Chapter 14
Mysterious Minke Whales: Acoustic Diversity and Variability

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Abstract The acoustic behavior of minke whale populations worldwide has been a mystery for the better part of the twentieth century. Several likely biological sound sources such as the 'boing' recorded in the North Pacific, or the 'bio-duck' with its ubiquitous distribution in the Southern Ocean, had been described by seafarers since the middle of the twentieth century. However, the origin of these sounds could only be revealed once technological advances allowed scientists to simultaneously acoustically and visually track the elusive species producing them. The current data show that, like other baleen whales, most minke whale populations produce long song sequences presumably in a reproductive context. Over the past two decades, by extending our listening efforts into remote habitats, we have learned much about minke whales and can assume that many more mysteries are waiting to be unlocked.

Keywords Minke whale · Antarctic minke whale · Vocal repertoire · Boing sound · Bio-duck sound · Star-wars sound · Pulse train

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Dedicated to Thomas F Norris

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Antarctic minke whale (*Balaenoptera bonaerensis*) with multi-sensor acoustic recording tag. Photo courtesy of Ari S. Friedlaender

14.1 Introduction

Although they are one of the most widely distributed baleen whale species, often found in coastal waters during summer, most minke whale populations have been little studied. Most of our knowledge about the species' life history originates from scattered observations in coastal habitats and whaling records (Horwood 1990), and much of their behavioral ecology remains unknown.

Common minke whales (*Balaenoptera acutorostrata*) inhabit all oceans from the tropics to the poles and are closely related to their sister species, the Antarctic minke whale (*Balaenoptera bonaerensis*), also referred to as the 'southern minke whale' (Rychel et al. 2004). Based on genetic evidence and geographic distribution, the common minke whale is split into three subspecies: *Balaenoptera acutorostrata acutorostrata* in the North Atlantic, *Balaenoptera acutorostrata scammoni* in the North Pacific, and an unnamed subspecies of dwarf minke whale in the Southern Hemisphere (Rice 1998). The exact placement of the dwarf minke whale in baleen whale taxonomy is still unclear. At least two different populations of dwarf minke whales appear to exist in the Southern Hemisphere, one in the South Atlantic where they were first described in the 1980s (Best 1985) and one in the South Pacific. Genetically, the South Atlantic dwarf minke whale is more closely related to the North Atlantic minke whale than to the South Pacific dwarf minke whale (Pastene et al. 2010).

The lack of data on minke whales is partly due to the difficulties in observing them. At an average adult body length of 7–9 m, minke whales are one of the smallest of the baleen whales, only larger than the pygmy right whale (*Caperea marginata*). Due to their small body size, inconspicuous blows, and brief surfacings, minke whales

have been described as elusive, especially in their more pelagic winter habitats. In addition, except in higher latitudes, where aggregations of up to a few hundred animals have been visually observed, larger aggregations are less prevalent than in other species (Edds and Macfarlane 1987). Indeed, across much of their range minke whales are often visually encountered as solitary individuals and exhibit a wide range of individually distinctive foraging behaviors (Hoelzel et al. 1989).

In contrast to this general reclusive demeanor, in some areas, common minke whales are known for their inquisitive behavior and tendency to actively associate with vessels. This more curious behavior is, for example, commonly observed in Australian's Great Barrier Reef region, where dwarf minke whales approach and spend extended time with swimmers and divers (Valentine et al. 2004). These interactions are particularly remarkable given that the winter distributions and behaviors of nearly all other minke whale populations are less understood than their distributions and behaviors in summer foraging habitats.

14.2   Mystery in All Oceans: A Brief Overview of Global Minke Whale Vocalizations

Comprehensive descriptions and behavioral functions of minke whale sounds remain incomplete. Vocalizations produced by the North Pacific, dwarf and Antarctic minke whales were only unequivocally assigned to these species in the early 2000s (Gedamke et al. 2001; Gedamke 2004; Rankin and Barlow 2005; Risch et al. 2014b), despite being recorded and described in parts of the world's oceans (Fig. 14.1) for decades (Wenz 1964; Thompson and Friedl 1982; Matthews et al. 2004; Dolman et al. 2005). It is now clear that minke whale populations produce a variety of sounds throughout their geographic ranges. However, given that the full acoustic repertoire and functional significance of their many different types of sounds are still largely unknown, many discoveries about their vocal behaviors are yet to be made.

