THE SEASONAL VARIATION OF ULTRASONIC VOCALIZATIONS PRODUCED BY WEDDELL SEALS (*LEPTONYCHOTES WEDDELLII*) IN MCMURDO SOUND, ANTARCTICA WITH AMBIENT ILLUMINATION LEVELS

by

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The Seasonal Variation of Ultrasonic Vocalizations Produced by Weddell Seals (*Leptonychotes Weddellii*) in Mcmurdo Sound, Antarctica with Ambient Illumination Levels

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Primary Thesis Advisor

Weddell Seals (*Leptonychotes weddellii*) are a species of polar seal found circumpolar in the waters of Antarctica. This species, like all marine mammals, use highly complex vocalizations to communicate in aquatic environments over vast distances, and phocids as a group are thought to have exceptionally extensive vocal repertoires. Until last year it was believed that all phocids (seals) did not utilize vocalizations in the ultrasonic frequency range (>20 kHz) and only used sonic vocalizations. In a paper by Cziko et al., it was demonstrated that Weddell Seals frequently used ultrasonic vocalizations. The vocal repertoire of Weddell Seals is extensive, even for phocids, and it varies in the composition of unique call types throughout the year. The reason for these yearly variations is unknown and understudied but may fluctuate with abiotic factors in the Weddell Seal's habitat, such as illumination. The aim of this study is to ascertain the purpose of ultrasonic vocalizations in the lives of Weddell Seals. Acoustic data were collected by the McMurdo Observation Station in McMurdo Sound, Antarctica (S 77.8510, E 166.6645) for 25 months. This data was analyzed by a human analyst with the acoustic analysis software, Raven, created by the Cornell Ornithology Lab. Ambient illumination levels were calculated using a Solar Elevation Calculator created by NOAA. There was a distinct peak in gross documented ultrasonic vocalizations in the austral winter, June, which is the darkest point of the year at this latitude. There were also variations in the predominant vocalization category of documented calls, the duration of specific calls, and the spectrographic signatures of some calls throughout the year. The reason for these variations is speculative as more specialized are needed.

Acknowledgments

I'd like to thank my advisors Dr. Lisa Munger, Dr. Richard Emlet, and Dr. Carol Paty. I'd also like to thank Dr. Paul Cziko for his assistance in putting together resources for this paper. And finally, I'd like to thank my friends and family who have supported me throughout my education and the composition of this thesis.

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Introduction

The Weddell Seal (*Leptonychotes weddellii*) is a circumpolar species of phocid (seal) found in the Southern Hemisphere and is the most southernly ranging mammal that permanently inhabits the Antarctic (Chris Muller, 2001; Doiron et al., 2012; Erbe et al., 2017; Heerah et al., 2013; Stirling, 1969, 1971; J. Thomas & Terhune, 2009). These seals live in the waters surrounding Antarctica, typically in the Weddell and Ross Seas, but can be found as far north as Southern Australia and New Zealand. They live primarily on sheets of fast ice, ice that extends from the shoreline into open water, and sea ice, ice that forms in open water (Castellini et al., 1992; Heerah et al., 2013; Stirling, 1969; J. Thomas & Terhune, 2009). This fast ice can extend from the Antarctic shoreline up to 400 km away (Castellini et al., 1992). Both the fast ice and sea ice within the Antarctic circle can become several meters thick (Castellini et al., 1992; Moors & Terhune, 2005).

Both fast ice and sea ice play important roles in the lives of Weddell Seals, providing them with both a place to haul out and rest and a place to birth and raise their offspring (B. Moors & Terhune, 2011; Castellini et al., 1992; Chris Muller, 2001; Erbe et al., 2017; Rouget et al., 2007; Stirling, 1969; J. Thomas & Terhune, 2009). Female Weddell Seals will start gathering on large sections of ice at the beginning of October for the breeding and pupping season (B. Moors & Terhune, 2011; Castellini et al., 1992; J. A. Thomas & Kuechle, 1982). During this time, male Weddell Seals vocalize heavily setting up underwater territories (B. Moors & Terhune, 2011; Castellini et al., 1992; Rouget et al., 2007; Terhune et al., 2008; J. A. Thomas & Kuechle, 1982; J. Thomas & Terhune, 2009). The pupping season for Weddell Seals is between September and November, varying by latitude, with the average pupping date for the population found within the McMurdo Sound, which is an extension of the Ross Sea, being the fourth week of October (Stirling, 1969; J. A. Thomas & Kuechle, 1982).

Weddell seals are well-adapted to living on and under large sections of ice. These seals will carve large breathing holes into the ice and maintain them using their canine teeth and similarly shaped incisors (Chris Muller, 2001; Rouget et al., 2007; Stirling, 1971; J. Thomas & Terhune, 2009; Webb, 1999). Weddell Seals have large and highly light-sensitive eyes with numerous adaptions that make them well-developed for low-light and high-turbidity conditions in the water column (Castellini et al., 1992; Elsner et al., 2011; Kooyman, 1975; Stirling, 1971; J. Thomas & Terhune, 2009; Webb, 1999). These adaptions include mostly rod photoreceptors in the retina, high blood flow to the membrane at the bottom of the eye, increased sensitivity to blue-green and green colors, as well as the presence of a reflective layer behind their retina called the tapetum lucidum (Castellini et al., 1992; Chris Muller, 2001; Kooyman, 1975; Schusterman, 1981; Simon, 2005; Stirling, 1971; J. Thomas & Terhune, 2009; Webb, 1999; Welsch & Riedelsheimer, 1997). Weddell Seals have highly sensitive vibrissae, or whiskers, that they can aid in navigating their environment underwater and locating their ice holes (Chris Muller, 2001; Simon, 2005; J. Thomas & Terhune, 2009; Webb, 1999). Weddell Seals also have a very well-developed sense of hearing, capable of perceiving frequencies above the ultrasonic range, with an estimated range of approximately 10 kilometers in water (Chris Muller, 2001; P. A. Cziko et al., 2020; Simon, 2005; J. Thomas & Terhune, 2009; Webb, 1999). Phocids also have a specially adapted skull structure involving a squamosal bone modified to be wider and flatter which enables them to better pinpoint the directionality of a sound's source, within three degrees of the source direction (Chris Muller, 2001; Elsner et al., 2011; Schusterman, 1981).

Phocids are known to have very diverse and extensive vocal repertoires, and the Weddell Seal is one of the most vocal phocids in the world (B. Moors & Terhune, 2011; Doiron et al., 2012; Rouget et al., 2007; TERHUNE et al., 1994; Terhune, 2016; Van Opzeeland et al., 2010). They have been documented producing dozens of unique vocalization types within multiple distinct vocalization categories, utilizing both sonic and ultrasonic frequencies. (Castellini et al., 1992; Rouget et al., 2007; Schusterman, 1981; Schusterman et al., 2000; Terhune et al., 2001; Webb, 1999). Their vocal repertoire is known to contain at least 12 categories of calls, including trills, whistles, chirps, and undulations, further described as 34 sonic calls and 12 ultrasonic calls (Castellini et al., 1992; P. A. Cziko et al., 2020; Terhune et al., 1993; Van Opzeeland et al., 2010; Webb, 1999). Many of these specifically classified calls have been documented multiple times in various papers, some of which possessed ultrasonic elements that were not observed until recently (J. A. Thomas & Kuechle, 1982).

