Weddell seal (*Leptonychotes weddellii*) proportional call type usage with seasons and light periods, and the relationships between call types near Davis, Antarctica.

by

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A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

Honours in Bachelor of Science

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THE UNIVERSITY OF NEW BRUNSWICK

March 2025

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Abstract

Weddell seals (*Leptonychotes weddellii*) have an extensive vocal repertoire. I investigated whether their proportional call type usage patterns vary across seasons and light periods, and the relationships between call types. Calls were recorded near Davis, Antarctica, and analyzed using R Studio and Raven Pro. A total of 6315 calls were identified, representing 16 call types. Call types were categorized and examined by season, light period, and season by light period using Chi-square tests. Clustering methods reclassified calls into broader groups based on common physical structures. For the 16 call types, proportional call usage did not significantly differ across seasons, but did significantly differ across light periods. Whistle Descending calls revealed significant difference across seasons by light period. The clustering analysis identified three call categories, showing seasonal significance, but no light period effect. This suggests no call types or groups are linked to reproduction, enhancing our understanding of Weddell seal behaviour.

Acknowledgements

I would like to express my sincere appreciation to my supervisor, Dr. John M. Terhune, for his guidance, support, and constructive feedback throughout the research and writing of this thesis. His expertise and insights have strengthened my understanding of bioacoustics and Weddell seals.

I extend my heartfelt thanks to Emma Simmonds, whose efforts during her Honours year (2024) were instrumental in laying the foundation for my work. I am grateful for her support and friendship throughout my research.

I also thank the Australian Antarctic Division (AAD), particularly Mr. John van den Hoff and Dr. Brian Miller, for their research and contributions, which were essential to this project.

I appreciate the guidance of Dr. Kurt M. Samways and the support of the Biological Sciences Department at the University of New Brunswick Saint John, whose academic and financial assistance made this research possible.

I am grateful for my friends and family for their continued support and encouragement throughout this process.

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Introduction

Weddell seals (*Leptonychotes weddellii*), order Carnivora and family Phocidae, are a large species of pinnipeds that live in high Antarctic regions and are the most southernly breeding mammal (Russel et al., 2016; Siniff, 1991; Smith, 1965; Stirling, 1969; Würsig et al., 2018). Weddell seals live beneath and on land-fast ice, and occasionally pack ice, until the ice breaks up and melts in the summer (Russell et al., 2016). Land-fast ice is a large sheet of ice extending many kilometres offshore, up to 2m thick, that is attached to the coastline. Pack ice is sea ice that has broken up into floes. Glacial ice is ice that forms from glaciers that flow down to the sea (icebergs), whereas land-fast ice is frozen sea water. Land-fast ice begins forming in May and breaks up in December. Breathing holes in the land-fast ice are provided by cracks from glacial movement or tides (Dorion et al., 2012; Lake et al., 2005; Lugg, 1966; Stirling, 1969). During this period, both male and female seals cooperate to maintain breathing holes by rasping the edges with their teeth to remove newly formed ice, preventing the holes from freezing over (Rouget et al., 2007). In the spring, the males defend territories under the breathing holes while the females haul out to give birth on the ice near these holes (Dorion et al., 2012; Lake et al., 2005; Lugg, 1966; Stirling, 1969). Maintaining this underwater territory allows males the advantage of increased access to the females during the breeding season (Dorion et al., 2012).

There are four distinguishable seasons for Weddell seal behaviour. The summer season ranges from late-December to April. The seals are presumed to be feeding offshore in open water during the summer, and then return to land-fast ice after it forms in the austral autumn (May) (Würsig et al., 2018). The winter season ranges from June to

late September. In mid-winter, Weddell seals can be subject to almost 24-hours of darkness and then longer daylight periods later in the season. In the winter, the Weddell seals do not haul out onto the ice since it is too cold. A study by Rouget et al., (2007), provided evidence that Weddell seals of all age and sex classes reside under the land-fast ice in the winter. The pupping season ranges from early October to mid-November. In the pupping season, females haul out on the ice to give birth and they remain on the land-fast ice to nurse their pups (Dorion et al., 2012; Würsig et al., 2018). The pupping and weaning stages are staggered among the females, so they return to the water at different times (Dorion et al., 2012; Würsig et al., 2018). Weaning of pups occurs approximately six weeks after the birth. A few mother-pup pairs remain on the ice in early December (Dorion et al., 2012; Würsig et al., 2018). The males are defending their underwater territories during this time (October to December) (Oetelaar et al., 2003; Würsig et al., 2018). The courtship/breeding period begins when the females return to the water after weaning their pups (Dorion et al., 2012; Würsig et al., 2018). The courtship/breeding period takes place from mid-November to early-December. In December, the seals are subject to 24-hours of daylight (Evans et al., 2004; Würsig et al., 2018).

Weddell seals have an extensive vocal repertoire (Evans et al., 2004; Pahl et al., 1997; Thomas & Kuechle, 1982) and are among the most vocal pinnipeds under water (Evans et al., 2004; King, 1983; Riedman, 1990; Terhune, 2019). Weddell seal calls have been suggested to be involved in social functions such as mate attraction, territorial defense, aggression, and social interaction (Dorion et al., 2012; Würsig et al., 2018). Calls made in air are presumed to be reflective of underwater calling (Oetelaar et al., 2003). Although the specific functions of most call types are unknown, trills are an

exception as they are exclusively produced by males (Oetelaar et al., 2003). There is other evidence of sex-specific calls (Oetelaar et al., 2003; Thomas, 1979; Thomas & Kuechle, 1982) which could help identify the sex of an underwater caller.

Ice-dwelling seals in Antarctica are among the most difficult to study (Evans et al., 2004; Poulter, 1966). Their underwater behaviours shed light on the difficulties researchers face. Due to the mobility of the seals, variable background noise, and difficulties with underwater observations, sound recordings can be difficult to interpret (Gentry, 1967; Morgan, 1973; Schusterman & Moore, 1978; Terhune & Ronald, 1976; Thomas et al., 1983). With most calls occurring underwater, associating behaviour with a call type can be difficult, as well as knowing which sex was making the call. Using recordings of Weddell seal calls made near Mawson, Antarctica, Dorion et al., (2012), found no presence-absence differences for call types in the seasons, but some call types varied with calling rate depending on the light exposure (dawn, day, dusk, night). Monitoring vocalizations may provide an effective means of studying seal behaviours that cannot be directly observed, offering insights into the underwater behaviours of Weddell seals.

Assigning behavioural functions to call types can be challenging, especially for calls that occur infrequently or outside of observable ranges (i.e., underwater) (Dorion et al., 2012). The Weddell seal is an ideal marine mammal to study vocalization behaviours since they have a large, well-documented vocal repertoire, and there is generally not often interference from background noise under the ice (Thomas et al., 1983). The calls' physical features are measured using a spectrogram, which depicts the amplitude of frequencies (on the Y axis) vs time (on the X axis). The features include call shape

(sound spectrogram pattern shapes), waveform (the amplitude (dB) over time), duration of the call (s), the number of elements (individual parts of the sound which are part of the same call), and frequency (Hz) components (Pahl et al., 1997). The frequency of Weddell seal calls ranged from 60 Hz to nearly 50 kHz (Cziko et al., 2020). These vocalizations vary in duration and complexity, with some comprising of single, sustained tones, while others consist of multiple elements within a sequence (Pahl et al., 1997). The repertoire includes distinct call types such as growls, characterized by low-frequency broadband pulses, and whistles, which are higher tonal frequencies. Whistles and trills can often be described as tonal sounds, ranging from low to high frequencies – tonal sounds are characterized by a sinusoidal waveform (Pahl et al., 1997). The diversity of the call features highlight the intricate acoustic behaviour of Weddell seals.

Some mammalian call types have been suggested to have a behavioural association. Morton (1977), hypothesized that low-frequency, pulsed sounds are likely to be associated with aggressive behaviour, while high-frequency, tonal sounds are more likely to indicate fear or submission. If this holds for Weddell seals, it may be possible to group call types into broad behavioural functions based on the physical structures of the calls. This would reduce the high number of putative call types (as identified by human observers; e.g., Pahl et al., 1997) into fewer functional categories. Testing this is not possible but an indication of the usefulness of this approach may be indicated by determining if there are different call type usage patterns over the seasons or light periods by the 16 call types versus the fewer numbers of call functional categories.