New technologies are helping to fill some of the existing data gaps. For example, small, multi-sensor tags can now be equipped with acoustic recorders, allowing measurements of fine-scale movement behavior while simultaneously recording sounds from tagged and nearby animals (Risch et al. 2014b). Networks of bottom-mounted acoustic recorders, deployed for several months to years, are being used to investigate migratory routes and changes in minke whale distribution and to identify previously unknown habitats (Clark and Gagnon 2002; Risch et al. 2014a). This chapter aims to summarize what is currently known about common and Antarctic minke whale vocalizations worldwide.
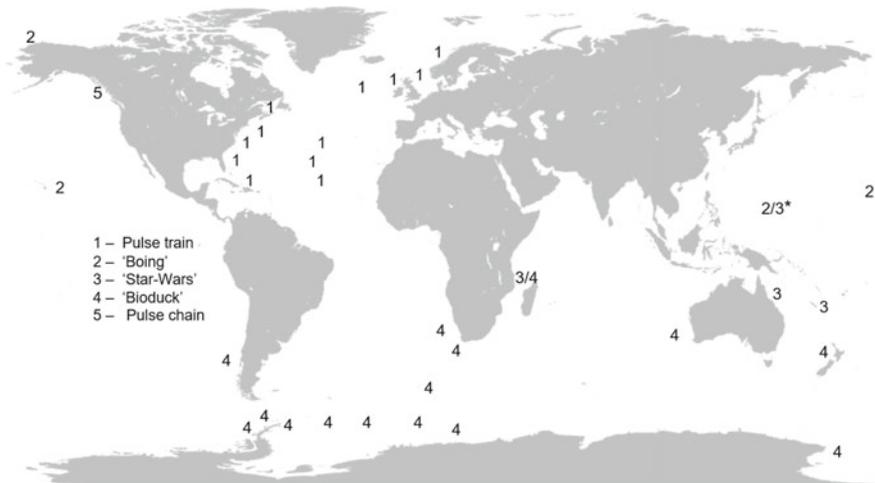
Fig. 14.1 Global distribution of the best described Antarctic and common minke whale vocalization types (Gedamke et al. 2001; Nieukirk et al. 2004, 2016; Matthews et al. 2004; Rankin and Barlow 2005; Dolman et al. 2005; Oswald et al. 2011; Martin et al. 2013; Risch et al. 2013, 2014a, 2019; b; Delarue et al. 2013; Dominello and Širović 2016; Norris et al. 2017; Cerchio et al. 2018, 2022; Nikolich and Towers 2018; Thomisch et al. 2019; Buchan et al. 2020; Shabangu et al. 2020; Filun et al. 2020). *Nieukirk et al. 2016 recorded a sound with similarities to the 'star-wars' vocalizations near the Marian Trench and hypothesized that it might be produced by minke whales

14.2.1 North Atlantic

On a summer feeding ground in the North Atlantic, a few sounds from a minke whale were first reported in the 1970s by Beamish and Mitchell (Beamish and Mitchell 1973). These authors used a calibrated hydrophone system to record a series of clicks in the 4–8 kHz range during a very close (20–80 m) encounter with a single animal. The clicks they described were 1–5 ms in duration and repeated at 6–7 clicks/second. About a decade later, in the Gulf of St Lawrence, Canada, Edds-Walton recorded sounds in the presence of minke whales; frequency-modulated (FM) downsweeps with a median start and end frequency of 118 Hz and 80 Hz, respectively (Edds-Walton 2000). These sounds had a median duration of 0.4 s and were produced by individual animals while traveling (Edds-Walton 2000).

In 1971, based on acoustic and visual observations conducted in the Caribbean Sea region, Winn and Perkins (1976) recorded low-frequency pulse trains with varying inter-pulse intervals (IPI) and peak frequencies from 55–150 Hz. In 1993–1996, with the advent of limited scientific access to the US Navy Sound Surveillance System (SOSUS), pulse trains described as songs and attributed unequivocally to minke whales in the Caribbean and throughout the Western North Atlantic were described and reported by Mellinger et al. (2000) and Clark and Gagnon (2002) (Fig. 14.2; Chap. 2). These pulse trains appear to be the most common in the repertoire of North Atlantic minke whales and have been recorded during migration and in several
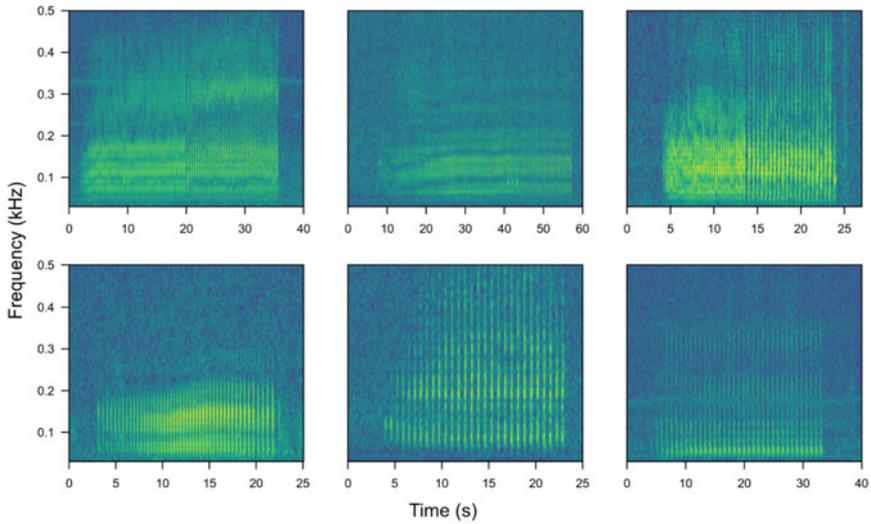
Fig. 14.2 Spectrograms of North Atlantic minke whale pulse train types identified by Risch et al. (2013) and recorded in the Stellwagen Bank National Marine Sanctuary, Eastern North Atlantic. Upper panel shows three different types of 'slow-down' pulse trains, and lower panel shows three types of 'constant' pulse trains. Not shown here is an example of a speed-up pulse train, which is mostly recorded in lower latitudes (Mellinger et al. 2000). Note the different time scales for these different pulse train types. Spectrogram parameters: 2000 Hz sample rate, 512 point FFT, 75% overlap = 75%, 3.9 Hz and 64 ms frequency and time resolution, respectively

