A project supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB).

Report for Collaborative Oceanography and Monitoring for Protected Areas and Species (IVA5015)

T4.4.2
Marine Mammal Report II:
Baleen whale detections in Scottish Seas

27/10/2020

Report by: Agri-Food & Biosciences Institute, Scottish Association for Marine Science and Marine Scotland Science

Report author: Catherine Gibson, Suzanne Beck, Simon von Sachsen-Coburg und Gotha, Denise Risch, Ewan Edwards

Executive Summary

This report aims to characterize the seasonal and diurnal patterns in two vocalizing baleen whale species in Scottish waters from the start of the COMPASS project to early 2019. The two focal species are the humpback whale (*Megaptera novaeangliae*) and minke whale (*Balaenoptera acutorostrata),* both species are regularly sighted in this region. Humpback whales and minke whales are both vocal species which makes them suitable candidates for passive acoustic monitoring. Baleen whales are protected by numerous pieces of legislation from international level to local level.

Soundtrap acoustic recorders (Ocean Instruments, New Zealand) were deployed at 10 sites throughout the study region between November 2017 and June 2020. Soundtraps were programmed to record at a sample rate of 96 kHz and with a duty cycle of 20 minutes every 60 minutes. The **analysis of humpback whale song** in this report considers a preliminary analysis of data from the Tolsta and Stanton Bank from November 2017 to February 2019. **Minke whale pulse trains** were analysed for data from five Scottish moorings deployed at Tolsta, Stoer Head, Shiant Isles, Hyskeir and Stanton Bank.

Humpback whale song was only detected between March and May at both sites producing a highly seasonal spring with no detections in the autumn. The timing and duration suggested this area is a migratory stopover for humpback whales on northbound migration. The presence of humpback whale song did not vary over the diel cycle. The song contained 15 units in six themes to be used in future studies to explore humpback whale song progression and transmission. The results from this study can be used to inform more effective conservation methods for humpback whales in the Northeast Atlantic.

A striking spatial pattern was discovered by this preliminary analysis with the overwhelming number of detection positive days for minke whales recorded at Stanton Bank yet few detections at other sites in the Inner Hebrides waters. This pattern might be related to a sexual segregation of minke whales on their summer feeding grounds. More work is needed however to confirm this proposition. At Stanton Bank, a clear diel pattern in acoustic detections was recorded (Figure 6). Most vocalisations occurring during night and the hours of dusk and dawn were visible for the months of April and May 2018

This work highlights the utility of broad-scale networks of acoustic monitoring moorings for monitoring protected areas and species year-round.

Contents

1. Introduction

Baleen whales in the Northeast Atlantic

Both humpback whales (*Megaptera novaeangliae*) and minke whales (*Balaenoptera acutorostrata*) are regularly sighted in UK coastal waters although minke whale sightings are the most common in the summer months (Reid, et al., 2003). In this region, minke whales have been visually observed mainly from April to October, although sightings have been documented year-round (Macleod, et al., 2004; Dolman et al., 2013; Northridge et al., 1995). As there is less survey effort in winter, it is unclear to what extent this occurrence pattern reflects observation effort. Off the coast of Scotland, minke whale visual sightings peak from July to August and have been shown to be related to meso-scale oceanographic features which likely link to increased foraging opportunities (Robinson et al. 2009).

There is a lack of information on the status of humpback whales in the Northeast Atlantic in comparison to other parts of the North Atlantic (Ryan et al. 2016). However, humpback whales are frequently observed in southern Irish waters, where they are known to feed on sprat (*Sprattus sprattus*) and herring (*Clupea harengus*; Ryan et al. 2014). Although, it is currently unknown if these waters are used as an over-wintering ground for non-breeding whales, a migratory corridor or are a key foraging ground. (Stevick et al. 2003). There has also been an increase of sightings of humpback whales off the west coast of Scotland in recent years (Risch et al. 2019). However, few consistently collected sightings data exist and it is not clear whether this constitutes an increase of animals visiting this area or a result of increased visual effort in recent years (Risch et al. 2019). Humpback whales undertake one of the best describe migration routes in the animal kingdom (Whitehead & Rendell, 2014) between sub-tropical & tropical breeding grounds (winter) and higher latitude feeding grounds (summer; e.g. Bettridge et al. 2015). Not all individuals of a population will migrate every year, with some individuals over-wintering in the high latitude feeding grounds (e.g. Corkeron & Connor, 1999; Mobley et al. 1999; Clapham, 2000; Magnúsdottir et al. 2014). There are thought to be two breeding populations in the North Atlantic, those that breed around the Caribbean and those that breed around the Cape Verde Islands (Wenzel et al. 2020). There is also evidence that minke whales undertake seasonal migrations in the North Atlantic (Risch et al. 2014) and two separate breeding population in the North Atlantic have been proposed (Anderwald et al. 2011).

Humpback whales and minke whales in the North Atlantic are currently listed as a species of 'least concern' under the International Union for Conservation of Nature (IUCN) red list. The status of humpback whales was changed from 'vulnerable' in 2008 (IUCN, 2018) due to the increased population size and it is currently estimated that there are around 12,000 individuals in the North Atlantic (NOAA, date accessed: 15/5/19). Humpback and minke whales are protected by a variety of legislation in the Northeast Atlantic at international (Bonn & Bern conventions) and local level (listed as a priority species in Northern Ireland (Northern Ireland Biodiversity Strategy (2002) & Scotland- (Marine Scotland Act 2010). All cetaceans are also protected species under the European Union Habitats Directive (European Commission, 2019) and EU member states are required by law to maintain 'favourable conservation status' and report on the status of protected species. All Irish waters within the Irish EEZ were declared a whale and dolphin sanctuary in 1991 by the Irish Whale and Dolphin Group (IWDG; Rogan & Berrow, 1995). Due to this collective legislation, there is a need for a better understanding of their distribution and population status throughout the Northeast Atlantic. Such information is essential as baleen whales face many threats including underwater noise, pollution, and entanglement in fishing gear and ship strike (Weilgart, 2007; Guzman et al. 2013; Ryan et al. 2013; Bettridge et al. 2015). Entanglement in fishing gear in particular is a serious risk to humpback and minke whales and it has been suggested, that Scottish waters could be an area of high mortality for baleen whales in the North Atlantic (Ryan et al. 2016). Data from the UK stranding scheme suggest that entanglement in fishing gear is a significant cause of death also for minke whales in Scotland, with over 50% of necropsies between 1990 and 2010 confirming entanglement (Northridge et al. 2010). More recently in 2015, three out of four stranded minke whales investigated at post mortem in Scotland died because of entanglement (Deaville et al. 2016). Minke whales are also still commercially hunted in parts of their summer range (Risch et al. 2019). Presently, it is impossible to report on the year-round status of humpback and minke whales in Northern Irish and Scottish waters, with data missing especially for winter months (Risch et al. 2019).

Humpback whale vocalisations

As a highly vocal species, humpback whales rely on sound for many important functions such as communication, foraging and finding a mate (e.g. Silber 1986; Dunlop et al. 2008). Their vocalisations can be categorised into song and non-song vocalisations (known as calls). The male humpback song is probably one of the best studied sounds in the animal kingdom and was first recorded from US Navy hydrophones in the late 1960's (Payne & McVay, 1971). Humpback whale song has a source sound level of roughly 155dB (re 1 µ Pa at 1m (Levenson, 1972; Au et al., 2006)), with frequency ranges from 100 Hz - 4kHz (Tyack & Clarke, 2000) and harmonics ranging to 24 kHz (Au et al., 2006). A song is defined as "a series of notes, generally of more than one type, uttered in succession and so related as to form a recognizable sequence or pattern in time" (Payne & McVay, 1971). Humpback whale song has a hierarchical, predictable structure from song units to song sessions ((Payne & McVay, 1971; Cholewiak, Sousa-Lima, Cericho, 2013). Discrete sounds are called units, several different units are then arranged in a phrase and this phrase is repeated a number of times (the number of repetitions can vary). The series of the same phrase repeated is called a theme and the singer will sing one theme for a number of minutes and then move on to the next one (Payne & McVay, 1971). Generally, humpback whale songs contain six different themes but this can vary spatially and temporally (i.e. between populations; Payne & McVay, 1971). The sequence typically lasts around 10-15 minutes and this sequence is then repeated without breaks, sometimes for hours (Payne & McVay, 1971; Winn & Winn, 1978). Humpback whale songs are transmitted via social learning so are therefore subject to cultural changes over time (Payne, Tyack & Payne, 1983) both evolutionary (slow and progressive) and revolutionary (rapid and dramatic; Payne & Payne, 1985; Garland et al. 2011; Allen et al. 2018).

Minke whale vocalisations

The sounds that minke whales produce are known to vary across their geographic range. In the past, series of clicks in the 5 – 6 kHz range, as well as lower frequency downsweeps (118 – 80 Hz) have been attributed to the species in the North Atlantic (Beamish & Mitchell 1973; Edds-Walton 2000). These call types have typically been described during short-term studies, in specific locations and not regularly been documented across habitats. Longer-term time series of these calls are to our knowledge currently not available. In contrast, low-frequency pulse trains (50 – 400 Hz) with varying inter-pulse interval structure were recorded in the presence of minke whales in the Caribbean, and subsequently documented and further described from recordings made in Massachusetts Bay (Mellinger et al. 2000; Risch et al 2013).

The Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS) project

Data used in this report are collected across a passive acoustic array deployed as part of the EU INTERREG VA Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS) project. The array comprises a network of 10 acoustic moorings deployed to monitor ambient noise and vocalising species within and surrounding, protected areas. Through this the project aims to develop long-term strategies to protect mobile species, in particular, cetaceans, and to provide baseline information on noise levels in the study area. The COMPASS acoustic array is located in the inner seas off the west coast of Scotland, Northern Ireland, and County Donegal in the Republic of Ireland (Figure 1). The acoustic moorings were first deployed in November 2017.

The purpose of this report is to characterise and present preliminary patterns in humpback whale song and minke whale pulse train detections across the COMPASS array, and to describe the structure of humpback whale song found in the region. This analysis is currently still ongoing and all sites will be analysed across all available years for both species.

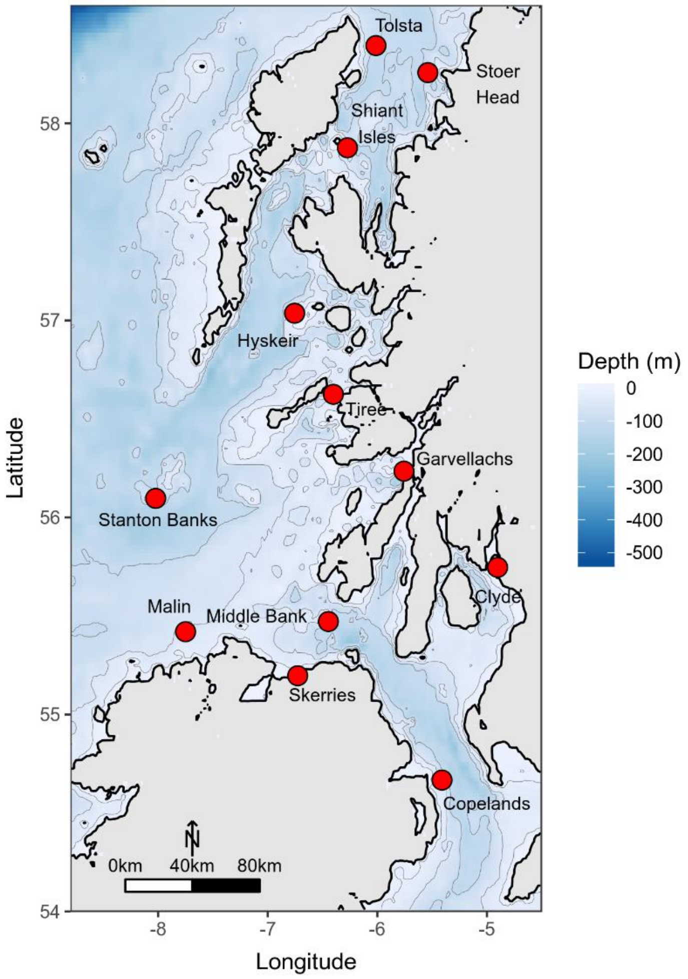

Figure 1. The COMPASS acoustic array, showing all recording sites. Note, not all data from each site was analysed. In general, the baleen whale detection analysis was centered on the more offshore sites considering the reduced probability of detecting low frequency baleen whale calls in shallow waters due to propagation effects.

2. Materials and Methods

Data collection and analysis period

Soundtrap (ST300) acoustic recorders (Ocean Instruments, New Zealand) were deployed at 10 sites throughout the cross-border region of Scotland, Northern Ireland and the Republic of Ireland between November 2017 and June 2020. Soundtraps were moored together with a C-POD click detector (Chelonia Limited, UK) for detection of high frequency cetaceans, using a VR2AR (VEMCO Limited, Canada) acoustic release and an RS Aqua ARC acoustic release canister (RS Aqua, UK). The recorders were moored approx. 5m above the seabed for six months at a time and actively collecting data for a maximum of 156 days. Soundtraps were programmed to record at a sample rate of 96 kHz and a duty cycle of 20 minutes recording every 60 minutes.

The **analysis of humpback whale song** in this report considers a preliminary analysis of data from the Tolsta and Stanton Bank from November 2017 to February 2019 (see Table 1). **Minke whale pulse trains** were analysed for data from five Scottish moorings deployed at Tolsta, Stoer Head, Shiant Isles, Hyskeir and Stanton Bank. While data from most sites were analysed for November 2017 to June 2018, data from the site with most initial detections, i.e. Stanton Bank, was analysed up to February 2019 (Table 2).

Table 1. Deployment locations and data used in humpback whale analysis

Location	Latitude	Longitude	Depth (m)	Start date	End date
Stanton Bank	56.096783	-8.022783	110	25/11/2017	09/02/2019
Tolsta	58.394697	-6.012348	102	01/03/2018	10/06/2018

Table 2. Deployment locations and data used in minke whale analysis

Location	Latitude	Longitude	Depth (m)	Start date	End date
Tolsta	58.394697	-6.012348	102	10/11/2017	10/06/2018
Stoer Head	58.257497	-5.538608	106	10/11/2017	12/04/2018
Shiant Isles	57.876122	-6.272677	84	09/11/2017	13/04/2018
Hyskeir	57.036327	-6.754578	54	08/11/2017	10/06/2018
Garvellachs	56.234868	-5.756675	95	08/11/2017	16/06/2018
Stanton Bank	56.096783	-8.022783	110	25/11/2017	09/02/2019

Humpback whale detection and detector validation

The "whistle and moans detector" module of PAMGuard Beta V 2.00.16 was used to detect humpback whale vocalisations (Gillespie et al. 2008) using a bandpass filter of 0-5000 Hz to select frequencies that are in the range of humpback whale song vocalisations (Thomson et al. 1979; Payne et al. 1983; Silber, 1986). The "whistle and moans detector" extracts contours of tonal sounds from the spectrogram display by running a Fast Fourier Transform (FFT) data (FFT length 512, FFT hop size 256, and Hann window). The detection contours were saved to binary folders and a SQLite database. In order to conduct reliable statistical analysis, the automated whistle and moan detector underwent quality control assessments by manually inspecting the detections to ensure it was suitable for detecting humpback whale vocalisations.

The efficacy of the "whistles and moans detector" at each site (Tolsta & Stanton Banks) was investigated using a test dataset of a 10 day subsample of recordings, where good examples of detected humpback whale vocalisations were found (Tolsta: 24/3/18- 3/4/18; Stanton Banks: 23/3/18- 2/4/18). The humpback whale detection metric was based on presence/absence in 20 minute bins as this was the recording schedule of the devices to maximise the length of time devices could be deployed for on a single battery pack. The test was to investigate whether the detector could identify vocalisations in each 20 minute period rather than each individual sound unit being detected. As the devices only recorded for the first 20 minutes of each hour, if humpbacks were detected in the 20mins then the whole hour was marked as vocalisations present. The sample of data was manually examined and all hours with humpback vocalisations detected were recorded. The same sample was then processed using the detector and compared with the manual result with false positives (falsely detected song) and negatives (missed song detection) recorded. If the detector results were satisfactory (i.e. over 90% of humpback vocalisations detected (<10% false negative) then the detector was used to scan all the data in the study.

Hours were marked as present if humpback whale song vocalisations were detected within the 20 minutes recording of each hour. For investigating the diel patterns, each day that had humpback whales detected was further investigated by manual (visual and aural) scanning and each hour was marked with presence/absence of humpback whale vocalisations. The data was Bernoulli distributed which is a special case of the binomial distribution, and this had to be taken into account when analysing and modelling the data. Time since sunrise (from www.timeanddate.com/sun) was used to investigate any diel patterns in the humpback whale detection data.

Minke whale detection

To focus the analysis on low frequencies for detection of minke whale pulse train presence, all data was initially downsampled to a sample rate of 2 kHz using the Decimator module in PAMGuard (Gillespie et al. 2008) and applying a low-pass 4th order Butterworth filter. A random subsample of 100 days, 10 days from each site, collected in 2016, was then reviewed visually and aurally, using spectrograms (FFT length 2048, 75% overlap, and a Hanning window) created in XBAT (Figueroa & Robbins 2008). After confirmation of minke whale pulse train presence at several recording sites, an automated detection algorithm, originally developed for pulse trains from the western North Atlantic, was used to analyse data from the COMPASS array. The detector was run in a batch process on sound files loaded in XBAT. The automatic detection consisted of a multi-stage process based on spectrogram intensity binarisation, energy projection, feature extraction and finally pulse train detection and classification (Popescu et al. 2013). The detector design and performance for data from the western Atlantic is described in more detail in Popescu et al. (2013). For the purposes of this report, the detector was not further evaluated. However, analysis of a subset of data from the Scottish east coast analysed with the same detector recently yielded recall and precision values of 74% and 20%, respectively. The false positive rate was 11% (Risch et al. 2019).

Due to expected similarly low precision values, all detection files were viewed with Raven Pro 1.5 (The Cornell Lab of Ornithology, 2019), to verify detector output and discard all false positive detections.

Seasonal and diel pattern in minke whale detections

After manual review of all detection hours recorded all false positive detection hours were removed from the final dataset, resulting in a time-series of minke whale pulse train presence at a daily resolution for each of the five recording sites.

Recordings from Stanton Bank produced the highest number of minke whale detections. This data set was therefore used to investigate the diel pattern of minke whale pulse train distribution. A pulse train detection was counted as animals present in that hour and the analysis moved on to the following detection hour. Similar to the daily analysis, detections were numbered one, no detection hours zero.

