

Corncrake recording sound analysis summary. Data reworked December 2020. Robert Arnold. Shelagh Parlane

Data

In 2020 we had 77 analysed recordings, some collected by locals using social media, of which 47 are 4-5 quality. (The 4-5 quality is defined as, 5 calls averaged, sharp rise at start of pulse, signal to noise moderately good, first pulse clear).

Having decided to reject lower sound quality recordings to improve the analysis, the total has become 127 recordings of male corncrakes from 2013 to 2020. They were made by RSPB Corncrake officer Shelagh Parlane, John Hawell and other Skye residents. In 2020 some improved microphone recordings and other mobile phone recordings were made.

The project

To analyse the recordings to match calls between recordings, in order to suggest the identities of birds. The data might reveal how much corncrakes move about the area during a season and whether they successfully return from their migration to Africa in following years. The procedure and theory are derived from the 1998 paper reproduced in full, below. *Individuality in Corncrake *Crex crex* vocalizations*. T.M.Peake, P.K.McGregor, K.W.Smith, G.Tyler, G.Gilbert, R.E.Green.

Method

Using all the quality 4-5 selected recordings an improved method has been devised to sort the similar recordings into arbitrarily numbered clusters. Each recording has been compared to all the others and pairs with $r > 0.95$ correlation coefficient have been grouped in descending order in Excel. The 8 top matches from these lists have been plotted to reveal the PPD pattern in a chart plot. The patterns have been further matched by eye to form the numbered clusters.

Raven pulse analysis

All the recordings have been checked visually in Raven and assigned a quality figure from 1 to 5. Only quality 4 and 5 have been used for the analysis. Only recordings with a geographical location have been used for this reworking in 2020.

I have manually marked the start edge of 11 pulses in each sound file of five first syllables and exported the numbers from Raven Lite (bird sound analysis software freely available from Cornell Lab of Ornithology) to an Excel file. The five sequences are averaged to make one sequence of 10 PPDs (pulse to pulse duration) for each recording.

Automated pulse train analysis is impossible with short, varied quality and low signal to noise ratio records (checked with a free trial of Raven Pro)

Measurement error

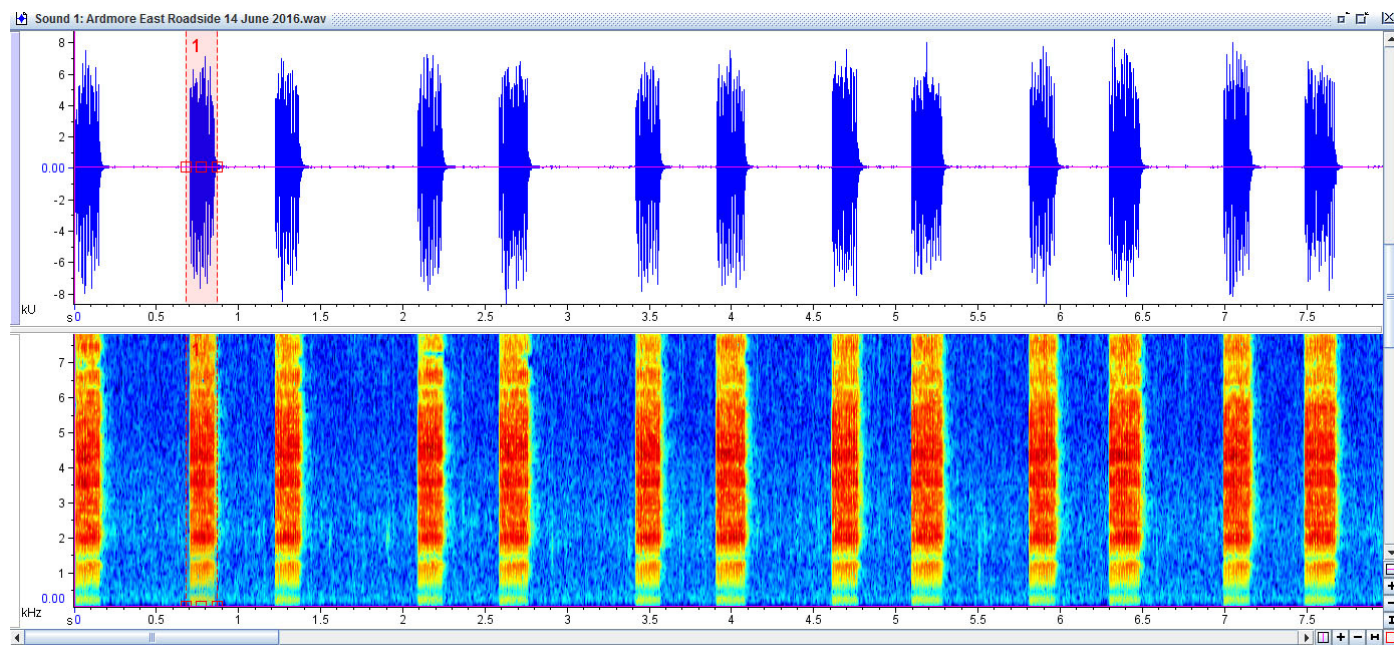
I estimate the possible error in PPD measurement of the order of ± 0.5 milliseconds. This is derived from variations in the selection of the start point of a pulse and digitising error. It could be greater for lower signal to noise ratio records.

A pattern diverging about 1 millisecond from another is within the range of measurement error for identical PPD chart patterns. The Y axis is in milliseconds in all charts. The range of variation of PPD over a 24 hour period documented in the 1998 paper is a similar size. (see figure 4 in *Individuality in Corncrake *Crex crex* vocalizations* at the end of this document.)

Records with significant wind noise have been band pass filtered in Raven Lite. 600Hz to 7kHz.

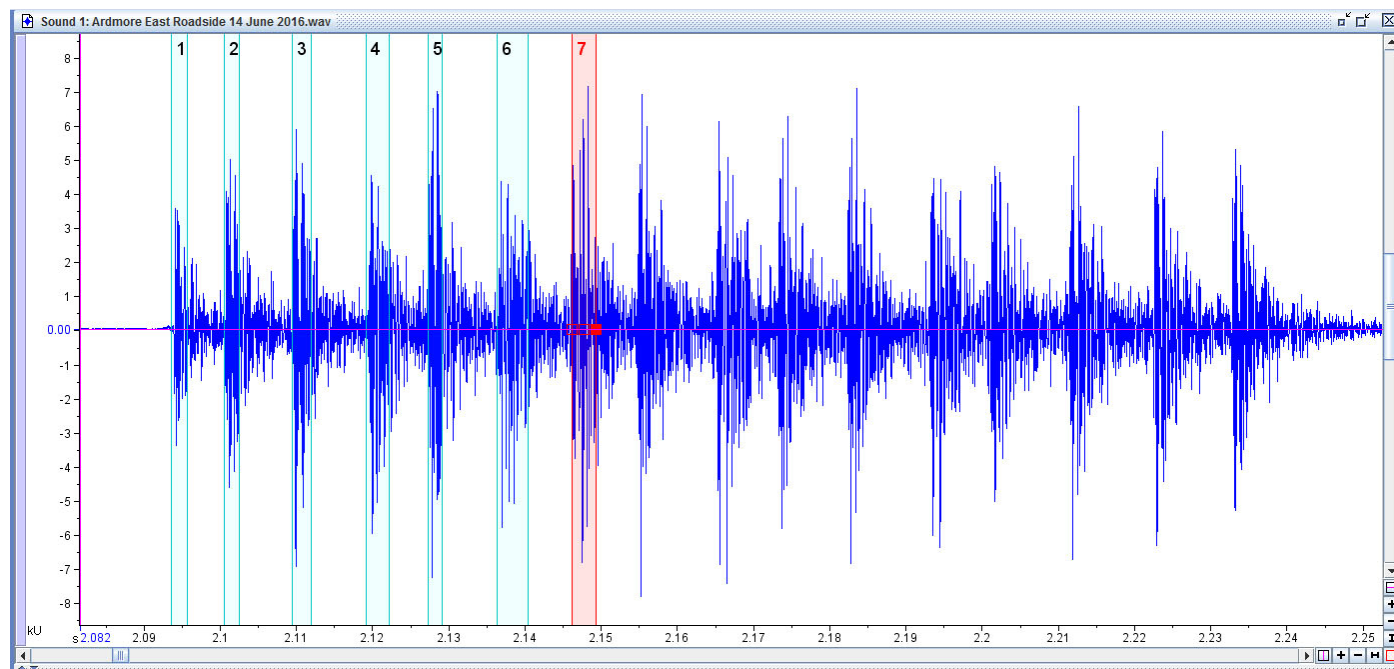
A record of 6 calls of 2 syllables each, displayed in Raven Lite.

The top chart is the amplitude or volume, the lower chart is a sonogram splitting the sound into frequencies (kHz scale on y axis). The sonogram is not used for this PPD analysis.



A single syllable expanded in Raven Lite to show the sound pulses that make it up (like the faint red highlighted area labelled "1" in the previous chart)

The blue cursor lines are the manual marking of the start of the pulse labelled 1,2 3 etc to 11. (the end line is ignored). This produces the Excel file of pulse timing that can be processed to make the 10 pulse to pulse durations (PPDs) and then then the average of five first syllables. This is the information taken from each record used in this study.



There is a single Excel database file which includes all the analysed sound files to date. Each column has 10 PPD's in milliseconds with each original sound file name, unaltered, copied and pasted at the top.

Using this as a database new records can be added as new columns and refer to each file by the excel column name which is A,B,C...AA,AB,AC, etc, much shorter than the original sound file name.

Correlations

It is possible to compare records using excel CORREL command which computes the correlation coefficient "r" between two records.

Excel can instantly produce a correlation matrix, with conditional formatting rule $r > 0.95$, which marks the closely matching pairs, comparing every record with every other record. (For 127 records that is 8,001 pairs)

The list of $r > 0.95$ matches has to be extracted from the horizontal and vertical lines of the matrix for each record. The matrix can be sorted using "filter" in columns and rows (using a transposed copy of the data).

These lists of record IDs have been copied in descending 'r' order below each record and used to plot a chart of the mathematically closest 8 records with $r > 0.95$ for each record. These have been grouped by checking the list for matching record IDs and by the shape of the PPD chart plot, into arbitrarily numbered clusters of similar pattern. Any recording files that appear in two clusters have been checked and assigned to only one cluster.

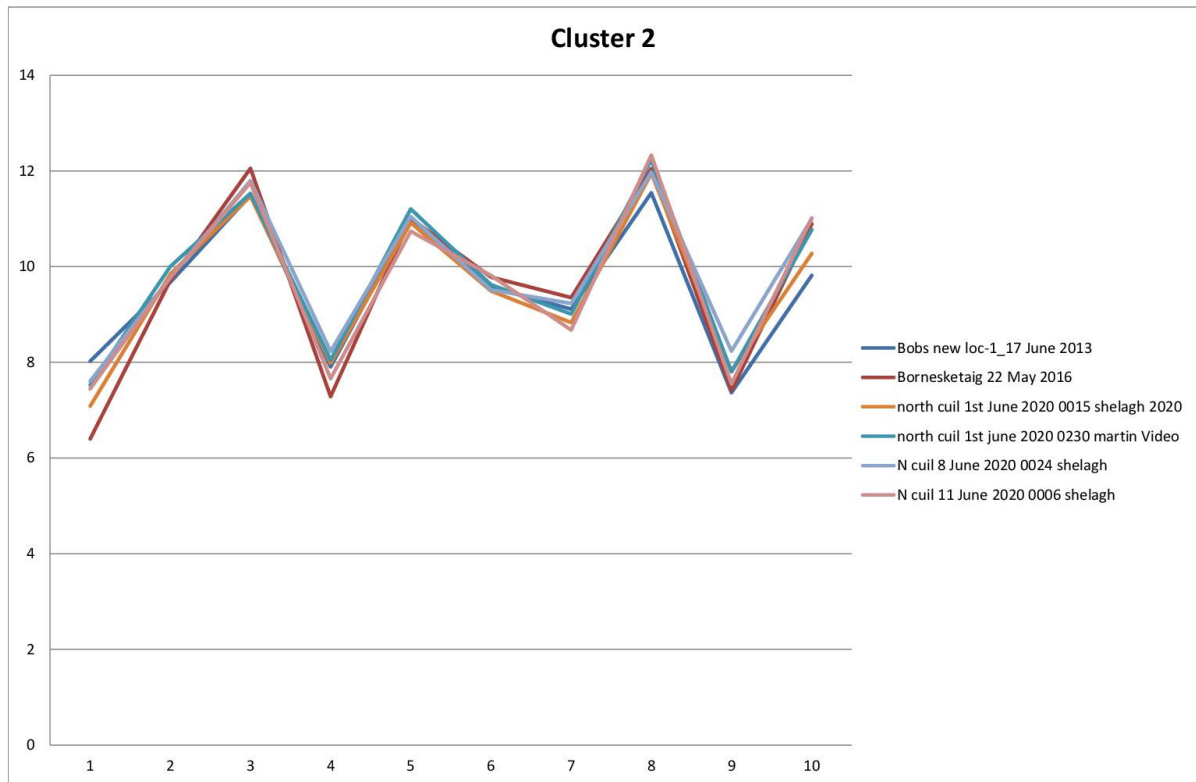
The cluster plots have been visually checked and where they are very similar and could be ambiguous they have been put together into groups in the cluster plots print outs.

The recordings in each cluster have been listed and plotted with their recording file names displayed in the chart legend.

Cluster plots

32 clusters appeared out of the 127 recordings and form the basis of the analysis. They have been plotted individually with a legend showing the file names in date order with a GIS map to show their locations. They may show returns from previous years and movements within a year.

Example of a Cluster plot



The chart title is the Cluster number.

The legend list shows the record names which include the date and place of each recording.

The vertical axis is in milliseconds measured between pulses 1 to 11, (that is 10 PPDs).

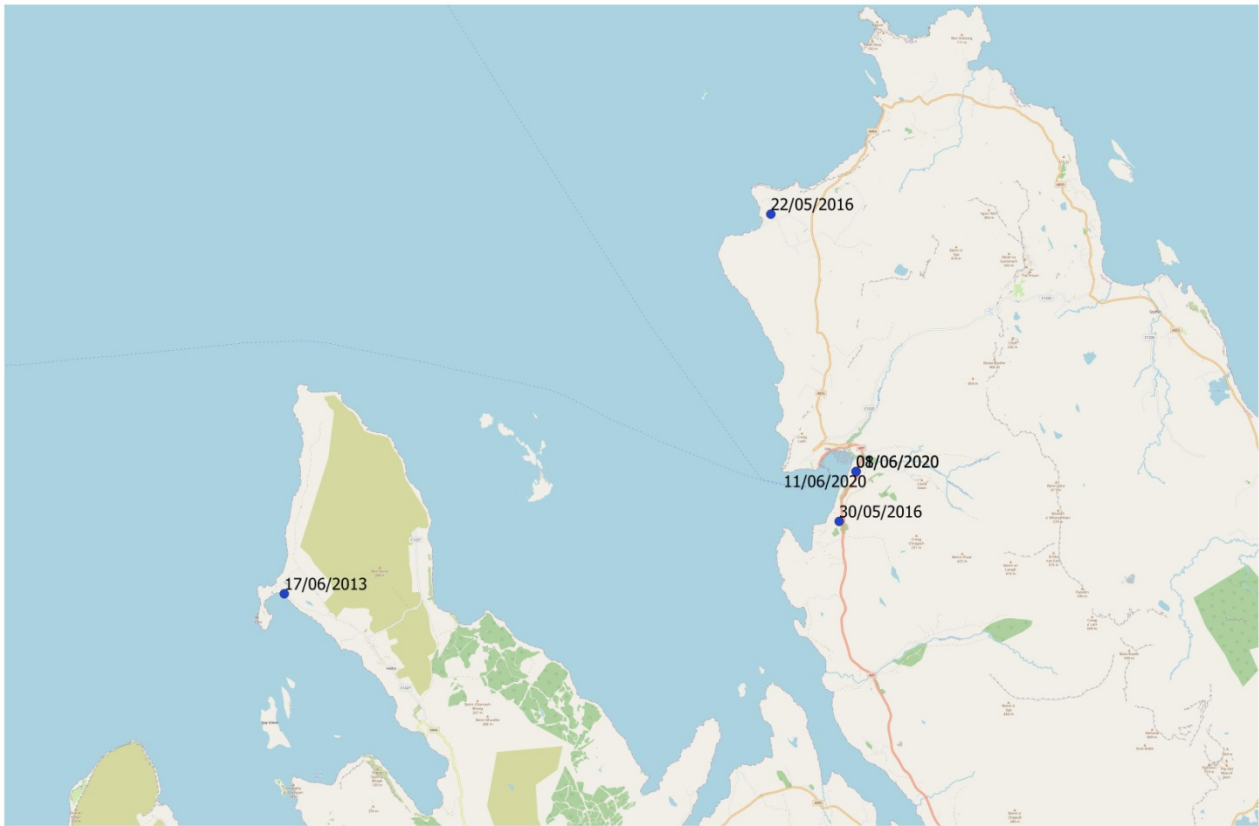
QGIS (open source Geographical Information System software)

Example of QGIS map for Cluster 2

The points are labelled with the date of each recording.

Cluster 2

Quality 4-5 recordings, analysed in 2020



QGIS

All the records have been imported into QGIS and can be plotted on a map provided they have some location information. Some cluster maps may show movement made by individuals within each year.

Notes on cluster plots

The uncertainties and limitations involved in this analysis are partially dealt with in the paper from 1998. (reproduced in full, below. *Individuality in Corncrake *Crex crex* vocalizations*)

These limitations are largely due to some birds sharing a PPD pattern. This makes it impossible to be certain of their identity but does allow definite separation of different individuals with different patterns, especially with small numbers of birds and recordings analysed as they happened sequentially over time.

It is clear that some conclusions about corncrake movement and survival could be drawn from matching PPD charts.

It is also clear that short mobile phone recordings are adequate especially with newer phones with 10kHz recording bandwidth which can capture the start of a pulse more readily than older phones with 5kHz bandwidth which spread the start point slightly. To use this procedure only 5 good calls are needed so a record of 20 seconds or more is enough. Improvements in the range of recording and the quality are possible using an external microphone and a reflector.

Year span spreadsheet

This spreadsheet shows which clusters or PPD patterns have occurred in other years. This may be evidence of returning birds or perhaps genetically related birds. It may also give an idea of their survival over several years. There are 32 clusters. (6,21,and 25 had duplicates and were removed.)

The cluster/PPD patterns that are very similar and could be ambiguous have been grouped together and are listed and marked in green. This becomes 24 'definitely different' PPD patterns.

Cluster	2013	2014	2015	2016	2017	2018	2019	2020
1	2013	2014		2016				
2	2013			2016				2020
3	2013	2014		2016				
14	2013	2014						
15			2015	2016				2020
29								2020
4		2014					2019	
26							2019	
32				2015				
5		2014	2015					2020
7		2014			2017		2019	
18		2014		2016				
8		2014						
9		2014	2015					
35								2020
10		2014						
11		2014				2018	2019	2020
12		2014						
13	2013	2014						2020
30							2019	2020
16			2015					
17			2015					
19				2016				
20				2016				2020
22	2015					2018		2020
23						2018		
24						2018		
27							2019	
28							2019	2020
31		2014		2016				2020
33		2014	2015					2020
34								2020

The recording effort was not constant over all years and the quality early on was not as high because of the frequency response limitation of the old mobile phone. Also some recordings lost their location data when a new phone was used and recordings transferred. However, there are still obvious inferences to be made despite the inevitable gaps in the data as outlined.

Some patterns are appearing in consecutive years. There are 39 that only appear in single consecutive years (although 18 of them reappear after a gap in time), 10 that span two years and one that spans 3 years. These all hint at the possible survival rate of corncrakes.

Notes on the analysis

This presentation is a summary of the data to date and an attempt to display it all so that some sort of evaluation and extraction of meaningful stories about bird survival and movement during and between years could be made. The male birds clearly do move around within a season and probably arrive back in different locations in following years. They may survive for several years although many only appear once and presumably do not survive or are not recorded again.

Sound recordings are very appropriate for locating male and occasionally female corncrakes and this data confirms that they have a signature PPD pattern which unfortunately can coincide with others making it difficult to be certain about matched identities. However different PPD patterns are a definite indication of a different bird. There are also clearly a few patterns that are particularly common and many individuals share something similar. This is shown in the groups of clusters that are identified in the **cluster plots** section and by the green bars in the **year span spreadsheet**.

The **year plots** show evidence of movement and numbers of individuals. The **year span spreadsheet** gives an indication of corncrake survival.

There is a list of all the files analysed at the end.

Year plots for 2013-2020

The files have been sorted into separate years and are identified by their cluster number.

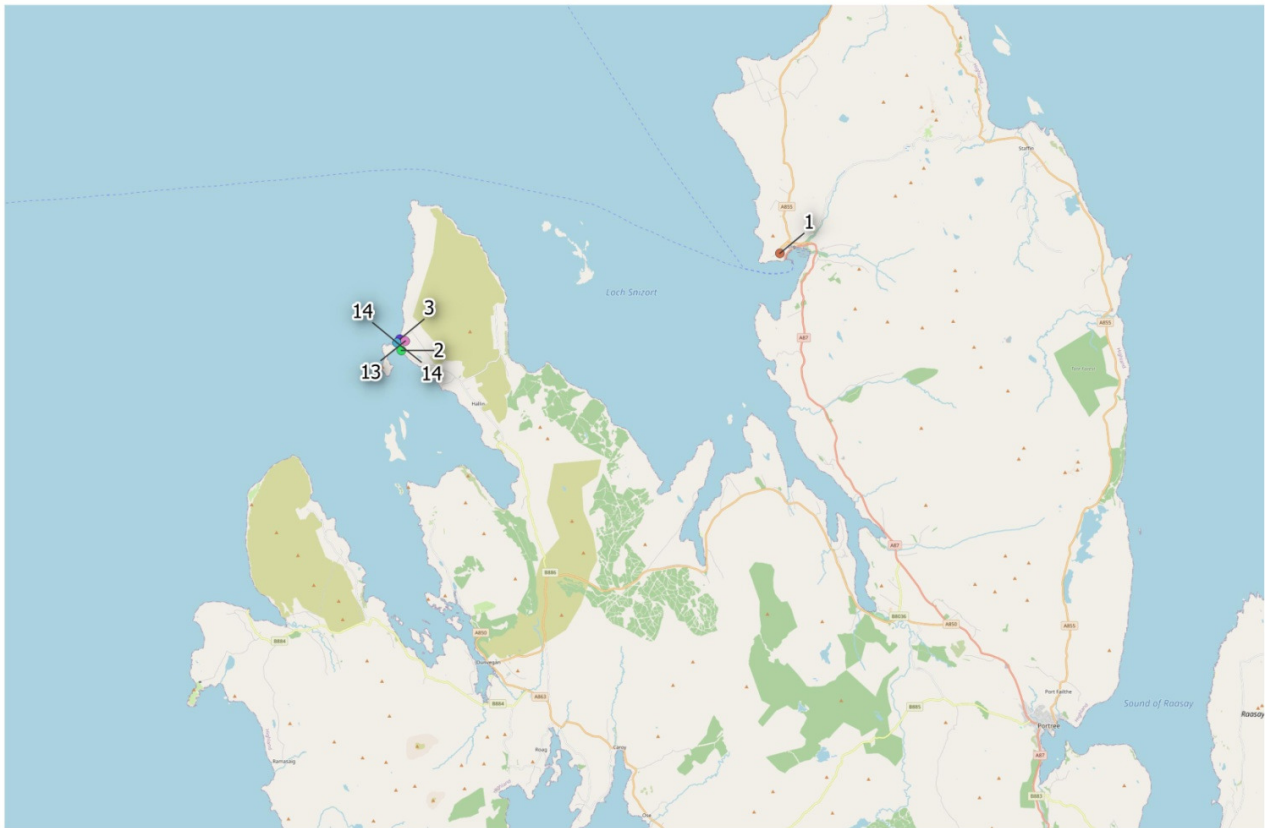
There is a list of the recording file names below each map.

For years with many recordings plotted on the GIS map, a simplified map with only one label for each cluster has been added, for clarity.

They indicate the number of individual birds and movements they may have made in the year.

At the end of each year section there is a note analysing the number of clusters for that year which may represent individuals and when a cluster appears in two locations it may show a movement during the year by the male bird.

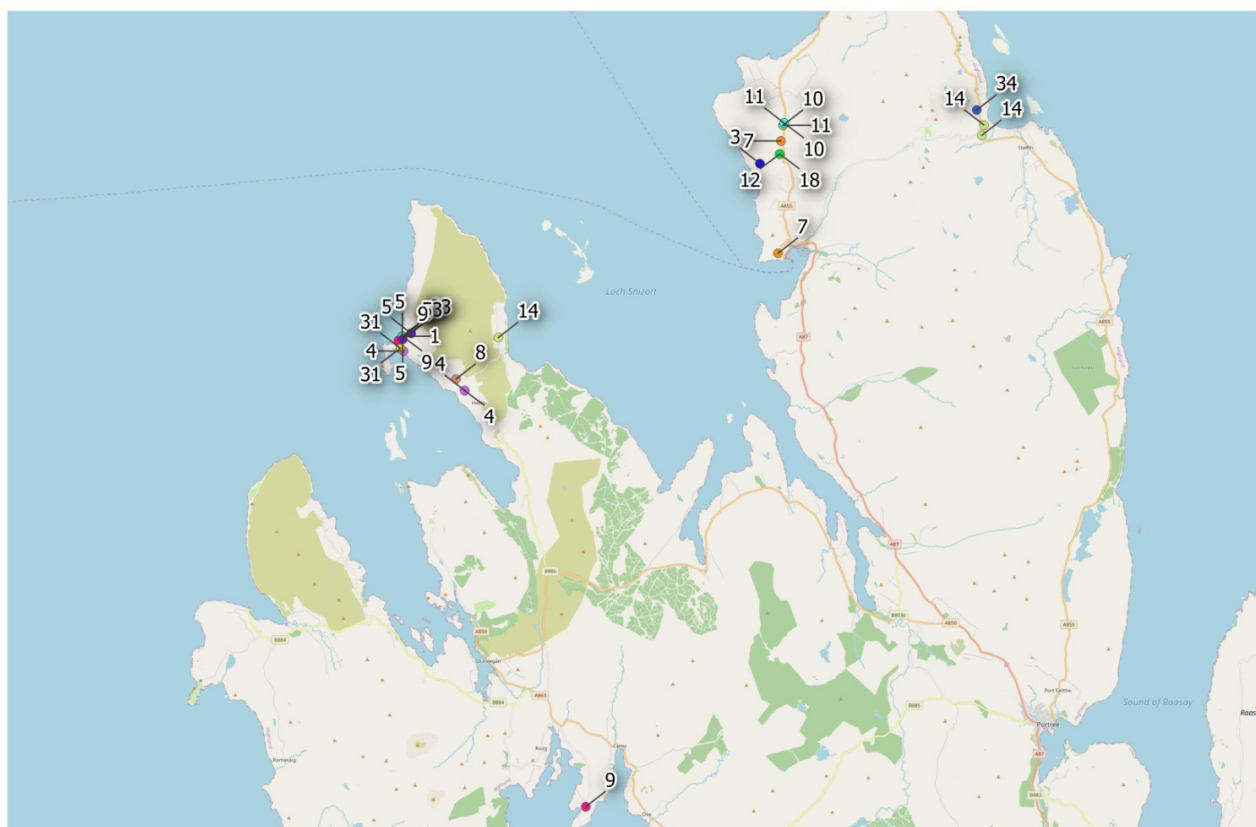
There is a note summarising this for each year under each list.



CLUSTER	ID	NAME	DATE
1	JL	Idrigil_29 May 2013	29/05/2013
2	JE	Bobs new loc-1_17 June 2013	17/06/2013
3	IS	Ardmore 3-1_21 June 2013	21/06/2013
13	JA	Bobs new loc-1_17 June 2013	17/06/2013
14	IV	Ardmore substation 2 - 3_27 June 2013	27/06/2013
14	IW	Ardmore substation-3_29 June 2013	29/06/2013

Notes 2013

There are 5 different patterns or clusters.