summer feeding grounds (Folkow and Blix 1991; Nieukirk et al. 2004; Risch et al. 2013, 2019). Pulse trains are stereotypic, and three different pulse train types have been described (e.g., 'speed-up', 'slow-down', and 'constant') based on IPI and peak frequency (Fig. 14.3), while individual pulses are typically FM upsweeps and sometimes paired with a slight temporal overlap within a pair (Mellinger et al. 2000).

In addition to these stereotypic types of pulse trains, higher frequency (3–12 kHz) clicks described from initial Caribbean recordings (Winn and Perkins (1976) have more recently been confirmed to be regular components of some of these low-frequency pulse trains (Risch et al. 2015). These higher frequency clicks might also correspond to the ones originally described by Beamish and Mitchell (1973).

The durations of North Atlantic pulse trains appear to vary between pulse train types and geographically, with significantly longer pulse trains recorded in lower latitudes than in higher latitudes (Risch et al. 2014a). The average source level of 164–168 dB re 1 μPa measured by Risch et al. (2014c) gave an approximate active space, defined as the area within which a receiver might perceive the call of a signaler (Brenowitz 1982), of up to 10 km in a habitat dominated by shipping noise (Risch et al. 2014c).
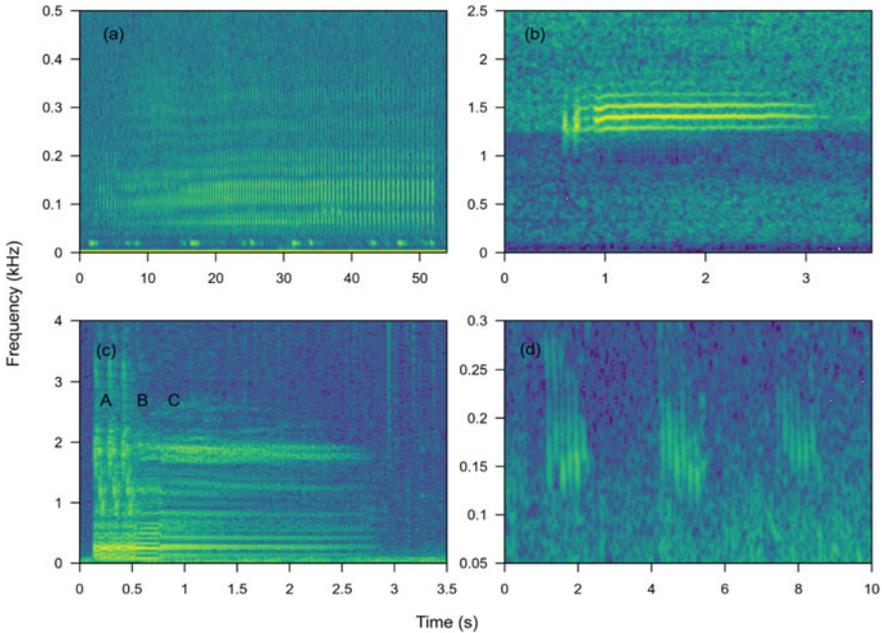
Fig. 14.3 Spectrogram of **a** North Atlantic slow-down pulse train type recorded during the spring migration season off Cape Cod; **b** North Pacific 'boing' sound; **c** South Pacific 'star-wars' sound. The sound is comprised of three sub-units: A, B, C (Gedamke et al. 2001); **d** Antarctic 'bio-duck' sound. Spectrogram parameters: **a** 2000 Hz sample rate, 512 point FFT, 75% overlap, 3.9 Hz and 64 ms frequency and time resolution, respectively; **b** 8000 Hz sample rate, 512 point FFT, 75% overlap, 15.6 Hz and 16 ms frequency and time resolution, respectively; **c** 16,000 Hz sample rate, 1024 point FFT, 90% overlap, 15.6 Hz and 6.4 ms frequency and time resolution, respectively; **d** 2000 Hz sample rate, 512 point FFT, 95% overlap, 3.9 Hz and 12.8 ms frequency and time resolution, respectively