If call types are indicative of distinct behavioural associations, the usage could be expected to vary across seasons, such as winter and breeding, and reflecting the different

ecological and social demands of these periods. This study will examine how seasonal (winter, pupping, breeding) and light periods (daylight exposure) variations influence Weddell seal call type usage, and the relationships and structural similarities between these call types. The underwater calls were recorded near Davis, Antarctica using an Autonomous Multichannel Acoustic Recorder from July to December, 2021. Every 10 days, 24 hourly recordings were analyzed. The calls were categorized by Simmonds (2024), into 16 call types.

The first objective in this study will determine if Weddell seal call type usage patterns vary with seasons (winter, pupping, breeding) and light periods (light exposure – dawn, day, dusk, night, sunlight conditions) variations. In a study by Rouget et al., (2007), photoperiod was anticipated to influence the vocal behaviour of Weddell seals across the seasons and daylight experienced. It was found that throughout the winter when darkness was more prominent that call rates were comparable to call rates observed during peak breeding season. There is also a diel pattern, with fewer calls during the daylight and night, and more calls in the dawn/dusk periods (Dorion et al., 2012; Rouget et al., 2007). This suggests that calling behaviours may vary not only between seasons, but also between periods of light and darkness (Dorion et al., 2012).

This analysis will align with a similar project performed using recordings from Mawson, Antarctica, by Dorion et al., (2012). The goal is to identify if Weddell seal call type usage patterns vary by season or light exposure at Davis, Antarctica. This will also allow for a comparison of calls from recordings made very close to the calling seals in Mawson, Antarctica (Dorion et al., 2012; Rouget et al., 2007), versus the longer-range recordings from the AMAR recorder (Davis, Antarctica). The received amplitude of calls

can vary with distance, potentially altering the perceived characteristics of the call. Additionally, high frequency components of calls may be more susceptible to absorption, which potentially can change some aspects of the received call structures.

The second objective of this study will be a pilot study to examine the relationships between the different Weddell seal call types and identify which types are structurally most similar to each other. There is some evidence that the behavioural function of a call may be related to its structure and frequency components (Morton, 1977). To examine the hypothesis of Morton (1977), the existing Weddell seal call types will be coalesced into fewer categories based on their structural similarities. This could help determine if the usage patterns are different than when using all 16 call types. Cluster analysis and Principal Component Analysis (PCA) will be used to analyze various call features and amalgamate similar call types. This analysis may help with the analyses of different call usage patterns and if the calls can be categorized into general functional categories based on their acoustic structures. The first objective will be reanalyzed based on the functional groups identified in the second objective.

Methods

Data Collection/Recordings

The data collection took place near Davis, Antarctica, using a Generation 4 Autonomous Multichannel Acoustic Recorder (AMAR G4; JASCO). The recorder was approximately 5.6 km from the Davis research station (Fig. 1), at a latitude of -68.56466° and longitude of 77.831447°, and a depth of 67m. The recordings from the AMAR alternated between a 32 kHz sampling rate for 9 min 40 s, 512 kHz sampling rate for 1 min, and a period of sleep for a total cycle duration of 15 min (Delarue et al., 2022). The recorder operated continuously from July 22, 2021 to February 8, 2022 (Delarue et al., 2022). The data included in the analyses were obtained every 10 days from July 24 to December 1. On each sampled day, every hour, on the half hour, an 8 min subsample within the 9 min, 40 s recording at 32 kHz was analyzed. For objective 1, the call types were categorized using Raven Pro 1.6 by Ms. E. Simmonds during her honours research (Simmonds, 2024) (Table 1).

The type of every call that started within the 8 min subsample was categorized based on the waveform, frequencies, duration, and number of elements shown in a spectrogram and compared to previously defined call types (Oetelaar et al., 2003; Pahl et al., 1997). The summer season was not analyzed because there were so few Weddell seal calls then (Simmonds, 2024).

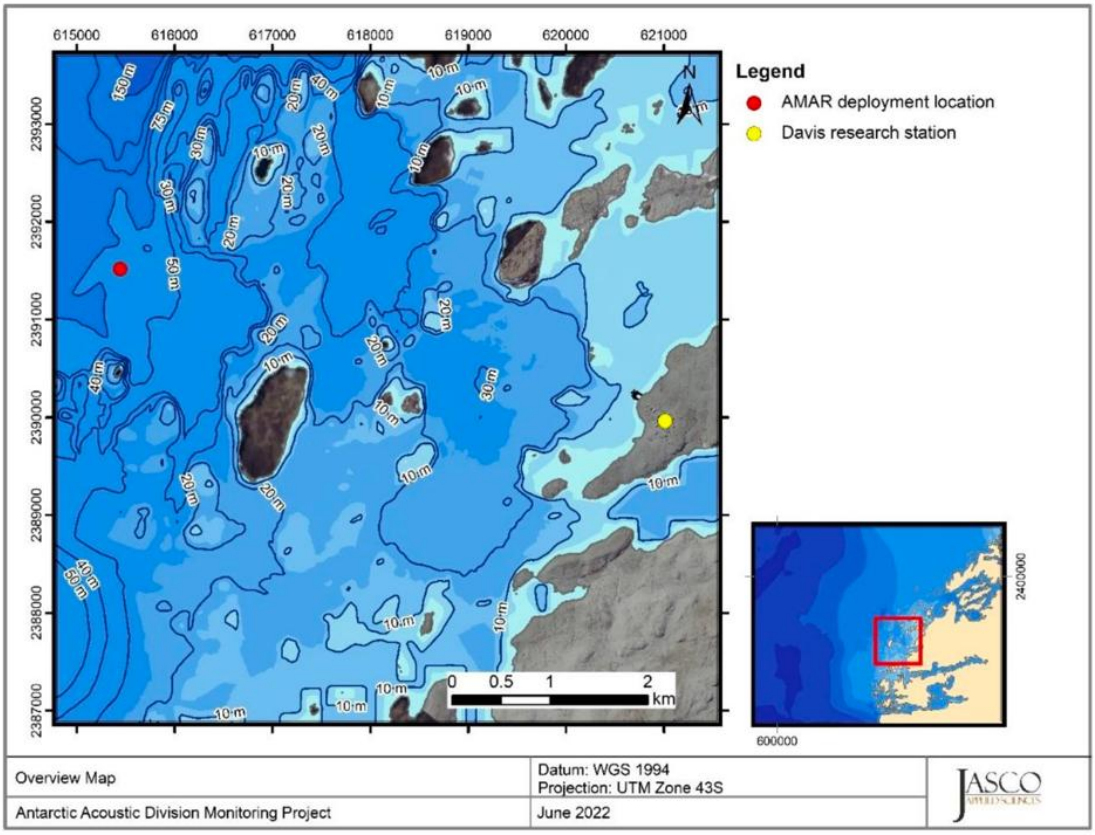
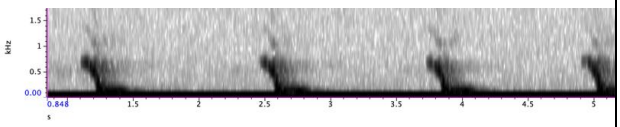
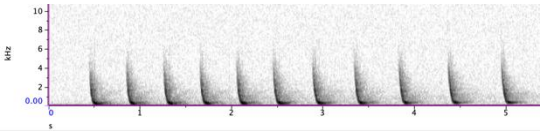
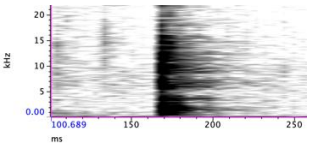
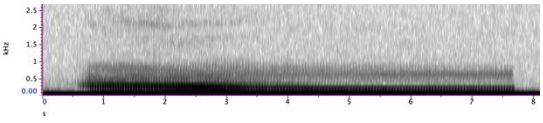
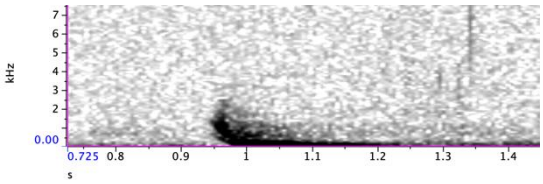
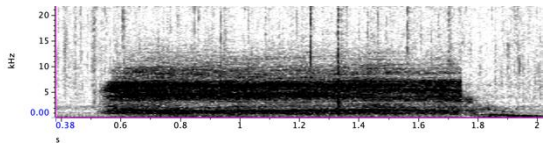
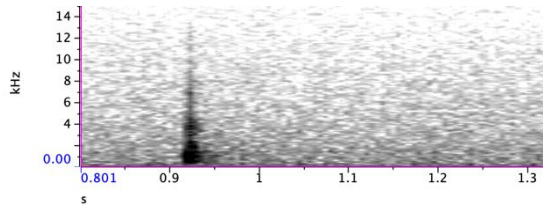
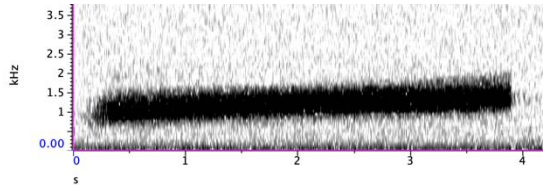
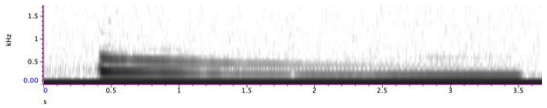
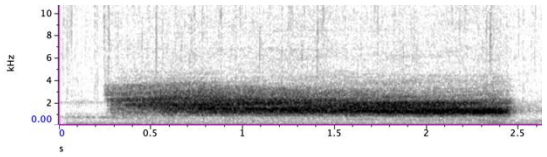
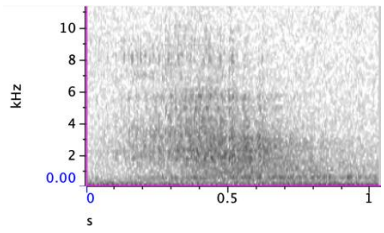
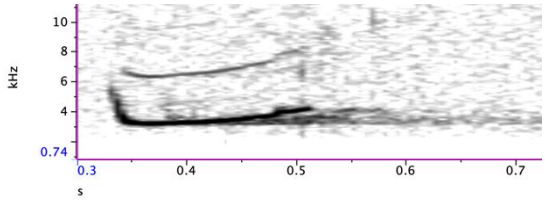
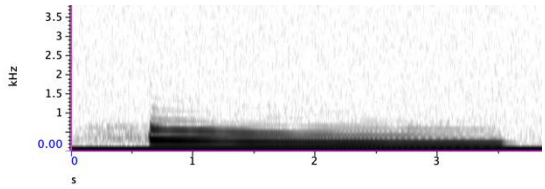
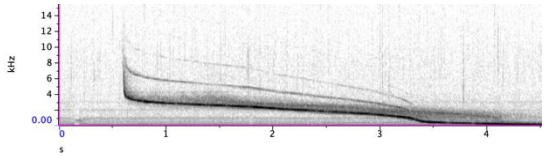
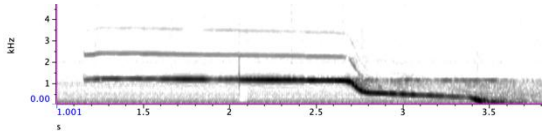