Fast ice and sea ice covers at least some part of McMurdo Sound for the entire year, through approximately April to January, and in some areas, until mid-February, there is a significant amount of surface coverage (Castellini et al., 1992; Kim et al., 2018). Fast ice is ice that is fastened to the shoreline and sea ice is ice that forms in the middle of a body of water. Typically, the sea ice extent surrounding the Antarctic is greatest in September and experiences a minimum of coverage in February (Handcock & Raphael, 2020). The most extensive coverage of sea ice occurs during the austral winter and early austral spring, the majority of which is fast ice (Kim et al., 2018). The extent of coverage and thickness of ice in McMurdo Sound, as well as snow cover over the ice, has an impact on the environment below it as it severely reduces light transmission (Castellini et al., 1992; Kim et al., 2018). It is estimated that ice with a thickness between 1.5 and 2 meters with a 4 cm snow covering will only allow for less than 1% of light transmission, while sea ice in this area can easily reach thicknesses up to 3 meters (Castellini et al., 1992; P. Cziko, 2019). Within McMurdo Sound, multiyear ice sometimes occurs, which is ice that does not entirely melt within the year and is typically thicker than the average ice in the area.

It was generally believed in earlier years that all marine mammals could echolocate, including phocids, though this is now thought to not be true (Castellini et al., 1992; Elsner et al., 2011; Schusterman, 1981; Schusterman et al., 2000; Simon, 2005; Webb, 1999). Echolocation is differentiated from other skills as a specialized adaptation resulting from evolution and not a generalized skill to be used when other sensory abilities can not to be used (Gareth Jones, 2005; Schusterman et al., 2000). All marine mammals are capable of producing vocalizations in air, though only the groups Pinnipedia (seals, sea lions, and walruses), Cetacea (whales and dolphins), and Sirenia (manatees and dugongs) are known to produce regular underwater vocalizations (Liu et al., 2010; PL Tyack & EH Miller, 2002; Schusterman, 1981; Schusterman et al., 2000). While most marine mammals use these underwater vocalizations, cetaceans are the most well-known marine mammal group to use them and a group of cetaceans, the odontocetes, are credited as the only marine mammals capable of echolocation (Schusterman et al., 2000). However, Weddell Seals possess the ability to produce ultrasonic vocalizations, much like cetaceans (P. A. Cziko et al., 2020). It has been proven that Weddell Seals do not use response-driven vocalization systems to produce sounds, unlike cetaceans, meaning that their production of ultrasonic vocalization is purposeful and not an effect of the changing pressure of their environment as they dive (B. Moors & Terhune, 2011). Further, it has not been disproven that phocids are capable of using sound to navigate their environment, but rather there is merely a lack of evidence that phocids use sound for navigation (Castellini et al., 1992; Chris Muller, 2001; Elsner et al., 2011; PL Tyack & EH Miller, 2002; Schusterman, 1981; Schusterman et al., 2000; Simon, 2005; Webb, 1999).

The amount of ambient light available changes based on latitude across the surface of the Earth. Above 66.5 degrees and below -66.5 degrees latitude, there are periods of 24 hours at certain points in the year in which there is no daytime. At the latitude of McMurdo Station (S 77.8510), the site of data collection, there are approximately four months a year without daytime (Fig. 7) (P. A. Cziko et al., 2020). Daytime is an ambient light level that can be defined as a solar elevation, which is the position of the Sun above the horizon, of 0 degrees or greater. When the solar elevation is 0 degrees or less below the horizon, a latitude experiences periods of twilight and nighttime. At a solar elevation between 0 and 6 degrees below the horizon, the ambient light level is called civil twilight (CT). During this time, only the brightest stars and only some terrestrial objects are visible (Australia Antarctic Program, 2022). At a solar elevation between 6 and 12 degrees below the horizon, the ambient light level is called nautical twilight (NT). During this time only the general outline of some ground objects and the horizon are still visible (Australia Antarctic Program, 2022). At a solar elevation between 12 and 18 degrees below the horizon, the ambient light level is called astronomical twilight (AT). During this time there is no color in the sky and the horizon is no longer visible (Australia Antarctic Program, 2022). At a solar elevation of 18 or more degrees below the horizon, the ambient light level is called nighttime.

The aim of this study is to ascertain the purpose of ultrasonic vocalizations in the lives of Weddell Seals. It is possible that Weddell Seals may use ultrasonic vocalizations when sight is not viable due to low or zero light conditions to navigate their environment to some degree. By tracking gross ultrasonic vocalization rates throughout several years of study and comparing calling rates to ambient light levels throughout the year, we can possibly understand whether ultrasonic vocalizations may be involved with navigating a zero-light aquatic environment.

Methods

Acoustic data were collected in the McMurdo Sound using a broadband, omnidirectional hydrophone with a dynamic range of 118 dB and a frequency sensitivity of 10 Hz to 200 kHz (P. A. Cziko et al., 2020). This hydrophone was attached to the McMurdo Oceanographic Observatory (MOO), which was designed and built by Dr. Paul Cziko. The MOO was positioned slightly offshore from the United States-controlled McMurdo Station on Ross Island in McMurdo Sound, Antarctica (S 77.8510, E 166.6645) at a depth of 21 meters, and collected data from November 2017 to November 2019 (Fig. 7) (P. A. Cziko et al., 2020). The data from the MOO was stored on shore as individual 10-minute .wav files with timestamps.

The MOO was also equipped with a pan-tilt-zoom camera to view the surrounding environment (P. A. Cziko et al., 2020). This camera was also used to acquire evidence that numerous vocalizations could solely be attributed to Weddell Seals. By syncing audio and video data from the MOO, specific instances of video showing Weddell Seals' throats undulating as vocalizations were collected by the hydrophone allowed us to determine with high confidence that Weddell Seals were the source of the ultrasonic vocalizations. There are also few other marine mammals known to exist within McMurdo Sound during periods of the year, specifically October to November (J. A. Thomas & Kuechle, 1982).

Acoustic data were analyzed from the 24 contiguous hours on or around new moons that occurred during the 25 months of this study as these days have the greatest potential for differences in ambient illumination levels within a single day (USNO, n.d.). Days on or near new moons have ambient illumination levels that range from some level of solar exposure, meaning the Sun is less than 18 degrees below the horizon for part or all of the day, to no ambient illumination due to the lack of sunlight reflecting off of the Moon and the Sun being more than 18 degrees below the horizon. During zero illumination conditions, seals must navigate under the ice without the aid of sight. This sampled 24 hours was not always on the date of the new moon as there was a discontinuous recording of audio data throughout the data set due to network and power outages as well as software bugs (P. A. Cziko et al., 2020). These outages and software bugs resulted in ~10% loss of the complete data set (P. A. Cziko et al., 2020).

A human analyst, Ryan McCarthy, searched audio data for ultrasonic seal vocalizations using Raven Pro 1.6 audio analysis software developed by the Cornell Ornithology Laboratory. In the spectrogram view, the focus was set to 9502, the smoothing setting was set to “On”, and the “Cool” color map setting was used. The window page size was set to 60 seconds with a page increment set to 90%. The window view size was set to view frequency ranges between 0 and 45 kilohertz. Using the Raven program, analyzed spectrograms with contrast and brightness settings adaptively adjusted to produce the clearest spectrogram. The in-program selection table included the start, end, and delta for both time and frequency, along with labels. Label names were adapted from Cziko et al. (P. A. Cziko et al., 2020).