14.2.2 North Pacific

A North Pacific sound type referred to as the 'boing' has been recorded in lower latitudes of the North Pacific since the late 1950s and was first described in the early 1960s (Wenz 1964). Although the sound was assumed to be biological, actual species attribution remained a mystery until 2003 when simultaneous visual observations and acoustic bearing angle localizations of individual animals were used to confirm that minke whales were the source of this mysterious sound (Rankin and Barlow 2005). Boing sounds consist of a relatively short introductory pulse followed by a longer amplitude modulation (AM) of a FM unit with decreasing amplitude over the course of the sound and a peak frequency of approximately 1.4 kHz (Fig. 14.3b; Thompson and Friedl 1982; Rankin and Barlow 2005; Oswald et al. 2011).

At least two types of the boing sound have been detected across the North Pacific, which may be indicative of geographic differences between genetically separate

populations. Boings in the Eastern North Pacific have pulse repetition rates of about 92 s^{-1}, whereas in the central part of the North Pacific, boings have pulse repetition rates of 115 s^{-1} (Wenz 1964; Rankin and Barlow 2005). Eastern and central boings also differ in overall durations, lasting 3.6 and 2.6 s, respectively (Rankin and Barlow 2005). Boings are primarily recorded in low-latitude presumed breeding grounds (Norris et al. 2012) and are repeated in long sequences with varying inter-boing intervals (ICI). Several studies have described a bi-modal distribution of boing repetition rates, with shorter intervals between boings (28–30 s) when several animals are presumed to be in acoustic contact with one another and longer intervals (350–600 s) when animals are further apart (Wenz 1964; Thompson and Friedl 1982; Rankin and Barlow 2005). Apart from having been recorded in lower latitudes, a few 'boings' have also been recorded in a summer feeding ground, the Northeastern Chukchi Sea, during late summer and autumn (Delarue et al. 2013).

In addition to boing sounds, North Pacific minke whale vocalizations from a summer feeding ground off Vancouver Island, Canada, were recently described as low-frequency downsweeps starting at 142 Hz and ending at 38 Hz, a peak frequency of 105 Hz, and a duration of 0.7 s (Nikolich and Towers 2018). At the same recording site, a series of sounds similar to North Atlantic pulse trains was attributed to a minke whale and described as "pulse chains" with variable pulse rates in the 330–1400 Hz frequency range. Overall, pulse train occurrence in this summer feeding ground was very low, despite regular visual sightings of minke whales (Nikolich and Towers 2018).

14.2.3   South Pacific

One of the most fascinating baleen whale sound is produced by animals in the Australian population of the dwarf minke whale. Named the 'star-wars' vocalization (Fig. 14.3c), due to its distinct synthetic or metallic quality, this sound type was first scientifically described and unequivocally linked to the species in the Northern Great Barrier Reef sing a combination of dedicated visual observations and acoustic localization (Gedamke et al. 2001). The reef is a winter habitat and presumed breeding ground for the species. The star-wars sound is somewhat similar in structure to the boing sound. The sound is composed of three sub-units (A, B, C; Fig. 14.3c), each of which is an amplitude modulation of a FM unit, with AM rate and FM characteristics being different for each of the three components. This complex combination results in a sound that seems oddly unworldly to the human ear, hence, the reference to artificial sounds produced for the movie 'Star Wars'. Individual star-wars sounds are usually repeated in stereotyped sequences of equal intervals ranging from 1–2 s to 3–4 min. Source-level estimates for these sounds ranged from 150–165 dB re 1 μPa (Gedamke et al. 2001).

Similar to North Atlantic minke whales, dwarf minke whales in the Great Barrier Reef region also produce low-frequency, downswept vocalizations starting around 250 Hz and sweeping down to around 50 Hz. These sounds are typically 0.2–0.3 s in

duration and have source levels of approximately 148–160 dB re 1 μPa (Gedamke et al. 2001). In addition, several 'noisy', broadband social sounds have been described for Great Barrier Reef dwarf minke whales (Gedamke 2004). As is the case in vocal repertoires of other baleen whales, the acoustic characteristics of these social sounds appear to be vary along a continuum, which makes their division into distinct call types difficult. They appear structurally similar to, but are generally less complex than, the typical star-wars sound (Gedamke 2004).

More recently, a complex call of unknown origin was recorded in the Mariana Trench, off the east coast of Guam and Saipan (Nieukirk et al. 2016; Fig. 14.1). This sound consisted of an AM 38 Hz moan, followed by a broadband sweep with energy up to 7.5 kHz. Due to the similarities to the star-wars sound, it was suggested that this call might be produced by either a dwarf or common minke whale (Nieukirk et al. 2016).

While dwarf minke whales are frequently visually observed in the South Atlantic (Zerbini et al. 1996; Acevedo et al. 2006), so far they have not been detected acoustically in the South Atlantic ocean basin.

