Aquatic Mammals 2017, *43*(5), 501-506, DOI 10.1578/AM.43.5.2017.501

Short Note

Twisting Movements During Feeding Behavior by a Bryde's Whale (*Balaenoptera edeni*) Off the Coast of Southeastern Brazil

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Rorqual whales (Balaenopteridae) use a lunge feeding strategy to engulf prey, which is facilitated by the positive allometry of the skull and oropharyngeal apparatus (Goldbogen et al., 2010). Lunge feeding allows the whales to filter a large volume of prey relative to their body size (Goldbogen et al., 2007). This ability to engulf and process prey rapidly also enables rorqual whales to exploit more agile prey successfully. During lunging behavior, the whale increases its speed, opens its jaws to surround a large amount of water, engulfs its prey, and then closes its jaws rapidly to filter the prey. The extreme angles of the jaws, high speed, and high mobility that are necessary to do the lunge increase the energy cost of a lunge (Goldbogen et al., 2010). This increased cost may be offset by the large amount of prey that can be captured during each lunge (Goldbogen et al., 2011).

Recent studies (Goldbogen et al., 2013; Kot et al., 2014; Ware et al., 2014) have revealed that different rorqual whale species share common feeding strategies. Observations suggest that rorqual whales adopt specific patterns of body rotation when lunge feeding to optimize foraging on different types and densities of prey, and in locations with varying environmental characteristics (Kot et al., 2014). Studies using tags indicate that both fin (*Balaenoptera physalus*) and humpback (*Megaptera novaeangliae*) whales also use twisting movements when feeding (Wiley et al., 2011; Ware et al., 2014). Off the coast of California, blue whales (*Balaenoptera musculus*) perform 360° rolls when lunge feeding; however, when foraging on small shoals of krill, they tend to engage in more acrobatic movements, including rotations of 180º, to capture their prey, and may perform fewer movements when feeding on krill shoals of higher density. Despite what has been described for other rorqual whale species, there is no such information in the literature on the feeding movements for Bryde's whales (*Balaenoptera edeni*).

The Bryde's whale is the least known baleen whale, and most aspects of this species' taxonomy, ecology, and behavior remain unclear (Kato, 2002). Up until the 1970s, the feeding ecology of this species was known only from data derived from distribution records and analysis of stomach contents (Nemoto & Kawamura, 1977). This scarcity of data may be at least partly due to the cryptic behavior of Bryde's whales, which typically make deep dives and spend little time at the surface (Alves et al., 2010). Around the world, Bryde's whales are known to feed solitarily or in small groups, but without the formation of coordinated foraging parties (Tershy, 1992).

This species is known to be associated with areas of upwelling, such as those found off California (Tershy, 1992), Gabon (De Boer, 2010), and South Africa (Penry et al., 2011), where the whales feed on small schooling fishes such as sardines. In Brazil, Bryde's whales are found mainly in offshore waters (Andriollo et al., 2010; Di Tullio et al., 2016), although they may visit the coastal waters of southeastern Brazil, in particular Rio de Janeiro (Figueiredo, 2014; Lodi et al., 2015; Maciel et al., in press) and São Paulo (Andriollo et al., 2010) during the late austral spring, summer, and autumn, providing an excellent opportunity to investigate their feeding ecology. This study describes the twisting movements performed by Bryde's whales while feeding off the coast of Cabo Frio in Rio de Janeiro, southeastern Brazil. To our knowledge, this is the first report of this behavior in Bryde's whales in the southwestern Atlantic.

The Cabo Frio coast (22° 50' 21" S, 41° 54' 37" W – 23° 00' 18" S, 42° 05' 53" W) is steeply

sloped and marked by a change in shoreline orientation from north–south to southwest–northeast (De Leo & Pires-Vanin, 2006). During the austral spring and summer, the increased intensity of the north-northeasterly winds, combined with meanders and eddies in the Brazil Current, provokes the mixing of two masses of water (the Brazil Current and the South Atlantic Central Water), leading to upwelling (Carbonel, 1998). Upwelling typically results in increased primary productivity and high fish yields, creating foraging opportunities for many cetacean species (Keiper et al., 2005).

The observed and reported feeding behavior was recorded during the *Cetáceos da Costa Azul* (Blue Coast Cetaceans) project, which investigated cetacean behavior and ecology between 2010 and 2014, using a small boat equipped with a 150-hp engine. Data collection was conducted only under good weather conditions (Beaufort scale < 2) due to logistic constraints, with the primary aim of maximizing encounters with cetaceans (Tardin et al., 2013; Maciel et al., in press).

Lunge feeding behavior was observed on three occasions during the first half of 2014 (on 30 March, and 7 and 8 May). The behavior was recorded using a Canon 40D still camera with a Canon 75 to 300 mm zoom lens to obtain sequences of photographs, and a Sony DCR-SX40 video camera to record the sequence of events. In the laboratory, the authors (T. Mello Neto & I. S. Maciel) analyzed the photographic sequences and video footage to characterize the whale feeding behavior. The 7 May event involved an adult Bryde's whale accompanied by a calf, whereas the other two events (30 March and 8 May) involved solitary adult Bryde's whales.

