Marine Mammal Scientific Support Research Programme MMSS/002/15

Harbour Seal Decline HSD2

Annual Report

Harbour seal decline – vital rates and drivers

Sea Mammal Research Unit
Report to
Marine Scotland, Scottish Government

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V3

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Executive summary

Numbers of harbour seals (*Phoca vitulina*) have dramatically declined in several regions of the north and east of Scotland, while numbers have remained stable or have increased in regions on the west coast. For any management and mitigation plans to address this situation, the relative contribution of various factors in the decline of harbour seals in Scotland needs to be identified, understood and assessed. Potential drivers of the decline include changes in prey quality and/or availability, increasing grey seal population size which may be influencing harbour seal populations through direct predation or competition for prey resources, and the occurrence and exposure of seals to toxins from harmful algae (domoic acid and saxitoxins).

Population model

Work continued to develop an integrated harbour seal population model. The model-fitting process was built upon, using a decision-support simulation tool to fit an age-structured population model to harbour seal count data, investigating the effect of 'reducing' the data by only including moult counts (excluding pup counts) and thinning the number of available data points. A visualisation tool was developed to support discussions about the relative impacts of effects that might be important during the different phases of harbour seal life-history. Based on simulated data, a number of scenarios were explored in which additional mortality, fecundity, and adult and pup survival were allowed to vary within plausible limits. The resulting effect on the predicted (simulated) population growth was visualised by means of a surface plot.

Photo-identification mark-recapture to estimate fecundity and survival

Photo-identification data were collected at selected harbour seal haulout sites in Orkney, Kintyre and Loch Dunvegan (Isle of Skye) during the pupping season in 2016 and 2017, primarily during the months of June and July. All photographs were graded for quality and individual seals identified from the unique patterns in their pelage. Photo-identification data collected in 2017 is currently being processed. For 2016, a summary of all catalogued seals by area with details on approximate age class and reproductive history has been made. Loch Dunvegan produced the highest number of catalogued seals. One of the monitored haulout sites in Kintyre was male-dominated, while mum-pup pairs were found in other sites.

Live capture-release studies

Live capture-release studies were conducted in Isle of Skye in March and Orkney in April and May 2017 in accordance with the SMRU Animal (Scientific Procedures) Act, 1986, (Home Office Licence No. 192CBD9F). Adult and juvenile harbour seals were captured, individual covariate data were collected from each seal, and telemetry tags (GSM/GPS and LO tags) were deployed primarily on adult females. Pregnancy status was determined from progesterone concentrations in the plasma and in blubber. The proportion of the live-captured adult females that were pregnant was 100% (95% CI 95% - 100%) in Isle of Skye and 67% (95% CI 39% - 95%) in Orkney, but the proportions were not statistically significantly different. Given the small sample size, further investigations must be carried out before any conclusions can be drawn. Domoic acid concentrations in the urine and faecal samples collected from the live capture-release animals were determined. Domoic acid concentrations were lognormally distributed, with some individuals having very high levels but in most animals concentrations were low. There was no difference in the median concentrations by region, with the Skye animals also being exposed to domoic acid.

Prey samples

Two fishing trips to collect prey samples were undertaken in July and November 2017 in the waters of Scapa Flow. Additionally, opportunistic fish samples were collected in North Ronaldsay. All fish viscera were analysed for domoic acid content, using the same method as for the seal samples. All samples were above the limit of detection, with the bullrout, and mackerel caught in the summer showing the highest concentrations. Fish guts sampled in Orkney in July 2017 and in Sinclair Bay (Caithness) in June 2017 were analysed for PSP toxins, but none of the samples contained any detectable level of saxitoxin.

Counts of harbour seals during the moult

Aerial surveys of harbour seals numbers hauled out during the moult were conducted in the study sites of Kintyre, Scapa Flow (Orkney) and Loch Dunvegan (Isle of Skye) in August 2015, 2016 and 2017, respectively, as part of the annual surveys conducted by SMRU (funded by Scottish Natural Heritage (SNH) and Natural Environment Research Council (NERC)). Results on the number of harbour and grey seals counted within the defined study areas are presented.

Stranded seals

A summary of all seal carcasses reported to Scottish Marine Animal Stranding Scheme (SMASS) within and nearby the study sites between March 2017 and February 2018 is provided, with details on species, age class and proximate cause of death when available.

Contents

1 Introduction

The UK has around 30% of Europe's harbour seals (*Phoca vitulina*), with Scotland having approximately 79% of the UK harbour seal population. The majority are distributed around the west coast and throughout the Inner and Outer Hebrides and Northern Isles. On the east coast, their distribution is more restricted with the main concentration now being in the Moray Firth (SCOS, 2017).

Harbour seals are listed under Annex II of the EU Habitats Directive, requiring specific areas to be designated as Special Areas of Conservation (SACs) for their protection. In Scotland, eight SACs have been designated specifically for harbour seals, with one additional site where harbour seals are a 'feature of qualifying interest'. In addition, it is an offence to intentionally or recklessly harass seals at any of the 194 haul-out sites that have been designated around the Scottish coast, of which 62 are used mainly by harbour seals and 67 shared by harbour and grey seals.

The Sea Mammal Research Unit (SMRU) has been conducting surveys to monitor the populations of harbour seals on an approximately five-year cycle since the late 1980s. These surveys detected a decline in Scottish harbour seals in the early 2000s (Lonergan *et al.*, 2007), which has continued in some of the surveyed regions. The decline is more apparent for the east and north coasts of Scotland and in the Northern Isles, with declines of around 52% along the east coast of Scotland, 85% in Orkney and 30% in Shetland (although the latter increased by 10% between 2009 and 2015), compared to counts in 2000. In contrast, populations on the west coast and in the Western Isles are either stable or increasing (SCOS, 2017). More importantly, the decline in seal counts represents real reductions in the numbers present in those regions rather than being a consequence of changes in seal behaviour (e.g. changes in the proportion of time seals spend onshore during the moult) (Lonergan *et al.*, 2013).

In order to determine the management and mitigation options to address this situation, the relative contribution of various factors potentially involved in the dramatic decline needs to be identified, understood and assessed. Potential drivers include changes in prey quality and/or availability, increasing grey seal population size which may be influencing harbour seal populations through direct predation or competition for resources, and the occurrence and exposure of seals to toxins from harmful algae. Irrespective of the factor or factors driving the decline, changes observed at the population level must originate from changes in vital rates (i.e. survival and fecundity rates). Consequently, it is fundamental to obtain information on such life history parameters from long-term studies (e.g. Bowen *et al.*, 2003) in regions with contrasting seal population trajectories (declining compared to stable or increasing populations). At present, life history information for harbour seals in Scotland is available only from Loch Fleet and the Moray Firth (Mackey *et al.*, 2008; Cordes and Thompson, 2013), but is completely lacking for other regions in Scotland. Survival and fecundity rates can be estimated from photographic capture histories of harbour seals, individually identified from their distinct and unique pelage patterns. Recognising differences in such population parameters and their drivers between regions of contrasting population trajectories will allow the determination of how and where the potentially important factors are acting.

In complex ecosystems, populations may experience pressure from multiple causes (e.g. food shortage, predation, toxin exposure and anthropogenic mortality). However, it is often difficult to estimate the likely impacts of stressors even where these are known to be at work in a population (e.g. observations of biotoxin exposure in individual animals, observations of carcasses showing signs of trauma). Causes of mortality or poor condition may impact different parts of the population in different ways (e.g. young or pregnant animals might be especially vulnerable to nutritional stress). Also, for long-lived animals such as harbour seals, considerable time lags may also be seen between cause and consequence in terms of population numbers. Consequently, the outcomes of combined effects at the level of population abundance may be difficult to predict intuitively. However, a structured population model allows for the explicit modelling of such impacts, integrating the effects of stressors that may be acting in combination, and allowing for the prediction of longer-term, population-level outcomes.

Matthiopoulos *et al.* (2014) developed and fitted an age-structured population model to data from the well-studied sub-population of harbour seals in Loch Fleet (Moray Firth) to evaluate the contributions of different proximate causes to the observed decline. Further work by Caillat and Smout (2015) saw improvements to this baseline model, including an improved treatment of seasonal haulout probabilities, to produce a more realistic and robust version. This will be the baseline model for the current task HSD2 under the Marine Mammal Scientific Support Research Programme MMSS/02/15.

Harbour Seal Decline: HSD2

A summary of the work carried out by the SMRU under the Marine Mammal Scientific Support Research Programme MMSS/02/15 during the year April 2017 to March 2018 for the task HSD 2 *Harbour seal decline – vital rates and drivers* under the theme Harbour Seal Decline is presented here.

This task has five main objectives:

- an improved understanding of the population dynamics of harbour seals;
- new estimates of harbour seal vital rates;
- an improved understanding of spatial overlap between grey and harbour seals;
- an improved understanding of the main (potential) extrinsic factors driving survival and reproduction and therefore population change;
- an improved understanding of the effects of predation by grey seals.

It comprises six 'approaches' entitled:

1. integrated population model;
2. investigate harbour seal vital rates and movements using capture-mark-recapture and telemetry;
3. live capture-release at the photo-ID study sites;
4. counts of harbour and grey seals at and adjacent to the study sites from air surveys;
5. improving understanding of potential drivers of population change;
6. carcass collection.

The deliverables for Year 3 under each approach are detailed in Appendix 1.

2 Approach 1. Integrated population model

2.1 Model fitting

In Year three of the project, work continued to build on the model-fitting process, using a decision-support simulation tool (DST) and investigating the effect of 'reducing' the data (see Arso Civil *et al.*, 2016). The population trajectory for harbour seals was estimated from simulated datasets which include both moult and pup counts for a number of years and where the population declines at a given point in time. The model performed well when only moult counts are available (Figure 1). This is important as pup counts will not be available for the study sites. Satisfactory performance of the model-fitting module was also achieved when some years were removed from the data, leaving intermittent moult counts similar to the true observational data set (Matthiopoulous *et al.*, 2014).

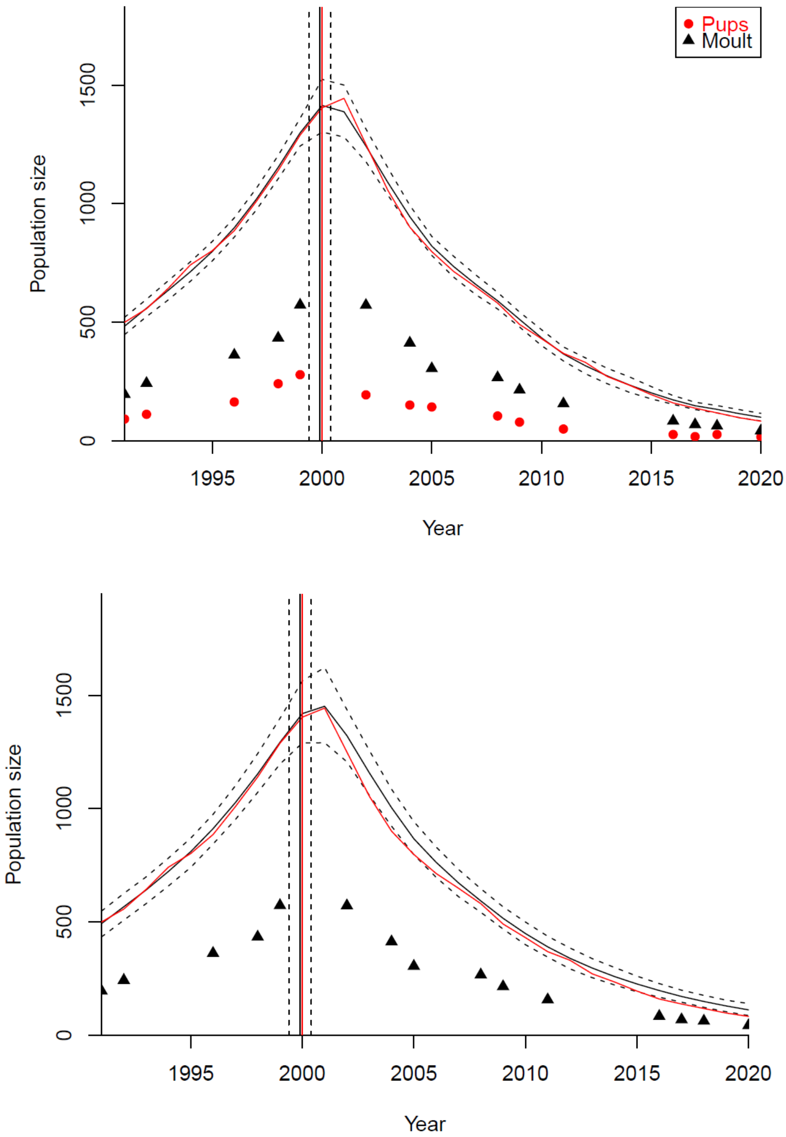

Figure 1. Population model showing estimated abundance and population trajectory (black lines) based on simulated (top) pup and moult counts and (bottom) moult counts only. Vertical black line = estimated change-point year when the population peaked in abundance, smoothed black line = estimated population trajectory, black dotted lines = uncertainty. The red smoothed line and the red vertical line are the true simulated population trajectory.