The analyst logged the number of occurrences of ultrasonic calls using the nomenclature described by Cziko et al., 2020. In addition, a stereotyped Sonic Standard Whistle (SSW), documented by Cziko et al., was also marked as it occurred throughout the data set to be used as a standard when comparing ultrasonic vocalization rates (Table 1) (P. A. Cziko et al., 2020). Stereotyped, single-element ultrasonic calls, consisting of a single sound, were marked if at least 50% of the duration of the call was visible in the spectrogram based on the average duration of that call type described by Cziko et al., 2020. Stereotyped, multi-element ultrasonic calls, consisting of more than a single sound, were documented if individual elements met the standard for single-element calls, occurring at 50% duration of the stereotyped average duration, regardless of whether all elements were present. If an undescribed vocalization occurred above 20 kilohertz and more than three times with the same spectrographic signature, it was documented and named using the same format adapted from Cziko et al. and was then documented throughout the rest of the data analysis. The documented calls from each audio data file were saved through Raven as .txt documents for each 10-minute audio file.

The level of ambient light being received at the MOO was determined using a Solar Position Calculator designed by NOAA (*NOAA Solar Position Calculator*, 2023). By entering the coordinates of the MOO and the timestamps associated with each audio file, the solar elevation could be determined. This solar elevation was then classified with an ambient illumination status as either day, civil twilight, nautical twilight, astronomical twilight, or night. Each category of illumination status was then totaled for each sampled day.

Results

The number of gross documented ultrasonic vocalizations fluctuated throughout the year, having the highest peak in austral winter, the point in the year when this latitude experiences the greatest and longest period of darkness (Fig. 1). This peak is nearly the exact date of the austral Winter Solstice (Fig 1). There was also a near minimum in the number of gross documented ultrasonic vocalizations during the middle of austral summer, the point in the year when this latitude experiences near constant daytime (Fig. 1). On the sampled day in December nearest the austral Summer Solstice in 2018, there were 202 total vocalizations and 137 ultrasonic vocalizations while on the sampled day in June of the austral Winter Solstice in 2018, there were 1,869 total vocalizations and 1,549 ultrasonic vocalizations, approximately a 925% increase and a 1,130% increase, respectively (Fig 1). There were also secondary peaks in the austral Spring/Summer.

The vocalization category and type of ultrasonic vocalization predominantly produced by Weddell Seals varied throughout the year and possibly with ambient light level. During the austral winter months of June-August, the click vocalization is the predominant vocalization category, at its peak composing approximately 75% and 70% of ultrasonic vocalizations in 2018 and 2019, respectively (Fig 6). During the austral summer months of November-February, the trill vocalization is the predominant vocalization category, at its peak composing approximately 92% and 50% of ultrasonic vocalizations in 2018 and 2019, respectively (Fig 6). The whistle and undulation vocalization categories varied randomly and remained in the minority of vocalization percentage types.

The C103 type was the most prominent click vocalization category during the study, peaking in the austral summer months (Fig. 2). The C101 and C104 vocalization types followed this trend as well, to a less extent (Table 1) (Fig. 2). The C102 vocalization type peaked during the austral winter months (Table 1) (Fig. 2). The T101 type was the most prominent trill vocalization category during the study, peaking in composition percentage during the austral winter months (Table 1) (Fig. 3). The T102 vocalization type followed the opposite trend, peaking in the austral summer months (Table 1) (Fig. 3).

The duration of specific types of vocalizations varied by time of year and ambient light level. Both the T101 and W102 vocalization types had variations in duration throughout the year (Table 1). The average duration of the W102 type peaked at nearly 10 seconds in duration and experienced a low in duration of approximately 4-5 seconds (Fig 4 and 5). The average duration of the T101 type peaked at approximately 40 seconds and experienced a low in the duration of approximately 5-10 seconds (Fig 4 and 5). Both vocalization types experienced their lows during the austral summer months, January and February, and experienced their highs in the austral spring months, from November and December (Fig 4 and 5). The standard deviation of both types' duration was random throughout the year (Fig 4 and 5).

Discussion

There appear to be two points within each year at which the gross documented number of vocalizations peaks. These points are the middle of the austral winter, June, and the end of austral spring or the beginning of austral summer, between October and November. There have been previously documented trends in sonic vocalization occurrence rates that are similar to the gross documented ultrasonic vocalization occurrence rates observed in this dataset (Rouget et al., 2007; Van Opzeeland et al., 2010). Previous trends also identified near-zero calls in February and distinct peaks in austral winter and austral spring/summer (Van Opzeeland et al., 2010). Previously reported peaks in documented trends in sonic vocalization occurrence rates are near equal to each other in the gross number of vocalizations, which is mirrored in the peaks found within this data (Rouget et al., 2007).

The occurrence of the first and highest peak in gross documented vocalizations in June may be related to the lack of visibility, both on land and in water, due to the constant zero or limited light conditions typical at this latitude during this time of year. It is possible that in these light conditions, Weddell Seals may be using vocalizations, specifically ultrasonic vocalizations, to better navigate their environment given there would be limited or no opportunity for the use of sight. The occurrence of the secondary peak in the gross documented number of calls in austral spring/summer may be related to this being the approximate birthing and pupping time of year for Weddell Seals. During this time of year, there would be an increase in gross vocalizations as during the breeding season males tend to be significantly more vocal when defending their territories (B. Moors & Terhune, 2011; Castellini et al., 1992; Rouget et al., 2007; Terhune et al., 2008; J. A. Thomas & Kuechle, 1982; J. Thomas & Terhune, 2009). During the mating seasons, Weddell Seals also congregate around breathing holes and may be vocalizing more for communicative purposes (Rouget et al., 2007; Terhune et al., 2008).

It is possible the unexpected drop off in gross documented vocalizations during the first half of the year among the 2019 data from March-July, especially during austral winter when there is expected to be a peak in vocalizations, is due to a lack of sea ice forming before approximately July 15th of 2019 (Cziko pers. com) (Fig. 8). A lack of sea ice is expected to have two effects on the number of gross documented vocalizations, especially during the austral winter. The first of these effects is an increase in ambient light penetration into the aquatic environment which would enable the use of sight and decrease the need to use sound to navigate. The second likely effect would be a decrease in resting and haul-out spots for Weddell Seals leading to lower residential populations during this time.

It is possible that the variation in the dominant ultrasonic vocalization category between seasons could be related to the purpose of each vocalization category. It could be hypothesized that the click vocalization category is used by Weddell Seals primarily to navigate in low to zero light conditions in the aquatic environment, especially under the sea ice in austral winter, using the click trains to rapidly determine the geographic features of the surrounding environment while swimming. This is evidenced by data suggesting that seals can better pinpoint the directionality of a pulsed acoustic source, similar in spectrographic similar to the Weddell Seal's own click vocalization category, and that Weddell Seals vocalized more as they approached their breathing holes (B. Moors & Terhune, 2011; Elsner et al., 2011). It could be hypothesized that the trill vocalization category is used by Weddell Seals primarily as a method of communicating with each other under the water, communicating with newly birthed pups or with rival males in territorial disputes in particular. This is supported by data suggesting that the trill vocalization category may be used somewhat exclusively by male Weddell Seals, especially when defending territory (B. Moors & Terhune, 2011; TERHUNE et al., 1994; J. A. Thomas & Kuechle, 1982).

Throughout the year, documented spectrograms tended to deviate from their stereotyped forms. These deviations occurred most frequently in the months of November and December and are likely a result of newly birthed Weddell Seal pups learning proper vocalizations from adult Weddell Seals.

Throughout the year the duration of the W102 and T101 vocalization types appeared to increase. The shortest duration being at the beginning of the year and the greatest duration being at the end of the year. After the end of the year, there was a sharp drop off to the lowest duration at the beginning of the year. The reason for this is unknown but is likely a result of each ultrasonic vocalization's primary purposes within the life of Weddell Seals.

