde's whales is more cryptic in comparison with other baleen whales, but may potentially result in movements either towards or away from the equator during winter months and in some cases, breeding may occur year-round (Best 1977; Jefferson et al. 2008; Wiseman 2008; Kato and Perrin 2018).

As filter feeders (Goldbogen et al. 2017), Bryde's whales have been documented using a variety of different behaviours to feed. For example, in southern Chinese waters, Bryde's whales have been observed to lateral lunge feed cooperatively, trap feeding (rising vertically in the water in the centre of prey aggregations with mouth agape at the water line, holding still for ~20 s, before closing their mouth and capturing the prey), tread-water feeding (similar to trap feeding, also observed in Taiwanese waters Iwata et al. 2017) and pirouette feeding (rising vertically up out of water with mouth open into a baitfish swarm, tilting and swinging laterally 180°, scooping fish at the surface (Chen et al. 2023)). Other diverse feeding behaviour examples include Bryde's whales in the Gulf of California, Mexico and the Hauraki Gulf in New Zealand, which are known to right-side lunge feed and sometimes surface-skim feed on their side with their mouth open (New Zealand only) (Tershy and Wiley 1992; Wiseman et al. 2011). Bryde's whales in South African waters have also been documented to make high-speed chases along the sea floor (Segre et al. 2022). Additionally, Bryde's whales off south-eastern Brazil have even been observed blowing bubbles to assist with feeding (Lodi et al. 2015). In Australian waters, Bryde's whales have been reported to feed in shallow waters (Paterson and Van Dyck 1988). The authors noted close shore presence 'in the surf-lines along adjacent beaches', whales performing 'surface rushes, lunges and circling' and individuals and pairs working 'adjacent schools of fish' (Paterson and Van Dyck 1988).

Apart from historical whaling records, rescue/stranding events, and a handful of field observations (Paterson and Van Dyck 1988; Priddel and Wheeler 1997), very little is

known about Bryde's whale occurrence in Australian waters. As such, Bryde's whales are listed nationally as *Migratory* under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Department of Climate Change, Energy, the Environment and Water, 2024) and *Data Deficient* as per the *The Action Plan for Australian Mammals 2012* (Burbidge et al. 2014) to mitigate potential anthropogenic impacts and enable their protection in Australian waters. As Australia's focus on renewable energy expands offshore (e.g. windfarm developments) adding to already existing anthropogenic impacts (i.e. seismic exploration, commercial fishing, vessel activity), it is crucial to develop a better understanding of the occurrence and behaviour of Bryde's whales to ensure their protection in Australian waters is targeted appropriately.

As a research tool, drones or remotely piloted aircraft (RPA's) provide unparalleled opportunities for non-invasive data collection (Pirotta et al. 2017; Raoult et al. 2020; Butcher et al. 2021), including observations without interfering with the natural behaviours of marine animals (Hodgson et al. 2020; Fettermann et al. 2022; Pirotta et al. 2022). Research tools like drones are particularly helpful for studying animals that are difficult to assess, such as whales (Pirotta et al. 2017). Given the increasing recreational use of drones by the public, footage thus collected constitutes a vast but currently untapped source of data.

Here we harness the power of citizen science (with the exception of one scientific operator, co-author PB) to document the occurrence of Bryde's whales in east Australian waters and to describe foraging behaviour. We collate information from opportunistically collected drone video footage and photographs and use sightings from whale-watching vessels and citizen scientist drone operators to add to the growing body of information on Bryde's whale in Australian waters.

## Materials and methods

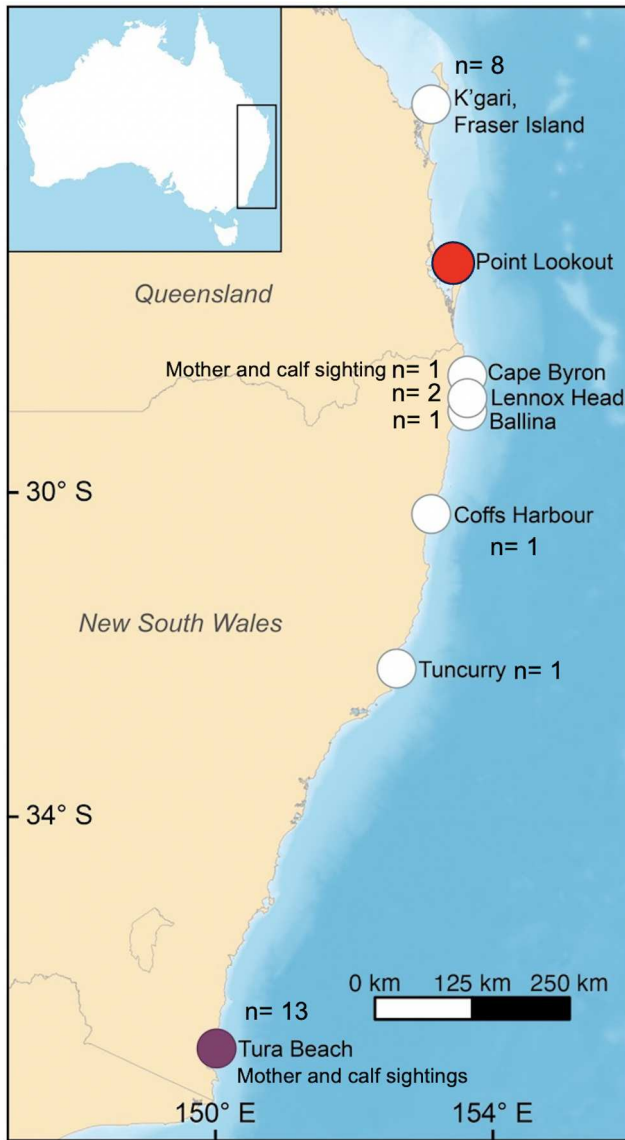
### Study locations

Data collected from this study was derived from evidence of Bryde's whale foraging observations along the Australian east coast, ranging from K'gari (Fraser Island), Queensland to Tura Beach, New South Wales (NSW) (Figure 1).