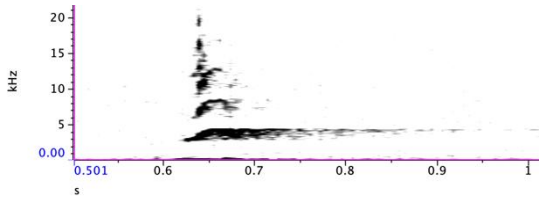
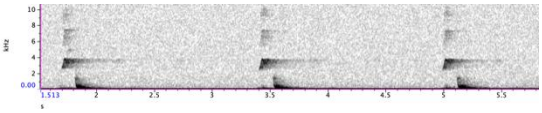
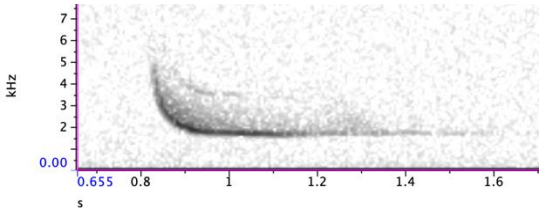
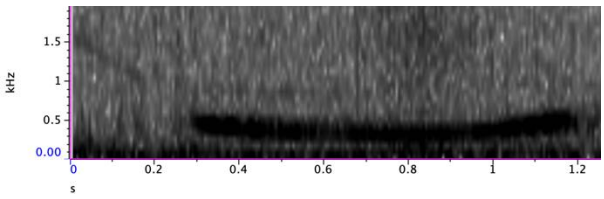
Figure 1. Map of the monitoring location (red dot) near the Davis research station (yellow dot) from Delarue et al., (2022).

Table 1. Call name, abbreviation, a brief description (Simmonds, 2024), and example of the call spectrogram in Raven Pro. Missing descriptions from Simmonds (2024) are noted with NA.

Call Name	**Call Abbreviation**	**Description**	**Call Example**
Chug	C	Low frequency, rapidly descending frequency: ~100 Hz	
Chug with a rising frequency		Short then longer duration chugs rising in frequency.	
Click		Short "taps".	
Growl	L	Typical mammalian growl: <500 Hz.	
Grunt	G	Short, abrupt, sometimes breathy call: <300 Hz.	

High roar		NA	
Knock	K	Short, abrupt pulse that can be in series: 3-4 kHz.	
Low roar	LR	Low frequency pulsed roar: <1 kHz.	
Mew	M	Low frequency tone that drops slightly: <500 Hz.	
Mid roar	MR	Mid frequency roar, flat frequency: 1-5 kHz.	

Pulse	P	NA	
Squeak	S	Short, rising frequency, sinusoidal: 3-4 kHz.	
Tone	O	Long tone with slightly rising pitch: ~400 Hz.	
Trill	T	NA	
Trill constant	TC	NA	

Whistle ascending	WA	Short, sharp upsweep: 1-4 kHz.	
Whistle ascending grunt	WAG	Short rising whistle immediately followed by a grunt: 0.1-4 kHz.	
Whistle descending	WD	Rapidly descending concave frequency followed by a flat ending: 1-10 kHz.	
Whoop	Q	Tone with rising frequency at the end: 0.1-0.5 kHz.	

For objective 2, Dr. J. Terhune selected a small subset of sample calls recorded at Weddell seal breeding sites in the Vestfold Hill for analysis. Detailed descriptions of the recording procedures and locations can be found in Terhune and Dell'Apa (2006), and Hayes and Terhune (2007). From the recordings, three to ten clear examples of each of thirty-three putative call types were randomly selected. The intent was to provide a range of examples to be reclassified into a smaller number of categories. The goal is to reclassify the call types into smaller groups that have similar structural features and thus

may have similar behavioural functions, as proposed by Morton (1977). Because the number of calls were small, this would not be a definitive reclassification of Weddell seal call types.

Objective 1: Statistical Analyses

In objective 1, the methods used for the statistical analyses were based on Dorion et al., (2012) but with Chi-square tests used to identify differences in proportional usage of the call types. The analysis focuses on call type usage by season (winter, pupping, breeding), by light exposure (dawn, daylight, dusk, night), and by season by light exposure. For every hour of each of the days sampled, the data provided by Simmonds (2024) included the numbers of each call type, the season and the light period. This information was recorded for 6315 calls in total, the number of calls per 8-minute period in each hour could be as few as 0 calls recorded to 40+.