To investigate number of detections based on light regimes, the hourly detection dataset was divided into daylight occurrence (day/night/twilight) based on the ‘suncalc package’ (Thieurmel, 2019) for the R software (R Core Team, 2019). The ‘suncalc package’ was used to determine the times of sunrise, sunset and twilight (dusk/dawn) for the Stanton Bank coordinates from March – May 2018. Dusk and dawn were specified from where the sun’s geometric centre is between 0° and the nautical twilight of 12° below the horizon. To test the null hypotheses that the difference between the means of the three light regimes was equal to zero, the data were tested first for normal distribution (Shapiro-Wilk test) and subsequently tested for differences between the light regimes with the Kruskal-Wallis test. To further compare significant differences between the light regimes, the Wilcoxon matched pair test with Benjamini & Hochberg corrections ($\propto = 0.05$) was used. All tests were conducted with the R-Studio 1.1.463 software (R Core Team, 2019). The data were plotted as the average and standard deviation by light regime.

Seasonal and diel pattern in humpback whale song

All data analysis were conducted using freeware R and R Studio using the MGCV library (Wood, 2006). Data exploration was undertaken prior to statistical modelling, in which outliers, collinearity and relationships between variables were investigated following the methods in Zuur et al. (2009). Analysis considered the presence/absence of humpback whale vocalisations across site, month and the standardised time since sunrise (month and time since sunrise both had cyclical smoothers applied). To investigate patterns in humpback whale song occurrence, a BAM (big additive model similar to a generalized additive model (GAM) was used to relate the predictor variables (month, site and time since sunrise) to the response variable (humpback whale presence/absence (HBW P/A; e.g. Embling et al., 2010).

A BAM model fits a GAM to a very large data set and the degree of smoothness of model terms is estimated as part of fitting (Wood, 2019). A BAM was constructed a priori based on biological knowledge and all variables were biologically meaningful and were therefore retained in the final model. The model included the predictor variables of site (Stanton Banks & Tolsta), month and time since sunrise. A cyclical smoother ('penalised cubic regression spline whose ends match up') (mgcv package manual 1.8-28) was applied to the time since sunrise and month variables (Wood, 2006). The formula used for the BAM was:

$$hbw_i \sim \text{Bernoulli}$$
$$E(hbw_i) = p$$
$$Var(hbw_i) = p(1-p)$$
$$Logit(hbw_i) \sim s(TimeSinceSunStd_i, bs = "cc") + s(M_i, bs = "cc") + sitec_i$$

Where hbw_i represents the probability of a humpback whale detection for the *i*th observation, $TimeSinceSunStd_i$ is the standardised time since sunrise in minutes, M_i is month of the year and bs=cc, denotes the use of a cyclical smoother for these variables. The last model variable, $sitec_i$ is a site code (1=StantonBanks & 2= Tolsta). P denotes the probability mass function, E denotes the expected value and var denotes the variance. Model validation was applied on the optimal model to verify the underlying assumptions of the model (Zuur et al., 2010). The observations were not statistically independent due to temporal autocorrelation (e.g. a form of pseudo replication; Hurlbert, 1984), therefore the final model contained a temporal autocorrelation structure to account for this.

The final model was used to predict the likelihood of a humpback whale detection in different temporal conditions. The effect of individual variables on the probability of humpback whales were graphically visualised from the GAM output summary and using the ggplot2 package.

Describing humpback whale song

RavenPro 1.5 (Bioacoustics Research Program, 2014) was used for visualising the song spectrogram and extracting the parameters of each unit. A good example of humpback whale song was used to make measurements and describe the song structure. Both sites contained the same song so only one was used to take measurements. Only signals with a high signal-noise ratio (SNR) were used in analysis. The SNR was measured by importing the song example sound file into RavenPro and measuring the sound level of the signal and measuring the background noise sound level and the difference in these is the signal to noise ratio. A high signal to noise ratio ensured that the maximum amount of the signal was detected and there was a minimal risk that not all of the signal was detected. This process was carried out 10 times throughout the duration of the recording to calculate an average SNR for the sound clip. Signal parameters were extracted from the humpback whale song and recorded, these were; max frequency (Hz), min frequency (Hz), peak frequency (frequency at which maximum energy occurs; Hz), max power (dB), energy (dB) and duration of signal (s), see Raven Pro 1.5 user manual for further details. The song units were detected both visually and orally and categorized into phrases and themes. A unit was defined as "the shortest sound in the song which seem continuous to the human ear" (Payne & McVay, 1971) and a theme as "an unbroken sequence of similar phrases (series of units)" (Payne & McVay, 1971).

3. Results

Descriptive summary

For both sites used for the **humpback whale analysis** combined, recordings were made on 648 days between 10th November 2017 and 9th February 2019 (351 days at Stanton Banks and 297 days at Tolsta). At Stanton Banks there were no acoustic data collected in October due to logistics of the ship schedule. A battery pack failure meant that no data was available for Tolsta in January and February 2018. Considering all available data, humpback whales were detected on 43 days at Stanton Banks and 16 days at Tolsta. Data used for the **minke whale analysis** were made on a total of 798 days (Tolsta: 139 days, Stoer Head: 154 days, Shiant Isles: 156 days, Hyskeir: 206 days, and Stanton Bank: 330 days). Most detection positive days were recorded at Stanton Bank (143 days). At Hyskeir 5 detection positive days were recorded. At both Tolsta and the Shiant Isles 4 detection positive days were recorded. No detections were made at Stoer Head.

Humpback whale song seasonal and diel patterns

All detections were between the months of March and May (Figure 2). The first humpback whale was acoustically detected on the 4th March 2018 at Stanton Banks and on 12th March 2018 at Tolsta (Figure 2). At Stanton Banks, humpback whales were present nearly every day until the 14th April 2018 (9 days with no detections) and then detections were less frequent until the last detection on the 29th May. The longest consecutive period with detections was 11 days from 23rd March 2018 to 2nd April 2018 (Figure 2). Humpback whales were not present as frequently at Tolsta compared with Stanton Banks, with the longest period of consecutive detections being 10 days from 23rd March 2018 to 1st April 2018 (Figure 2). Detections at Tolsta became less frequent with only a couple of days with detections until the 5th May 2018, when the last detection was recorded. There was no significant difference in the detection positive hours per day between the sites (Wilcox test, p=0.2706). When the raw data from investigating the diel cycle were plotted, they showed that humpback whales were detected throughout the diel cycle with no real pattern (Figure 3).

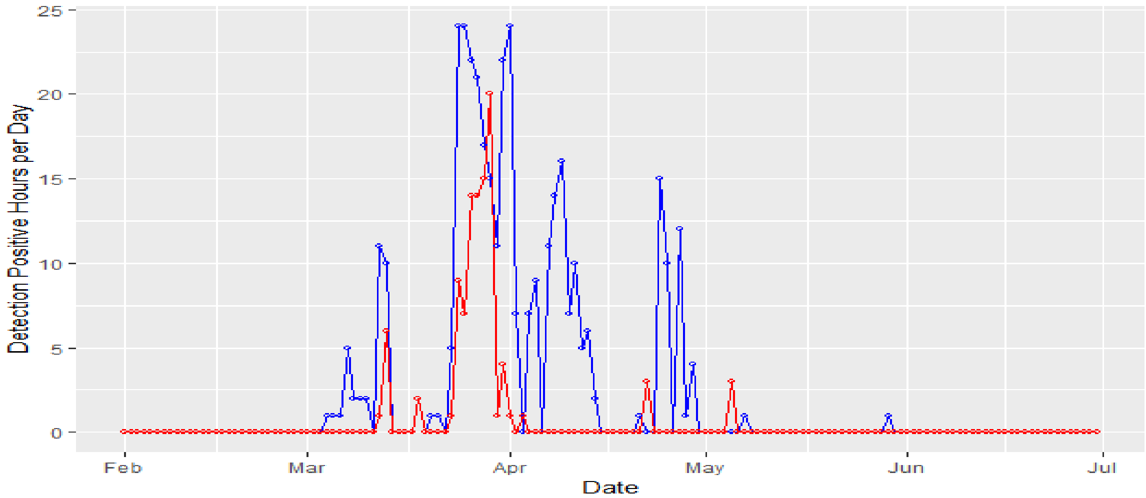

Figure 2. Detection positive hours per day of humpback whale song at both sites; blue: Stanton Bank, red: Tolsta.