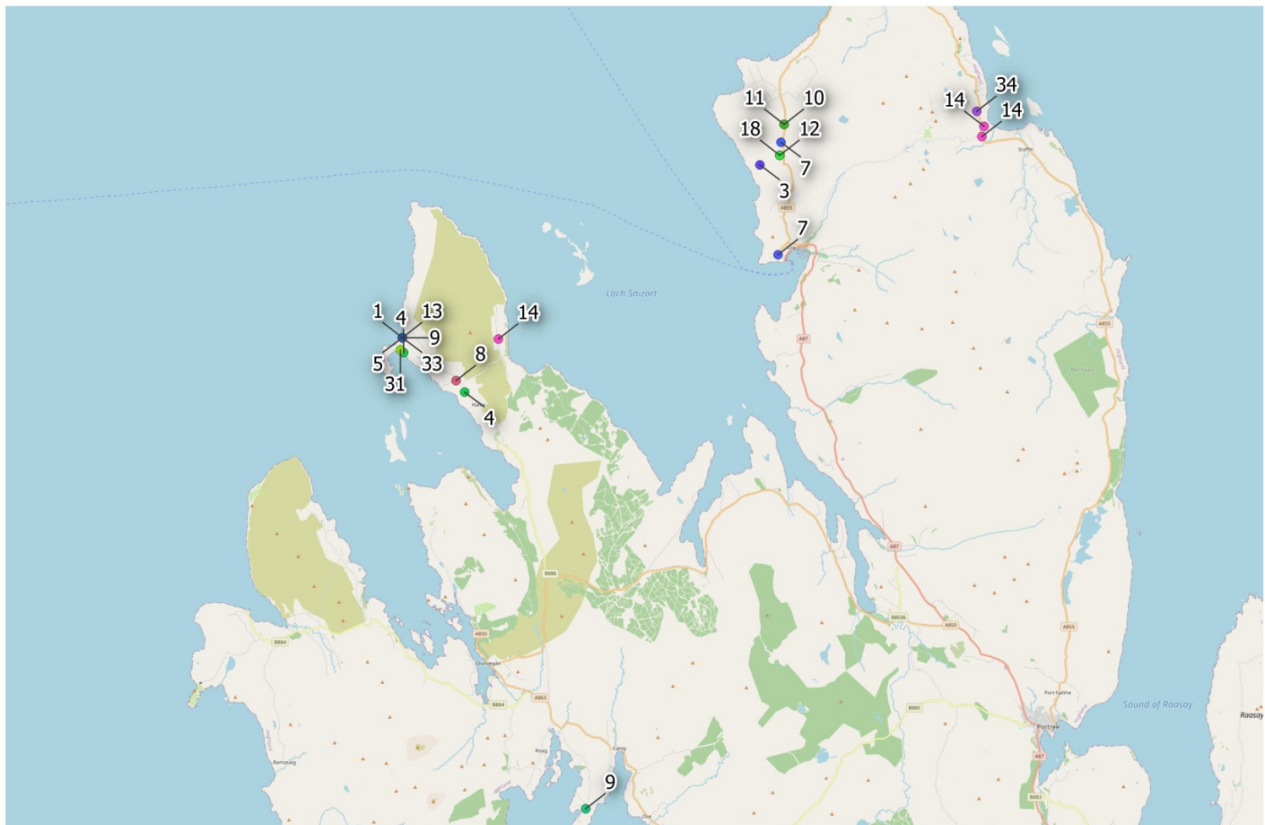


CLUSTER	ID	NAME	DATE
1	GI	16-06-2014, 04_01 ardmore 1 of 2	16/06/2014
1	GM	19-06-2014, 01_45 ardmore	19/06/2014
3	DU	08-05-2014, 01_16 monkstadt	08/05/2014
4	DX	08-05-2014, 03_05 trump pan davy	08/05/2014
4	FU	03-06-2014, 00_04 7 hallin park	03/06/2014
4	FX	04-06-2014, 01_15 7 hallin park	04/06/2014
5	DZ	08-05-2014, 03_15 ardmore east field	08/05/2014
5	EK	12-05-2014, 01_03 ardmore nora reeds	12/05/2014
5	GL	19-06-2014, 01_41 ardmore	19/06/2014
5	X	R09_0001 ~ 2014 ~ CORNCRAKE @ TRUMPAN ~ 22 July 2014 ~ 0pm to 10-30pm ## from NG 22562-61317	22/07/2014
5	AF	R09_0001 ~ 2014 ~ CORNCRAKE @ TRUMPAN ~ 22 July 2014 ~ 10pm to 10-30pm ## from NG 22562-61317	22/07/2014
7	EP	17-05-2014, 01_12 idrigill	17/05/2014
7	FQ	30-05-2014, 03_12 whitewave quail	30/05/2014
8	EQ	17-05-2014, 03_28 1 halistra or 8 hallin park	17/05/2014
9	ES	24-05-2014, 00_45 harlosh 2 birds	24/05/2014
9	FW	03-06-2014, 00_24 ardmore west field	03/06/2014
9	GG	16-06-2014, 03_40 ardmore	16/06/2014
10	EY	25-05-2014, 02_55 lionacro below school 1	25/05/2014
10	FB	25-05-2014, 02_56 lionacro below manse 2 of 2	25/05/2014
11	EZ	25-05-2014, 02_55 lionacro below school 2	25/05/2014
11	FA	25-05-2014, 02_56 lionacro below manse 1 of 2	25/05/2014
12	GF	16-06-2014, 02_31 lionacro	16/06/2014
13	GH	16-06-2014, 03_47 ardmore	16/06/2014

14	EL	12-05-2014, 01_29 geary nissan hut	12/05/2014
14	GQ	20-06-2014, 01_01 glasphein	20/06/2014
14	GR	20-06-2014, 01_05 brogaig	20/06/2014
18	FR	30-05-2014, 03_13 lionacro	30/05/2014
31	FV	03-06-2014, 00_19 trumpan bobs	03/06/2014
31	FZ	04-06-2014, 01_40 ardmore bob	04/06/2014
33	EA	08-05-2014, 03_22 ardmore nora reeds	08/05/2014
33	GK	19-06-2014, 01_39 ardmore	19/06/2014
34	GP	20-06-2014, 00_44 digg	20/06/2014

Clusters in 2014, simplified

Quality 4-5 recordings, analysed in 2020

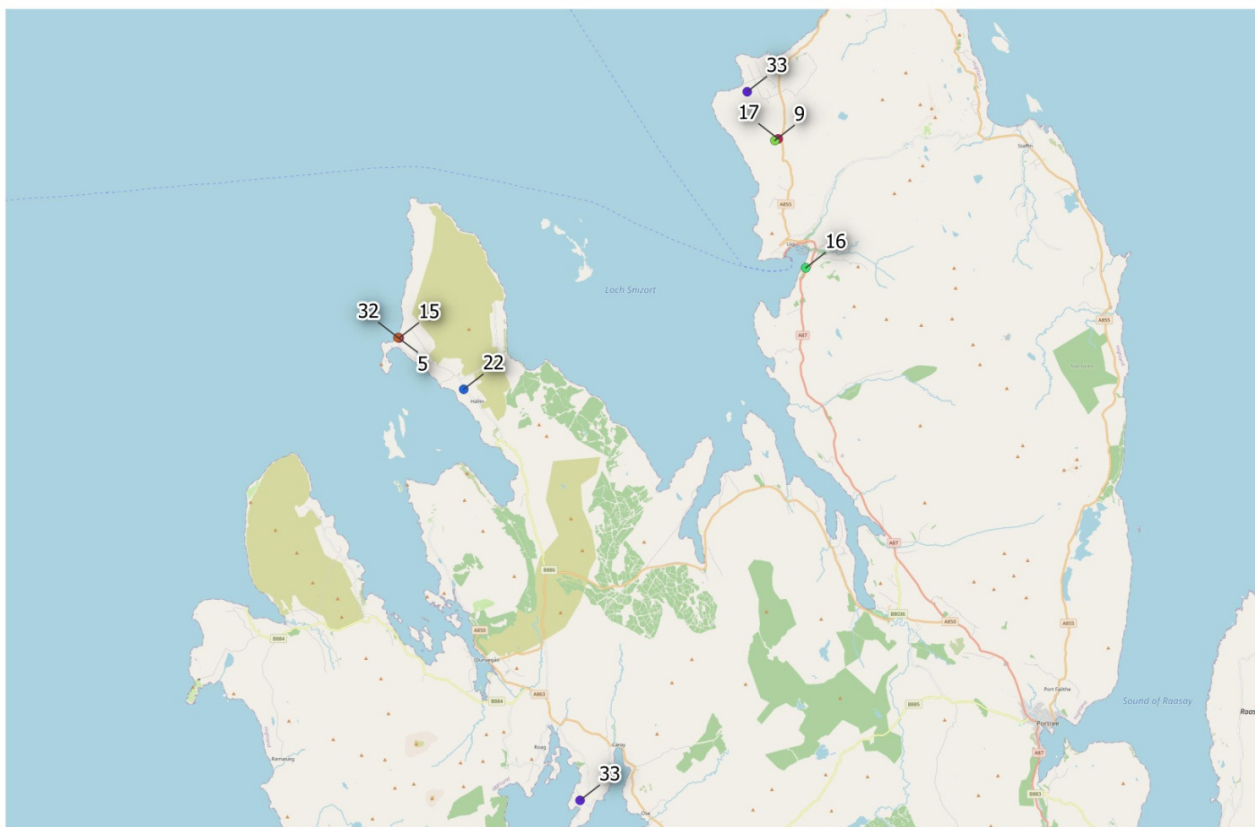


Notes 2014

There are 16 different patterns or clusters.

Several made movements.

4	from Hallin Park	to Trumpan	
7	from Idrigill	to Lionacro	
9	from Harlosh	to Ardmore	
14	from Geary	to Glasphein	to Brogaig



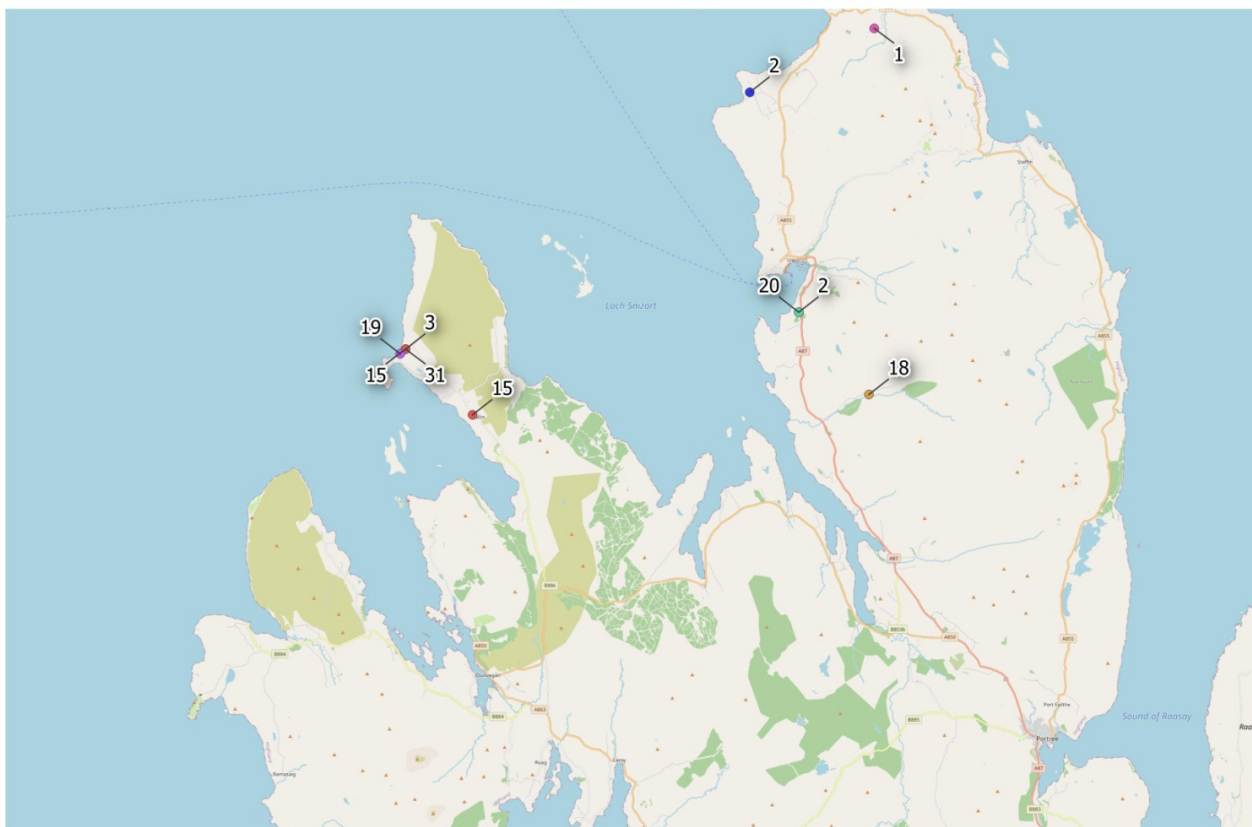
CLUSTER	ID	NAME	DATE
5	BU	14-07-2015, 00_25 ardmore 2 crakes	14/07/2015
9	BE	08-06-2015, 02_09 trotternish NG3868	08/06/2015
15	AH	14-05-2015, 00_29 ardmore carpark nettle	14/05/2015
16	AR	23-05-2015, 00_13 trotternish S cuil	23/05/2015
17	AT	23-05-2015, 02_02 trotternish lionacro loch area	23/05/2015
22	BW	17-06-2015, 00_00 5 hallin park.Table	17/06/2015
32	BI	09-07-2015, 03_30 ardmore 2 crakes	09/07/2015
33	CG	30-05-2015, 01_33 harlosh duneilerich	30/05/2015
33	BF	08-06-2015, 02_20 trotternish NG3773	08/06/2015

Notes 2015

There are 8 different patterns or clusters.

One made a movement.

33 from Harlosh to Bornesketaig



CLUSTER	ID	NAME	DATE
1	DC	Conista 26 June 2016	26/06/2016
2	DB	Bornesketaig 22 May 2016	22/05/2016
2	DE	Earlish 30 May 2016	30/05/2016
3	CX	Ardmore East Roadside 12 June 2016	12/06/2016
15	CU	1 Hallin Park 5 June 2016	05/06/2016
15	CY	Ardmore East Roadside 14 June 2016	14/06/2016
18	DH	Glen Hinnisdale 24 May 2016	24/05/2016
19	K	Ardmore Nettles 23 May 2016	23/05/2016
20	DF	Earlish Upper July 2016	01/07/2016
31	CW	Ardmore east roadside 11 June 2016	11/06/2016

Notes 2016

There are 8 different patterns or clusters.

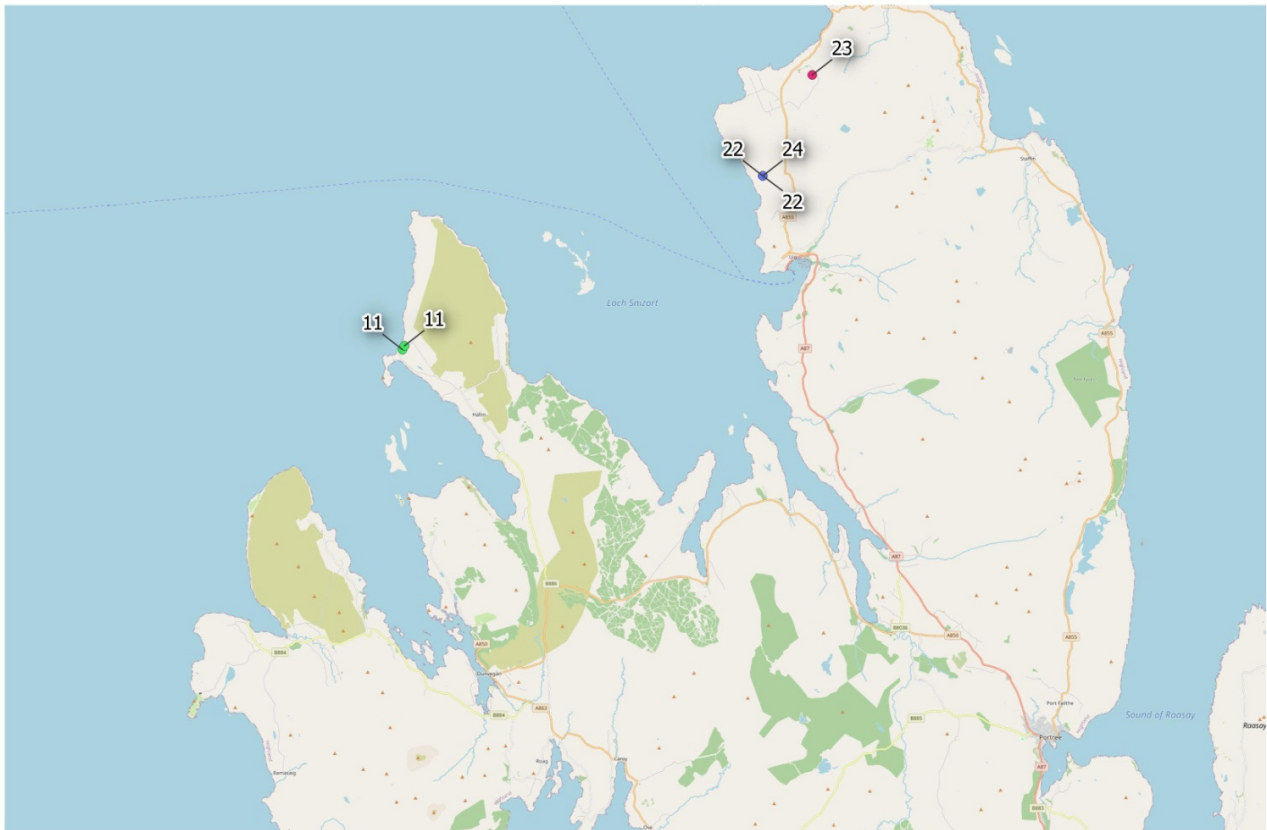
Two made movements.

2 from Bornesketaig to Earlish
 15 from Hallin Park to Ardmore



CLUSTER	ID	NAME	DATE
7	DJ	Hazel Upper Halistra 19 June 2017	19/06/2017

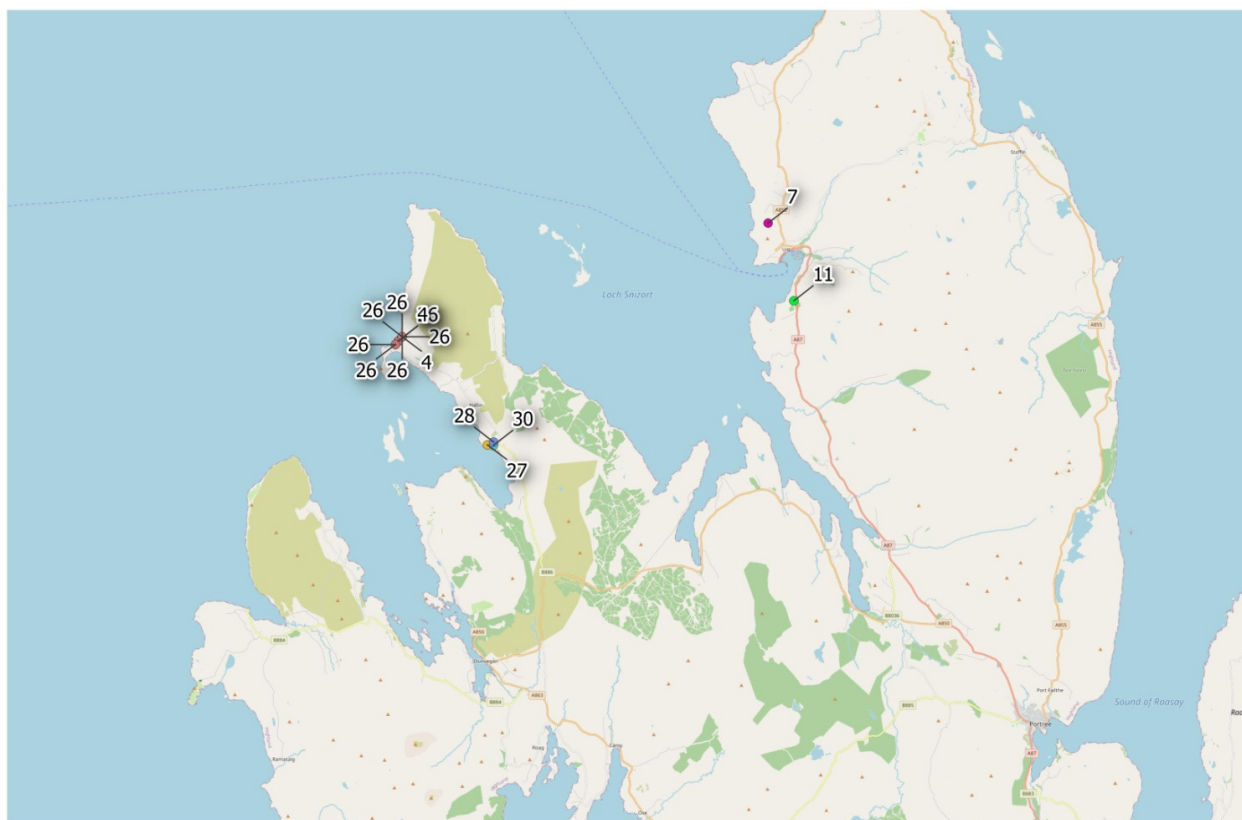
Notes 2017
There is 1 pattern or cluster.



CLUSTER	ID	NAME	DATE
11	L	Ardmore West 12 July 2018.Table.1.selections	12/07/2018
22	KI	Monkstadt 1 - 29 June 2018	29/06/2018
22	KG	Monkstadt X2 29 June 2018 1 of 2	29/06/2018
23	KK	Peingown 29 June 2018	29/06/2018
24	KJ	Monkstadt 10 July 2018	10/07/2018

Notes 2018

There are 4 different patterns or clusters.

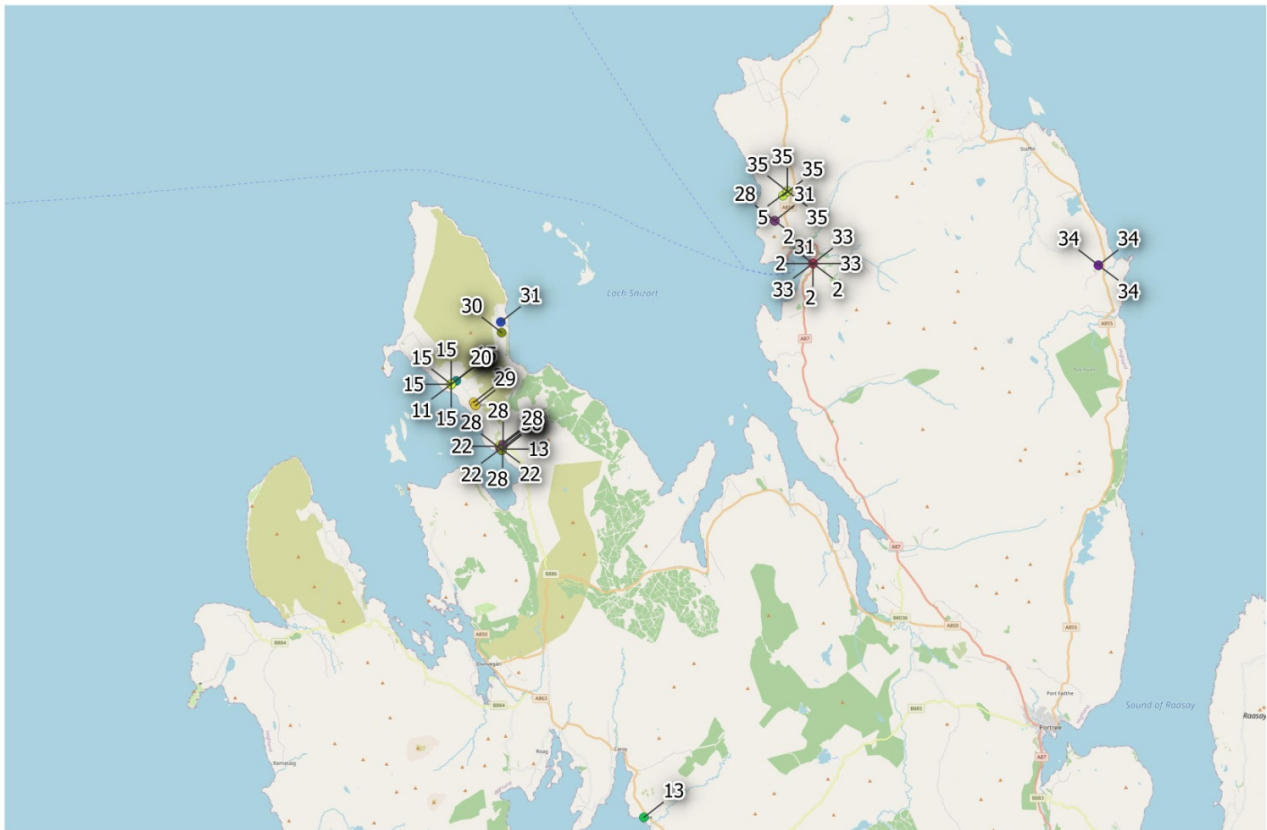


CLUSTER	ID	NAME	DATE
4	JP	Ardmore west 5 July 2019 from road	05/07/2019
7	JW	Scudiburgh 7 June 2019	27/06/2019
11	JU	Earlish x roads 11 June 2019-3	11/06/2019
26	O	Ard carpark nettles 14 June 2019	14/06/2019
26	R	Ardmore nettles 16th june 2019 robert 20190616_174506	16/06/2019
26	JQ	Ardmore west 5 July 2019 from s gate	05/07/2019
26	JR	Ardmore west 12 July 2019	12/07/2019
26	JS	Ardmore west 12 July 2019-2	12/07/2019
26	JT	Ardmore west field 20 July 2019	20/07/2019
26	U	20190721_010002 21st july 2019 ardmore lime dump	21/07/2019
26	V	28th july 2019 ardmore lime dump	28/07/2019
27	F	Waternish farm oans 6-7-19 10pulses av5	06/07/2019
28	JZ	Waternish farm 12 July 2019	12/07/2019
30	G	Waternish farm stein 6-7-19 10pulses av5	06/07/2019



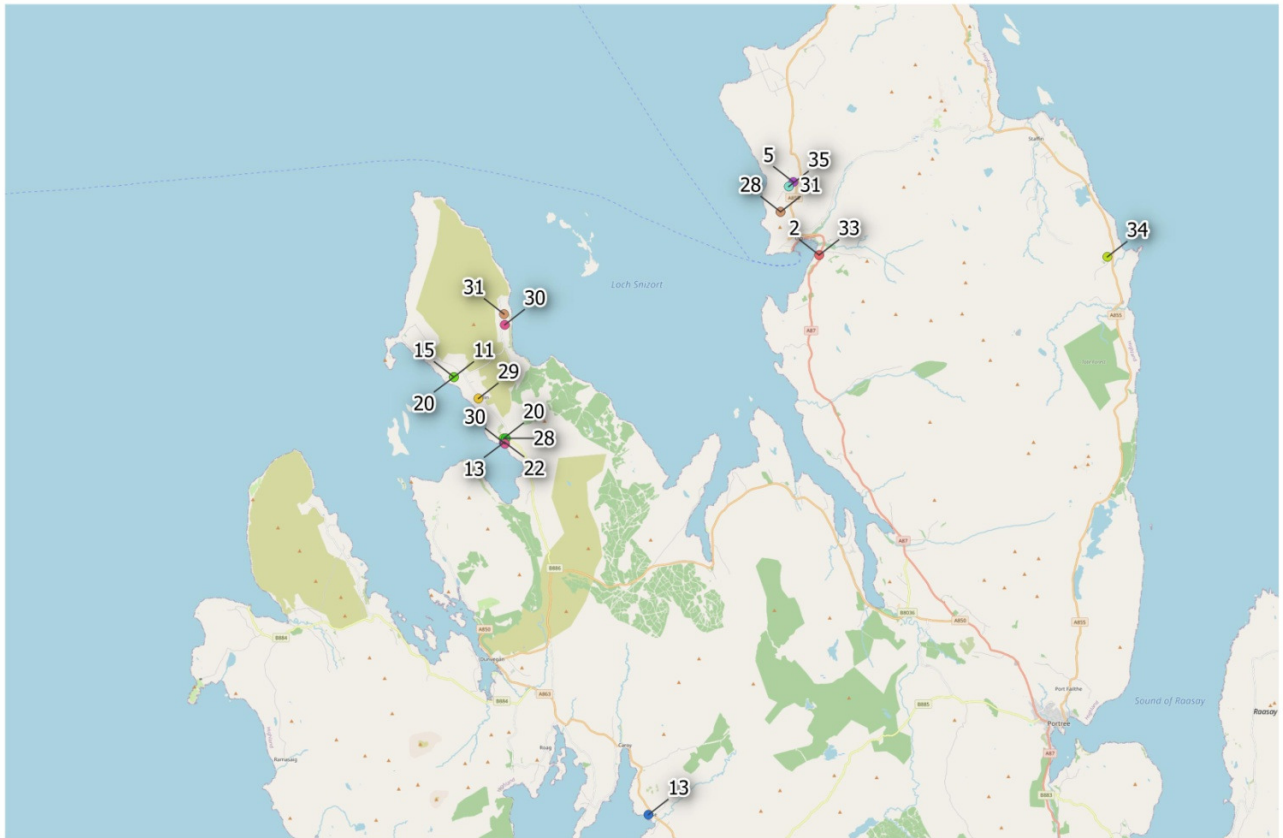
Notes 2019

There are 7 different patterns or clusters.



CLUSTER	ID	NAME	DATE
2	LR	north cuil 1st June 2020 0015 shelagh 2020	01/06/2020
2	LQ	north cuil 1st june 2020 0230 martin Video	01/06/2020
2	LY	N cuil 8 June 2020 0024 shelagh	08/06/2020
2	ME	N cuil 11 June 2020 0006 shelagh	11/06/2020
5	NH	N totescore 3 25 June 2020 shelagh	25/06/2020
11	MQ	gordon taylor 16th june 2020 0039 gordon 2020_06_16_00_39_41	16/06/2020
13	LJ	stein May 19th 2020 2350 lynn VID-20200522-WA0000	19/05/2020
13	LT	Ose 3 June 2020 2358	03/06/2020
15	MG	CARNACH 12 June 2020 2337 john R09_0003	12/06/2020
15	MH	LOWER HALISTRA CARNACH 12 June 2020 2338 john R09_0005	12/06/2020
15	MF	Gordon Taylor 13 June 2020-2 0100 shelagh	13/06/2020
15	MN	gordon taylor 16th june 2020 0000 roland AUD-20200616-WA0000	16/06/2020
15	MP	gordon taylor 16th june 2020 0041 gordon 2020_06_16_00_41_42	16/06/2020
15	MO	gordon taylor 16th june 2020 0042 gordon 2020_06_16_00_42_33	16/06/2020
15	MR	carnach 19th june 2020 0010 shelagh AUD-20200619-WA0001	19/06/2020
15	MU	carnach 19th june 2020 0010 shelagh AUD-20200619-WA0003	19/06/2020
15	MT	carnach 19th june 2020 0010 shelagh AUD-20200619-WA0004	19/06/2020
15	MS	carnach 19th june 2020 0010 shelagh AUD-20200619-WA0005	19/06/2020
20	KU	stein May 9th 2020 0054 R09_0004 CORNCRAKE STEIN 9 May 2020 @ 00-54	09/05/2020
20	NJ	carnach 27th june 2020 1200 roland AUD-20200627-WA0000 qu4	27/06/2020
22	KN	stein-May 3rd 2345 video-1588547291	03/05/2020
22	KO	stein May 4th 2020 2245 video-1588676289	04/05/2020
22	KT	stein May 6th 2020 0024 R09_0012 CORNCRAKE STEIN 6 May 2020 @ 00-24	06/05/2020
28	LL	stein May 9-10th 2020 night lynnVID-20200522-WA0001	09/05/2020

28	LK	stein May 9-10th 2020 night lynnVID-20200522-WA0002	09/05/2020
28	LC	stein May 17th 2020 1600 graham_332054104440263	17/05/2020
28	LB	stein May 17th 2020 1600 graham_707356706679683	17/05/2020
28	LH	stein 19th May 2020 2135 shelagh AUD-20200519-WA0000	19/05/2020
28	NK	Scudiburgh 29 june2020 qu4-10calls	29/06/2020
29	LF	HALLIN PARK (Mary Campbell's) 19 May 2020 0046 John 00-46 R09_0013	19/05/2020
29	LG	HALLIN PARK (PAIRC MHOR) 19 May 2020 016 John R09_0001	19/05/2020
30	LM	stein May 20th 2020 night jamie_1931280013673273	20/05/2020
30	LO	stein May 20th 2020 night jamie_248369789837114	20/05/2020
30	LN	stein May 20th 2020 night jamie_249695306129222-3 calls	20/05/2020
30	LS	Geary 4 June 2020-2 0318 shelagh	04/06/2020
31	LI	geary26 20th May 2020 2230 shaz IMG_5773	21/05/2020
31	MK	Scudiburgh 14 June 2020-2 shelagh	14/06/2020
31	MI	Scudiburgh 14 June 2020-3 shelagh	14/06/2020
33	MD	N cuil 11 June 2020-2 0202 shelagh	11/06/2020
33	MJ	N cuil 14 June 2020 shelagh	14/06/2020
33	MM	N cuil 15 June 2020 shelagh	15/06/2020
34	NE	Grealine 1 24 June 2020 shelagh qu4	24/06/2020
34	NA	Grealine 2 24 June 2020 shelagh qu4	24/06/2020
34	NB	Grealine 5 24 June 2020 shelagh qu4	24/06/2020
35	MA	Totescore1 8 June 2020-2 0117 shelagh	24/06/2020
35	NG	N totescore 1 25 June 2020 shelagh	25/06/2020
35	NF	N totescore 2 25 June 2020 shelagh	25/06/2020
35	NO	North totescore 3 July 2020 with phone	03/07/2020



Notes 2020

There are 15 different patterns or clusters.

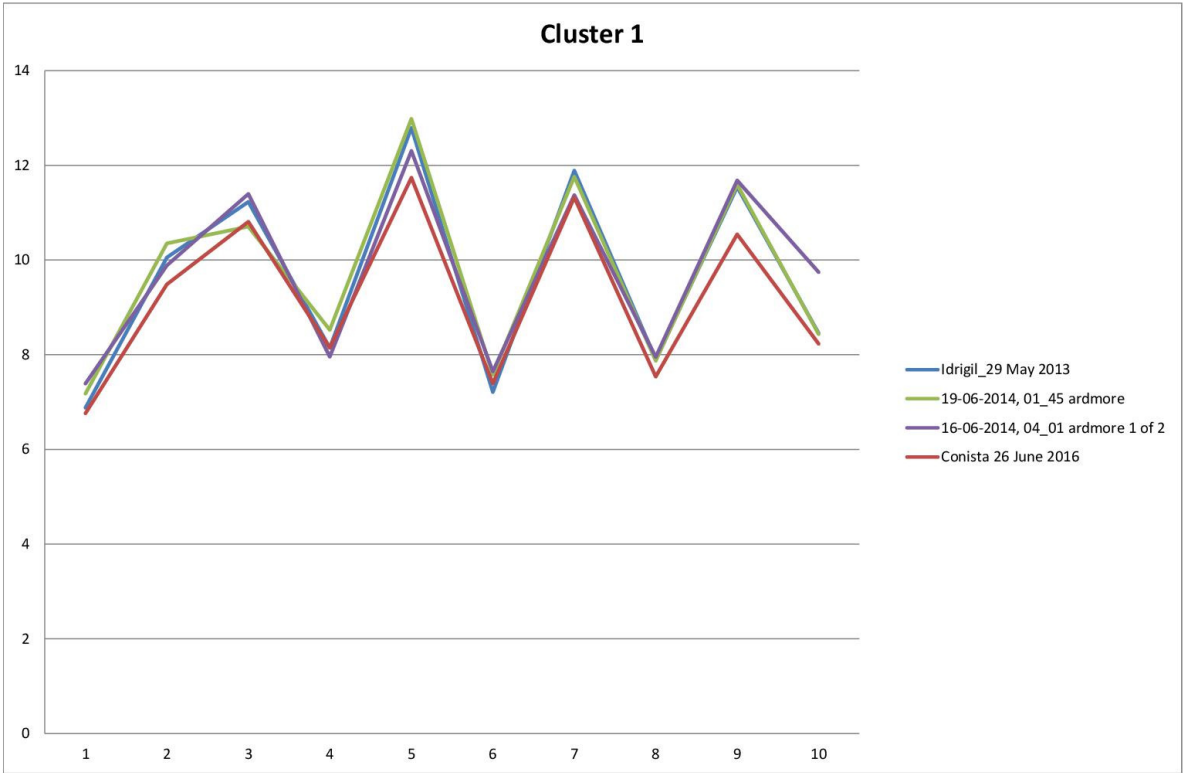
Four made movements.

