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Natural Resources Wales

Temporal trends and phenology in grey seal (*Halichoerus grypus*) pup counts at Marloes Peninsula, Wales

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We work for the communities of Wales to protect people and their homes as much as possible from environmental incidents like flooding and pollution. We provide opportunities for people to learn, use and benefit from Wales' natural resources.

We work to support Wales' economy by enabling the sustainable use of natural resources to support jobs and enterprise. We help businesses and developers to understand and consider environmental limits when they make important decisions.

We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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Contents

1. Crynodeb Gweithredol

Mae'r morlo llwyd (*Halichoerus grypus*) wedi'i nodi yn Atodiad II o Gyfarwyddeb Cynefinoedd yr UE ac mae'n nodwedd gymwys o dair Ardal Cadwraeth Arbennig yng Nghymru. Mae gan gytrefi Sir Benfro'r boblogaeth fridio fwyaf yn ne-orllewin Prydain. Nod yr astudiaeth hon oedd darparu tystiolaeth ar statws niferoedd y morloi llwyd bychain o amgylch Penrhyn Marloes, Sir Benfro, ar sail data arolwg a gasglwyd rhwng 1993 a 2013.

Tri phrif amcan oedd: 1) Meintoli'r twf diweddar yn y boblogaeth 2) Dadansoddi newidiadau yn amseru'r tymor esgor. 3) Darparu argymhellion ar gyfer dyfodol yr arolwg hwn.

1) Gwelwyd cynnydd o 6.2% y flwyddyn yn niferoedd y morloi bychain ar Benrhyn Marloes ar gyfartaledd. Gellir cymharu hyn â chynnydd blynyddol o 6–7% ledled y DU trwy gydol y 1960au a'r 1970au ac amcangyfrifon diweddar o 6–10% y flwyddyn o amgylch Ynysoedd Erch ac Ynysoedd Heledd.

2) Gwelwyd tuedd gyson tuag at ddechrau tymor cynharach, sydd wedi dod dwy wythnos ynghynt ar gyfartaledd yn ystod yr ugain mlynedd ddiwethaf.

3) Cyflwynir cyfres o argymhellion, gan gynnwys parhau â'r arolwg o leiaf tan fydd nifer y morloi bychain yn sefydlogi, ymchwilio i'r sbardunau amgylcheddol sy'n ennyn llwyddiant o ran esgor morloi bychain, a chyfuno data Marloes gyda data eraill ar forloi yng Nghymru er mwyn llywio cynllunio gofodol morol.

2. Executive Summary

The grey seal (*Halichoerus grypus*) is listed in Annex II of the EU Habitats Directive and is a qualifying feature of three Special Areas of Conservation in Wales. Pembrokeshire colonies represent the largest breeding population in southwest Britain. The aim of this study was to provide evidence on the status of grey seal pup numbers around the Marloes Peninsula, Pembrokshire, based on survey data collected from 1993-2013.

Three key objectives were: 1) Quantify recent population growth. 2) Analyse changes in the timing of the pupping season. 3) Provide recommendations for the future of this survey.

1) Marloes peninsula pup counts increased by an average of 6.2% per year. This is comparable to annual increases around the UK of 6-7% through the 1960s and 1970s and recent estimates around Orkney and the Hebrides of 6-10% per year.

2) There has been a consistent trend towards an earlier season start, coming forward by two weeks on average in the last twenty years.

3) A series of recommendations are presented, including continuation of the survey at least until pup counts stabilize, investigation of environmental drivers of pupping success, and combining Marloes data with other Welsh seal data to inform marine spatial planning.

3. Introduction

3.1. Grey seal population status

Quantifying the abundance and distribution of a species is fundamental to understanding its population dynamics, as well as predicting likely responses to future change; this is particularly important for species of conservation concern, such as marine mammals. The grey seal (*Halichoerus grypus*) of the northeast Atlantic and Baltic Sea is a species listed in Annex II of the EU Habitats Directive (Council Directive 92/43EEC). Consequently, considerable local, national and international efforts have been made to assess the status of grey seal populations across Europe.

In Wales, grey seals are qualifying features of three Special Areas of Conservation (SACs): Pembrokeshire Marine / Sir Benfro Forol SAC in the southwest, Cardigan Bay / Bae Ceredigion SAC in the west and Lleyn Peninsula and the Sarns / Pen Llŷn a'r Sarnau SAC in the north. One of the responsibilities of Natural Resources Wales (NRW) is to monitor the number of grey seal pups born in these SACs (Stringell *et al*., 2014).

Seal numbers can be hard to quantify, due to their elusive and highly mobile nature. In terms of overall population size, it has recently been estimated that 44% of the global total is resident in the UK, based on an extrapolation from pup production (57,000 out of 129,000. Table 3 of SCOS, 2014). 88% of the UK population breed at large colonies in Scotland (SCOS, 2014). Of the remainder, around 4% breed in Wales, where most are found in Pembrokeshire (Duck, 2009). The Pembrokeshire colonies represent the largest breeding population in southwest Britain and the Irish Sea (Baines *et al*., 1995; Strong *et al*., 2006; Duck & Thompson, 2007).

3.2. Grey seal phenology

Phenology is the investigation of annual life cycle events, such as breeding and migration (Edwards & Richardson, 2004). The study of phenology can provide sensitive indicators of the effects of climate change (from global warming; or regionally, e.g., the El Niño / La Niña cycle; or more locally, e.g., The North Atlantic Oscillation) on ecosystem status and function (Hughes, 2000). In particular, mismatches in seasonal events, for example between predator and prey populations or flowering plants and their pollinators, can decouple biological communities and lead to critical transitions in population structure, biological regime shifts and even collapse of ecosystem services (Kudo & Ida, 2013; Conversi *et al*., 2015; Stevenson *et al*., 2015).