### Data collection

Data were collected through; (1) commercial whale-watching operators (Sapphire Coastal Adventures, via co-authors SM and JM, photos and drone vision), (2) shore-based observations (co-author GP, photos only) and (3) recreational and scientific drone pilots (BD, PB, among others, drone vision only). All data represented opportunistic, presence only data. Co-author BD flew a DJI Mavic 3 Classic drone 3–5 nautical miles from shore and above 100 m from ground level, as per NSW State drone guidelines (New South Wales Government 2024). Co-author PB's contractors flew a DJI Phantom 4 drone as part of shark surveillance flights at heights of greater than 60 m from shore (NSW DPI and NSW Office of Environment & Heritage scientific permits (Ref. P01/0059; MWL000102746)).

Much of the citizen science data collection for this paper was derived alongside observations of humpback whales feeding during their southward migration (August-



**Figure 1.** Bryde's whale (*Balaenoptera edeni*) occurrence and foraging observations along eastern Australia. White dots indicate locations of shallow water surf feeding observations and the number of observations collected at each location. This includes from north to south; K'gari, Fraser Island, Queensland, Cape Byron, NSW, Lennox Head, NSW, Ballina, NSW, Coffs Harbour, NSW, and Tuncurry, NSW. The single purple dot is the location of deep water feeding observations off the NSW south coast. The single red dot is the location of shallow water feeding behaviour documented by Paterson and Van Dyck (1988). Bathymetry is represented in different shades of blue. The Inset map indicates study locations respective to continental Australia.

October) between Narooma and Eden, NSW, where Bryde's whales were also observed exploiting similar resources (Pirott et al. 2021). We sourced drone observations from social media platforms (e.g. Facebook, Instagram and YouTube) via an online search using a variety of search terms including: *Bryde's whale footage Australia*, *whale*

*feeding footage Australia, whale drone Australia* and *Bryde's whale drone Australia*. We collected photos from the Sapphire Coastal Adventures Facebook page (@sapphirecoastaladventures, September 2011 to September 2023). We ensured all videos and photos collected from social media were from Australian waters by liaising directly with the photographers (e.g. confirming location and date, four of which are co-authors of this paper) and/or through cross-checking the validity of each sighting via online articles (e.g. the data was reproduced by Australian media).

Prior to sighting video and photos, we determined categories as a method to assess the data. We used a quality rating to assess both videos and photos, which consisted of 'high quality' (Good lighting, non-grainy clear focus, coloured images with the ability to further increase image resolution e.g. >300 dots per inch and whale in frame), 'medium quality' (subpar lighting, medium focus and whale in frame) and 'low quality' (poor lighting, pixelated, whale partially in frame). We also included two categories; 'species identification certain' and 'species identification uncertain'. For this study, we used the following distinguishing Bryde's whale features as primary diagnostic e.g. three rostral ridges (if visible) with additional secondary features, e.g. colour of baleen (if visible), dorsal position, shape and pigmentation.

### **Behavioural analysis**

Bryde's whale foraging observations were divided into two main groups based on where they occurred. Feeding observations occurred in both (1) shallow (<10 m, visible seafloor, beach present, breaking waves near Bryde's whale/s) and (2) deep waters (in this paper defined as observations in >10 m, seafloor not visible, no beach or breaking waves) from 2012 to 2022.

The number of foraging observations varied with each location (Figure 1). For each foraging observation, multiple recordings of feeding behaviour were sometimes made during the same day. As feeding in shallow waters was observed within or near the surf, we refer to this as *shallow water surf feeding*.

While we took precautions to avoid including photos/videos taken of the same animal on the same day, we cannot exclude the possibility that our data contain repeated observations of the same individuals across days/years. Social media posts sometimes documented the same observation more than once (repeated content in additional posts). Accordingly, all efforts we made to ensure duplicates were identified and removed. We assessed all videos *ad libitum* for evidence of foraging and described foraging behaviours using behavioural descriptions adapted from prior published studies (where available) detailed in Table 1. To determine a successfully captured feeding event, the video (drone flight) had to show a Bryde's whale directly feeding (at some stage during the flight). From the total minutes of videos analysed, we derived the total minutes of usable videos that contain evidence of feeding behaviour. We also documented times when whales were unlikely to feed (no observed feeding in the video) and swimming with no apparent behaviour change or evidence of bait balls observed at surface (labelled as an undefined activity). In addition to feeding, we also documented evidence of Bryde's whale defaecation by individuals (i.e. a visible faecal plume).

We further noted the presence of putative mother-calf pairs, as evidenced by close associations between two whales, with one whale smaller in size ( $1/3$  of the accompanying

**Table 1.** Bryde's whale (*Balaenoptera edeni*) foraging behaviours used in this study, adapted from existing sources.

Behaviour	Definition	Source
Surrounding bait balls	Observations of Bryde's whales swimming within an area pre/post where active feeding has been observed.	Observation described for this paper
Rapid acceleration*	Increased velocity (i.e. speed in a specific direction), usually prior to engulfment, propulsive fluke movements sometimes visible. Not always observed. *Minor modification: addition of increased velocity to depict speed of the behaviour and observations of fluke movements when behaviour is observed.	(Goldbogen et al. 2006; Cade et al. 2016; Segre et al. 2022)
Lateral lunge feeding Sub category: cooperative lunge feeding*	Lateralised swimming on a single side with mouth agape and throat pleats expanded. Rotations about the whale's longitudinal axis (roll) of approximately 90° and 180°. Two or more whales observed actively feeding synchronously, lateral lunge feeding side by side. *Minor modification: No clockwise swimming behaviour observed, as described in the Chen et al. 2023 definition.	(Goldbogen et al. 2006) (Chen et al. 2023)
Sub surface/surface skim feeding	Mouth agape, slowly moving through a prey patch sub surface or at the surface of the water. Lacks rapid acceleration. Whales are positioned in ventral side down, upright lunge swimming position i.e. not laterally to either side.	(Wiseman 2008; Constantine et al. 2012)
Pass through/non lunging	Swimming/moving sub surface through prey patches or bait balls, no lunging behaviour observed. Mouth appears shut.	Observation described for this paper.
Undefined activity	Swimming/moving through waters with no evidence of feeding behaviour or bait ball presence.	N/A
Defaecation	A visible plume of secretion behind a whale, in a liquid form, which disperses.	(Lavery et al. 2010)
Putative nursing behaviour*	Apparent nursing during rest or slow travel with the mother and calf partially exposed at the water surface, only the calf below the surface, or both animals below the surface.	(Smultea et al. 2017)

