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Classification of underwater vocalizations of wild spotted seals (*Phoca largha*) in Liaodong Bay, China

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Underwater vocalizations were recorded and classified from wild spotted seals (*Phoca largha*) in Liaodong Bay, China. The spotted seals exhibited an extensive underwater vocal repertoire but with limited complexity. Four major call types, representing 77.8% of all calls recorded, were identified using multivariate analyses of ten acoustic parameters; knock, growl, drum, and sweep. The calls were relatively brief (12–270 ms, mean of –10 dB duration) pulsating sounds of low-frequency (peak frequency <600 Hz) and narrow bandwidth (169–232 Hz, mean of –3 dB bandwidth; 237–435 Hz, mean of –6 dB bandwidth). Frequency variables (–3/–6 dB frequency bandwidth, center frequency, and top three peak frequencies) were the primary descriptors used to differentiate the call types. Comparing the spotted seal underwater vocalizations with those of the closely related Pacific harbor seal (*Phoca vitulina richardii*) indicated that the two species use similar bandwidths and peak frequencies but spotted seal calls were generally shorter. Knowledge of underwater vocalizations of wild spotted seals is important for understanding the species behavior and for planning future acoustic surveys of its distribution and occurrence.

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I. INTRODUCTION

Spotted seals (*Phoca largha*) are distributed in the north and west of the North Pacific Ocean (Rugh *et al.*, 1997) where Liaodong Bay (LB) (38°43'–40°58' N, 119°50'–122°18' E), China, represents the southernmost geographic breeding concentration of this species (Boveng *et al.*, 2009). Spotted seals are difficult to survey using traditional visual techniques, particularly during the breeding season when they are sensitive to air borne noise and spend relatively more time in the water (Rugh *et al.*, 1997; Boveng *et al.*, 2009). Passive acoustics methods have been successfully applied to record the underwater sounds of different seal species, including harbor seals (*Phoca vitulina*) (Hanggi and Schusterman, 1994; Van Parijs *et al.*, 2000; Van Parijs *et al.*, 2003; Nikolich *et al.*, 2016), ringed seals (*Phoca hispida*) (Stirling, 1973; Cummings *et al.*, 1984), leopard seals,

(*Hydrurga leptonyx*) (Rogers *et al.*, 1996; Rogers and Cato, 2002), bearded seals (*Erignathus barbatus*) (Risch *et al.*, 2007), harp seals (*Phoca groenlandica*) (Watkins and Schevill, 1979; Terhune and Ronald, 1986), and Weddell seals (*Leptonychotes weddelli*) (Thomas and Kuechle, 1982; Rouget *et al.*, 2007; Doiron *et al.*, 2012). Results from previous research have indicated that most species become more vocal underwater during the breeding season (Watkins and Schevill, 1979; Miksis-Olds *et al.*, 2016). There is currently no published information available on wild spotted seal underwater vocalizations, however, there are two previous reports of underwater sounds of captive spotted seals from the Bering Sea (Beier and Wartzok, 1979; Gailey-Phipps, 1984).

The spotted seal is listed as Least Concern by the IUCN (International Union for the Conservation) Red List of Threatened Species (Boveng, 2016) and as a Grade 2 State Protection Species by China's Wild Animal Protection Law, enacted in 1988. The population in LB has declined from approximately 2300 individuals to less than 1000 individuals over the past three decades due to hunting and environmental pollution (Han *et al.*, 2010). The LB population inhabits both Chinese and South Korean waters and in 2000 the

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species was designated protected status under the Wildlife Conservation Act of South Korea, however the population has continued to decline (Han *et al.*, 2010).

Spotted seals form large groups during migration, mating, pupping, feeding, and moulting in LB between November and April (Wang, 1986). Spotted seals, like many other marine mammals, rely on vocalizations to attract partners, maintain aquatic territories, and for mother-pup interactions and other communication (Stirling and Thomas, 2003; Sills *et al.*, 2014).

The objectives of this study were to (1) characterize the underwater vocal repertoire of wild spotted seals in LB using multivariate statistical and spectrogram analyses, (2) provide detailed descriptions of each call type, and (3) give recommendations for future monitoring of behavior, distribution, and occurrence of spotted seals using acoustic recordings.