In the model-fitting code, temporal changes in model parameters were originally represented using a step-function (i.e. as an instantaneous change), with the model-fitting then estimating the year in which the change had occurred. In practice, this caused some technical problems with the convergence of the model-fitting, as there was rather poor mixing of the Markov chain for this parameter in some instances. The model was modified so that the step-change was replaced by a more gradual function. For the quantity 'additional mortality' m where a general increase in mortality was applied across all age classes, a scaled logistic curve was used with asymptotic level M, centre Y and spread w.

$$m = \frac{Me^{w(t-Y)}}{1 + e^{w(t-Y)}}$$

The shape of this function is illustrated in Figure 2.

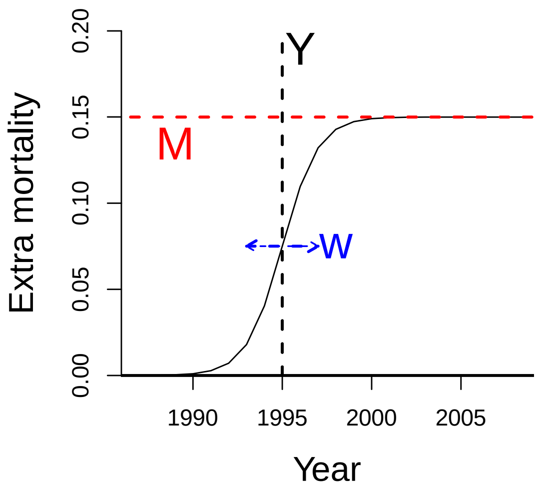

Figure 2. Smooth change in vital rate with time: the parameter representing additional mortality is estimated to change smoothly over time. The figure illustrates changes in this quantity given parameter values M=0.15, w=1 and Y=1995.

The implementation of the gradual change in mortality resulted in improved model fitting performance with good mixing of the Markov chain for parameters Y, w and M (see Figure 2 legend). Exploration of the ability of the model to capture the change-point year using the sparse data for the Orkney study region (Scapa Flow) showed that it was able to estimate this with reasonable uncertainty (vertical line in the plot shows the estimated change point year and the dotted lines show the 95% credible interval) (Figure 3).

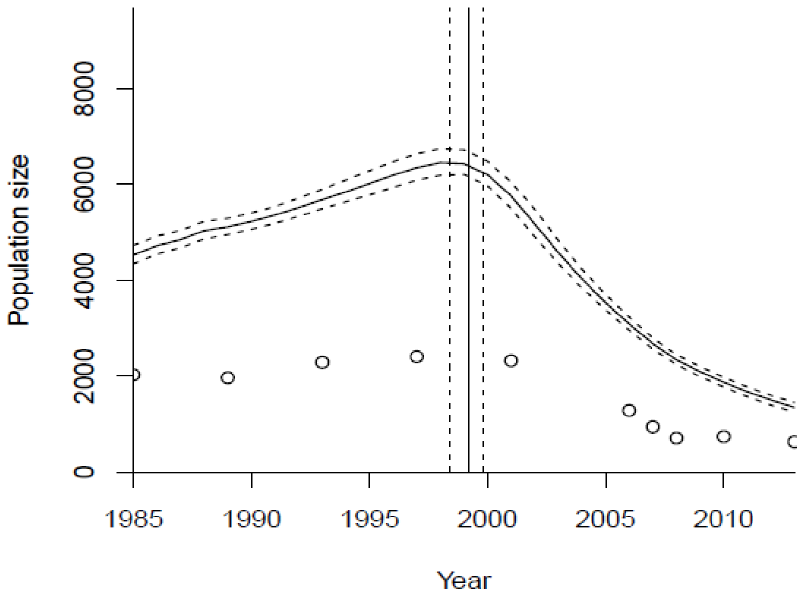

Figure 3. Time series of Scapa Flow surveys, estimated population size, and estimated 'Change year' in which mortality rate was estimated to have been changing most rapidly. The estimation was based on an age-structured population model fitted to the survey data, with changing mortality modelled as a scaled logistic function. Mortality was assumed to change across the full age range here, and the magnitude of this change was estimated at 0.15. Vertical line = change-point year when the population peaked in abundance, smoothed line = population trajectory, dotted lines = uncertainty.

The following scenario investigations are presented in order to demonstrate some of the capabilities of the modelling and decision-support simulation tool work. This approach offers a way to test competing theories concerning the combined effects of different stressors on harbour seal populations. **However at this stage of model development, results should not be interpreted as conclusive or diagnostic of causes of decline.**

To illustrate the approach, the modelling only focussed on the Scapa Flow (Orkney) site, though similar analyses can readily be performed for the other sites. A simple age-structured model was fitted to the Scapa Flow data set of population counts using Bayesian methodology implemented in JAGS (Plummer, 2003). The number of ecological processes included in the model was deliberately kept minimal because the data set available for fitting the model was restricted (e.g. surveys were not carried out in all years).

The model makes the following assumptions.

- The harbour seal population in Scapa Flow can be represented as a closed, age-structured population in which there are specific mortality rates for males aged 1 and older, females aged 1 and older, and pups.
- Within these categories, individuals are identical. The population is perfectly mixed.
- Females breed annually and only give birth to one pup. Fecundity is fixed throughout the time period of the study.
- Half of births are male, half are female.
- An additional source of mortality (AM) starts to impact the population in one specific year during the time period of the study, and then continues. This source of mortality removes a proportion of animals of all ages.

The ‘best estimate’ values of parameters (Table 1) were then used to code a baseline simulation model which could reproduce the behaviour of the population either before or after the change-point year (see Appendix 2).

Table 1. Parameter values here were estimated by fitting the baseline model to the Scapa Flow count data. Survival and fecundity rates are probabilities per animal per year. The change-point year was estimated as 2001.

Parameter	**Mean estimated value**
Pup survival	0.24
Male survival (animals aged 1 and older)	0.86
Female survival (animals aged 1 and older)	0.95
Additional mortality rate after the change-point year	0.15
Fecundity rate (fixed in the model)	0.90

A surface of resulting population growth values was plotted across combinations of two demographic rates which were allowed to vary, e.g. fecundity could vary in the y direction and adult female survival in the x direction. The rate of population growth is shown using a colour scale, and a curve added to separate the area on the plot for which the population is growing from the zone over which the population would be expected to decline. This is one way in which changes in more than one driver of population decline can be compared and contrasted, in terms of their ultimate impact on population growth.

At present, this has been implemented using a simple population model without population density dependence, and this is likely to be an acceptable simplification where population levels are low. If this tool is deemed useful, it could be further developed to include the effects of any possible density dependence.

Using the baseline model parameters set (Table 1), different variations of the model were explored in turn. For every pair of parameter values, each was varied, and pairwise combinations were used to project the population forward over 10 years. The average population growth rate ‘r’ was then calculated (e.g. r=1 is a constant population, 1.06 is a population that grows by 6% per year, and values of r<1 represent populations in decline).

The variations explored were:

1. Additional mortality AM and fecundity were allowed to vary within plausible limits.
2. Fecundity and Adult Female survival were varied between plausible limits with (a) AM set to 0.00 (b) AM set to 0.15.
3. Fecundity and pup survival were varied between plausible limits with (a) AM set to 0.00 (b) AM set to 0.15.

The effects of adult male survival were not investigated because vital rates for this part of the population are less well constrained by data, and the number of males has a relatively small effect on the productivity of the population (i.e. the birth-rate).

2.2 Results

The plots represent the results of many simulation runs. The surface colours represent the annual population growth rate from the simulation, given parameter values corresponding to those shown on the horizontal and vertical axes of the surface plots. Note that the colour scaling is unique to each plotted scenario, as described by the legend associated to each of the sub-figures in Figures 4 to 7. All other parameters were set as given in Table 1. The black contours link pairs of values for parameters for which the population growth rate is 1, i.e. the population is constant. On each of the plots, if this contour is shown, it separates an area in which the population is declining from one in which the population can increase. To the right of this contour, the population is declining. To the left, the population can increase If no contour is shown then the whole area of the plot corresponds to parameter values that suggest either a decrease or an increase in population size.

In Scenario 1, both AM (additional mortality) and fecundity vary. Population growth could occur when levels of AM were sufficiently low and fecundity was sufficiently high. At the levels of AM estimated by the model fit (0.15) no plausible increase in fecundity would allow this population to recover (Figure 4).

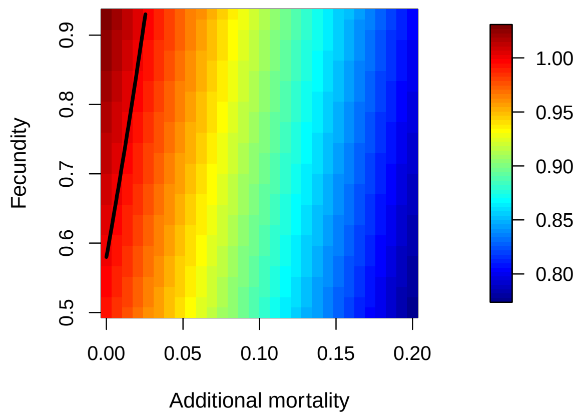

Figure 4. Scenario 1: AM (additional mortality) and fecundity vary.

In Scenario 2, fecundity and adult female survival can vary, with AM set to 0.00 or 0.15. At the levels of additional mortality AM estimated by the fitted model, the population would not recover even if rates of fecundity and background female survival were simultaneously very high (right panel in Figure 5).

