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Short Note

Diurnal and Seasonal Acoustic Trends in Northward Migrating Eastern Pacific Gray Whales (*Eschrichtius robustus*)

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The vocal repertoire of gray whales (*Eschrichtius robustus*) in breeding areas has been well-documented, identifying six core and several other auxiliary call types (Dahlheim et al., 1984; Dahlheim, 1987; Ollervides, 2001; Charles, 2011; López-Urbán et al., 2016). However, vocalizations employed in foraging areas and on migration routes are less well-described, with several past works indicating the scarcity in vocal behaviours (see Rasmussen & Head, 1965; Cummings et al., 1968; Fish et al., 1974; Moore & Ljungblad, 1984; Dahlheim, 1987; Petrochenko et al., 1991; Crane & Lashkari, 1996; Stafford et al., 2007). These studies were often hampered by limitations in spatial and temporal extent, or with whales displaying anomalous behaviours given the primary use of the area where the calls were recorded (e.g., Dahlheim, 1987; Youngson & Darling, 2016).

The acoustic activity of gray whales on the northward migration has been described as infrequent, noting that calls largely punctuate long periods of silence (Rasmussen & Head, 1965; Dahlheim, 1987; Crane & Lashkari, 1996). In this study, an Autonomous Multichannel Acoustic Recorder (AMAR, JASCO G3A) fitted with a GeoSpectrum M8E-132 calibrated omnidirectional hydrophone (effective bandwidth 5 Hz to 150 kHz, gain of 6 dB) was deployed in the migration corridor of gray whales, approximately 5 nmi southwest of Siwash Point on the southwest coast of Flores Island on the west side of Vancouver Island, Canada (49° 12' 37" N, -126° 14' 48" W) at a depth of 51 m. This is the location of a long-term ecological study of gray whales, where movements and behaviour are well-known. Also, vessel based observations in this area found migrating whales to pass the deployment site prior to and during the recording period. The passive acoustic monitoring (PAM) device recorded continuously for 64 d from 21 February to 25 April 2015. The recording period captured the peak of the whales' passage through this approximate halfway point of their migration (Duffus, pers. obs., 1984-2017), with this deployment affording new insight into gray whales' use of acoustics.

Herein, we analyze the temporal patterns of vocalizing gray whales to establish whether there is periodicity in calling on a daily or monthly scale. Manual verification of call presence was made via spectrogram analysis on a minimum of 340 s of every 900 s (to a maximum of 3,040 s in 3,600 s periods), totaling 44% of the full recording period. From this analysis, 7,824 calls were identified and classified according to the six core call types (Dahlheim, 1987), with low-frequency moan-like calls evident throughout the migration period. Although all six call types were identified, moan calls far outweighed other call types. However, all call types were treated equally and without distinction in our analysis.

Changes of calling rate over time were also examined, expressing the number of calls identified as a function of time. Daily temporal partitioning of vocal behaviours was examined by categorizing call times corresponding to light levels: day, night, and twilight (i.e., dawn and dusk). Twilight was defined as 2 h before and after sunrise and sunset, making up a total of 8 h of twilight conditions per day. Day and night periods varied slightly, according to the seasonal shift in daylight hours. Diel periodicity, initiated by light-triggered sleep cycles (e.g., Lyamin et al., 2008), has been described for many mammals, including baleen whales (e.g., Baumgartner & Fratantoni, 2008; Oleson et al., 2009). However, in these examples, acoustic behaviours were alternated with feeding behaviours, with the energy used for vocalizing shifted to foraging when prey becomes more available.

In this study, we presumed no feeding was present due to the positioning of the recording device in an offshore location, with prey resources in this area found close to the coast in waters not exceeding 25 m depth, and the timing of the recordings, during the northbound migration and before broods of zooplankton prey have become established and stabilized (see Burnham, 2015) and, therefore, a viable food source for gray whales. Instead, the assumption was made that gray whales conducted continuous travel behaviour during migration as shown by consistent surfacing intervals on the southward migration by Perryman et al. (1999), from captive studies (e.g., Wisdom et al., 2001), and from long-term observations in the study area (Duffus, pers. obs., 1984-2017). Therefore, we expected gray whales would not demonstrate a significant difference in their rate of calling between various light conditions, and we anticipated an even distribution of calls throughout day, night, and twilight periods. However, vocalizing occurred more at night and in twilight hours ($\chi^2 = 13.24$, df = 2, $p = 0.0013$), with calls detected more frequently during dusk than during dawn ($\chi^2 = 9.55$, df = 1, $p = 0.0019$; Figure 1).