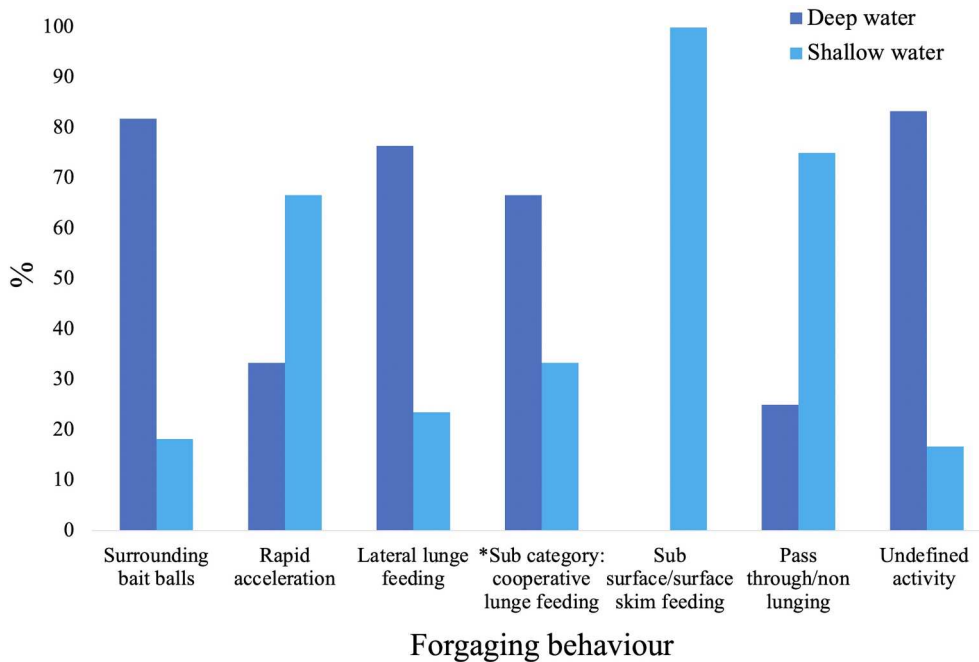
Some behaviours have been slightly modified from the original source. Use of \* indicates slight modification from the original source. Some behaviours have been described in this paper to add further detail regarding observations made.

adult) and swimming in 'echelon' position, typical of cetacean calves (McBride and Kritzler 1951). We also recorded the presence of other species and their (foraging) behaviour to document potential multispecies foraging associations.

## Results

We screened 1.21 hours (mean  $\pm$  SD of individual video clips = 3:08  $\pm$  1:34 min) of drone vision and 200 + photos of citizen science data for evidence of Bryde's whale occurrence and foraging. The most northerly observation was from K'gari, Fraser Island, Queensland and the most southerly observation was from Tura beach along the NSW far south coast. Forty-four minutes of footage was useable for documenting feeding (Table 2), and 80 images contained Bryde's whales, of which 22 images provided direct observations of foraging behaviour by Bryde's whales. In some cases, images from the same feeding event where photos have had 'species identification certain', have also had images which met the criteria 'species identification uncertain'.

We documented a total of 27 foraging observations, across seven locations in NSW and Queensland (Figure 1), with a range of different behaviours



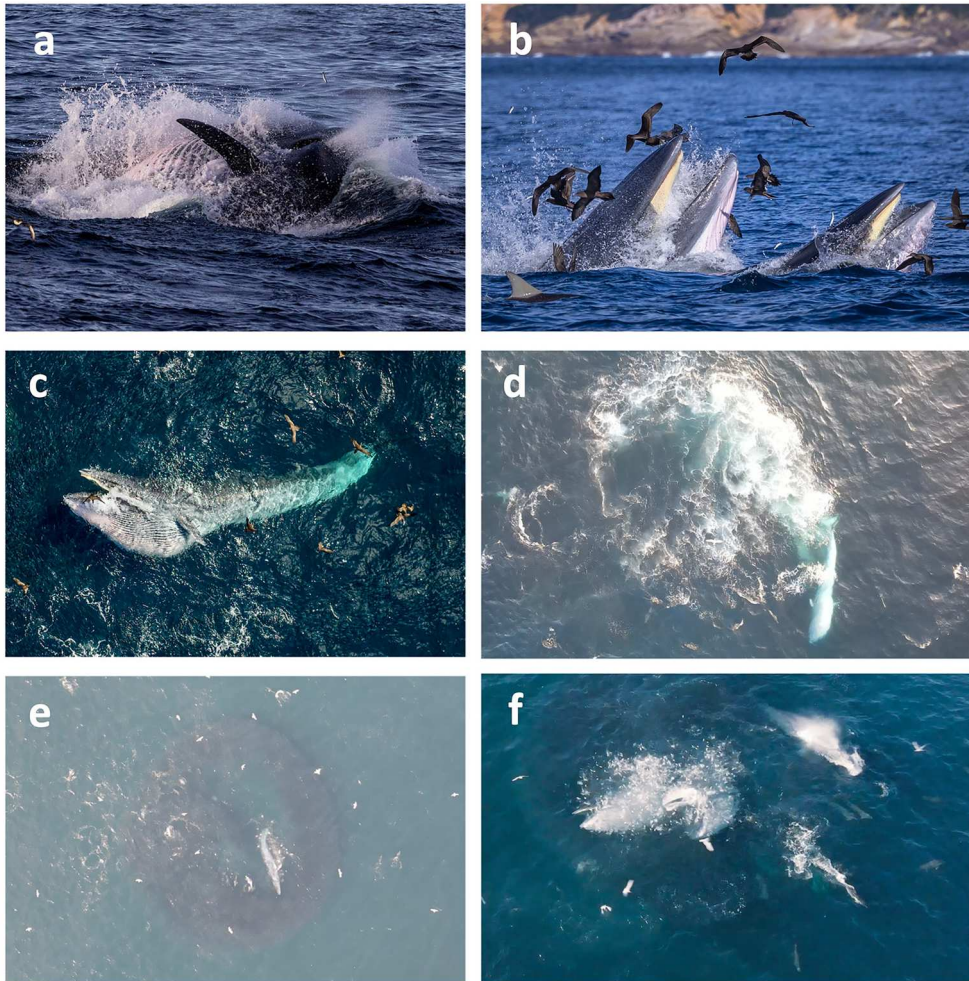
**Figure 2.** Percentage of observed foraging behaviours of Bryde's whale (*Balaenoptera edeni*) in shallow and deep waters along the Australian east coast. Sub surface/surface skim feeding behaviour was observed only in shallow waters.