14.2.4 Southern Ocean

For over five decades, a regular pulsed signal (Matthews et al. 2004) referred to as the 'bio-duck' has been recorded in the Southern Ocean, but the animal producing this mysterious sound remained unknown until recently. The signal was first described by submarine officers in the 1960s. Since then, it has been described off the west coast of Australia and in the Ross and Weddell Seas, as well as in sub-Antarctic waters (Poulter 1964; Matthews et al. 2004; McCauley 2004; Dolman et al. 2005; Klinck and Burkhardt 2008; Van Opzeeland 2010). It was not until 2013 that the 'bio-duck' was unequivocally linked to Antarctic minke whales based on analysis of multi-sensor acoustic recording tags deployed on two individuals of this species in Wilhelmina Bay, Western Antarctica (Risch et al. 2014b). The 'bio-duck' vocalization consists of one to six pulses in the 50–300 Hz frequency band (Fig. 14.3d), typically with harmonics up to 1 kHz, although recent descriptions of the different subtypes of the 'bio-duck' vocalization describe harmonics up to 2 kHz and beyond (Shabangu et al. 2020). These pulse trains are then often repeated in long sequences at very regular ICIs (Fig. 14.4).

Along with the first description of the 'bio-duck' signal from Antarctic minke whales, low-frequency downsweeps were also recorded from the same tagged individuals during several of their dives. These downsweeps were in the frequency range of 60–130 Hz with a mean duration of 0.2 s (Risch et al. 2014b). Similar downsweeps had previously been reported from the Ross Sea (Schevill and Watkins 1972; Leatherwood et al. 1981), as well as together with 'bio-duck' vocalizations that were recorded in the Weddell Sea and off Western Australia (Matthews et al. 2004; Klinck and Burkhardt 2008).
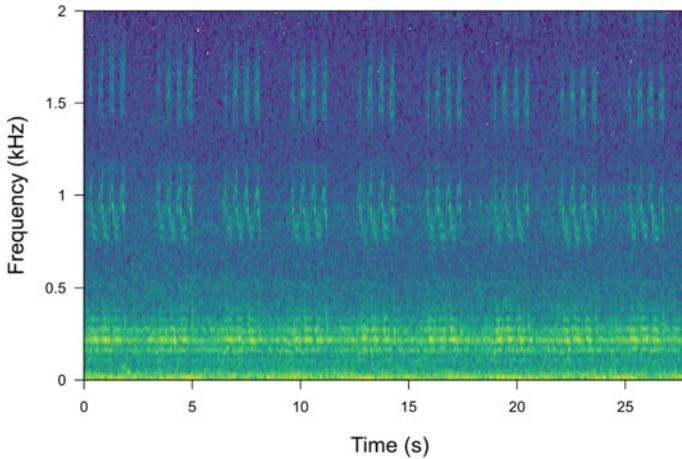
Fig. 14.4 Spectrogram of a partial Antarctic 'bio-duck' song sequence recorded during austral winter at PALAOA station, Antarctica, (acoustic sample courtesy of I. van Opzeeland). Spectrogram parameters: 48 kHz sample rate, 4096 point FFT, 75% overlap, 11.7 Hz and 21.3 ms frequency and time resolutions, respectively

A recent study of minke whale pulse trains collected near the Western Antarctic Peninsula distinguished at least four different variants of the bio-duck sound and several subtypes for one variant. These variants were based on frequency content, the number of pulses and IPIs within a train, and the pulse train repetition rate (Dominello and Širović 2016). Different bio-duck sound variants have also been described to co-occur in Western Australian and South African recordings (Matthews et al. 2004; Shabangu et al. 2020).

14.3 Commonalities Between Minke Whale Vocal Repertoires and a Definition of Minke Whale Song

Despite a remarkable amount of variability in the vocal repertoires currently described for common and Antarctic minke whales, there are some commonalities. Most minke whale populations produce series of relatively stereotypic low-frequency sounds that are often repeated in sequences lasting several minutes to hours. Although the sex of the caller is still unknown for most of these sequences (Sect. 14.5), the dwarf and North Atlantic minke whale vocalizations have been classified as song (Gedamke et al. 2001; Clark and Gagnon 2002; Clark and Ellison 2004; Gedamke 2004). This classification is based on the definition of song, commonly used to describe the patterned sequences produced by many birds species, where song is defined as: '…*long, complex, vocalizations produced by males in the breeding season*'. (Catchpole and Slater 2008) and by the description of male humpback whale song defined

as *'…a series of notes, generally of more than one type, uttered in succession and so related as to form a recognizable sequence or pattern in time'* (Payne and McVay 1971; Chap. 11). Given that the North Pacific boing and the Antarctic bio-duck sounds are also produced in long sequences (Fig. 14.4) and both are produced on presumed breeding grounds (Sect. 14.5), they could similarly be classified as songs, making 'song' a common acoustic behavior among minke whale populations worldwide.