The rates of calling (call/unit time) also confirm this trend, with more calls/s at night than during daylight hours and twilight acting as an intermediate (night = 0.0042 calls/s, twilight = 0.0032 calls/s, and day = 0.0025 calls/s). This suggests that acoustic activity is more pronounced when vision is impaired by darkness, with perhaps an increase of calling during periods of dusk in anticipation of nightfall (Table 1). It could also be that vision supplements acoustics as the dominant sense during the day for fine-scale cues to locate conspecifics, thus minimizing the energy outlay from calling. It does not, however, replace acoustics as vocalizations remain present, likely to maintain a long-range information stream—for

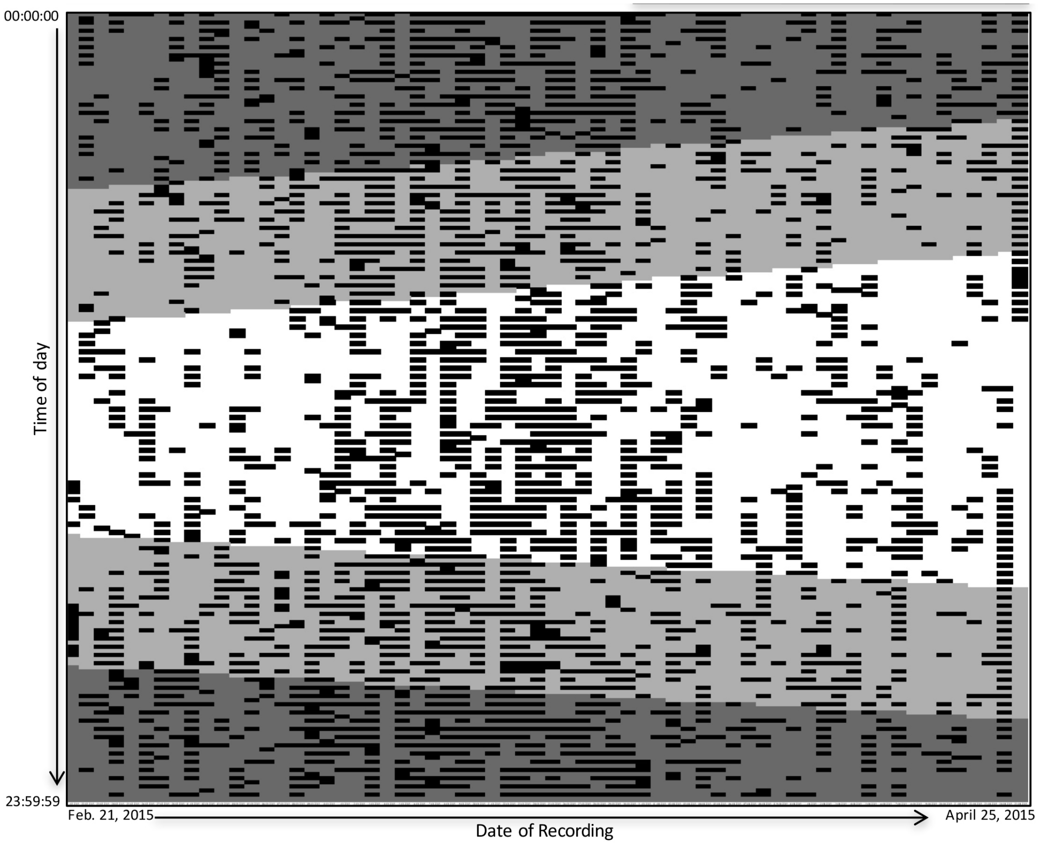

Figure 1. Visual representation of gray whale (*Eschrichtius robustus*) calls manually identified in recordings during the migration period. Call presence per 15 min is indicated by a black dash. The darker grey background represents periods of night/dark, the lighter grey represents periods of dawn and dusk/twilight, and the white represents periods of day/light. The biphasic pattern (Phase A = males and lone females, and Phase B = cow–calf pairs) of migrating gray whales passing the recorder has been indicated.