(Supplementary tables 1 and 2, Figure 2). Sightings occurred across all seasons, with the highest number of observations recorded during the austral winter (69%: 11% July, 58% Aug, 16% spring (Sept only), 5% summer (Jan only) and 5% Autumn (10%: 5% March and 5% May)). We were unable to conduct photo-identification on individuals, as much of the data was collected by drone. We recorded 13 foraging observations in deep waters and 14 foraging observations of shallow water surf feeding. It is possible that there were repeat observations of the same whale captured more than once each day. We collected 20 documented examples of lateralised lunge feeding behaviours, all of which were right-sided and occurred in both deep and shallow water feeding events. *Lateral lunges* were the most recorded foraging behaviour, more commonly observed in deep waters (>10 m), whereas *sub surface/surface skim feeding* behaviours were only observed in shallow waters (<10 m).

### **Deep water foraging**

Opportunistic drone footage ( $n = 13$  videos, 1 location, Figure 1) of 19 Bryde's whales (total number of adults and calves observed in footage) in coastal NSW waters, Australia were collected between 2019 and 2022 and captured a variety of behaviours (Supplementary table 1, Figure 3). Behaviours included: surrounding bait balls, rapid acceleration, lateral lunge feeding (right side only, sub-surface/surface), cooperative lunge feeding (a sub-category of lateral lunge feeding, with side-by-side lunge feeding) and pass through/non-lunge feeding events. Multispecies associations were also documented

with a humpback whale, common dolphins (*Delphinus delphis*), long-nosed fur seals (*Arctocephalus forsteri*) and various species of sea birds (e.g. flesh-footed shearwater, *Ardenna carneipes*), apparently targeting the same prey resources (most likely schooling fish). Drones captured movements of Bryde's whale mother-calf pairs close (~500 m to 1 km) to bait balls. It is possible that feeding may have occurred sub-surface and was not visible via the drone, and/or feeding may have occurred but not captured during drone flights. Additionally, observations made from the drone were also unable to



**Figure 3.** Drone and vessel-based observations of Bryde's whale (*Balaenoptera edeni*) feeding behaviour in deep waters (>10 m) in New South Wales, Australia, showing (a) right-sided lung feed with evidence of small bait fish in shot; (b) evidence of cooperative feeding and multispecies associations e.g. dolphins and birds; (c) right-sided lunge from the air; (d) example of tight turning and rolling behaviour post-lunge (right-sided); (e) Bryde's whale in the middle of large bait ball; (f) three Bryde's whales, two engaged in right-sided lunge with baitfish visible, the third whale does not complete a side lunge but passes through the area. Dolphins and birds present in the images indicate multispecies association. Vessel images and drone image (a, b and c) were collected by Sapphire Coastal Adventures. Images d, e and f were collected by Brett Dixon.

provide verification of prey type. In contrast, vessel-based observations complimentary to the drone footage were able to provide evidence of prey type (e.g. small bait fish), but unable to document widespread surface behaviour observed via drone. We also documented three examples of defaecation, as well as a mother-calf pair putatively nursing.

### **Shallow water foraging**

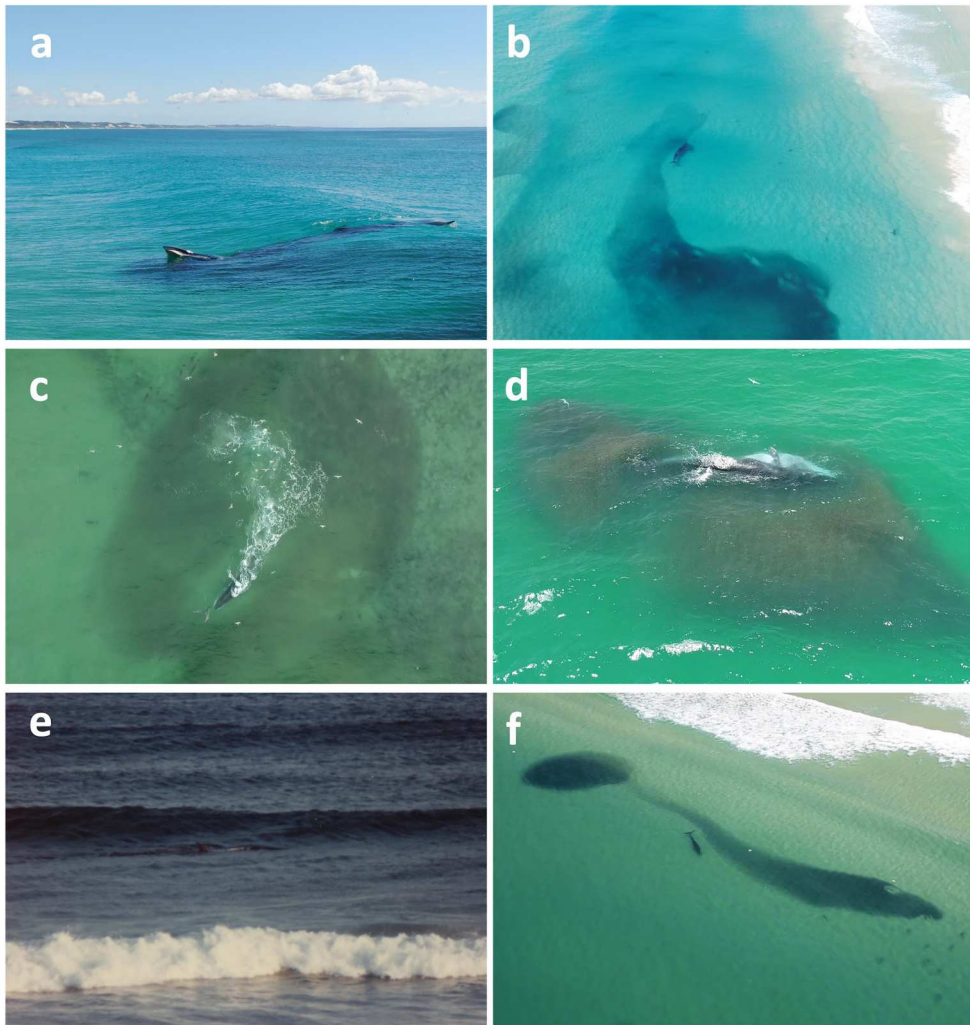
A total of 15 shallow water surf feeding observations were collected between 2012 and 2021 (Supplementary table 2, Figure 4). These sightings (six locations, Figure 1) ranged from K'gari (Fraser Island, 25.2398° S, 153.1325° E), Queensland in the north, to Merimbula, New South Wales (36.8879° S, 149.9064° E) in the south, provide direct evidence of Bryde's whales feeding in shallow waters either directly within or near the surf break. Behaviours included; surrounding bait balls, lateral lunge feeding on the right side, cooperative lunge feeding, pass through/non lunge events and sub surface/surface skim feeding.