II. METHODS

A. Sound recordings

Underwater sound recordings were conducted of spotted seal groups on 14 March 2014 between 06:00 and 07:30 in the morning and between 20:00 and 22:30 in the evening at Liao River Estuary in LB, China (40°54' N, 121°49' E). The chosen day and recording times are within the breeding season, during the time period when spotted seals are most frequently observed in the area (Wang, 2014) and when human activities are limited by melting sea ice (Halpern *et al.*, 2008). The Liao River Estuary is one of the main breeding areas for spotted seals in LB (Han *et al.*, 2004) (Fig. 1). The water depth at the recording location was 10–15 m depending on the tide. The bottom sediment was mud (determined from sampling cores), limiting the long range propagation of underwater sound. The acoustic detections were compared with locations of sighted seal groups to confirm that vocalizations recorded originated from spotted seals. Further,

there were no other seal species or other marine mammals observed in the study area during the time of the recordings.

Audio recordings were made using a digital acoustic recorder (DSG) (Loggerhead Instruments, Inc., Sarasota, FL) with a sampling frequency of 80 kHz and resolution of 16 bit. Sounds were stored on 128 GB removable SD cards in 2-min.wav format files. The recorder has an omnidirectional hydrophone with a sensitivity of -180.6 dB re 1 V/ μ Pa and a flat frequency response from 20 Hz to 40 kHz (± 2 dB). The hydrophone was deployed at 5 m water depth from a 12 m anchored fishing boat. A 2.5 kg weight attached to the hydrophone and surface buoy was used to reduce flow noise and vertical motion over the hydrophone. To minimize potential effect on the seals' behavior, no light or sound generating equipment were used on the vessel. There was a minimum of 20 seals present at the surface within 20 m range of the recording location during both the morning and evening recording sessions. However, the sex, age, underwater number, and exact location of the calling seals were not known.

B. Sound analysis

The sound recordings were first analyzed qualitatively using oscillograms (sound pressure vs time) and spectra [Hamming window, fast Fourier transform (FFT) size = 1024 points, frequency overlap = 50%] produced in SONIC VISUALISER 2.4.1 (Center for Digital Music at Queen Mary, University of London, London) and RAVEN 1.5 (Cornell Lab of Ornithology, Ithaca, NY) to identify and extract the seal vocalizations. Only vocalization signals with clear vocal contours and a signal-to-noise ratio >10 dB were manually selected. In total, 120 2-min separate recording samples of wild spotted seals were collected in LB. From these, 366 calls in the morning and 338 calls in the evening were of sufficient quality to allow further analysis.

To quantify the acoustic characteristics for each recorded vocalization, ten temporal and spectral parameters

FIG. 1. (Color online) Map showing the morning (1, solid dot) and evening (2, circle) locations where spotted seal (*Phoca largha*) underwater vocalizations were recorded in Liao River estuary, in Liaodong Bay, China.

(see Table I for a summary of the acoustic parameters) were extracted using a custom code written in MATLAB R2016a (Mathworks, Natick, MA). Oscillograms were used to calculate three temporal parameters [Fig. 2(a)] and the remaining seven spectral parameters were measured or calculated from the normalized amplitude spectra of the vocalizations [Hamming window, FFT size = 40 000 points, frequency overlap = 100%, frequency resolution of 2 Hz; Fig. 2(b)].

C. Statistical analysis

Statistical analyses were conducted using MINITAB 17.0 (Minitab Inc., PA) or SPSS STATISTICS 19.0 (IBM SPSS, Inc., Chicago, IL). Multivariate statistical approaches were applied to the acoustic parameters to quantitatively classify the seals' vocalizations. Specifically, a combination of principal component analysis (PCA) and hierarchical cluster analysis (HCA) was used to assess the number and types of the spotted seals underwater vocalizations. PCA was used to reduce the number of original acoustic parameters, many of which are highly correlated, into a few orthogonal variables [principal components (PCs)] that would explain most of the variation in the data (Patras *et al.*, 2011). Given that the acoustic parameters were measured in different units, the individual values were standardized on a common scale (z-scores) before running the PCA. These standardized values were used as input variables in the PCA to reduce data dimensionality and data dependency. Finally, we performed a HCA, which is an unsupervised classification method, on all the vocalizations using the PCs with eigenvalues greater than 1 as variables. To obtain the hierarchical associations, the squared Euclidean distance was measured for each call sample and clusters were combined using the complete-linkage-between-groups method (Terhune *et al.*, 1993; McCreery and Thomas, 2009; Patras *et al.*, 2011; Reyes *et al.*, 2015). In the HCA, calls were grouped on the basis of similarities and the results were shown as a dendrogram displaying all call types.