Next to humpback whale song (Payne and McVay 1971), baleen whale songs have been described for several species, including blue (*Balaenoptera musculus*; Chap. 9), fin (*Balaenoptera physalus*), Omura's (*Balaenoptera omurai*; Chap. 15), and bowhead (*Balaena mysticetus*; Chap. 12) whales, and singing is generally thought to function in mediating reproductive behavior (Cummings et al. 1987; Croll et al. 2002; Oleson et al. 2007a; Chap. 7).

In contrast to the highly dynamic characteristics of humpback and bowhead whale song (Cholewiak et al. 2013; Stafford et al. 2018; see Chaps. 10 and 11, respectively), minke whale songs appear more typical of the stereotypic songs of other balaenopterid whales such as blue and fin whales (Oleson et al. 2007b; Širović et al. 2013; Chap. 9), consisting of patterned phrases of a few notes with limited variability between years and individuals (Clark and Ellison 2004). That being said, individual song units can be structurally complex (e.g., the star-wars sound) and some variation has recently been shown in the Western North Atlantic where at least two different calling patterns or songs, consisting of three to four stereotyped pulse train types, have been described (Risch et al. 2014c). Across all populations, minke whale song units are typically low-frequency, pulsed FM-AM signals, with most energy below 1–2 kHz. Some geographic variation in boing song production has been described in the North Pacific (Rankin and Barlow 2005), while pulse train song units in the North Atlantic appear to increase in duration in lower latitude winter breeding grounds (Risch et al. 2014a).

The second sound type in most minke whale populations for which vocalizations have been partially described, are low-frequency (<500 Hz) downsweeps. These are usually not produced in patterned sequences and have most often been recorded in presumed summer feeding habitats (Schevill and Watkins 1972; Edds-Walton 2000; Shabangu et al. 2020).

14.4 Seasonal Distribution and Temporal Variation in Minke Whale Vocalizations

Marine environments are generally 'open' environments, with few natural barriers. Driven by wind, waves and upwellings, the distribution of available resources is variable over large spatial and temporal scales. Baleen whales have adapted to these dynamic conditions by capitalizing on large home ranges, with many species' annual migrations ranging over thousands of kilometers from high-latitude feeding to low-latitude breeding grounds (Whitehead 2001; Stevick et al. 2011; Corkeron

and Connor 1999; Chaps. 4 and 7). Migratory routes are well described for some species such as humpback (Dawbin 1966; Clapham and Mead 1999; Calambokidis et al. 2001) and right whales (Kraus et al. 1986; Mate et al. 2011; Chap. 4).

Long longitudinal migrations have also been documented for common minke whales (Kasamatsu et al. 1995; Skaug et al. 2004; Risch et al. 2014a). It is during these migrations and in their presumed winter breeding habitats that minke whale songs are most often recorded (Gedamke et al. 2001; Nieukirk et al. 2004; Oswald et al. 2011; Delarue et al. 2013; Risch et al. 2014a). In contrast, while low-frequency downsweeps have been described from summer feeding and winter breeding grounds, they have been more commonly recorded in higher latitude feeding grounds (Schevill and Watkins 1972; Edds-Walton 2000; Gedamke et al. 2001; Dominello and Širović 2016; Shabangu et al. 2020).

As is the case in other baleen whales, results from long-term passive acoustic recordings of minke whales are increasingly providing evidence for complex migration and seasonal distribution patterns. For example, the bio-duck song of the Antarctic minke whale has been detected simultaneously in high and low latitudes during austral winter (Matthews et al. 2004; Buchan et al. 2020; Filun et al. 2020; Shabangu et al. 2020). This indicates that while part of the population migrates to warmer waters during winter, a large part of the population stays in high latitudes year-round. This finding was corroborated by satellite tag data, showing animals staying south of the Antarctic Circumpolar Current year-round (Lee et al. 2017). To understand these distribution patterns and migratory pathways, it is important to better describe the seasonality and behavioral context of minke whale vocalizations in different populations and habitats, by using long-term passive acoustic data in combination with direct visual observation and multi-sensor tags.

Distinct diel patterns in vocalizations have been described for several minke whale populations. In the North Atlantic, minke whale pulse trains are produced primarily at night (Risch et al. 2013, 2019). The same pattern was found in South African waters and near the Greenwich meridian in the Southern Ocean for 'bio-duck' song (Menze et al. 2017; Shabangu et al. 2020). The authors hypothesized that the bio-duck song might be related to feeding, as the observed diel pattern was closely linked to diel vertical migration of zooplankton, with high concentrations near the surface at night (Menze et al. 2017). However, in contrast to these findings, in the Western Antarctic Peninsula and other parts of Antarctica, the bio-duck song either showed no distinct diel pattern or was more commonly detected during daylight hours (Dominello and Širović 2016; Shabangu et al. 2020). Similarly, no significant diel patterns were found in Hawaii for North Pacific minke whale 'boing' song (Oswald et al. 2011).