All sub surface/surface skim feeding behaviours (n = 5) were carried out by one whale on the same day (K'gari, Fraser Island, Queensland, Figure 4(a, b)). Drone footage shows the individual moving with the surf as it sub-surface and surface-skim feeds with its mouth open. The whale slowly moves through the prey/bait ball using what appears to be the momentum of the water. On one occasion, the individual held its mouth agape sub surface/surface skim feeding for an extended period time of 37 s. This is an underestimation of the full time the mouth was held open, as the initial moment when the animal opened its mouth was not visible. This time was determined from the moment in the video where the whale's mouth is first observed open to the moment it closed its mouth. Drone evidence of Bryde's whales feeding directly in the surf is also supported by non-drone observations made by co-author GP at Gallows Beach, Coffs Harbour (30.3119° S, 153.1427° E) (Figure 4(e)). This individual was observed on the 28 March 2012, entering the outer break and then swerving out again repeatedly, with small fish scattering in front of the whale. The same whale (confirmed via dorsal fin) was found stranded the next day just south of the location at Valla Beach (30.5910° S, 153.0090° E), suspected to have been caught at the end of the gutter where it grounded on the sand and died later that day on the beach.

Additionally, a single mother-calf observation provided evidence of cooperative feeding with interspecific species (supplementary table 2, Cape Byron, NSW). Multispecies observations were also made across most feeding events (excluding Coffs Harbour and Cape Byron (28.6335° S, 153.6383° E)). This included the presence of dolphins (*Delphinus delphis* and *Tursiops aduncus*) and sharks (unconfirmed whaler species), sometimes within metres of the whale. Schooling fish appeared to be the main prey targeted by Bryde's whales in shallow-feeding water observations.

### **Discussion**

Using opportunistically collected footage and photographs by commercial whale watching operations, citizen scientists, and recreational drone operators, we provide the first documentation of Bryde's whale feeding behaviour in New South Wales, Australia.



**Figure 4.** Shallow water surf feeding (<10 m) by Bryde's whales (*Balaenoptera edeni*) in Australian waters; (a) behind the surf break at K'gari, Fraser Island, Queensland, Australia, 6/5/2021. Sub surface and surface skim feeding behaviour, with mouth agape but no lunging behaviour observed by drone; (b) the same Bryde's whale as Figure 4(a) feeding in shallow waters with evidence of shark presence and proximity to the beach (image credit 4a & b: T. Arnell and A. Ihle (@TakeThe M.A.P)); (c) drone observations post right sided lunge feed in shallow waters (seafloor visible) off Ballina, NSW. Feeding on baitfish with the multispecies presence of dolphins, two prey observable ahead of the whale's rostrum. The disturbed water/white wash indicates the whale's movements (image credit Paul Butcher, Department of Primary Industries, 12/1/2019); (d) drone vision shows a single Bryde's whale post lunge, within a bait ball in shallow waters of Lennox Head, New South Wales (image credit Paul Butcher, Department of Primary Industries, 17/7/2017); (e) a Bryde's whale feeding behind the surf break at Gallows Beach, Coffs Harbour, New South Wales, 28/3/2012 (image credit Greg, photo taken from land, hand held camera). (f) helicopter observations of a Bryde's whale targeting bait fish at Tuncurry, near Forster, New South Wales 26/9/2017 (image credit: NSW Department of Primary Industries). Sharks are present foraging in the image.

Bryde's whale foraging behaviour was previously described in the Queensland region in Australian waters (Paterson and Van Dyck 1988).

### **Occurrence**

Observations presented in this paper occur across all seasons, with the highest number of observations documented during the winter months. This likely coincides with efforts documenting humpback whale presence in Australian waters (Pirota et al. 2020). It is possible that Bryde's whales also occur and feed along other coastal regions of Australia and at other times of the year, although this was not documented in this paper. Observations made in both shallow and deep waters suggest that Bryde's whale may occupy different marine environments in order to feed.

### **Foraging behaviours in shallow and deep waters**

Drone footage captured off the New South Wales south coast documented a variety of Bryde's whale foraging behaviours in deep waters with a preference for right-sided lunge feeding, also known as right lateral lunge feeding (Chen et al. 2023). Often, individuals were observed accelerating towards prey and then rolling on their right side to lunge feed – a type of feeding behaviour consistent with that observed in Bryde's whales in the Hauraki Gulf, New Zealand (Wiseman et al. 2011; Izadi et al. 2022), Gulf of California, Mexico (Tershy and Wiley 1992) and northern Beibu Gulf, southern China (Chen et al. 2023). Also of note, was the semi-circle formation post lunge (Figure 3 (d)), which involved briefly rotating an additional 90 degrees beyond laterisation, thus fully inverting to 180 degrees with ventrum at the surface. This is similar to twisting movements described in lunge feeding Bryde's whales in Brazilian waters (de Mello Neto et al. 2017) and the ~90 degree rolls post lunges observed in Bryde's whales in New Zealand waters, as a possible way to minimise prey escape at the surface (Izadi et al. 2022). The height at which the drone was flown (>100 m by co-author BD) was able to document the extent of the feeding activity in the area and evidence of multispecies associations. This is consistent with other multispecies feeding observations, particularly observed off South Africa (Penry et al. 2011) and the Hauraki Gulf, New Zealand (Stockin et al. 2008; Wiseman et al. 2011), where Bryde's whales associate with common dolphins (*Delphinus delphis*) and different gannet species (*Morus* spp.).