Figures

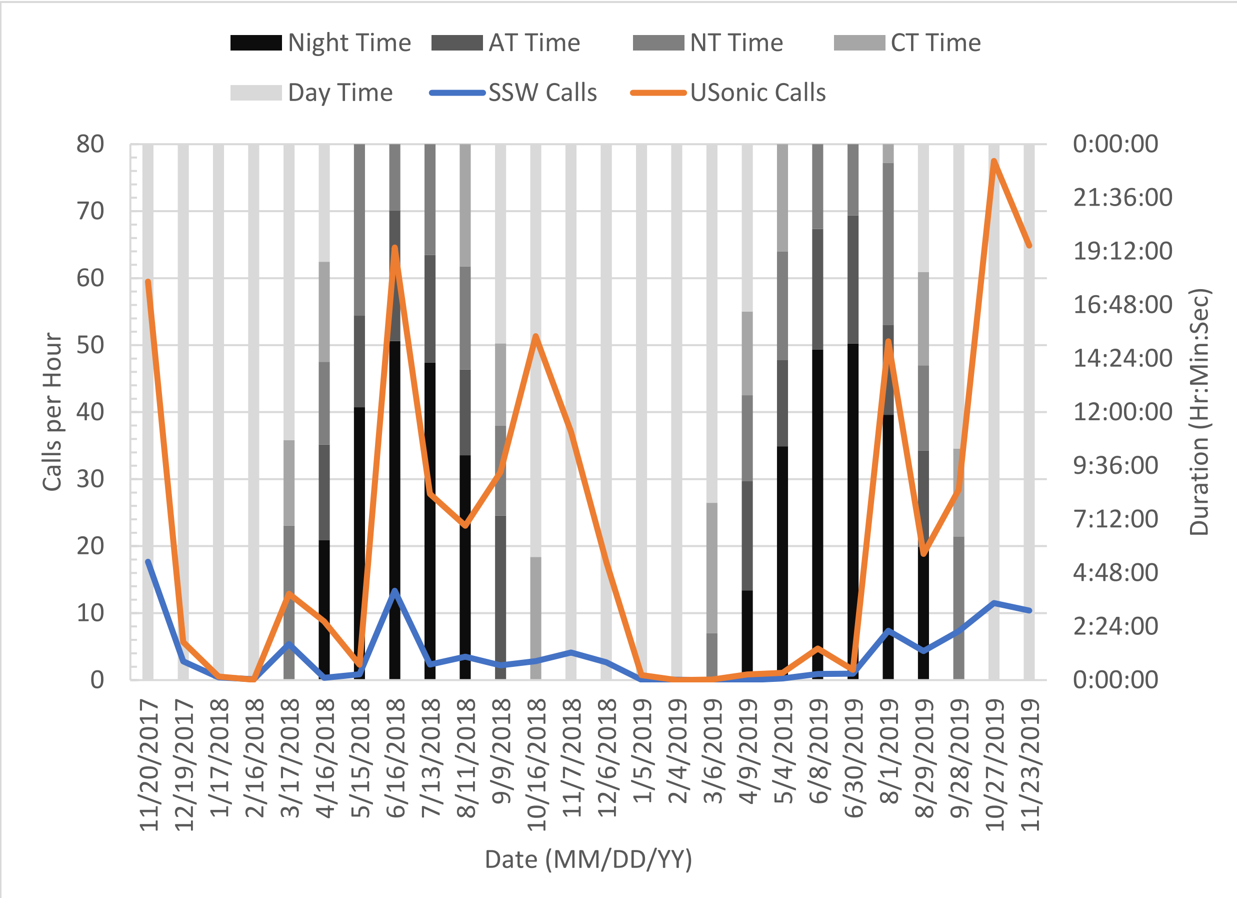


Figure 1: Variation of hourly ultrasonic vocalizations and Sonic Standard Whistle (SSW) vocalizations with the duration of ambient illumination levels between November 2017 and November 2019