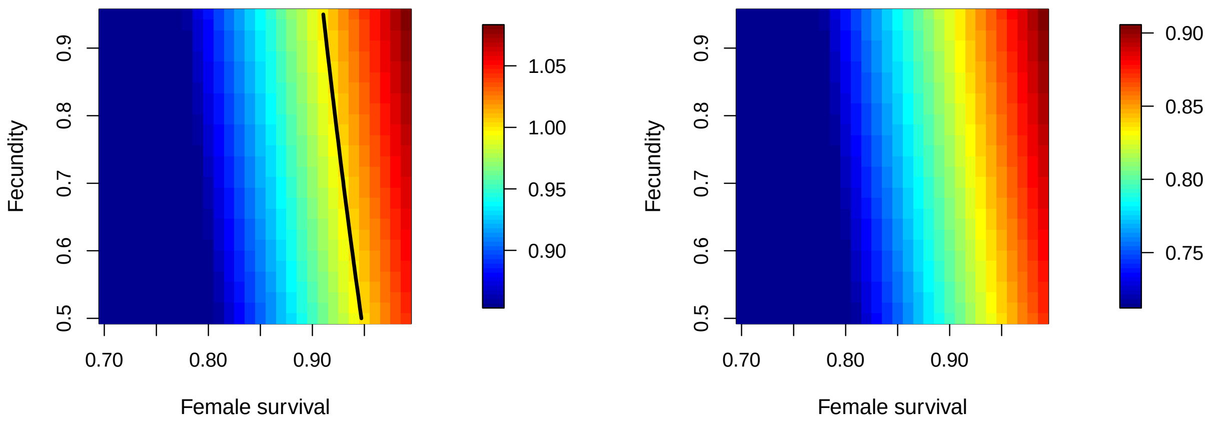

Figure 5. Scenario 2: Fecundity and adult female survival vary with AM set to 0.00 (left panel) or set to 0.15 (right panel).

In Scenario 3, fecundity and pup survival vary with AM set to 0.00 or 0.15. At the levels of additional mortality AM estimated by the fitted model for the later years of the study, the population would not recover even if rates of fecundity and background pup survival were simultaneously very high (Figure 6). These two parameters which contribute to the net recruitment of individuals to the breeding population seem to trade off against one another in terms of population growth e.g. high pup survival rates appear to somewhat offset the consequences of low fecundity.

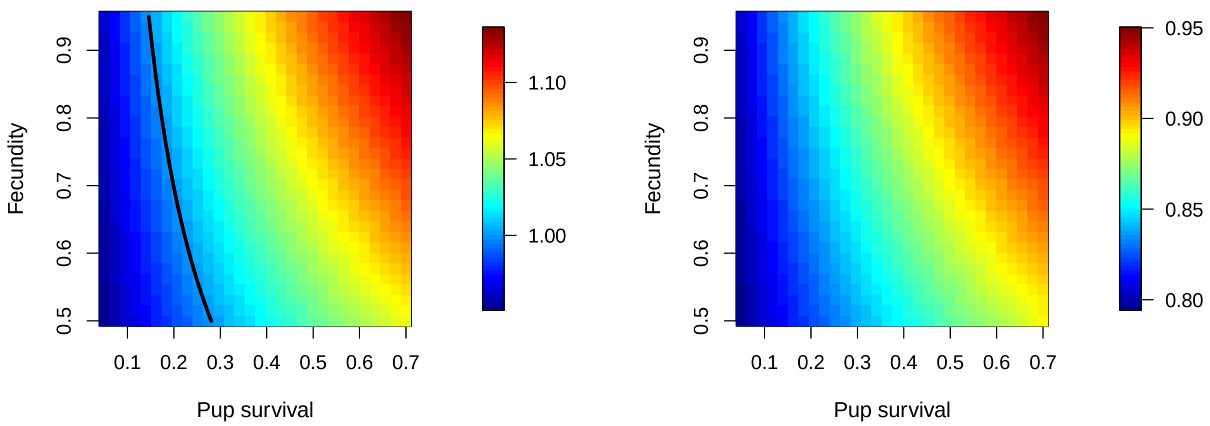

Figure 6. Scenario 3: Fecundity and pup survival vary with AM set to 0.00 (left panel) or set to 0.15 (right panel).

In Scenario 4, female and pup survival vary with AM set to 0.00 or 0.15. When female and pup survival were allowed to vary, population growth was feasible under no AM, but possible with high AM only if survival rates for both age classes were very high (Figure 7). It is unlikely however that pup survival would take such high values.

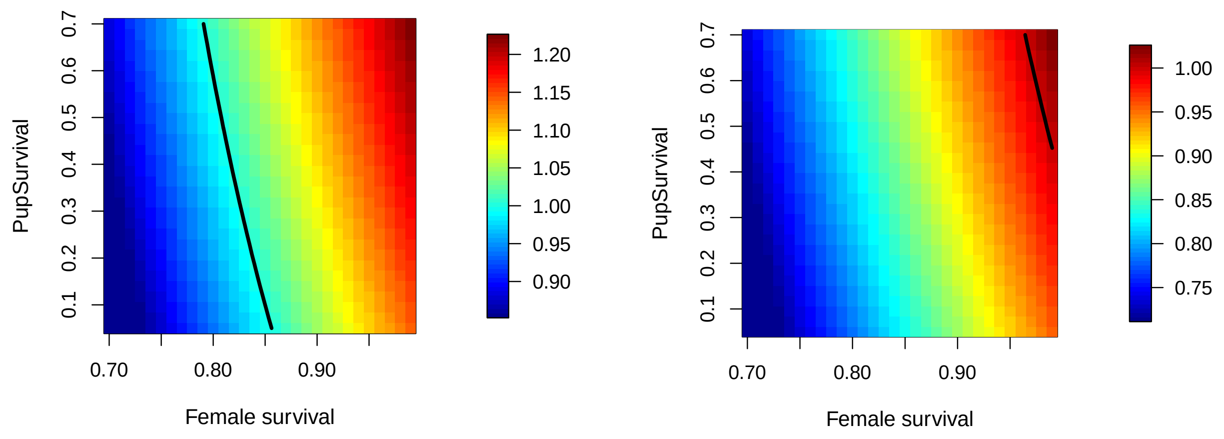

Figure 7. Scenario 4: Female and pup survival vary with AM set to 0.00 (left panel) or set to 0.15 (right panel).

2.3 Discussion

The scenario testing suggested that the modelled population is strongly influenced by adult mortality: if this is set at the estimated level of 0.15, there are few scenarios under which this population could recover and these require very high (probably unrealistic) natural survival rates for adults and pups. Population growth predicted by this model is particularly sensitive to adult female survival and is less sensitive to changes in fecundity or pup survival.

The baseline model is considerably simplified. Scenario testing allows its parameters (such as survival rates) to be varied, but does not easily incorporate ecological effects such as temporal change in fecundity, or density dependence in fecundity or survival. It may therefore be appropriate to fit a model in which such changes can occur, in addition to changes in mortality.

The additional mortality term in the baseline model represents a per capita rate i.e. the model currently assumes that the number of harbour seals lost is directly proportional to the number in the population. If predation by grey seals (Brownlow *et al.*, 2016) and/or by killer whales (Bolt *et al.*, 2009) were responsible for such additional mortality, then the relationship between numbers lost and harbour seal population size might be non-linear. Such non-linearities might come about if (i) the predators become satiated by limited capacity to digest or process food (Gentelman *et al.*, 2003) (ii) they show an aggregative response which attracts them in larger numbers to rich feeding grounds with abundant harbour seal pups (Suryawanshi *et al.*, 2017) (iii) if the individual predators show a change in preference as prey becomes more abundant (Smout *et al.*, 2010). While it is plausible that predation with these characteristics might inhibit the recovery of a seal population that has been depleted by some other process (Sinclair *et al.*, 1998) it is not so clear how such predation could give rise to the apparent step-change in population growth that occurred around the year 2001. Such a change would seem to require a stepwise increase in predator numbers, or a sudden change in predator behaviour, occurring at this time. Before 2000, 15% of the Scapa Flow population would have been approximately 900 animals per year. If the removals are postulated to be by killer whales, then this is somewhat more than the estimated pup consumption suggested by Bolt *et al.* (2009) for the Shetland area based on bioenergetic modelling, so it seems difficult to accept that killer whale predation alone could have imposed the change in harbour seal population trend. At current population levels, adult mortality of 15% would correspond with about 225 individuals being removed from the Scapa Flow population which is well below Bolt *et al.* (2009) estimates of harbour seals removed from the neighbouring Shetland area by killer whales and so is perhaps more plausible than the estimate of Bolt *et al.* (2009). However, the model currently allocates mortality in the same way to adults and pups, while killer whale predation seems to be especially focused on pups of the year in the summer.

Additional mortality could be modelled explicitly to represent predation by 1) predators with an aggregative response, 2) predators whose numbers can be estimated using other data (e.g. grey seal counts) or 3) predators with a type 2 or 3 functional response to the abundance of prey. A type 2 response assumes the predator is limited by its capacity to process food and a type 3 response is similar but at low prey density levels the number of prey consumed and the density of the prey population is more than a linear function of the prey consumed by the predator. The model could also include predation that is preferentially focussed on one component of the population (e.g. year 0 animals in the case of killer whales). It may also be used to explore the effect of additional mortality due to the uptake of toxins from harmful algae.

Pre-2000 data show a relatively level population in Scapa Flow historically, which could indicate a population effectively at carrying capacity. If density dependent effects on pup survival or fecundity were important during this period, then the population might have higher productivity when it is smaller as is the current situation (Stenson *et al.,* 2016). The population might then be more resilient with potential to recover more quickly if pressures on the population were to be alleviated. The addition of density dependence into the model structure would allow exploration of the effects if the carrying capacity of the area were to be reduced (for example by food shortage), and this would allow for some additional scenario testing.

The current structure of the simulation code (Appendix 2) should easily allow for additional ecological mechanisms to be included if parameter estimates become available. Fitting more complex models including such effects to data will become more valuable and defensible when the results of field campaigns and the analysis of mark-recapture photo ID data provide stronger prior information and more precise estimates for important population parameters. Model selection criteria may then allow determination of how important additional ecological mechanisms are, so that future simulations can be run at an appropriate level of complexity (King *et al.,* 2009).

3 Approach 2. Investigate harbour seal vital rates and movement using capture mark-recapture and telemetry

The calculation of vital rates will not start until year five, following the collection of field data for four consecutive pupping seasons (2016 to 2019). Until then, progress on the processing of photo-identification data collected at the different study sites is reported. Here we report on results deriving from the processing of photo-identification data collected in 2016; the 2017 data is currently being processed and will be reported in the annual report for Year four.

3.1 Photo-identification data collected in 2016 across the study sites

3.1.1 Data collection and processing

Photo-identification data were collected at selected haulout sites in Orkney, Kintyre and Skye during the pupping season in 2016, primarily during the months of June and July. In Orkney and Kintyre, selected sites were visited on a daily basis when weather conditions and time allowed. Sites were visited around low tide, as that is when the highest number of seals are likely to haul out. Photographs were taken from a distance (50 to 150 m away) of as many seals as possible, ideally from both right and left sides, using a digital camera attached to a scope, mounted on a tripod. During field observations, relevant information was recorded with a time-stamp in order to link photographs to each observation. Such information included evidence of pregnancy, presence of a pup associated with a female, presence of umbilical cord in pups, evidence of suckling, injuries and particular behaviours.

In Orkney, the main photo-identification study sites were located in South Burray and Widewall Bay, although another haulout site in North Burray was visited less regularly. Unfortunately, access issues to the haulout site (specifically, presence of cattle in the surrounding fields during the summer months) prevented the regular collection of data and consequently this haulout site was not considered as a main monitoring site. In total there were 144 trips to collect photo-identification data at the main monitored sites, with 8,215 photographs collected.

In Kintyre, four main haulout sites were visited to obtain photo-identification data (Seal Rock, Yellow Rock and Island Muller North and South), with a fifth being visited occasionally (Southend) (Figure 8). In total, 86 trips were conducted which allowed the collection of 3,367 photographs.