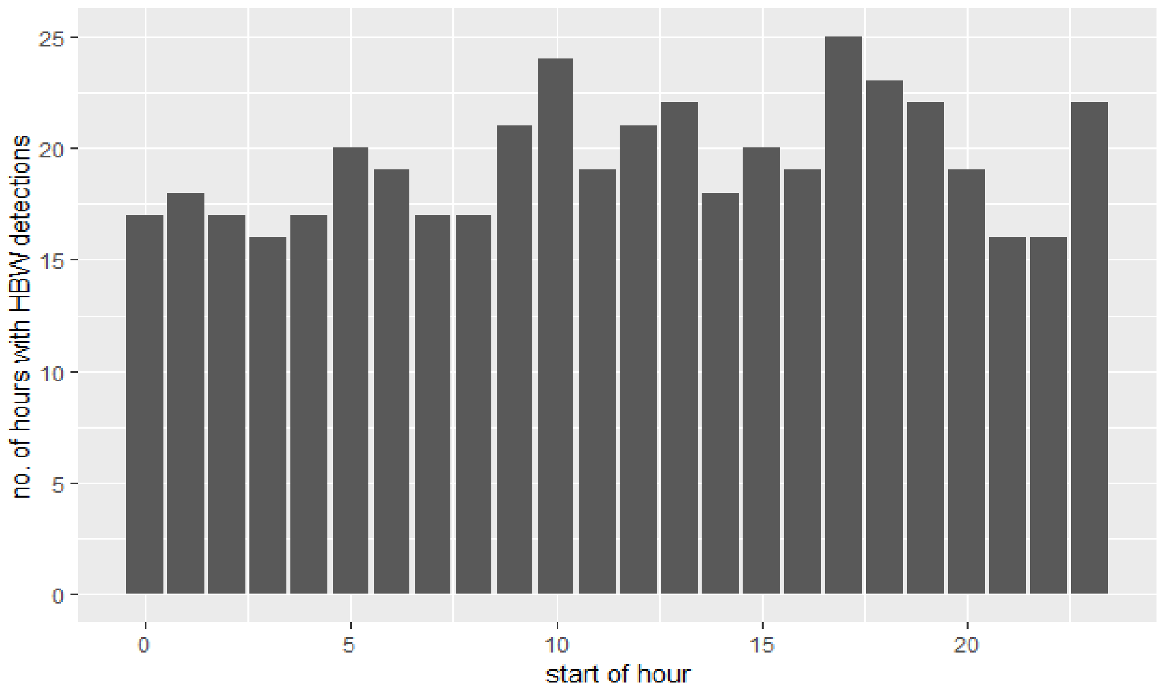

Figure 3. Number of detection positive hours across the diel cycle of both sites combined.

The BAM model confirmed that the recording site and month were significant covariates in determining the probability of a humpback whale detection and the time since sunrise was a non-significant covariate with regards to detection of humpback whales. Month (i.e. seasonality) was the best explanatory variable for humpback whale presence at Stanton Banks and Tolsta, explaining 39.5 % of the variance. This was calculated by subtracting the percentage variance explained when removed the desired covariate from when no covariates were removed i.e. 2.86% variance explained when the covariate Month was dropped from the model subtracted from the 42.4% variance explained when no covariates were dropped (Table 3). The model showed that it was more likely to detect a humpback whale singing (at both sites) between February (month 2) and June (month 6) than the rest of the year (Figure 4). The model also predicted that the time since sunrise was not significant in the detection of humpback whale vocalisations, i.e. there was no diel pattern with humpback whale singing at Tolsta and Stanton Banks. The location of the site was significant in determining humpback whale presence ($p < 0.05$) but it only explained 4.1% of the variance in the model (Table 3).

Table 3. Showing which explanatory variable was the most effective for explaining humpback whale presence at Tolsta and Stanton Banks using the variance explained when each covariate was dropped from the final model and the fREML scores (lower score indicates a better fit).

Model number	**Covariate dropped**	**fREML score**	**% variance explained**
m7	None	10438	42.4
m8	Sitec	10523	38.3
m9	TimeSinceSunStd	10438	42.3
m10	Month	11257	2.86

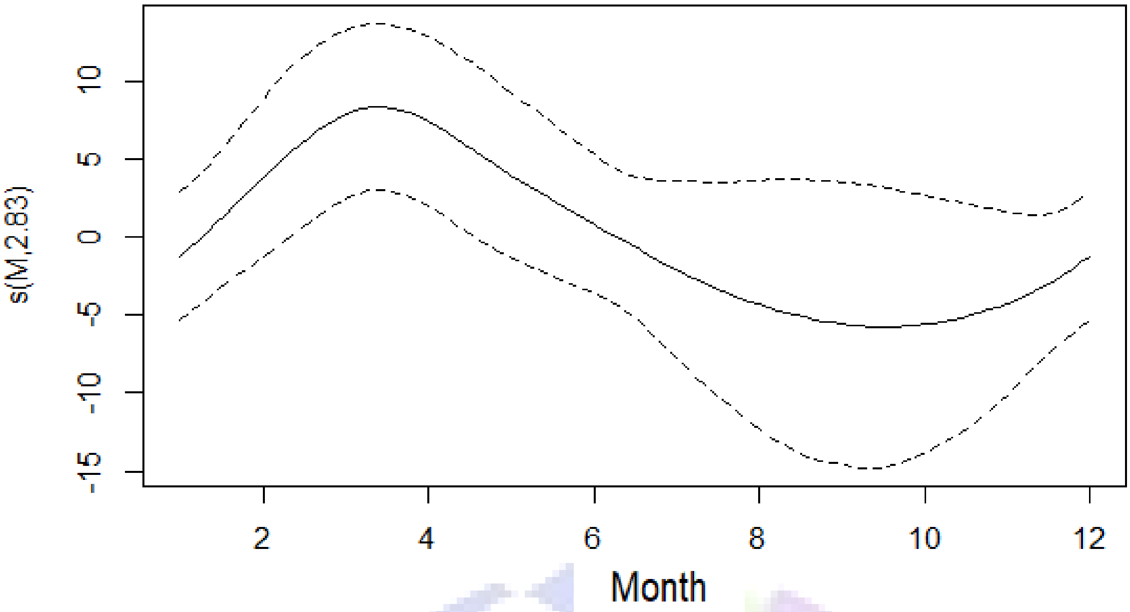

Figure 4. Model of seasonal presence of humpback whale song at Stanton Banks and Tolsta.

Minke whale seasonal and diel patterns

Across the whole array, most minke whale pulse trains were recorded in April and May 2018. Minke whales were detected at four of the six stations with the majority of detections recorded at the Stanton Bank recording site (Figure 5). Here, minke whales were detected from late March to at least mid-September. For the winter period, only one detection was made on the 11th of November 2017 at Tolsta (Figure 5). No pulse trains have so far been detected from December to February, although more data from the winter period still needs to be analysed.

Detections of minke whale pulse trains showed a statistically significant diel pattern between the three groups of light regimes: daylight, night and dusk/dawn (Figure 6). Testing the mean-adjusted averages dataset for normality (Shapiro-Wilk test, W = 0.82613, p < 454 2.2^{-16}) showed no normal distribution and the differences between the light regime adjusted average means showed to be statistically significant (Kruskal-Wallis test, $x5$ = 103.73, df = 2, $p < 2.2^{-16}$). The comparison of means between groups (Wilcoxon matched pair test, $\propto$ = 0.05) were significant between day and night ($p < 2^{-16}$) and night and twilight (p = 9.9^{-6}).

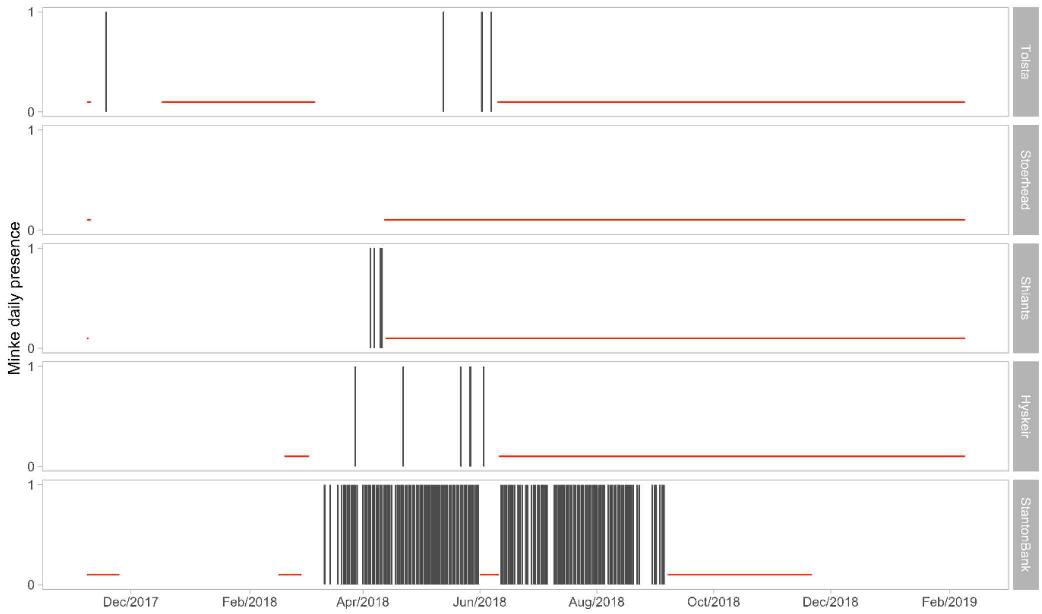

Figure 5. Seasonal distribution of minke whale pulse train detections for the data analysed so far. Red bars represent missing data or data not yet analysed.