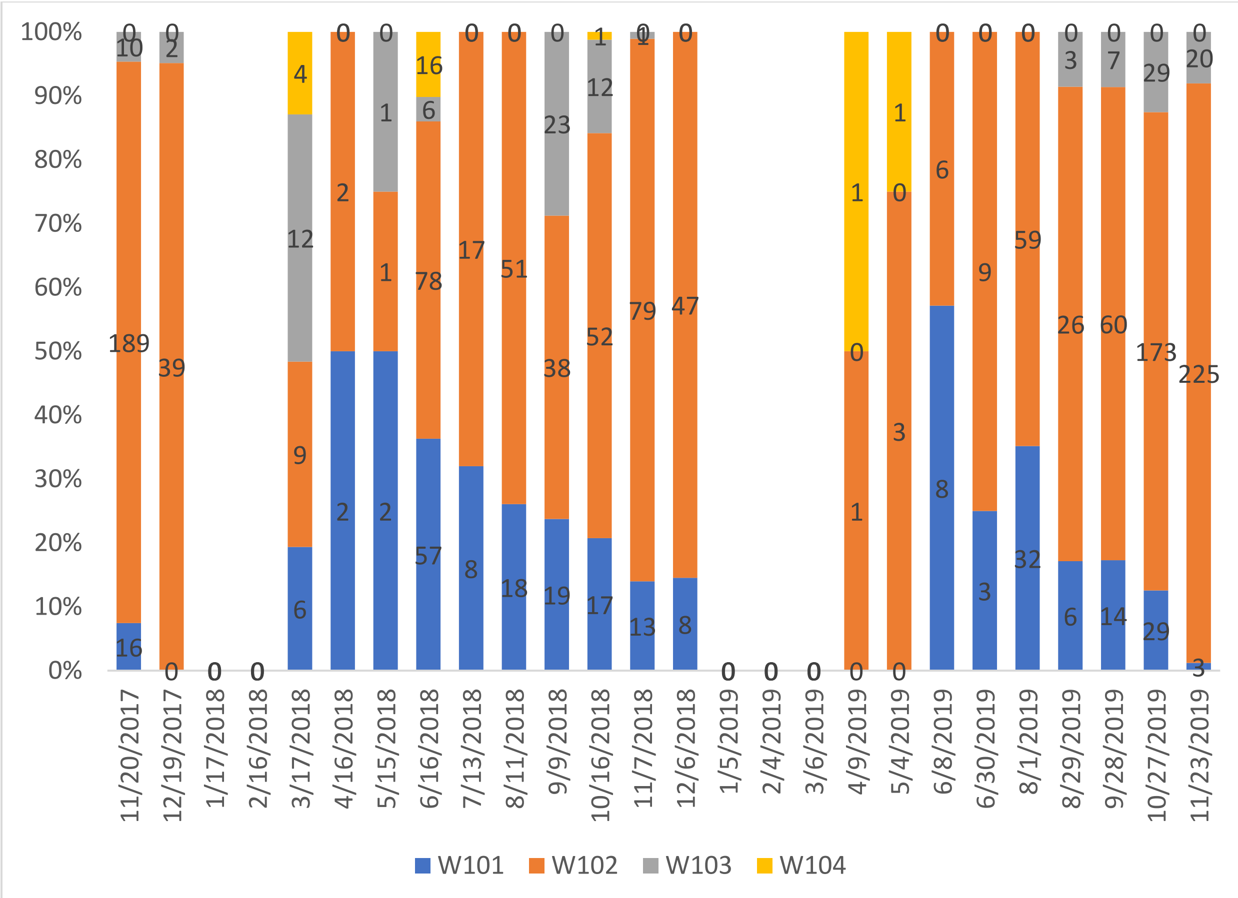


Figure 2: Percentage breakdown of all click category calls per day

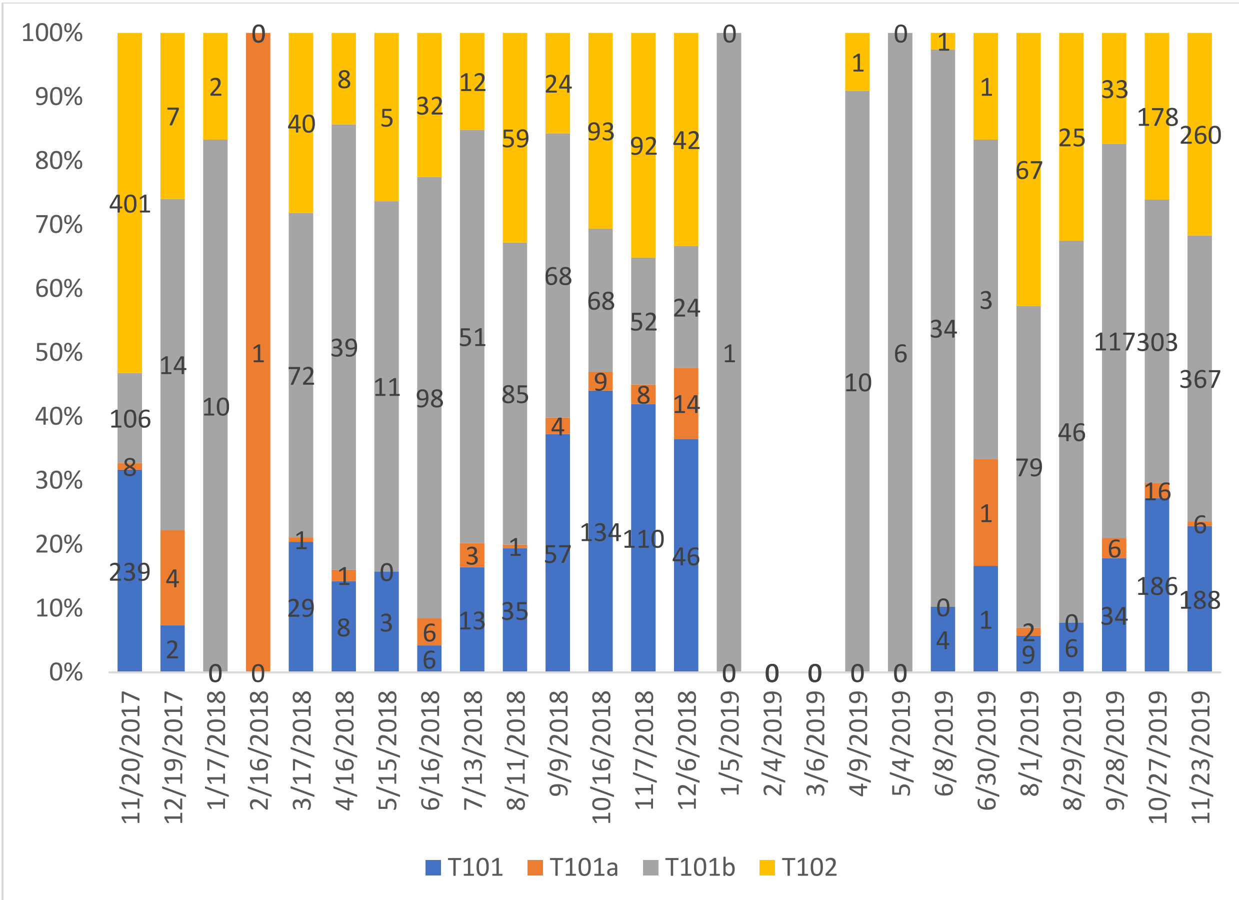


Figure 3: Percentage breakdown of all trill category calls per day

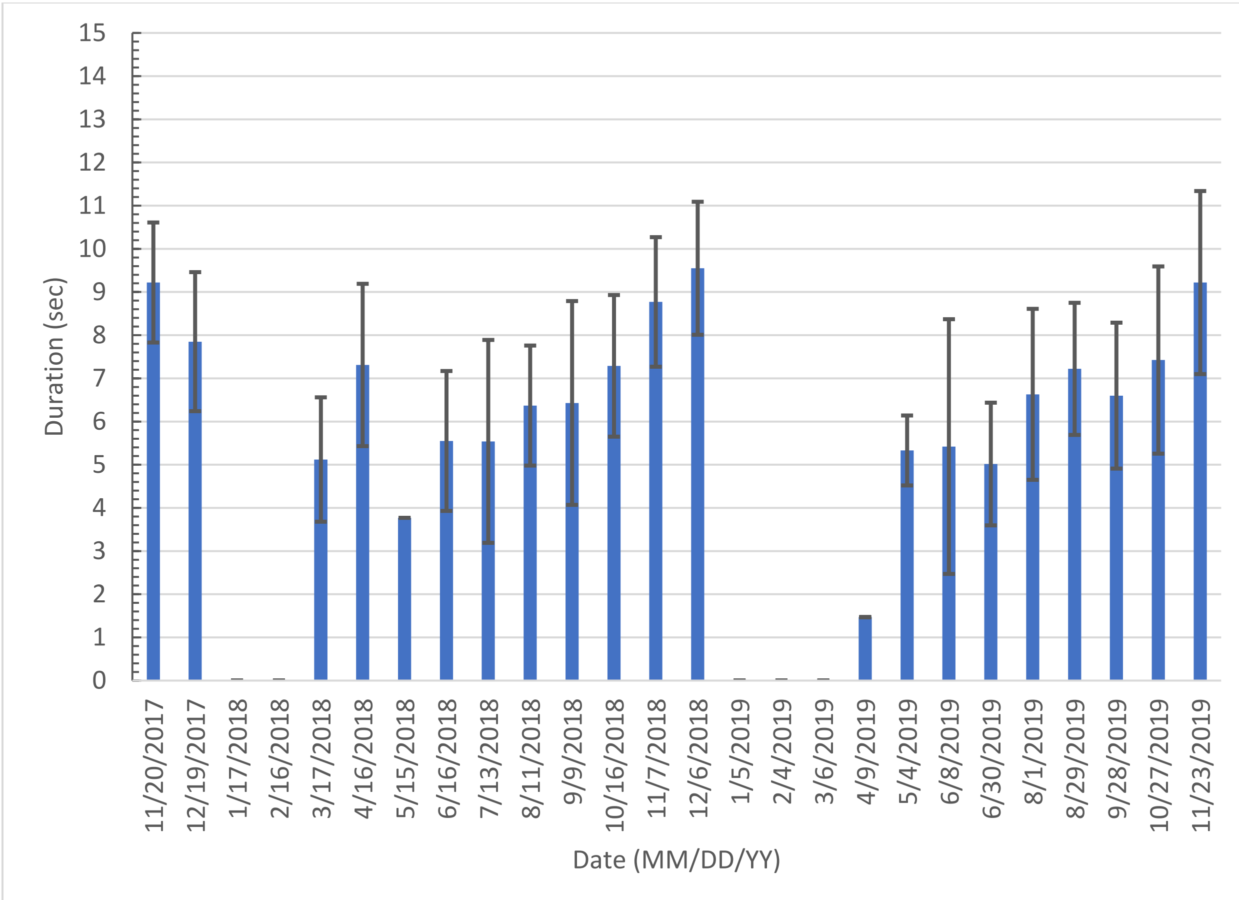


Figure 4: Change in duration of W102 vocalization subtype with standard deviation between November 2017 and November 2019