On the Isle of Skye, photo-identification data were collected from boat platforms using a digital camera with a x 400 zoom lens, two to three times per week in May, June and July 2016. The boats used departed from Dunvegan Castle grounds for seal-watching trips around the nearby skerries (Figure 9), offering an opportunity to take close-up photographs of the seals. A total of 25 trips were conducted, and 8,874 photographs collected.

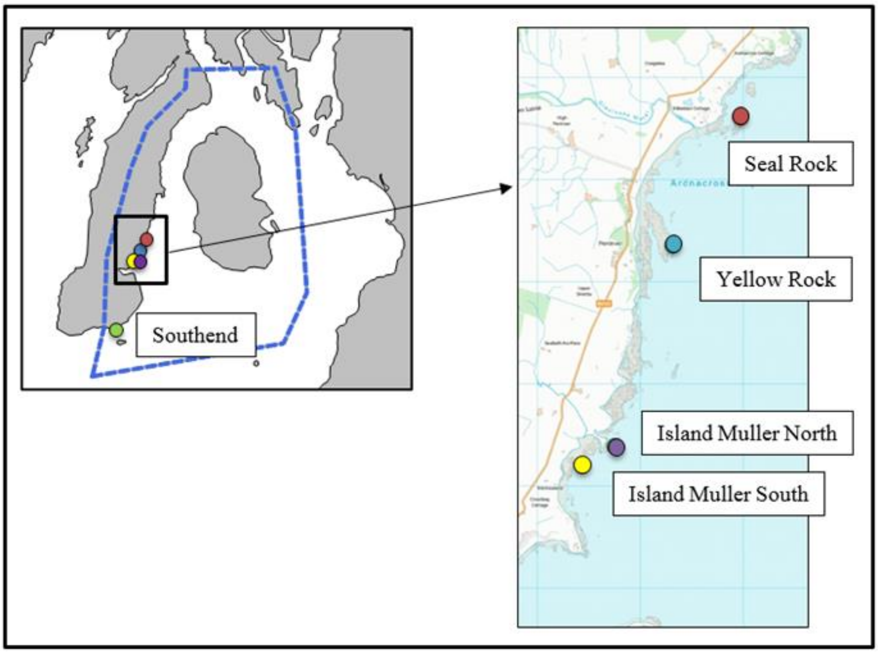

Figure 8. Locations of the main four haulout sites in Kintyre where photo-identification data were collected.

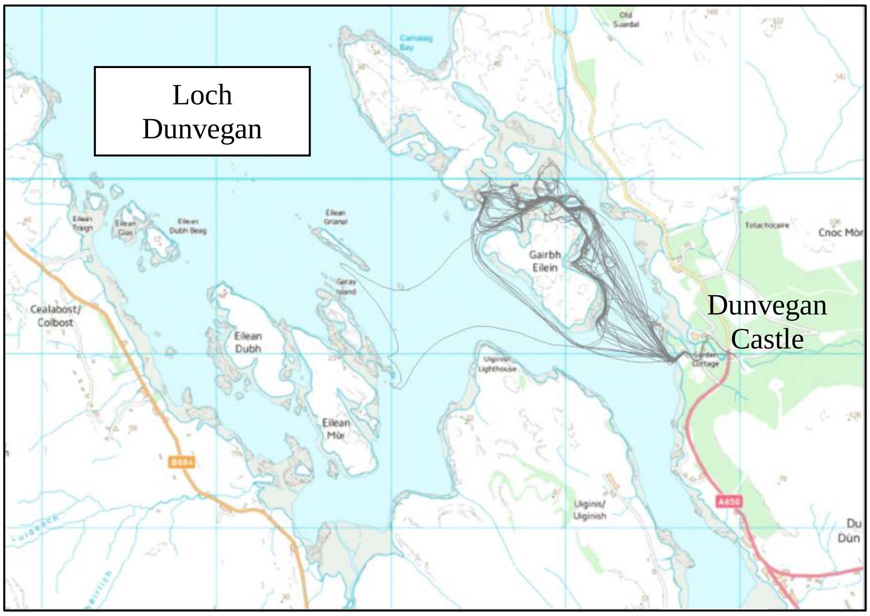

Figure 9. Map showing the boat tracks of the photo-identification trips conducted in 2016 in Loch Dunvegan.

All photographs were graded for their quality, following a protocol adapted from Cunningham (2009) to take account of photographic quality (focus, resolution of the image), the angle of the seal and the visibility of the pelage patterns (e.g. wet versus dry pelage) (Figure 10). Seals were individually identified from their unique pelage pattern markings, mainly using the head and neck areas, as those were the easiest to photograph in hauled-out seals (i.e. other parts such as the back or a full lateral body length view are more difficult to obtain consistently for all observed seals). All identified individual seals were given an ID number and the best left-side (L) and right-side (R) photographs added to a catalogue of uniquely identified seals from each study site. Three age classes were defined based on the size of the seal: pup, juvenile and adult. Sex was determined from photographs of the genitalia. To help identify mum-pup pairs through the season, as well as pups left on their own, efforts were made to identify pups from the unique pattern in their pelage when possible.

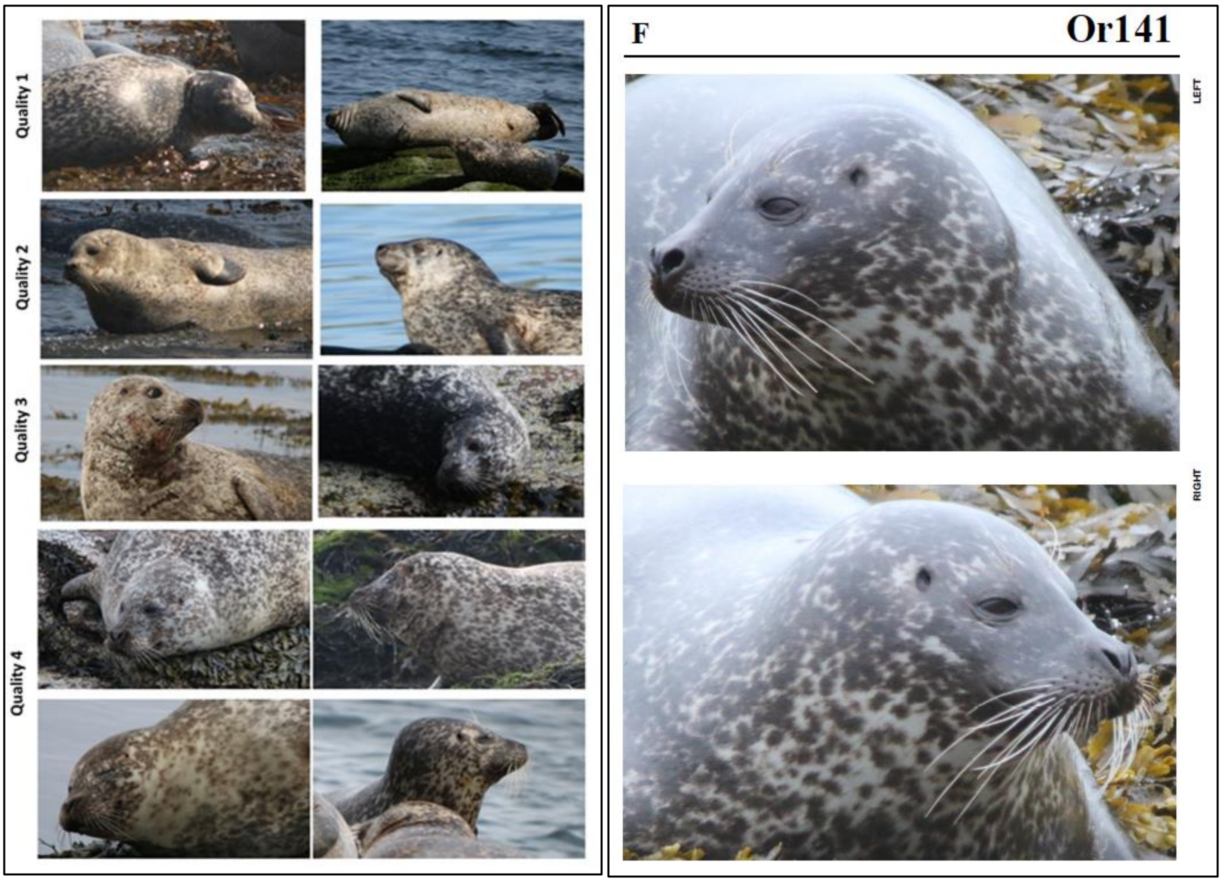

Figure 10. Criteria to grade photographs based on their photographic quality (left) and example of catalogued seal Or141 photographed in Orkney in 2016 (right).

3.1.2 Catalogued individuals and sighting histories of mum-pup pairs

Below is a summary of the number of catalogued seals from photographs taken in 2016 at the main monitored sites in the different study areas. For each of the study areas, a summary of the number of seals identified in each age class and sex is shown. The proportion of adult females that had a pup is also provided for each study area, as a percentage of the total number of adult females identified that were associated to a pup (i.e. constituted a mum-pup pair). At the end of the project's data collection in 2020, the sighting and reproductive histories of these females will be used to estimate fecundity (and survival) rates at each of the study areas, fitting appropriate capture-mark-recapture models (e.g. Cordes and Thompson, 2013). Consequently, the proportions shown here should not be interpreted as fecundity rates.

3.1.2.1 Orkney

In Orkney, a total of 8,215 photographs were taken at the main monitored sites, which included two sites in South Burray and sites in Widewall Bay. Of these, 3,819 photographs (46%) were graded as qualities 3 and 4 (best photographic quality). Overall, 192 different seals of all age classes where identified in Orkney and included in the catalogue for that region, including 121 adults, 19 juveniles and 51 pups. Of these, 125 seals had good quality photographs for both the right- and left-hand side of the head and neck (Table 2). A complete list of all identified seals from Orkney with information on their sex, age and reproductive status can be found in Appendix 3, to exemplify the catalogue information available for a study area.

Seventy one adult females were identified, of which 46 were seen associated with a pup (65%). There were five other pups that could not be associated to a known female because they were on their own when photographed, and their pelage markings did not match any other pup. Efforts were made to identify as many individual pups as possible from the photographs. However, good quality photographs were only available for 28 out of the 51 pups (55%), meaning some or all of the five unknown pups might actually have belonged to identified females. The data collection protocol was consequently modified for 2017 onwards to try and obtain good quality photographs of pups as often as possible, in all study sites.

Table 2. Summary of individual seals by age class and sex identified in Orkney in 2016; Q1-2-3-4 = based on all photographic qualities, Q3-4 = only based on quality 3 and 4 photographs and for both right- and left-side of head and neck area (i.e. it excludes seals for which Q3-4 photographs are only available for one side).

	Adults		**Juveniles**		**Pups**		**Total**	
Qualities	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4
Females	71	59	6	6	1	0	78	65
Males	26	15	5	5	3	3	34	23
Unknown	24	8	8	4	48	25	80	37
Total	121	82	19	15	51	28	192	125

Figure 11 shows the sighting histories for six selected females to illustrate some of the types of sighting data collected through photo-identification. For example, females Or001 and Or043 were photographed early in the season (end of May to start of June) obviously pregnant but then 'disappeared' for the rest of the pupping season; in Or001's case the female reappeared at the end of the season (mid to end of July) on her own. Females such as this could have moved to a different haulout site to pup, returning or not to the study site afterwards. In cases such as females Or009 and Or086, they were regularly photographed during the season, but were never seen pregnant or associated with a pup. Finally, females such as Or094 and Or059 were photographed whilst pregnant at the start of the season, then in association with and suckling their pup for about a month and finally, in the case of Or059, seen alone again at the end of the season.