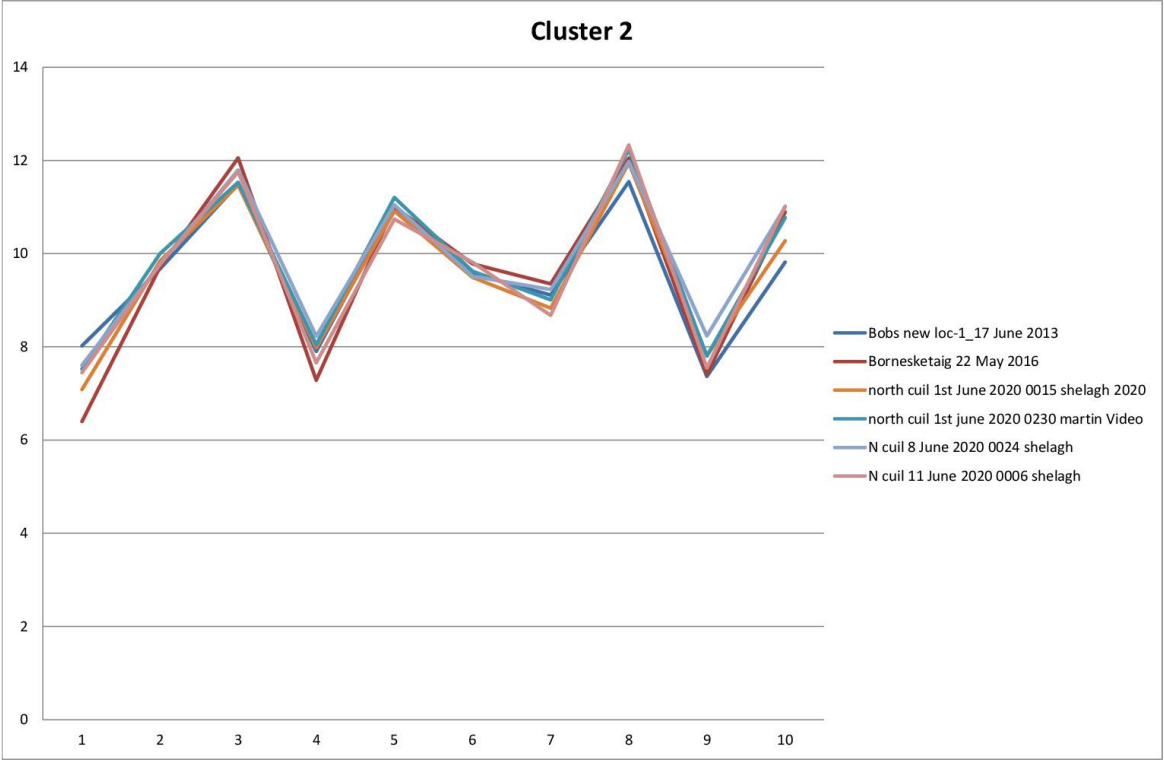
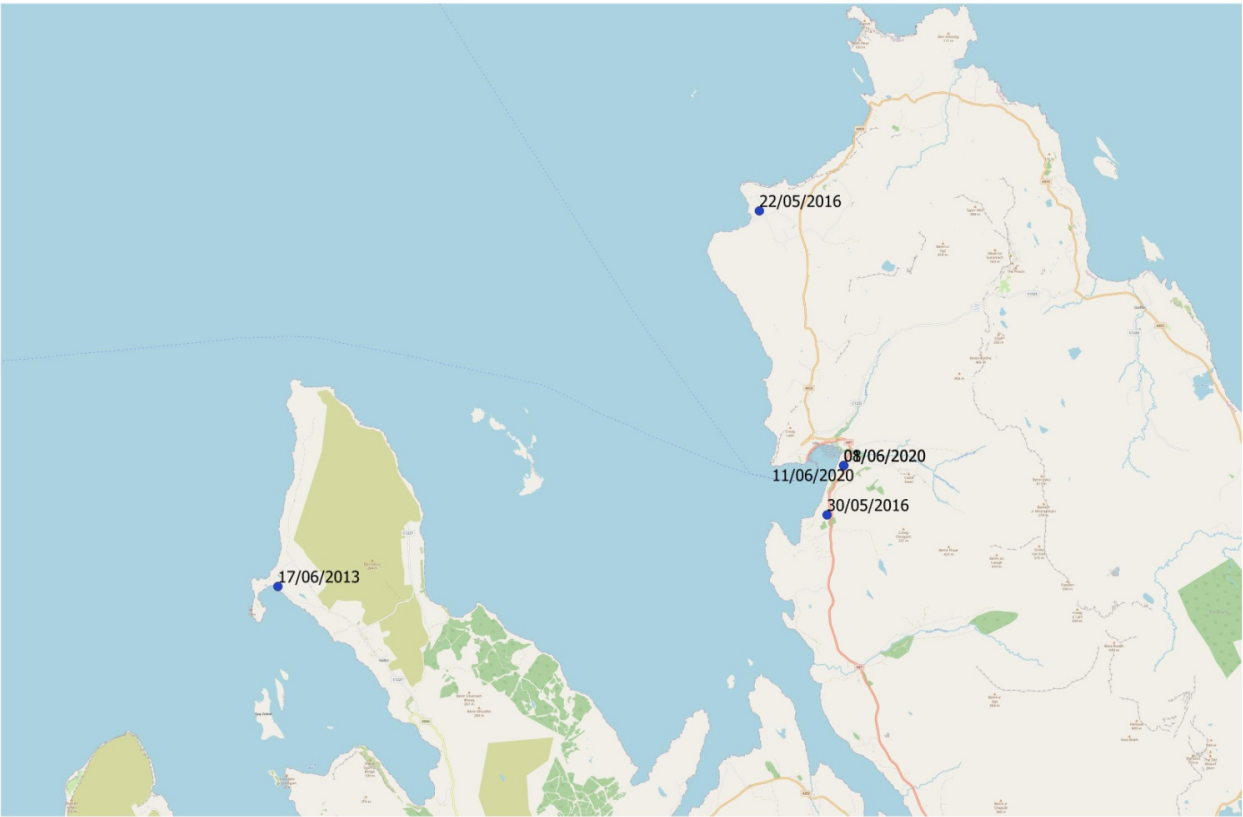
- | | | |
|----|------------|--|
| 13 | from Stein | to Ose (maybe Ose to Carnach is more likely, as we recorded in the initial 2020 summary) |
| 20 | from Stein | to Carnach |
| 30 | from Stein | to Geary |
| 31 | from Geary | to Scudiburgh |

32 Cluster plots, from 2013-2020

Cluster 1

Quality 4-5 recordings, analysed in 2020

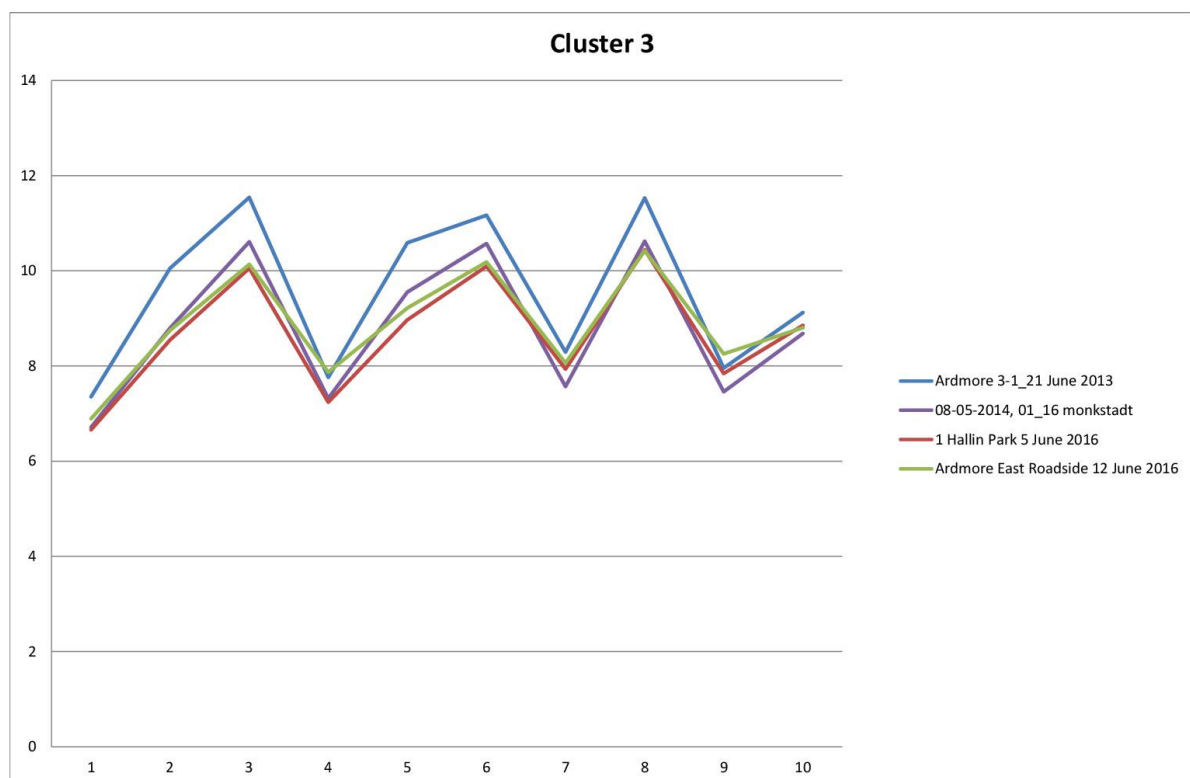




Clusters 3, 14 and 15 are similar

Cluster 3

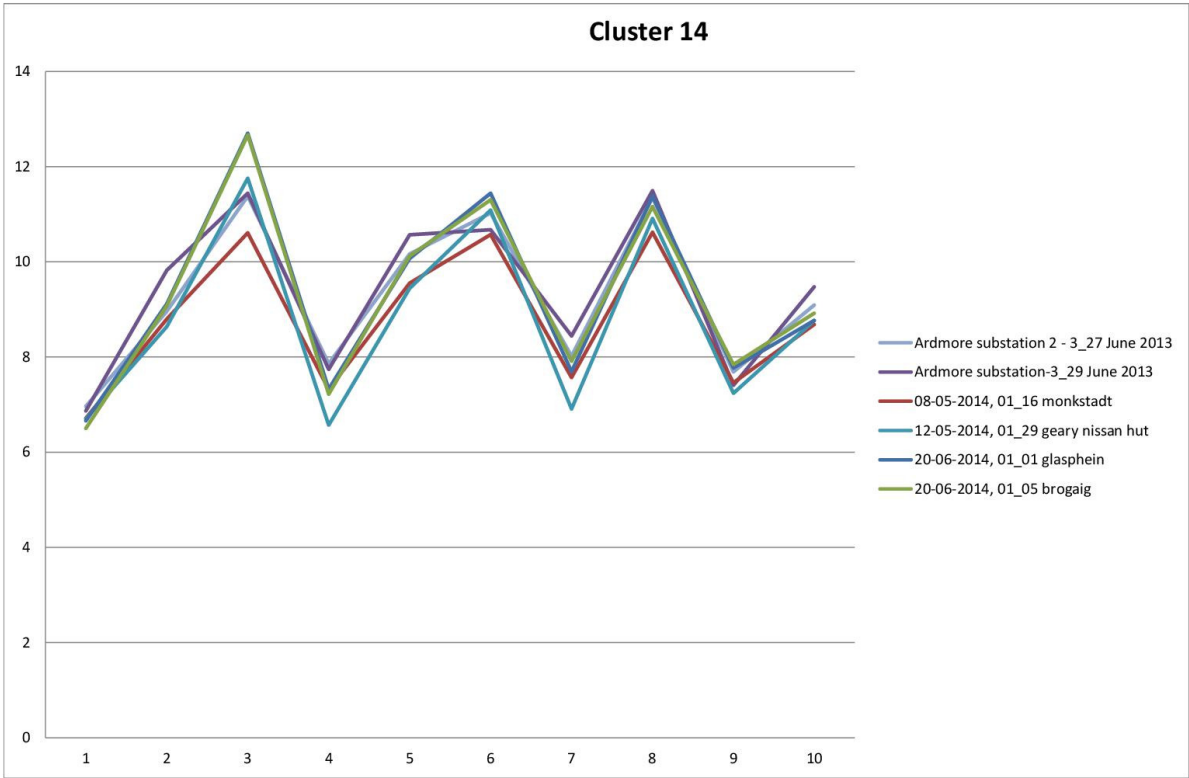
Quality 4-5 recordings, analysed in 2020



Clusters 3, 14 and 15 are similar

Cluster 14

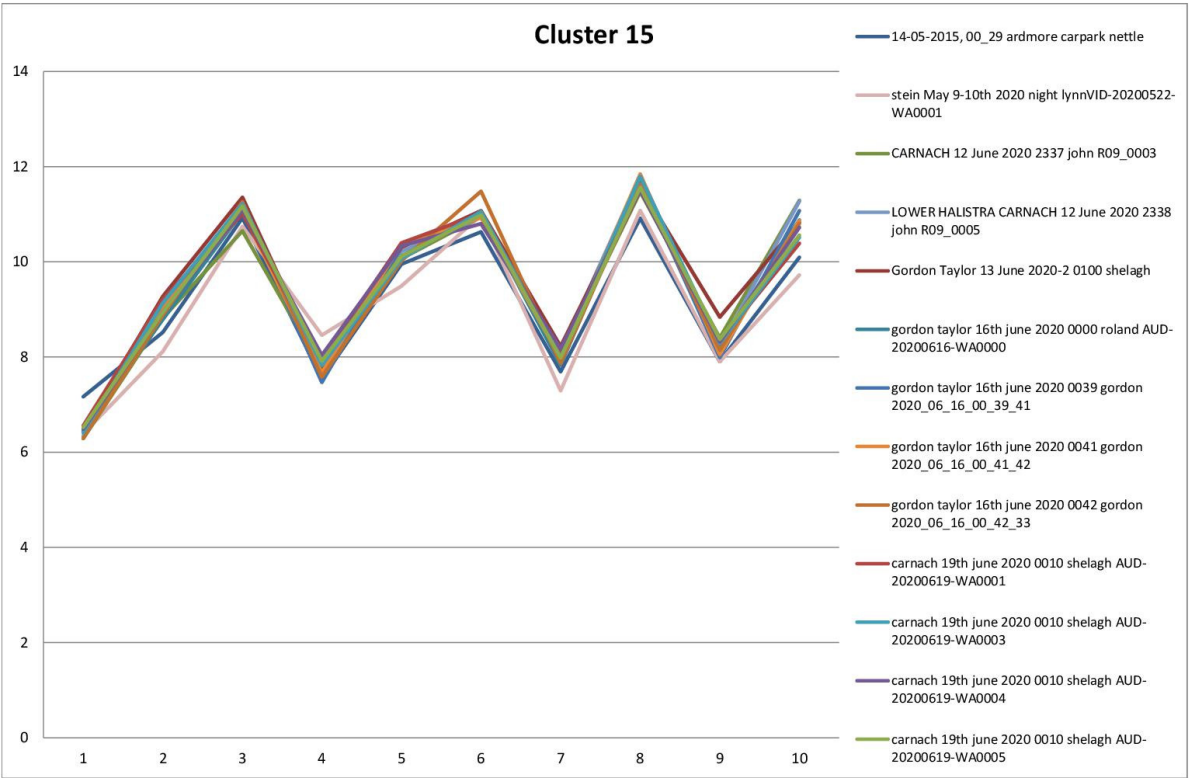
Quality 4-5 recordings, analysed in 2020



Clusters 3, 14 and 15 are similar

Cluster 15

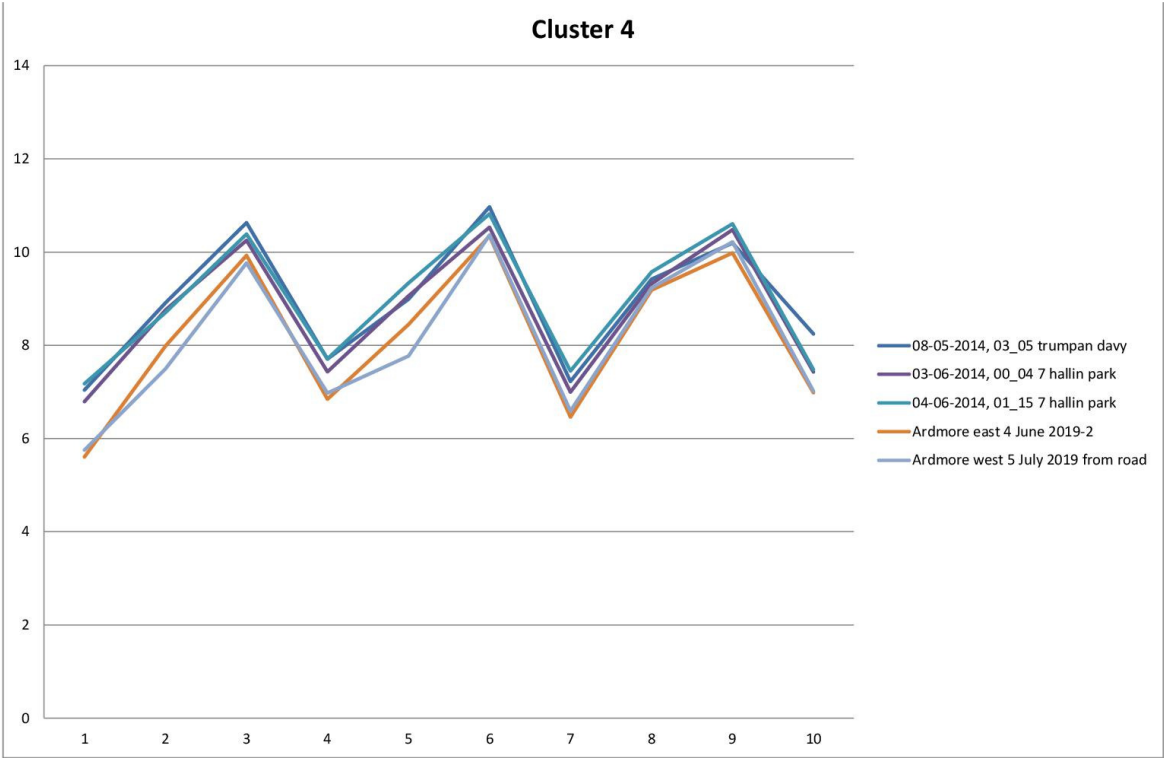
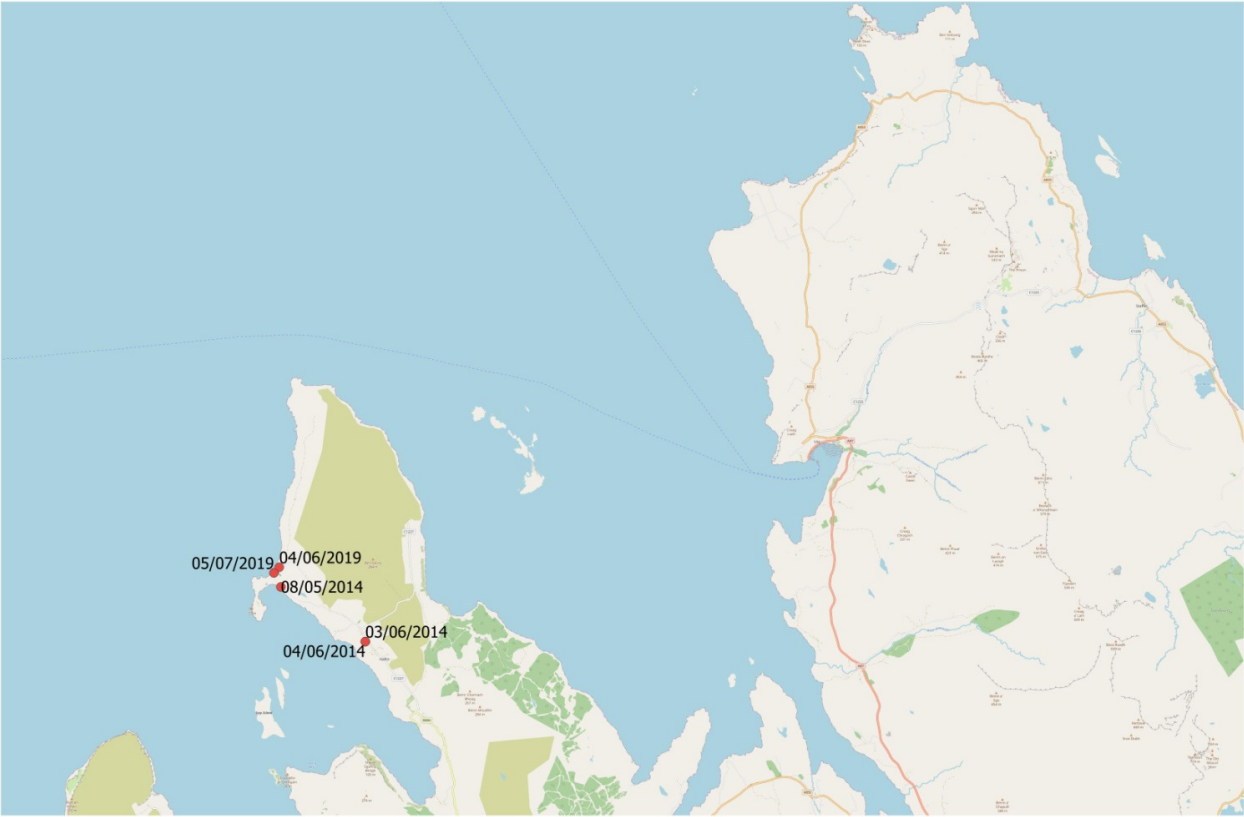
Quality 4-5 recordings, analysed in 2020



Clusters 4, 26 and 32 are similar

Cluster 4

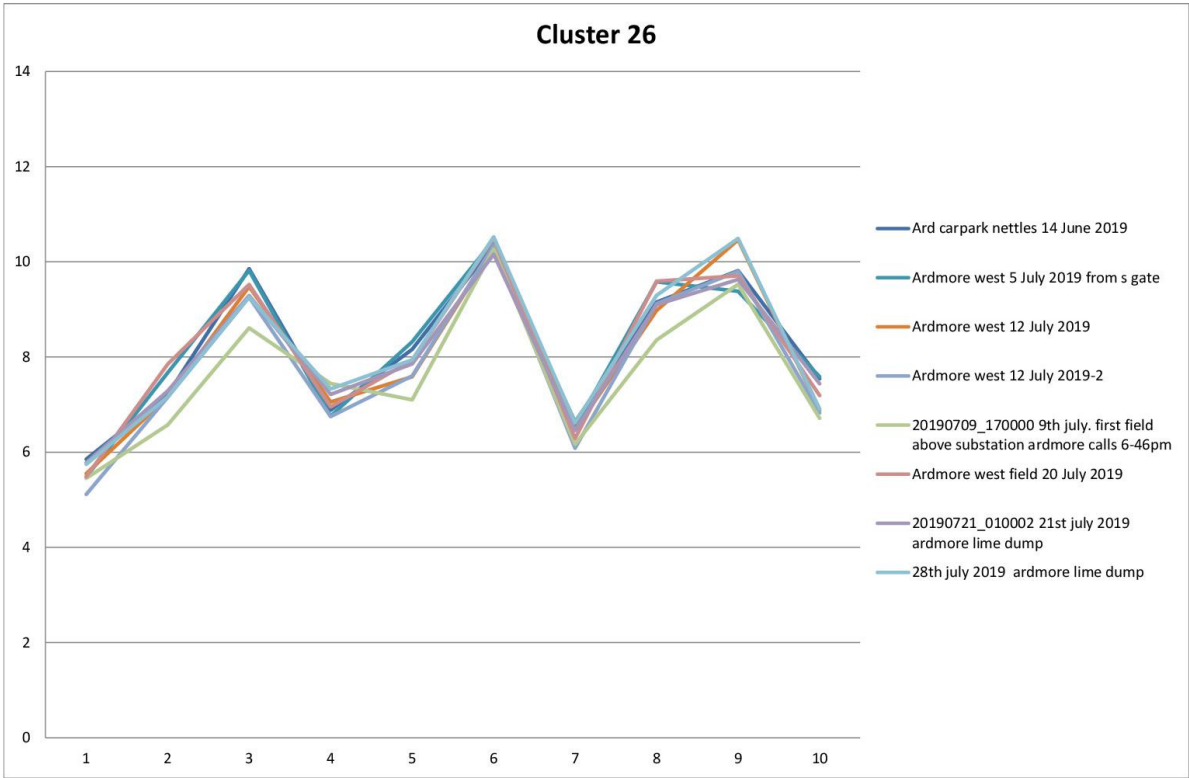
Quality 4-5 recordings, analysed in 2020



Clusters 4, 26 and 32 are similar

Cluster 26

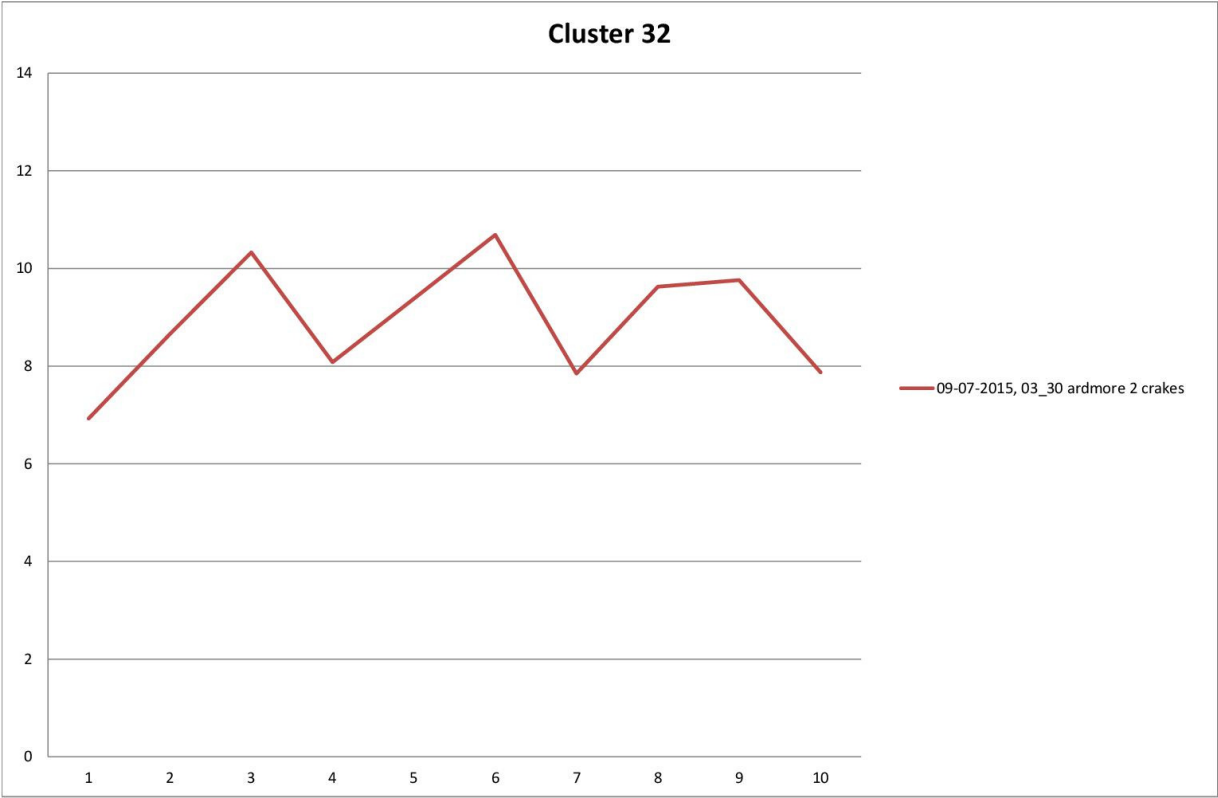
Quality 4-5 recordings, analysed in 2020

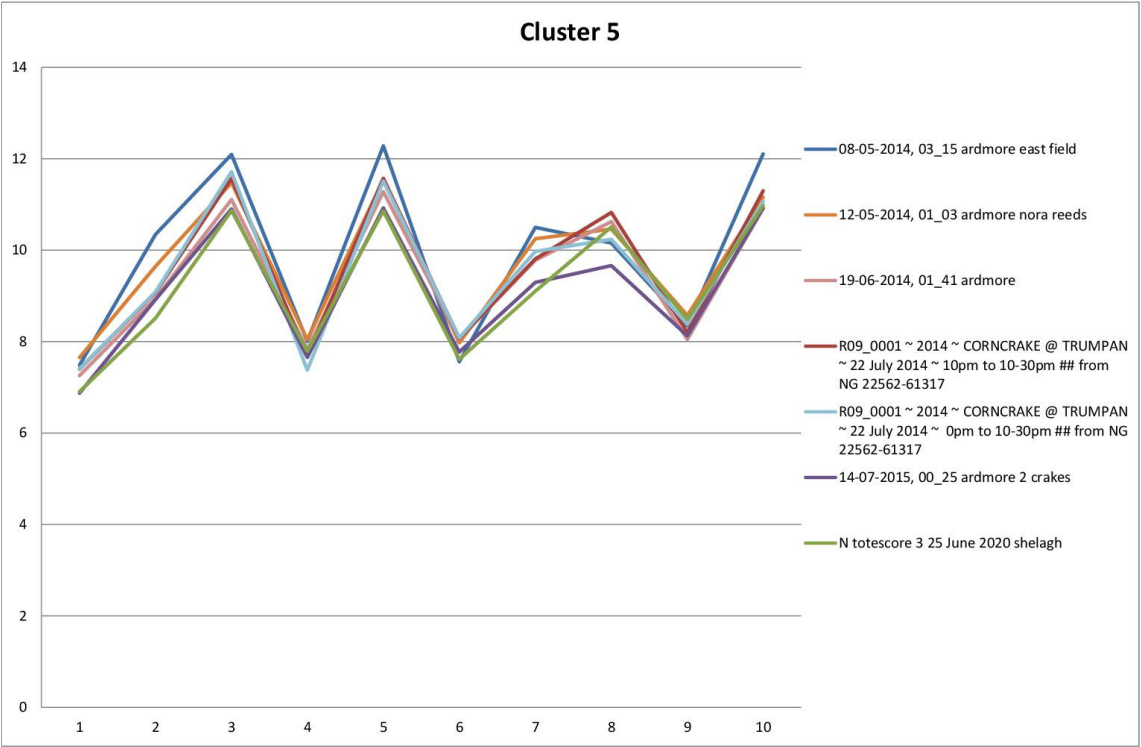
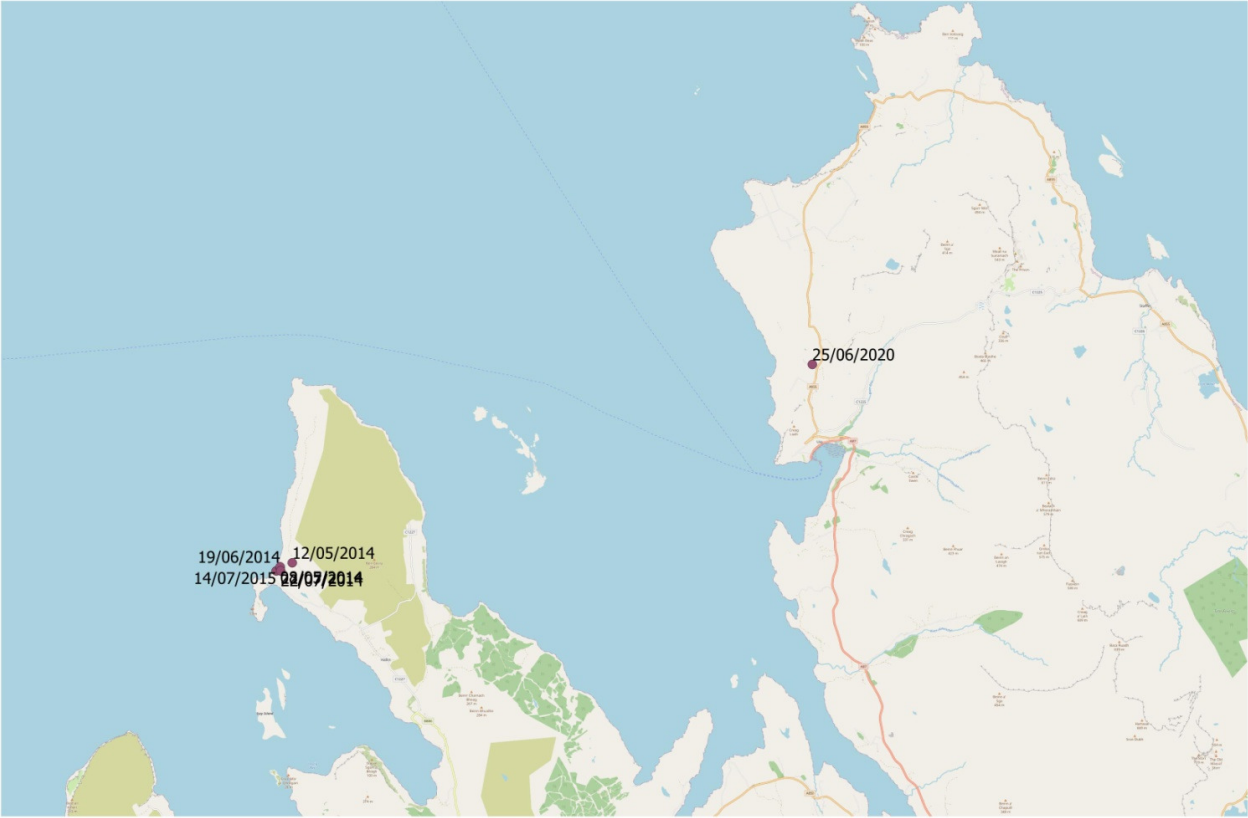