We further observed shallow water surf feeding behaviour in several locations. It is possible that the surf may be of assistance to feeding, as there are examples where individuals appear to be riding the surf or using it for momentum to feed. Further observations of one particular whale, where it's recorded holding its mouth open for over 37 s, are similar to the upright lunge feeding behaviour described by Chen et al. (2023) in southern Chinese waters and observations from the Hauraki Gulf, New Zealand, where Bryde's whales laterally skim feed at the surface (Wiseman et al. 2011). Overall, observations of shallow water surf feeding behaviour reported here support initial field observations published by Paterson and Van Dyck (1988) from Queensland waters. This is consistent with the drone footage presented in this paper, and the observations made from Coffs Harbour. Paterson and Van Dyck (1988) also noted Bryde's whales targeting schooling fish at all times of the day when present.

We acknowledge that it is not uncommon for Bryde's whales to feed in shallow waters, for example, individuals in Brazilian waters have been documented following sardines (*Sardinella brasiliensis*) using shallow waters (15–122 m) to spawn (Siciliano et al. 2004). Shallow water feeding also regularly occurs in the Hauraki Gulf, New Zealand where the average depth is ~50 m (Izadi et al. 2022). Additionally, inshore Bryde's whales in South African waters have been found to make high speed, seafloor chases on low-density schools in depths between 18 and 98 m (Segre et al. 2022). Although no depth measurements were collected in this study, all shallow water surf feeding observations reported here occurred in waters estimated to be 10 m or less. Often the events occurred in the surf or the waters just behind the surf break based on the sandy substrate being visible. While shallow water feeding and other foraging behaviours described in this paper have been observed elsewhere in other locations, we believe the point of difference in these observations is that Bryde's whales are feeding (ventrum down) directly within or behind the surf break. This may indicate our description of *shallow water surf feeding* as a novel feeding behaviour not previously documented for this species.

### **Implications for Bryde's whale conservation in Australian waters**

This paper provides a basis of occurrence information to directly inform targeted conservation efforts for Bryde's whales that use the waters along the Australian east coast. Evidence of Bryde's whale occurrence across all seasons supports the hypothesis that Bryde's whales may remain in Australian waters year round, preferring warm temperate waters (Kato and Perrin 2018). This is timely given the continuation of existing anthropogenic activities (e.g. shipping, commercial fishing, tourism), and the future of new anthropogenic activities such as coastal/offshore developments such as offshore windfarms. Whilst here we document the potential overlap of Bryde's whales with anthropogenic activities, we were unable to determine if any of these activities directly or indirectly impact individuals. As such, while acknowledging the limitations of our study, we suggest a precautionary approach be applied to Bryde's whale occurrence, at least along the Australian east coast when assessing existing and future anthropogenic activities. Furthermore, Bryde's whale occurrence may also be reflective of prey and local productivity in shallow/deep water marine environments, as previously documented with humpback whale feeding in New South Wales waters (Pirootta et al. 2021). Climatic-driven changes in the ocean (e.g. warming sea temperatures, changing currents) have the potential to alter when and where prey are distributed and in Australian waters (Gervais et al. 2021), which may result in changes to Bryde's whale occurrence. Whilst we do not yet understand the exact fish and/or potential krill species Bryde's whales are consuming, climatic-driven changes in the Australian marine environment must be given consideration when assessing potential Bryde's whale occurrence in the future.

The presence of mothers with calves documented in this study indicates that some parts of the Australian east coast could possibly serve as an important area for nursing Bryde's whales, and possibly could be used for calving. Direct evidence of assumed mother and calf feeding (both observed lunging in sync) was recorded in shallow waters on baitfish, while there was no direct evidence of feeding from presumed mothers with calves in deep water observations. Mothers with calves may have been passing through the area and not engaged feeding at all. Regardless, this information

**Table 2.** Summary of Bryde's whale (*Balenoptera edeni*) footage/photos assessed from social media documenting Bryde's whale occurrence and foraging along the east coast of Australia.

Data type	Image/footage quality			Species identification	
	High	Medium	Low	certain	uncertain %
Bryde's whale feeding footage (video) 44 mins	80	20	0	100	0
80 images containing Bryde's whales	85	15	0	95	5
22 images of Bryde's whale feeding	86	14	0	68	32

Data are shown in percentage per data type for both quality and species identification.

should be considered when defining biologically important areas for this species in Australian waters. Both feeding and calving have been observed in neighbouring Bryde's whale populations in the Hauraki Gulf, New Zealand (Wiseman et al. 2011). While beyond the scope of this study, an investigation of potential trans-Tasman movements of Bryde's whales in Australian and New Zealand waters is prudent to better understand behaviour, potential migration and to support conservation management of the species. Future photo-identification of Bryde's whales off the east coast of Australia matched to individuals from the Hauraki Gulf, New Zealand (Tezanos-Pinto et al. 2017) could offer insight into potential trans-Tasman movements.

### **Citizen science to support Bryde's whale sightings**

The findings in this paper are reflective of the ever-growing contribution citizen scientists have to offer to the scientific community (Kelly et al. 2020). Citizen science efforts and access to tools, such as drones, have been incredibly useful in documenting Bryde's whale occurrence and behaviour in Australian waters. These observations have been crucial for this paper; however, we do acknowledge that there are limitations to this type of data collection. Being opportunistic, this type of data collection only considers presence data, rather than the collection of both presence/absence data. Additionally, citizen science data collected rarely conforms to a systematic pre-designed method, and typically lacks the consultation of scientists and/or managers with experience in scientific method design (Pirota et al. 2020; Johnston et al. 2023). We also acknowledge that additional citizen science sightings of Bryde's whales along the Australian east coast may exist but have yet to be publicly shared. With this understanding, we recommend a cautionary approach when analysing citizen science information. Acknowledging these limitations, we believe citizen science contributions, along with scientific guidance, will continue to help grow our understanding of Bryde's whale occurrence in Australian waters.