For the call type usage by season, the data was subsetted into the three seasons. The winter period had 7 recording days (day 1-7: July 24, 2021 – September 23, 2021), the pupping period had 3 recording days (day 8-10: October 2, 2021 – November 1, 2021), and the breeding period had 3 recording days (day 11-13: November 11, 2021 – December 1, 2021). Counts of each call type in each season were calculated. The analysis programs used were R 4.4.1 (R Core Team, 2023) and R Studio 2024.04.2+764 (RStudio Team, 2020).

In R Studio, the packages “tidyr”, “ggplot2”, “writeexl”, and “dplyr” were loaded. From the datasheet provided by Simmonds (Simmonds, 2024), only “Season”, “Call

Name", and "Call_Count" columns were used for the seasonal analysis. A contingency table was made using the "xtabs" function for "Total_Call_Count ~ Season + Name". Using the contingency table, a Pearson's Chi-square analysis was run using the "chisq.test" function. Any call type with an expected value less than 5 in any of the seasons was combined into an "Other" category to ensure infrequent calls were retained in the data rather than discarded. For the seasonal analysis, the call types categorized into "Other" were: C, G, K, L, M, MR, Q, TC, and WAG. The remaining call types were: LR, O, P, S, T, WA, and WD. The Chi-square analysis was rerun with the low expected values in the "Other" category and produced statistical values without any warnings. Using the "ggplot2" function, a scatterplot was created to show the proportional call count for the call types in the winter, pupping, and breeding seasons.

For the light period analysis, the data was subsetted into the four light periods: night, dawn, day, and dusk by Simmonds (Simmonds, 2024). In R Studio, the packages "tidyr", "ggplot2", "writeexl", and "dplyr" were loaded. From the datasheet, only "Light Period", "Call Name", and "Call_Count" columns were used for the light period analysis. The proportional call usage was calculated and added as a column to the dataset. From the datasheet, only the "Light_Period", "Name", and "Call_Count" columns were used for the analysis. Any call type with an expected value below 5 in any light period was grouped into an "Other" category to retain infrequent calls in the dataset rather than discarding them. For the light period analysis, the call types categorized into "Other" were: C, G, K, L, LR, M, MR, O, P, S, Q, TC, and WAG. The remaining call types were: T, WA, WD. The Chi-square analysis was rerun with the low expected values in the "Other" category and produced statistical values without any warnings. Using the

"ggplot2" function, a scatterplot was created to show the proportional call usage for the call types in the night, dawn, day, dusk light periods.

To analyze the relationship between light period (night, dawn, day, dusk) by season (winter, pupping, breeding), only the WD call type had a sufficiently high count to meet the Chi-square assumptions. The proportion of WD calls were calculated by season and light period (from the total call count). Using the "xtabs" function, a contingency table was created. Due to the low sample size, since just the WD calls were being analyzed, a Fisher's Exact Test was run using the "fisher.test" function. Using the "ggplot" function, a heatmap was created to show the proportion of WD calls for light period by season.

Objective 2: Call Type Analyses

Using Raven Pro 1.6.5, a software program for acquisition, visualization, measurement, and analysis of sounds (Cornell Lab of Ornithology, 2024), a small subset of Weddell seal calls' physical features were analyzed. The 'Brightness' and 'Contrast' features of the spectrogram display were adjusted to enhance the visual signal-to-noise ratio without removing the call features. The FFT value ('Focus' feature in Raven) was set to 512 for all samples, which led to a 62.5 Hz analyzing bandwidth. The selection of the call is referred to as an "annotation", which is created using a sound spectrogram display. To make an annotation, the user selects the starting point of the call by placing the cursor on the spectrogram and then drags it to the end of the call, producing a rectangular box on the screen. The Raven software automatically generates a table containing information such as Begin Time (s), End Time (s), Low Frequency (Hz), High

Frequency (Hz), duration of the call (s), and allows manual entry of the call name and the "Start_Frequency" and "End_Frequency" of each call.

Objective 2 : Statistical Analyses

For the second objective, in R Studio, the packages "ggplot2", "cluster", "factoextra", "dendextend", and "dplyr" were used. The columns "Duration", "Low_Freq", "High_Freq", "Start_Freq", and "End_Freq" were standardized using the Z score normalize function. A Principal Component Analysis (PCA) plot was created based on a temporary cluster assignment. All distances were measured in Euclidian distance. An Elbow plot was generated to help determine the optimal number of clusters. To visualize the results, a hierarchical clustering dendrogram was plotted using Ward's method. This supported the creation of three groups. The K-means Cluster was run to identify which of the original call types were to be reduced into the three groups.

Reanalysis of Objective 1 based on Objective 2

The original call types were assigned to one of the three clusters. The "P" and "WAG" call types were excluded since they were not analyzed in Objective 2 and were not placed in a cluster. A contingency table was made (Total_Calls ~ Season + Cluster), and the Chi-square analyses were conducted. The expected values per season, light period were all ≥ 5, so the Chi-square requirements were met. The proportions were calculated within each season, then a scatterplot was created using the "ggplot2" function. For the light period analysis, a contingency table was created using the "xtabs" function

(Total_Calls ~ Light_Period + Cluster), then the Chi-square test was run – the expected values all ≥ 5, therefor meeting the Chi-square requirements. The proportions within each season was calculated and a scatterplot was created to show the proportional call usage for the three clusters. To analyse the relationship between light period and season, only the C1 cluster had a sufficiently high count to meet the Chi-square requirements. The proportional usage for each cluster was calculated by season and light period. A contingency table was created. Using the "ggplot2" function, a heatmap was created to show the proportions of C1 for light period by season.

Results

Objective 1

The Chi-square analyses of call type frequencies across the three seasons (winter, pupping, and breeding) revealed no statistically significant difference in call type usage patterns (X^2 value = 21.288, DF = 14, and the p = 0.09448). The highest total call counts were observed in the winter, and the lowest were in the breeding season. The call types Whistle Descending (WD) and Whistle Ascending (WA) had the highest proportional counts across all seasons (Fig. 2). Call types that showed an expected count frequency below 5 were categorized into "Other".

The light period analysis across the four light conditions (night, dawn, day, and dusk) revealed a statistically significant variation in call type usage. The X^2 value = 27.293, the degree of freedom = 9, and the p-value = 0.001251. The majority of call types were dominant during night, with significantly lower counts observed at dawn and dusk. The call type WD remained the most frequently observed call in all light conditions (Fig. 3).

A Fisher's Exact Test was conducted to assess the interaction between seasons and light periods for the Whistle Descending (WD) call type. This is the only call type that had sufficiently high counts in each of the twelve light periods/seasons to permit a statistical analysis. The test resulted in a statistically significant p-value (p = 0.00001), indicating a strong relationship between the seasons and light period specific call patterns. The heatmap (Fig. 4) supports this finding by illustrating variation in call proportions across different light periods and seasons. The winter season has a generally consistent proportion of the WD calls throughout the light periods, with a lower

proportion during Dusk. The pupping season shows a high concentration at dusk and day, whereas the breeding season shows a high concentration of the WD call during dawn and night.

