Chapter 2
A Review of Blue Whale Studies from HARUphones in the Pacific

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Abstract The earliest long-term monitoring of low-frequency signals of large whales was via cabled military arrays. These arrays provided valuable new data but were restricted in the locations that were monitored and there was no open access to the data collected. In order to monitor the low-frequency signals of large whales in different areas and over shorter time scales, Haruphones, single hydrophone, autonomous recording packages, were developed by the Pacific Marine Environmental Laboratory of the US National Oceanic and Atmospheric Administration and deployed in the Gulf of Alaska and the eastern tropical Pacific. By integrating the acoustic data from these broadly spaced deployments with other data streams, new discoveries about blue whales in the eastern Pacific Ocean were made. These included establishing the geographic range and migratory patterns of eastern north Pacific blue whales; establishing that the eastern tropical Pacific appears to be a blue whale "hot spot" where as many as four, but primarily three, acoustic populations of blue whales occur; determining that the Gulf of Alaska is a region where eastern and western North Pacific blue whales overlap in space and time; and showing that blue whale calling behavior has a diel pattern whereby animals produce more sounds at night than during the day. In aggregate, these data show that passive acoustic monitoring is a valuable tool for establishing blue whale population identity, determining habitat range, and studying behavioral ecology over long time periods and in remote regions of the ocean.

2.1 Introduction

Many of the first long-term recordings of baleen whale sounds came from military arrays placed in different oceans to listen for the acoustic signatures of submarines (Nishimura and Conlon 1994). Those recordings contained thousands of low-frequency signals of unknown origin. Based on the seasonal occurrence and repetition rates of these signals, they were believed to be produced by "unknown biological

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sources." As recordings were made in the presence of large whales, these sources were identified as different species of baleen whale. Probably the most written about were the "20-Hz pulses" recorded around the world and later attributed to fin whales (*Balaenoptera physalus*). Second to these were the "long 20-Hz pulses" that have since been identified as blue whale (*B. musculus spp.*) vocalizations. In general, most signals produced by the great whales are relatively long (1–20 s) and of low frequency (<1000 Hz). Although these signals share the characteristics of being low frequency (often overlapping in bandwidth), and therefore capable of long-distance propagation, the best studied stereotyped signals are readily distinguishable to species. The development of "dual use" of the Integrated Undersea Surveillance System (IUSS) allowed scientists access to these acoustic time series (Nishimura and Conlon 1994). This allowed multiple species of baleen whales to be acoustically monitored remotely over great temporal and spatial scales at fixed locations on these ocean bottom arrays (cf. Thompson and Friedl 1982; Clark 1995; Clark and Fristrup 1997; Clark and Gagnon 2002; Stafford et al. 2001; Mellinger et al. 2000; Watkins et al. 2000, 2004; Charif et al. 2001; Mellinger and Clark 2003).

2.2 Haruphone Deployments

In order to monitor seismic signals in other oceans of the world and over shorter time scales, single hydrophone, autonomous recording packages (sometimes called Haruphones) were developed by the Pacific Marine Environmental Laboratory of the US National Oceanic and Atmospheric Administration (Fox et al. 2001). These instruments can be deployed in any ocean of the world, usually in the sound channel. Each instrument is an autonomous recording package that writes acoustic data to an on-board hard drive and is moored in or near the sound channel axis. Unlike long-term cabled arrays, the instrument and mooring hardware have to be recovered in order to access the data. Further, the recording package acquires data from a single, omni-directional hydrophone. By deploying multiple instruments in an array, sound sources can be localized in postprocessing, depending on the spacing of the instruments and the frequency of the signal of interest. Haruphones were designed to be deployed for 1–2 years. Since their development, the sample rate of these instruments has varied from 100 Hz to 2 kHz (0.1–40 Hz and 0.1–970 Hz), and 1–2 byte resolution. The long-term deployments of these instruments have provided surprising new data on large whales from remote areas of the globe, including the Pacific, and illustrate the power of passive acoustic monitoring over broad temporal and spatial scales. In this review, results from the deployment of Haruphones in the eastern tropical Pacific (ETP) and the Gulf of Alaska (Fig. 2.1) are presented with a particular focus on blue whales.