### **Acknowledgements**

The authors would like to thank citizen scientist drone contributors Taylor Arnell and Austin Ihle (Instagram: @Take.The.M.A.P), Daniel Cook (Instagram: @the.drone.d.c) and NSW Department of Primary Industries (Shark Management Strategy) drone pilots for their footage of Bryde's whale feeding behaviours. The authors would like to acknowledge the Traditional Custodians of Country throughout Australia and their connections to land, sea and community. We pay our respect to their Elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples today.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Data availability statement

The authors confirm that the data supporting the findings of this study are available within the supplementary materials.

## ORCID

Vanessa Pirotta  <http://orcid.org/0000-0003-0395-1859>  
 Daniele Cagnazzi  <http://orcid.org/0000-0002-7901-4565>  
 Paul A. Butcher  <http://orcid.org/0000-0001-7338-6037>  
 Karen A. Stockin  <http://orcid.org/0000-0002-2981-3983>  
 Katharina J. Peters  <http://orcid.org/0000-0002-5967-0928>

## References

- Best P. 1977. Two allopatric forms of Bryde's whale off South Africa. Reports of the International Whaling Commission (Special Issue). 1:10–35.
- Burbidge A, Harrison P, Woinarski JZ. 2014. The action plan for Australian mammals 2012. Collingwood, Australia: CSIRO Publishing.
- Butcher PA, Colefax AP, Gorkin III RA, Kajiura SM, López NA, Mourier J, Purcell CR, Skomal GB, Tucker JP, Walsh AJ, et al. 2021. The drone revolution of shark science: a review. *Drones*. 5(1):8. doi:10.3390/drones5010008.
- Cade DE, Friedlaender AS, Calambokidis J, Goldbogen JA. 2016. Kinematic diversity in rorqual whale feeding mechanisms. *Current Biology*. 26(19):2617–2624. doi:10.1016/j.cub.2016.07.037.
- Chen B, Wu C, Ballance LT, Fertl D, Jiang H, Qiao Y, Du Z, Zhang Y, Yang F, Yang G, et al. 2023. Cooperative feeding and foraging lateralization by Eden's whales off southern China. *Marine Mammal Science*. 39(1):200–219. doi:10.1111/mms.12974.
- Committee on Taxonomy. 2024. List of Marine Mammal Species and Subspecies. The Society for Marine Mammalogy; [accessed 2023 Sep 1]. <https://marinemammalscience.org/science-and-publications/list-marine-mammal-species-subspecies/>.
- Constantine R, Soto NA, Johnson M. 2012. Sharing the waters: minimising ship collisions with Bryde's whales in the Hauraki Gulf. Research Progress Report. Auckland, New Zealand: University of Auckland.
- de Mello Neto T, de Sá Maciel I, Tardin RH, Simão SM. 2017. Twisting movements during feeding behavior by a Bryde's whale (*Balaenoptera edeni*) off the coast of southeastern Brazil. *Aquatic Mammals*. 43(5):501–506. doi:10.1578/AM.43.5.2017.501.
- Department of Climate Change, Energy, the Environment and Water. 2024. Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Canberra, ACT; [accessed 2023 Sep 1]. [http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon\\_id=35](http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=35).
- Fettermann T, Fiori L, Gillman L, Stockin KA, Bollard B. 2022. Drone surveys are more accurate than boat-based surveys of bottlenose dolphins (*Tursiops truncatus*). *Drones*. 6(4):82. doi:10.3390/drones6040082.
- Gervais CR, Champion C, Pecl GT. 2021. Species on the move around the Australian coastline: a continental-scale review of climate-driven species redistribution in marine systems. *Global Change Biology*. 27(14):3200–3217. doi:10.1111/gcb.15634.
- Goldbogen JA, Cade DE, Calambokidis J, Friedlaender AS, Potvin J, Segre PS, Werth AJ. 2017. How baleen whales feed: the biomechanics of engulfment and filtration. *Annual Review of Marine Science*. 9:367–386. doi:10.1146/annurev-marine-122414-033905.