Marine mammal phenology has been cited as evidence of a major system shift in the Indian Ocean and parts of the Southern Ocean (Weimerskirch *et al*., 2003) and climate-driven changes in seasonal timing are predicted to have substantial negative effects on marine mammal populations themselves (Learmonth *et al*., 2006). There are now observable changes in the timing of seal life history in the northeast Atlantic (Osinga *et al*., 2012). This makes it vitally important that the UK continues to develop a robust evidence-base for grey seal population status, remaining vigilant for early warning signs of changes in life history timing.

3.3. Aims and objectives

The aim of this study was to provide evidence on the status of grey seal pup numbers around the Marloes Peninsula, Pembrokshire, based on intensive survey data collected by Natural Resources Wales (and its precursor agency, Countryside Council for Wales), from 1993-2013. The following objectives were explored:

1. Quantify temporal trends from over twenty years of annual pup surveys, highlighting the shape of recent population growth and provide an estimate of the annual rate of change.

2. Calculate the length of the pupping season, defined as the number of days between the first and last pup sighting on beaches around the Marloes Peninsula, and analyse changes through time (phenology).

3. Relate findings to equivalent population growth rate estimates from around the UK, and provide a series of recommendations for the future of this survey.

4. Methods

4.1. Study site

Marloes peninsula forms the mainland component of the Skomer Marine Conservation Zone (SMCZ) area in Pembrokeshire, south Wales (51° 43′ 55.2″ N, 5° 16′ 33.6″ W) (Figure 1). Adult female grey seals haul out on sheltered beaches throughout this area to give birth and nurse pups until weaning.

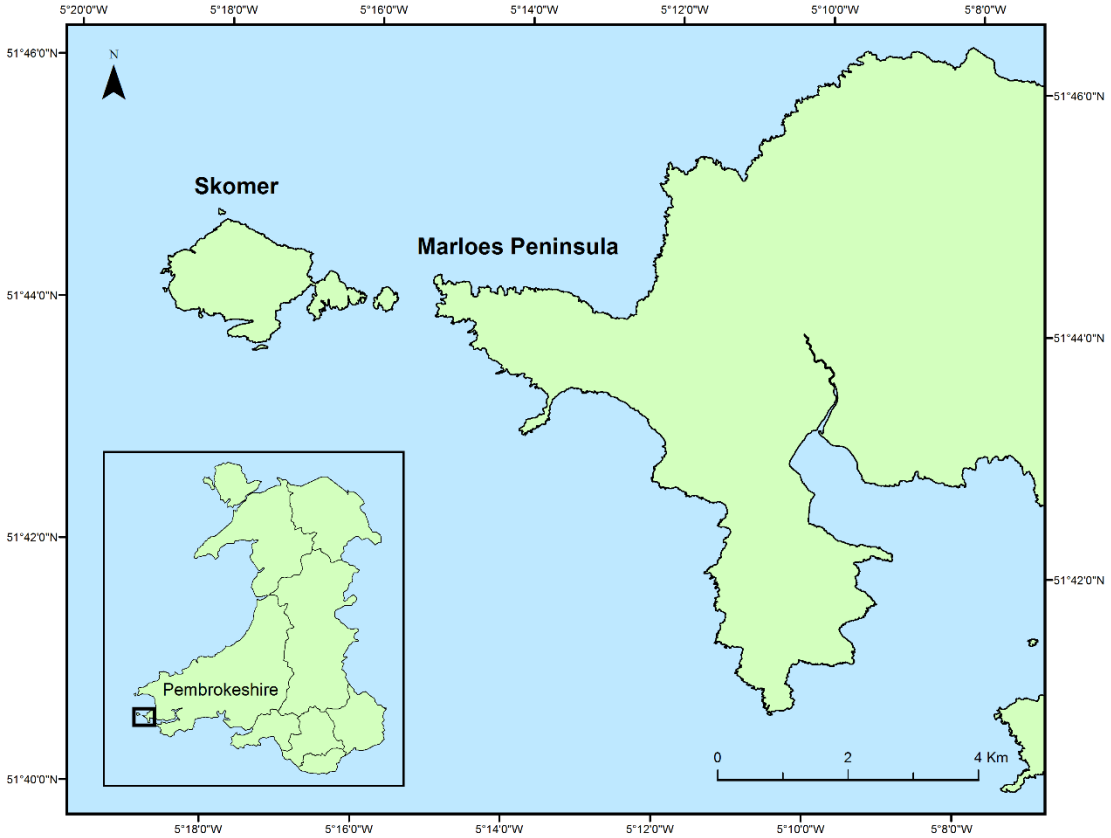

Figure 1. Marloes peninsula within the Skomer Marine Conservation Zone, Southwest Pembrokeshire. (Wales inset).

4.2. Data collection and processing

Each year, trained SMCZ staff carried out regular walking surveys along a predefined route most days during pupping season (typically every 2-3 days from August-January). A standardized protocol and recording sheet was used (Appendix 1). For this report, these paper-based records of seal pup counts were obtained for the period 1993-2013. All recording forms were scanned (pdfs deposited with, and available from NRW) and quantitative details compiled into a spreadsheet. Details included a unique numerical pup identifier, the location (beach name) and date of first observation, the developmental stage (1-5) of the pup (Smith, 1966), date of subsequent observations, and a record of the (often presumed) fate of the pup after weaning. Although pups were not marked, numbers on each beach around the Marloes peninsula were low, allowing individuals to be identified and their development recorded, with high confidence on subsequent days.

4.3. Statistical analysis

Aggregated (annual totals for the whole Marloes peninsula) counts of pup numbers were analysed in this report (Appendix 2, Table A1).