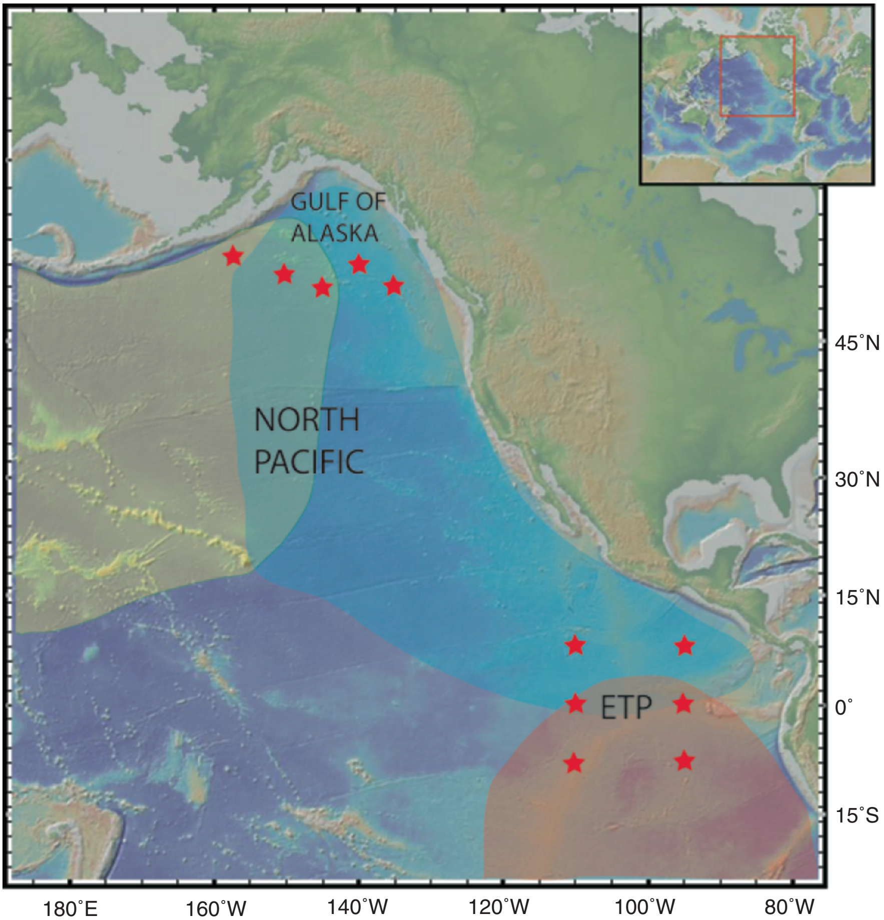

Fig. 2.1 Locations (*red stars*) of Haruphones moored in the eastern Pacific Ocean. *Blue shading* shows approximate distribution of eastern North Pacific blue whales. *Red* and *yellow shadings* show approximate distribution of eastern South Pacific and western North Pacific blue whales respectively. Note the overlap between the acoustic populations of blue whales

2.3 Studying Blue Whales with Passive Acoustic Monitoring

Blue whales are a wide-ranging species found in all of the world's oceans. Their apparent preference for pelagic habitats has made it difficult to assess whether or not over 50 years of international protection has led to increases in populations that were greatly reduced by commercial whaling. The question of the recovery of an endangered species such as the blue whale is important not just because United States law currently mandates recovery, but also because these animals play a role in larger ecological systems (Katona and Whitehead 1988). Monitoring signs of recovery of different populations have been the focus of many research efforts and most of these have involved traditional methodologies such as shipboard and aerial line-transect surveys that are expensive, time-consuming, and restricted by weather and light conditions and, most importantly, the behavior of individual animals. These studies tend to be focused in small areas for short periods of time. For over the past two decades or so, the use of passive acoustic monitoring has become increasingly important in understanding the seasonal and geographic occurrence of large whales.

The use of acoustic detections of whale calls has been useful in providing a very broad view of whale occurrence and seasonality in the Northeast Pacific over relatively long time spans. The advantages of this passive acoustic monitoring include being able to remotely monitor widespread areas at all times of day and year for vocalizations of multiple species and acoustic populations of whales. Additionally, animals are monitored while underwater, where they spend most of their time. Finally, while blue whale calls throughout the world share the characteristics of having long (>10 s), low-frequency (<20 Hz) notes, the sounds they make are geographically distinct such that different "acoustic populations" have been suggested as a means to distinguish among blue whales (Thompson et al. 1996; Stafford et al. 1999a, b, 2001; Mellinger and Clark 2003). Stereotyped call types recorded in the eastern North Pacific (ENP) consist of a two-part phrase, often called AB where the A call is a series of low-frequency pulses and the B call is a long, low-frequency tonal (Fig. 2.2a).

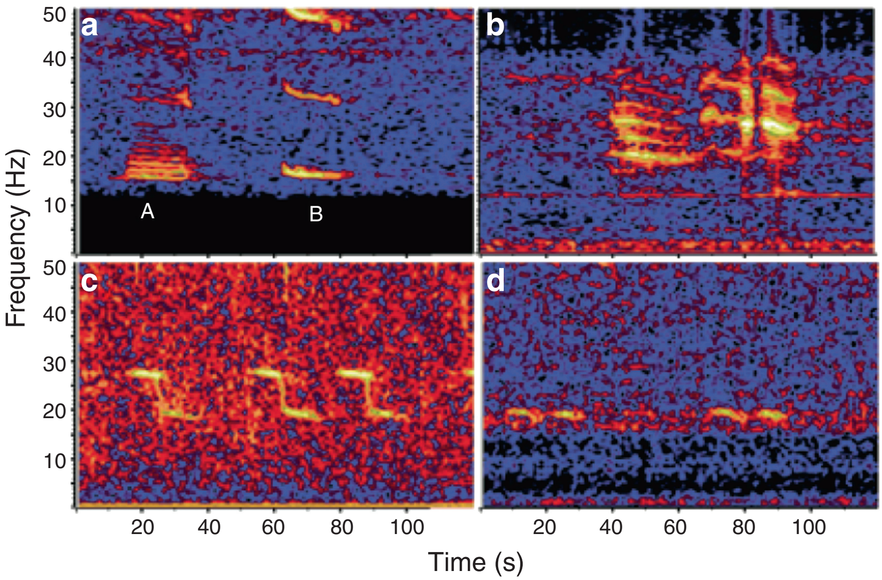

Fig. 2.2 Spectrograms of four blue whale call types recorded in the Pacific Ocean. (**a**) Eastern North Pacific AB phrase; (**b**) Eastern South Pacific phrase; (**c**) Three Antarctic 28 Hz calls; (**d**) Two western Pacific calls. Phrases from ENP and ESP blue whales are multipart, frequency and amplitude-modulated signals whale and those from the Antarctic and the western Pacific are simple, frequency-modulated signals

