Supplementary Material

# Supplementary Tables

## Supplementary Table 1.

Parameter description of all variables used in the random forest analysis.

|  |  |
| --- | --- |
| **Acoustic parameter** | **Description** |
| Duration (s) | Vocalisation length |
| High frequency (Hz) | Maximum frequency |
| Low frequency (Hz) | Minimum frequency |
| Bandwidth (Hz) | High – Low frequency |
| Frequency range (Hz) | High / Low frequency |
| Start frequency (Hz) | Start frequency |
| End frequency (Hz) | End frequency |
| Frequency trend (Hz) | Start / End frequency |
| Peak frequency (Hz) | Frequency of the spectral peak |
| Number of inflections | Number of reversals in slope |

## Supplementary Table 2.

Summaryof all identified phrase types and the number of phrases (excl. transitional phrases, n=72) across the defined study period. Set medians as unit sequences (=phrase) representing each identified phrase type across the entire dataset, regardless of recording period. Within-set similarity reveals the average similarity of all phrase sequences within the same phrase type, again, regardless of recording period (0=no similarity, 1=complete similarity).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phrase type** | **No. of phrases** | **Period** | **Set median (unit sequence)** | **Within-set similarity** |
| **1** | 22 | Jan-18 | sqcr, asw, asqcr, asw, sqcr, asw, sqcr, asw, asw, sqcr, asw, sqcr, asw, dtp | 0.51 |
| 6 | Feb-18 |
| **1A** | 12 | Feb-18 | vsqcr, ahsqk, vsqcr, ahsqk, asw, vsqcr, ahsqk, asw, vsqcr, ahsqk, asw, vsqcr, dsqws, asw, ahsqk, asw, asw, ahsqk, asw, ahsqk, asw, asw, ahsqk, asw, asw, dhsqk, asw, asw, ahsqk, asw, dtp | 0.46 |
| 14 | Mar-18 |
| **1B** | 6 | Mar-18 | sawl, asw, sawl, ahsqk, asw, dsqws, ahsqk, asw, sawl, ahsqk, asw, asw, dsqcr, ahsqk, asw, dsqws, hsqk, asw, dtp | 0.48 |
| 16 | Apr-18 |
| **1C** | 7 | Jan-19 | sawl, sqcr, saws, sawl, saws, saws, asqcr, sawl, sqcr, saws, saws, saws, saws, ldgr | 0.53 |
| **2** | 8 | Jan-18 | dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dr, dtp | 0.71 |
| 7 | Feb-18 |
| 6 | Mar-18 |
| 2 | Jan-19 |
| **3-a** | 7 | Jan-18 | sbsgr, sbsgr, sbsgr, sbsgr, sbsgr, dmo | 0.73 |
| 2 | Feb-18 |
| **3-ab** | 5 | Jan-18 | sbsgr, sbsgr, grl, grl, dmo | 0.66 |
| 2 | Feb-18 |
| **3-b** | 21 | Jan-18 | grl, grl, grl, grl, grl, dmo | 0.81 |
| 5 | Feb-18 |
| **3A-a** | 4 | Jan-18 | sdgr, sdgr, sdgr, sdgr, dgrl, dgrl, dgrl, dgrl, dmo | 0.73 |
| 6 | Feb-18 |
| 9 | Mar-18 |
| 9 | Apr-18 |
| **3A-ab** | 2 | Jan-18 | dgrl, dgrl, dgrl, dgrl, grl, grl, grl, dmo | 0.63 |
| 6 | Feb-18 |
| 8 | Mar-18 |
| 11 | Apr-18 |
| **3A-b** | 2 | Jan-18 | grl, grl, grl, grl, grl, dmo | 0.76 |
| 11 | Feb-18 |
| 8 | Mar-18 |
| 24 | Apr-18 |
| **3B** | 10 | Jan-19 | dgt, dgt, dgt, dgt, lmo | 0.74 |
| **4** | 18 | Jan-18 | acr, awmo, acr, mmo, dgr, grl | 0.65 |
| 35 | Feb-18 |
| 27 | Mar-18 |
| **4A** | 18 | Jan-18 | acr, awmo, acr, mmo, ldwgr, grl | 0.73 |
| 16 | Mar-18 |
| **4B** | 34 | Mar-18 | cr, awmo, cr, awmo, ldgr, grl | 0.83 |
| 38 | Apr-18 |
| **4C** | 85 | Apr-18 | cr, dwmo, cr, mmo, ldgr, grl | 0.84 |
| **4D** | 27 | Jan-19 | dcr, vsmo, dcr, vsmo, ldgr, grl | 0.75 |
| **5** | 78 | Jan-18 | sdgr, sawmo, dtru, prp, prp, prp, prp | 0.57 |
| 16 | Feb-18 |
| **5A** | 35 | Feb-18 | sdgr, awmo, dtr, prp, prp, prp | 0.74 |
| 79 | Mar-18 |
| 92 | Apr-18 |
| **5B** | 92 | Jan-19 | sdmo, sdwmo, atr, grup, grup | 0.60 |
| **6** | 13 | Jan-18 | dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, dtrb, sqcr, sqcr, sqcr | 0.69 |
| 6 | Feb-18 |
| **6A** | 8 | Jan-18 | grup, grup, grup, grup, grup, grup, grup, grup, grup, grup, sqcr, sqcr | 0.84 |
| **6B** | 9 | Feb-18 | dtrb, sbstr, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, atrb, dtrb, vsqcr, ahsqk, vsqcr, vhsqk, vsqcr, vhsqk | 0.82 |
| **6C** | 6 | Feb-18 | dtrb, dtrb, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, asqk, dsqk, sawl, svhws, sawl, svhws, sawl, svhws | 0.73 |
| 23 | Mar-18 |
| 47 | Apr-18 |
| 18 | Jan-19 |
| **7-a** | 8 | Jan-19 | asw, sawl, sawl | 0.69 |
| **7-ab** | 11 | Jan-19 | dr, sawl | 0.72 |
| **7-b** | 12 | Jan-19 | dr, dr | 1.00 |
| **Total** | 1109 |  |  |  |