Initially, temporal correlation in the time series was assessed using autocorrelation functions ('acf' and 'pacf' base R functions). For autocorrelation analysis, the pup count time series was natural logarithm-transformed to ensure the variance remained constant through the series (typically, the variance increases with the mean for 'count' data), then first-differenced (y[t] = n[t] – n[t-1]) to remove any overall trend through the series (autocorrelation functions should be applied to data with no overall trend).

To accurately estimate population dynamic parameters such as growth rate, autocorrelation in time series must be accounted for. In addition, autocorrelation may be interpreted as evidence of density dependence (Box & Jenkins, 1976) but with the important caveat that trying to infer ecological processes from statistical patterns is based on association rather than causality – i.e. more than one process can generate statistically indistinguishable patterns (e.g., Berryman & Turchin, 2001).

Subsequently, the population abundance trend was quantified by fitting an exponential growth model (log-linear regression) to the time series of annual pup counts. This was conducted using a Generalised Least Squares approach, incorporating first order autoregressive (AR1) temporal correlation.

Metrics used in phenology analysis were the date of first pup observed and the date of the last pup observation around the Marloes peninsula each year. Non-parametric regression (LOESS) was used to explore the hypothesis that the pupping season duration has extended over time; further quantifying whether this comes about through extension to the start of the season, the end of the season, or both.

All statistical analysis was undertaken using R v3.2.1 (R Core Team, 2015). Generalised Least Squares regression was performed using the 'gls' function in the 'nlme' package.

5. Results and discussion

5.1. Temporal correlation

We initially assessed temporal correlation through autocorrelation analysis, supported by ARIMA (AutoRegressive Integrated Moving Average) modelling. Figure 2 shows a combination of alternating negative and positive time-lagged correlation structure, decreasing in magnitude with increasing time lags (ACF) and a significant negative lag 1 partial autocorrelation (PACF). This is characteristic of a first-order autoregressive process (AR1) with negative temporal correlation (i.e. a given year is negatively correlated with the previous year). This was further assessed by fitting a series of ARIMA models to quantify the underlying processes (Table 1). The AR1 model was the best fitting model (lowest Akaike Information Criterion (AIC), with a difference of >2 representing a substantial improvement in model fit).

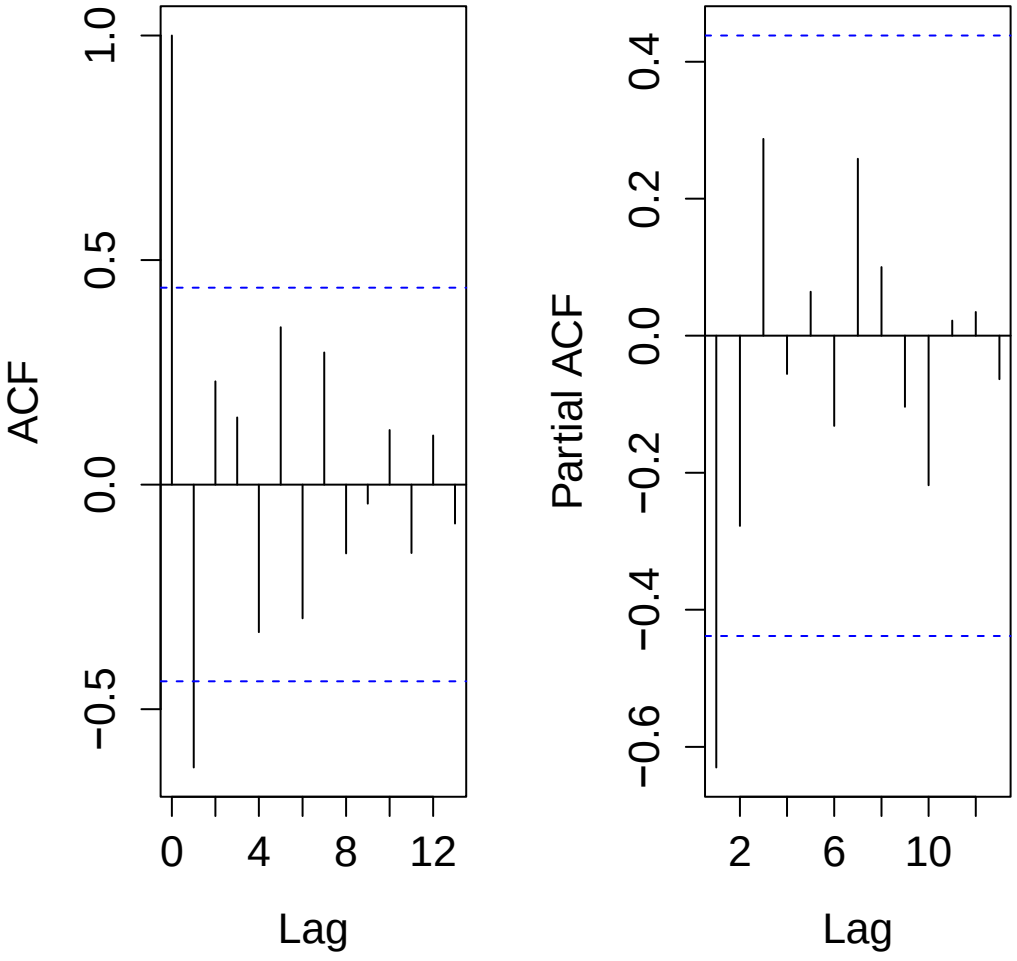

Figure 2. Autocorrelation analysis of annual pup counts from Marloes peninsula. Left-hand panel: autocorrelation function (ACF) fitted to detrended time series. Right-hand panel: the corresponding partial autocorrelation function (PACF). Dashed lines show 95% confidence intervals.