The eastern North Pacific blue whales are the best studied in the world.

Near shore line-transect and photographic identification studies have been undertaken numerous times off the coast of central and southern California (Calambokidis and Barlow 2004) and provided one of the first postwhaling population estimates for blue whales. It was thought that this population of blue whales ranged only from California during the summer to Baja, California, Mexico during the winter. Acoustic recordings of these animals were all of the northeastern Pacific vocalization type (Thompson et al 1996; Rivers 1997; Clark and Fristrup 1997). This same call type was also recorded off Oregon, Washington and Vancouver Island, Canada (Stafford et al. 2001). Acoustic data, in combination with photo ID and satellite telemetry, have shown that the range of this population is much greater and extends from the equator up to the far northern Pacific.

Blue whales had been seen in the ETP during different seasons and different locations during shipboard surveys in the 1970s–1980s. Initially these sightings were attributed to wintering animals from the California/Mexico stock (Berzin 1978; Wade and Friedrichsen 1979). Because they were seen in the region year-round, it was thought that these animals might be a resident population of blue whales or possible animals from a southern hemisphere population (Reilly and Thayer 1990).

In 1996, the first Haruphones were deployed in the ETP on either side of the East Pacific Rise in order to monitor seismicity in this area (Fox et al. 2001). Six instruments were first deployed in May (Fig. 2.1). Because they were "listening" for high amplitude, low-frequency earthquakes, these instruments were spaced widely apart in three lines at 8° N, 0°, and 8° S and 95° W and 110° W. This spacing was too great to detect the same signal from an individual baleen whale so each of the six locations represents a discreet sampling region. Although the instruments were deployed for a study of seismicity, when the data were recovered, there were whale calls on every instrument, including blue whales.

Northeastern blue whale calls were recorded on the very first day the instrument at 8° N 95° W sampled data and were detected on almost 80 % of the days during the first year of deployment. Detection of these calls was highest from November through May and lowest from June through October (Fig. 2.3). More calls were recorded per day and during more days per month during the northern hemisphere winter and this pattern was complementary to that of the same call type at more northerly latitudes. This correspondence, combined with decreasing detection of this call type at the more southern hydrophones, strongly suggested that at least some of the blue whales seen during visual surveys were from the "California/Mexico" stock, that this population produced AB calls year-round, and that their distribution extended south from Mexico to the tropical Pacific off central America supporting the idea that the ETP might be a possible wintering ground for these animals (Stafford et al. 1999a, b). Presently, in part due to these acoustic results, the population is no longer referred to as the California/Mexico stock and is known as the Eastern North Pacific stock (Carretta et al. 2010).

However, although ENP blue whale call types were recorded in many months of the year in the ETP, they were recorded mostly on a single hydrophone, that at 8° N 95° W in proximity to the Costa Rica Dome. Blue whales had been seen on either

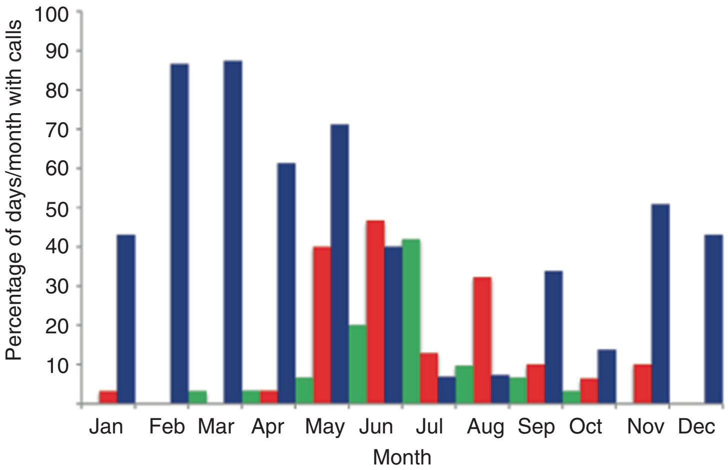

Fig. 2.3 Seasonal occurrence in percentage of days per month with calls for three different acoustic populations of blue whales in the eastern tropical Pacific: eastern North Pacific (*blue*), eastern South Pacific (*red*), and Antarctic (*green*)