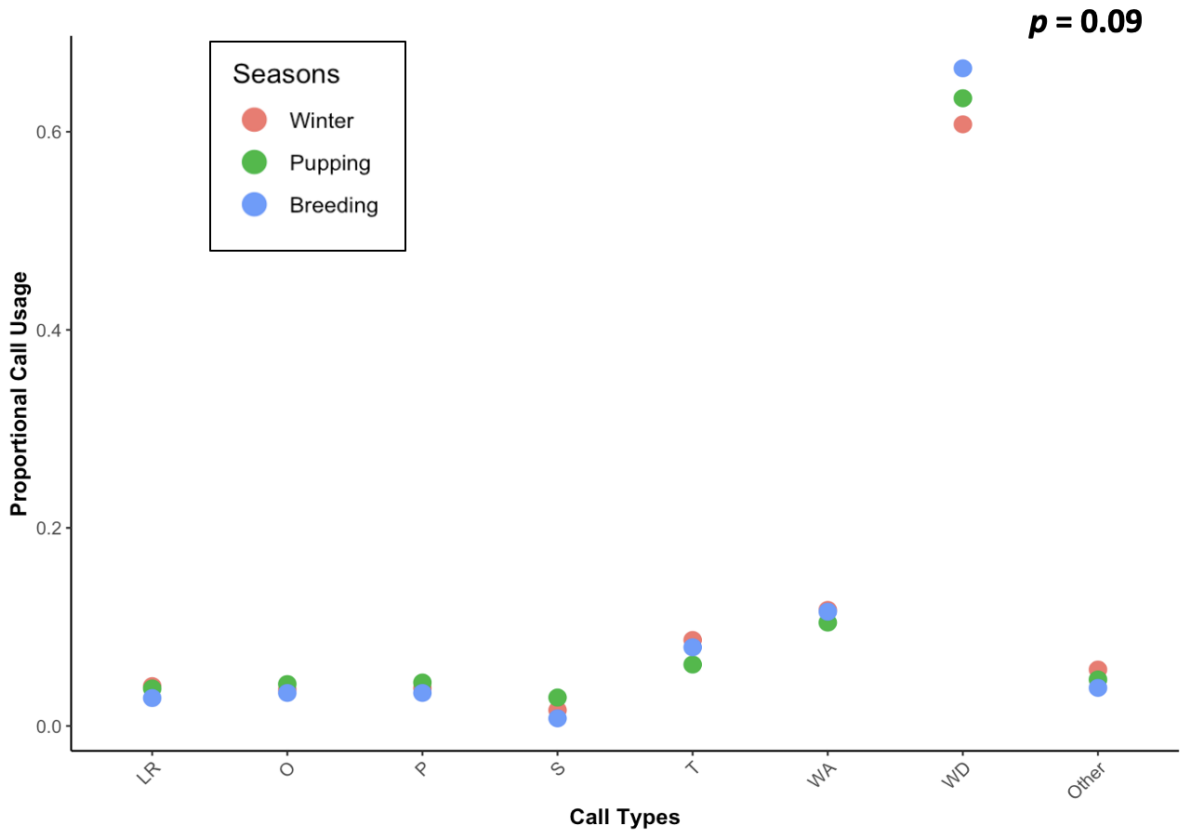


Figure 2. The proportional call count for each call type over the three seasons (winter, pupping, and breeding).

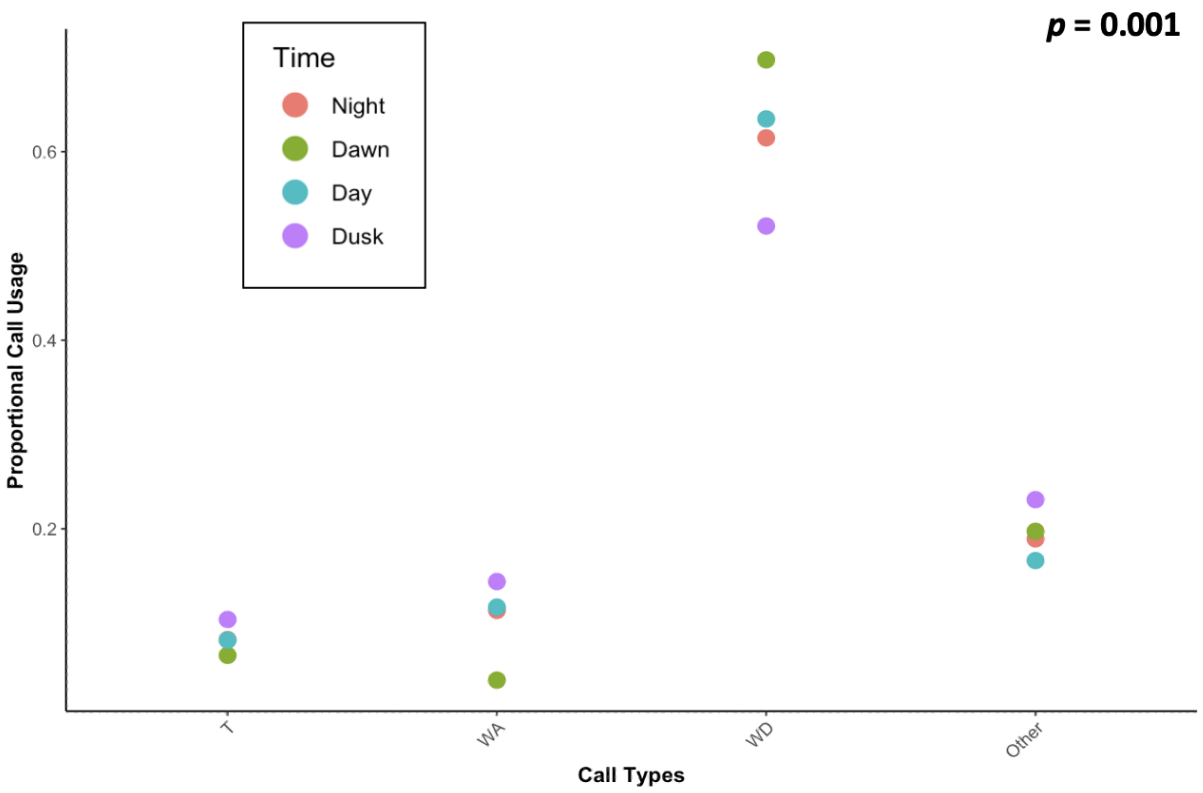


Figure 3. The proportional call count for each call type over the four light periods (night, dawn, day, and dusk).

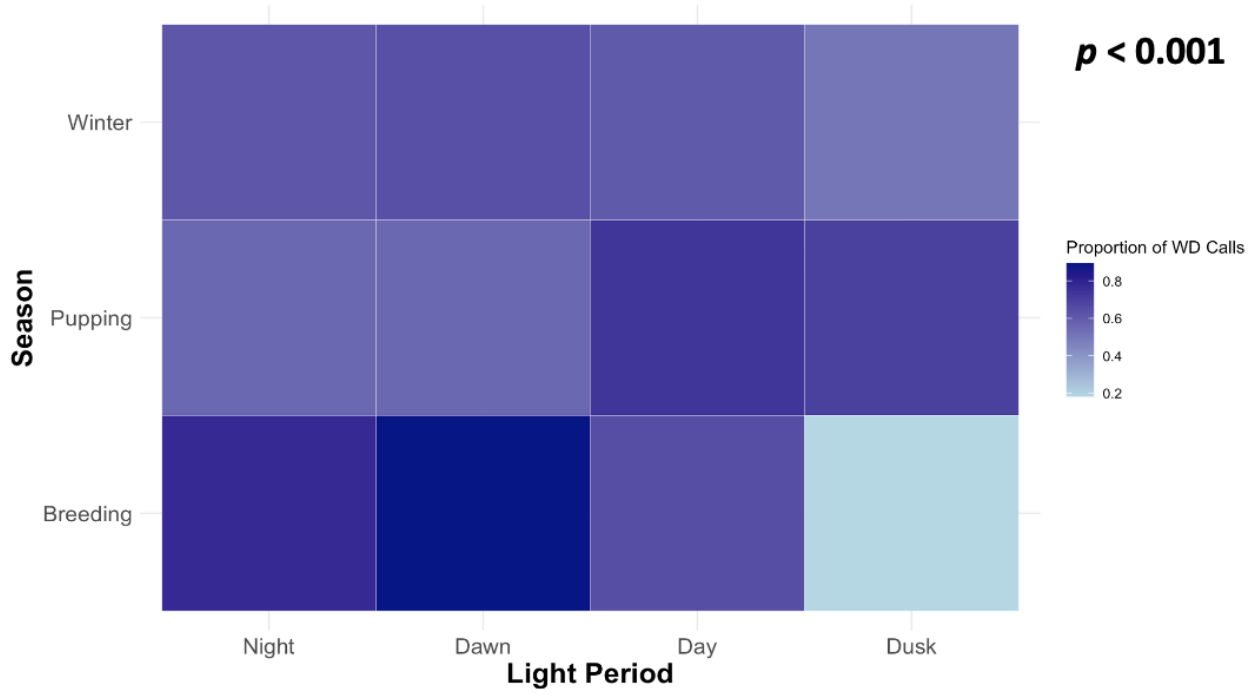


Figure 4. A heatmap showing the proportional distribution of Whistle Descending calls across the seasons (winter, pupping, and breeding) and light periods (night, dawn, day, and dusk).