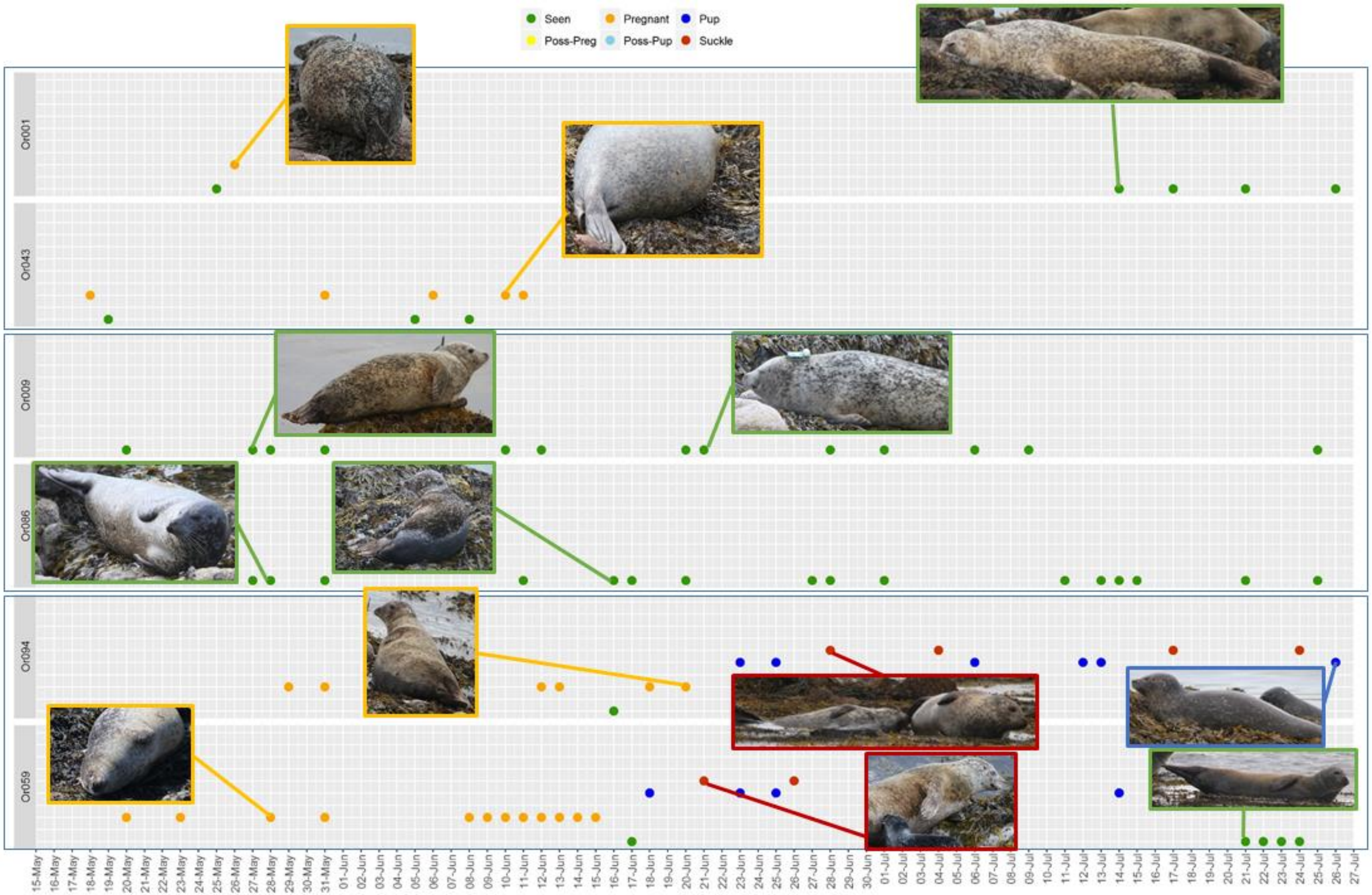

Figure 11. Sighting histories of six selected females photographed during the pupping season of 2016 in Orkney. Seen = female photographed; Poss-preg = visual observation indicates possible pregnancy; Pregnant = visual confirmation of pregnancy; Poss-pup = female possibly in association with a pup; Pup = mum-pup pair; Suckle = visual evidence of suckling.

3.1.2.2 Kintyre

In Kintyre, a total of 3,367 photographs were taken at the main monitored sites, which included two sites in Island Muller, and sites of Seal Rock and Yellow Rock (Figure 8). Of these, 1,621 photographs (48%) were graded as qualities 3 and 4 (best photographic quality). Overall, 227 different seals of all age classes were identified in Kintyre and included in the catalogue for that region, including 156 adults, 48 juveniles and 23 pups. Of these, 122 seals had good quality photographs for both the right- and left-hand side of the head and neck (Table 3).

Table 3. Summary of individual seals by age class and sex identified in Kintyre in 2016; Q1-2-3-4 = based on all photographic qualities, Q3-4 = only based on quality 3 and 4 photographs and for both right- and left-side of head and neck area (i.e. it excludes seals for which Q3-4 photographs are only available for one side).

	Adults		**Juveniles**		**Pups**		**Total**	
Qualities	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4
Females	40	30	4	3	0	0	44	33
Males	56	44	5	2	1	0	62	46
Unknown	60	17	39	14	22	12	121	43
Total	156	91	48	19	23	12	227	122

Forty adult females were identified at the main haulout sites, of which 18 (45%) were seen associated with a pup. Another ten adult females (25%) were photographed early in the season (start of June) very obviously pregnant, and then were either not seen again (n=7) or seen at the end of the pupping season (end of July) (n=3) looking much thinner and without a pup. These females could have pupped in another site away from the monitored sites. Additionally, there were five pups who could not be associated to a known female because they were on their own when photographed and their pelage markings did not match any other pup photographed at the site(s).

Based on photographs, the haulout site of Yellow Rock was a male-dominated site. Of 99 seals identified at that haulout site, 50 were identified as males (50%) and only six (6%) were identified as females. The site was clearly not a main pupping site as no pups were seen and only one female present on the site was seen to be pregnant.

The Southend haulout site (Figure 8) was not visited during the 2015 fieldwork to identify potential monitoring sites due to weather and time restrictions. However, it was visited in 2016 to investigate its suitability as a monitored photo-identification site. Photo-identification data were taken at Southend on three occasions towards the end of the season (mid-July), taking a total of 139 photographs of seals. From those, 36 seals were identified, including 23 adults and 13 pups. No juvenile seals were photographed. The adult seals comprised eight females, four males and eleven seals of unknown sex. Of the eight adult females identified, seven of them were associated with a pup. Additionally, another eight pups were photographed but could not be associated to a known female. The site is frequently visited by walkers due to its proximity to a path and main road and seals may flush into the water when people get too close, interfering with the collection of photo-identification data.

Given the characteristics of the different haulout sites, photo-identification effort conducted in 2017 was changed to focus more on those sites with the highest number of pups (i.e. Island Muller North and South sites), and less on the male-dominated site at Yellow Rock. Efforts were made to visit Southend, however there were limitations due to time constraints (i.e. it is a greater distance to the site than the other main ones).

3.1.2.3 Isle of Skye

On the Isle of Skye, a total of 8,874 photographs were taken around the skerries of Loch Dunvegan, near Dunvegan Castle (Figure 9). Of these, 6,090 photographs (68%) were graded as qualities 3 and 4 (best photographic quality). Overall, 395 different seals of all age classes where identified in Loch Dunvegan and included in the catalogue for that region, including 290 adults, 22 juveniles and 83 pups. Of these, 205 seals had good quality photographs for both the right- and left-hand side of the head and neck (Table 4).

Table 4. Summary of individual seals by age class and sex identified in Kintyre in 2016; Q1-2-3-4 = based on all photographic qualities, Q3-4 = only based on quality 3 and 4 photographs and for both right- and left-side of head and neck area (i.e. it excludes seals for which Q3-4 photographs are only available for one side).

	Adults		**Juveniles**		**Pups**		**Total**	
Qualities	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4	Q1-2-3-4	Q3-4
Females	77	63	2	0	1	0	80	63
Males	51	44	0	0	2	1	53	45
Unknown	162	73	20	4	80	20	262	97
Total	290	180	22	4	83	21	395	205

In total, 77 adult females were identified at the main haulout sites, of which 60 (78%) were associated with a pup. Another five adult females (6.5%) were photographed early in the season (first half of June) very obviously pregnant, and then were either not seen again (n=4) or seen at the end of the pupping season (end of July) (n=1) without a pup. These females could have pupped at another site away from the monitored ones. Additionally, there were 22 pups who could not be associated to a known female because they were on their own when photographed and their pelage markings did not match any other pup photographed at the site(s).

Because the photo-identification effort is conducted from the small boats as they go along the different skerries there is no possibility to stop the boat for certain periods of time in front of the haulout sites. Consequently, efforts were primarily focused on getting good quality photographs of the face and neck area. As a result, a high proportion (66%) of the 395 seals identified in Loch Dunvegan are of unknown sex. In 2017, efforts were made to take photographs of the genitals as often as possible, although photographs of the head and neck area remained as the priority.

Given the large number of seals identified in this study area compared to the other study sites, there are still large number of photographs of juvenile individuals that remain unidentified. Efforts will be made to identify as many of these juveniles as possible from the photographs.

3.2 Summary of photo-identification effort conducted in 2017 across the study sites

In 2017, photo-identification data were collected in Orkney, Kintyre and Isle of Skye. Efforts focused on the main monitoring sites to facilitate daily collection of photographs. Other sites that had been visited in 2016 but proved to be less suitable due to accessibility issues, number of seals or number of pups were not visited. Photo-identification data were collected during 85, 94 and 26 trips in Orkney, Kintyre and Isle of Skye, respectively. The processing of the 2017 photographs is currently ongoing, and results will be reported in the annual report for Year four.

4 Approach 3. Live capture-release at the photo-ID study sites

4.1 Methods

4.1.1 Live captures at Orkney and Isle of Skye in 2017

Trips to carry out live capture-release studies of harbour seals in Isle of Skye in March and in Orkney in April-May 2017 were conducted in accordance with the SMRU Animal (Scientific Procedures) Act, 1986, (Home Office Licence No. 192CBD9F). Additionally, three more harbour seals were captured in Orkney in late May 2017 during a separate project.

All trips focused on capturing adult females where possible. In Orkney, efforts were made to capture seals at the haulout sites where photo-identification data collection occurs during the pupping season (June and July). These include sites at South Burray and Widewall Bay. However, due to weather conditions and limited numbers of seals available for capture in those areas, other sites within Scapa Flow were also targeted (North Burray, Fara, South Walls and North Bay in Hoy) (Figure 12). On the Isle of Skye, capture-release studies took place in Loch Dunvegan. Priority was given to capture seals hauled out at Dunvegan skerries, where the photo-identification effort occurs in the pupping season. However, those haulout sites appeared to be male dominated in March, thus effort was extended to other nearby haulout sites in search of females (Skinidin, Garay Island and Sgeir nam Biast skerry) (Figure 13).