- Goldbogen JA, Calambokidis J, Shadwick RE, Oleson EM, McDonald MA, Hildebrand JA. 2006. Kinematics of foraging dives and lunge-feeding in fin whales. *Journal of Experimental Biology*. 209(7):1231–1244. doi:10.1242/jeb.02135.
- Hodgson JC, Holman D, Terauds A, Koh LP, Goldsworthy SD. 2020. Rapid condition monitoring of an endangered marine vertebrate using precise, non-invasive morphometrics. *Biological Conservation*. 242:108402. doi:10.1016/j.biocon.2019.108402.
- Iwata T, Akamatsu T, Thongsukdee S, Cherdskujai P, Adulyanukosol K, Sato K. 2017. Tread-water feeding of Bryde's whales. *Current Biology*. 27(21):R1154–R1155. doi:10.1016/j.cub.2017.09.045.
- 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. doi:10.1111/mms.12918.
- Jefferson TA, Weber MA, Pitman RL. 2008. *Marine mammals of the world: a comprehensive guide to their identification*. San Diego: Academic Press.
- Johnston A, Matechou E, Dennis EB. 2023. Outstanding challenges and future directions for biodiversity monitoring using citizen science data. *Methods in Ecology and Evolution*. 14(1):103–116. doi:10.1111/2041-210X.13834.
- Jönsson KI. 1997. Capital and income breeding as alternative tactics of resource use in reproduction. *Oikos*. 78(1):57–66. doi:10.2307/3545800.
- Kato H, Perrin WF. 2018. In: B. Würsig, J. G. M. Thewissen, K. M. Kovacs, editors. *Encyclopedia of marine mammals*. United States of America: Academic Press.
- Kelly R, Fleming A, Pecl GT, von Gönner J, Bonn A. 2020. Citizen science and marine conservation: a global review. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 375(1814):20190461. doi:10.1098/rstb.2019.0461.
- Lavery TJ, Roudnew B, Gill P, Seymour J, Seuront L, Johnson G, Mitchell JG, Smetacek V. 2010. Iron defecation by sperm whales stimulates carbon export in the Southern Ocean. *Proceedings of the Royal Society B: Biological Sciences*. 277(1699):3527–3531. doi:10.1098/rspb.2010.0863.
- Lodi L, Tardin RH, Hetzel B, Maciel IS, Figueiredo LD, Simão SM. 2015. Bryde's whale (*Cetartiodactyla: Balaenopteridae*) occurrence and movements in coastal areas of southeastern Brazil. *Zoologia (Curitiba)*. 32(2):171–175. doi:10.1590/S1984-46702015000200009.
- McBride AF, Kritzler H. 1951. Observations on pregnancy, parturition, and postnatal behavior in the bottlenose dolphin. *Journal of Mammalogy*. 32(3):251–266. doi:10.2307/1375657.
- New South Wales Government. 2024. Approaching marine mammals in New South Wales. [accessed 2023 Sep 11]. <https://www.environment.nsw.gov.au/topics/animals-and-plants/native-animals/approaching-marine-mammals-in-nsw>.
- Paterson R, Van Dyck S. 1988. Bryde's whale in the coastal waters of eastern Australia. *Scientific Reports of the Whales Research Institute*. 39:21–29.
- Penry GS, Cockcroft VG, Hammond PS. 2011. Seasonal fluctuations in occurrence of inshore Bryde's whales in Plettenberg Bay, South Africa, with notes on feeding and multispecies associations. *African Journal of Marine Science*. 33(3):403–414. doi:10.2989/1814232X.2011.637617.
- Pirotta V, Hocking DP, Iggleden J, Harcourt R. 2022. Drone observations of marine life and human-wildlife interactions off Sydney, Australia. *Drones*. 6:75. doi:10.3390/drones6030075.
- Pirotta V, Owen K, Donnelly D, Brasier MJ, Harcourt R. 2021. First evidence of bubble-net feeding and the formation of 'super-groups' by the east Australian population of humpback whales during their southward migration. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 31(9):2412–2419. doi:10.1002/aqc.3621.
- Pirotta V, Reynolds W, Ross G, Jonsen I, Grech A, Slip D, Harcourt R. 2020. A citizen science approach to long-term monitoring of humpback whales (*Megaptera novaeangliae*) off Sydney, Australia. *Marine Mammal Science*. 36(2):472–485. doi:10.1111/mms.12651.
- Pirotta V, Smith A, Ostrowski M, Russell D, Jonsen I, Grech A, Harcourt R. 2017. An economical custom-built drone for assessing whale health. *Frontiers in Marine Science*. 4:425. doi:10.3389/fmars.2017.00425.

- Priddel D, Wheeler R. 1997. Rescue of a Bryde's Whale *Balaenoptera edeni* entrapped in the Manning River, New South Wales: unmitigated success or unwarranted intervention? *Australian Zoologist*. 30(3):261–271. doi:10.7882/AZ.1997.002.
- Raoult V, Colefax AP, Allan BM, Cagnazzi D, Castelblanco-Martínez N, Ierodiaconou D, Johnston DW, Landeo-Yauri S, Lyons M, Pirotta V, et al. 2020. Operational protocols for the use of drones in marine animal research. *Drones*. 4(4):64. doi:10.3390/drones4040064.
- Rice DW. 1998. *Marine mammals of the world: systematic and distribution*. Lawrence, Kansas: Society for Marine Mammalogy, Lawrence, K.S. (Society for Marine Mammalogy Special Publication Number 4).
- Segre PS, di Clemente J, Kahane-Rapport SR, Gough WT, Mejer MA, Lombard AT, Goldbogen JA, Penry GS. 2022. High-speed chases along the seafloor put Bryde's whales at risk of entanglement. *Conservation Science and Practice*. 4(5):e12646. doi:10.1111/csp2.12646.
- Siciliano S, de Oliveira Santos MC, Vicente AF, Alvarenga FS, Zampirolli É, Brito JL, Azevedo AF, Pizzorno JLA. 2004. Strandings and feeding records of Bryde's whales (*Balaenoptera edeni*) in south-eastern Brazil. *Journal of the Marine Biological Association of the United Kingdom*. 84(4):857–859. doi:10.1017/S0025315404010082h.
- Smultea M, Fertl D, Bacon C, Moore M, James V, Würsig B. 2017. Cetacean mother-calf behavior observed from a small aircraft off southern California. *Animal Behavior and Cognition*. 4(1):1–23. doi:10.12966/abc.01.02.2017.
- Stockin KA, Pierce GJ, Binedell V, Wiseman N, Orams MB. 2008. Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Aquatic Mammals*. 34(2):200–211. doi:10.1578/AM.34.2.2008.200.
- Tershy BR. 1992. Body size, diet, habitat use, and social behavior of *Balaenoptera* whales in the Gulf of California. *Journal of Mammalogy*. 73(3):477–486. doi:10.2307/1382013.
- Tershy BR, Wiley DN. 1992. Asymmetrical pigmentation in the fin whale: a test of two feeding related hypotheses. *Marine Mammal Science*. 8(3):315–318. doi:10.1111/j.1748-7692.1992.tb00416.x.
- Tezanos-Pinto G, Hupman K, Wiseman N, Dwyer SL, Baker CS, Brooks L, Outhwaite B, Lea C, Stockin KA. 2017. Local abundance, apparent survival and site fidelity of Bryde's whales in the Hauraki Gulf (New Zealand) inferred from long-term photo-identification. *Endangered Species Research*. 34:61–73. doi:10.3354/esr00839.
- Wiseman N. 2008. Genetic identity and ecology of Bryde's whales in the Hauraki Gulf, New Zealand. Ph.D. thesis, University of Auckland, Auckland, New Zealand. 231 pp.
- Wiseman N, Parsons S, Stockin KA, Baker CS. 2011. Seasonal occurrence and distribution of Bryde's whales in the Hauraki Gulf, New Zealand. *Marine Mammal Science*. 27(4):E253–E267. doi:10.1111/j.1748-7692.2010.00454.x.