Clusters 4, 26 and 32 are similar

Cluster 32

Quality 4-5 recordings, analysed in 2020

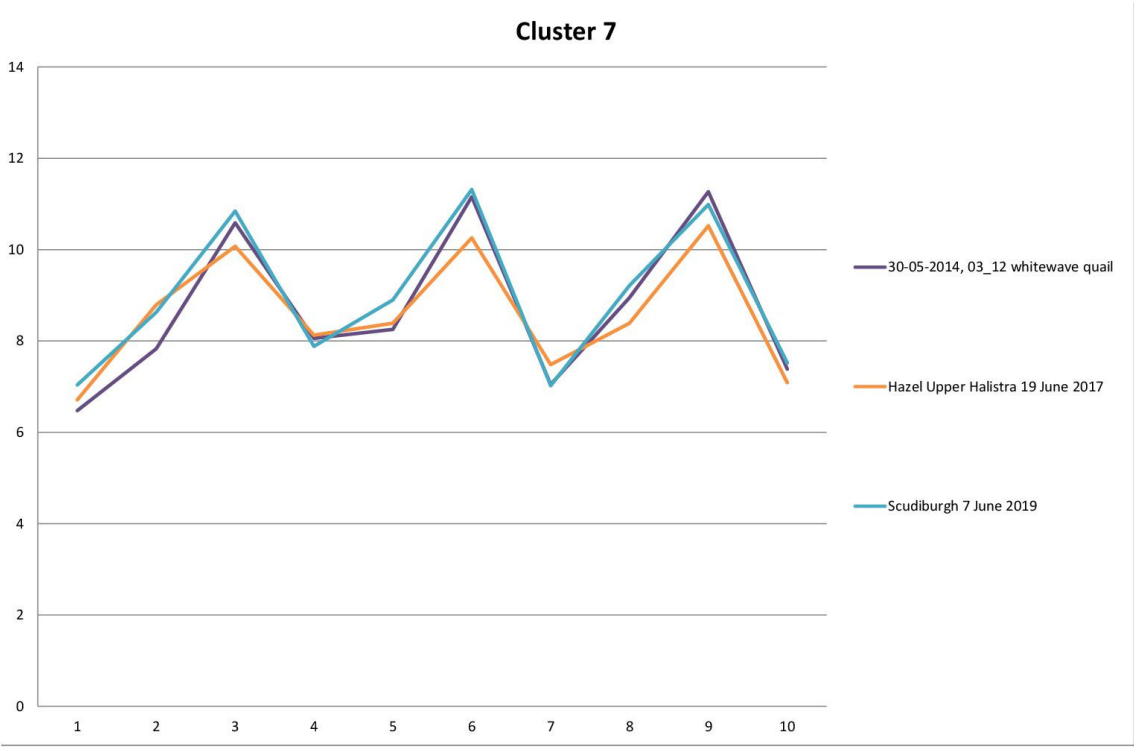




Clusters 7 and 18 are similar

Cluster 7

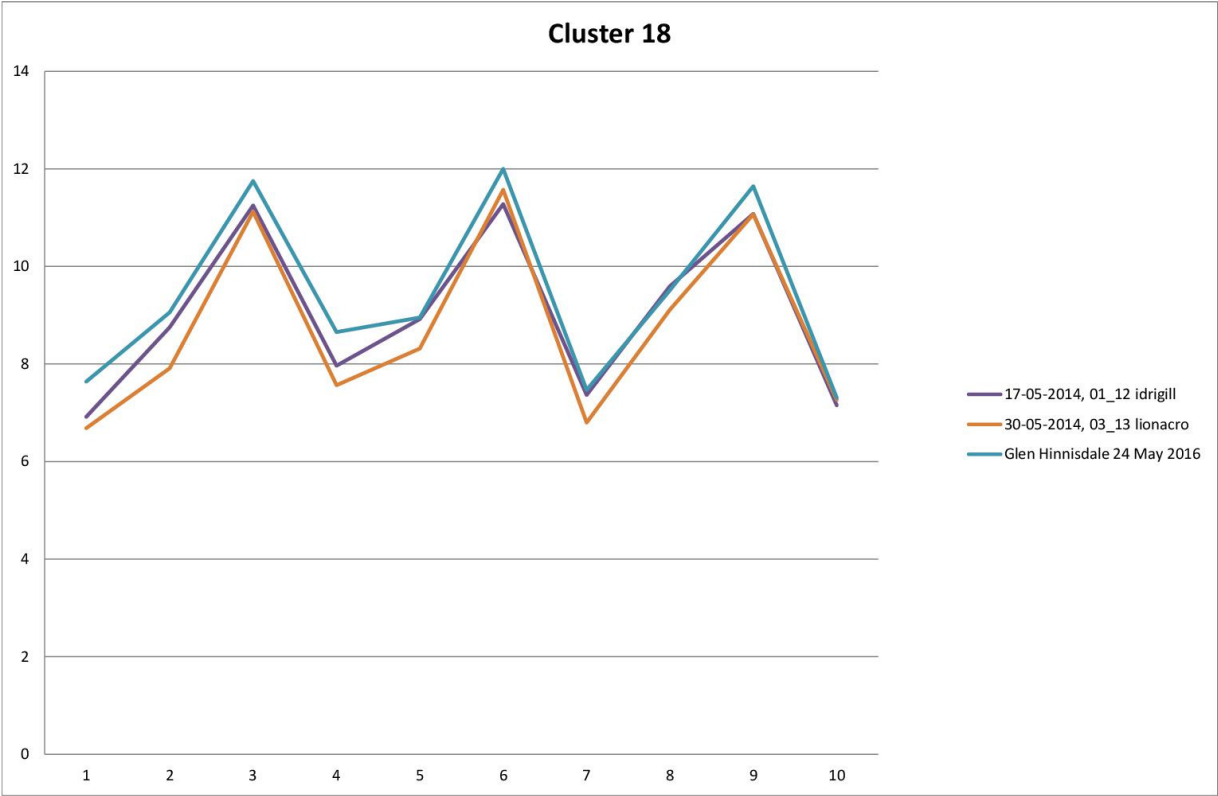
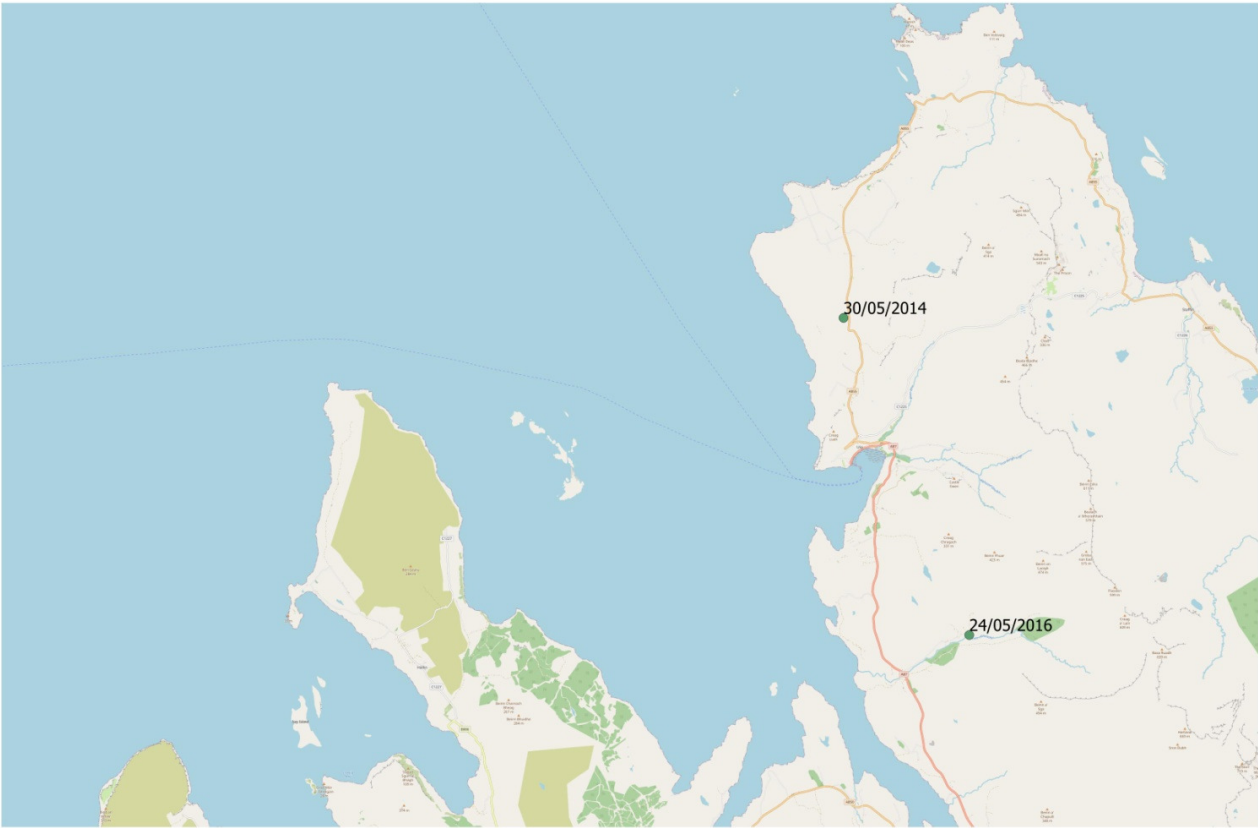
Quality 4-5 recordings, analysed in 2020

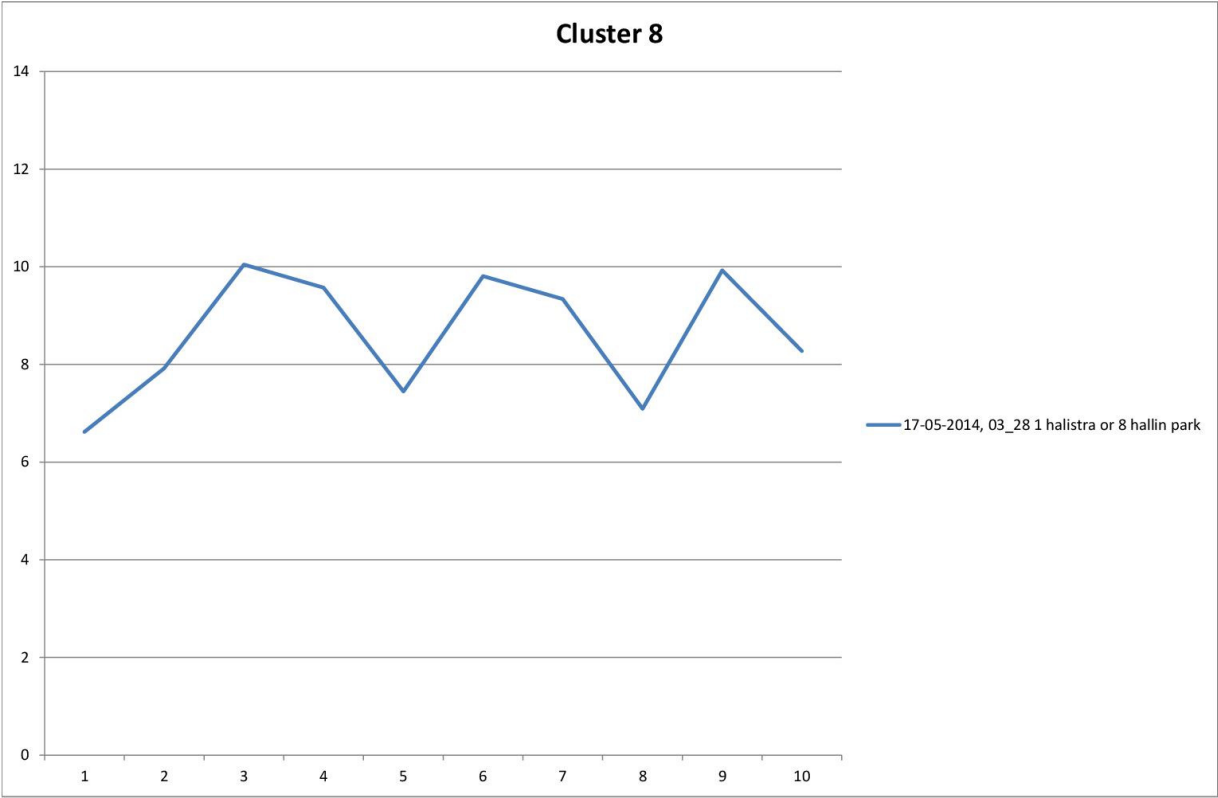


Clusters 7 and 18 are similar

Cluster 18

Quality 4-5 recordings, analysed in 2020

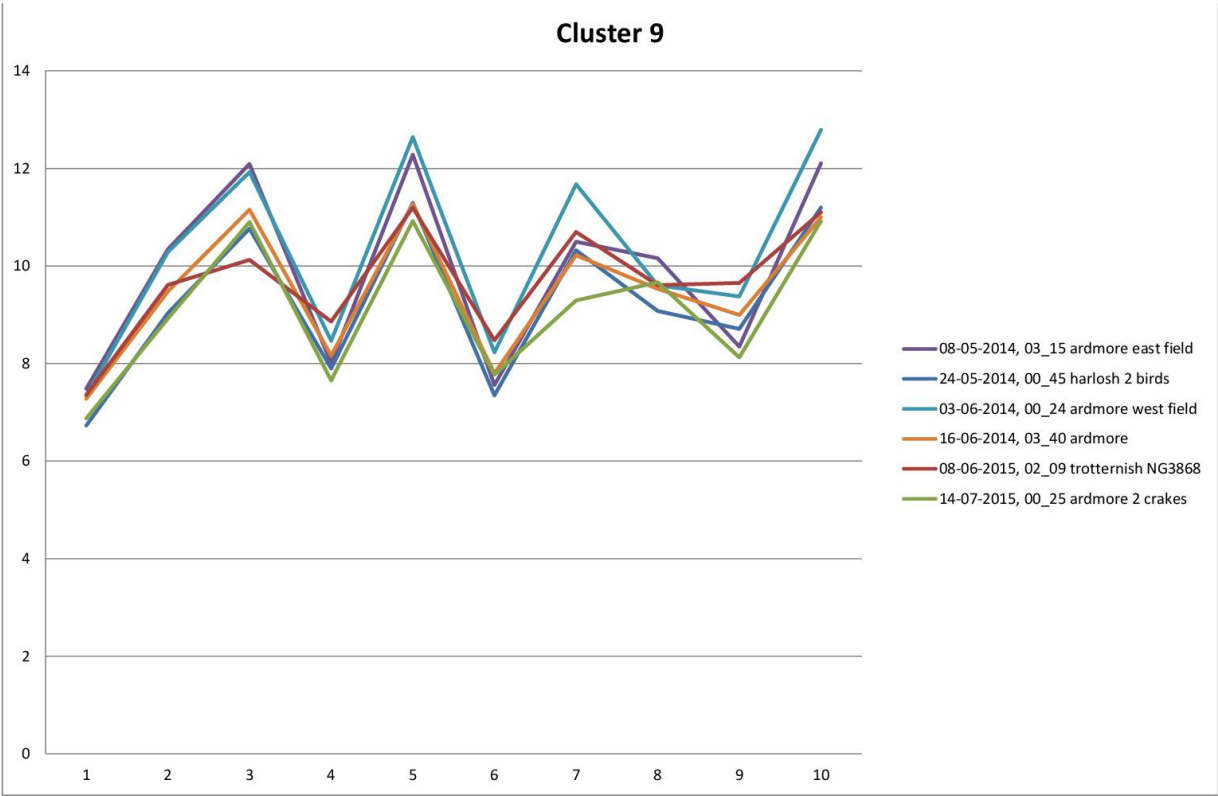




Clusters 9 and 35 are similar

Cluster 9

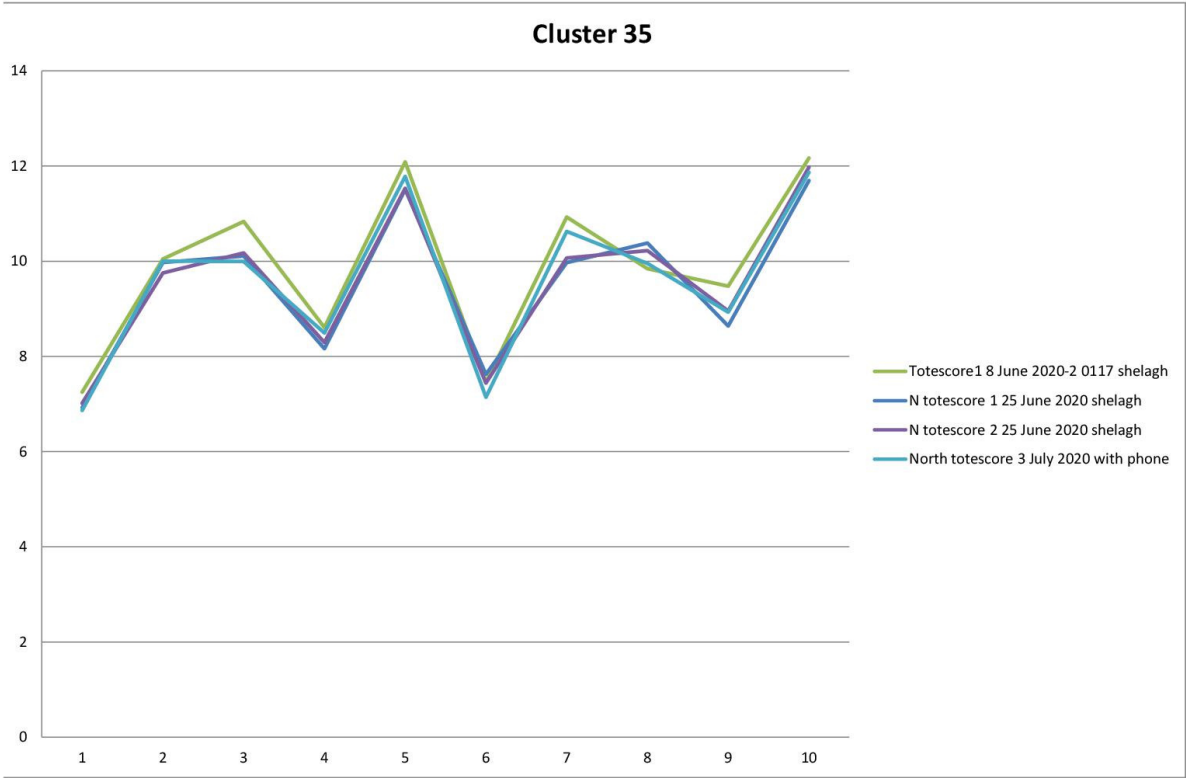
Quality 4-5 recordings, analysed in 2020

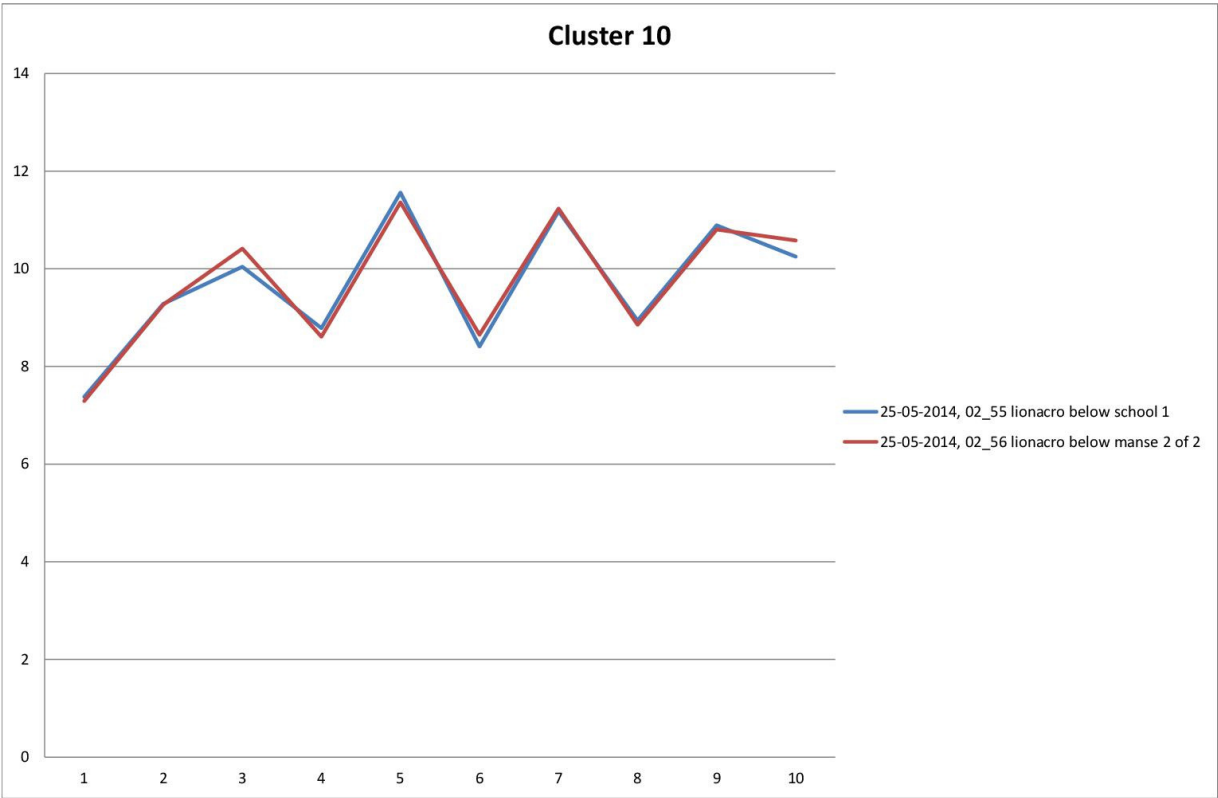
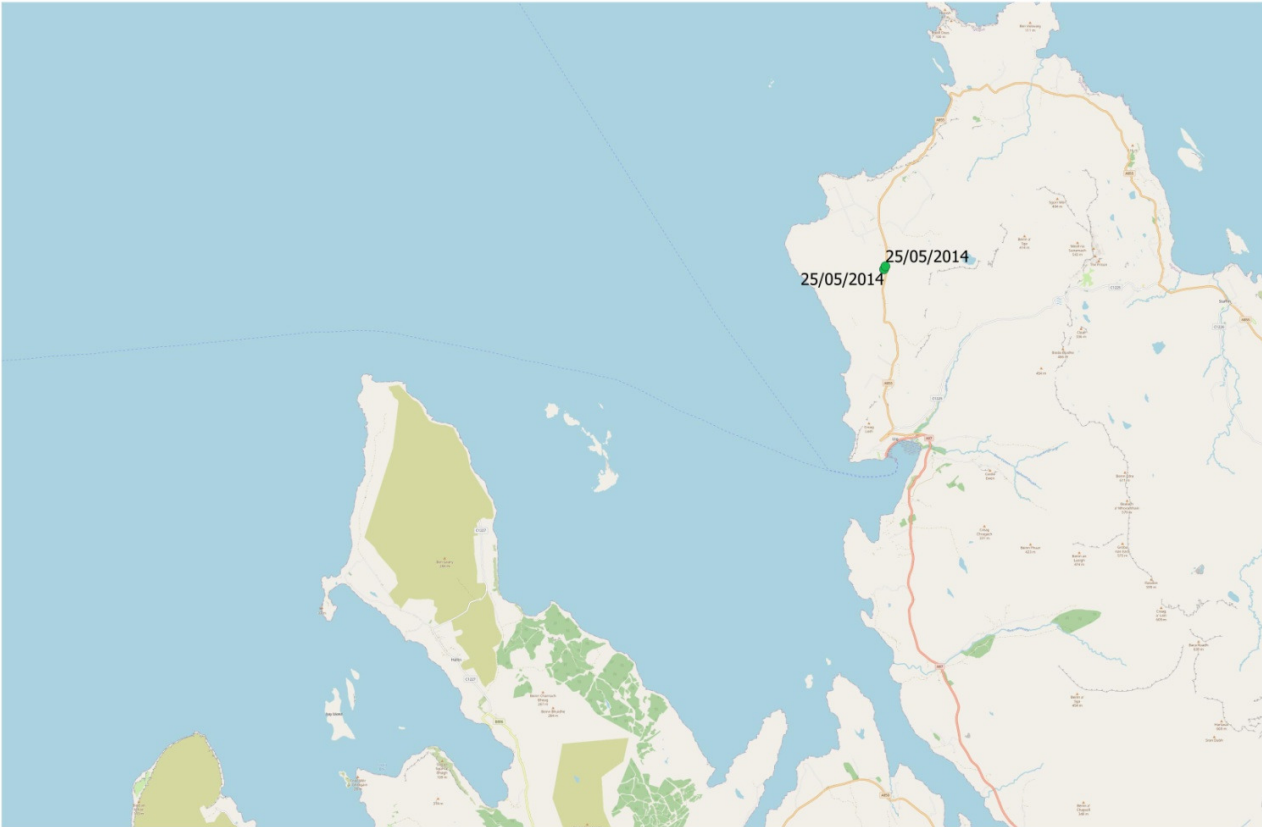


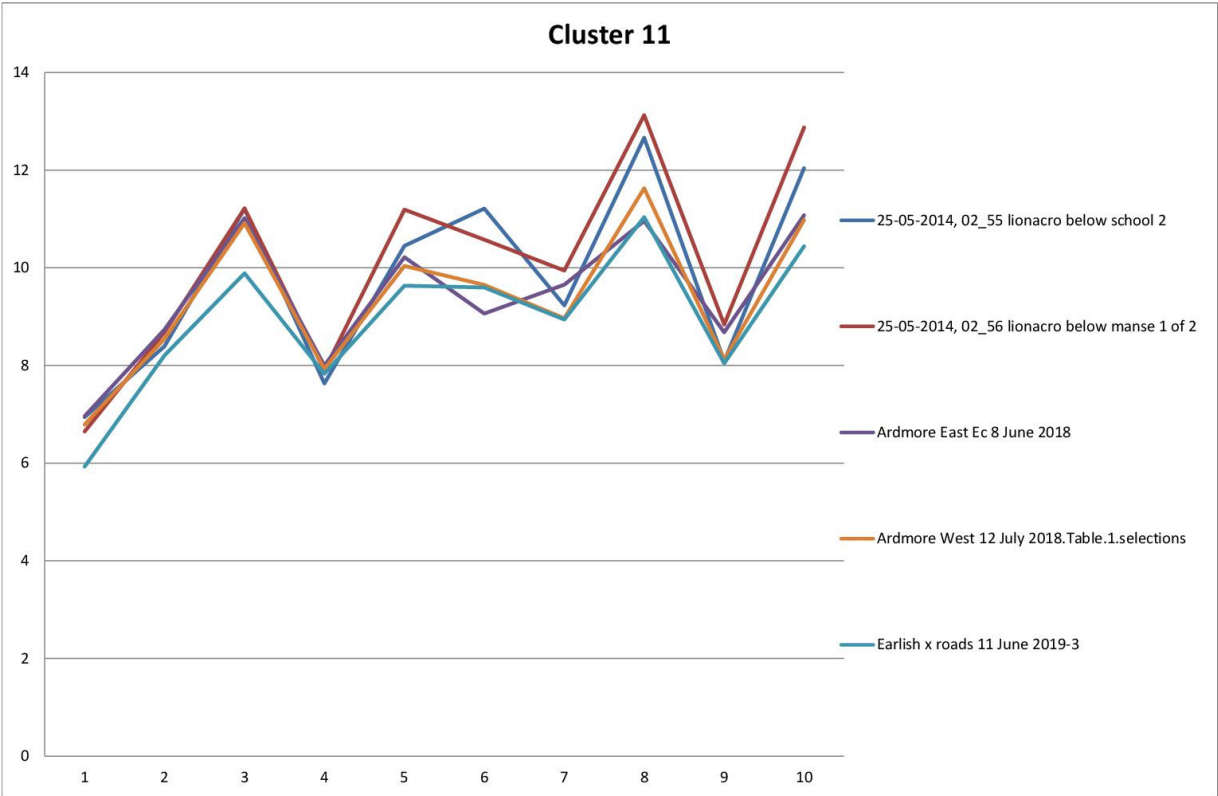
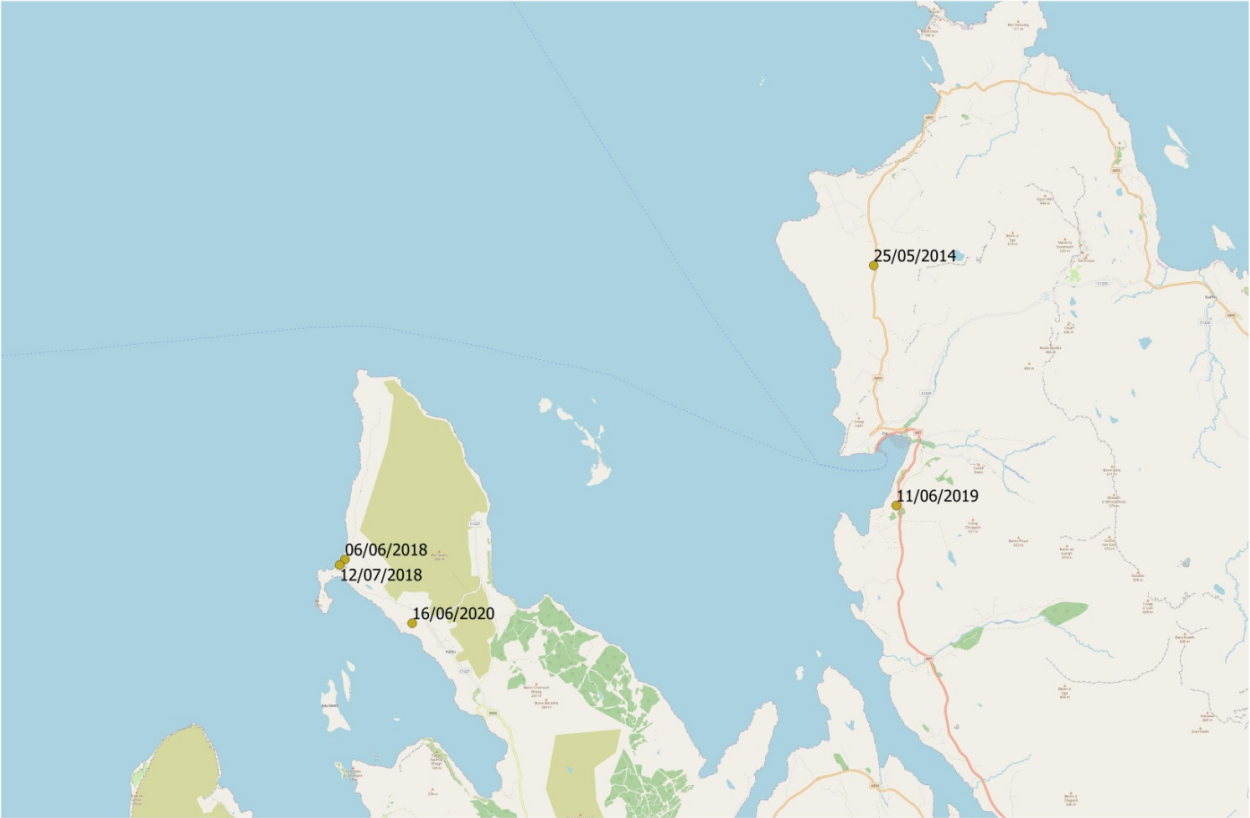
Clusters 9 and 35 are similar