Objective 2

Using the Elbow method, three clusters were identified as the optimal number for k-means clustering (Fig. 5). The cluster assignments revealed three grouping of the call types, a PCA plot was then created to visualize the groupings (Fig. 6). Hierarchical clustering using Ward's method supported these findings with a dendrogram illustrating similar group separations. (Fig. 7).

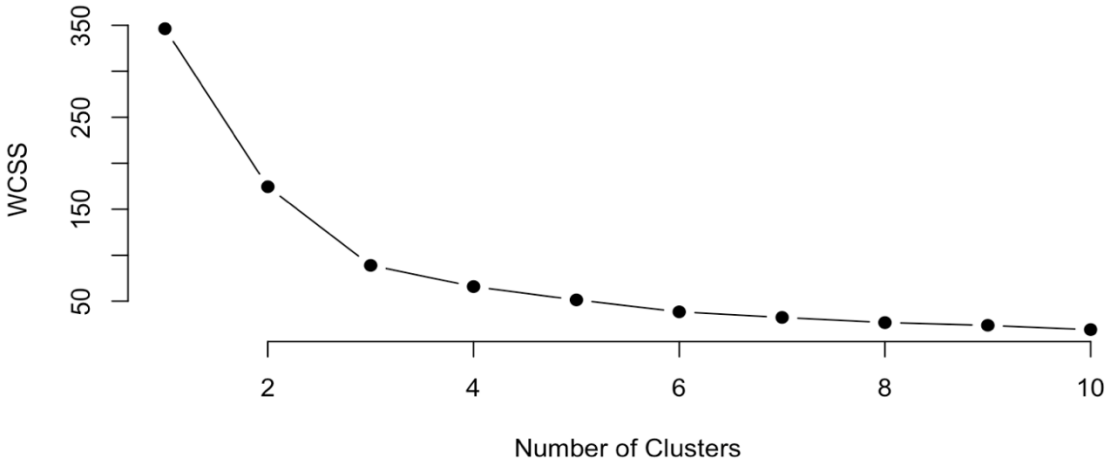


Figure 5. Elbow plot showing within-cluster sum of squares (WCSS) across different numbers of clusters, with the optimal number of clusters identified at the point of inflection (k = 3).

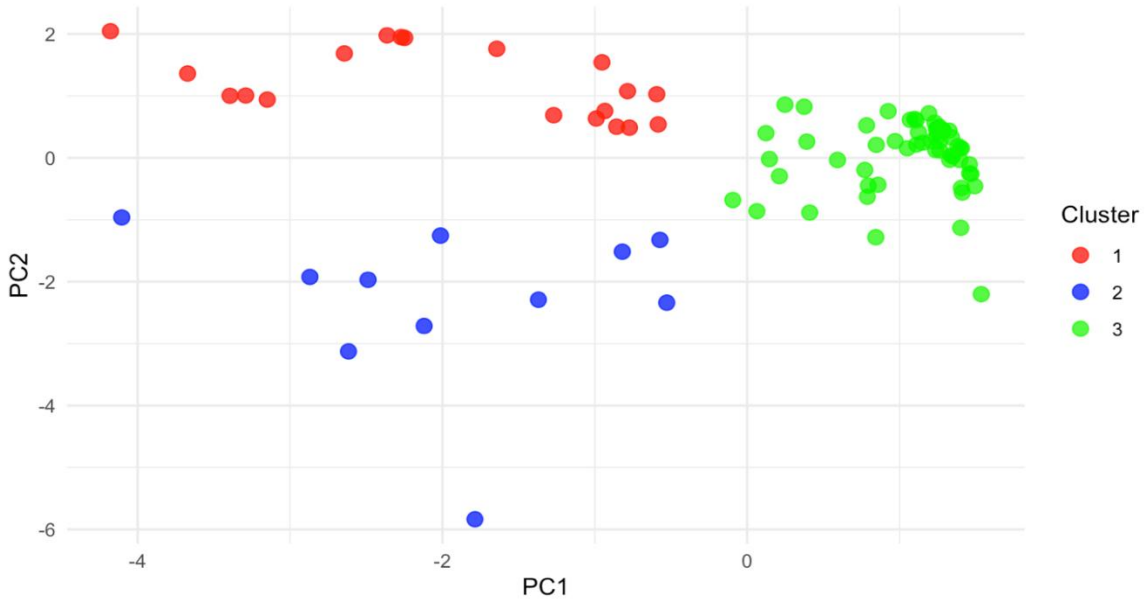


Figure 6. Principal Component Analysis (PCA) plot illustrating the distribution of calls in reduced-dimensional space, revealing three clusters.

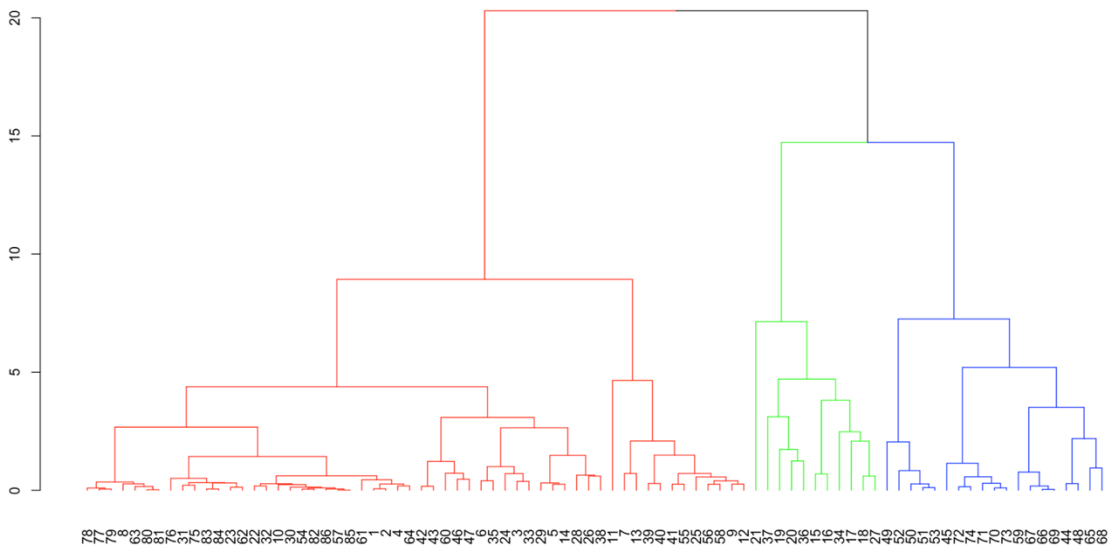


Figure 7. Denrogram generated using hierarchical clustering with Euclidean distance and Ward's method, showing the hierarchical relationship among call types.

Reanalysis of Objective 1 based on Objective 2

The calls were grouped into three clusters based on the cluster analysis results in Objective 2. To redefine these classifications, an adjusted clustering scheme was developed to group the higher frequency calls, trills, and the lower frequency calls together (Table 2). Calls that were not analyzed either in Objective 1 or 2 were excluded from the reanalysis of Objective 1 based on the clustered groupings from Objective 2. A Chi-square test examining the relationship between season and cluster distribution revealed a significant association ($X^2 = 10.939$, DF = 4, $p = 0.027$). Expected observations were all greater than 5, confirming the validity of the association. The scatterplot (Fig. 8) indicated that C1 dominated across all seasons, whereas cluster 2 and 3 had lower call usage across all seasons. The relatively lower proportional usage of C1 in the winter and the relatively higher usage in the pupping and breeding seasons may be a source of the statistical difference.

A Chi-square test evaluating the relationship between light period and cluster distribution was not statistically significant ($X^2 = 9.373$, DF = 6, $p = 0.154$), suggesting no strong pattern for call clustering based on light period (Fig. 9).