Site-specific diel patterns are not uncommon in baleen whale vocalization behavior. For example, in North Atlantic right whales (*Eubalaena glacialis*), differences in diel patterns between two recording sites have been linked with prey availability (Mellinger et al. 2007), and the observed variation in diel patterns of the bio-duck song in different parts of Antarctica might be related to prey distribution as well. Since prey behavior and distribution will also vary seasonally, some of these diverging patterns might be linked to seasonal shifts in prey distribution. More

concurrent passive acoustic and prey distribution data are needed to fully explain these patterns.

14.5 Behavioral Contexts and Potential Function of Minke Whale Vocalizations

Acoustic communication using high-amplitude, low-frequency (<1 kHz) signals with the potential to propagate over large distances is a common feature of baleen whale social systems, where individual whales are dispersed over a wide area. In such large acoustically mediated networks, individuals may employ eavesdropping to obtain information about conspecifics and maintain social cohesion (McGregor and Dabelsteen 1996). Although difficult to demonstrate in the field (McComb and Reby 2005), eavesdropping has been suggested to occur in humpback whales, where females could listen to vocal interactions between competing males (Cholewiak 2008; Chap. 11). In addition to true eavesdropping, it has been shown that many mammals attend to vocalizations even if these are not directed at them. Baleen whales might use passive listening to obtain information about a productive food source by attending to calls from conspecifics, and perhaps from heterospecifics, sharing the same acoustic habitat and possibly over very large distances. Finally, baleen whales might be alerted to the presence of predators such as killer whales by passive listening.

In the North Atlantic, minke whale song patterns, consisting of three to four different pulse train types, have been described through localization of individual animals. The localized individuals were in audible range of one another which suggests that these song patterns might play an important role in conspecific interactions. However, due to a lack of visual observation data, the actual behavioral function of these sequences remains unknown (Risch et al. 2014c). Uncertainty regarding the function of baleen whale vocalizations is a common feature across the different species, subspecies, and populations. Given that most known minke whale sounds have only been identified and described within the past 20 years, the biological significance of these sounds any associated acoustic behavior of these elusive species is still in its infancy.

In other baleen whales such as humpback, fin, and blue whales, only males produce song in a reproductive context (Glockner 1983; Croll et al. 2002; Oleson et al. 2007a). Although it is currently unknown whether this is similar in minke whales, the absence of North Atlantic minke whale song in habitats with a high proportion of females, such as the Gulf of St Lawrence, Canada, and west of Greenland, provides circumstantial evidence that it might be (Risch et al. 2014a). It has, therefore, been suggested that minke whale song, which has now been described to occur in all ocean basins (14.3), might also play a role in the reproductive behavior in this species complex (Risch et al. 2013). Another indication that minke whale song in the North Atlantic might be related to reproductive behavior is based on the observation that pulse trains recorded in presumed Caribbean winter breeding grounds are about 20 s longer and exhibit

more than twice as many pulses compared to those recorded in the Gulf of Maine during spring and autumn when the whales are on migration (Mellinger et al. 2000; Risch et al. 2013). In other mammal species, such as baboons and giant pandas, it has been shown that call duration can increase with heightened arousal state during the breeding season (Rendall 2003; Charlton et al. 2011).

Minke whale boing sounds recorded in the North Pacific have so far mostly been recorded in the lower latitudes around Hawaii and the Mariana Trench region, and their occurrence appears to be seasonal, with most boings being recorded from October to February, which coincides with minke whale visual sightings in those areas and the presumed breeding period for the population (Rankin et al. 2007; Oswald et al. 2011; Norris et al. 2017). Similar to the situation in the North Atlantic, direct data on age or sex of calling animals are still missing. Based on analogous lines of evidence regarding the stereotypy of the signals, their seasonal and spatial distribution, and in comparison to song and its function described for other baleen whale species, it has been suggested that the boing song might be produced by males in a reproductive context (Norris et al. 2017).

In the South Pacific, given the stereotypy and regular repetition of the star-wars sound recorded on the Great Barrier Reef and its primary production during the breeding season, it has also been speculated that these sounds function as a reproductive advertisement display, although comparable data gaps to those for North Atlantic pulse trains and North Pacific boing sounds exist (Gedamke et al. 2001).

Compared to common and dwarf minke whale songs, the seasonal and spatial distribution patterns of occurrence of Antarctic minke whale bio-duck song appear to be more complex, with songs being produced in high- and low-latitude habitats (Fig. 14.4). It has been shown that bio-duck song in most areas peaks during austral spring and winter (June to August), although some sites show another peak later in the year (December). In addition, bio-duck song units appear to increase in duration during winter (Dominello and Širović 2016). Based on these data and reports of visually observed breeding behavior between August and October, it has been hypothesized that bio-duck song functions in a reproductive context, and mating in this species might take place across a wide range of habitats (Filun et al. 2020).