Table 1. ARIMA modelling of annual pup count time series from the Marloes peninsula. p = autoregressive parameter, q = moving average parameter. The best fitting model is shown in bold. Akaike Information Criterion (AIC) is a measure of 'goodness of fit', with the lowest value representing the best model. ΔAIC represents the change in AIC in relation to the best model.

Model	AIC	ΔAIC	p	q
Null (p=0, q=0)	-10.89	2.32	NA	NA
AR1 (p=1, q = 0)	**-13.21**	**0.00**	**-0.438**	**NA**
MA1 (p = 0, q = 1)	-11.46	1.75	NA	-0.266
AR1 MA1 (p = 1, q = 1)	-11.32	1.89	-0.511	0.090

5.2. Population growth

Annual pup counts around the Marloes peninsula show a consistent increase through time (Figure 3, Appendix Table A1). While counts of around 40-46 pups per year were typical in the early years (1990s) of the study, this has risen to over 100 in each of the last four years. Figure 2 shows that an exponential growth model provides a good fit to the data. The fitted gradient parameter from log-linear regression provides a direct estimate for annual growth (in pup counts) of 6.2% (SE = 0.6%, t = 10.1, $p < 0.001$) per year. This is comparable to annual increases around the UK of 6-7% through the 1960s and 1970s (Summer, 1978) and more recent estimates around Orkney and the Hebrides of 6-10% per year between 2010 and 2012 (SCOS, 2014). Elsewhere around the UK, grey seals have been increasing in recent years, with annual population growth rates of between 3% and 15% reported, although there is evidence that many Scottish colonies in particular are now stabilising (Table 2 of SCOS, 2014).

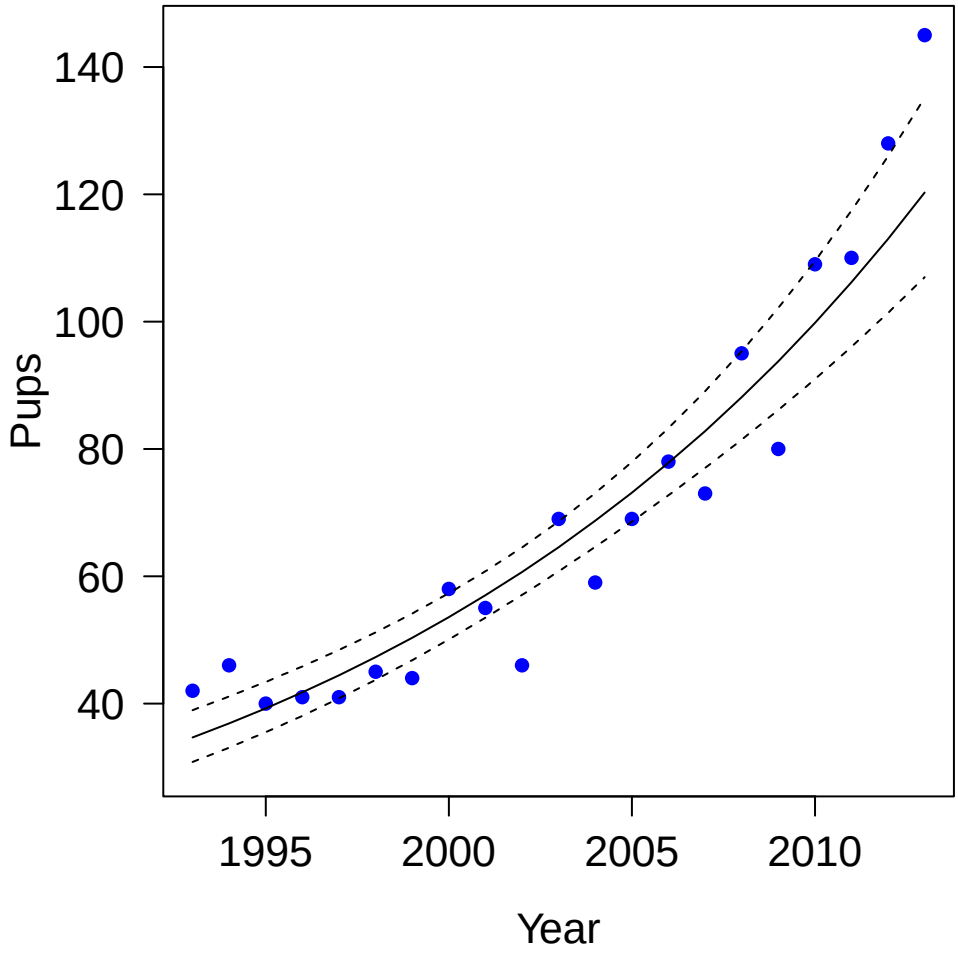

Figure 3 Time series of annual pup counts from the Marloes peninsula (blue dots). Solid line shows fitted exponential growth. Dashed lines show 95% confidence intervals of the fit.

5.3. Phenology

The pupping season typically began in late August or early September at the start of the study period (1990s) (Appendix Table A2). However, there has been a consistent trend towards an earlier start of season (first pup sighting) around the Marloes peninsula, with the season brought forward by two weeks on average in the last twenty years (Figure 4).