All calls were then rechecked by aural and visual inspection of spectrograms to assess the validity of the call type classification generated by the HCA. To classify a call as distinctive, it had to include all of the following characteristics; it could be grouped into one main cluster defined by a similarity greater than 95% of the HCA, it was heard more than ten times both in the morning and evening, its vocal contour was stereotyped, and there was obvious and consistent difference between call types (Serrano, 2001). Finally, descriptive statistics of the ten acoustic parameters for each call type were obtained, including mean and standard deviation. To compare proportional use of the four call types between morning and evening, chi-square tests (expected equal proportions) were conducted on the data sets. *P* values <0.05 were considered statistically significant.

D. Ethical statement

This study was performed with the approval of Liaoning Fisheries Administration Bureau, Liaoning, China (No. LSYXFZ20111105), and followed the current Chinese Wildlife Protection Act or institutional guidelines for the survey of animals.

III. RESULTS

Spotted seals in LB produced an extensive but with limited complexity vocal repertoire under water. All vocalizations were pulsed with varying repetition rates, relatively brief (12–270 ms, mean of ~10 dB duration), of low-frequency (peak frequency <600 Hz) and narrow bandwidth (169–232 Hz, mean of ~3 dB bandwidth; 237–435 Hz, mean of ~6 dB bandwidth).

Combining the morning and evening data sets in the PCA for the first three principal components with eigenvalues greater than 1, accounted for 77.9% of the variation (Table II). Principal component 1 (PC1) explained 40.2% of the variance and was most closely correlated with several frequency parameters (–3 dB_BW, –6 dB_BW, PF1, PF2, PF3, and CF). Principal component 2 (PC2) explained

TABLE I. Description of ten parameters measured or calculated for spotted seals (*Phoca largha*) underwater vocalizations recorded in Liaodong Bay, China.

Acoustic parameters	Description
–10 dB duration ($\tau_{-10\text{dB}}$)	This is the vocalization duration in (ms) 10 dB below the peak of the envelope of the waveform (Möhl <i>et al.</i> , 1990; Villadsgaard <i>et al.</i> , 2007).
Positive start-up time of oscillation (τ_{PSO})	This describes the duration in (ms) from beginning of the vocalization to maximum amplitude.
Negative start-up time of oscillation (τ_{NSO})	This describes the duration in (ms) from beginning of the vocalization to minimum amplitude.
Center frequency (CF)	This is defined as the central frequency in (Hz) between the upper and lower cut-off frequencies of –3 dB_BW (Madsen and Wahlberg, 2007).
–3 dB bandwidth (–3dB_BW)	This describes the frequency width in (Hz) between $1/\sqrt{2}$ of amplitude points of the spectrum on the linear scale (Au, 2012).
–6 dB bandwidth (–6dB_BW)	This describes the frequency width in (Hz) between 1/2 of amplitude points of the spectrum on the linear scale.
First peak frequency (PF1)	This is measured from the frequency spectra. It describes the frequency value of first maximum in amplitude (Hz).
Second peak frequency (PF2)	This is measured from the frequency spectra. It describes the frequency value of second maximum in amplitude (Hz).
Third peak frequency (PF3)	This is measured from the frequency spectra. It describes the frequency value of third maximum in amplitude (Hz).
Number of extreme amplitude points (NumE)	This describes the number of extreme amplitude points in the –3 dB bandwidth.

FIG. 2. (Color online) Oscillogram (a) with signal envelope (dotted line) and average energy spectrum (b) examples of spotted seals (*Phoca largha*) underwater vocalizations recorded in Liaodong Bay, China, showing the vocal parameters measured for acoustic description and definition of the calls: τ_{-10dB} duration (τ_{-10dB}), positive start-up time of oscillation (τ_{PSO}) and negative start-up time of oscillation (τ_{NSO}), top three peak frequencies (PF1, PF2, and PF3), center frequency (CF), τ_{-3dB} frequency bandwidth (τ_{-3dB}), and τ_{-6dB} frequency bandwidth (τ_{-6dB}). PF1 and PF2 represent two extreme amplitude points in the τ_{-3dB} bandwidth (NumE).