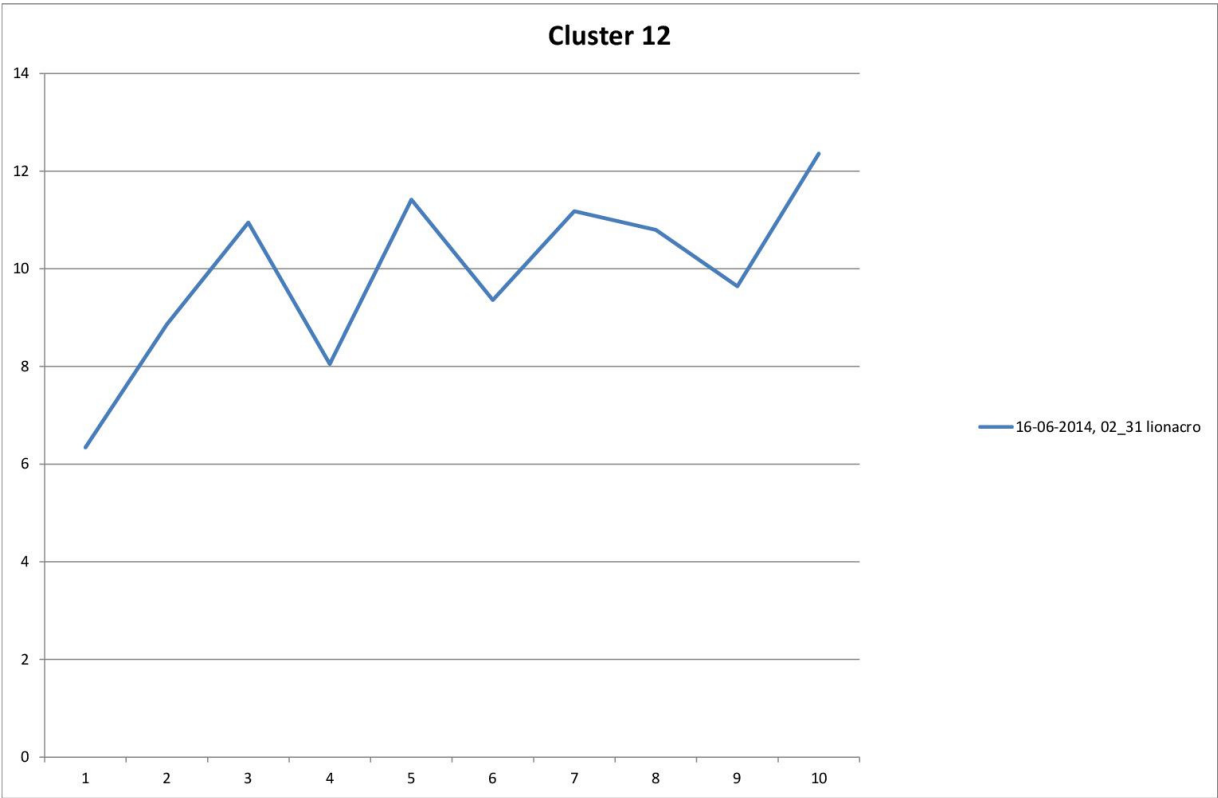
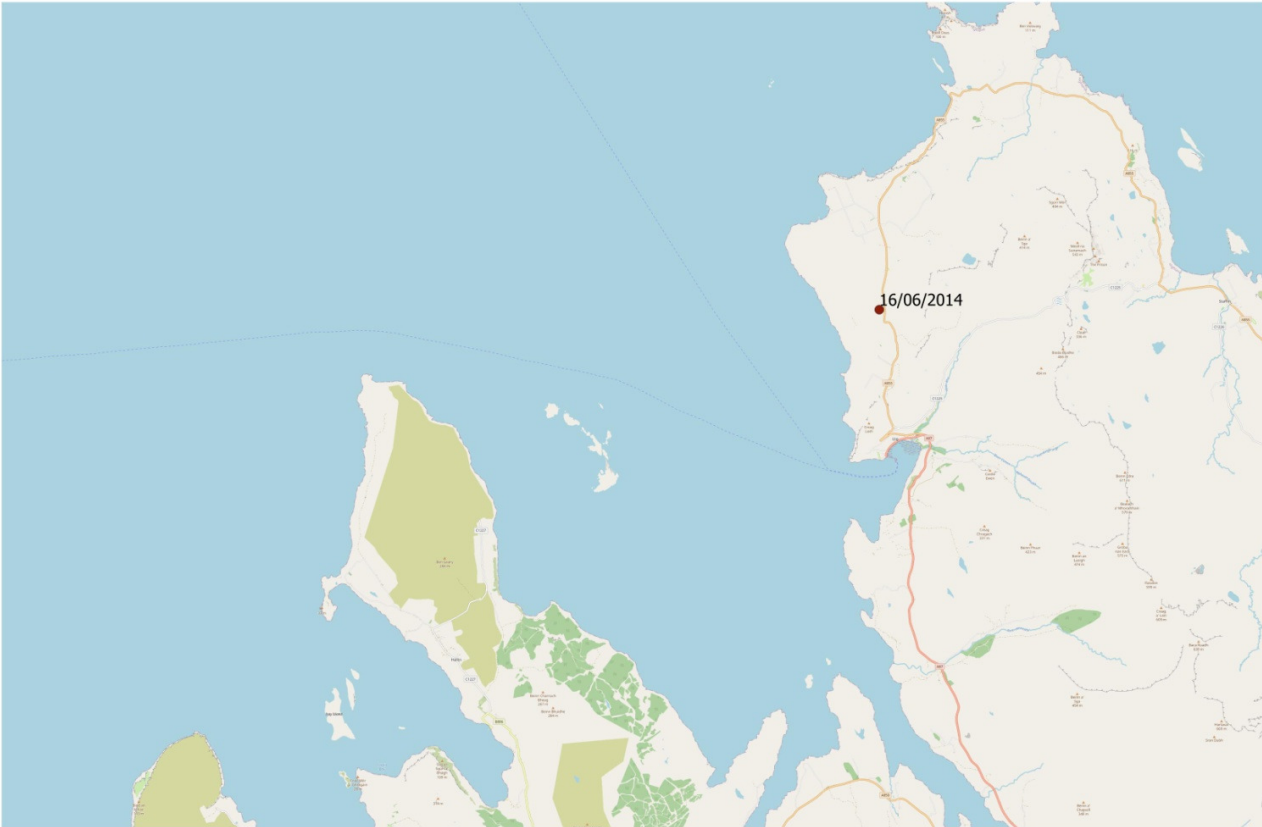
Cluster 35

Quality 4-5 recordings, analysed in 2020





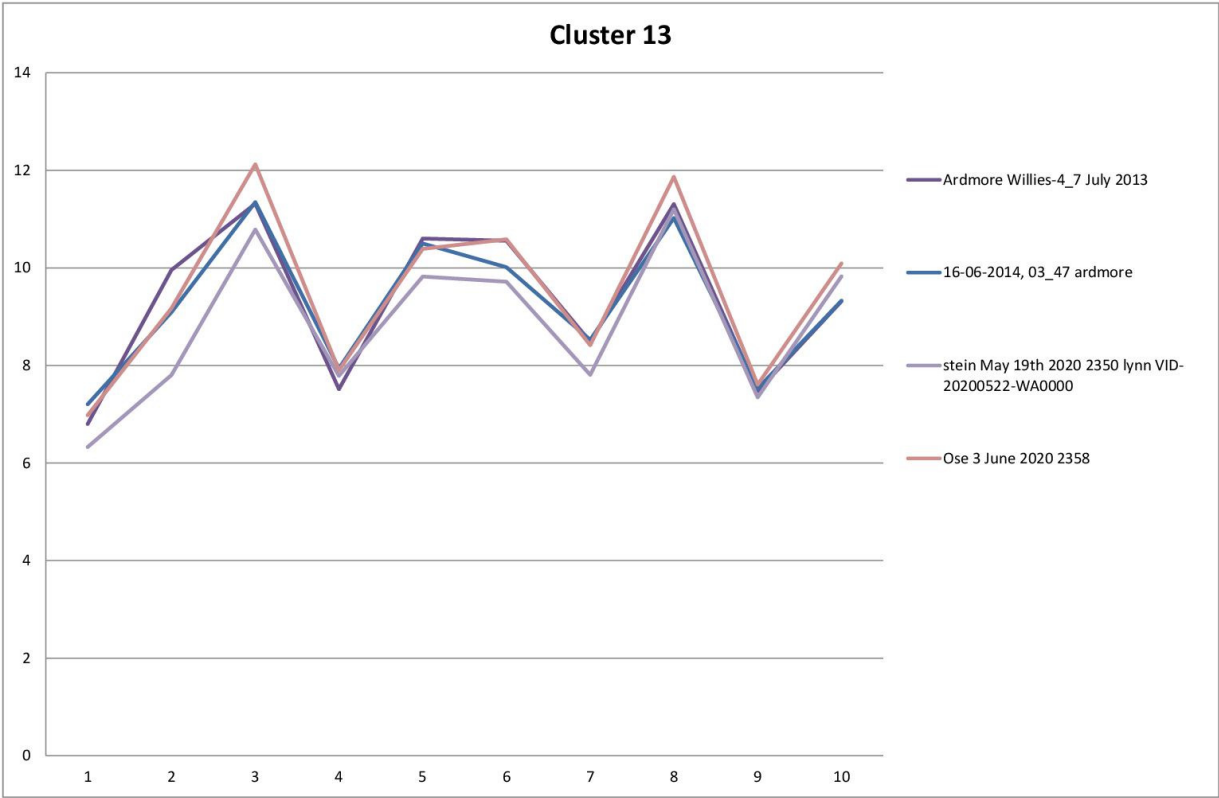




Clusters 13 and 30 are similar

Cluster 13

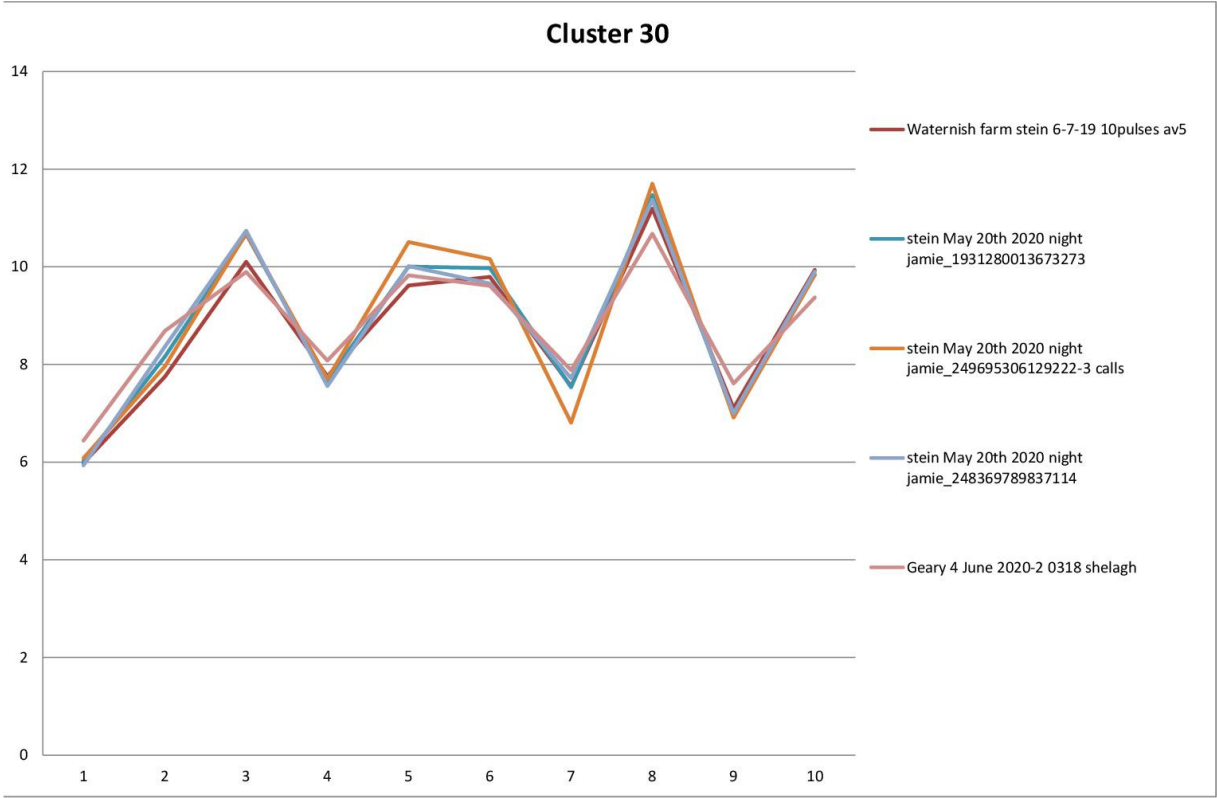
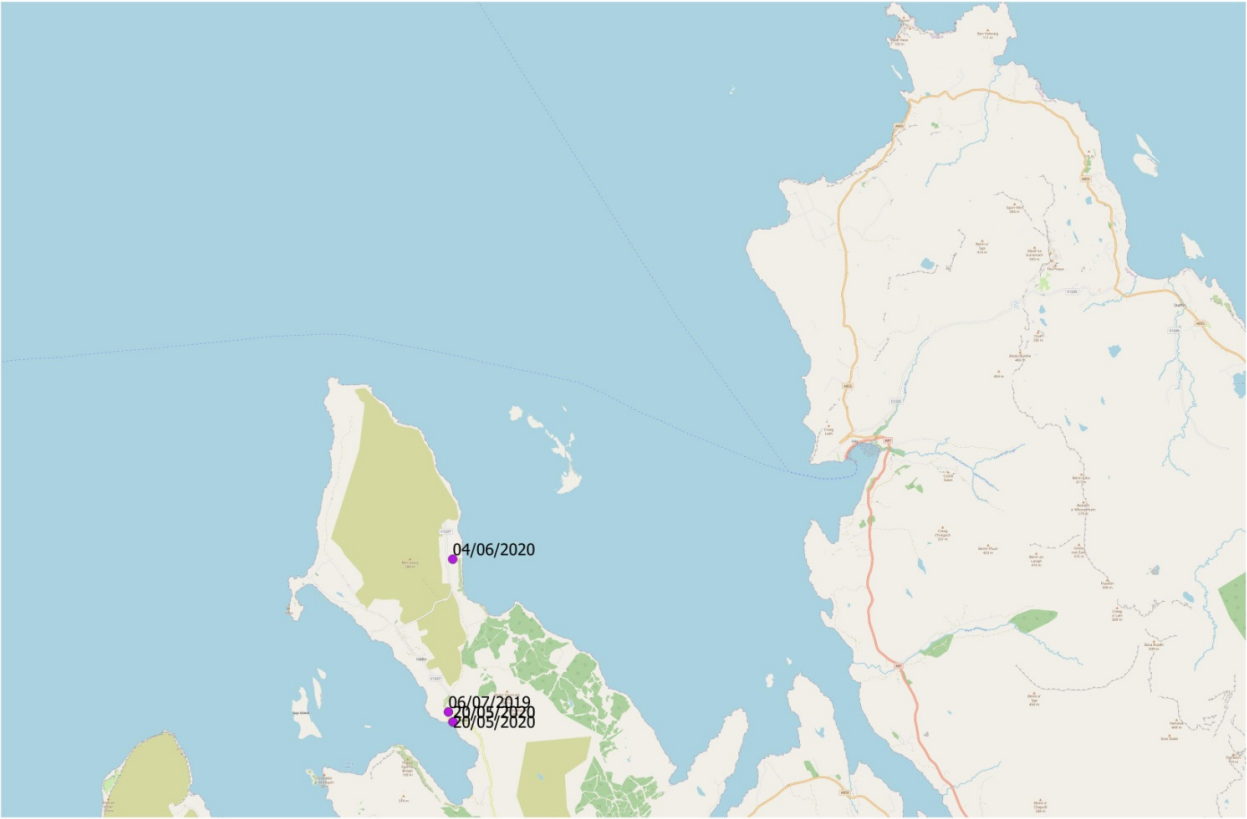
Quality 4-5 recordings, analysed in 2020

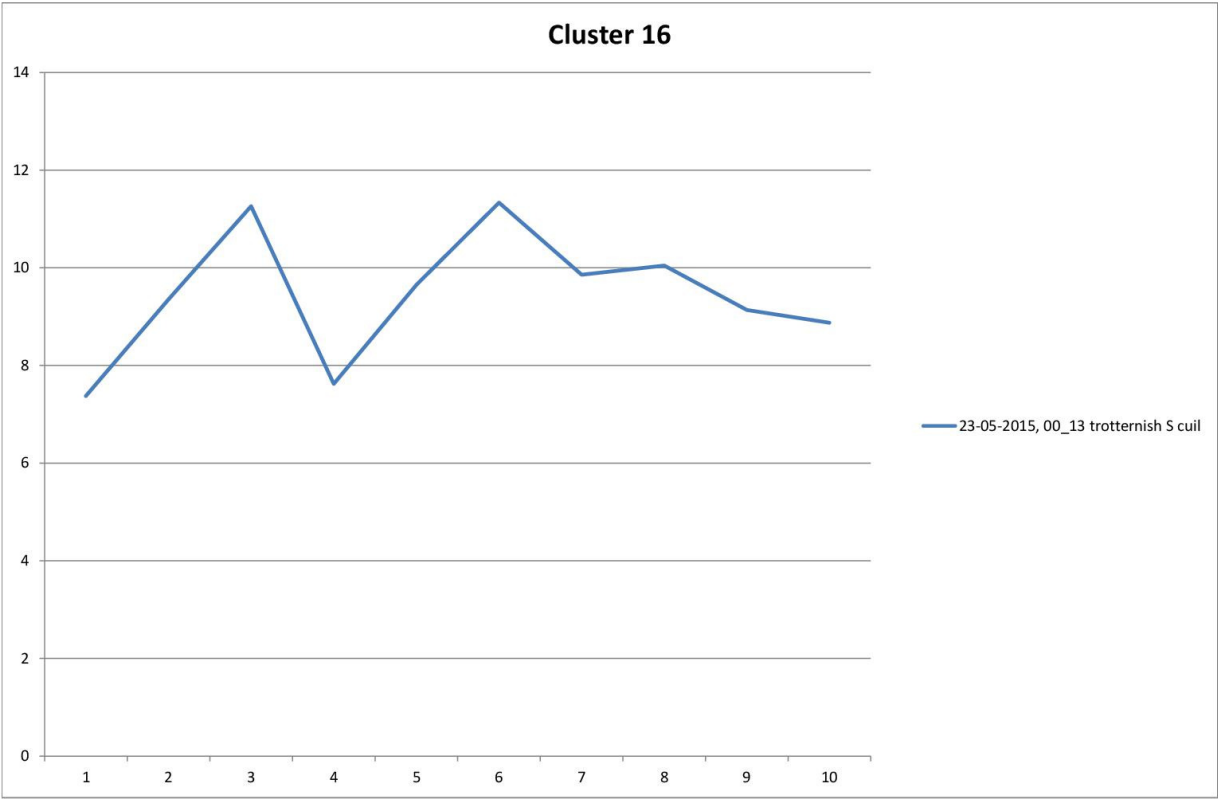
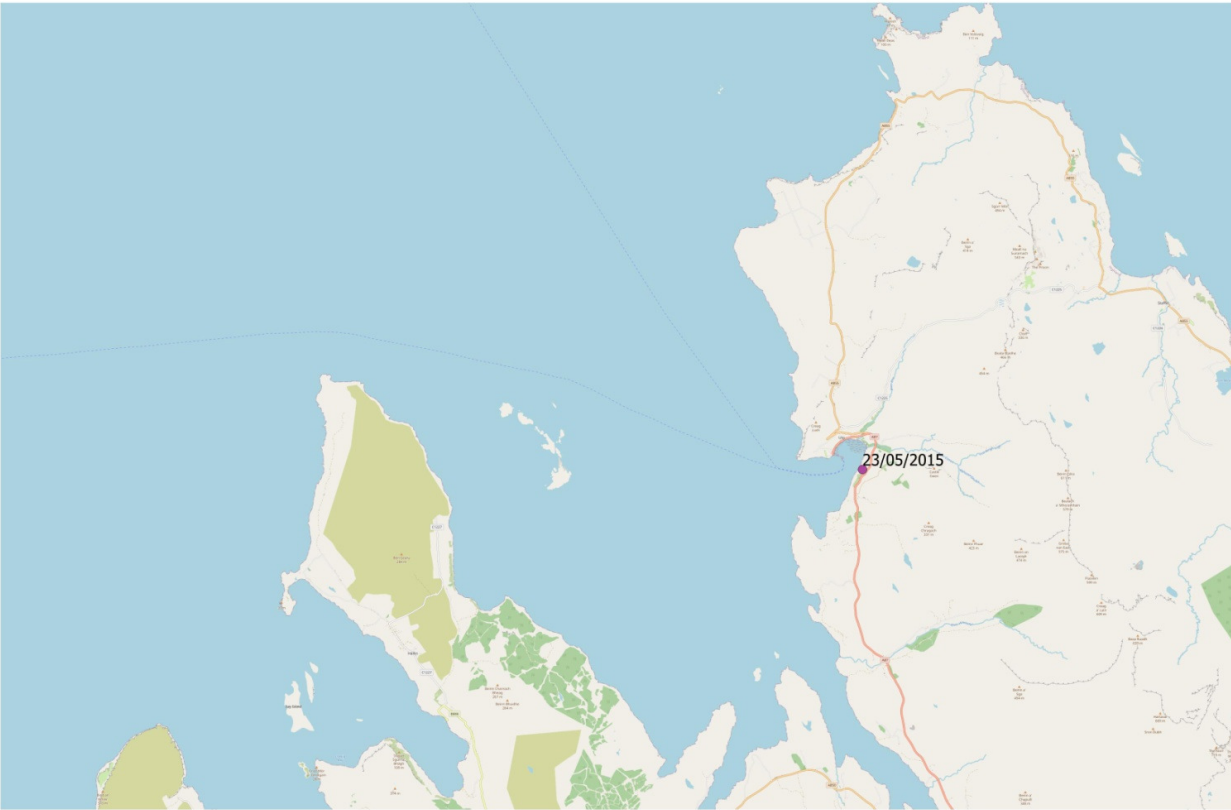


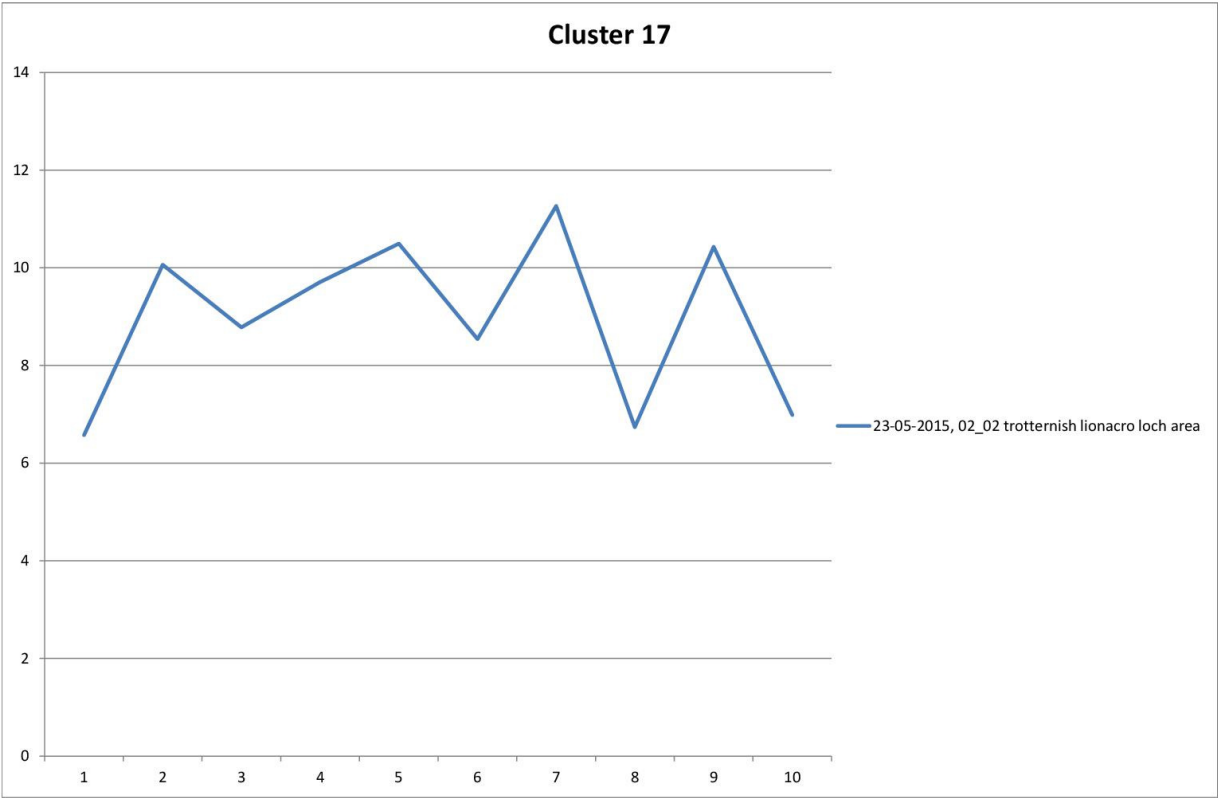
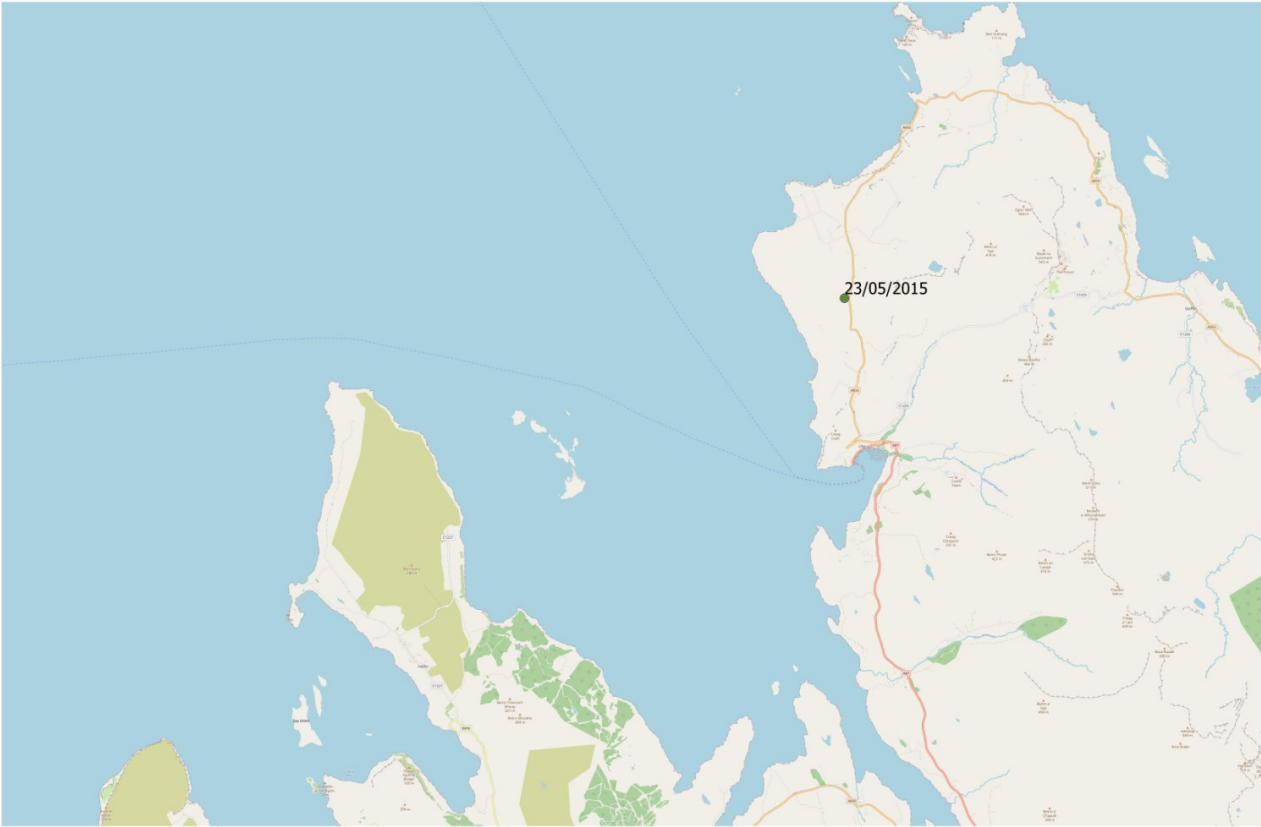
Clusters 13 and 30 are similar