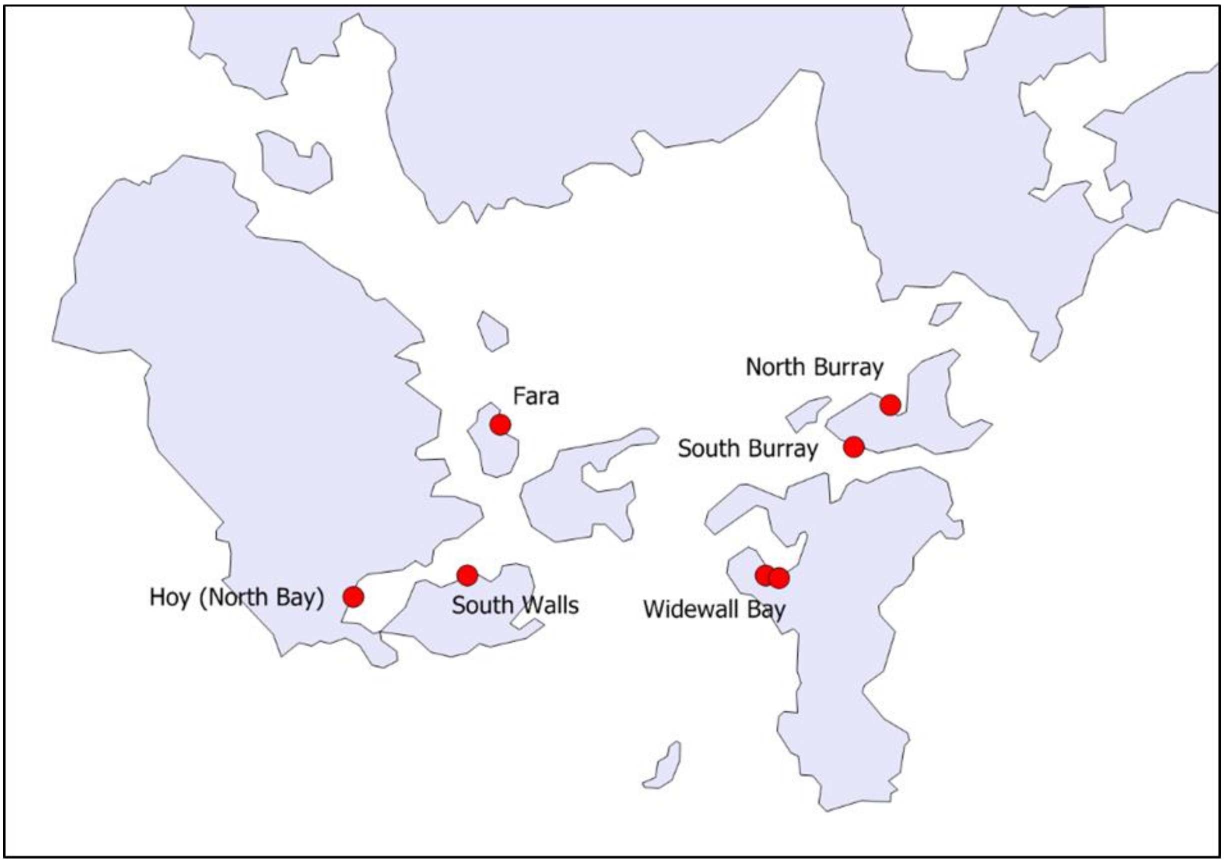

Figure 12. Map of Scapa Flow in Orkney showing the locations of live captures in 2017.

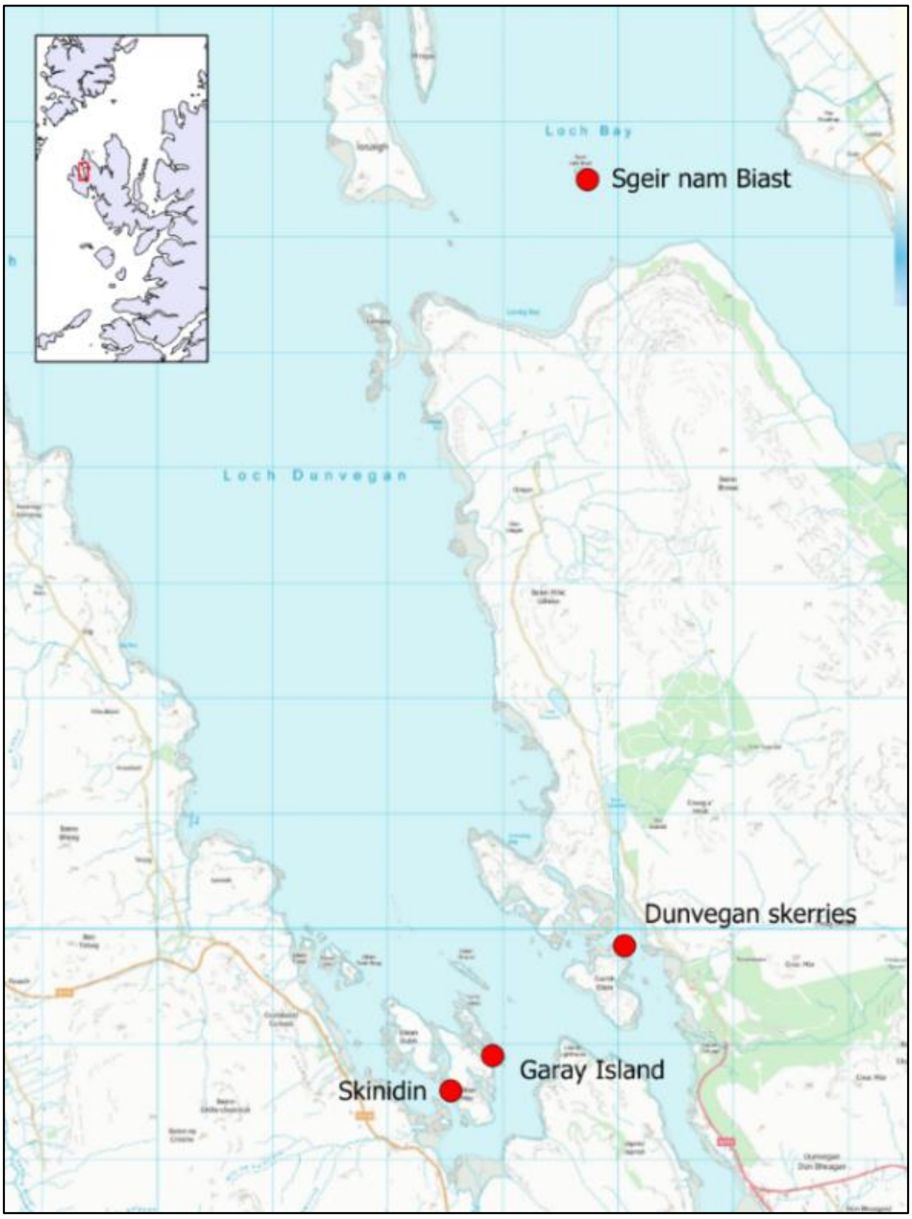

Figure 13. Map of Loch Dunvegan in Isle of Skye showing the locations of live captures in 2017.

In all trips adult and juvenile harbour seals were captured, individual covariate data were collected from each seal and telemetry tags (GSM/GPS and LO tags) were deployed on adult seals, primarily on females. Photographs of their pelage were taken for photo-identification purposes. The following samples were collected for analysis:

- blood samples (for pregnancy hormone and clinical blood chemistry analysis),
- blubber biopsy samples (for pregnancy hormone analysis, only from non-juvenile females),
- small incisor tooth (for aging, only from non-juvenile females),
- urine (for harmful algal toxin exposure) and
- skin (for genetic studies, not from all seals).

Two different telemetry tags were deployed: GSM telemetry tags (GSM) and GPS haulout site location-only (LO) tags. The LO tags were designed at SMRU to provide low-cost tracking of haulout sites visited. These tags are programmed to send a GPS position once every seven hours, dependant on availability of phone signal coverage at that time. On the Isle of Skye, eight adult female harbour seals were equipped with GSM tags and two adult females and one adult male were equipped with LO tags. In Orkney, eight adult female harbour seals were equipped with GSM tags. Two females and one male were tagged with LO tags[1]. On the Isle of Skye, 32 seals were captured during March 2017, of which 15 were females and 17 were males. Based on mass and length, 24 of the seals were adults (10 females and 14 males) and the other eight were juveniles (five females and three males). In Orkney, 21 seals were captured during April and May 2017, of which 10 were females and 11 were males. Based on mass and length, 19 of the seals were adults (ten females and nine males) and the other two males were juveniles. Three of the seals captured in Orkney, two males (flipper tags 00586 and 55128) and one female (flipper tag 00591) were recaptured animals from 2016. Consequently, no skin or teeth samples were taken from these individuals as these samples had already been collected.

4.1.2 Analysis of samples

The Growth Layer Groups (GLGs) in the collected teeth were counted to determine the age of the individuals. GLGs in the cementum of the incisor teeth from the live animals were counted from decalcified, stained sections (Dietz *et al*., 1991). Teeth were fixed in formalin and decalcified using a rapid decalcifier solution (RDO, Apex Engineering Products, Illinois or Rapid Decalcifier, J.T. Baker, London). Sections 15-20 µm thick were cut longitudinally using a cryostat and stained with toluidine blue (1 % in sodium bicarbonate) for between 5-10 minutes. Excess stain was removed using deionised water and a number of sections from each tooth were mounted onto gelatin coated slides. Slides were dried and protected with a cover slip using DPX mounting medium (Sigma Aldrich, Poole). GLGs were counted using a light microscope at 10x magnification and using photomicrographs enhanced using Adobe Photoshop where necessary.

Blood samples were analysed for progesterone to determine the pregnancy status of the adult females, using commercially available ELISA assays (Gardiner *et al*., 1996). Progesterone was determined in the blubber samples using the same assay following solvent extraction of the steroids (Kellar *et al*., 2006). In addition, all serum and plasma samples collected in 2016 and 2017 are being analysed for specific clinical chemistry parameters to determine health condition. Urine and faecal samples were analysed for domoic acid concentrations following the validated and published ELISA method using the Biosense ASP ELISA kit (Hall and Frame, 2010).

4.2 Results and Conclusions

4.2.1 Individual covariates

4.2.1.1 Age from growth layer groups in teeth

The ages estimated from the growth layer groups in the teeth are given in Table 5. Unfortunately, some of the teeth from 2016 could not be aged because they were inadvertently stored in ethanol in the field which caused them to split during the sectioning stage of the process (marked with 'x' in Table 5). Teeth were not taken from juveniles or from all males (marked with a '-' in Table 5). There was no significant difference in the mean age of the males compared to the females (males = 9.2 y ± 4.3 S.D., females = 10.3 ± 5.4 S.D. y, $p>0.05$). In addition there was no significant difference in the age of the pregnant compared to the non-pregnant adult (>133 cm nose-tail length) females (see below for pregnancy determination method, Figure 10, not-pregnant = 10.2, pregnant = 11.4, $p>0.05$).

4.2.1.2 Pregnancy status

Concentrations of plasma progesterone and blubber progesterone in the samples are shown in Figure 14 and Table 5. Progesterone concentrations were determined in the plasma samples from all the live captured animals using an immunoassay method that has been validated for use in harbour seals (Gardiner *et al*., 1996). The horizontal line in Figure 14 indicates the estimated length of juveniles and probably immature females based on estimated age-length relationships.

The pregnancy thresholds shown (as a vertical line) are based on the previously published estimates from harbour seal plasma (~20 ng/ml, Gardiner *et al*., 1996) and from cetaceans' blubber (>50 ng/ml, Kellar *et al*., 2006). The threshold for plasma progesterone is likely to be slightly higher for the particular progesterone assay kit being used for this study, as two of the juvenile females had circulating concentrations slightly higher than 20 ng/ml. This suggests that 25 ng/ml might be a better threshold. The pregnancy outcome for the known females observed during the mark-recapture study will be used to determine the correct thresholds to use.