A Chi-square test was conducted to assess the interaction between season and light period for the cluster, C1. This is the only cluster that had sufficiently high counts to permit the Chi-square analysis. The test resulted in a statistically significant p-value ($X = 766.35$, DF = 6, $p < 0.000001$), indicating a strong relationship between seasons and light period-specific call patterns. The heatmap (Fig. 10) supports this finding by highlighting the different proportion levels across seasons and light periods. The heatmap followed the same trend as seen in Objective 1 for the WD proportional call usage.

Table 2. The assigned clusters in Objective 2 and the rearranges clusters for the reanalysis.

Cluster	Assigned Call Types	Rearranged Call Types
1 (red)	Whistle Ascending, Whistle Descending, Squeak, High Roar, 3/5 Mid Roar	Whistle ascending, Whistle descending, Squeak, Click, Knock
2 (blue)	Click, High trill, 1/5 Medium trill, 3/5 Knock	Trill, Trill constant
3 (green)	Chug, Chug with rising frequency, Low Trill, 4/5 Medium Trill, Grunt, 2/5 Knock, Low Roar, 2/5 Mid Roar, Tone, Trill Constant, Whoop, Growl, Mew	Chug, Grunt, Low roar, Mid roar, Tone, Whoop, Growl, Mew

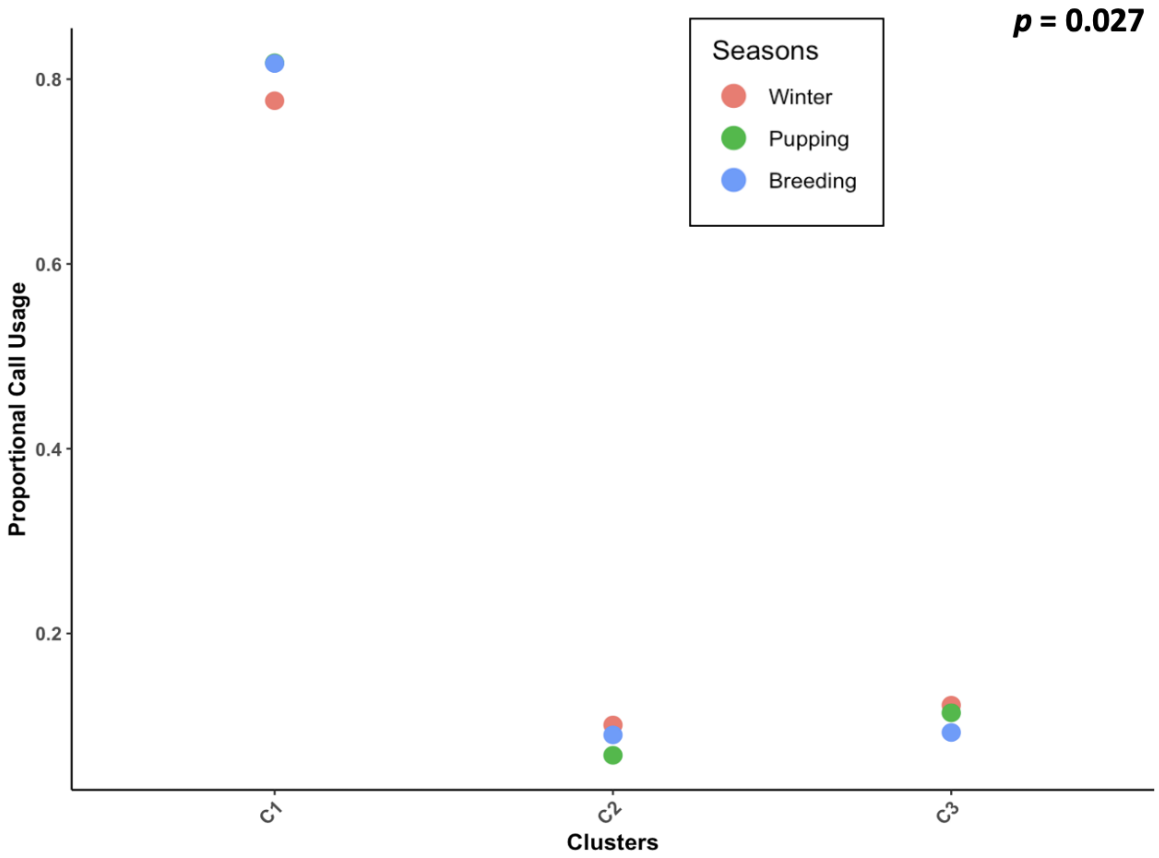


Figure 8. The proportional call usage for each cluster over the three seasons (winter, pupping, and breeding). In C1, the Pupping point is overlapped by the Breeding point.

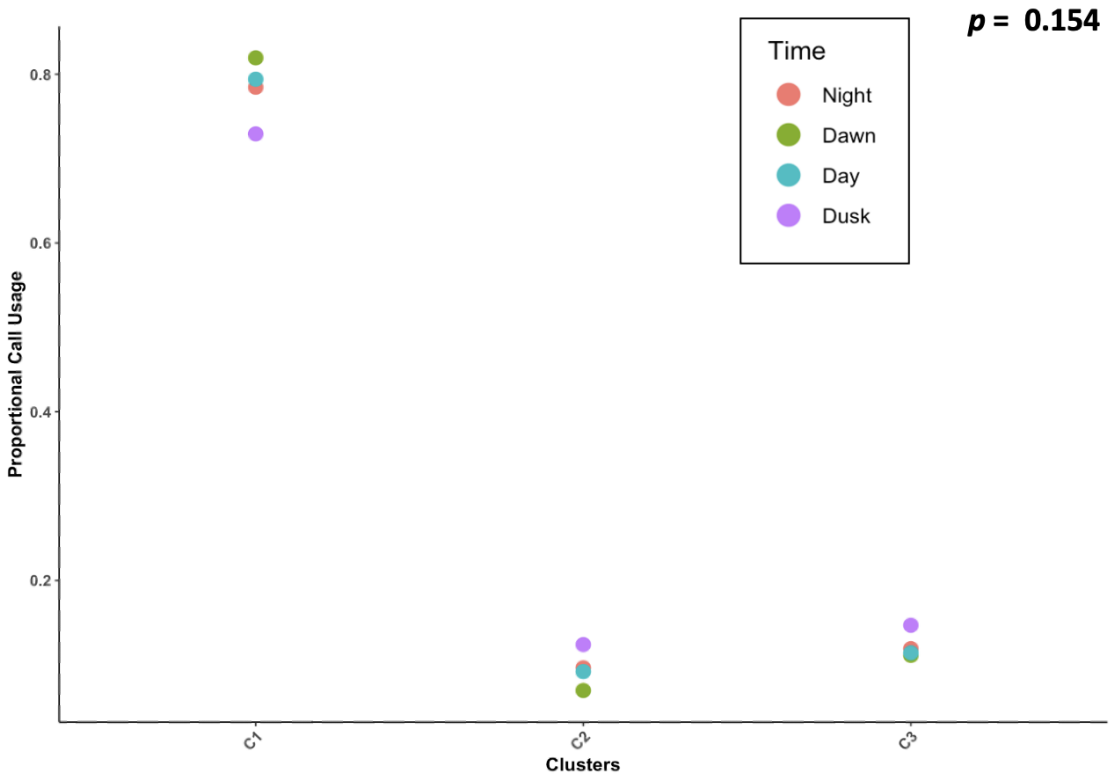


Figure 9. The proportional call usage for each cluster over the four light periods (night, dawn, day, and dusk).