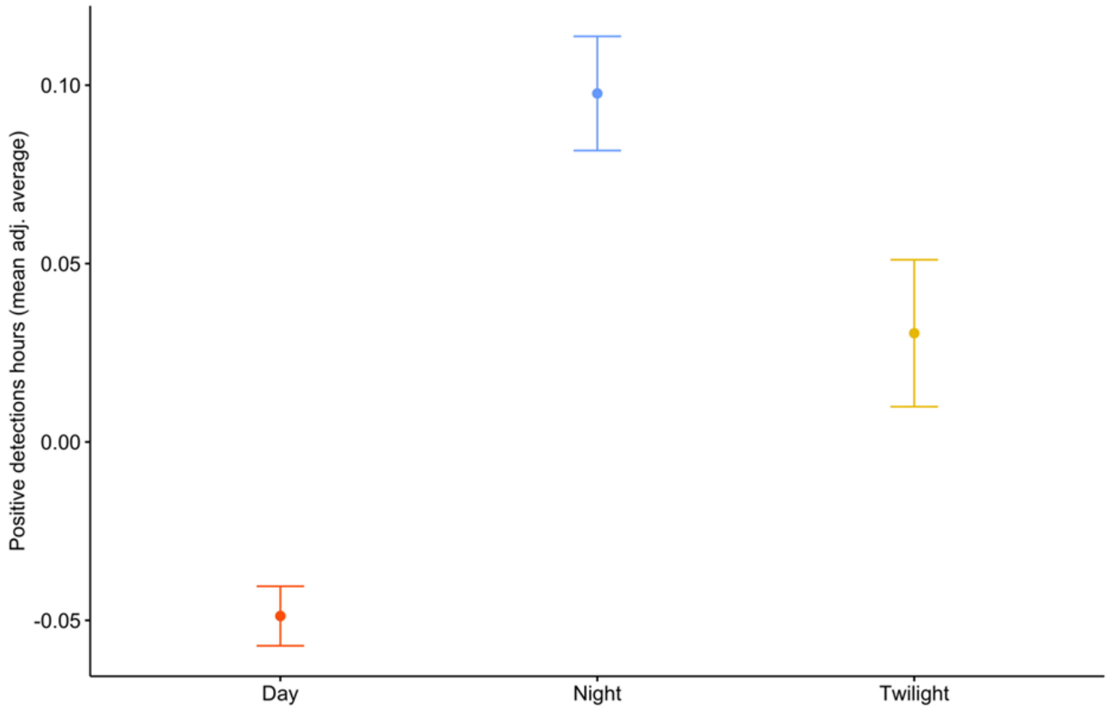

Figure 6. Mean-adjusted average number of hours by day and light regimes over the period March – May 2018 at Stanton Bank.

Description of humpback whale song

Six themes and 15 units were identified in the song recorded at the two study sites, see Table 4 for parameters of each unit and Table 3.5 for the general sequence of these units in the song. Units, phrases, and themes were defined using standard terminology following Payne & McVay (1971). An example of the spectrogram of each unit is shown in Figure 7 and a spectrogram of the song recorded in shown in Figure 8. Due to the recording schedule of the Soundtraps (20 mins every 60mins), the full song cycle may not have been captured within this window but the units and themes described and shown in Tables 4 and 5 were found at both Tolsta and Stanton Banks throughout the study.

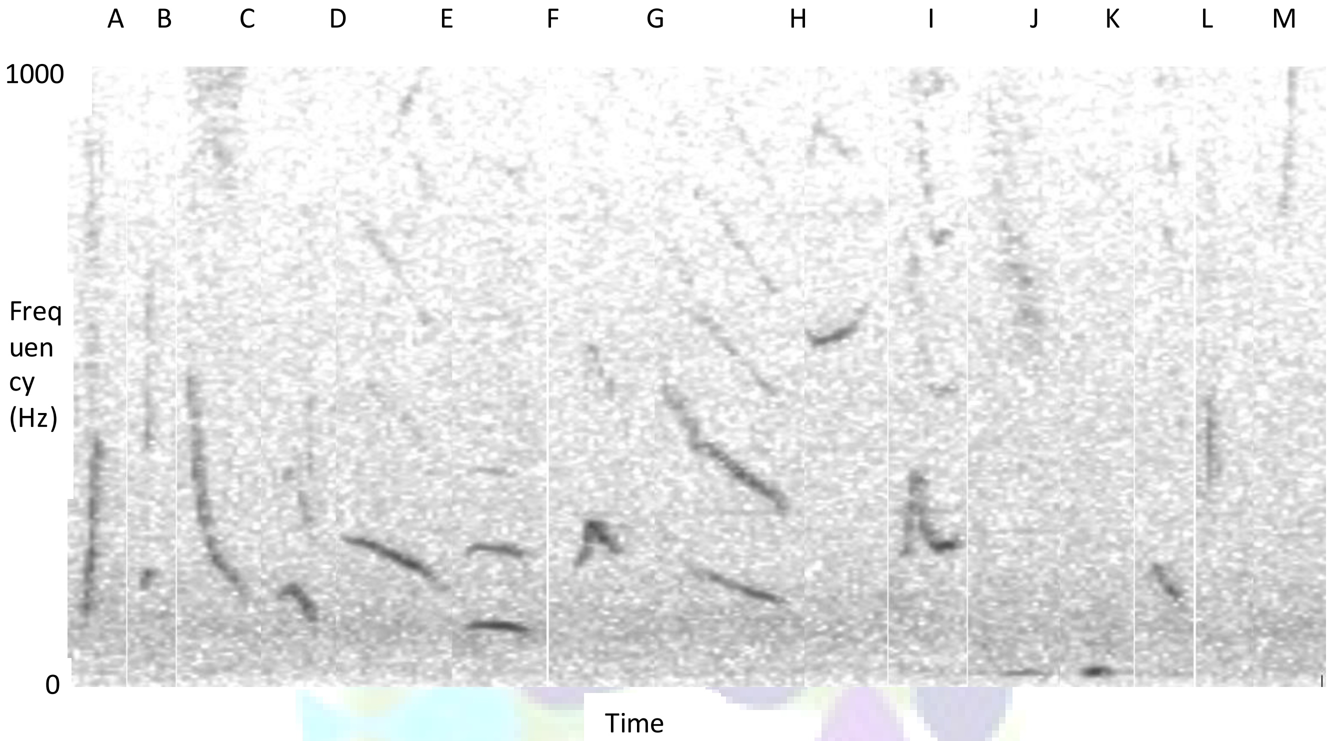

Figure 7. Spectrogram representation of the 15 units of the song found at Tolsta and Stanton Banks

Table 4. The general sequence of units producing the six themes observed in the recordings. The symbol | denotes the separation of phrases within the themes. Important to note- In theme two in the 2nd phrase the unit D gradually changes to become unit F.

Theme	**Order of units**
1	|A A B| A A B |A A A B |A C|
2	|D D D D D D D D E| D D F F F F E| F F F F F E| F F F F E |
3	|G| H F I G I J |H F I G I J |H F I G I J| H F I G I J |H F I G I J |H F I G I J |H F |
4	|G K L L M| G K L L L M| G K L L L L M| G K L L L L L M| G K L L L L L M| G K L|
5	|N N N N N N N N N N N N N N N|(15s rest)|N N N N N N N N N N N N N N N N N N|
6	|O O C |O O O O O O O C |O O O |

Table 5. The extracted parameters of each song unit where peak frequency is the frequency at which the maximum power occurs.

Unit	Low Freq (Hz)	High Freq (Hz)	Energy (dB)	Max Power (dB)	Peak Freq (Hz)	Duration (s)
A	183.2	450.3	58.4	47.6	214.8	0.403
B	181	229.6	50	44.4	214.8	0.345
C	161.1	516.6	59.5	52.1	222.7	0.460
D	106	183.2	60.8	54.8	148.4	0.288
E	178.8	258.3	65.4	58.9	210.9	1.151
F	108.2	152.3	64	57.6	136.7	1.669
G	207.5	289.2	65.5	60.5	277.3	1.381
H	125.8	203.1	59.7	52.9	171.9	1.439
I	549.7	640.2	55.2	48.8	558.6	2.360
J	220.8	309.1	68.3	64.5	269.5	1.554
K	443.7	737.3	47.4	35	632.8	1.726
L	39.7	57.4	59.4	56.7	46.9	3.280
M	150.1	218.5	56.9	53.9	175.8	2.762
N	326.7	472.4	47.4	40.6	363.3	1.842
O	834.4	1000	43.8	40.7	859.4	1.554

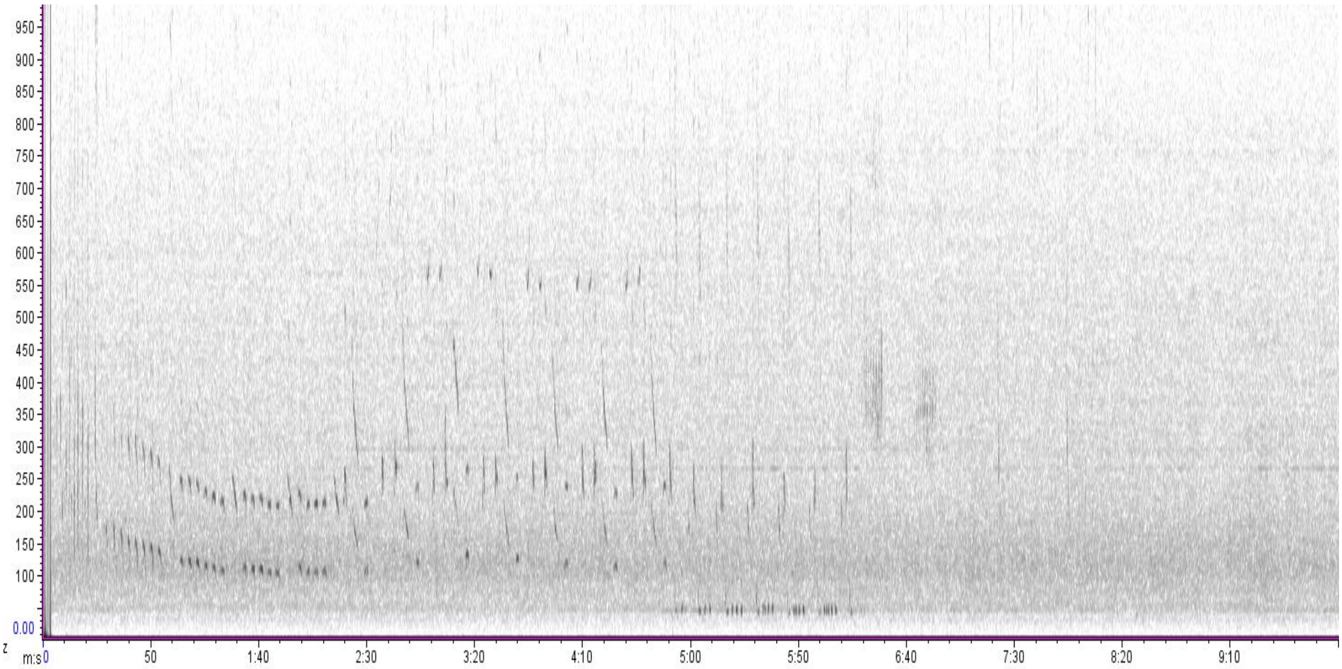

Figure 8. Full spectrogram of recorded song showing the order of themes and units.