25.9% and was strongly correlated with temporal parameters (τ_{-10dB} , τ_{PSO} , and τ_{NSO}). Finally, principal component 3 (PC3) explained 11.7% and was mainly correlated with number of extreme amplitude points (NumE). There was no correlation between the three PCs which made them appropriate to use as input variables in the HCA. A dendrogram (Fig. 3) was constructed from the HCA results which revealed several main clusters that were used to describe the underwater call type classifications of spotted seals.

Based on the HCA results and further investigations of the spectrograms of each vocalization, four major call types were identified from the underwater vocalizations produced by the spotted seals in LB: knock, growl, drum, and sweep.

TABLE II. Loadings by factor from principal component analysis of ten acoustic parameters from underwater vocalizations by wild spotted seals (*Phoca largha*) in Liaodong Bay, China. Significant loading values shown in bold (≤ -0.60 or ≥ 0.60).

Factor	PC1	PC2	PC3
τ_{-10dB} (ms)	-0.53	0.76	0.13
τ_{PSO} (ms)	-0.51	0.79	0.20
τ_{NSO} (ms)	-0.49	0.81	0.18
-3 dB_BW (Hz)	0.61	0.39	-0.53
-6 dB_BW (Hz)	0.66	0.38	-0.26
CF (Hz)	0.84	0.29	0.25
PF1 (Hz)	0.73	0.18	0.31
PF2 (Hz)	0.76	0.17	0.36
PF3 (Hz)	0.72	0.10	0.31
NumE	0.30	0.53	-0.60
Variance (%)	40.2	25.9	11.7
Cumulative (%)	40.2	66.1	77.9

The naming of these call types were consistent with their onomatopoeia or those used in earlier studies on seal vocalizations (Gailey-Phipps, 1984). An example of each call is shown in Fig. 4 and the statistics of the acoustic parameters for each call type are presented in Table III.

In general, knocks were the most common vocalizations produced by spotted seals under water both in the morning (Chi-square test: $\chi^2_{\text{morning}} = 139.66$, $P < 0.05$) and in the evening (Chi-square test: $\chi^2_{\text{evening}} = 87.01$, $P < 0.05$). 152 knock calls were recorded in the morning and 125 knock calls were recorded in the evening representing 39.3% of all calls recorded. On average, the time parameters (τ_{-10dB} , τ_{PSO} , and τ_{NSO}) of the knocks were of much shorter duration compared to the other three call types (Table III). Spotted seals often used knocks in series of repetitive knocks (knock trains which sounded similar to rapid knocking, see Fig. 4). The frequency range of a single knock was relative large, but its center frequency was < 600 Hz. Growl was the second most common call type, representing 20.3% of all calls. A growl resembled a pulsed call with high pulse repetition rate and was characterized by a relatively long duration (up to 0.5 s),

FIG. 3. (Color online) A dendrogram of the underwater vocalizations recorded from spotted seals (*Phoca largha*) based on hierarchical cluster analysis. Different main clusters (similarity over 95%) are shown in different colors. 704 observations (calls) were analyzed and 548 of these (77.8%) were identified as four different call types (knock, growl, drum, and sweep).

FIG. 4. (Color online) Oscillograms (above) and spectrograms (below, sampling rate 80 kHz, hamming window, FFT size = 1024 points, frequency overlap = 50%) of four underwater call types, knock, growl, drum and sweep, identified from recordings of spotted seals (*Phoca largha*) in Liaodong Bay, China.

narrow bandwidth and a frequency <400 Hz (Fig. 4). The drum call was characterized by a series of repetitive pulses with different amplitudes, superficially resembling the echolocation sounds produced by odontocetes (Au, 2012). However, the interval between each pulse was not distinct, which made the calls sound like muffled drums. The duration of drums was about half the length of growls and the value varied considerably (Table III). Although the frequency

TABLE III. Descriptive statistics of acoustic characteristics of underwater vocalizations by wild spotted seals (*Phoca largha*) in Liaodong Bay, China. Mean and standard deviation (in parentheses) are given for ten acoustic parameters for each call type. N represents the number of vocalizations analyzed.