## Supplementary Table 3.

LSI matrix showing similarities (0=no similarity, 1=complete similarity) between the set medians (most representative string per song session) of each phrase type (sequence of units).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Phrase type** | **1** | **1A** | **1B** | **1C** | **2** | **3**  **-a** | **3**  **-ab** | **3**  **-b** | **3A**  **-a** | **3A-ab** | **3A**  **-b** | **3B** | **4** | **4A** | **4B** | **4C** | **4D** | **5** | **5A** | **5B** | **6** | **6A** | **6B** | **6C** | **7**  **-a** | **7**  **-ab** | **7**  **-b** |
| **1** | 0.64 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1A** | 0.42 | 0.57 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1B** | 0.39 | 0.41 | 0.65 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **1C** | 0.35 | 0.20 | 0.22 | 0.72 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **2** | 0.32 | 0.29 | 0.27 | 0.13 | 0.71 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3-a** | 0.06 | 0.04 | 0.04 | 0.08 | 0.06 | 0.71 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3-ab** | 0.05 | 0.04 | 0.04 | 0.08 | 0.06 | 0.43 | 0.68 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3-b** | 0.05 | 0.03 | 0.04 | 0.08 | 0.06 | 0.35 | 0.59 | 0.93 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3A-a** | 0.11 | 0.07 | 0.08 | 0.11 | 0.11 | 0.34 | 0.29 | 0.36 | 0.72 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3A-ab** | 0.08 | 0.06 | 0.06 | 0.10 | 0.09 | 0.36 | 0.40 | 0.55 | 0.57 | 0.65 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3A-b** | 0.05 | 0.03 | 0.04 | 0.09 | 0.06 | 0.32 | 0.56 | 0.87 | 0.36 | 0.54 | 0.85 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **3B** | 0.05 | 0.03 | 0.04 | 0.11 | 0.08 | 0.17 | 0.15 | 0.20 | 0.22 | 0.23 | 0.20 | 0.80 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **4** | 0.06 | 0.04 | 0.04 | 0.08 | 0.06 | 0.30 | 0.30 | 0.31 | 0.19 | 0.26 | 0.31 | 0.14 | 0.78 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **4A** | 0.06 | 0.04 | 0.04 | 0.08 | 0.05 | 0.30 | 0.26 | 0.25 | 0.17 | 0.23 | 0.26 | 0.11 | 0.70 | 0.89 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **4B** | 0.06 | 0.04 | 0.04 | 0.08 | 0.05 | 0.34 | 0.27 | 0.27 | 0.19 | 0.25 | 0.28 | 0.16 | 0.69 | 0.69 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |
| **4C** | 0.05 | 0.03 | 0.03 | 0.07 | 0.05 | 0.24 | 0.24 | 0.26 | 0.16 | 0.23 | 0.26 | 0.15 | 0.70 | 0.67 | 0.82 | 0.98 |  |  |  |  |  |  |  |  |  |  |  |
| **4D** | 0.07 | 0.04 | 0.05 | 0.10 | 0.06 | 0.29 | 0.26 | 0.28 | 0.21 | 0.27 | 0.29 | 0.17 | 0.59 | 0.55 | 0.74 | 0.68 | 0.82 |  |  |  |  |  |  |  |  |  |  |
| **5** | 0.08 | 0.05 | 0.06 | 0.07 | 0.08 | 0.27 | 0.29 | 0.28 | 0.35 | 0.33 | 0.27 | 0.17 | 0.30 | 0.27 | 0.29 | 0.25 | 0.25 | 0.82 |  |  |  |  |  |  |  |  |  |
| **5A** | 0.08 | 0.05 | 0.05 | 0.08 | 0.08 | 0.31 | 0.27 | 0.30 | 0.32 | 0.32 | 0.30 | 0.18 | 0.39 | 0.38 | 0.38 | 0.34 | 0.33 | 0.63 | 0.91 |  |  |  |  |  |  |  |  |
| **5B** | 0.04 | 0.03 | 0.03 | 0.05 | 0.04 | 0.18 | 0.20 | 0.14 | 0.09 | 0.11 | 0.13 | 0.09 | 0.26 | 0.24 | 0.22 | 0.23 | 0.21 | 0.19 | 0.27 | 0.88 |  |  |  |  |  |  |  |
| **6** | 0.26 | 0.19 | 0.17 | 0.16 | 0.17 | 0.08 | 0.07 | 0.07 | 0.18 | 0.13 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.06 | 0.09 | 0.10 | 0.10 | 0.05 | 0.79 |  |  |  |  |  |  |
| **6A** | 0.08 | 0.06 | 0.04 | 0.06 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.17 | 0.13 | 1.00 |  |  |  |  |  |
| **6B** | 0.14 | 0.18 | 0.13 | 0.06 | 0.10 | 0.04 | 0.04 | 0.03 | 0.09 | 0.07 | 0.03 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 | 0.03 | 0.39 | 0.02 | 1.00 |  |  |  |  |
| **6C** | 0.16 | 0.18 | 0.12 | 0.09 | 0.11 | 0.04 | 0.04 | 0.04 | 0.11 | 0.08 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.03 | 0.05 | 0.06 | 0.06 | 0.03 | 0.33 | 0.03 | 0.35 | 0.76 |  |  |  |
| **7-a** | 0.14 | 0.10 | 0.14 | 0.22 | 0.08 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.04 | 0.08 | 0.08 | 0.07 | 0.07 | 0.08 | 0.05 | 0.09 | 0.09 | 0.09 | 0.08 | 0.03 | 0.06 | 1.00 |  |  |
| **7-ab** | 0.08 | 0.05 | 0.08 | 0.11 | 0.09 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.03 | 0.07 | 0.06 | 0.05 | 0.05 | 0.06 | 0.04 | 0.07 | 0.07 | 0.05 | 0.05 | 0.02 | 0.03 | 0.52 | 1.00 |  |
| **7-b** | 0.08 | 0.05 | 0.06 | 0.07 | 0.16 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 | 0.04 | 0.04 | 0.05 | 0.05 | 0.07 | 0.07 | 0.03 | 0.02 | 0.01 | 0.02 | 0.24 | 0.57 | 1.00 |