4. Discussion

Seasonal pattern of humpback whale occurrence

The model showed there was a strong seasonal pattern in humpback whale detections with a peak in the spring (March-May). Humpback whales were detected continuously for 10-12 days at both sites at the end of March which could indicate that they are remaining in the area for longer periods rather than quickly passing through (although it is not possible to tell if these are the same individuals or not). Due to the timings and duration of the acoustic detections it is possible that these waters are used as a migratory stopover (e.g. for feeding or resting; Stone et al. 1987; O'Neil et al. 2019) on the north bound migration to the summer feeding grounds rather than being the final destination for migration (Figure 9). The absence of an acoustically detected south bound migration in the autumn is noteworthy. This may indicate that humpback whales are not vocalising on the return journey or the animals have taken an alternative route towards the breeding grounds (Charif et al. 2001). A recent study on the east coast of Scotland (Firth of Forth) by O'Neil et al. (2019) showed a strong seasonal peak of humpback whale sightings during the winter months (Jan-Mar). It is possible that the COMPASS acoustic array detected humpback whales migrating north towards their summer feeding grounds and providing comparison with O'Neil et al. (2019) who have recorded humpback whales on a migratory stop on their southbound journey to the sub-tropical breeding grounds (Figure 4; Whaletrack, 2018; O'Neil et al. 2019). Humpback whales have been sighted throughout the year within the study area. There is a visual presence of humpback whales throughout the year as well as a strong spring seasonal peak in acoustic detections at Stanton Bank and Tolsta (more offshore). This could imply that some individuals may not be undertaking the full migration each year and may remain in mid-high latitude feeding grounds throughout the breeding season (e.g. Clapham et al. 1993; Magnúsdottir et al. 2014; Kowarski, 2018).

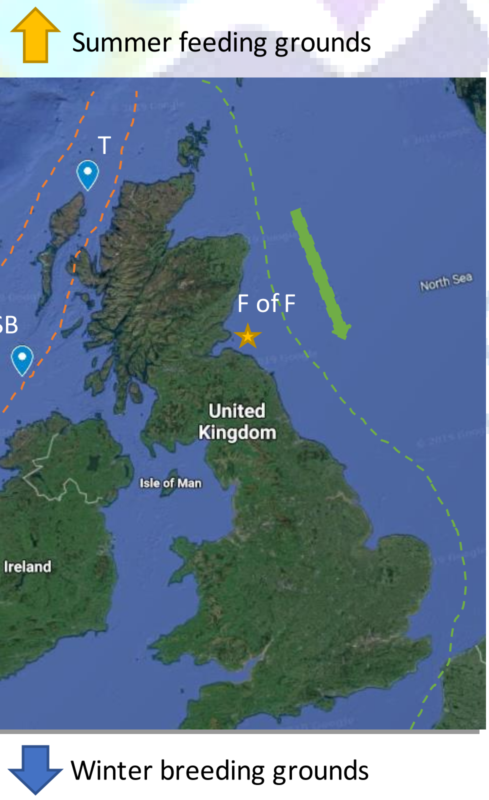

Figure 9. Showing the potential routes of humpback whales using results from this study and O'Neil et al. 2019. SB=Stanton Bank, T=Tolsta, F of F= Firth of Forth.

This study recorded humpback whale song in the mid-latitudes. Only male humpback whales will sing (Helweg, 1990) and as it has a reproductive function, the behaviour has been strongly associated with the breeding grounds of humpback whales (e.g. Darling et al., 2006; Cholewiak, 2008; Magnúsdóttir & Lim, 2019). However, reports of singing outside the traditional, known breeding grounds has increased dramatically over the past number of years (Clapham and Matilla, 1990; Clarke & Clapham, 2004; Vu et al. 2012; Magnúsdóttir & Lim, 2019) and it has raised questions about the main function of humpback whale song. Song has now been recorded along migratory routes (e.g. Clapham and Matilla, 1990) and on high latitude feeding grounds (e.g. Baker et al. 1985; Clarke and Clapham, 2004). The occurrence of singing on the northbound migratory route could be due to the habit of males travelling from their breeding ground still singing the full song and once they move closer to the feeding ground they concentrate on feeding (Vu et al. 2012). Singing on the migratory route may also be a low-cost opportunistic form of advertisement to any females in the area (Clarke and Clapham, 2004) and there is no reason that mating cannot take place outside of the traditional tropical breeding grounds spatially and temporally (Charif et al. 2001; Clarke & Clapham, 2004) and this study adds to the growing body of literature exploring song outside of these areas. There is evidence that testosterone levels are also elevated in the springtime which could drive singing in the study area (Clarke and Clapham, 2004). It is highly likely that humpback song has multiple functions (Herman, 2017) which could also explain its occurrence outside of the known breeding grounds. It has been suggested that song is used as migratory beacons (Winn & Winn 1978) or that it can be used to recruit new individuals to new wintering grounds (Herman, 2017). It has also been suggested that singing is used for sonar, using echoes to locate conspecifics or other objects of interest (Frazer & Mercado 2000; Mercado 2018).

Humpback whale song was detected throughout the diel cycle but there was no pattern for either site or when the data was pooled together. This study only detected song in the months of March- May so it is possible that there could be a diel pattern of humpback whale song in other months- particularly at the breeding grounds where song is most frequent (Winn & Winn, 1978). At some tropical breeding grounds there is an increase in song activity and sound level during the night (Ceyrac et al. 2018; Helweg & Herman 1994; Cholewiak 2008). This is because during the daylight hours, males can rely on visual tactics and engage in direct competition for females (Ceyrac et al. 2018; Helweg & Herman 1994; Cholewiak 2008). During the night, males must rely on sound and use their song to attract females (Au et al. 2006; Ceyrac et al. 2018). This pattern of increased acoustic activity at night is seen in other baleen whale species such as blue whales (Wiggans et al. 2005) and minke whales (Risch et al. 2013) which is why the time since sunrise covariate was retained in the final model. The lack of diel pattern at Tolsta and Stanton Banks may reflect the fact the whales may not be relying on the song to secure a mate, as suggested by Vu et al. (2012). Rather, the males could simply be in the habit of singing as they travel north from their breeding ground (Vu et al. 2012).

This study only investigated two sites which are relatively close in terms of humpback whale migratory distances (Darling et al. 1996; Stevick et al. 2010). Stanton Banks and Tolsta are roughly 320km apart and on average a singing humpback whale on a migratory route could travel 2.5km/h (~5 days travel) and a non- singing whale could travel 4km/h (~3 days travel) (Noad & Cato, 2007). The model showed that although site was statistically significant in predicting humpback whale presence, it was not the main driver of this (accounting for 4.1% of variance). On a larger scale, it is highly likely that there would be geographic variation in humpback whale presence and song (Clapham et al. 1993; Vu et al. 2012; Garland et al. 2011). In the future, further COMPASS sites will be scanned for humpback whale song and the geographic variation will be investigated at a larger scale.

Seasonal and diel pattern of minke whale occurrence

This study is the first attempt to describe the spatial distribution of minke whale vocalisations on the west coast of Scotland. A striking spatial pattern was discovered by this preliminary analysis with the overwhelming number of detection positive days for minke whales recorded at Stanton Bank and very few detections at other sites in the Inner Hebrides waters. While this pattern might partly be explained with the more offshore siting of the Stanton Bank mooring, which might therefore have a larger detection radius than the other sites and might have recorded minke whales who were migrating or summer feeding along the continental shelf edge. Interestingly, minke whales at Stanton Bank were detected across the whole summer (Figure 5), which stands in contrast to detections on the east coast of Scotland, where minke whales in the Moray Firth are detected in early summer and autumn with a dip in later summer (Risch et al. 2019). The relative absence of minke whale pulse trains in the Inner Hebrides was surprising, since minke whales are commonly sighted visually in the area throughout the summer. This pattern might be related to a sexual segregation of minke whales on their summer feeding grounds. It has been suggested that minke whale pulse trains might be produced by males exclusively (see Risch et al. 2014), which, if true, might indicate that minke whales visiting the Inner Hebrides are mostly female and juveniles. More work is needed however to confirm this suggestion.