side of the equator during shipboard surveys and in months when there were few or no AB calls recorded. A survey of the other five hydrophones in the array revealed the acoustic presence of an additional three call types that have since been definitively attributed to blue whales. The most commonly recorded, after the ENP AB calls, were two call types that closely resembled the signals that were the first blue whale calls ever identified. These were three to four part amplitude-modulated and frequency-modulated notes recorded off southern Chile in 1970 (Cummings and Thompson 1971; Fig. 2.2b) and the recordings from the ETP were the first time these calls had been "heard" since they were first recorded. This "eastern South Pacific" (ESP) call type was recorded most commonly on the hydrophones at the equator and at 8° S 95° W, due south of the equator from the hydrophone that recorded the greatest number of ENP calls. These signals were recorded primarily from March through August (Fig. 2.3; Stafford et al. 1999b). This seasonality is opposite of the ENP calls and, when combined with the location of the 1970 recording, strongly suggests that these are southern hemisphere blue whales that migrate northwards to the ETP during the southern hemisphere winter (Stafford et al. 1999b, Buchan et al. 2014). The different geographic and seasonal patterns of the different blue whale vocalizations identified supported a separation of northern and southern hemisphere animals and showed that each use different regions of the ETP at different times of year and migrate north or south during summer and fall.

The ETP is clearly an area that is an important habitat used regularly by two coastal populations of blue whales that, despite presently considered the same subspecies as most blue whales worldwide (*B m musculus*), are morphologically more similar to so-called 'pygmy' blue whales (*B m brevicauda*). It is also, based on acoustic detections, an area sometimes used by Antarctic blue whales (*B m intermedia*;

Stafford et al. 2004). Unlike the coastal blue whales, Antarctic blue whales repeat a simpler, single FM call that is somewhat higher in frequency than the ENP or SEP calls (Ljungblad et al. 1998; Rankin et al. 2005; Fig. 2.2c). This call type has been recorded around the Antarctic (Stafford et al. 2004; Širović et al. 2009). Antarctic blue whale populations were decimated by whaling in the early twentieth century and presently may be at less than 1 % of their original numbers (Branch et al. 2004). Because most of the whaling was concentrated at high latitudes in the Southern Ocean, nothing was known of the wintering grounds of these animals except that they were believed to migrate northwards (Mackintosh 1966).

Antarctic blue whale calls were detected every year, primarily in July (Fig. 2.3), from 1996 to 2002 at the two southernmost of the six hydrophones in the ETP (8° S 95° W and 8° S 110° W, Stafford et al. 2004). During each year, a large number of calls were recorded over only a few days at a time suggesting that perhaps only a few, vocal animals were in the area during that time. Simultaneous recording of the same call type at low latitudes in the Indian Ocean (Stafford et al. 2004), and near South Georgia in the South Atlantic (Pangerc 2010), demonstrates that there are likely multiple wintering destinations for this population of blue whales.

The ETP is an area in which blue whales have been sighted year-round (Reilly and Thayer 1990; Palacios 1999). Because it is nearly impossible to visually distinguish among subspecies, without acoustic recordings it would not be clear that rather than a resident single population of blue whales, animals from three different populations use this area at different times of year. Although the northern and southern hemisphere populations are somewhat geographically segregated, each occurs near the equator, albeit at different times of the year.

Similar to Antarctic blue whales, blue whales in the far North Pacific, particularly the Gulf of Alaska and along the Aleutian Islands, were hunted extensively such that no animals were seen during shipboard surveys in this region until the mid-2000s. Like the ETP, the population affiliation of whales taken in the North Pacific was unclear. As many as five populations were thought to occupy the whole North Pacific. These included not only the eastern North Pacific discussed above but also northwestern and central Pacific populations as well as an eastern Gulf of Alaska population (Ohsumi and Wada 1973). Acoustic data from cabled hydrophones off Hawaii, in the western North Pacific and the west coast of the United States up to Canada, showed that there were only two different call types recorded in all of the North Pacific: that attributed to the eastern North Pacific population (ENP) and a distinct call type (Fig. 2.2d) that was recorded primarily in the western North Pacific, along the Aleutians, and off Hawaii (WNP call type, Thompson and Friedl 1982; Stafford et al. 2001). From an acoustic population standpoint, it appears that rather than five populations in the North Pacific there were perhaps only two: a western North Pacific population that occurred off Kamchatka, south of the Aleutians and Hawaii (where it overlapped in space but not time with the eastern North Pacific population) and an eastern North Pacific population the ranged from the equator along the west coast of North America to Canada.

To determine if blue whales might still be found in the Gulf of Alaska, and if so, to what acoustic population they belonged, five Haruphones were deployed there from 1999 to 2002 (Fig. 2.1). This was the first deployment of these instruments to