To describe the qualitative components of the twisting feeding behavior, we divided the behavior into three phases: (1) *ventral lunge – the initial phase*—when the whale comes up to the surface and opens its mouth to catch the available prey (Figure 1a). This may involve exposure of the belly and ventral pleats (Figure 1b) immediately prior to submerging; (2) *side lunge – the intermediate phase*—when the whale rolls and rotates the lateral axis, exposing its caudal fin (Figure 2a). When close to the surface, the eye and pectoral fin may also be exposed (Figure 2b); and (3) *dorsal lunge – the final phase*—when the whale dives back into deeper water, reorientating its body and exposing its dorsal fin (Figures 3a & b). Clear observation of the three phases was not always possible; still, they all had at least a portion of these three phases.

On all 3 d of observation, the whale(s) were accompanied by seabirds, including the brown booby (*Sula leucogaster*), magnificent frigatebird (*Fregata magnificens*), and royal tern (*Thalasseus maximus*). These shallow-diving birds may benefit from this association by capturing fish propelled to the surface by the whales (Gill et al., 2000).

In this note, we present the first description of the rotational feeding behavior of Bryde's whales in the waters of the southwestern Atlantic Ocean. During the initial phase of the behavior, the whale swims towards the surface, generating a stream of water, which corners the prey and impedes escape. During the second and third phases, the whale rotates on the horizontal axis, with its mouth expanded and open, confusing and trapping the prey in its mouth. When expanded, the oropharyngeal apparatus ensures capture of the largest possible number of prey, and then it contracts, expelling water through the sides of the mouth (Goldbogen et al., 2015). All rorqual whales of the family Balaenopteridae have ventral pleats that enable them to perform this lunge feeding behavior efficiently (Goldbogen et al., 2015). In many large rorqual species, the amount of water engulfed during the lunge is proportional to the body size of the whale (Goldbogen et al., 2011). The feed mode requires precise coordination of the body with the engulfment apparatus extended to maximize capture capability because the water is captured in a matter of seconds. The energy demanded by this behavior can be offset by the large amounts of prey that can be captured during the lunge (Goldbogen et al., 2011).

Off the Cabo Frio coast, Bryde's whales feed on Brazilian sardines (*Sardinella brasiliensis*), other small schooling fishes such as Atlantic thread herring (*Opisthonema oglinum*), and scombrids, like the Chub mackerel (*Scomber japonicas*) (Tershy, 1992; Siciliano et al., 2004; De Boer, 2010). These fish species tend to form large shoals, which use confusion and dilution effects to avoid predation, thus making them hard to capture without an efficient foraging strategy. Similarities in this feeding behavior, such as the twisting movements, are found also in common minke (*Balaenoptera acutorostrata*) and other Bryde's whales (Gill et al., 2000), possibly because they both feed on these fish species. Despite differences observed in the number of acrobatic movements and the degree of rotation, which may vary with prey type, the different rorqual species all perform the three phases of twisting lunges described in this note (Goldbogen et al., 2013; Kot et al., 2014; Ware et al., 2014). Alternatively, the similarities in feeding behavior of the different balaenopterid species may represent a primitive adaptation, linking them phylogenetically (Gill et al., 2000; Goldbogen et al., 2007). Further research is needed to test this phylogenetic hypothesis.

Figure 1. *Phase 1:* Initial/ventral lunge. *Top image:* The Bryde's whale (*Balaenoptera edeni*) is in the dorsal/ventral plane, opening its mouth to catch prey. *Lower image:* The whale is exposing its belly at the surface. Note the presence of seabirds—in this case, the brown booby (*Sula leucogaster*). (Photographs by Israel de Sá Maciel)

The observations presented herein provide additional insights into the feeding behavior of Bryde's whales. It is especially important to better understand the behavior and ecology of the species given its "Data Deficient" conservation status by the International Union for Conservation of Nature (IUCN).

Figure 2. *Phase 2:* Side lunge with the whale lying on its side in the horizontal plane, exposing its caudal fin (*top*) and pectoral fin and eye (*bottom*) (Photographs by Israel de Sá Maciel)

Figure 3. *Phase 3:* The dorsal lunge or the final phase in which the whale reorients its body and exposes its blowhole (*top*) and its dorsal fin (*bottom*) (Photographs by Israel de Sá Maciel)

Acknowledgments

Many thanks to the Fundation O Boticário de Proteção a Natureza and Universal edital of CNPq for financing the Project *Cetáceos da Costa Azul* (Blue Coast Cetaceans). Thanks also to CAPES for supporting and financing Thamires de Mello Neto's Master's degree and Israel de Sá Maciel's doctoral degree research with a scholarship, and FAPERJ for supporting and financing Rodrigo Tardin's fellowship.

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