## Supplementary Table 4.

LSI matrix showing similarities (0=no similarity, 1=complete similarity) between the set medians (most representative string per song session) of songs (sequence of themes).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MonthYear** | **Jan18** | **Jan18** | **Jan18** | **Feb18** | **Feb18** | **Feb18** | **Mar18** | **Mar18** | **Mar18** | **Apr18** | **Apr18** | **Apr18** | **Jan19** | **Jan19** | **Jan19** |
| **Session** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **1** | **2** | **3** |
| **Jan18\_1** | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Jan18\_2** | 0.92 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Jan18\_3** | 0.79 | 0.71 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |
| **Feb18\_4** | 0.92 | 1.00 | 0.71 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |
| **Feb18\_5** | 0.70 | 0.62 | 0.58 | 0.62 | 1.00 |  |  |  |  |  |  |  |  |  |  |
| **Feb18\_6** | 0.44 | 0.52 | 0.33 | 0.52 | 0.65 | 1.00 |  |  |  |  |  |  |  |  |  |
| **Mar18\_7** | 0.44 | 0.52 | 0.33 | 0.52 | 0.65 | 1.00 | 1.00 |  |  |  |  |  |  |  |  |
| **Mar18\_8** | 0.54 | 0.62 | 0.56 | 0.62 | 0.75 | 0.77 | 0.77 | 1.00 |  |  |  |  |  |  |  |
| **Mar18\_9** | 0.55 | 0.63 | 0.50 | 0.63 | 0.65 | 0.67 | 0.67 | 0.84 | 1.00 |  |  |  |  |  |  |
| **Apr18\_10** | 0.30 | 0.38 | 0.26 | 0.38 | 0.32 | 0.61 | 0.61 | 0.51 | 0.67 | 1.00 |  |  |  |  |  |
| **Apr18\_11** | 0.38 | 0.46 | 0.33 | 0.46 | 0.49 | 0.81 | 0.81 | 0.67 | 0.79 | 0.75 | 1.00 |  |  |  |  |
| **Apr18\_12** | 0.38 | 0.46 | 0.33 | 0.46 | 0.49 | 0.81 | 0.81 | 0.67 | 0.79 | 0.75 | 1.00 | 1.00 |  |  |  |
| **Jan19\_1** | 0.22 | 0.22 | 0.17 | 0.22 | 0.22 | 0.40 | 0.40 | 0.33 | 0.35 | 0.42 | 0.42 | 0.42 | 1.00 |  |  |
| **Jan19\_2** | 0.41 | 0.42 | 0.37 | 0.42 | 0.42 | 0.38 | 0.38 | 0.53 | 0.55 | 0.36 | 0.41 | 0.41 | 0.67 | 1.00 |  |
| **Jan19\_3** | 0.22 | 0.22 | 0.17 | 0.22 | 0.25 | 0.41 | 0.41 | 0.35 | 0.38 | 0.39 | 0.45 | 0.45 | 0.62 | 0.69 | 1.00 |

# Supplementary Audio Files

## Supplementary Audio 1.

Acoustic file of theme 1 and its evolved versions themes 1A and 1B observed in 2018. Themes are represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

## Supplementary Audio 2.

Acoustic file of theme 1C observed in January 2019, evolved from theme 1B in 2018 (Supplementary Audio 1). The theme is represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2019. Sampling rate was set to 64 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 11.4 Hz and a 70% overlap.

## Supplementary Audio 3.

Acoustic file of theme 2 observed in 2018 and 2019. The theme is represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

## Supplementary Audio 4.

Acoustic file of theme 7 observed in January 2019. The theme is represented by a single phrase showing the shifts of successive phrase types 7-a, 7-ab and 7-b. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2019. Sampling rate was set to 64 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 11.4 Hz and a 70% overlap.

## Supplementary Audio 5.

Acoustic file of theme 3 and its evolved version 3A observed in 2018. Themes are represented by three phrases to show the shifts of successive phrase types -a, -ab and -b. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

## Supplementary Audio 6.

Acoustic file of theme 3B observed in January 2019, evolved from theme 3A in 2018 (Supplementary Audio 5). The theme is represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2019. Sampling rate was set to 64 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 11.4 Hz and a 70% overlap.

## Supplementary Audio 7.

Acoustic file of theme 4 and its evolved versions 4A, 4B and 4C observed in 2018. Themes are represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

## Supplementary Audio 8.

Acoustic file of theme 4D observed in January 2019, evolved from theme 4C in 2018 (Supplementary Audio 7). The theme is represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2019. Sampling rate was set to 64 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 11.4 Hz and a 70% overlap.

## Supplementary Audio 9.

Acoustic file of theme 5 and its evolved version 5A observed in 2018. Themes are represented by multiple phrases to show the shifts of successive phrases. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

## Supplementary Audio 10.

Acoustic file of theme 5B observed in January 2019, evolved from theme 5A in 2018 (Supplementary Audio 9). The theme is represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2019. Sampling rate was set to 64 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 11.4 Hz and a 70% overlap.

## Supplementary Audio 11.

Acoustic file of theme 6 and its evolved versions 6A and 6B observed in 2018, and 6C observed in 2018 and 2019. Themes are represented by a single phrase. Recorded off Northern Norway by Equinor and IMR Ocean Observatory (<http://love.statoil.com/>) in 2018. Sampling rate was set to 32 kHz and the audio file was viewed using Raven Pro 1.6 with the following parameters: FFT size 8092, Hann-window with a frequency resolution of 5.69 Hz and a 70% overlap.

# Supplementary Figures

## Supplementary Figure 1.

Spectrographic representation of an observed humpback whale song cycle in March 2018 (A) and January 2019 (B) showing changes within the structure between years. Note, no harmonics are visible in spectrogram (C) due to a decreased quality of the recording. The spectrograms were produced using fast Fourier transform (FFT) size 8092 Hann-window with frequency resolutions of 5.69 Hz (A) and 11.4 Hz (B), and a 70% overlap.

Timeline

Description automatically generated