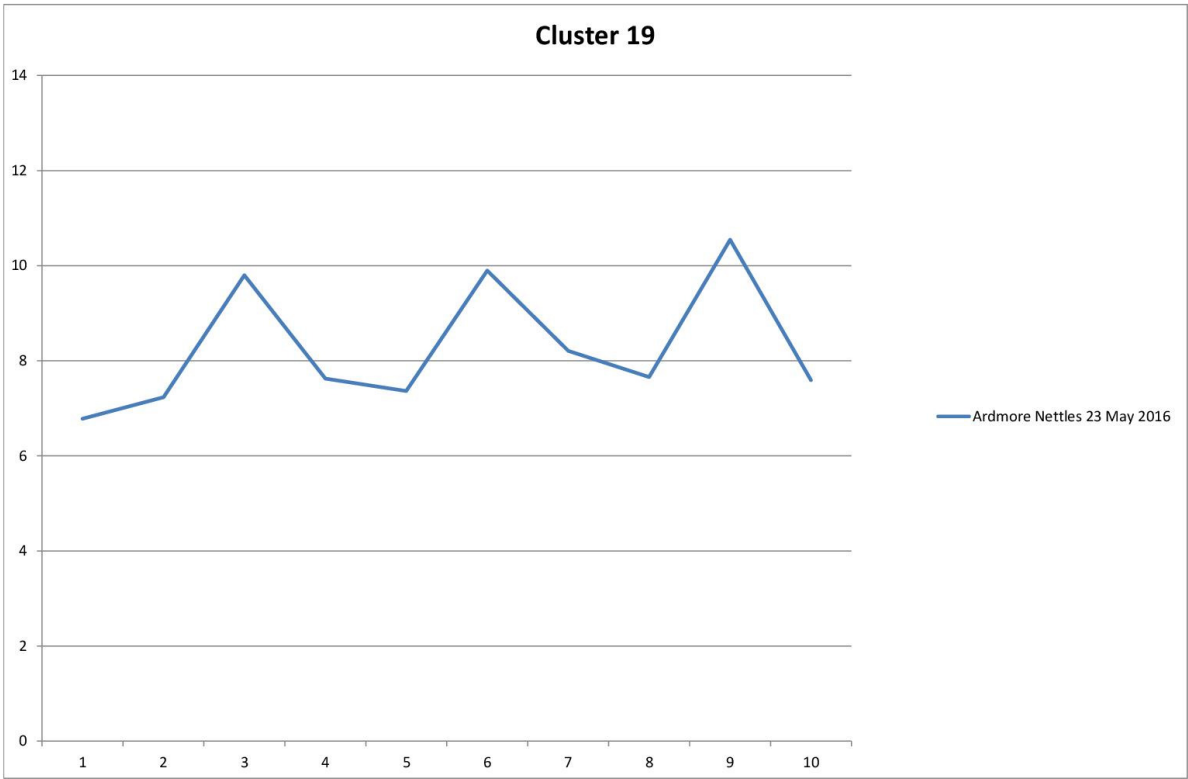
Cluster 30

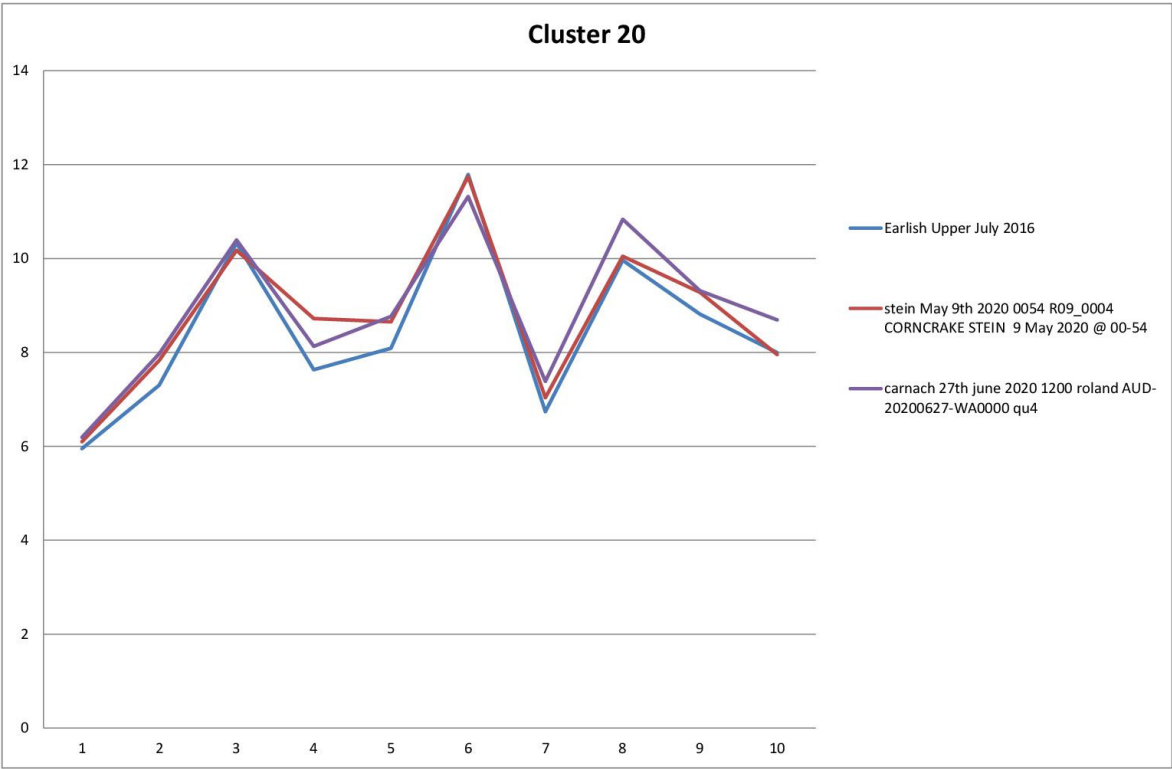
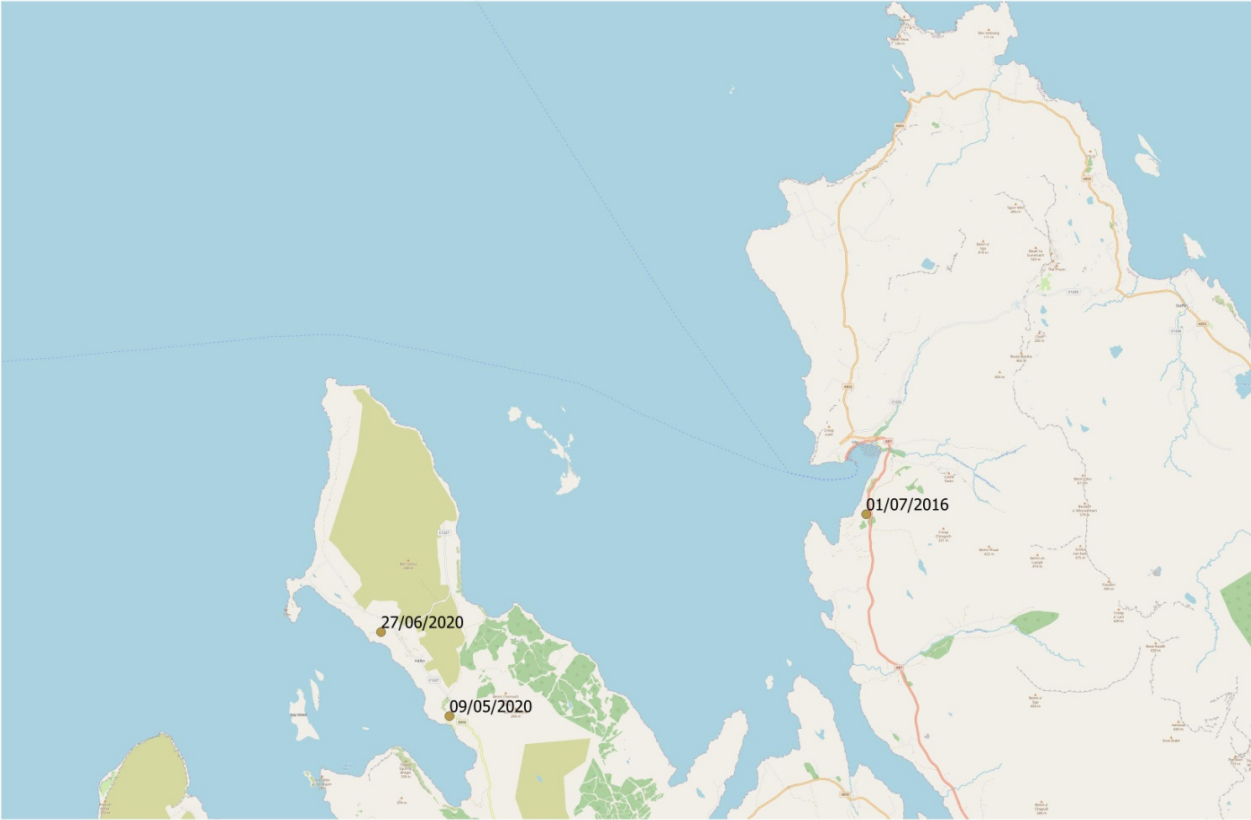
Quality 4-5 recordings, analysed in 2020

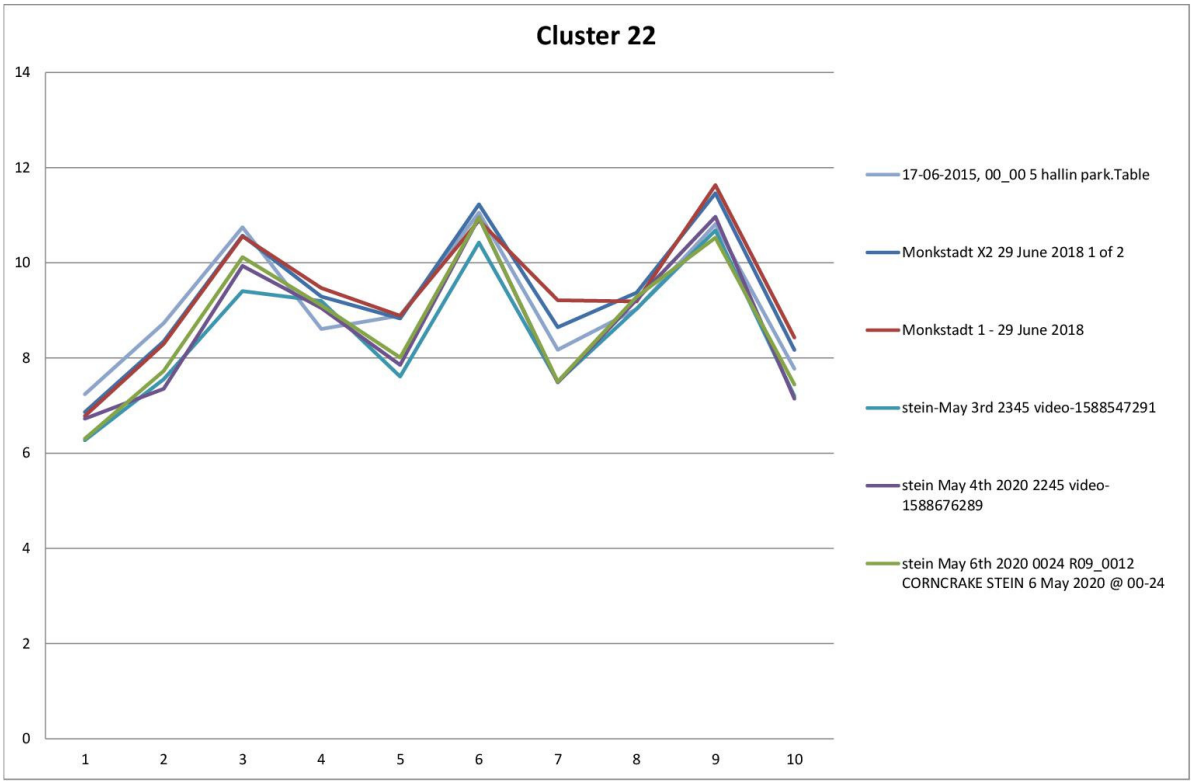
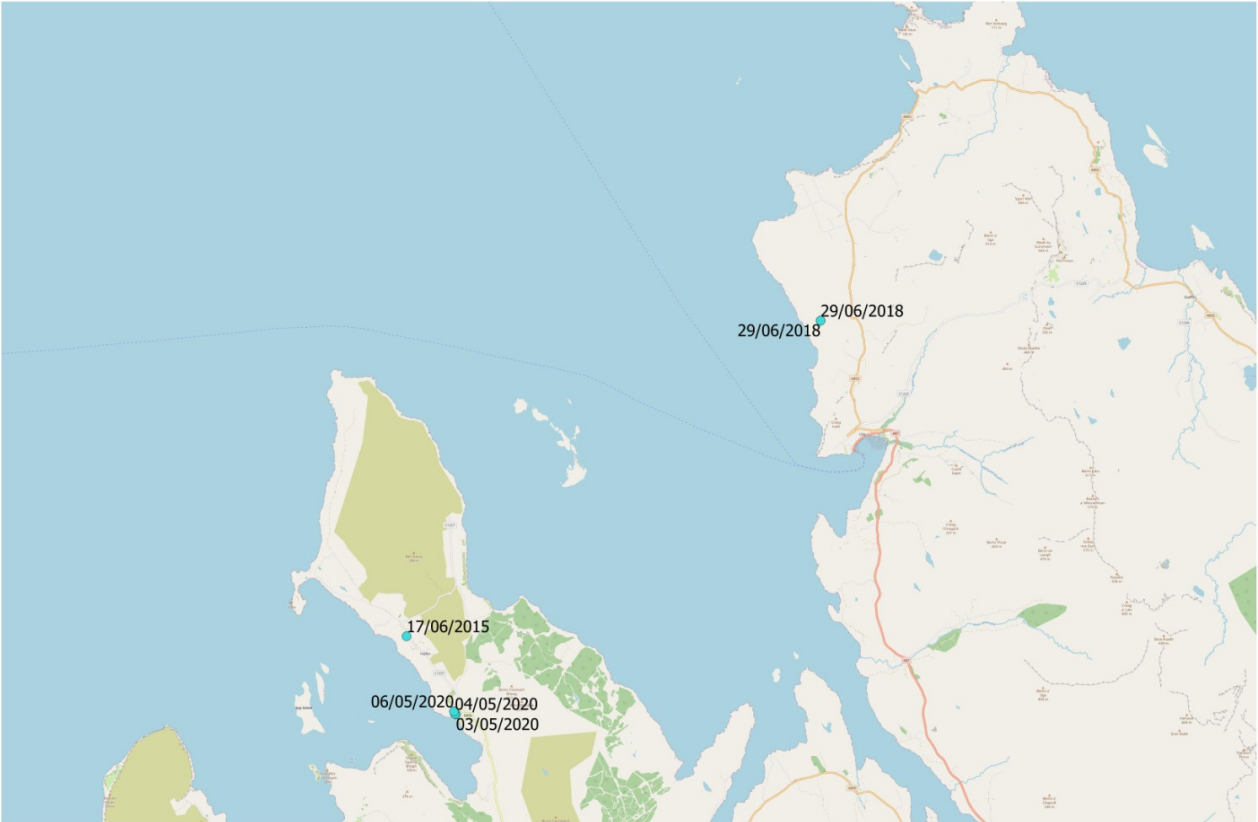


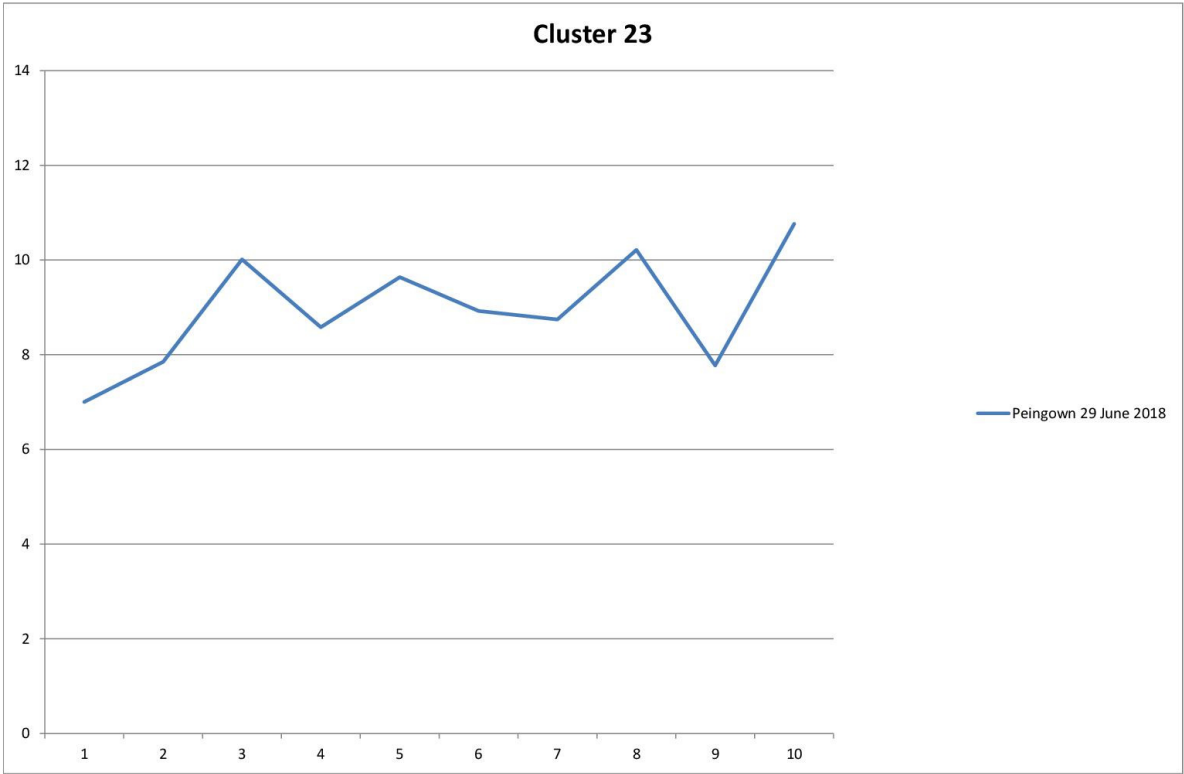


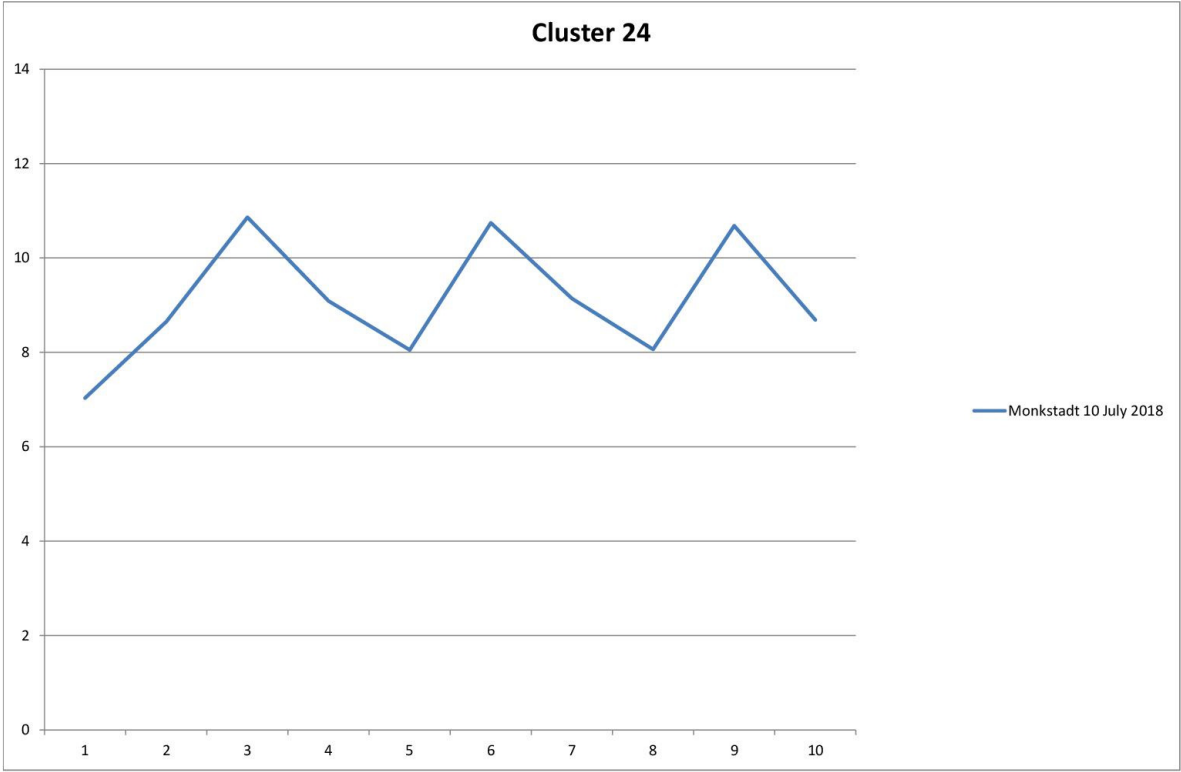
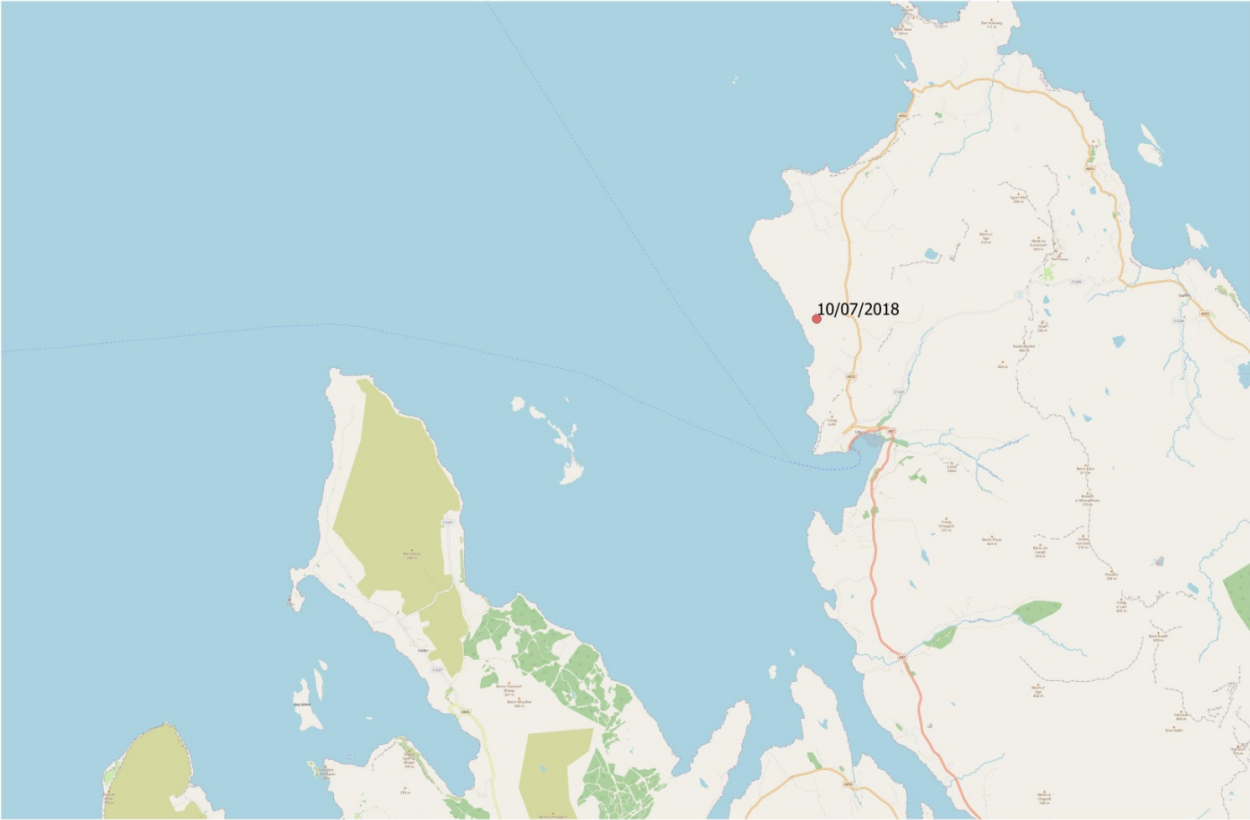


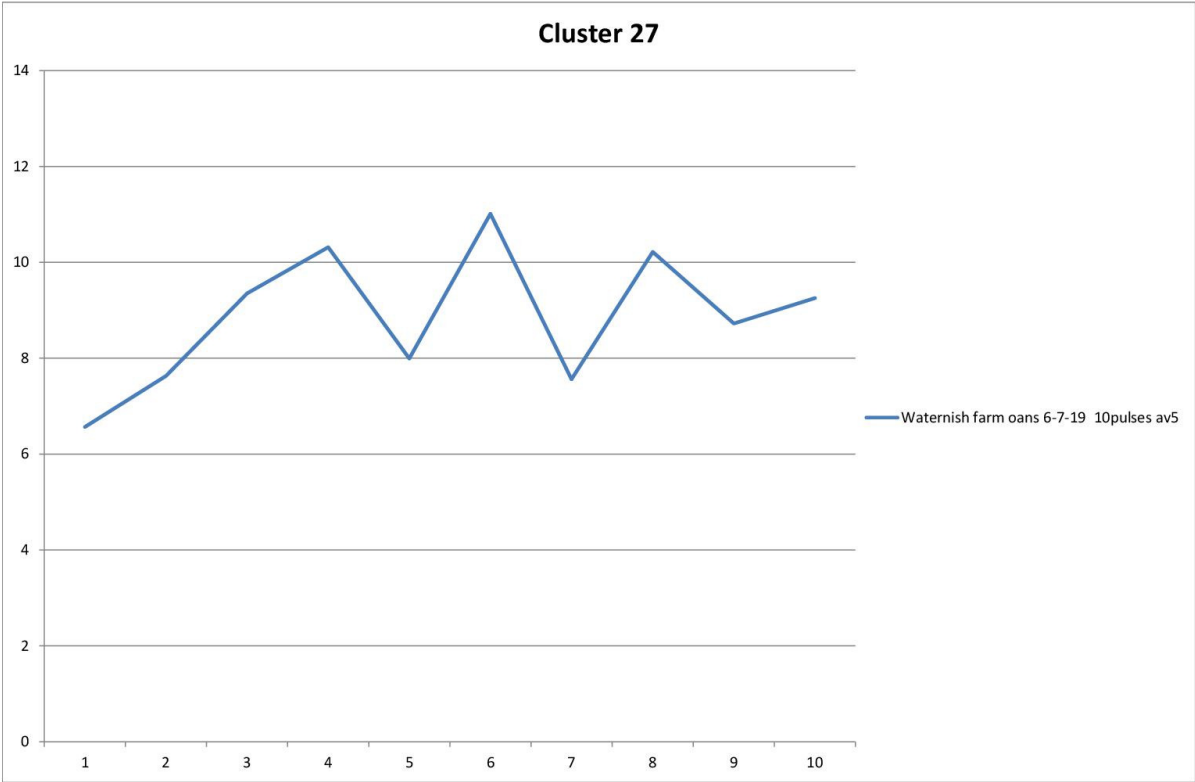


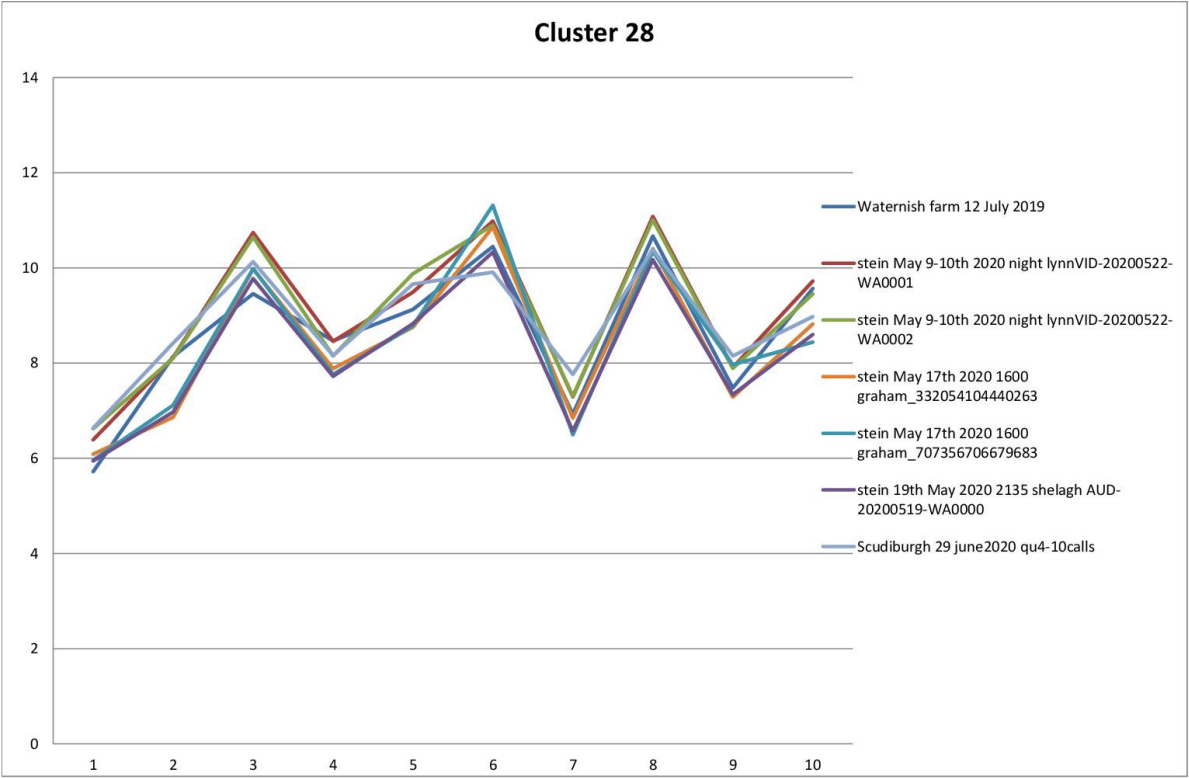


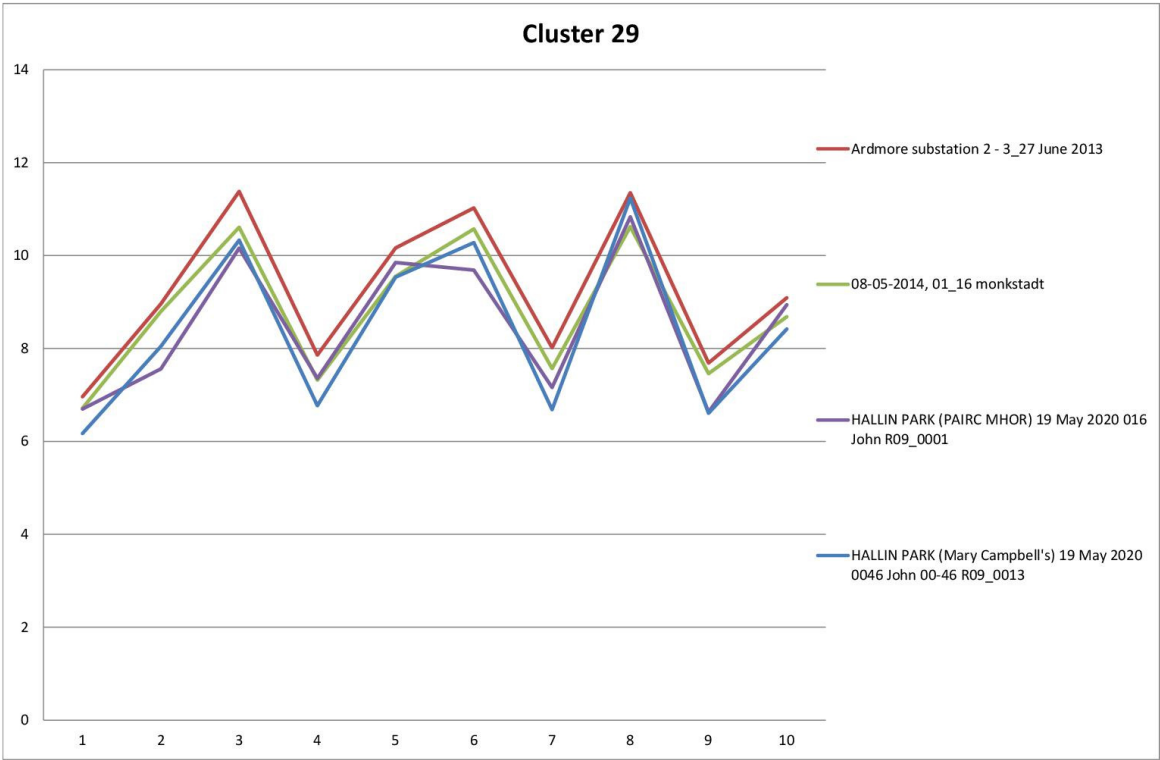
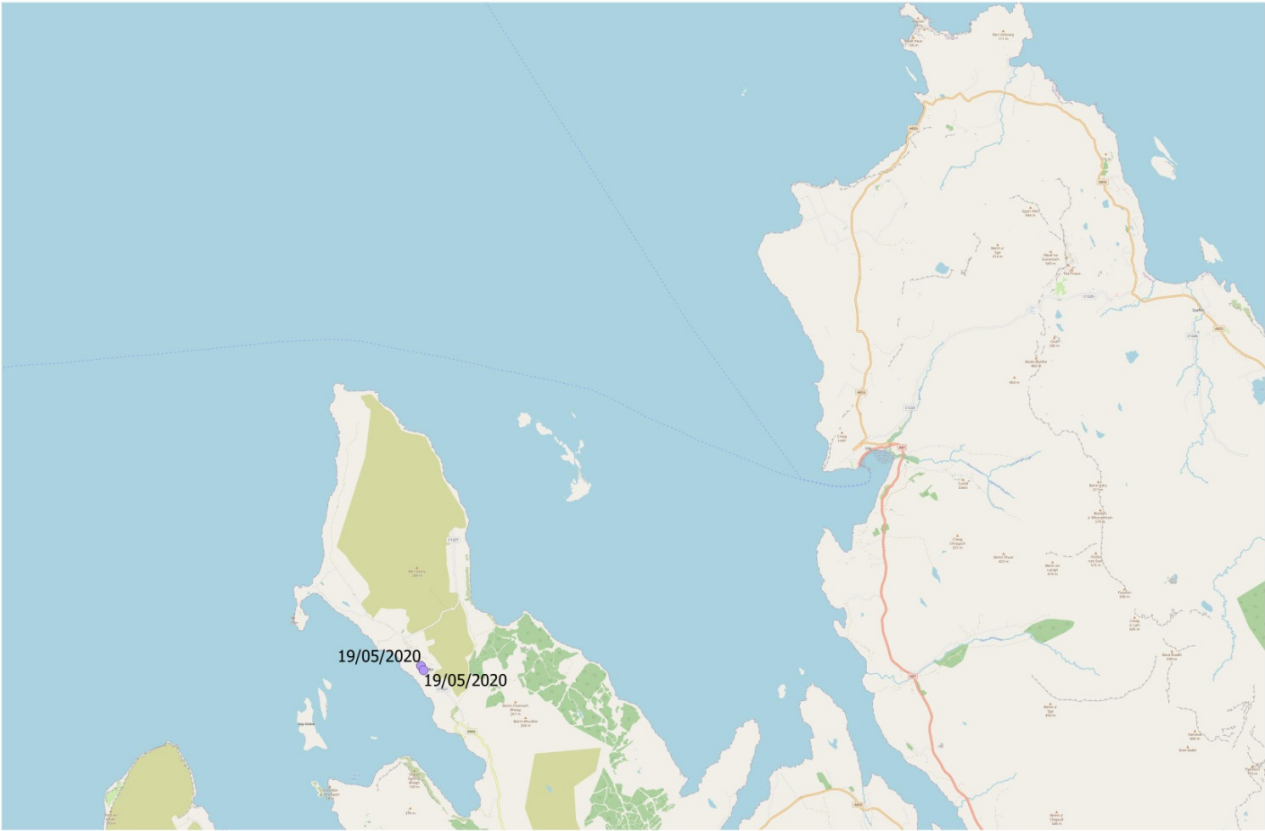