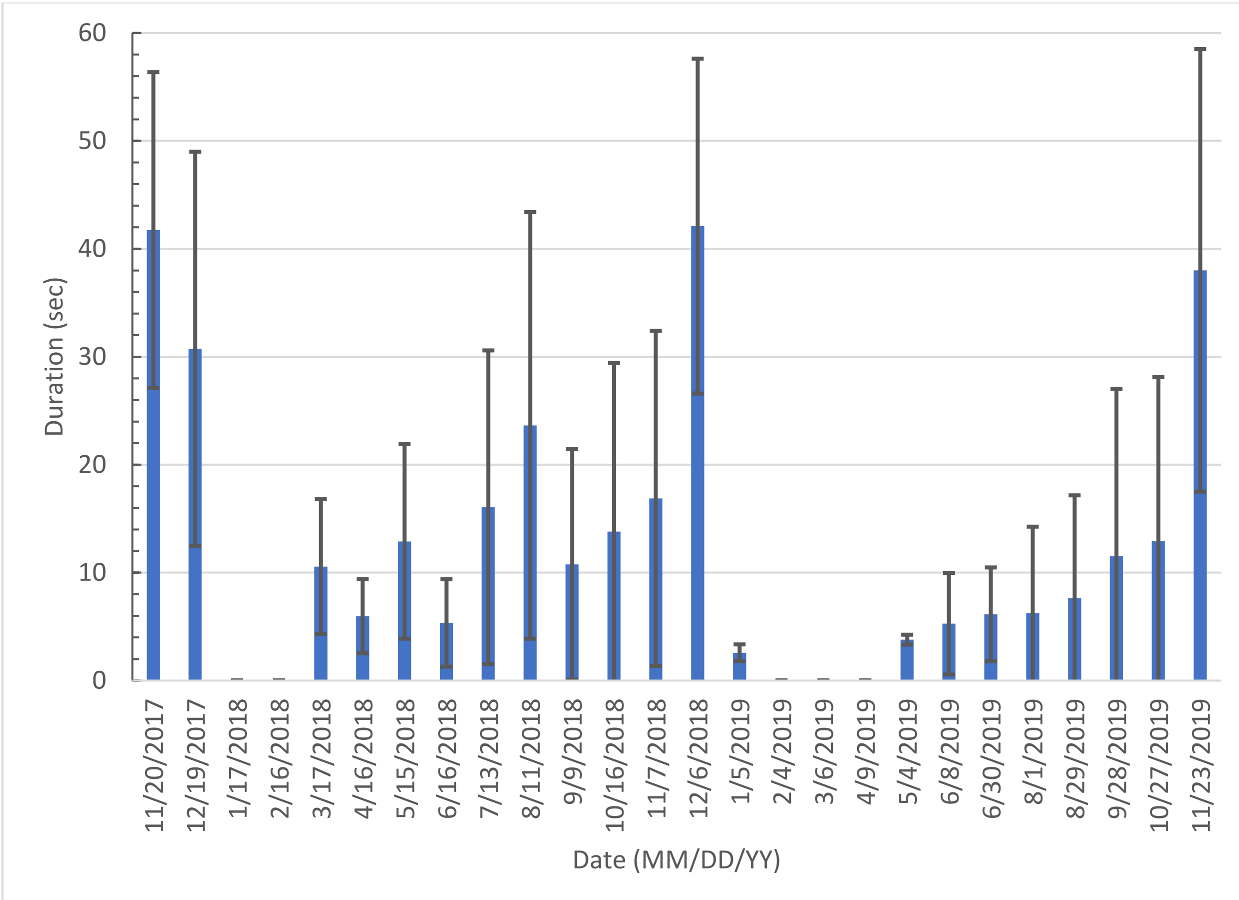


Figure 5: Change in duration of T101 vocalization subtype with standard deviation between November 2017 and November 2019

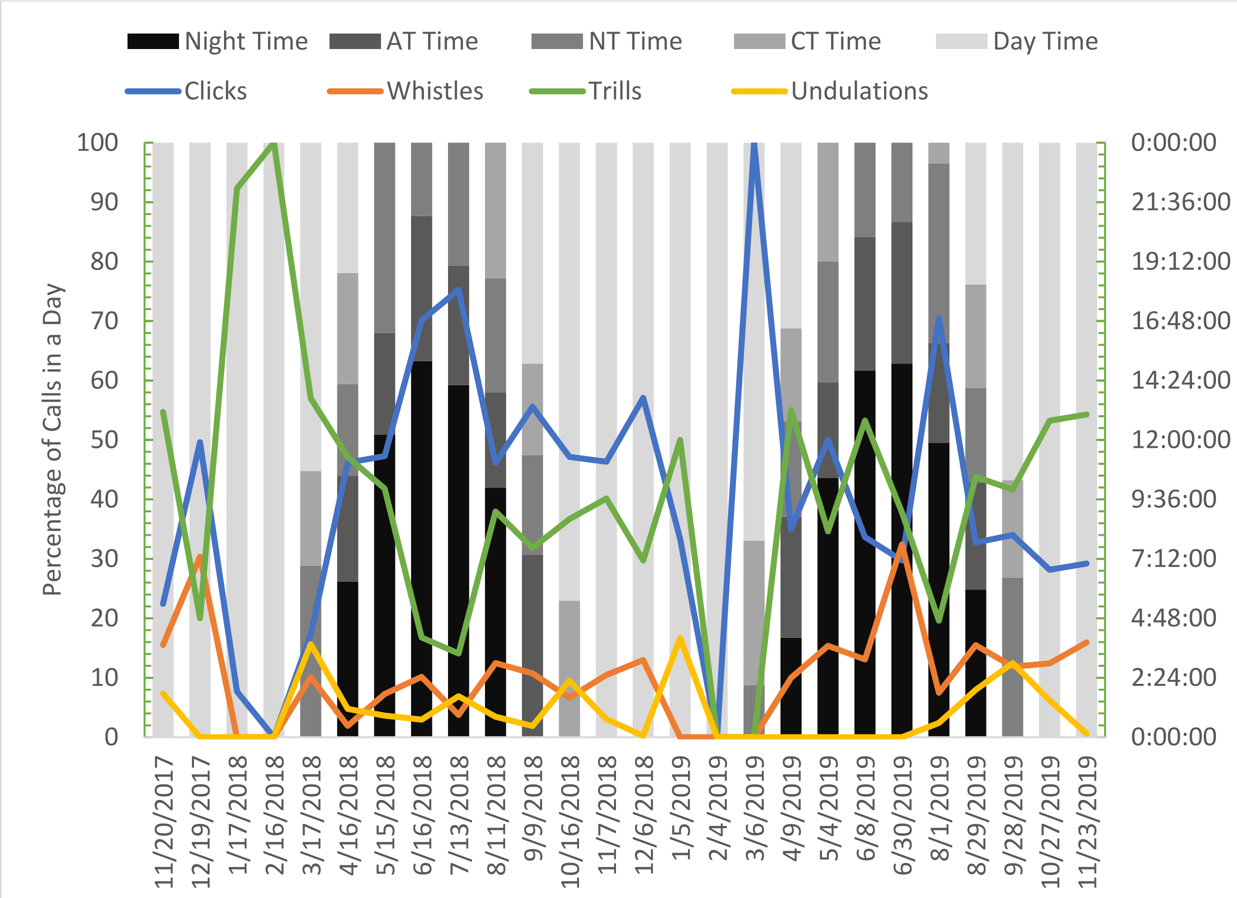


Figure 6: Variation in percentile breakdown of ultrasonic call types with the duration of ambient illumination levels between November 2017 and November 2019