At Stanton Bank, a clear diel pattern in acoustic detections was recorded (Figure 6). Most vocalisations occurring during night and dusk/dawn hours was visible for the months of April and May 2018. Such a pattern has been described for minke whales by Risch et al. (2013, 2019), and in other baleen whale species (Širović et al. 2017). According to Risch et al. (2013) a peak of vocalising minkes during night could also be related to higher individual vocalisation rates, increase number of vocalising animals or a change in animal abundance at different times of day. A cause for this behaviour might be due to two reasons: no foraging at night, therefore socialising; or a display of fitness by vocal means at night. Vocalisation at night might be related to feeding activity (Risch et al., 2013). With sandeels (*Ammodytes tobianus*) returning to their sediments at night (van der Kooij et al. 2008), minke whales may be forced to pause their feeding activity due to a lack of prey and visibility. This would give time to actively socialize among conspecifics. Another possibility is that during daytime fitness can be demonstrated visually where no vocalisation is required whereas at night a reproductive display could only be vocally transmitted (Risch et al. 2013, 2019). Risch et al. (2013) suggest that albeit the behavioural context of minke whale vocalisation is not yet entirely comprehended, their observed strong diel pattern in the Gulf of Maine indicated a stronger relationship between vocalisation and foraging than reproductive displays under light regime influence.

Implications of findings

It is well understood, that entanglement in fishing gear is a serious risk to humpback and minke whales, especially in coastal waters of the Northeast Atlantic as well as ship strike and pollution (Weilgart, 2007; Guzman et al. 2013; Ryan et al. 2013; Bettridge et al. 2015). The more we can understand about these species distributions temporally and spatially, the more effectively we will be able to monitor these threats and also mitigate against them.

There are many anthropogenic noise inputs that are cause concern for cetacean species including shipping noise, military sonar, industrial activities (e.g. pile driving), seismic activity and deterrent devices (Filadelfo et al. 2009; Hildebrand, 2009). There are four major concerns for cetaceans that are exposed to high levels of noise including temporary (TTS) and permanent threshold shift (PTS), behavioural changes and signal masking (Nowacek et al. 2007). TTS and PTS are physical changes to the auditory system (Southall et al. 2007). TTS is reversible whereas PTS is can lead to an irreversible loss of hearing which is often fatal to cetaceans (Southall et al. 2007). Fatalities due to PTS can be caused by strandings (become disorientated) or decompression sickness (disorientation and panic) (Fernandez et al. 2005). Humpback whale song can be masked by anthropogenic signals such as shipping noise (Nowacek et al. 2007; Dunlop, 2016). Masking occurs when ambient or anthropogenic noise obscures or masks the calls of conspecifics or other important signals (such as predators or prey) (Nowacek et al. 2007). This is a huge concern as cetaceans are highly vocal animals who rely on sound for so many different functions from navigation to reproduction (Weilgart, 2007). For example, humpback whale song plays a vital role in the reproductive system (Herman, 2017) therefore, signal masking could mean that females are unable to detect a suitable male for mating. Increased noise can also because behaviour changes an can cause cetaceans to abandon an area which could be important for certain activities such as resting or foraging (Nowacek et al. 2007). The more we can understand about the acoustic behaviour of cetaceans the better we can advise on how to protect them.

Future research

This research is currently still ongoing as all COMPASS sites including the most up to date data from 2020 are being analysed for baleen whale presence. This study only focused on minke whale pulse trains and humpback whale song. However, in future it would be useful to run a detector for social sounds of humpback whales (e.g. Dunlop et al. 2008) to see if and what frequency these occur in the study area at different times of year. Additionally, other minke whale calls, and fin (*Balaenoptera physalus*) and blue whale (*Balaenoptera musculus*), as well as potential sei whale (*Balaenoptera borealis*) presence will be explored using automated detectors.

5. Acknowledgements

Thanks to the scientists and crew of the Corystes, Alba na Mara and Scotia for the logistical and technical support in the deployment and recovery of monitoring equipment. Robert Watret, Paul Stainer, Charlotte Altass, Ross Culloch, Adrian Tait (MSS), Adam Mellor and Raymond Gilmore (AFBI) have been instrumental in seagoing fieldwork. The Collaborative Oceanography and Monitoring for Protected Areas and Species (COMPASS) project is supported by the European Union's INTERREG VA programme, managed by the Special EU Programmes Body (SEUPB).

6. References

Allen, J. A., Garland, E. C., Dunlop, R. A. & Noad, M. J., 2018. Cultural revolutions reduce complexity in the songs of humpback whales. *Proceedings of the Royal Society B,* 285(1891), p. 20182088.
Anderwald, P. et al., 2011. Possible cryptic stock structure for minke whales in the North Atlantic: Implications for conservation and management. *Biological Conservation,* 144(10), pp. 2479-2489.
Au, W. W. et al., 2006. Acoustic properties of humpback whale songs.. *The Journal of the Acoustical Society of America,* 120(2), pp. 1103-1110.
Beamish, P. & Mitchell, E., 1973. Short pulse length audio frequency sounds recorded in the presence of a Minke whale (Balaenoptera acutorostrata). *Deep Sea Res. Oceanogr.,* Volume 20, p. 375–386.
Bettridge, S. O. M. et al., 2015. *Status review of the humpback whale (Megaptera novaeangliae) under the Endangered Species Act.,* s.l.: s.n.
Bioacoustics Research Program, 2014. *Raven Pro: Interactive Sound Analysis Software (Version 1.5) [Computer software],* Ithaca, NY: The Cornell Lab of Ornithology.
Ceyrac, L. et al., 2018. Using passive acoustic monitoring to assess humpback whale occurrence and breeding activity around La Réunion Island. *Western Indian Ocean Journal of Marine Science,* pp. 65-73.
Charif, R. A., Clapham, P. J. & Clark, C. W., 2001. Acoustic detections of singing humpback whales in deep waters off the British Isles. *Marine Mammal Science,* 17(4), pp. 751-768.
Cholewiak, D., 2008. *Evaluating the role of song in the humpback whale (Megaptera novaeangliae) breeding system with respect to intra-sexual interactions,* Ithaca, NY: A Dissertation Presented to the Faculty of the Graduate School of Cornell University .
Cholewiak, D. M., Sousa-Lima, R. S. & Cerchio, S., 2013. Humpback whale song hierarchical structure: Historical context and discussion of current classification issues. *Marine Mammal Science,* 29(3), pp. E312-E332.
Clapham, P. H. & Mattila, D. K., 1990. Humpback whale songs as indicators of migration routes. *Marine Mammal Science,* 6(2), pp. 155-160.
Clapham, P. J., 2000. The humpback whale. In: *Cetacean Societies, field studies of dolphins and whales.* Chicago: The University of Chicago, pp. 173-196.
Clapham, P. J. et al., 1993. Seasonal occurrence and annual return of humpback whales, Megaptera novaeangliae, in the southern Gulf of Maine. *Canadian Journal of Zoology,* 71(2), pp. 440-443.
Corkeron, P. J. & Connor, R. C., 1999. Why do baleen whales migrate. *Marine Mammal Science,* 15(4), pp. 1228-1245.
Darling, J. D. et al., 1996. Movement of a humpback whale (Megaptera novaeangliae) from Japan to British Columbia and return. *Marine Mammal Science,* Volume 12, p. 281–287.
Deaville, R. e. a., 2016. *Annual report for the period 1st January 2005-31st December 2015. UK Cetacean Strandings Investigation Programme(CSIP),* s.l.: s.n.
Dolman, S. J. et al., 2013. Harbour porpoises (Phocoena phocoena) and minke whales (Balaenoptera acutorostrata) observed during land-based surveys in The Minch, north-west Scotland. *J. Mar. Biol. Assoc. UK,* Volume 94, p. 1185–1194.
Dunlop, R. A., Cato, D. H. & Noad, M. J., 2008. Non-song acoustic communication in migrating humpback whales (Megaptera novaeangliae). *Marine Mammal Science,* 24(3), pp. 613-629.
Edds-Walton, P., 2000. Vocalizations of minke whales Balaenoptera acutorostrata in the St. Lawrence Estuary. *Bioacoustics,* Volume 11, pp. 31-50.
Embling, C. B. et al., 2010. Using habitat models to identify suitable sites for marine protected areas for harbour porpoises (Phocoena phocoena). *Biological Conservation,* 143(2), pp. 267-279.
Figueroa, H. K. & Robbins, M., 2008. XBAT: An Open-Source Extensible Platform for Bioacoustic Research and Monitoring. In: K. H. Frommolt, R. Bardeli & M. Clausen, eds. *Computational bioacoustics for assessing biodiversity.* s.l.:Bundesamt für Naturschutz, p. 143–155.
Frazer, L. N. & Mercado III, E., 2000. A sonar model for humpback whale song. *IEEE Journal of Oceanic Engineering,* 25(1), pp. 160-182.