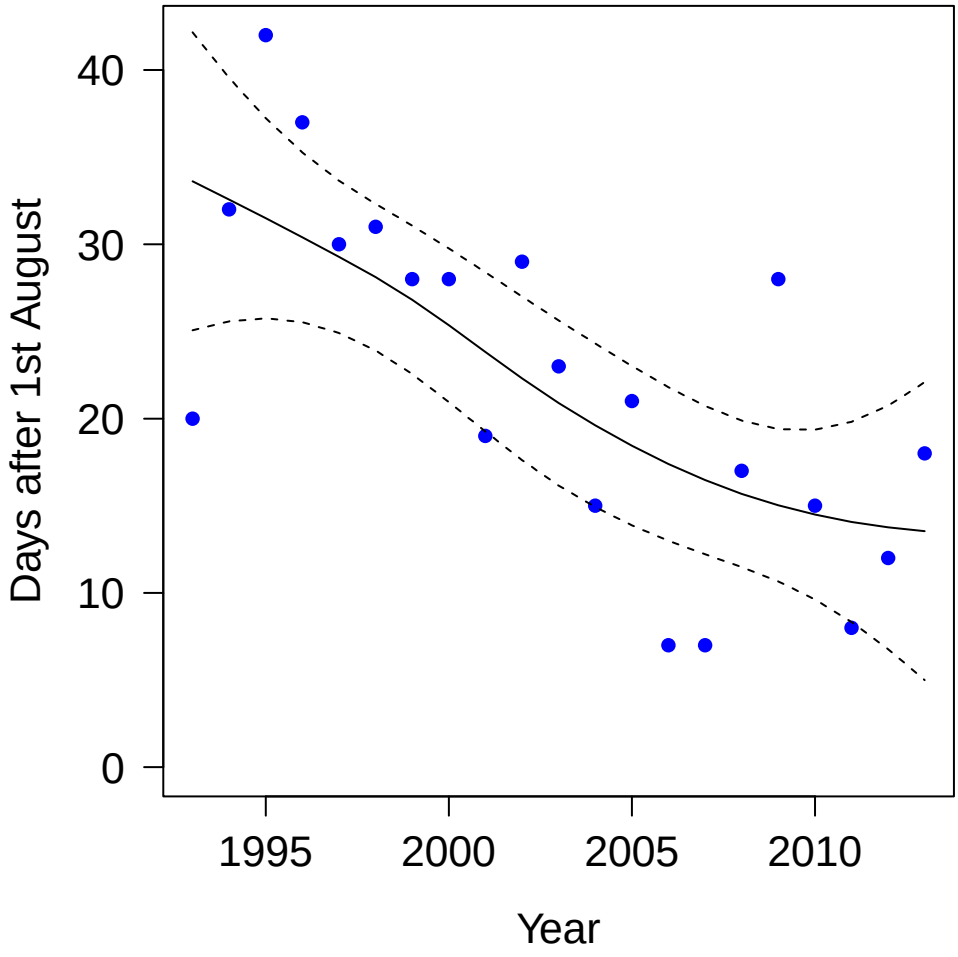

Figure 4. Phenological trends in the start of the grey seal pupping season from the Marloes peninsula, 1993-2013. Blue dots show data points. Solid line shows fitted trend line (using LOESS). Dashed lines show 95% confidence intervals.

There has been considerable variation in the end of the pupping season on the Marloes peninsula (Appendix Table A3), with the last sighting becoming earlier through the initial few years of the study, but substantially later in the latter years (Figure 5). Although the trend is less consistent over the length of the study, the magnitude of variation in the end of the pupping season is considerably larger than the changes in the start of the pupping season. It should be noted that, in contrast to the start of the pupping season, the last sightings of pups are often made more uncertain by winter weather and poor recording conditions, with some final sightings reported by members of the public on an opportunistic basis. Caution should be exercised in interpreting changes to the end of the season.

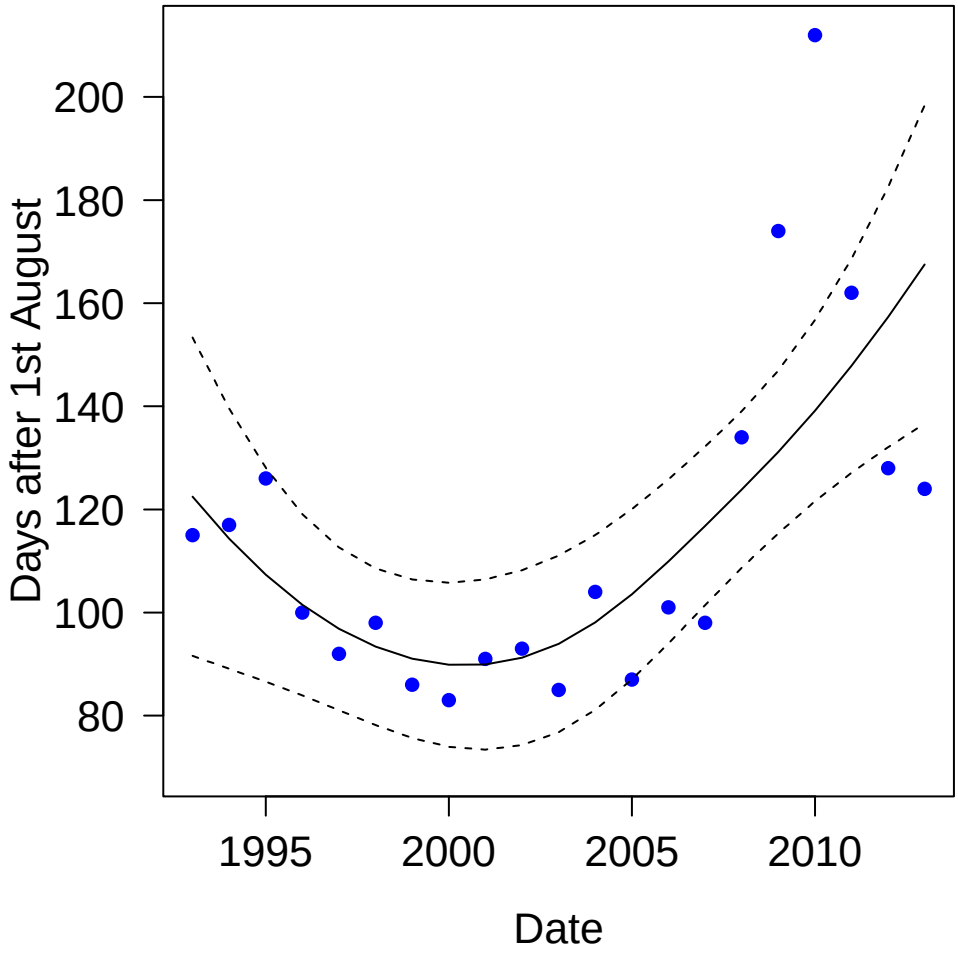

Figure 5. Phenological trends in the end of the grey seal pupping season from the Marloes peninsula, 1993-2013. Blue dots show data points. Solid line shows fitted trend line (using LOESS). Dashed lines show 95% confidence intervals.