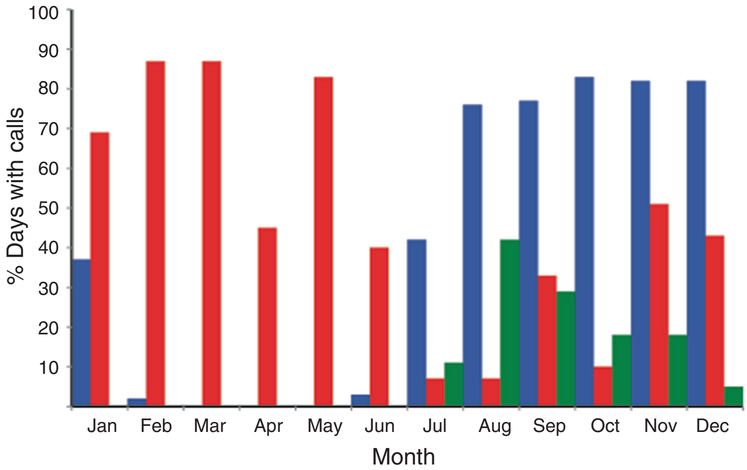

Fig. 2.4 Seasonal and geographic occurrence of ENP blue whale calls in the eastern tropical Pacific (*red*), off California/Oregon/Washington (*blue*), and in the Gulf of Alaska (*green*) in percentage of days per month with calls

specifically monitor for marine mammal vocalizations rather than for geophysical monitoring. As with the data from the ETP, blue whale calls were detected on the first days the instruments began recording. Both ENP and NWP call types were recorded from August to December annually and overlapped in space and time at all locations except on the westernmost hydrophone, closest to the Aleutian chain. Despite this overlap, there was an east–west trend in call detections where NWP calls were recorded more often on the hydrophones west of 145° W longitude and ENP calls were more frequently recorded east of this longitude (Stafford 2003).

These data provide evidence that the range of the eastern North Pacific stock extends into the Gulf of Alaska and thus covers the entire west coast of Central and North America (Fig. 2.4). It also shows that the Gulf of Alaska is a shared habitat for two acoustic populations of blue whales (eastern and western North Pacific) and that there is no "eastern Gulf of Alaska" population.

The overlap of these two acoustic populations in the fall and early winter, which is thought to be the breeding season for blue whales, suggests that acoustic call type differences may be used as population identifiers and/or as an isolating mechanism to prevent interbreeding between these congeners. Globally, for as long as it has been monitored, blue whale song has been relatively stable (but see McDonald et al. 2009 and Gavrilov et al. 2012 for changes in the fundamental frequency of notes) and this stability makes the signals robust for population differentiation. There has only been one documented instance of a hybrid song produced by a blue whale; a single animal in the Gulf of Alaska combined WNP and ENP units in a single song bout (Stafford and Moore 2005). This long-term stability in song units within an acoustic population allows the seasonal and geographic distributions and changes therein to be monitored over broader spatial and temporal scales than is possible using more traditional methods for assessing blue whale populations.

Many of the call types detected for these studies were long, repeated bouts of calling and focused exclusively on the stereotyped units known to make up parts of blue whale song. These units are only part of the repertoire of blue whale calls and are believed to possibly serve as a male display (McDonald et al. 2001; Oleson et al. 2007a). As far as we know, "songs" seem to be produced by solitary, mobile animals although single A and B units and D calls (which are higher frequency short down-swept signals, Rankin et al. 2005) are produced by whales in feeding groups (Oleson et al. 2007a). Information on gender and behavior has come from short-term tagging studies; data on specific behaviors while vocalizing cannot currently be obtained from single fixed sensors. These are the types of data needed to better understand the behavioral ecology of sound production, not just in blue whales, but also in all large whales.

However, some behavioral aspects to sound production can be hypothesized when the environment in which sounds are produced is understood. Unlike humpback whales (*Megaptera novaeangliae*), or fin whales, for instance, that sing primarily in the winter, blue whales produce songs year-round (Stafford et al. 1999a, 2011; Watkins et al 2000; Širović et al. 2009; Samaran et al. 2010). Further, because they tend to be found in areas of high productivity where food is likely available (Branch et al. 2007), sound production could serve a role in food advertisement as has been suggested for fin whales (Croll et al. 2002), or may be incompatible with active feeding.

The ETP, particularly near the Costa Rica Dome, is an area of high year-round productivity. It is also one of the regions proposed as wintering or breeding grounds for blue whales. Blue whales feed almost exclusively on krill, large zooplankton that aggregate in immense swarms that are exploited by feeding blue whales. Most species of krill, including those in the ETP, undertake diel vertical migrations where they disperse surfacewards at night after spending daylight hours often in dense patches at depth (Sameoto et al. 1987). Day–night differences in blue whale feeding behavior have been documented by whalers and by ecological studies of blue whales on known feeding grounds (Fiedler et al. 1998; Croll et al. 2001).

Counts of ENP blue whale calls by hour showed a diel pattern in call rate (calls/h) and call occurrence (Stafford et al. 2005). When the data were divided into Light, Dark, and Dusk by hour, there were significantly more calls per hour during dark and dusk than during light (Fig. 2.5). Blue whales were calling more often in the dark. A similar pattern was also found for singing ENP blue whales off southern California (Clark and Fristrup 1997; Oleson et al. 2007b).