Compared to the song sequences, low-frequency downsweeps produced by most minke whale populations are less well described and their behavioral function remains also unclear. The most comprehensive study of minke whale downsweeps was carried out in the Gulf of St Lawrence, Canada, where no distinct temporal pattern of downsweep production was found (Edds-Walton 2000). For this summer foraging ground, it was suggested that downsweeps might function to maintain spacing between feeding individuals (Edds-Walton 2000). Downsweeps produced by Antarctic minke whales are positively correlated with sea ice presence, but more data from direct observation or multi-sensor acoustic tags are necessary to confirm the behavioral context of these downsweep vocalizations (Dominello and Širović 2016).

14.6   Minke Whale Hearing and Impacts of Noise Pollution

While information about minke whale hearing capabilities is limited, we assume they can hear one another. In the absence of field measurements, minke whale hearing sensitivity can either be inferred from species-specific vocalizations, behavioral responses to sounds, or anatomical measurements on which model predictions can be based (Mellinger et al. 2000; Tubelli et al. 2012; Yamato et al. 2012; Boisseau et al. 2021; Chap 3). While general estimates of audiograms for baleen whales assume highest sensitivities between 200 and 19,000 Hz (Southall et al. 2019), simulations of the minke whale auditory pathway suggests that the most sensitive frequency range is between approximately 30 and 25,000 Hz (Tubelli et al. 2012).

There are numerous natural biotic and abiotic sound sources in the world's oceans, including weather events such as lightening/thunder and waves, sediment movement due to tidal currents, ice noise in the Arctic and Antarctic, and earthquakes, as well as biological sounds from a variety of taxa from invertebrates to the large whales (Bass and Clark 2003). Like other baleen whales, minke whales have adapted to these natural soundscapes by producing sounds with lower fundamental frequencies and higheramplitudes that increase sound transmission range (Clark 1983).

Since the beginning of the twentieth century, noise levels in some ocean regions have been steadily increasing and have remained high since at least the 1960s (Andrew et al. 2002; McDonald et al. 2006). These increases in and continuing high levels of anthropogenic noise have been driven primarily by shipping noise and noise from seismic airgun arrays for offshore oil exploration. Other sources of man-made noise include offshore construction work, multi-beam echosounders, fish finders, and naval sonar (Duarte et al. 2021).

An 80% loss of communication space for minke whale pulse trains relative to historical 'quiet' conditions has recently been modeled for minke whale habitat in the Northwest Atlantic (Cholewiak et al. 2018). In other parts of the world, minke whale densities have been observed to decrease during naval exercises, and minke whale strandings occurred during at least two mass stranding events linked to military sonar activity (Parsons et al. 2000; Balcomb and Claridge 2001). Another study showed minke whales responding to mid-frequency active sonar by a reduced calling rate and avoidance of the sound source. This behavior was observed even at relatively low estimated received sound levels (Sivle et al. 2015; Martin et al. 2015; Kvadsheim et al. 2017). Minke whales have also been shown to strongly avoid acoustic deterrent devices (ADDs) that are frequently used to mitigate underwater noise of offshore construction activities (Boisseau et al. 2021).

North Pacific minke whales off Hawaii increase the amplitude of their boing sounds in association with increased background noise. However, despite this compensation, the detected increases in sound intensity were not of the same magnitude as increases in background noise, and thus, reductions of communication space with potentially negative impacts would still be expected (Helble et al. 2020).

It is likely that chronically elevated noise levels such as those found in increasingly industrialized ocean regions as a result of human activities can also increase stress

levels in minke whales, as has been documented in right whales (Rolland et al. 2012), with unknown consequences for long-term health and reproduction. More research is needed to fully understand the impacts of anthropogenic noise on all baleen whale species, but it is likely that aggregate (e.g., vessel noise, seismic surveys, and sonar) and cumulative effects due to a variety of stressors including underwater noise, habitat loss, and pollution will eventually reach levels that could impact population survival. It is, therefore, important to address known and potential impacts as early as possible using effective mitigation and management actions (Andersen and Clubb 2013).

14.7 Conclusions

Minke whales live in large-scale, acoustically mediated social systems, and similar to other baleen whales, the combination of advanced vocal learning has given rise to some unique and intriguing social behaviors, much of which have yet to be discovered for the different minke populations and subspecies. Future research should focus on elucidating the functions of the different minke whale call and song types in different contexts, differences in age and sex of acoustically active individuals, and changes in their acoustic behaviors in relation to both natural and anthropogenically modified noise conditions. Effort should also be directed toward the identification and description of sounds of unknown but presumed biological origin, especially in regions, such as the South Atlantic, for which data are currently lacking. Finally, new machine learning techniques to enhance automated detection and classification of baleen whale vocalization (Bergler et al. 2019; Allen et al. 2021), coupled with a better description of individual calling rates and source levels using localization techniques, will enhance the application of density estimation methods to assess and monitor population size using passive acoustics (Marques et al. 2013; Martin et al. 2013; Norris et al. 2017).

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