Combining start and end dates from this study (Appendix Table A4), it is clear that the variation in the end of the pupping season dominates the changes evident in the overall length of the season (Figure 6). Without a predictive framework, based on identifying and quantifying the intrinsic (e.g., competition) and extrinsic (e.g., climatic) factors driving seal dynamics, it is impossible to state with any confidence how these trends are likely to develop in future.

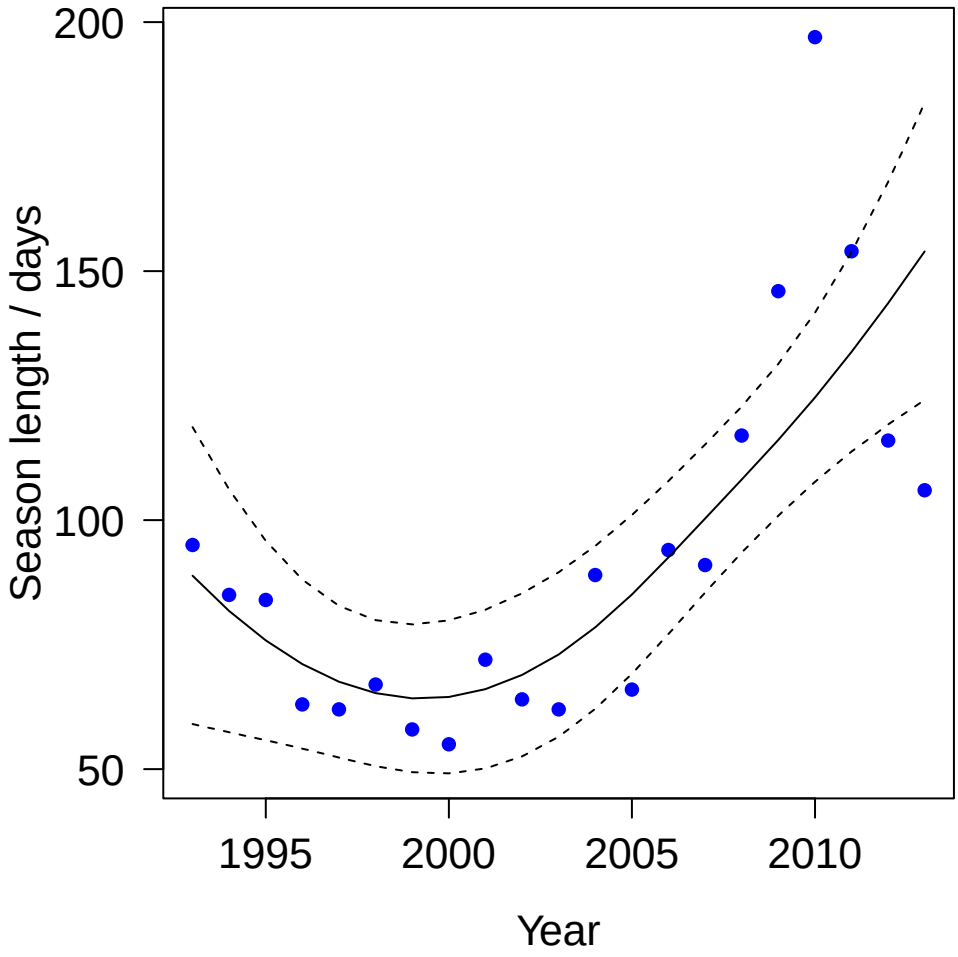

Figure 6. Phenological trends in the length of the grey seal pupping season from the Marloes peninsula, 1993-2013. Blue dots show data points. Solid line shows fitted trend line (using LOESS). Dashed lines show 95% confidence intervals.

However, there has been a sustained and substantial increase in grey seal pup numbers over the last two decades and this coincides with an extension of the length of the pupping season (Figure 7, Kendall's $\tau = 0.49$, $z = 3.09$, $p = 0.002$).