This increase in call rate occurred at the same time in the evening that many krill species are migrating towards the surface of the ocean where they are more dispersed, and the morning decrease matched that time when krill move back down in the water column as the sun rises. These are also the times when whalers documented whales' stomachs as being more 'full' than at other times of the day. The similarity between the diel pattern of blue whale calls and their prey behavior suggests that calling in blue whales may be inversely related to foraging. When prey is concentrated at depth, blue whales spend time feeding on this prey, and not calling. When prey is more disperse, it may be more energetically conservative to spend this time displaying as has been suggested for sei whales (*B borealis*; Baumgartner and Fratantoni 2008). Data from tagged whales and vertical hydrophone arrays have shown that blue whales make calls relatively close to the surface (Thode et al. 2000;

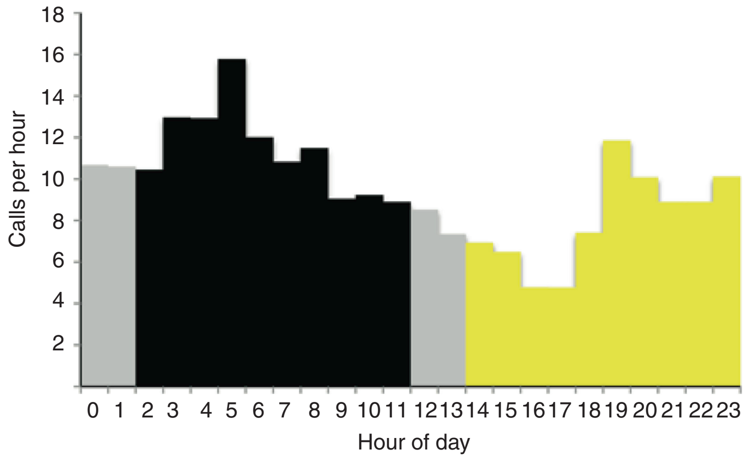

Fig. 2.5 Diel variation in call occurrence for blue whales in the eastern tropical Pacific. Overall, there were more calls per hour during dark (*black bars*) and dusk (*gray bars*) than during daylight (*yellow bars*)

Oleson et al. 2007a) and that actively feeding whales are not likely to be singing (Oleson et al. 2007a).

Although the information presented here provides a very broad overview of geographic, seasonal, and diel variations in blue whale vocal behavior, this overview can provide baseline data for new questions of interest. These questions may be as simple as where blue whales are found during any month of the year, and to which acoustic population the calling animals belong, to more complicated exploration of the role of acoustic signaling in the behavioral ecology of blue whales. New techniques are being developed that may soon allow whale populations to be counted using acoustic data from single hydrophones and "acoustic tags" have provided exceptional insight into the behavioral context of signaling in blue whales. While single hydrophone data provided the first long-term understanding of populations' differences, deep-water habitat, and seasonal occurrence of blue whales, the best chance for a complete understanding of acoustic ecology in these animals is via an interdisciplinary approach that combines new methods and technologies and integrates sighting, molecular, and telemetry data with acoustic recordings.

2.4 Key Findings

1. Blue whales seen in the ETP and the Gulf of Alaska are related to blue whales off California and western Mexico. Formerly known as the California/Mexico stock of blue whales, these animals are now considered the northeastern Pacific stock and range all along the coasts of North and Central America.
2. The ETP is a hotspot for multiple acoustic populations of blue whales.

(a) Eastern North Pacific.
(b) Eastern South Pacific—recordings of the same call type that was the very first to be attributed to blue whales from off Chile.
(c) Antarctic.

3. The Gulf of Alaska is a region where eastern and western North Pacific blue whales overlap in time and space suggesting that acoustic identification might be used for animals from different populations to tell each other apart.
4. Blue whales produce more calls at night and during dusk hours than during the day suggesting a partitioning of energetic effort between calling and foraging behaviors.

This work provided new information on the population identity and migration patterns of blue whales in the eastern North Pacific, provided the long-term information on eastern South Pacific blue whales since 1971, and showed that two different acoustic populations overlap in space and time in the Gulf of Alaska.

References

M.F. Baumgartner, D.M. Fratantoni, Diel periodicity in both sei whale vocalization rates and the vertical migration of their copepod prey observed from ocean gliders. Limnol. Oceanogr. **53**, 2197–2209 (2008)

A. Berzin, Distribution and number of whales in the Pacific whose capture is prohibited. Sov. J. Mar. Biol. **4**, 738–743 (1978)

T. Branch, K. Matsuoka, T. Miyashita, Evidence for increases in Antarctic blue whales based on Bayesian modelling. Mar. Mamm. Sci. **20**, 726–754 (2004)

S. Buchan, K. Stafford, R. Hucke-Gaete, Seasonal occurrence of southeast Pacific blue whale songs in southern Chile and the eastern tropical Pacific. Mar. Mamm. Sci. **31**, 440–458 (2014)

J. Calambokidis, J. Barlow, Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Mar. Mamm. Sci. **20**, 63–85 (2004)

J.V. Carretta, K.A. Forney, M.S. Lowry, J. Barlow, J. Baker, D. Johnston, B. Hanson, R.L. Brownell, J. Robbins, D.K. Mattila, K. Ralls, M.M. Muto, D. Lynch, L. Carswell, *U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-453* (U.S. Department of Commerce, Washington, DC, 2010), p. 336

R. Charif, P. Clapham, C.W. Clark, Acoustic detections of singing humpback whales in deep waters off the British Isles. Mar. Mamm. Sci. **17**, 751–768 (2001)

C.W. Clark, Application of US Navy underwater hydrophone arrays for scientific research on whales. Rep. Intl. Whal. Commn. **45**, 210–212 (1995)