	Knock	Growl	Drum	Sweep
$\tau_{-10 \text{ dB}}$ (ms)	12(10)	270(195)	141(136)	48(43)
τ_{PSO} (ms)	4(3)	115(97)	66(88)	10(2)
τ_{NSO} (ms)	4(5)	121(119)	72(104)	13(5)
-3 dB_BW (Hz)	232(21)	171(19)	169(14)	226(65)
-6 dB_BW (Hz)	435(69)	237(35)	352(22)	385(35)
CF (Hz)	546(49)	354(41)	391(15)	339(71)
PF1 (Hz)	504(89)	313(41)	359(21)	269(78)
PF2 (Hz)	536(82)	317(38)	392(21)	334(79)
PF3 (Hz)	557(97)	331(27)	404(20)	364(34)
NumE	3(2)	4(3)	4(3)	3(3)
N	277	143	75	53

parameters of drums were similar to that of growls, drums sounded discontinuous, which made them different from growls. Only 53 sweep calls (7.5% of all calls) were identified, suggesting that this call type was less frequently used by spotted seals under water. Sweep calls were of short duration (< 100 ms) and narrow bandwidth signal (226 Hz, mean of -3 dB bandwidth; 385 Hz, mean of -6 dB bandwidth). However, they had distinctly sweep-frequency characteristics, which were given as a relatively intense brief downward sweep in frequency (Fig. 4).

IV. DISCUSSION

Spotted seals are unusual among the phocids in that they are considered to be annually monogamous (Boveng *et al.*, 2009) and regarded as a shy and wary species (Rugh *et al.*, 1997). Hence, before our field recordings we hypothesized that the spotted seals would have limited vocal behavior under water. However, the results from our study clearly demonstrate that the underwater vocal repertoire of spotted seals in LB is more extensive than expected. More than 700 distinct calls were obtained during the two recording periods. Spotted seals are highly gregarious to facilitate and maintain pair contact throughout the breeding season (Beier and Wartzok, 1979; Wang, 1986), which may explain the need for frequent use of acoustic communication among individuals. The anthropogenic development and pollution of Bohai Sea have gradually decreased the quality and available habitat for the inhabiting seals (Han *et al.*, 2004). It is possible that this loss of habitat has increased seal densities in some areas and caused increased intra-species competition that may explain the relatively broad vocal repertoire found in this region.

A combination of multivariate and spectrogram analyses was performed to quantitatively categorize the underwater vocalizations of spotted seals in LB. The ten original acoustic parameters were transformed into three new uncorrelated PCs using the PCA, which indicated that frequency variables (-3/-6 dB bandwidth, center frequency, and top three peak frequencies) were of primary importance in describing the variability in call types. These results are similar to those presented in previous studies using PCA on vocalizations in other pinnipeds, including leopard seals (*Hydrurga leptonyx*) (Thomas and Golladay, 1995), northern elephant seals (*Mirounga angustirostris*) (Insley, 1992), crabeater seals (*Lobodon carcinophagus*) (McCreery and Thomas, 2009), and Mediterranean monk seals (*Monachus monachus*) (Muñoz *et al.*, 2011).

The method presented provides an objective approach to classify the distinctive vocalizations made by spotted seals and other pinniped species in the wild. The underwater vocal repertoire observed in this study resulted in only four call types and all calls were variations of lower frequency pulsed sounds. Compared to other phocid species, e.g., harp, Weddell and bearded seals, the diversity of the calls was relatively low (Watkins and Schevill, 1979; Thomas and Kuechle, 1982; Risch *et al.*, 2007). In addition to the four identified call types, we were also able to describe other calls (representing 22.2% of all calls recorded), although these

were less distinctive and included harmonics and other random noise (Riede *et al.*, 2004). Given the variation among these other calls it was not possible to use the HCA to classify them into additional distinctive clusters/call types. Further research is needed to extract additional acoustic parameters (e.g., number of harmonics, harmonic frequency, call interval and sound pressure levels) that may allow classification of these less distinctive vocalizations.

Previous research that described calls of spotted seals were based on vocalizations recorded from two seals (a male and a female) kept in captivity (Beier and Wartzok, 1979; Gailey-Phipps, 1984), which may not be representative of wild populations. Both these previous studies identified calls similar to the growls and drums presented here and described that these two call types were recorded when copulatory behavior occurred under water. Our recordings were conducted during the breeding season of the LB spotted seal population, suggesting that growls and drums may be associated with their underwater mating behavior. In addition, we identified two new call types (i.e., knock and sweep), which have not been documented previously. Unfortunately, we were unable to collect data on seal behavior during this study which prevent us from interpreting what behaviors knock and sweep calls may be related to.