Garland, E. C. et al., 2011. Dynamic horizontal cultural transmission of humpback whale song at the ocean basin scale. *Current biology,* 21(8), pp. 687-691.
Gillespie, D. et al., 2008. PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. *Journal of the Acoustical Society of America,* 30(5), pp. 54-62.
Guzman, H. M., Gomez, C. G., Guevara, C. A. & Kleivane, L., 2013. Potential vessel collisions with Southern Hemisphere humpback whales wintering off Pacific Panama.. *Marine Mammal Science,* 29(4), pp. 629-642.
Helweg, D. A., 1990. Comparison of songs of humpback whales (Megaptera novaeangliae) recorded in Japan, Hawaii and Mexico during in the winter of 1989. *Scientific Reports of Cetacean Research,* Volume 1, pp. 1-20.
Helweg, D. A. & Herman, L. M., 1994. Diurnal patterns of behaviour and group membership of humpback whales (Megaptera novaeangliae) wintering in Hawaiian waters. *Ethology,* 98(3-4), pp. 298-311.
Herman, L. M., 2017. The multiple functions of male song within the humpback whale (Megaptera novaeangliae) mating system: review, evaluation, and synthesis. *Biological Reviews,* 92(3), pp. 1795-1818.
Hurlbert, S., 1984. Pseudoreplication and the design of ecological field experiments. *Ecological monographs,* 54(2), pp. 187-211.
IUCN, 2018. *Humpback whale.* [Online]
Available at: https://www.iucnredlist.org/species/132832/3463914
[Accessed 1 May 2019].
JNCC, unknown. *Stanton Banks- Designated special area of conservation.* [Online]
Available at: https://sac.jncc.gov.uk/site/UK0030359
[Accessed 4 May 2019].
Kowarski, K. et al., 2018. Singing through winter nights: Seasonal and diel occurrence of humpback whale (Megaptera novaeangliae) calls in and around the Gully MPA, offshore eastern Canada. *Marine Mammal Science,* 34(1), pp. 169-189.
Macleod, K. et al., 2004. Seasonal distribution of minke whales Balaenoptera acutorostrata in relation to physiography and prey off the Isle of Mull, Scotland. *Marine Ecology Progress Series,* Volume 277, pp. 263-274.
Magnúsdóttir, E. E. & Lim, R., 2019. Subarctic singers: Humpback whale (Megaptera novaeangliae) song structure and progression from an Icelandic feeding ground during winter. *PloS one,* 14(1), p. e0210057.
Magnúsdóttir, E. E., Rasmussen, M. H., Lammers, M. O. & Svavarsson, J., 2014. Humpback whale songs during winter in subarctic waters. *Polar biology,* 37(3), pp. 427-433.
Marine Scotland, 2014. *Scottish MPA Project data confidence assessment. North East Lewis MPA proposal,* s.l.: s.n.
Mellinger, D. K., Carson, C. D. & Clark, C. W., 2000. Characteristics of minke whale (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico. *Mar. Mammal Sci.,* Volume 16, pp. 739-756.
Mercado III, E., 2018. The Sonar Model for Humpback Whale Song Revised. *Frontiers in Psychology,* Volume 9, p. 1156.
Mobley, J. R., Bauer, G. & Herman, L. M., 1999. Changes over a ten-year interval in the distribution and relative abundance of humpback whales (Megaptera novaeangliae) wintering in Hawaiian waters. *Aquatic Mammals,* Volume 25, pp. 63-72.
Northridge, S., Cargill, A. & Coram, A., 2010. *Entanglement of minke whales in Scottish waters; an investigation into occurrence, causes and mitigation,* s.l.: s.n.
Northridge, S. P., Tasker, M. L., Webb, A. & Williams, J. M., 1995. Distribution and relative abundance of harbour porpoises (Phocoena phocoena L.), white-beaked dolphins (Lagenorhynchus albirostris Gray), and minke whales (Balaenoptera acutorostrata Lacepède) around the British Isles. *ICES J. Mar. Sci. J. du Cons.,* Volume 52, p. 55.
O'Neil, K. E., Cunningham, E. G. & Moore, D. M., 2019. Sudden seasonal occurrence of humpback whales Megaptera novaeangliae in the Firth of Forth, Scotland and first confirmed movement between high-latitude feeding grounds and United Kingdom waters. *Marine Biodiversity Records,* 12(1), pp. 1-5.
Payne, K. a. P. R., 1985. Large scale changes over 19 years in songs of humpback whales in Bermuda. *Zeitschrift für Tierpsychologie,* 68(2), pp. 89-114.

Payne, K., Tyack, P. & Payne, R., 1983. Progressive changes in the songs of humpback whales (Megaptera novaeangliae): a detailed analysis of two seasons in Hawaii. *Communication and behavior of whales,* pp. 9-57.
Payne, R. S. & McVay, S., 1971. Songs of humpback whales. *Science,* 173(3997), pp. 585-597.
Popescu, M. et al., 2013. Bioacoustical periodic pulse train signal detection and classifcation using spectrogram intensity binarization and energy projection. *ICML 2013 Workshop on Machine Learning for Bioacoustics*.
Reid, J. B., Evans, P. G. H. & Northridge, S. P., 2003. *Atlas of cetacean distribution in north-west European waters,* s.l.: Joint Nature Conservation Committee (JNCC).
Risch, D. et al., 2013. Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. *Marine Ecology Progress Series,* Volume 489, pp. 279-295.
Risch, D., Corkeron, P. J., Ellison, W. T. & Van Parijs, S. M., 2012. Changes in humpback whale song occurrence in response to an acoustic source 200 km away. *PloS one,* 7(1), p. e29741.
Risch, D. et al., 2014. Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. *Movement ecology,* 2(1), p. 24.
Risch, D. et al., 2019. Seasonal and diel acoustic presence of North Atlantic minke whales in the North Sea. *Scientific reports,* 9(1), pp. 1-11.
Robinson, K. P., Tetley, M. J. & Mitchelson-Jacob, E. G., 2009. The distribution and habitat preference of coastally occurring minke whales (Balaenoptera acutorostrata) in the outer southern Moray Firth, northeast Scotland. *J. Coast. Conserv,* Volume 13, p. 39–48.
Robinson, K. P., Tetley, M. J. & Mitchelson-Jacob, E. G., 2009. The distribution and habitat preference of coastally occurring minke whales (Balaenoptera acutorostrata) in the outer southern Moray Firth, northeast Scotland. *J. Coast. Conserv,* Volume 13, pp. 39-48.
Rogan, E. & Berrow, S. D., 1995. *The management of Irish waters as a whales and dolphin sanctuary. In Developments in Marine Biology, 4. Whales, seals, fish and man, Eds Blix, A.S., Walloe, L. and Ulltang. O. Proceedings of the International Symposium on the Biology of Marine Mammals in.* Tromso, Elsevier.
Ryan, C. et al., 2016. *Entanglement: an emerging threat to humpback whales in Scottish waters,* s.l.: In Scientific Committee Meeting of the International Whaling Commission.
Ryan, C. et al., 2013. Levels of persistent organic pollutants in eastern North Atlantic humpback whales. *Endangered Species Research,* 22(3), pp. 213-223.
Ryan, C. W. F. L.-S. P. a. B. S., 2014. An abundance estimate for humpback whales Megaptera novaeangliae breeding around Boa Vista, Cape Verde Islands. *Zoologia Caboverdiana Journal,* 5(1), pp. 20-28.
Silber, G. K., 1986. The relationship of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale (Megaptera novaeangliae). *Canadian Journal of Zoology,* 64(10), pp. 2075-2080.
Širović, A. et al., 2017. Fin whale song variability in southern California and the Gulf of California. *Scientific reports,* 7(1), pp. 201-209.
Stevick, P. T. et al., 2003. North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. *Marine Ecology Progress Series,* Volume 258, pp. 263-273.
Stone, G. S., Katona, S. K. & Tucker, E. B., 1987. History, migration and present status of humpback whales Megaptera novaeangliae at Bermuda. *Biological Conservation,* 42(2), pp. 133-145.
Thieurmel, B., 2019. *Elmarhraoui. A. suncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase,* s.l.: s.n.
Thompson, T. J., Winn, H. & Perkins, P. J., 1979. Mysticete sounds. In: *Behavior of marine animals.* Boston: Springer, pp. 403-431.
Tyack, P. L. & Clark, C. W., 2000. Communication and acoustic behavior of dolphins and whales. In: *Hearing by whales and dolphins .* New York: Springer, pp. 156-224.
van der Kooij, J., Scott, B. E. & Mackinson, S., 2008. The effects of environmental factors on daytime sandeel distribution and abundance on the Dogger Bank. *Journal of Sea Research,* 60(3), pp. 201-209.
Vu, E. T. et al., 2012. Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean. *Aquatic Biology,* 14(2), pp. 175-183.

Weilgart, L. S., 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian journal of zoology,* 85(11), pp. 1091-1116.
Wenzel, F. W. et al., 2020. Humpback Whales (Megaptera novaeangliae) in the Cape Verde Islands: Migratory Patterns, Resightings, and Abundance. *Aquatic Mammals.*
Whitehead, H. & Rendell, L., 2014. *The cultural lives of whales and dolphins.* Chicago: University of Chicago Press.
Wiggins, S. M., Oleson, E. M., McDonald, M. A. & Hildebrand, J. A., 2005. Blue whale (Balaenoptera musculus) diel call patterns offshore of Southern California. *Aquatic Mammals,* 31(2), p. 161.
Winn, H. E. & Winn, L. K., 1978. The song of the humpback whale Megaptera novaeangliae in the West Indies. *Marine Biology,* 47(2), pp. 97-114.
Wood, S. N., 2006. *R-Manual: the MGCV package. Version 1.3–22. Technical Report.,* s.l.: s.n.
Wood, S. & Wood, M. S., 2015. Package 'mgcv'. *R package version,* Volume 1, p. 29.
Zuur, A. F., Ieno, E. N. & Elphick, C. S., 2010. A protocol for data exploration to avoid common statistical problems. *Methods in ecology and evolution,* 1(1), pp. 3-14.
Zuur, A. et al., 2009. *Mixed effects models and extensions in ecology with R.* s.l.:Springer Science & Business Media.