C.W. Clark, K.M. Fristrup, Whales '95: a combined visual and acoustic survey of blue and fin whales off southern California. Rep. Intl. Whal. Commn **47**, 583–600 (1997)

C.W. Clark, G.J. Gagnon, Low-frequency vocal behaviors of baleen whales in the North Atlantic: insights from Integrated Undersea Surveillance System detections, locations, and tracking from 1992 to 1996. J. Underwater Acoust. **52**(3), 48 (2002)

D.A. Croll, A. Acevedo-Gutiérrez, B.R. Tershy, J. Urbán-Ramírez, The diving behavior of blue and fin whales: is dive duration shorter than expected based on oxygen stores? Comp. Biochem. Physiol. A **129**, 797–809 (2001)

D.A. Croll, C.W. Clark, A. Acevedo, B. Tershy, S. Flores, J. Gedamke, J. Urban, Only male fin whales sing loud songs. Nature **417**, 809 (2002)

W. Cummings, P. Thompson, Underwater sounds from the blue whale, Balaenoptera musculus. J. Acoust. Soc. Am. **50**, 1193–1198 (1971)
P.C. Fiedler, S.B. Reilly, R.P. Hewitt, D. Demer, V.S.A. Philbrick, S. Smith, W. Armstrong, D.A. Croll, B.R. Tershy, B.R. Mate, Blue whale habitat and prey in the California Channel Islands. Deep-Sea Res. I **45**, 1781–1801 (1998)
C.G. Fox, H. Matsumoto, T. Lau, Monitoring Pacific Ocean seismicity from an autonomous hydrophone array. J. Geophys. Res.-Sol. EA **106**, 4183–4206 (2001)
A.N. Gavrilov, R.D. McCauley, J. Gedamke, Steady inter and intra-annual decrease in the vocalization frequency of Antarctic blue whales. J. Acoust. Soc. Am. **131**, 4476 (2012)
S. Katona, H. Whitehead, Are Cetacea ecologically important? Oceanogr. Mar. Biol. Ann Rev. **26**, 553–568 (1988)
D.K. Ljungblad, C.W. Clark, H. Shimada, A comparison of sounds attributed to pygmy blue whales (*Balaenoptera musculus brevicauda*) recorded south of the Madagascar Plateau and those attributed to 'true' blue whales (*Balaenoptera musculus*) recorded off Antarctica. Rep. Intl. Whal. Commn. **48**, 439–442 (1998)
N.A. Mackintosh, The distribution of southern blue and fin whales, in *Whales, Dolphins and Porpoises*, ed. by K.S. Norris (University of California Press, Berkeley, CA, 1966), pp. 125–144
M. McDonald, J. Calambokidis, A. Teranishi, J. Hildebrand, The acoustic calls of blue whales off California with gender data. J. Acoust. Soc. Am. **109**, 1728–1735 (2001)
M. McDonald, J. Hildebrand, S. Mesnick, Worldwide decline in tonal frequencies of blue whale songs. Endanger Species Res. **9**, 13–21 (2009)
D.K. Mellinger, C.W. Clark, Blue whale (*Balaenoptera musculus*) sounds from the North Atlantic. J. Acoust. Soc. Am. **114**, 1108–1119 (2003)
D. Mellinger, C. Carson, C.W. Clark, Characteristics of minke whale (*Balaenoptera acutorostrata*) pulse trains recorded near Puerto Rico. Mar. Mamm. Sci. **16**, 739–756 (2000)
C.E. Nishimura, D.M. Conlon, IUSS dual use: Monitoring whales and earthquakes using SOSUS. Marine Technology Society Journal. **27**, 13–13 (1994)
S. Ohsumi, S. Wada, Status of whale stocks in the North Pacific, 1972. Rep. Intl. Whal. Commn. **25**, 114–126 (1973)
E.M. Oleson, J. Calambokidis, W.C. Burgess, M.A. McDonald, C.A. LeDuc, J.A. Hildebrand, Behavioral context of call production by eastern North Pacific blue whales. Mar. Ecol. Prog. Ser. **330**, 269–284 (2007a)
E. Oleson, S. Wiggins, J. Hildebrand, Temporal separation of blue whale call types on a southern California feeding ground. Anim. Behav. **74**, 881–894 (2007b)
D.M. Palacios, Blue whale (*Balaenoptera musculus*) occurrence off the Galápagos Islands, 1978–1995. J. Cetacean Res. Manag. **1**, 41–51 (1999)
T. Pangerc, Baleen whale presence around South Georgia. Ph.D. dissertation, University of East Anglia, 2010
S. Rankin, D. Ljungblad, C. Clark, H. Kato, Vocalisations of Antarctic blue whales, *Balaenoptera musculus intermedia*, recorded during the 2001/2002 and 2002/2003 IWC/SOWER circumpolar cruises, Area V, Antarctica. J. Cetacean Res. Manag. **7**, 13–20 (2005)
S.B. Reilly, V.G. Thayer, Blue whale (*Balaenoptera musculus*) distribution in the eastern tropical Pacific. Mar. Mamm. Sci. **6**, 265–277 (1990)
J.A. Rivers, Blue whale, *Balaenoptera musculus*, vocalizations from the waters off central California. Mar. Mamm. Sci. **13**, 186–195 (1997)
F. Samaran, O. Adam, C. Guinet, Discovery of a mid-latitude sympatric area for two Southern Hemisphere blue whale subspecies. Endanger Species Res. **12**, 157–165 (2010)
D. Sameoto, L. Guglielmo, M.K. Lewis, Day/night vertical distribution of euphausiids in the eastern tropical Pacific. Mar. Biol. **96**, 235–245 (1987)
A. Širović, J.A. Hildebrand, S.M. Wiggins, D. Thiele, Blue and fin whale acoustic presence around Antarctica during 2003 and 2004. Mar. Mamm. Sci. **25**, 125–136 (2009)
K.M. Stafford, Two types of blue whale calls recorded in the Gulf of Alaska. Mar. Mamm. Sci. **19**, 682–693 (2003)