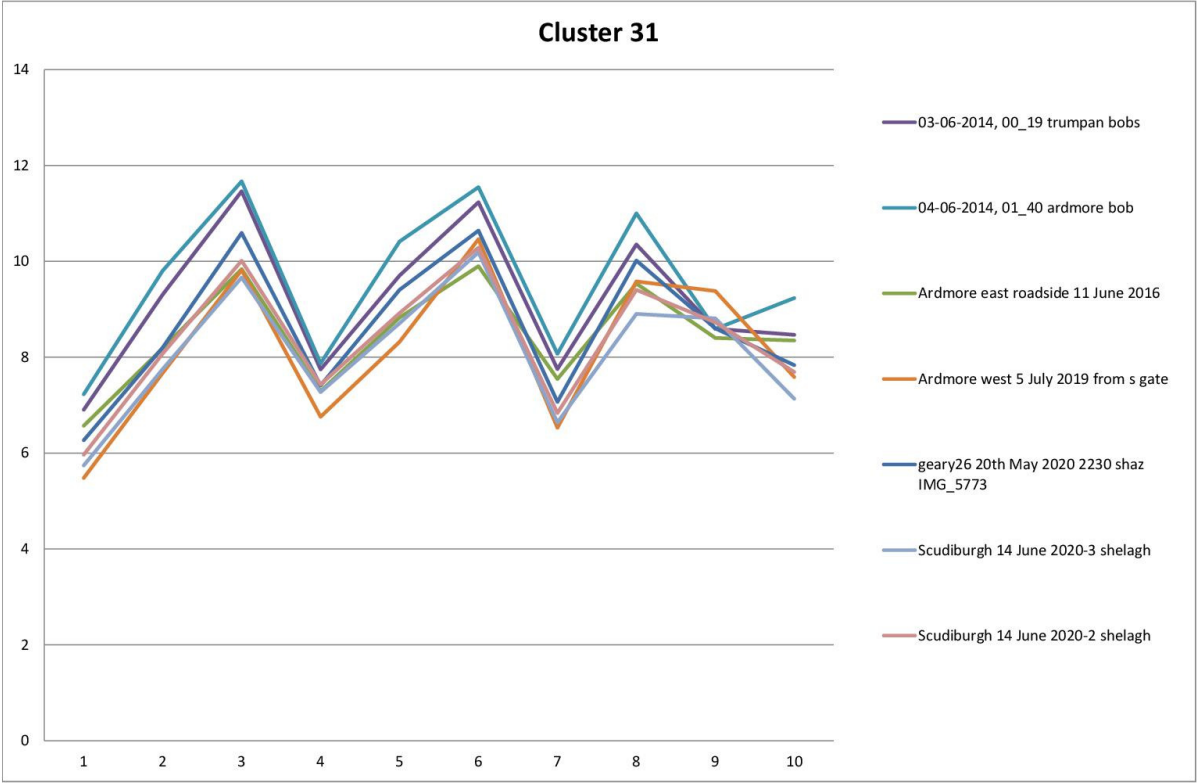


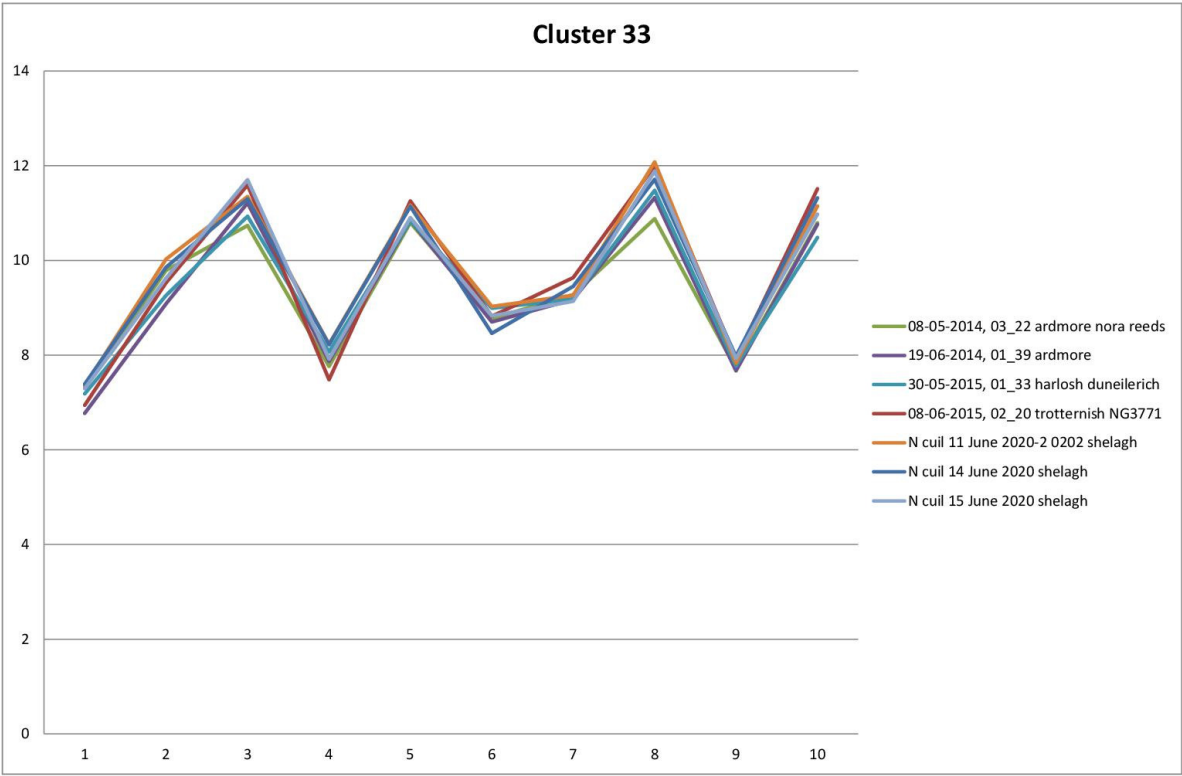
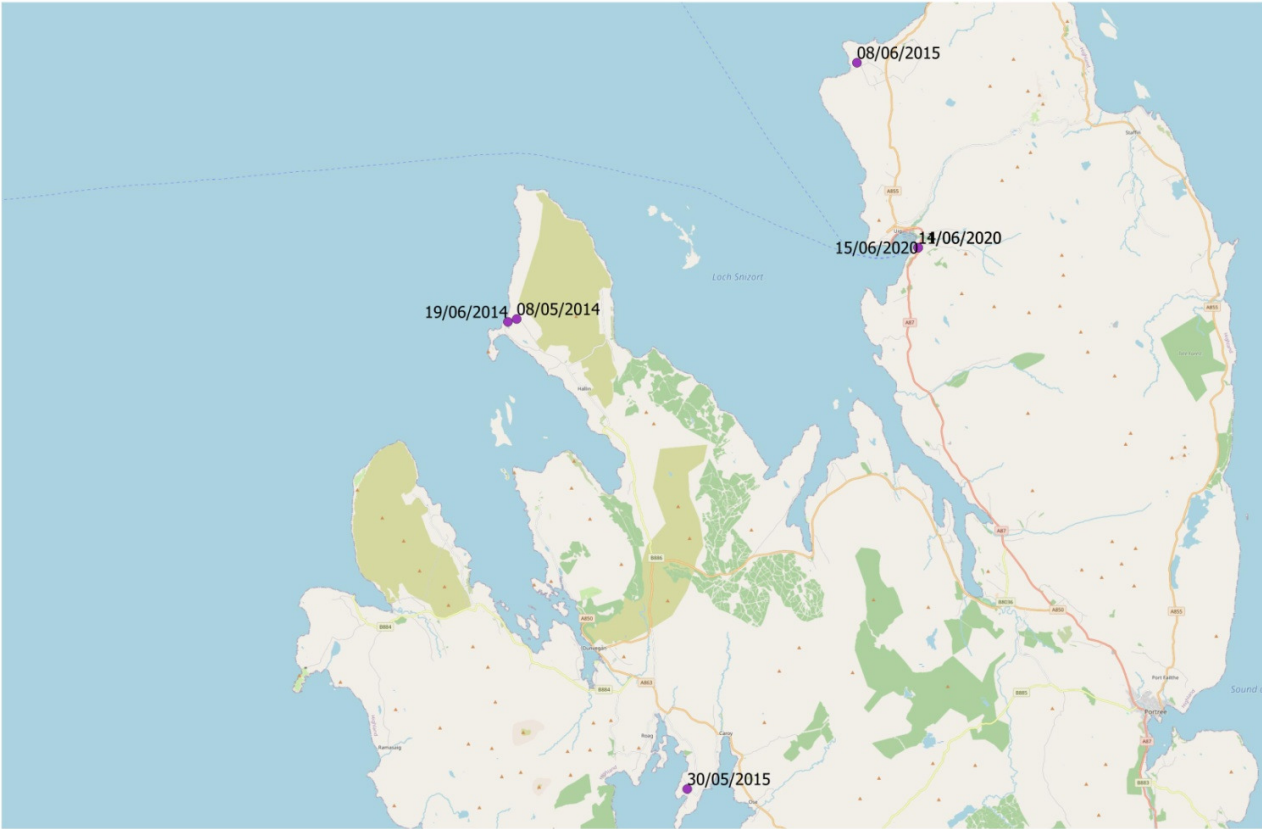


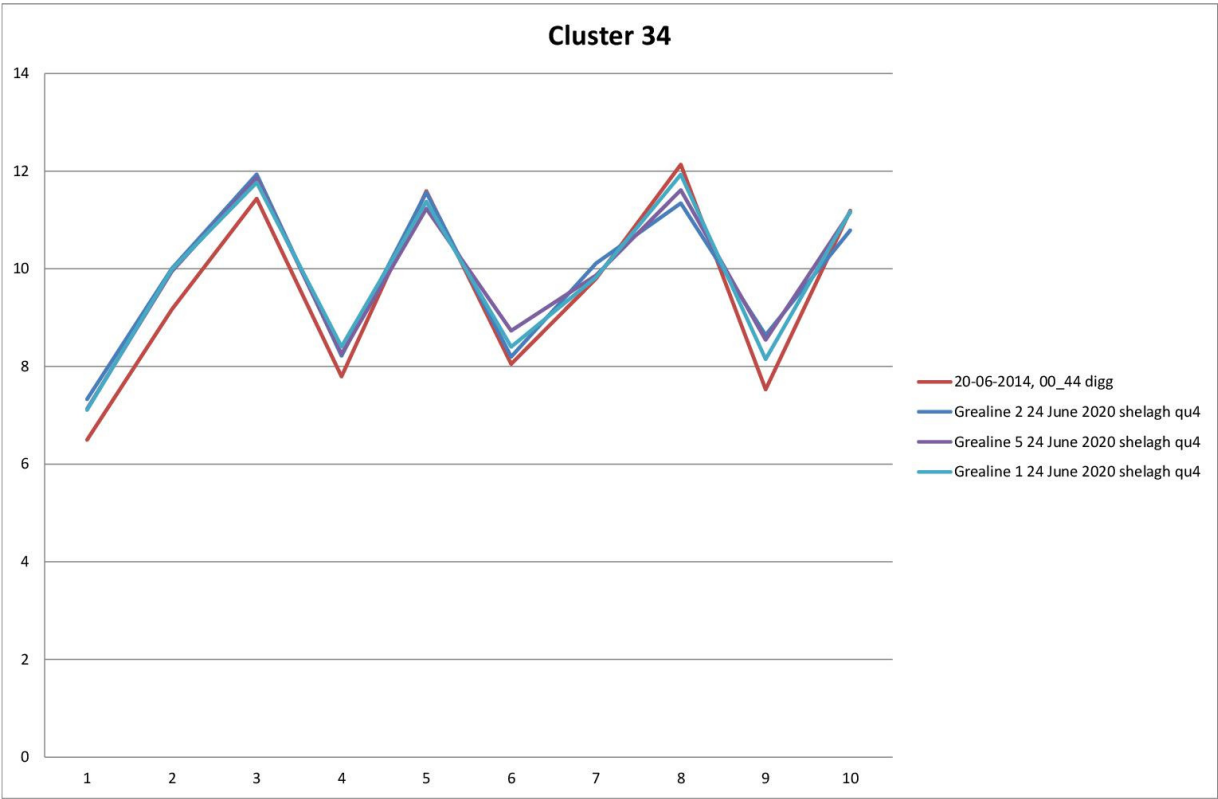
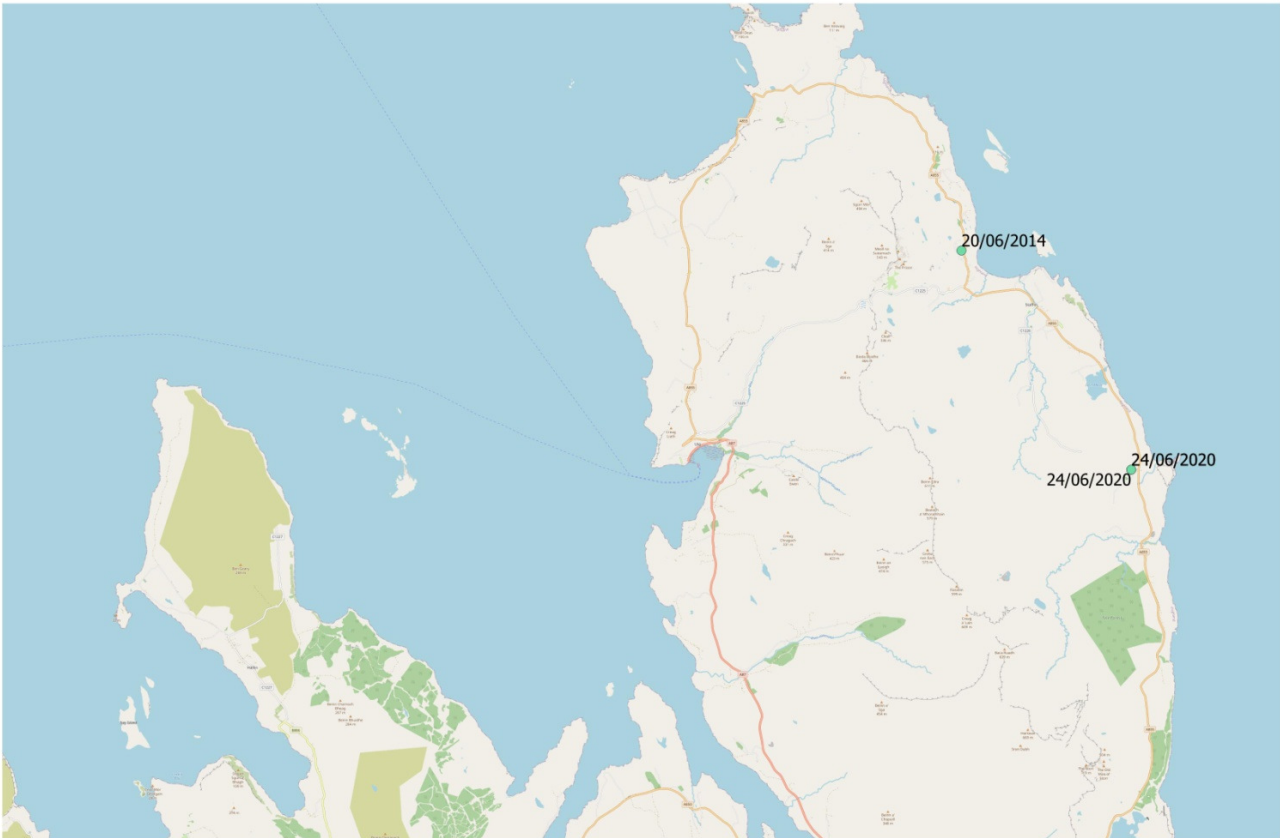












127 Analysed crex recordings, 2012-2020. Skye, 4-5 quality with location.

	qu	date	district	recd
Idrigill_29 May 2013.wav	4	29/05/2013	trotternish	shelagh
Bobs new loc-1_17 June 2013.wav	4	17/06/2013	waternish	shelagh
Ardmore 3-1_21 June 2013.wav	4	21/06/2013	waternish	shelagh
Ardmore substation 2 - 3_27 June 2013.wav	4	27/06/2013	waternish	shelagh
Ardmore substation-3_29 June 2013.wav	4	29/06/2013	waternish	shelagh
Ardmore Willies-4_7 July 2013.wav	4	07/07/2013	waternish	shelagh
08-05-2014, 01_16 monkstadt.wav	4	08/05/2014	monkstadt	shelagh
08-05-2014, 03_05 trumpan davy.wav	4	08/05/2014	trumpan	shelagh
08-05-2014, 03_15 ardmore east field.wav	4	08/05/2014	ardmore	shelagh
08-05-2014, 03_22 ardmore nora reeds.wav	4	08/05/2014	ardmore	shelagh
12-05-2014, 01_03 ardmore nora reeds.wav	4	12/05/2014	ardmore	shelagh
12-05-2014, 01_29 geary nissan hut.wav	4	12/05/2014	geary	shelagh
17-05-2014, 01_12 idrigill.wav	4	17/05/2014	idrigill	shelagh
17-05-2014, 03_28 1 halistra or 8 hallin park.wav	4	17/05/2014	hallin	shelagh
24-05-2014, 00_45 harlosh 2 birds.wav	4	24/05/2014	harlosh	shelagh
25-05-2014, 02_55 lionacro below school.wav 1 of 2	4	25/05/2014	lionacro	shelagh
25-05-2014, 02_55 lionacro below school.wav 2 of 2	4	25/05/2014	lionacro	shelagh
25-05-2014, 02_56 lionacro below manse.wav 1 of 2	4	25/05/2014	lionacro	shelagh
25-05-2014, 02_56 lionacro below manse.wav 2 of 2	4	25/05/2014	lionacro	shelagh
30-05-2014, 03_12 whitewave quail.wav	4	30/05/2014	trotternish	shelagh
30-05-2014, 03_13 lionacro.wav	4	30/05/2014	trotternish	shelagh
03-06-2014, 00_04 7 hallin park.wav	5	03/06/2014	waternish	shelagh
03-06-2014, 00_19 trumpan bobs.wav	4	03/06/2014	waternish	shelagh
03-06-2014, 00_24 ardmore west field.wav	4	03/06/2014	waternish	shelagh
04-06-2014, 01_15 7 hallin park.wav	4	04/06/2014	waternish	shelagh
04-06-2014, 01_40 ardmore bob.wav	4	04/06/2014	waternish	shelagh
16-06-2014, 02_31 lionacro.wav	4	16/06/2014	trotternish	shelagh
16-06-2014, 03_40 ardmore.wav	4	16/06/2014	waternish	shelagh
16-06-2014, 03_47 ardmore.wav	5	16/06/2014	waternish	shelagh
16-06-2014, 04_01 ardmore.wav 1 of 2	4	16/06/2014	waternish	shelagh
19-06-2014, 01_39 ardmore.wav	5	19/06/2014	waternish	shelagh
19-06-2014, 01_41 ardmore.wav	4	19/06/2014	waternish	shelagh
19-06-2014, 01_45 ardmore.wav	4	19/06/2014	waternish	shelagh
20-06-2014, 00_44 digg.wav	5	20/06/2014	trotternish	shelagh
20-06-2014, 01_01 glasphein.wav	4	20/06/2014	trotternish	shelagh
20-06-2014, 01_05 brogaig.wav	4	20/06/2014	trotternish	shelagh
R09_0001 ~ 2014 ~ CORNCRAKE @ TRUMPAN ~ 22 July 2014 ~ 0pm to 10-30pm ## from NG 22562-61317	4	22/07/2014	ardmore	john
R09_0001 ~ 2014 ~ CORNCRAKE @ TRUMPAN ~ 22 July 2014 ~ 10pm to 10-30pm ## from NG 22562-61317	4	22/07/2014	ardmore	john
14-05-2015, 00_29 ardmore carpark nettle	5	14/05/2015	ardmore	shelagh
23-05-2015, 00_13 trotternish S cuil	4	23/05/2015	trotternish	shelagh
23-05-2015, 02_02 trotternish lionacro loch area	5	23/05/2015	trotternish	shelagh
30-05-2015, 01_33 harlosh duneilerich	4	30/05/2015	harlosh	shelagh
08-06-2015, 02_09 trotternish NG3868	4	08/06/2015	trotternish	shelagh
08-06-2015, 02_20 trotternish NG3771	4	08/06/2015	trotternish	shelagh
17-06-2015, 00_00 5 hallin park.Table	5	17/06/2015	hallin park	shelagh
09-07-2015, 03_30 ardmore 2 crakes	4	09/07/2015	ardmore	shelagh
14-07-2015, 00_25 ardmore 2 crakes	4	14/07/2015	ardmore	shelagh
Bornesketaig 22 May 2016.wav	4	22/05/2016	bornesketaig	shelagh
Ardmore Nettles 23 May 2016	4	23/05/2016	ardmore glen	shelagh
Glen Hinnisdale 24 May 2016.wav	5	24/05/2016	hinnisdale	shelagh
Earlish 3 30 May 2016.wav	4	30/05/2016	earlish	shelagh
1 Hallin Park 5 June 2016.wav	4	05/06/2016	hallin park ardmore	shelagh
Ardmore east roadside 11 June 2016.wav	4	11/06/2016	east	shelagh
Ardmore East Roadside 12 June 2016.wav	4	12/06/2016	ardmore	shelagh

			east	
Ardmore East Roadside 14 June 2016.wav	4	14/06/2016	ardmore east	shelagh
Conista 26 June 2016.wav	4	26/06/2016	conista	shelagh
Earlish Upper July 2016.wav	4	01/07/2016	earlish	shelagh
Hazel Upper Halistra 19 June 2017.wav	4	19/06/2017	halistra	hazel
Ardmore East Ec 8 June 2018	4	06/06/2018	ardmore	shelagh
Monkstadt X2 29 June 2018.m4a 1 of 2	4	29/06/2018	trotternish	shelagh
Monkstadt 1 - 29 June 2018.m4a	5	29/06/2018	trotternish	shelagh
Peingown 29 June 2018.m4a	5	29/06/2018	trotternish	shelagh
Monkstadt 10 July 2018.m4a	4	10/07/2018	trotternish	shelagh
Ardmore West 12 July 2018	4	12/07/2018	ardmore	shelagh
Ardmore east 4 June 2019-2.wav	4	04/06/2019	waternish	shelagh
Earlish x roads 11 June 2019-3.wav	4	11/06/2019	trotternish	shelagh
Ard carpark nettles 14 June 2019	4	14/06/2019	ardmore	shelagh
Scudiburgh 7 June 2019.wav	4	7/06/2019	trotternish	shelagh
Ardmore west 5 July 2019 from road.wav	4	05/07/2019	waternish	shelagh
Ardmore west 5 July 2019 from s gate.wav	4	05/07/2019	waternish	shelagh
Waternish farm oans 6-7-19 10pulses av5	5	06/07/2019	waternish farm	shelagh
Waternish farm stein 6-7-19 10pulses av5	4	06/07/2019	waternish farm	shelagh
20190709_170000 9th july. first field above substation ardmore calls 6-46pm	4	09/07/2019	ardmore	robert
Ardmore west 12 July 2019.wav	4	12/07/2019	waternish	shelagh
Ardmore west 12 July 2019-2.wav	4	12/07/2019	waternish	shelagh
Waternish farm 12 July 2019.wav	4	12/07/2019	waternish	shelagh
Ardmore west field 20 July 2019.wav	4	20/07/2019	waternish	shelagh
20190721_010002 21st july 2019 ardmore lime dump	5	21/07/2019	ardmore	robert
28th july 2019 ardmore lime dump	5	28/07/2019	ardmore	robert
stein-May 3rd 2345 video-1588547291	4	03/05/2020	stein	aileen
stein May 4th 2020 2245 video-1588676289	4	04/05/2020	stein	aileen
stein May 6th 2020 0024 R09_0012 CORNCRAKE STEIN 6 May 2020 @ 00-24	4	06/05/2020	stein	john
stein May 9th 2020 0054 R09_0004 CORNCRAKE STEIN 9 May 2020 @ 00-54	4	09/05/2020	stein	john
stein May 9-10th 2020 night lynnVID-20200522-WA0002	5	09/05/2020	stein	lynn
stein May 9-10th 2020 night lynnVID-20200522-WA0001	5	09/05/2020	stein	lynn
stein May 17th 2020 1600 graham_707356706679683	5	17/05/2020	stein	graham
stein May 17th 2020 1600 graham_332054104440263	5	17/05/2020	stein	graham
HALLIN PARK (Mary Campbell's) 19 May 2020 0046 John 00-46 R09_0013	5	19/05/2020	pairc mhor	john
HALLIN PARK (PAIRC MHOR) 19 May 2020 016 John R09_0001	5	19/05/2020	pairc mhor	john
stein 19th May 2020 2135 shelagh AUD-20200519-WA0000	4	19/05/2020	stein	shelagh
stein May 19th 2020 2350 lynn VID-20200522-WA0000	5	19/05/2020	stein	lynn
stein May 20th 2020 night jamie_1931280013673273	4	20/05/2020	stein	jamie
stein May 20th 2020 night jamie_249695306129222-3 calls	4	20/05/2020	stein	jamie
stein May 20th 2020 night jamie_248369789837114	4	20/05/2020	stein	jamie
geary26 20th May 2020 2230 shaz IMG_5773	5	21/05/2020	geary	shaz
north cuil 1st june 2020 0230 martin Video	5	01/06/2020	north cuil	martin
north cuil 1st June 2020 0015 shelagh 2020	5	01/06/2020	north cuil	shelagh
Ose 3 June 2020 2358	5	03/06/2020	ose	shelagh
Geary 4 June 2020-2 0318 shelagh	5	04/06/2020	geary	shelagh
N cuil 8 June 2020 0024 shelagh	5	08/06/2020	north cuil	shelagh
Totescore1 8 June 2020-2 0117 shelagh	5	08/06/2020	totescore	shelagh
N cuil 11 June 2020-2 0202 shelagh	5	11/06/2020	north cuil	shelagh
N cuil 11 June 2020 0006 shelagh	4	11/06/2020	north cuil	shelagh
CARNACH 12 June 2020 2337 john R09_0003	5	12/06/2020	carnach	john
LOWER HALISTRA CARNACH 12 June 2020 2338 john R09_0005	5	12/06/2020	carnach	john
Gordon Taylor 13 June 2020-2 0100 shelagh	5	13/06/2020	carnach	shelagh
Scudiburgh 14 June 2020-3 shelagh	5	14/06/2020	scudiburgh	shelagh
N cuil 14 June 2020 shelagh	5	14/06/2020	north cuil	shelagh
Scudiburgh 14 June 2020-2 shelagh	5	14/06/2020	scudiburgh	shelagh
N cuil 15 June 2020 shelagh	5	15/06/2020	north cuil	shelagh

gordon taylor 16th june 2020 0000 roland AUD-20200616-WA0000
 gordon taylor 16th june 2020 0042 gordon 2020_06_16_00_42_33
 gordon taylor 16th june 2020 0041 gordon 2020_06_16_00_41_42
 gordon taylor 16th june 2020 0039 gordon 2020_06_16_00_39_41
 carnach 19th june 2020 0010 shelagh AUD-20200619-WA0001
 carnach 19th june 2020 0010 shelagh AUD-20200619-WA0005
 carnach 19th june 2020 0010 shelagh AUD-20200619-WA0004
 carnach 19th june 2020 0010 shelagh AUD-20200619-WA0003
 Grealine 2 24 June 2020 shelagh qu4
 Grealine 5 24 June 2020 shelagh qu4
 Grealine 1 24 June 2020 shelagh qu4
 N totescore 2 25 June 2020 shelagh
 N totescore 1 25 June 2020 shelagh
 N totescore 3 25 June 2020 shelagh
 carnach 27th june 2020 1200 roland AUD-20200627-WA0000 qu4
 Scudiburgh 29 june2020 qu4-10calls
 North totescore 3 July 2020 with phone

5	16/06/2020	carnach	roland
5	16/06/2020	carnach	gordon
5	16/06/2020	carnach	gordon
5	16/06/2020	carnach	gordon
4	19/06/2020	carnach	shelagh
5	19/06/2020	carnach	shelagh
5	19/06/2020	carnach	shelagh
5	19/06/2020	carnach	shelagh
4	24/06/2020	grealine	shelagh
4	24/06/2020	grealine	shelagh
4	24/06/2020	grealine	shelagh
4	25/06/2020	totescore	shelagh
4	25/06/2020	totescore	shelagh
4	25/06/2020	totescore	shelagh
4	27/06/2020	carnach	roland
4	29/06/2020	scudiburgh	shelagh
4	03/07/2020	totescore	shelagh

Individuality in Corncrake *Crex crex* vocalizations

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³ Royal Society for the Protection of Birds, 17 Regent Terrace, Edinburgh EH7 5BN, UK

Vocal individuality has potential for the monitoring of bird species that are otherwise difficult to observe. In this study we assessed the potential of this technique for the monitoring of the globally threatened Corncrake *Crex crex* based on the analysis of calls recorded in Ireland and Scotland in 1993 and 1994. Discriminant function analysis correctly attributed >80% of individual calls based on five temporal parameters. A high level of individual distinctiveness was also found in the fine temporal structure of calls. When information on fine structure was added to the discriminant function analysis, classification of calls to individuals was improved to 100%. The structure of an individual's call was found to be consistent over the 2-year period. This study highlighted the problems associated with setting criteria for re-identifying individuals by calls. The consequences of these problems and the potential of vocal individuality for providing monitoring information in this species are discussed.

Vocal individuality in birds has been shown to be a widespread phenomenon (reviews by Beer 1970, Falls 1982, Catchpole & Slater 1995) and its potential, as a means of monitoring the fates of individuals or for enhancing the accuracy of census techniques (Beightol & Samuel 1973), has been strengthened recently by the widespread availability of relatively cheap, but sophisticated, recording and analysis equipment.

A number of studies have established individual differences based on the visual comparison of spectrograms (Hutchison *et al.* 1968, Wooller 1978, Wooller & Bradley 1981, Saunders & Wooller 1988). However, such a qualitative approach lacks the objectivity and repeatability of quantitative analysis such as discriminant function analysis of parameters measured from spectrograms (Martindale 1980). This method has been used to show individuality in a number of species including the Tawny Owl *Strix aluco* (Galeotti & Pavan 1991) and the Bittern *Botaurus stellaris* (McGregor & Byle 1992, Gilbert *et al.* 1994). More recently, spectrograms have been compared directly and quantitatively using cross-correlation routines (Charif *et al.* 1993, Khanna *et al.* in press). This latter technique has been used to show individual differences in the vocalizations of the European Bee-eater *Merops apiaster* (Lessells *et al.* 1995), two hummingbird species *Colibri coruscans* and *Colibri thalassinus* (Gaunt *et al.* 1994) and the Fan-tailed Warbler *Cisticola juncidis* (McGregor *et al.* 1995).