The Pacific harbor seal is the closest relative to the spotted seals (Boveng, 2016). There are two recognized subspecies of the Pacific harbor seal, the Kuril seal (*Phoca vitulina stejnegeri*), and the eastern Pacific harbor seal (*Phoca vitulina richardii*). The former is distributed from the coast of Hokkaido to the Commander Islands along the Northwestern Pacific (Kobayashi *et al.*, 2014) which is close to the LB breeding colony of spotted seals, while the latter ranges along the eastern Pacific coast from Mexico to the Gulf of Alaska (Hanggi and Schusterman, 1994). There is currently no data available describing the underwater sounds of Kuril seals, however, the vocal behavior of the eastern Pacific harbor seal has been well documented (Hanggi and Schusterman, 1994; Van Parijs *et al.*, 2000; Van Parijs *et al.*, 2003; Nikolich *et al.*, 2016). Similar to spotted seals, the eastern Pacific harbor seals produce vocalizations during their underwater mating (Van Parijs *et al.*, 2000). The two species use similar frequency parameters including bandwidth and peak, however, the harbor seals have longer underwater vocalizations than spotted seals (Van Parijs *et al.*, 2003; Nikolich *et al.*, 2016). The difference in duration may represent intrinsic species differences and/or related to differences in group size or habitat preferences. Alternatively, the difference in duration may be artificial due to the different analytical methods applied. In our study, the –10 dB duration of each vocalization was calculated using the MATLAB program whereas the Pacific harbor seal studies calculated the sound spectrum duration manually (Van Parijs *et al.*, 2003; Nikolich *et al.*, 2016). Two call types (growl and sweep) have been distinguished in both species (Nikolich *et al.*, 2016), however, roar calls have not been described for spotted seals. Roar is the underwater vocalization over 5 s in duration which is likely used by male harbor seals to attract females and while competing with other

males (Van Parijs *et al.*, 2000; Van Parijs *et al.*, 2003). Spotted seals likely use other call types for these purposes.

Comparing the spectral characters of all call types identified in this study with previously estimated underwater hearing threshold of two captive spotted seals (Sills *et al.*, 2014), indicate that the species' optimal hearing frequency is between 3.2 and 25.6 kHz which is higher than the vocalizations recorded in our study. If the hearing threshold of the LB spotted seals is close to the result of Sills *et al.* (2014), this may suggest that the function of the relatively high frequency hearing range is to detect vocalizations from potential predators, e.g., killer whales (*Orcinus orca*) and that the seals' low frequency vocalizations, which may be transmitted over longer distances under water, are used for intra-specific communication.

In conclusion, this study represents the first report on underwater vocalizations recorded from spotted seals in the wild. Four typical call types were identified using multivariate statistical analyses of call properties and the detailed acoustic characteristics of each distinctive call type were described. The seals also used a number of other calls which were more variable and not possible to group into call types based on call properties. However, future research using additional acoustic parameters and larger sample size may allow classification of these additional calls. Age, sex, individual variation, behavior, and other parameters may influence the underwater vocalization of spotted seals. Detailed behavior studies and use of animal borne recording tags would facilitate obtaining this information from wild spotted seals and help interpret the function of the different seal calls. However, the descriptions of the spotted seals' underwater vocalizations presented here represents a first step in understanding the social function of these calls (Serrano, 2001). Acoustic studies on wild spotted seals will improve the understanding of the species' behavior and may also be important for future surveys of its distribution and occurrence.

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Au, W. W. (2012). *The Sonar of Dolphins* (Springer, New York), pp. 115–123.

Beier, J. C., and Wartzok, D. (1979). "Mating behaviour of captive spotted seals (*Phoca largha*)," *Anim. Behav.* 27, 772–781.