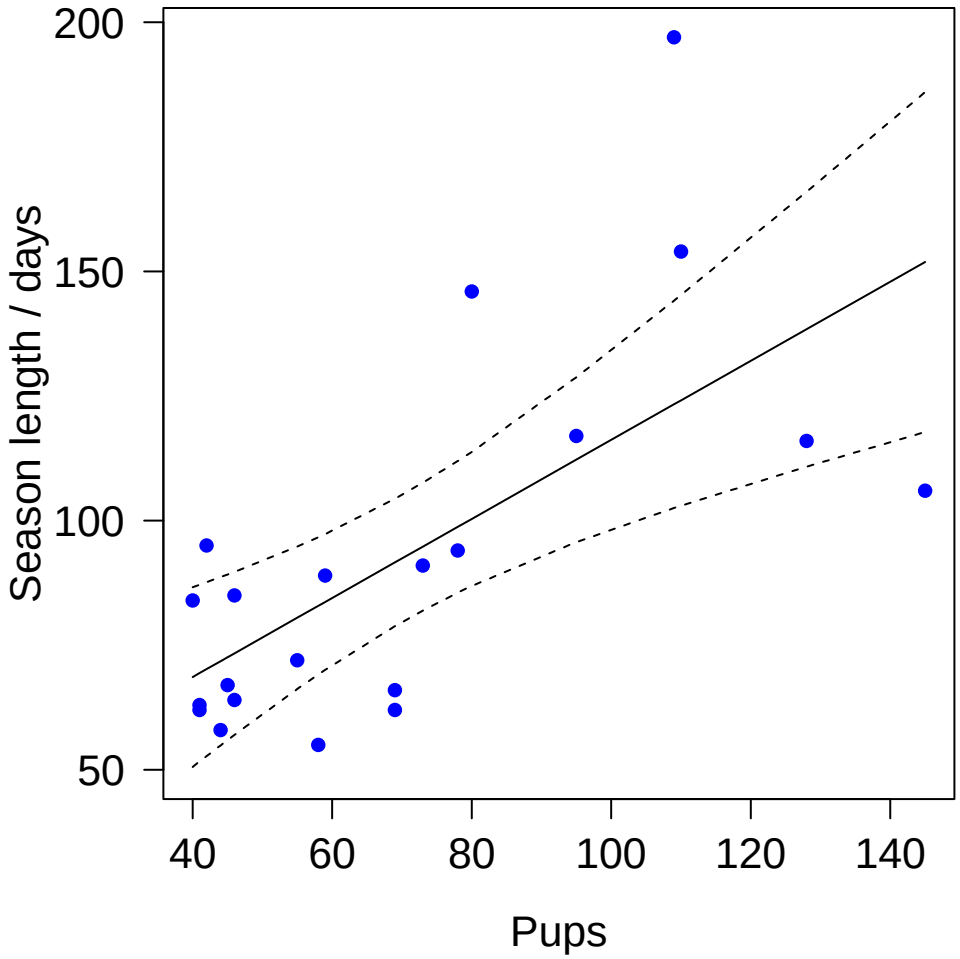

Figure 7. Correlation between annual grey seal pup counts and the length of the pupping season from the Marloes peninsula, 1993-2013. Blue dots show data points. Solid line shows correlation. Dashed lines show 95% confidence intervals.

6. Conclusions and recommendations

The Marloes peninsula, Pembrokeshire, is one of the most intensively surveyed grey seal breeding sites in Wales. Moreover, the consistency of methodology and effort, combined with the continuity of monitoring over many years, makes this area an internationally important study site. This dataset is capturing the rapid expansion of a population that, currently, shows no signs of slowing from its growth rate of over 6% per annum. As the local grey seal population grows, its ecological importance will also increase, making it essential to consider these changes in any management strategy. To move from quantifying observed patterns to understanding ecological processes, with a view to informing evidence-based management, it is crucially important to:

- Relate pup counts to appropriate environmental (e.g., climatic) factors, to identify abiotic drivers.

- Continue current seal pup monitoring at least until the Marloes population reaches a stable equilibrium level, to quantify intrinsic biotic drivers (e.g., density dependence underpinned by intraspecific competition). The rate at which population growth approaches equilibrium is a key component in the construction of a predictive framework for population dynamics.

- Combine pup data from the Marloes peninsula with equivalent data from other major grey seal breeding colonies in Wales (e.g., Skomer and Ramsey in Pembrokeshire, as well as other breeding colonies in North Wales, such as Bardsey).

- Integrate pup counts within a wider programme of adult seal censuses, to develop a full understanding of grey seal life history and local population viability.

- Develop techniques (e.g., using photo ID and tagging) to quantify movement between seal colonies, to assess spatial population turnover and regional population viability (metapopulation dynamics).

Encouragingly, many of these elements are already in place around Wales, thanks to long-term ecological monitoring carried out by NRW (and its predecessors) and collaborators. This study improves the understanding of this iconic species, which underpins NRW's evidence-based advice.