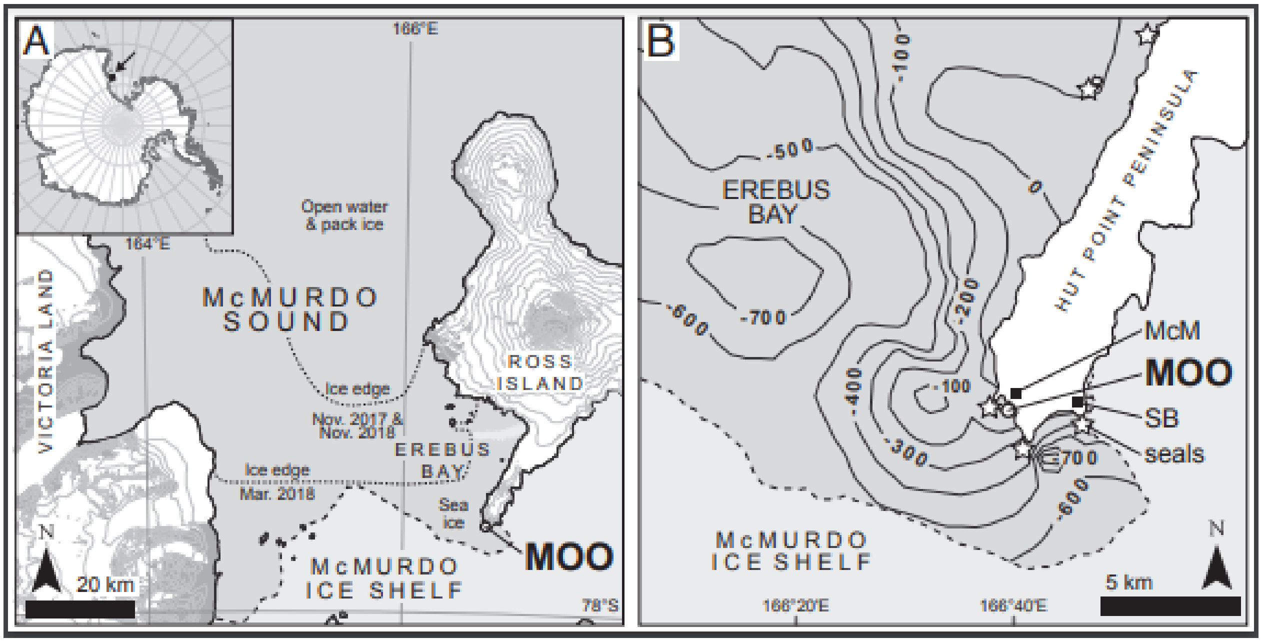


Figure 7: Location of data collection site with bathymetry, location markers, and estimated ice boundaries (Reused with permission from Cziko et al., 2020)

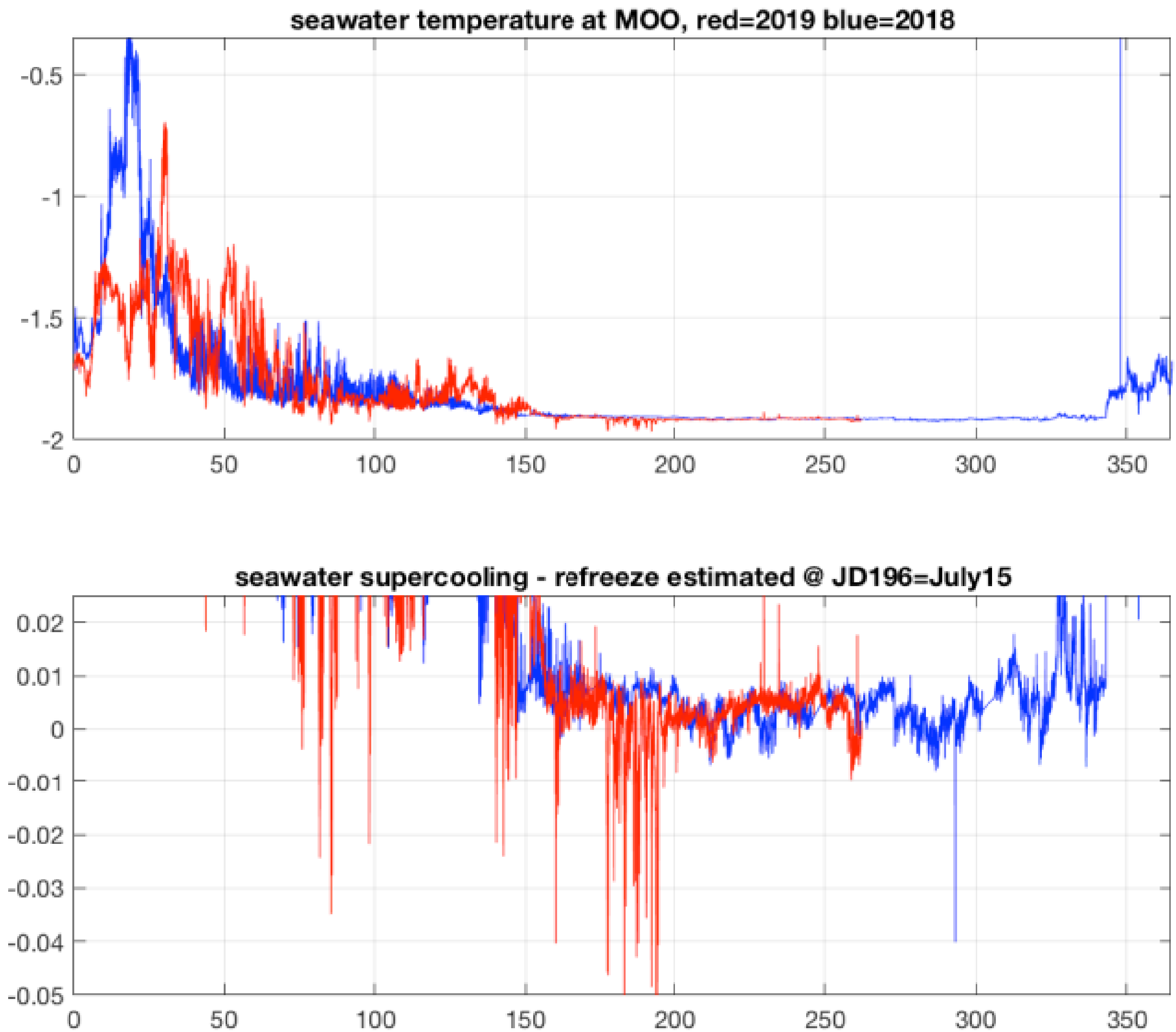
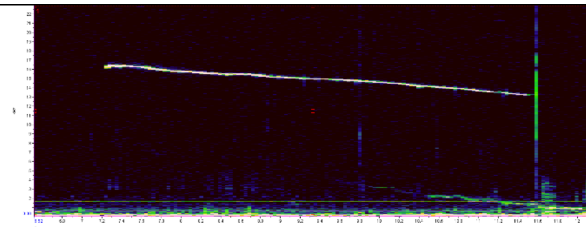
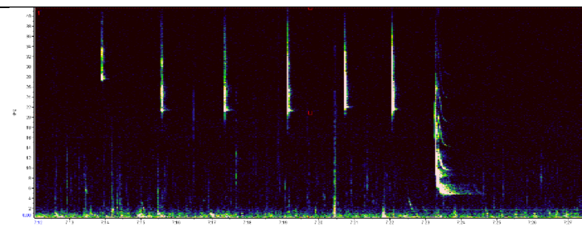
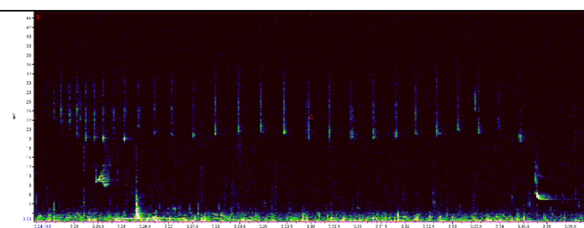
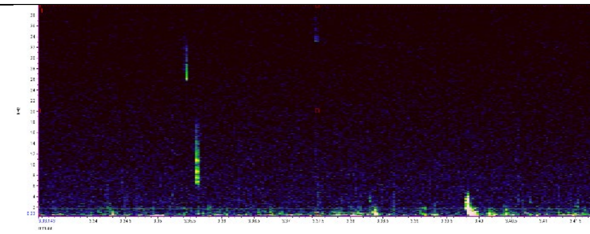
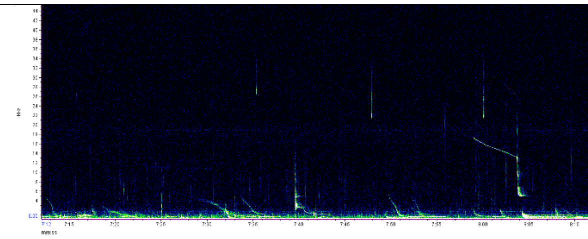
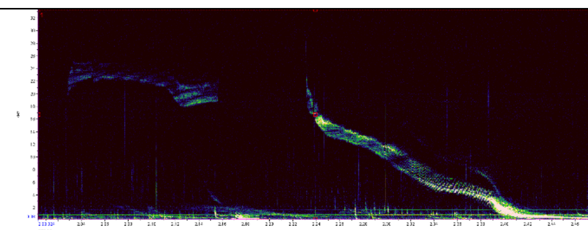