[1] Ten of the GSM tags were funded by Vodafone UK, five were funded by Scottish Natural Heritage and one was provided by Paul Thompson (University of Aberdeen). Their support is gratefully acknowledged.

Table 5. Summary of all captured seals in Orkney and Skye in 2016 and 2017.

Date	Region	Sex	Age (yrs)	Flipper tag	Telemetry tag	Mass (kg)	Length (cm)	Girth (cm)	Progesterone in blood (ng/ml)	Pregnancy state blood	Progesterone in blubber (ng/g)	Pregnancy state blubber	Reproductive status	Pupped (photo-ID)	Urine domoic acid (pg/ml)	Faeces domoic acid (pg/g)
08/04/16	Ork	M	-	00583		86	154	107							5184	
11/04/16	Ork	F	5	00584	GSM-14259	93	148	110	85.51	Pregnant	113.34	Pregnant	Pregnant	No[2]		
14/04/16	Ork	M	5.5	55126	GSM-14260	78	143	98							3453	
14/04/16	Ork	F	x	00585	GSM-14263	78	143	106	1.4	Not Pregnant	15.73	Not Pregnant	Not Pregnant	No	2803	
14/04/16	Ork	M	x	00586	GSM-14261	99	156	116							1695	
15/04/16	Ork	F	12.5	55127	GSM-14257	87	142	111	99.81	Pregnant	196.28	Pregnant	Pregnant	No[3]	816	
15/04/16	Ork	M	7.5	55128	GSM-14258	79	147	110							301	
17/04/16	Ork	M	9.5	55129		106	157	121							2083	<LOD
19/04/16	Ork	F	11	55189	GSM-14264	84	149	104	3.94	Not Pregnant	61.24	Pregnant	Pregnant	Yes	1227	
19/04/16	Ork	F	8	55191	GSM-14265	86	146	109	1.33	Not Pregnant	14.82	Not Pregnant	Not Pregnant	No		
19/04/16	Ork	F	12	55192	GSM-14262	80	148	107	2.39	Not Pregnant	23.13	Not Pregnant	Not Pregnant	No	2297	
19/04/16	Ork	M	x	55193		51	132	90							28191	
19/04/16	Ork	F	x	55196	GSM-14256	97	148	108	55.57	Pregnant	225.46	Pregnant	Pregnant	Yes		
19/04/16	Ork	F	9.5	55197		89	145	109	73.47	Pregnant	295.74	Pregnant	Pregnant	Yes	18728	
09/05/16	Ork	F	9	55186	LO-F1638	78	142	104	2.0	Not Pregnant	23.21	Not Pregnant	Not Pregnant	No		
09/05/16	Ork	F	-	55187	LO-B1927	98	145	110	141.7	Pregnant	223.02	Pregnant	Pregnant	Yes	62938	
09/05/16	Ork	F	-	55188		40	119	82	2.07	Not Pregnant	NA	NA	Not Pregnant	No		
09/05/16	Ork	M	-	55190		45	124	87							16596	
09/05/16	Ork	M	4.5	55198		87	150	111							6977	
09/05/16	Ork	M	5	55199		92	150	114							15566	
12/05/16	Ork	M	19.5	73349		90	148	111							4134	
13/05/16	Ork	F	4	00590	LO-D5294	79	136	105	3.05	Not Pregnant	352.78	Pregnant	Pregnant	Yes		

[2] This female was seen pregnant at the start of the season. Telemetry data showed this female was away from the monitored haulout sites for most of the pupping season and had no pup when returning to the monitored haulout.
[3] This female was only seen on one trip during the 2016 pupping season. She could have pupped at a non-monitored site.

13/05/16	Ork	F	14	00591	LO-A2497	67	141	97	45.52	Pregnant ?	8.91	Not Pregnant	Not Pregnant	No	27352
13/05/16	Ork	F	8	00600	LO-E2610	107	146	111	152.25	Pregnant	117.01	Pregnant	Pregnant	No[4]	27557
11/03/17	Sk	M	9.5	D078		97	152	118							5757
12/03/17	Sk	F	2	D079		49	123	87	11.53	Not Pregnant	20.75	Not Pregnant	Not Pregnant		190
12/03/17	Sk	M	6	D080		94	151	114							2279
12/03/17	Sk	M	x	D081		99	154	121							644
12/03/17	Sk	M	-	D082		56	131	94							521
12/03/17	Sk	F	-	D083		36	107	85	24.91	Pregnant ?	NA	NA	Not Pregnant[5]		
13/03/17	Sk	M	11	D084		94	158	116							4566
13/03/17	Sk	M	10.5	D085		100	153	119							828
13/03/17	Sk	M	x	D086		95	151	115							2754
15/03/17	Sk	F	4.5	D087		46	117	93	3.27	Not Pregnant	NA	NA	Not Pregnant		
15/03/17	Sk	M	18	D088		109	158	121							609
15/03/17	Sk	M	12.5	D089		100	152	111							2058
15/03/17	Sk	M	-	D090		47	114	93							47350
16/03/17	Sk	M	7	D091		94	149	113							5518
16/03/17	Sk	M	11	D092		109	155	116							3210
16/03/17	Sk	F	9	D093	GSM-14362	71	133	104	133.35	Pregnant	139.7	Pregnant	Pregnant		
17/03/17	Sk	F	9.5	D094	GSM-14506	97	144	118	79.64	Pregnant	126.17	Pregnant	Pregnant		1937
18/03/17	Sk	M	-	D095		102	153	113							5759
18/03/17	Sk	F	14	D096	GSM-14497	99	150	116	90.59	Pregnant	73.28	Pregnant	Pregnant		25855
19/03/17	Sk	F	25	D097	GSM-14498	78	139	110	64.55	Pregnant	134.16	Pregnant	Pregnant		4195
19/03/17	Sk	F	16	D098	GSM-14507	91	146	112	50.27	Pregnant	110.99	Pregnant	Pregnant		3304
19/03/17	Sk	M	5.5	D099		98	151	116							917
19/03/17	Sk	M	8	D100		82	141	108							1038
19/03/17	Sk	M	-	D101		41	120	88							21316
19/03/17	Sk	F	3.5	D102		35	114	84	16.72	Not Pregnant	42.74	Not Pregnant	Not Pregnant		
19/03/17	Sk	F	-	D103		27	100	76	24.91	Pregnant ?	NA	NA	Not Pregnant[5]		
22/03/17	Sk	F	16	D104	GSM-14152	73	142	97	122.91	Pregnant	530.73	Pregnant	Pregnant		813920
22/03/17	Sk	M	6.5	D105	LO-ST09	81	140	105							1343

[4] This female was seen pregnant but was not observed with a pup.
[5] Given the morphometric data, these animals are juveniles and unlikely to be pregnant.

22/03/17	Sk	F	7.5	D106	GSM-14211	79	144	105	75.92	Pregnant	249.59	Pregnant	Pregnant		2119	
23/03/17	Sk	F	9	D107	GSM-14425	72	133	103	114.96	Pregnant	1547.50	Pregnant	Pregnant		5314	
23/03/17	Sk	F	7	D108	LO-ST01	88	140	105	45.6	Pregnant ?	1062.12	Pregnant	Pregnant		1737	
23/03/17	Sk	F	9	D109	LO-ST02	86	141	105	85.15	Pregnant	1189.07	Pregnant	Pregnant		4682	
18/04/17	Ork	M	8.5	55128		79	145	105							767	
19/04/17	Ork	M	-	D124		94	147	113							44572	
19/04/17	Ork	M	-	D125		93	151	110							712	
23/04/17	Ork	M	-	D126		88	154	111							25965	
23/04/17	Ork	M	-	D127		95	155	104							420	
26/04/17	Ork	F	15	00591	GSM-14476	91	139	106	223	Pregnant	1925.5	Pregnant	Pregnant	Yes	2803	
26/04/17	Ork	F	24	D128	GSM-14120	102	144	109	136.12	Pregnant	375.54	Pregnant	Pregnant		1277	
26/04/17	Ork	M	-	D129		66	139	95							847	
27/04/17	Ork	M	x	00586		100	152	114							1432	
28/04/17	Ork	F	8	D130	GSM-14465	82	150	109	7.67	Not Pregnant	32.03	Not Pregnant	Not Pregnant			
28/04/17	Ork	M	-	D131		84	149	103							1068	<LOD
28/04/17	Ork	M	-	D132		109	155	119							3234	
30/04/17	Ork	F	4.5	D133	LO-ST12	51	127	88	1.8	Not Pregnant	37.49	Not Pregnant	Not Pregnant		1191	
30/04/17	Ork	F	5	D134	GSM-14150	67	126	98	61.37	Pregnant	894.41	Pregnant	Pregnant	Yes		<LOD
02/05/17	Ork	F	18.5	D135	GSM-14151	76	142	99	7.9	Not Pregnant	99.13	Pregnant	Possibly Pregnant		2506	1886
02/05/17	Ork	F	10.5	D136	GSM-14469	104	146	103	46.06	Pregnant ?	554.14	Pregnant	Pregnant			<LOD
02/05/17	Ork	M	-	D137		25	96	74							1109	
03/05/17	Ork	F	11.5	D138	GSM-14435	79	140	98	136.13	Pregnant	1559.18	Pregnant	Pregnant		2493	
21/05/17	Ork	F	8.5	D139	GSM-14475	83	131	104	156.09	Pregnant	3261.76	Pregnant	Pregnant		1752	
21/05/17	Ork	M	-	D140	LO-ST14	76	145	102							2899	
23/05/17	Ork	F	9.5	D141	LO-ST05	89	133	89	184.09	Pregnant	624.74	Pregnant	Pregnant	Yes	1433	

Only one female shorter than the estimated length at maturity (seal with flipper tag D134 from Orkney) had an elevated progesterone concentration in her blood and given her length (126 cm) it is conceivable that this is a younger, primiparous animal. This was further confirmed by the photo-identification effort as this female was observed pregnant on 16 June 2017 and with a new pup on 17 and 18 June 2017. After this time it is probable that she abandoned her pup, as she was repeatedly seen from 20 June onwards without a pup. There was a significant positive linear relationship between the concentrations of progesterone in the two matrices (linear regression model, p=0.0005). Concentrations of progesterone in the plasma and blubber of only the mature animals (>133 cm long) captured are shown in Figure 15.