Table 1. Rate of calling, shown as number of calls/s, for night, dawn, day, and dusk over the deployment period, calculated on a weekly basis

	Night	Dawn	Day	Dusk
21-27 Feb	0.0029	0.0010	0.0013	0.0055
28 Feb-6 March	0.0025	0.0014	0.0009	0.0034
7-13 March	0.0038	0.0044	0.0027	0.0043
14-20 March	0.0097	0.0082	0.0047	0.0068
21-27 March	0.0070	0.0047	0.0056	0.0063
28 March-3 April	0.0046	0.0022	0.0032	0.0032
4-10 April	0.0021	0.0019	0.0013	0.0028
11-17 April	0.0027	0.0012	0.0015	0.0024
18-25 April	0.0026	0.0036	0.0011	0.0041

example, the location of conspecifics and topographical surroundings. Diel calling patterns have previously been shown to occur in breeding areas where calls were found to be more prevalent during the evening than the day; and as with this study, overall rates of vocalization peaked at sunrise and sunset and was at its lowest in the mid-afternoon (Ponce et al., 2012). No trends in ambient noise were detected over the 24-h cycle for the recording period in this study, with noise from vessel traffic and anthropogenic additions more a concern for the summer months in this area with more discernible day–night patterns in noise levels than during the spring.

A binary coding for whale call presence, (Figure 1) shows a pattern on a longer time scale. Gray whales are thought to migrate consistently south to north throughout the study period, and so a peak in calling presence in the acoustics data may be indicative of changes in the numbers of individuals transiting the area, or it could show the bi-phased pattern in the gray whale northward migration. Phase A consists of the first adults (males and lone females) to leave the breeding lagoons, while Phase B are the mothers and calves (Herzing & Mate, 1984; Poole, 1984). Phase B's acoustic use may differ from Phase A on a number of counts. For example, mothers and calves may vocalize less due to the use of tactile cues, with cow–calf pairs often swimming in close proximity (Smultea et al., 2017). Calls could also be lower amplitude at this time and so would be less likely to be detected over distance (López-Urbán et al., 2016). A lack of vocalizations could also be an anti-predator tactic for protection from killer whales (*Orcinus orca*) (Crane & Lashkari, 1996).

From our recordings, vocalizations in late February to mid-March could represent Phase A migrators, and those calls after mid- to late-March represent Phase B, with a second, smaller peak in rate of calls in mid-April (Figure 1; Table 1). This increased rate of calling in mid-March (Table 1) is in agreement with the expected peak of whales migrating through this area based on when they leave the lagoons and sightings made along the coast, with the second, smaller calling pulse resulting from cow–calf pairs employing one of several different acoustic strategies, including calves learning and refining their vocal repertoire or for cow–calf cohesion (Charles, 2011) as seen in other cetaceans (e.g., see Lenneberg, 1967; Marler & Peters, 1982; Sayigh et al., 1990; Edds et al., 1993; McCowan & Reiss, 1997; Baumgartner et al., 2008; Bruck, 2013; Cazau et al., 2013; Lipkind et al., 2013). Although periodic vessel observations were made during the recording period, when weather and conditions allowed, the possible conclusions in terms of animal number, migration behaviour, and rate of passage are limited without more visual data to pair with the acoustics monitoring. However, PAM recorders still act as a means to chronicle the whales' migratory movements and use of the area over time. The rate of calling at any one time (see Table 1) may give an indication of whale abundance (see Ponce et al., 2012), but the number of vocalizing individuals, as well as those not calling, remains unknown.

This first look at the use of acoustics as a survey tool shows a significant vocal component to migrating gray whales, which up to now has been underestimated. Our findings of increased calling at night may be indicative of vocalizations replacing other cues of conspecific presence and hint at the importance of the acoustic sense for navigation or other functions. Gray whales may receive information on topographical features and landmarks (e.g., Wladichuk et al., 2008), or acoustics and passive listening may serve group-cohesion and membership functions as seen in other whale species (e.g., Patterson & Hamilton, 1964; Norris, 1969; Payne & Webb, 1971; Thompson et al., 1979; Ellison et al., 1987; Clark & Ellison, 2004; Gannon et al., 2005; Oleson et al., 2007).

Communicating acoustically is no doubt an advantage under water; however, increasingly, the ocean soundscape is changing. Acoustic signaling by cetaceans has evolved in the context of varying natural ambient conditions (Payne & Webb, 1971; Wiley & Richards, 1978; Brumm & Slabbekoorn, 2005); however, with increased levels of underwater anthropogenic noise (see Ketten, 2002; Firestone & Jarvis, 2007; Weilgart, 2007; Rolland et al., 2012), acoustic behaviours, habitat use, and perhaps health and survival rates may be altered (e.g., Payne & Webb, 1971; Tyack & Clark, 2000; Weilgart, 2007; Clark et al., 2009; Castellote et al., 2012). Changes in migration behaviours have been seen in gray whales as a response to noise (Malme et al., 1983, 1984, 1988), with the species already facing an expanding migration distance and other changes due to receding Arctic ice (see Moore, 2008). All of these factors speak to the need for current baseline call data such as that described herein.

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