- Boveng, P. L. (2016). "*Phoca largha*. The IUCN red list of threatened species 2016," Report No. e.T17023A45229806, <http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T17023A45229806.en> (Last viewed 25 July 2016).
- Boveng, P. L., Bengtson, J., Buckley, T., Cameron, M., Dahle, S., Kelly, B., Megrey, B., Overland, J., and Williamson, N. (2009). "Status review of the spotted seal (*Phoca largha*)," NOAA Technical Memo No. NMFS-AFSC-200 (U.S. Department of Commerce, Springfield, VA).
- Cummings, W. C., Holliday, D., and Lee, B. (1984). "Potential impacts of man-made noise on ringed seals: Vocalizations and reactions," Outer Continental Shelf Environmental Assessment Program, final report, OCS Study No. MMS 86-0021; NITS PB87-107546 (NOAA, Anchorage, AK).
- Doiron, E. E., Rouget, P. A., and Terhune, J. M. (2012). "Proportional underwater call type usage by Weddell seals (*Leptonychotes weddellii*) in breeding and nonbreeding situations," *Can. J. Zool.* **90**, 237–247.
- Gailey-Phipps, J. J. (1984). "Acoustic communication and behavior of the spotted seal (*Phoca largha*)," Ph.D. dissertation, Johns Hopkins University, Baltimore, MD.
- Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., and Fox, H. E. (2008). "A global map of human impact on marine ecosystems," *Science* **319**, 948–952.
- Han, J., Sun, F., Gao, X., He, C., Wang, P., Ma, Z., and Wang, Z. (2010). "Low microsatellite variation in spotted seal (*Phoca largha*) shows a decrease in population size in the Liaodong Gulf colony," *Ann. Zool. Fenn. (BioOne)* **47**(1), 15–27.
- Han, J., Wang, W., and Ma, Z. (2004). "Spotted seals in the estuary of Shuangtaizi River of Liaodong Bay," *Mar. Environ. Sci.* **24**, 51–53.
- Hanggi, E. B., and Schusterman, R. J. (1994). "Underwater acoustic displays and individual variation in male harbour seals, *Phoca vitulina*," *Anim. Behav.* **48**, 1275–1283.
- Insley, S. J. (1992). "Mother-offspring separation and acoustic stereotypy: A comparison of call morphology in two species of pinnipeds," *Behaviour* **120**, 103–122.
- Kobayashi, Y., Kariya, T., Chishima, J., Fujii, K., Wada, K., Baba, S., Ito, T., Nakaoka, T., Kawashima, M., and Saito, S. (2014). "Population trends of the Kuril harbour seal, *Phoca vitulina stejnegeri*, from 1974 to 2010 in southeastern Hokkaido, Japan," *Endanger. Species Res.* **24**, 61–72.
- Madsen, P. T., and Wahlberg, M. (2007). "Recording and quantification of ultrasonic echolocation clicks from free-ranging toothed whales," *Deep Sea Res. Pt. I: Oceanogr. Res. Pap.* **54**, 1421–1444.
- McCreery, L., and Thomas, J. A. (2009). "Acoustic analysis of underwater vocalizations from crabeater seals (*Lobodon carcinophagus*): Not so monotonous," *Aquat. Mamm.* **35**, 490–501.
- Miksís-Olds, J. L., Van Opzeeland, I. C., Van Parijs, S. M., and Jones, J. (2016). "Pinniped sounds in the polar oceans," in *Listening in the Ocean* (Springer, Berlin), pp. 257–308.
- Møhl, B., Surlykke, A., and Miller, L. A. (1990). "High intensity narwhal clicks," in *Sensory Abilities of Cetaceans* (Springer, New York), pp. 295–303.
- Muñoz, G., Karamanlidis, A. A., Dendrinos, P., and Thomas, J. A. (2011). "Aerial vocalizations by wild and rehabilitating Mediterranean monk seals (*Monachus monachus*) in Greece," *Aquat. Mamm.* **37**, 262–279.
- Nikolich, K., Frouin-Mouy, H., and Acevedo-Gutiérrez, A. (2016). "Quantitative classification of harbor seal breeding calls in Georgia Strait, Canada," *J. Acoust. Soc. Am.* **140**, 1300–1308.
- Patras, A., Brunton, N. P., Downey, G., Rawson, A., Warriner, K., and Gernigon, G. (2011). "Application of principal component and hierarchical cluster analysis to classify fruits and vegetables commonly consumed in Ireland based on *in vitro* antioxidant activity," *J. Food Compos. Anal.* **24**, 250–256.