7. Acknowledgements

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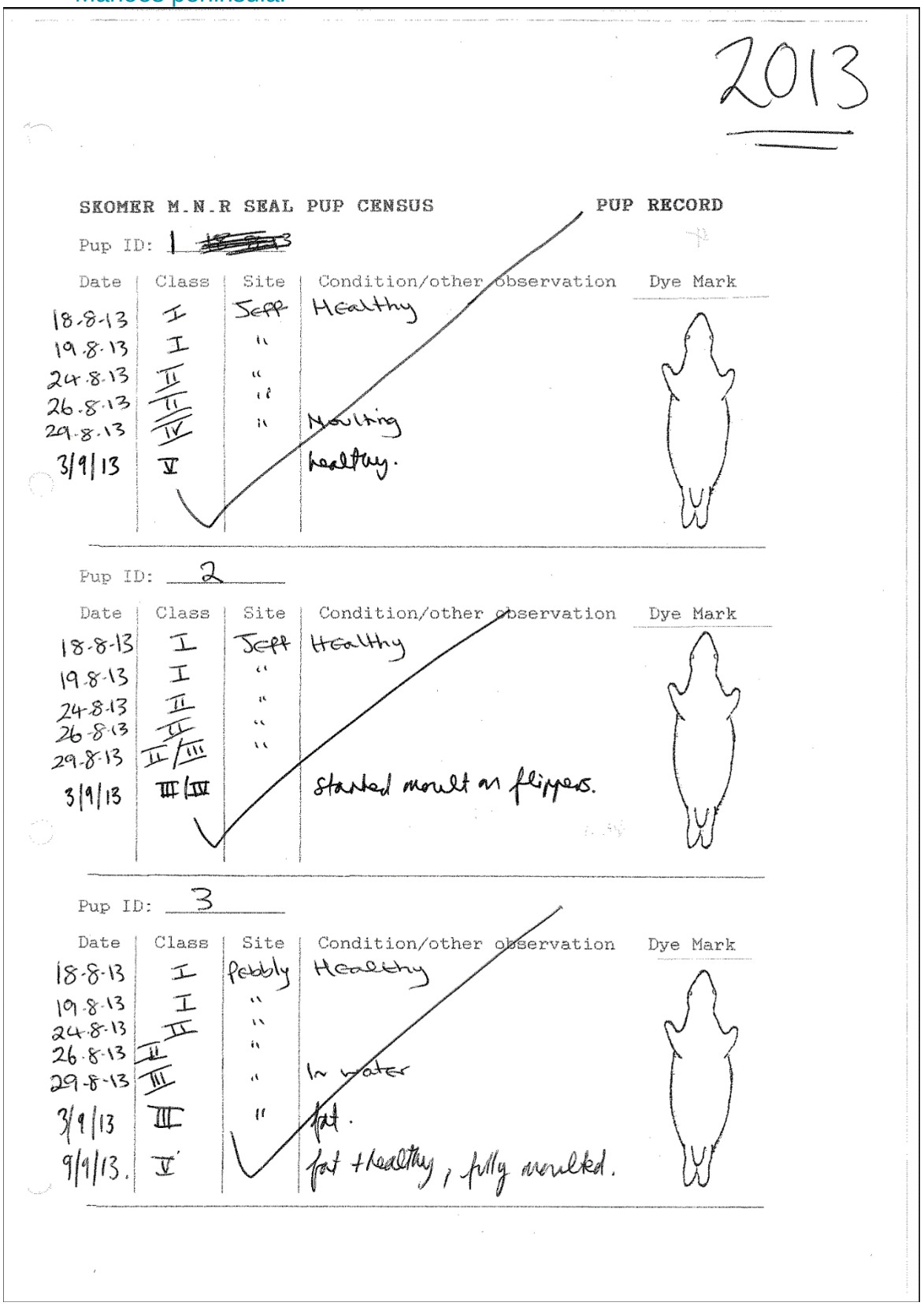
9. Appendices

9.1. Appendix 1 – Example recording form used in grey seal monitoring around Marloes peninsula.



2013

SKOMER M.N.R SEAL PUP CENSUS — PUP RECORD

Pup ID: 1

Date	Class	Site	Condition/other observation	Dye Mark
18-8-13	I	Jeff	Healthy	
19-8-13	I	"		
24-8-13	II	"		
26-8-13	II	"		
29-8-13	IV	"	Moulting	
3/9/13	V		healthy.	

Pup ID: 2

Date	Class	Site	Condition/other observation	Dye Mark
18-8-13	I	Jeff	Healthy	
19-8-13	I	"		
24-8-13	II	"		
26-8-13	II	"		
29-8-13	II/III	"		
3/9/13	III/IV		started moult on flippers.	

Pup ID: 3

Date	Class	Site	Condition/other observation	Dye Mark
18-8-13	I	Pebbly	Healthy	
19-8-13	I	"		
24-8-13	II	"		
26-8-13	II	"		
29-8-13	III	"	In water	
3/9/13	III	"	fat.	
9/9/13.	IV		fat + healthy, fully moulted.	

9.2. Appendix 2 – Raw data used in this report

Table A1. Annual grey seal pup counts from the Marloes peninsula, 1993-2013.

Year	Count	Year	Count	Year	Count
1993	42	2000	58	2007	73
1994	46	2001	55	2008	95
1995	40	2002	46	2009	80
1996	41	2003	69	2010	109
1997	41	2004	59	2011	110
1998	45	2005	69	2012	128
1999	44	2006	78	2013	145

Table A2. Date of first grey seal pup sighting from the Marloes peninsula, 1993-2013.

Year	Date	Year	Date	Year	Date
1993	20-Aug	2000	28-Aug	2007	07-Aug
1994	01-Sep	2001	19-Aug	2008	17-Aug
1995	11-Sep	2002	29-Aug	2009	28-Aug
1996	06-Sep	2003	23-Aug	2010	15-Aug
1997	30-Aug	2004	15-Aug	2011	08-Aug
1998	31-Aug	2005	21-Aug	2012	12-Aug
1999	29-Aug	2006	07-Aug	2013	18-Aug

Table A3. Date of last pup sighting from the Marloes peninsula, 1993-2013. Where dates are January or February, these refer to the following year.

Year	Date	Year	Date	Year	Date
1993	23-Nov	2000	22-Oct	2007	06-Nov
1994	25-Nov	2001	30-Oct	2008	12-Dec
1995	04-Dec	2002	01-Nov	2009	21-Jan
1996	08-Nov	2003	24-Oct	2010	28-Feb
1997	31-Oct	2004	12-Nov	2011	09-Jan
1998	06-Nov	2005	26-Oct	2012	06-Dec
1999	25-Oct	2006	09-Nov	2013	02-Dec

Table A4. Length of the grey seal pupping season at the Marloes peninsula.

Year	Days	Year	Days	Year	Days
1993	95	2000	55	2007	91
1994	85	2001	72	2008	117
1995	84	2002	64	2009	146
1996	63	2003	62	2010	197
1997	62	2004	89	2011	154
1998	67	2005	66	2012	116
1999	58	2006	94	2013	106

10. Data Archive Appendix

Data outputs associated with this project are archived at Project 478, media 1555 on server–based storage at Natural Resources Wales.

The data archive contains:

The final report in Microsoft Word and Adobe PDF formats.

A spreadsheet named Marloes Peninsula census data.xlsx in Microsoft Excel format

An R software statistical analysis script called phenology basic analysis marloes.R

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue http://libcat.naturalresources.wales/webview/ (English Version) and http://libcat.naturalresources.wales/cnc/ (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record no 119129

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