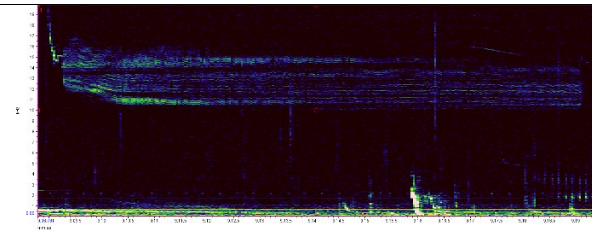
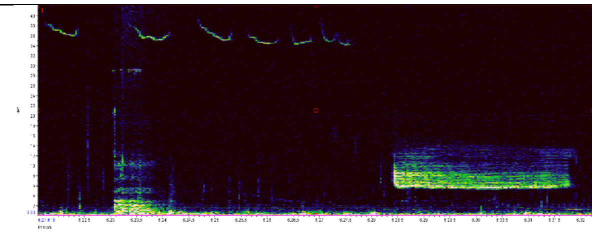
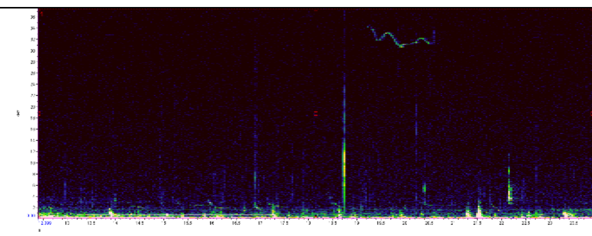
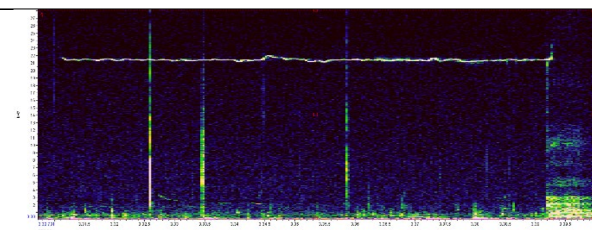
Figure 8: Estimated refreezing of McMurdo Sound based on supercooling on seawater (Created by Dr. Paul Cziko)

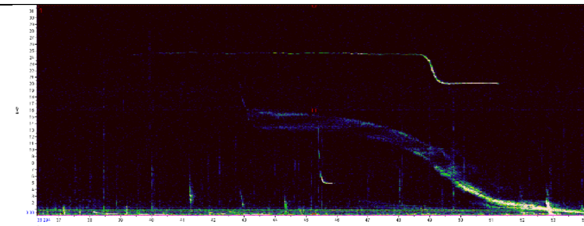
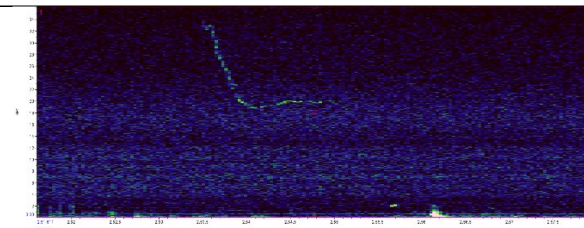
Tables

Table 1: Examples and information on vocalizations referenced within this paper

Long-Form Call Name	**Short-Form Call Name**	**Call Type**	**Description**	**Example**
Sonic Standard Whistle	SSW	Sonic	Narrow-banded; Descends from 17 to 13 kHz	
Click 101	C101	Ultrasonic	3 elements Wide-banded; Occurs 40 to 6 kHz; Part B intervals 1-2 seconds	
Click 102	C102	Ultrasonic	3 elements; Wide-banded; Occurs 32 to 6 kHz; Part B intervals increase over time	

Click 103	C103	Ultrasonic	4 elements; Wide-banded; Occurs 38 to 0 kHz; Interval between each part varies	
Click 104	C104	Ultrasonic	3 elements; Wide-banded; Occurs 36 to 6 kHz; Part B intervals >10 seconds	
Trill 101	T101	Ultrasonic	2 elements; Wide-banded; Occurs 25 to 0 kHz; Part A consistent frequency, Part B frequency descends	

Trill 102	T102	Ultrasonic	Wide-banded; Occurs 20 to 10 kHz; Consistent frequency; 6-10 seconds	
Undulation 101	U101	Ultrasonic	2 elements; Part A narrow-banded at 38 kHz; Part B wide-banded occurs at 14 to 6 kHz	
Whistle 101	W101	Ultrasonic	Narrow-banded; Undulates at 32 kHz; 2-4 seconds	
Whistle 102	W102	Ultrasonic	Narrow-banded; Consistent frequency at 22 kHz; 1-10 seconds	

Whistle 103	W103	Ultrasonic	Narrow-banded; ~10 seconds; Drops from 25 kHz to 20 kHz halfway through	
Whistle 104	W104	Ultrasonic	Narrow-banded; ~3 seconds; Drops from 34 kHz to 20 kHz after the first second	

Appendices

Appendix 1: C104

The C104 call has an A, B, and C element, as is the case with nearly all other ultrasonic click category calls. The A element is a singular, short, broad-banded call and occurs between 26-36 kHz for a fraction of a second. The B element is a series of short, broad-banded calls and occurs between 22-34 kHz for a fraction of a second at a time. The series that composed element B consisted of one or more calls, the number of calls varying with each occurrence of C104. The C element is a singular, short, broad-banded call that occurs between 6-24 kHz. The spacing between elements A and B is between 10-15 seconds. The spacing within the series of element B was consistent and between 10-15 seconds. The spacing between elements B and C is between 3-5 seconds.

Appendix 2: W104

The W104 call is a single-element, narrow-banded call, similar to all other calls within the ultrasonic whistle category. This call occurs between 18-34 kHz and lasts between 1-3 seconds. This call starts from 34 kHz, then descends to 18 kHz over approximately a third of the total call time. Over the rest of the total call time, the frequency rises to 20 kHz and fluctuates between 20-21 kHz.

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