- Reyes, M. V. R., Iníguez, M. A., Hevia, M., Hildebrand, J. A., and Melcón, M. L. (2015). "Description and clustering of echolocation signals of Commerson's dolphins (*Cephalorhynchus commersonii*) in Bahía San Julián, Argentina," *J. Acoust. Soc. Am.* **138**, 2046–2053.
- Riede, T., Owren, M. J., and Arcadi, A. C. (2004). "Nonlinear acoustics in pant hoots of common chimpanzees (*Pan troglodytes*): Frequency jumps, subharmonics, biphonation, and deterministic chaos," *Am. J. Primatol.* **64**, 277–291.
- Risch, D., Clark, C. W., Corkeron, P. J., Elepfandt, A., Kovacs, K. M., Lydersen, C., Stirling, I., and Van Parijs, S. M. (2007). "Vocalizations of male bearded seals, *Erignathus barbatus*: Classification and geographical variation," *Anim. Behav.* **73**, 747–762.
- Rogers, T. L., and Cato, D. H. (2002). "Individual variation in the acoustic behaviour of the adult male leopard seal, *Hydrurga leptonyx*," *Behaviour* **139**, 1267–1286.
- Rogers, T. L., Cato, D. H., and Bryden, M. M. (1996). "Behavioral significance of underwater vocalizations of captive leopard seals, *Hydrurga leptonyx*," *Mar. Mamm. Sci.* **12**, 414–427.
- Rouget, P., Terhune, J. M., and Burton, H. (2007). "Weddell seal underwater calling rates during the winter and spring near Mawson Station, Antarctica," *Mar. Mamm. Sci.* **23**, 508–523.
- Rugh, D. J., Sheldon, K. E., and Withrow, D. E. (1997). "Spotted seals, *Phoca largha*, in Alaska," *Mar. Fish. Rev.* **59**, 1–18.
- Serrano, A. (2001). "New underwater and aerial vocalizations of captive harp seals (*Pagophilus groenlandicus*)," *Can. J. Zool.* **79**, 75–81.
- Sills, J. M., Southall, B. L., and Reichmuth, C. (2014). "Amphibious hearing in spotted seals (*Phoca largha*): Underwater audiograms, aerial audiograms and critical ratio measurements," *J. Exp. Biol.* **217**, 726–734.
- Stirling, I. (1973). "Vocalization in the ringed seal (*Phoca hispida*)," *J. Fish. Res. Board Can.* **30**, 1592–1594.
- Stirling, I., and Thomas, J. A. (2003). "Relationships between underwater vocalizations and mating systems in phocid seals," *Aquat. Mamm.* **29**, 227–246.
- Terhune, J. M., Burton, H., and Green, K. (1993). "Classification of diverse call types using cluster analysis techniques," *Bioacoustics* **4**, 245–258.
- Terhune, J. M., and Ronald, K. (1986). "Distant and near-range functions of harp seal underwater calls," *Can. J. Zool.* **64**, 1065–1070.
- Thomas, J. A., and Golladay, C. (1995). "Geographic variation in leopard seal (*Hydrurga leptonyx*) underwater vocalizations," in *Sensory Systems of Aquatic Mammals*, edited by P. E. Nachtigall, J. A. Thomas, and R. A. Kastelein (De Spil, Woerden, the Netherlands), pp. 201–221.
- Thomas, J. A., and Kuechle, V. B. (1982). "Quantitative analysis of Weddell seal (*Leptonychotes weddellii*) underwater vocalizations at McMurdo Sound, Antarctica," *J. Acoust. Soc. Am.* **72**, 1730–1738.
- Van Parijs, S. M., Corkeron, P. J., Harvey, J., Hayes, S. A., Mellinger, D. K., Rouget, P. A., Thompson, P. M., Wahlberg, M., and Kovacs, K. M. (2003). "Patterns in the vocalizations of male harbor seals," *J. Acoust. Soc. Am.* **113**, 3403–3410.
- Van Parijs, S. M., Hastie, G. D., and Thompson, P. M. (2000). "Individual and geographical variation in display behaviour of male harbour seals in Scotland," *Anim. Behav.* **59**, 559–568.
- Villadsgaard, A., Wahlberg, M., and Tougaard, J. (2007). "Echolocation signals of wild harbour porpoises, *Phocoena phocoena*," *J. Exp. Biol.* **210**, 56–64.
- Wang, P. (1986). "Distribution, ecology and resource conservation of the spotted seal in the Huanghai and Bohai Seas," *Acta Oceanol. Sin.* **1**, 1–14.
- Wang, P. (2014). (private communication).
- Watkins, W. A., and Schevill, W. E. (1979). "Distinctive characteristics of underwater calls of the harp seal, *Phocagroenlandica*, during the breeding season," *J. Acoust. Soc. Am.* **66**, 983–988.