K.M. Stafford, S.E. Moore, Atypical calling by a blue whale in the Gulf of Alaska (L). J. Acoust. Soc. Am. **117**, 2724–2727 (2005)
K.M. Stafford, S.L. Nieukirk, C.G. Fox, An acoustic link between blue whales in the eastern tropical Pacific and the northeast Pacific. Mar. Mamm. Sci. **15**, 1258–1268 (1999a)
K.M. Stafford, S.L. Nieukirk, C. Fox, Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. J. Acoust. Soc. Am. **106**, 3687–3698 (1999b)
K.M. Stafford, S.L. Nieukirk, C.G. Fox, Geographic and seasonal variation of blue whale calls in the North Pacific. J. Cetacean Res. Manag. **3**, 65–76 (2001)
K.M. Stafford, D.R. Bohnenstiehl, M. Tolstoy, E. Chapp, D.K. Mellinger, S.E. Moore, Antarctic-type blue whale calls recorded at low latitudes in the Indian and eastern Pacific Oceans. Deep-Sea Res. I **51**, 1337–1346 (2004)
K.M. Stafford, S.E. Moore, C.G. Fox, Diel variation in blue whale calls recorded in the eastern tropical Pacific. Anim. Behav. **69**, 951–958 (2005)
K.M. Stafford, D.K. Mellinger, S.E. Moore, C.G. Fox, Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. J. Acoust. Soc. Am. **122**, 3378–3390 (2007)
K.M. Stafford, S.E. Moore, P.J. Stabeno, D.V. Holliday, J.M. Napp, D.K. Mellinger, Biophysical ocean observation in the southeastern Bering Sea. Geophys. Res. Lett. **37** (2010)
K.M. Stafford, E. Chapp, D.R. Bohnenstiel, M. Tolstoy, Seasonal detection of three types of “pygmy” blue whale calls in the Indian Ocean. Mar. Mamm. Sci. **27**, 828–840 (2011)
T. Branch, K.M. Stafford, D. Palacios, C. Allison, J. Bannister, C. Burton, E. Cabrera, C.A. Carlson, B. Galletti Vernazzani, P.C. Gill, R. Hucke-Gaete, K.C.S. Jenner, M.N.M. Jenner, K. Matsuoka, Y.A. Mikhalev, T. Miyashita, M.G. Morrice, S. Nishiwaki, V.J. Sturrock, D. Tormosov, R.C. Anderson, A.N. Baker, P.B. Best, P. Borsa, R.L. Brownell Jr., S. Childerhouse, K.P. Findlay, T. Gerrodette, A.D. Ilangakoon, M. Joergensen, B. Kahn, D.K. Ljungblad, B. Maughan, R.D. Mccauley, S. Mckay, T.F. Norris, Oman Whale And Dolphin Research Group, S. Rankin, F. Samaran, D. Thiele, K. Van Waerebeek, R.M. Warneke, Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. Mammal Rev. **37**, 116–175 (2007)
A.M. Thode, G.L. D'Spain, W.A. Kuperman, Matched-field processing, geoacoustic inversion, and source signature recovery of blue whale vocalizations. J. Acoust. Soc. Am. **107**, 1286–1300 (2000)
P.O. Thompson, W.A. Friedl, A long term study of low frequency sounds from several species of whales off Oahu, Hawaii. Cetology **45**, 1–19 (1982)
P. Thompson, L. Findley, O. Vidal, Underwater sounds of blue whales, *Balaenoptera musculus*, in the Gulf of California, Mexico. Mar. Mamm. Sci. **12**, 288–293 (1996)
L.S. Wade, G.L. Friedrichsen, Recent sightings of the blue whale, *Balaenoptera musculus*, in the northeastern tropical Pacific. Fish. Bull. **76**, 915–919 (1979)
W.A. Watkins, M.A. Daher, G.M. Repucci, J.E. George, D.L. Martin, N. DiMarzio, D. Gannon, Seasonality and distribution of whale calls in the North Pacific. Oceanography **13**, 62–67 (2000)
W. Watkins, M. Daher, J. George, D. Rodriguez, Twelve years of tracking 52-Hz whale calls from a unique source in the North Pacific. Deep-Sea Res. I **51**, 1889–1901 (2004)

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