The Corncrake is a trans-Saharan migrant rail which breeds throughout northern Europe between late April and early August (Cramp & Simmons 1980). It is currently un-

der threat of extinction (Collar & Andrew 1988). British and Irish numbers have been in decline for more than a century, the British population numbering fewer than 500 birds in 1993, 92% of which are found in the Inner and Outer Hebrides (Green 1995).

The Corncrake is highly secretive, inhabiting areas of tall vegetation such as iris *Iris pseudacorus* patches and hay meadows, and sightings are rare. However, it is easy to detect males during the breeding season by their distinctive, loud, rasping calls and this provides the basis for censuses of Corncrakes (Hudson *et al.* 1990, Green 1995). Males vocalize at a high rate during the night from around 23.00 h to 04.00 h, producing some 10,000 calls per night at a rate of 35–55 per min (M. Fangrath, 1994, unpublished MSc thesis, University of Osnabruck). While the number of calling males present in an area on any one night is relatively simple to count, the accuracy of a season's census is difficult to ascertain as conventional marking techniques are precluded by the habitat and behaviour of the bird. Radio-tracking studies have provided a great deal of information on movements and habitat use (Stowe & Hudson 1988, 1991), but little is known about the movements of birds between subpopulations, the survival rates between breeding seasons or the year-to-year site fidelity of males. The high level of vocal activity shown by males means that large numbers of calls can be recorded relatively easily from many males in a single night. A pilot study by May (1994) revealed consistent differences in some temporal parameters of the calls of presumed individual males over a short time span. The aim of our study was to explore vocal individu-

ality in this species with a large sample of known individuals throughout a full breeding season and between seasons.

METHODS

Acquisition of recordings

Recordings were made in Ireland in 1993 and 1994 and in North Uist, Outer Hebrides, in 1994. In 1993 at the Shannon Callows, Ireland, males were captured and fitted with radio-tags and metal rings (methods as given by Stowe & Hudson 1991), and calls of 16 radio-tagged males were recorded on at least one night between 30 April and 9 July 1993 (seven of these birds being recorded on two nights, one on three nights and one on four nights). In 1994, 46 males were recorded, captured and ringed in Ireland. Recording usually took place on the night of capture, either prior to capture or immediately after release. In three cases, the birds were recorded 24 h before capture, relying on the high faithfulness to the same calling site each night (Stowe & Hudson 1988). Two of these 46 males were captured and recorded on two separate occasions in 1994. Three of the birds first captured and recorded in 1993 were recaptured and recorded in 1994.

Recordings were made using a Sennheiser MKH816T directional microphone, an AKB-11 preamplifier and either a Marantz CP430 cassette recorder (Ireland) or a Uher 4000 Report Monitor tape recorder (North Uist). Tape speed variation was measured for the North Uist recordings (440-Hz calibration tone, Wittner Quartz-Metronom Taktell QM3 guitar tuner); the wavelength of the tone varied by ± 0.04 ms (s.d.) and thus variation in recording fidelity was thought to have a minor effect on our data.

All Irish recordings were made from a distance of less than 20 m and between 23.00 h and 04.00 h, the period when calling was commonest. To evaluate the effect of time of day on call structure, two males on North Uist were recorded throughout a 24-h period.

Analysis of recordings

Recordings were analysed using the Canary 1.1 sound analysis package (Charif *et al.* 1993) on a Macintosh Quadra 840AV. Calls were filtered to remove some of the background noise before digitization using a Kemo VBF/3 filter, set at 0.5 kHz high pass (series enabled). Ten calls were digitized from each bird for each night; each group of ten calls from a single bird on a single night will be subsequently referred to as a "set" of calls. Calls constituting a set were not randomly chosen, usually they were the first ten good-quality calls (i.e. those with a high signal-to-noise ratio and little interference from other birds) from each recording session.

Figure 1 shows a spectrogram of a complete Corncrake call consisting of two syllables (referred to as elements by May [1994]; hereafter referred to as syllables I and II) sep-

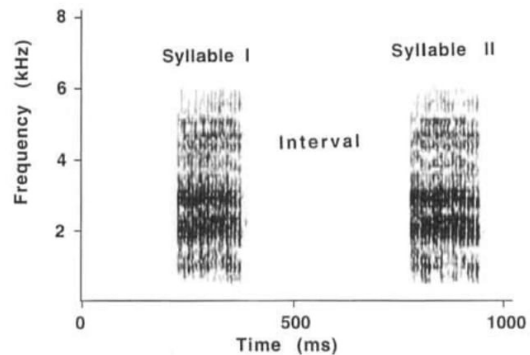


Figure 1. Spectrogram (time v frequency) of a complete Corncrake call showing the two syllables separated by an interval (spectrogram produced by Canary 1.1, grid resolution: 5.8 ms, 43.5 Hz).

arated by an interval. The majority of the energy within a Corncrake call occurs between 2 and 7 kHz with the spectrogram showing indistinct bands throughout the frequency range. Preliminary analysis found little or no consistent difference in the arrangement of these bands between individuals, giving little prospect of using this information to identify individuals (T.M. Peake & P.K. McGregor, unpubl. data). Figure 2a shows the waveform of a complete Corncrake call. When the time axis is expanded (Figs 2b, c), it becomes clear that each syllable is made up of a number of pulses of sound (usually 14–22). Pulses are on average 3–5 ms in length and are separated by intervals of 4–8 ms. We define the time from the start of one pulse to the start of the next as the pulse-to-pulse duration (P-PD); from Figure 2c it is clear that P-PDs vary within a syllable. Syllable II is generally longer, and contains more pulses, than syllable I. Henceforth we shall refer to large-scale temporal call features (syllable and interval durations) as "syllable characters" and small-scale temporal features (those based on pulses) as "P-PD characters".

All measurements were made using Canary's on-screen cursors. Measurements of syllable characters were made from waveforms displayed at the level of Figure 2a, resulting in a cursor increment of 0.5 ms. Pulse-to-pulse durations were measured from waveforms displayed at the level of Figure 2c with a cursor increment of 0.08 ms.

Quantitative analyses

The potential identification value of syllable characters (e.g. those used by May 1994) was assessed with canonical linear discriminant function analysis (forced-entry method) using five syllable characters: the duration of syllable I, the number of pulses in syllable I, the duration of the interval, the duration of syllable II and the number of pulses in syllable II. Upon inspection of the frequency distributions of these five variables, all appeared normally distributed and none of the variables was transformed before entry into the analysis.

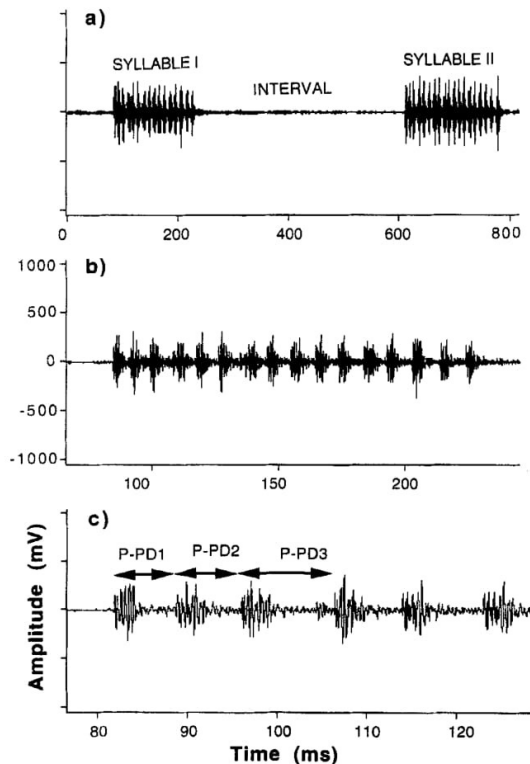


Figure 2. Waveform (time v amplitude) representations. (a) One complete Corncrake call; (b) Syllable I of the same call; (c) The first six pulses of this syllable. P-PD refers to the pulse-to-pulse duration as explained in the text.

Classification was carried out according to Bayes' rule; prior probability of group membership was selected so that any given call was equally likely to be classified to any individual bird, i.e. 0.06 (1/16) for the 1993 data set and 0.02 (1/46) for the 1994 data set. Each call was then classified to the bird for which it had the highest probability (Norusis/SPSS Inc. 1988).

The ability of the discriminant function analysis to classify successfully new data was assessed using jack-knife analysis (Manly 1986). This involved splitting the data set into two halves, using the first half (i.e. parameters from five calls from each male on each night) to create the discriminant functions and the other half (data from the other five calls for each male on each night) as 'new' data for classification. Within-year discrimination was assessed using this method for both the 1993 and the 1994 data sets.

Each syllable can be described by a sequence of P-PDs, P-PD1 being the time from the start of the first pulse to the start of the second and so on (Fig. 3). For each bird on each night a set of calls was represented by a mean P-PD sequence to avoid problems of pseudoreplication. The similar-

ity of any two P-PD sequences was assessed by correlation with a correlation coefficient (r) of +1 meaning that the sequences were identical. The first 13 P-PDs of syllable I and the first 16 P-PDs of syllable II were used in the correlation analysis as these were the numbers of pulses in the shortest syllables in the data set.

The effect of combining P-PD characters with syllable characters was then investigated using discriminant function analysis. Due to the sample size of 16 males in 1993, we were limited to 15 variables in the analysis. In addition to the five measures used previously, we entered the first ten P-PDs from syllable I for each call for each bird. The rationale for this was that P-PDs become more variable along the length of the syllable (see Fig. 4). The discriminant function analysis was carried out in an identical manner to that described previously, i.e. within-year discrimination was assessed separately for each year. In order to assess between-year changes in call structure, discriminant functions derived from the entire 1993 data set were used to classify all the calls from the 1994 data set.

The extent of similarity between sets of calls can be represented using Euclidean distances between group centroids (defined by the mean discriminant function scores for a given set of calls). All discriminant function scores were used for each set of calls; these scores were standardized to a mean of zero and a standard deviation of one.

All statistical analyses were carried out using SPSS for Windows version 5.0.

RESULTS

24-h studies

Calling patterns for two birds recorded over 24 h were found to be similar to those reported by Hudson *et al.* (1990). Both birds called sporadically (two or three calls) throughout the day, culminating in near continuous calling at night (22.45–03.10 h for one bird, 23.05–02.50 h for the other). In the hours immediately preceding and succeeding such peak times, bouts of 20–30 calls were common. Sporadic daytime calling was too brief and unpredictable to be captured on tape, but the longer bouts either side of peak times were sampled. In total, 140 calls were analysed for one bird and 120 for the other. The P-PD distribution of calls remained unchanged throughout the night for both birds (Fig. 4). Four of the five syllable characters varied little (Table 1). However, interval duration was more variable in both birds. This variation was largely caused by about 10% of the calls which were 10–20% longer than average. There was no significant difference in interval duration during peak-calling times as compared with non-peak times for either bird (male A: mean during peak times = 337.7 ± 2.49 (s.e.), mean during non-peak times = 332.9 ± 1.72 , $F_{1,118} = 2.45$, n.s.; male B: mean during peak times = 367.9 ± 2.35 , mean during non-peak times = 370.8 ± 2.08 , $F_{1,138} = 0.83$, n.s.).

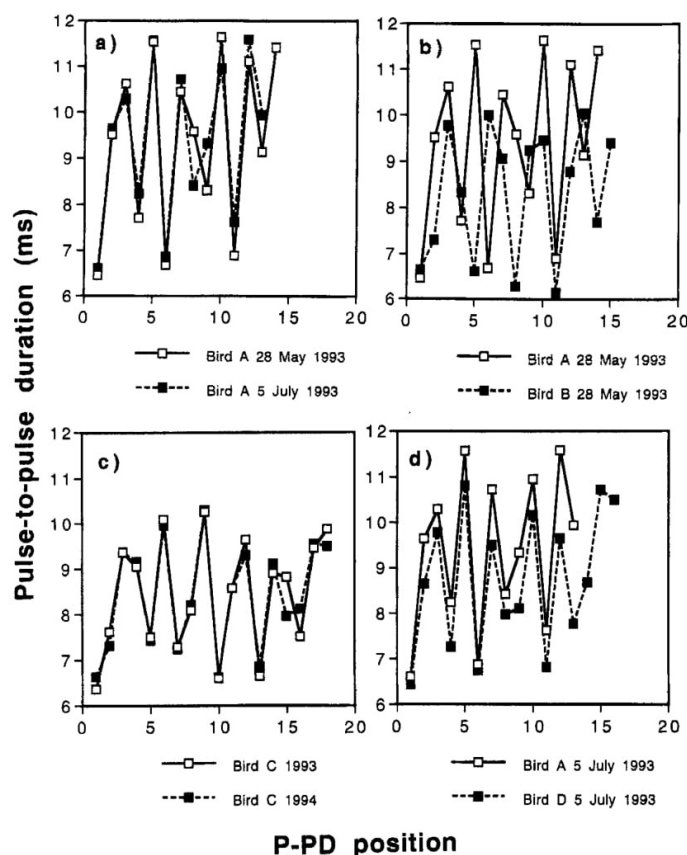


Figure 3. Graphic representations of P-PD distributions of syllable 1 of the calls of Corncrakes. Each graph plots two such distributions, either from the same bird on different nights (a, c) or from two different birds (b, d).

Within-year analyses

Discriminant function analysis

Discriminant function analysis of the five syllable characters generated five discriminant functions which correctly assigned 87% of calls to the individual from which they were recorded in the 1993 data set (16 birds) and 85% correct classification in the 1994 data set (46 birds). The classification of data not used in the creation of discriminant functions (the jack-knife analysis) achieved 84% correct classification of calls of the 1993 birds and 83% correct classification of calls of the 1994 birds.

Analysis of P-PD distribution

The P-PD characters of the same bird on different nights and of different birds are shown graphically in Figure 3 and as Pearson correlations in Figure 5. While small differences occurred between the distributions of the same bird on different nights (e.g. the middle of Fig. 3a), the P-PD characters of different birds showed greater differences (Figs 3b, d). Table 2 (first two columns) compares the median and

range of r for same-bird, between-night and within-year comparisons. The lowest value of r was 0.77; thus we set the arbitrary criterion for deciding that P-PD distributions were from the same bird below this, at 0.7. This means that a correct match is a value of $r > 0.7$ for a same-bird dyad and an incorrect match is a value of $r > 0.7$ for a different-bird dyad. Table 2 (final four columns) shows the percentage of incorrect matches occurring in the analysis, together with the median and range of r .

Combined discriminant function analysis

Discriminant function analysis using the five syllable characters and the ten P-PD characters generated 15 discriminant functions which correctly classified all of individuals' calls in both years. The jack-knife analysis also correctly attributed all calls to the correct individuals.

Between-year analyses

We assessed between-year variation using the combined discriminant function analysis. Discriminant functions were

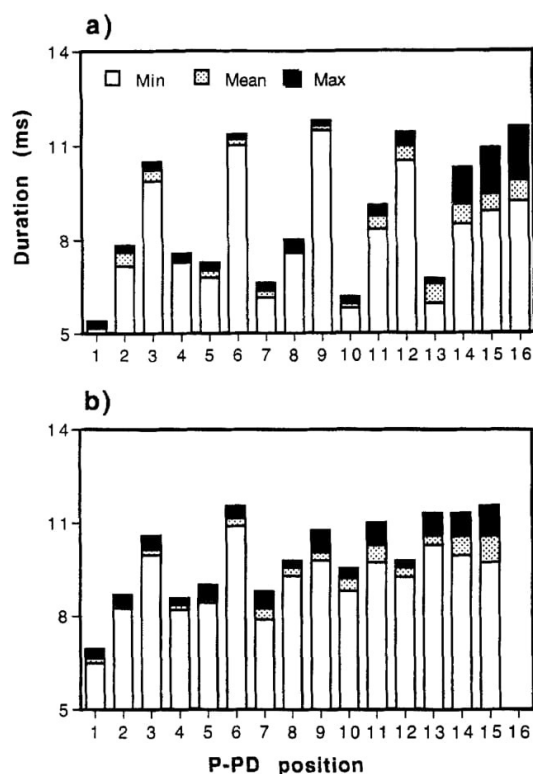


Figure 4. Bar graph illustrating the range of variation in the P-PD distribution of syllable I of two male Corncrakes (a, b) over a 24-h period. The top and bottom of the shaded regions represent maximum and minimum values, respectively. The horizontal line within the shaded region represents the mean.

created using the entire 1993 data set and were used to classify calls from the 1994 birds. All calls were correctly classified between years for the three individuals recorded in both years.

The trade-offs involved in setting threshold criteria for re-identification can be seen clearly by examining the frequency distributions of Euclidean distances between group centroids for same-bird dyads and different-bird dyads (Fig. 6). Criteria which are too lenient allow a higher proportion of incorrect matches, whilst those which are too stringent will fail to recognize a proportion of correct matches. For example, setting a criterion based on a Euclidean distance between group centroids of eight would correctly identify all birds recorded in both years but would also make a number of incorrect matches. Setting the criteria at four would make virtually no incorrect matches but would fail to recognize a number of correct matches. Euclidean distances between the group centroids of the same individuals on different nights showed no significant trend with time ($r_s = 0.20$, n

Table 1. Means $\pm$ standard errors of five syllable characters measured from the calls of two male Corncrakes over a 24-h period ($n = 120$ calls for male A and 140 calls for male B)

Variable	Male A	Male B
Number of pulses in syllable I	17.6 $\pm$ 0.09	15.7 $\pm$ 0.08
Duration of syllable I (ms)	150.0 $\pm$ 0.84	147.7 $\pm$ 0.75
Number of pulses in syllable II	19.9 $\pm$ 0.08	18.4 $\pm$ 0.08
Duration of syllable II (ms)	169.5 $\pm$ 0.74	170.1 $\pm$ 0.71
Duration of interval (ms)	335.3 $\pm$ 1.53	369.4 $\pm$ 1.57

$= 23$, n.s.; Fig. 7), i.e. call structure appeared to remain constant over 1 year.

DISCUSSION

We found that temporal features of the loud advertising vocalizations of male Corncrakes varied little within 24 h, within years and, to a lesser extent, between years. These results have implications for monitoring Corncrakes using such individually distinctive vocalizations and these results also highlight some general considerations of the technique.

Discriminant function analysis was able to correctly classify all individual Corncrake calls, confirming May's (1994) suggestion that temporal parameters may be useful in discriminating between individual Corncrakes. This is comparable with published data on Pygmy Owls *Glaucidium passerinum* (84%; Galeotti *et al.* 1993), Bald Eagles *Haliaeetus leucocephalus* (83–100%; Eakle *et al.* 1989) and Woodcock *Scolopax rusticola* (90%; Ferrand 1987). It is worth noting that our sample size of 46 males in 1994 is large in comparison with similar studies and, indeed, represented nearly 10% of the British population (Green 1995). Discriminant function analysis is a useful technique for demonstrating individuality objectively and allowing comparison with published literature; however, it has the practical limitation that it can only attribute new recordings to birds which have been recorded previously.

Our study appears to be the first to describe individually distinctive temporal characters at such a fine scale. Other studies have used large-scale temporal or frequency parameters measured from spectrograms. Our results suggest that future studies of individuality should also examine fine-scale temporal call structure visible in time-amplitude waveforms.

In discussing the potential application of vocal individuality to census and monitoring problems in general, it is useful to distinguish between issues of discrimination and those of identification. Discrimination requires only that two individuals can be distinguished from one another. In census situations where a recorder is unsure whether to count one bird or two for a particular site, the ability to distinguish

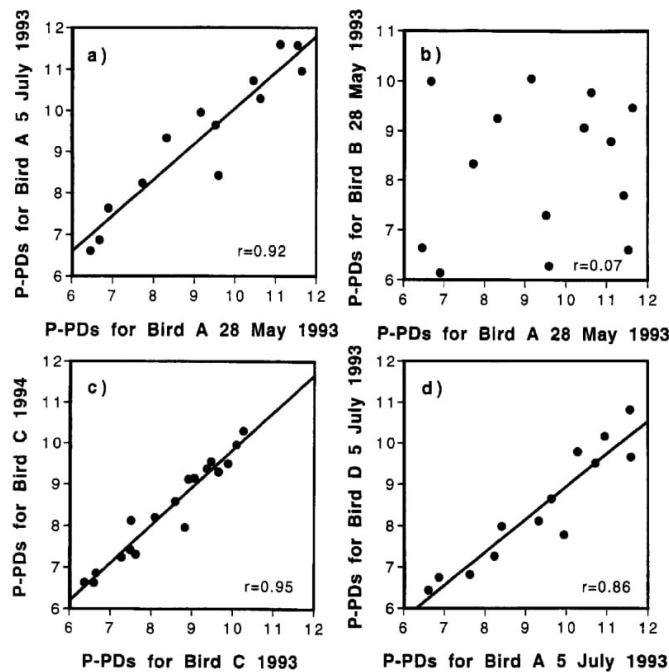


Figure 5. Scatterplots comparing the P-PD distributions of syllable I of the male Corncrakes shown in Figure 3. Plots a-d correspond to graphs a-d in Figure 3. The values of r shown are Pearson correlation coefficients.

between recordings on different nights would be useful. This study has shown that it is possible to distinguish individual calling birds with 100% certainty within the limits of the samples used. Sound recordings can therefore have a direct application in studies of census efficiency.

Identification is more demanding, because it requires that individuals can be unambiguously identified whenever encountered. Thus it is not only necessary that individuals can be discriminated but that call structure remains sufficiently similar with time so that further recordings can be attributed to the correct individual. Such individual identification allows important demographic parameters such as survival rates between seasons and site fidelity to be measured. In this study, we have shown that call structure remained largely constant over time, contrary to Mason's (1940) observation that differences in the quality of calls could be

heard over a season. We were able to measure small differences in temporal structure over a season, but these differences were small when compared with differences between individuals. In addition, predictions can be made about likely patterns of movement from results found during radio-tracking (Stowe & Hudson 1988). This sort of prior knowledge increases the usefulness of this technique in following within-season movements because mistakes of identification are less likely to occur. Between years, the problems of individual identification are greater, due to the difficulties of incorrect matches and the setting of threshold criteria. In this sense, our current methods are limited by the classic signal-detection threshold trade-off, i.e. incorrect attribution of calls to individuals and the failure to make correct matches cannot be minimized simultaneously (see review by Wiley & Richards 1983). For studies within restricted sites, it is

Table 2. Analysis of dyads of Corncrake call P-PD sequences. The values given for % correct are simply $100 - \% \text{ incorrect}$ (i.e. $r > 0.7$; see Results). Further details of the analysis are given in Methods

	Same-bird dyads		Different-bird dyads			
	n	Median r (range)	n	Median r (range)	% $r > 0.7$	% correct
Within 1993	15	0.93 (0.77–0.99)	351	0.36 (–0.33–0.95)	14.5	85
Within 1994	2	0.91 (0.87–0.94)	1128	0.34 (–0.40–0.94)	24.6	75
Between 1993 and 1994	6	0.95 (0.84–0.97)	1296	0.32 (–0.32–0.96)	20.0	80
Total	23	0.94 (0.77–0.99)	2775	0.33 (–0.40–0.96)	19.4	81

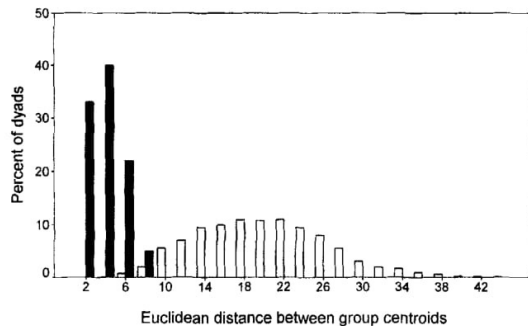


Figure 6. Percentage distributions of Euclidean distances between group centroids (mean discriminant function scores of sets of Corncrake calls) of same-bird dyads (solid bars; i.e. sets of calls recorded from the same bird on different nights; $n = 23$ dyads) and different-bird dyads (open bars; i.e. sets of calls recorded from different birds; $n = 2775$ dyads).

possible that a sample of birds could be recognized from one year to the next and, provided that this study population was not biased in any other way, could be used to produce overall return rate estimates. It may also be possible to generate an index of return rate using all the recordings which could be used to compare rates between sites. Studies of year-to-year site movements and site fidelity are more of a problem with our current technique as any chance mismatch is likely to lead to highly erroneous conclusions.

One obvious limitation of the use of calls in survival rate and site fidelity work is that the technique can be applied only to male birds that are at least 1 year old. We are therefore unable to investigate survival and site fidelity of female birds or to look at key parameters such as the survival and site fidelity of young birds.

In addition to the presence of consistent vocal individuality, to be useful as a monitoring technique it is important that recordings can be collected efficiently. Corncrakes are highly predictable, calling on 75–80% of nights (Stowe & Hudson 1988) at a rate of 35–55 calls per min for several hours. We found no significant effect of the time of night at which recordings were made on parameters used to identify individuals, hence large numbers of calls from many males can be recorded in a single night. This compares with a study of Black-throated Divers *Gavia arctica* (Gilbert *et al.* 1994) which found that, although highly individually distinctive, calls were so difficult to record as to render the technique inappropriate.

Corncrakes are thus an ideal species with which to use this kind of technique, especially when one considers that monitoring data cannot easily be collected by any other means. Colour ringing is not feasible due to the rarity of sightings, mark and recapture is impractical for both logistic and welfare reasons and radio-tracking cannot follow birds from one season to the next. There are clearly many areas, such as census studies and investigations of survival and year-to-year site fidelity, where the recognition of individual

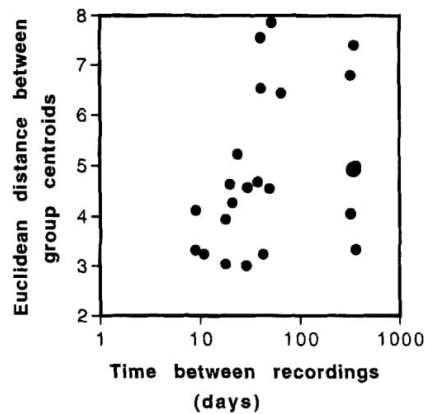


Figure 7. Scatterplot of Euclidean distances between group centroids of same-bird dyads v time (log. scale) between recordings ($r_s = 0.20$, $n = 23$, n.s.) of Corncrakes.

birds is required. Any technique which allows this to be done without catching and resighting birds has logistic and welfare advantages.

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REFERENCES

- Beer, C.G. 1970. Individual recognition of voice in the social behaviour of birds. In Lehrman, D.S., Hinde, R.A. & Shaw, E. (eds) *Advances in the Study of Behaviour*, Vol. 3: 27–74. New York: Academic Press.
- Beightol, D.R. & Samuel, D.E. 1973. Sonographic analysis of the American Woodcock's peent call. *J. Wildl. Mgmt* 37: 470–475.
- Catchpole, C.K. & Slater, P.J.B. 1995. *Bird Song: Biological themes and variations*. Cambridge: Cambridge University Press.
- Charif, R.A., Mitchell, S. & Clark, C.W. 1993. *Canary 1.1 User's Manual*. Ithaca, N.Y.: Cornell Laboratory of Ornithology.
- Collar, N.J. & Andrew, P. 1988. *Birds to Watch: The ICBP world checklist of threatened birds*. London: International Council for Bird Preservation.
- Cramp, S. & Simmons, K.E.L. 1980. *Handbook of the Birds of Europe, the Middle East and North Africa*, Vol. 2. Oxford: Oxford University Press.
- Eakle, W.L., Mannan, R.W. & Grubb, T.G. 1989. Identification of individual breeding Bald Eagles by voice analysis. *J. Wildl. Mgmt* 53: 450–455.
- Falls, J.B. 1982. Individual recognition by sound in birds. In

- Kroodsma, D.E. & Miller, E.H. (eds) *Acoustic Communication in Birds*, Vol. 2: 237–278. New York: Academic Press.
- Ferrand, Y. 1987. Reconnaissance acoustique individuelle de la bécasse des bois (*Scolopax rusticola*) à la croule. *Gibier Faune Sauvage* 4: 241–254.
- Galeotti, P. & Pavan, G. 1991. Individual recognition of male Tawny Owls (*Strix aluco*) using spectrograms of their territorial calls. *Ethol. Ecol. Evol.* 3: 113–126.
- Galeotti, P., Paladin, M. & Pavan, G. 1993. Individually distinct hooting in male Pygmy Owls *Glaucidium passerinum*: A multivariate approach. *Ornis Scand.* 24: 15–20.
- Gaunt, S.L.L., Baptista, L.F., Sanchez, J.E. & Hernandez, D. 1994. Song learning as evidenced from song sharing in two hummingbird species (*Colibri coruscans* and *C. thalassinus*). *Auk* 111: 87–103.
- Gilbert, G., McGregor, P.K. & Tyler, G. 1994. Vocal individuality as a census tool: Practical considerations illustrated by a study of two rare species. *J. Field Ornithol.* 65: 335–348.
- Green, R.E. 1995. The decline of the Corncrake *Crex crex* in Britain continues. *Bird Study* 42: 66–75.
- Hudson, A.V., Stowe, T.J. & Aspinall, S.J. 1990. Status and distribution of Corncrakes in Britain in 1988. *Br. Birds* 83: 173–187.
- Hutchison, R.E., Stevenson, J.G. & Thorpe, W.H. 1968. The basis for individual recognition by voice in the Sandwich Tern (*Sterna sandvicensis*). *Behaviour* 32: 150–157.
- Khanna, H., Gaunt, S.L.L. & McCallum, D.A. In press. Digital spectrographic cross-correlation: Tests of sensitivity. *Bioacoustics* 7.
- Lessells, C.M., Rowe, C.L. & McGregor, P.K. 1995. Individual and sex differences in the provisioning calls of European bee-eaters. *Anim. Behav.* 49: 244–247.
- Manly, B.J.F. 1986. *Multivariate Statistical Methods: A primer*: 86–99. London: Chapman & Hall.
- Martindale, S. 1980. On the multivariate analysis of avian vocalisations. *J. Theor. Biol.* 83: 107–110.
- Mason, A.G. 1940. On some experiments with Corncrakes. *Ir. Nat. J.* 7: 226–237.
- May, L. 1994. Individually distinctive Corncrake *Crex crex* calls: A pilot study. *Bioacoustics* 6: 25–32.
- McGregor, P.K. & Byle, P. 1992. Individually distinctive bittern booms: Potential as a census tool. *Bioacoustics* 4: 93–109.
- McGregor, P.K., Anderson, C.M., Harris, J., Seal, J.R. & Soul, J.M. 1995. Individual differences in songs of Fan-tailed Warblers *Cisticola juncidis* in Portugal. *Afro* 5: 17–21.
- Norusis, M.J./SPSS Inc. 1988. *SPSS, PC+ Advanced Statistics, Version 2.0 Manual*. Chicago, Ill.: SPSS Inc.
- Saunders, P.A. & Wooller, R.D. 1988. Consistent individuality of voice in birds as a management tool. *Emu* 88: 25–32.
- Stowe, T.J. & Hudson, A.V. 1988. Corncrake studies in the Western Isles. *Royal Society for the Protection of Birds Conservation Review* 2: 38–42.
- Stowe, T.J. & Hudson, A.V. 1991. Radio-telemetry studies of Corncrakes in Great Britain. *Vogelwelt* 112: 10–16.
- Wiley, R.H. & Richards, D.G. 1983. Adaptations for acoustic communication in birds: Sound transmission and signal detection. In Kroodsma, D.E. & Miller, E.H. (eds) *Acoustic Communication in Birds*, Vol. 2: 131–181. New York: Academic Press.
- Wooller, R.D. 1978. Individual recognition in the Kittiwake Gull, *Rissa tridactyla* (L.). *Z. Tierpsychol.* 48: 68–86.
- Wooller, R.D. & Bradley, J.S. 1981. Consistent individuality in the calls of Spinifexbirds *Eremiornis carteri* on Barrow Island, WA. *Emu* 81: 40.

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