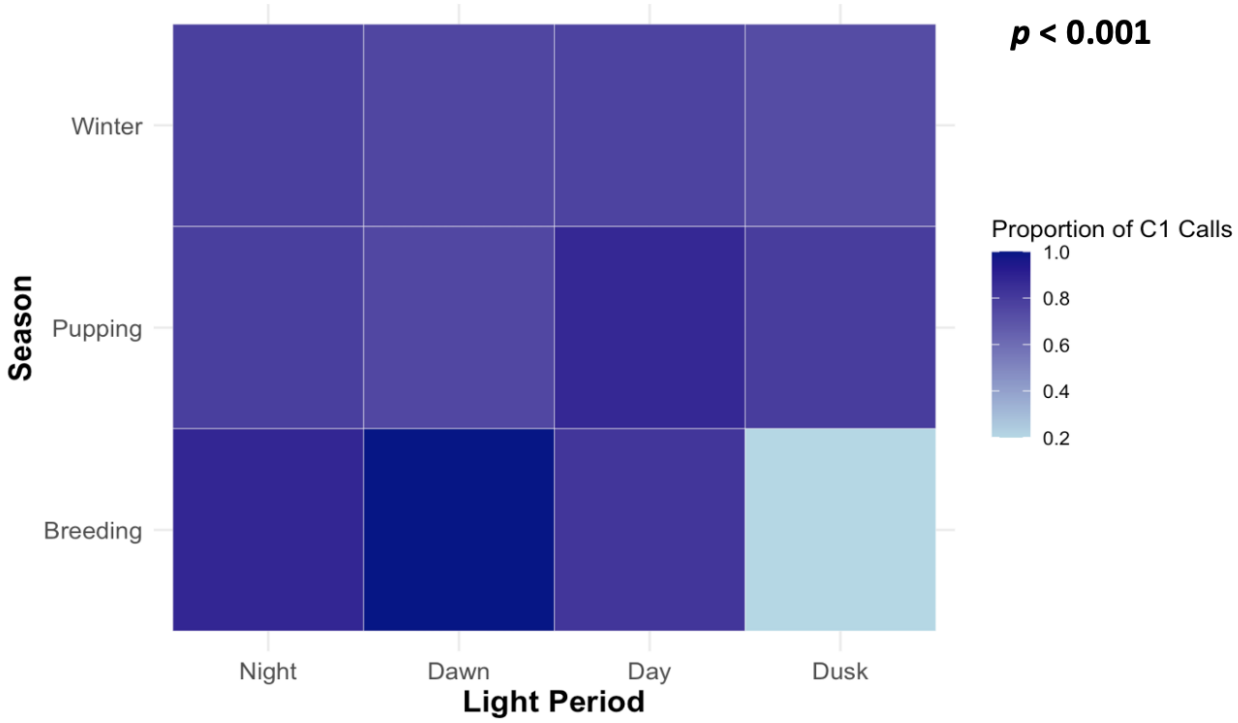


Figure 10. A heatmap showing the proportional distribution of Cluster 1 calls across the seasons (winter, pupping, and breeding) and light periods (night, dawn, day, and dusk).

Discussion

Validity of the Data

The placement and conditions of the recorder may have influenced data collection. In mid-November, the land-fast ice broke up, leaving the recorder in open water. The Weddell seals may have relocated to the nearby fjords where the recorder may have been too far away to detect their calls, affecting seasonal comparisons (Delarue et al. 2022; Simmonds, 2024). Additionally, as the recordings were collected acoustically without direct visual confirmation, factors such as age, sex, or behaviour of the individuals remain unknown (Oetelaar et al., 2003). Trill calls have been identified as a male-specific call type, while the association of other call types with age and sex remain unconfirmed (Oetelaar et al., 2003). This introduces limitations in interpreting call functions and individual variation – whether the calls originated from a few vocal individuals or a broader group remains uncertain. Detection rates may have also been influenced by the distance between the seals and the recorder, potentially underrepresenting quieter, high-frequency, or distant calls.

The validity of the data was carefully considered to ensure the robustness of the analyses. To address potential statistical biases in the Chi-square tests, call types with an expected frequency of less than five were grouped into an “Other” category. This adjustment helps mitigate the influence of low-occurrence call types, ensuring more reliable results. The low occurrence of some call types, along with the fewer days of recordings in the three seasons (7 recording days in winter, 3 in pupping, and 3 in breeding), and the fewer hours of the dawn and dusk recording periods are all factors that can make the sample size unbalanced. Proportional usage analyses have the disadvantage

that when one proportion increases, others have to decrease. The call counts in Simmonds (2024) indicate relative activity, but it is important to measure these counts under consistent durations or conditions. Since the seals were free to move outside the recorder's range, this could have affected the accuracy of the call count analyses. Proportional analyses help mitigate this issue to some extent.

Interpretation of the Results

The analysis of call type usage across seasons, light periods, and season by light period revealed some patterns in Weddell seal vocalizations. While no significant seasonal differences were found in the proportional call type analysis (Objective 1), Whistle Descending (WD) and Whistle Ascending (WA) were the most proportionally used call types across all seasons. In contrast, proportional call usage showed a significant difference, with WD most frequent at dawn and least at dusk, whereas WA peaked at dusk and was least frequent at dawn. A Fisher's exact test confirmed a strong interaction between season and light period for WD calls, with distinct patterns observed across seasons. Clustering analysis identified three call groups – higher frequency calls, trills, and lower frequency calls – validated by PCA and hierarchical clustering. Reanalysing Objective 1 using these clusters revealed a significant seasonal influence on proportional call usage, while no strong association was found with light periods. A Chi-square test revealed a similar strong interaction between season and light period for the cluster analysis, which was consistent with the WD proportional call usage analysis.

WD calls may serve as a submissive function, aligning with Morton's (1977) motivational-structural hypothesis, which suggest that higher-frequency, tonal, calls are

often associated with submission or fear. This interpretation is based on the call's acoustic structure, which is similar to vocalizations in other species that function in a similar manner. While the specific call function of WD calls in Weddell seals remains unclear, the widespread use across season and light periods suggest it might play a role in social cohesion or interactions that consistently occur throughout all the seasons. Further research into the behavioural context surrounding WD calls could provide more insight into the function of WD calls within Weddell seal communication.

Although there were statistically significant differences in proportional call usage by light period and season, these patterns were not consistent. Specifically, changes in proportional call usage were observed across light periods but not seasons for Objective 1, while the reanalysis using the three clusters showed seasonal variations but no differences across light periods. The minimal changes in proportional call usage across both factors suggest that none of the call types, or groups of call types, are primarily associated with reproductive activities. In contrast, other species, such as some birds, have distinct vocalizations linked to breeding. For example, the common cuckoo (*Cuculus canorus*) produces its characteristic "cu-coo" call repeatedly throughout the breeding season to establish territories (Moskát et al., 2021). Unlike birds, these findings indicate that Weddell seal vocalizations do not exhibit strong seasonal or light period-specific patterns, suggesting they are not closely tied to reproductive behaviours.

There were no call types that were found to be unique to, or absent from, any specific season or light period in this study. A similar study conducted by Dorion et al. (2012) in Mawson, Antarctica, found no presence-absence differences in call types across seasons or light periods. In contrast, this study found no significant difference in

proportional call usage across seasons, but a significant difference was observed across light periods. Both studies revealed that no call types were primarily associated with breeding. In comparison, Russell et al. (2016) in McMurdo Sound, Antarctica, provided strong evidence that vocalizations played an important role during courtship. Their study, alongside significant behavioural sequences, both vocal and non-vocal, offered deeper insights into the function of vocalizations during this period. Together, these studies suggest that while vocalization may play a role in specific behaviours, including courtship, they do not appear to be strongly associated with breeding vocalization patterns in the same way across different Antarctic locations.

Contributions to Thesis

This research is driven by two primary objectives aimed at understanding the variation in Weddell seal call types. The first objective involves analyzing call types across different seasons, light period, and season by light period. The original recordings for this analysis were provided by Mr. John van den Hoff and Dr. Brian Miller of the Australian Antarctic Division (AAD). Call types were identified by Ms. Emma Simmonds during her 2024 honours research. Through this objective using the programs R and R Studio, I explored the patterns in proportional call usage over seasons, light periods, and season by light period.

The second objective centres around determining the similarities between Weddell seal call types. For this part of the study, I received sample recordings from Dr. John Terhune. I made the duration and frequency measurements of these sample calls using a program called Raven Pro. I ran analyses to cluster the call types into three groups, which were analyzed for the proportional usage across seasons, light periods, and season by light period. This approach was expected to provide a more robust interpretation of how call usage varies across the factors I analyzed.

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