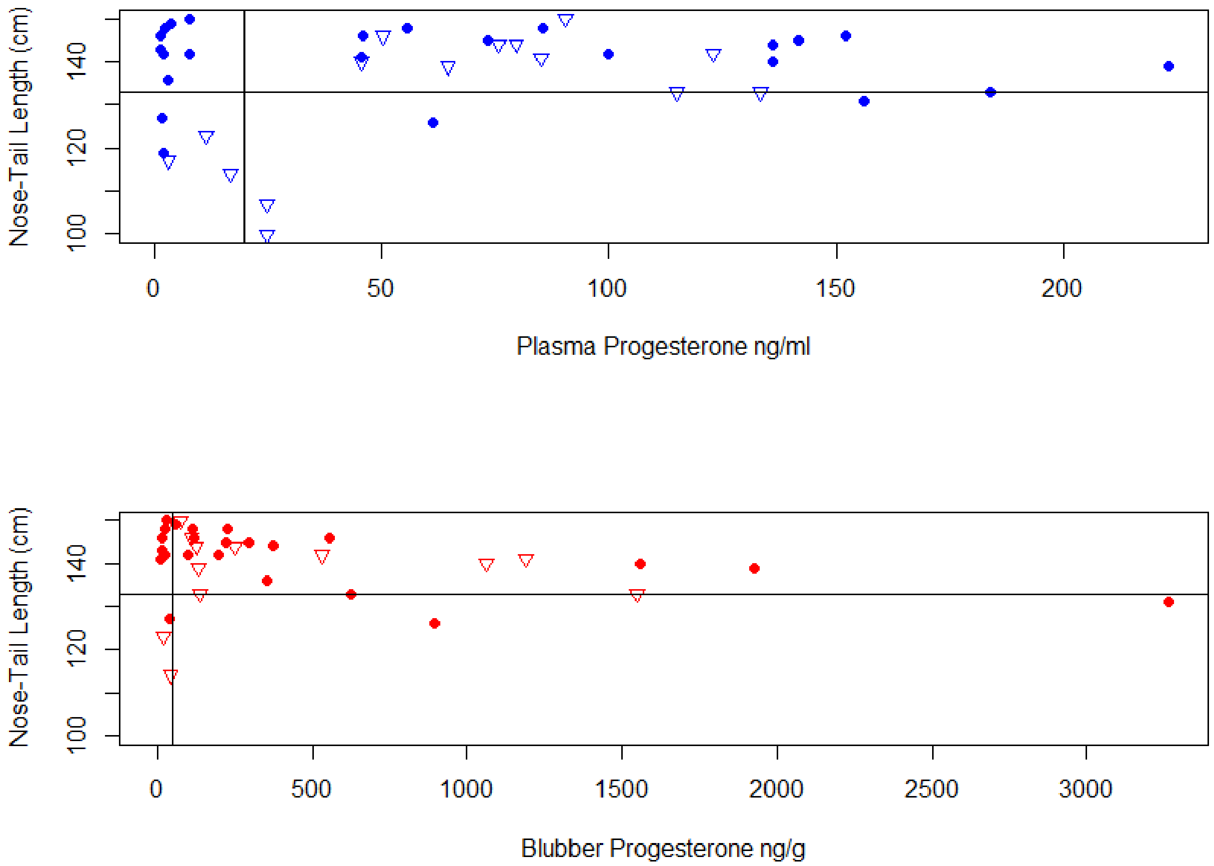

Figure 14. Plasma (top) and blubber (bottom) progesterone concentrations in live captured females vs. nose-tail length, triangles = Skye, dots = Orkney. Horizontal line indicates length at maturity (133 cm) and vertical line estimated progesterone threshold (20 ng/ml in blood from Gardiner *et al*., 1996 and 50ng/g in blubber from Keller *et al*., 2006).

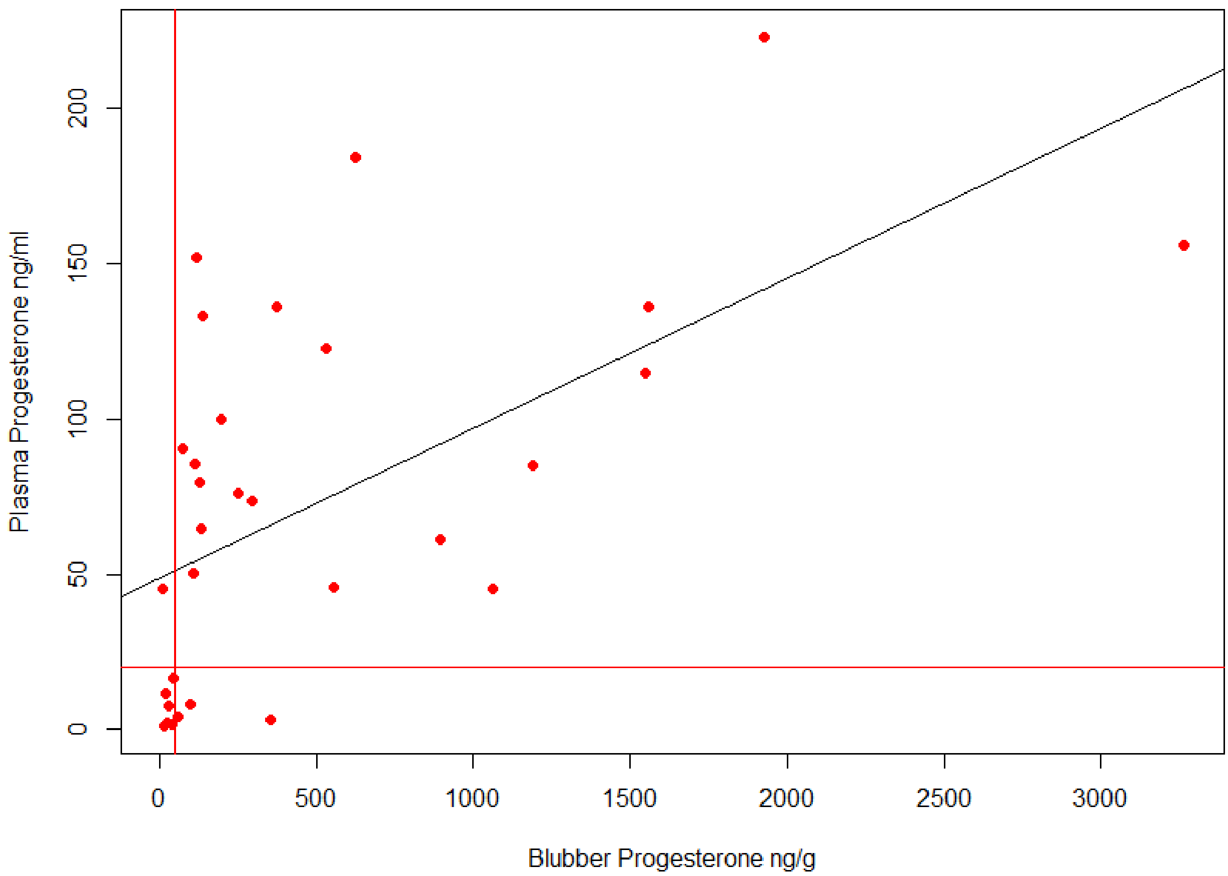

Figure 15. Relationship between plasma progesterone and blubber progesterone concentrations in mature females (>133 cm nose-tail length). The horizontal line and vertical red lines are the estimated thresholds for pregnancy determination. The black line shows the linear model fit.

To investigate the differences in the percentage of pregnant females between Orkney (2016 and 2017) and Skye (2017) the mature females were categorised as 'pregnant', 'not pregnant' and 'possibly pregnant' (Table 5, column 'Reproductive status'). The latter category was created to account for the uncertainty in the published thresholds or where there was discrepancy between the categorisations from plasma or blubber Animals with concentrations of plasma progesterone above 50 ng/ml were categorised as 'pregnant', those below 20 ng/ml were 'not pregnant' and those in between were 'possibly pregnant'. Where there was not agreement in the assignments in the blubber and plasma, they were also categorised as 'possibly pregnant' (unless they were confirmed juveniles based on their mass and length). For the 2016 and 2017 data, where possible the final assignments were taken as confirmed by field observations.

The 2017 photo-identification data is currently being processed. However, from the data processed so far three captured females (flipper tag numbers 00591, D134, and D141) have been seen with a pup in Orkney, which agrees with their categorisation as 'pregnant' from both plasma and blubber (Table 5). The resulting proportions are shown in Table 6. The proportion of pregnant females from Orkney (67%) was lower than for Skye (100%) but the proportions were not significantly different (Chi-squared test, p=0.116) due to the small sample sizes. Additional data from females captured in the Moray Firth will provide information for a third site but the problem of estimating a true pregnancy proportion from the small number of mature females captured in Orkney still remains. As such, it was not practical to separate the data by year.

Table 6. Percentage of live captured females in pregnancy categories by region.

Region	State	n	%	Lower 95% CI	Upper 95% CI
Orkney	Pregnant	14	67	39	95
	Possibly Pregnant	1	4.5	0	97
	Not Pregnant	6	28.5	0	74
Skye	Pregnant	10	100	95	100

How important this finding may be for understanding the drivers of the population decline in Orkney is unclear and further investigations should be carried out before any conclusions can be drawn. In addition, samples from females in this region, particularly later in the year after the period of delayed implantation in October or November, should be analysed for reproductive hormone levels as this may indicate whether the females are implanting and then perhaps aborting the foetuses before they reach the third trimester in April and May, or whether the problem is occurring early in the reproductive cycle. Further work, incorporating data collected from animals captured at other haul out sites, will also be used to construct a predictive model, with confidence limits, for estimating pregnancy status using these reproductive hormones in plasma and blubber.

4.2.1.3 Domoic acid concentrations

Domoic acid concentrations in the urine and faecal samples collected from the live capture-release animals are shown in Table 7. Domoic acid concentrations were lognormally distributed, with some individuals having very high levels but in most animals concentrations were low. Boxplots of the concentrations in all the samples (including two additional faecal samples collected on the haulout sites in April and May which had concentrations of 3,146 and 2,210 pg/g respectively) are shown in Figure 16. There was no difference in the median concentrations by region, with Isle of Skye animals also being exposed to domoic acid. Indeed the highest concentration (>800,000 pg/ml) was recorded in an adult female captured on Isle of Skye. When comparing only the results from the urine samples the finding was the same, i.e. there was no significant difference in the concentrations between the regions.

Further analysis of these preliminary results will be carried out, including determining the foraging movements of the tagged animals for which domoic acid (DA) exposure estimates are also available. Due to the short half-life (<24 h in urine) of DA in the samples these results will be confounded by differences in trip duration as levels may be low when animals had been foraging further before capture. However, the caveat to this analysis is that it will assume that the behaviour of the animal prior to capture was the same (in terms of average trip duration) as that determined from the telemetry data collected following capture and release.

Table 7. Domoic acid concentrations in urine and faecal samples collected from live captured harbour seals from Orkney and Skye in 2017 (<LOD = limit of detection, 1000 pg/ml or g).

Date	Region	Sex	Age	Flipper tag	Matrix	DA (pg/ ml or g)
18/04/2017	Orkney	M	Adult	55128	Urine	<LOD
19/04/2017	Orkney	M	Adult	D125	Urine	<LOD
19/04/2017	Orkney	M	Adult	D124	Urine	44,572
23/04/2017	Orkney	M	Adult	D126	Urine	25,965
23/04/2017	Orkney	M	Adult	D127	Urine	25,965
26/04/2017	Orkney	M	Juvenile	D129	Urine	<LOD
26/04/2017	Orkney	F	Adult	D128	Urine	1,277
27/04/2017	Orkney	M	Adult	00586	Urine	1,432
28/04/2017	Orkney	M	Adult	D131	Urine	1,068
28/04/2017	Orkney	M	Adult	D132	Urine	3,234
28/04/2017	Orkney	M	Adult	D131	Faeces	<LOD
30/04/2017	Orkney	F	Adult	D133	Urine	1,191
30/04/2017	Orkney	F	Adult	D134	Faeces	<LOD
02/05/2017	Orkney	F	Adult	D135	Faeces	1,886
02/05/2017	Orkney	F	Adult	D135	Urine	2,506

02/05/2017	Orkney	M	Juvenile	D137	Urine	1,109
02/05/2017	Orkney	F	Adult	D136	Faeces	<LOD
03/05/2017	Orkney	F	Adult	D138	Urine	2,493
21/05/2017	Orkney	F	Adult	D139	Urine	1,752
21/05/2017	Orkney	M	Adult	D140	Urine	2,899
23/05/2017	Orkney	F	Adult	D141	Urine	1,433
11/03/2017	Skye	M	Adult	D078	Urine	5,757
12/03/2017	Skye	F	Juvenile	D079	Urine	<LOD
12/03/2017	Skye	M	Juvenile	D082	Urine	<LOD
12/03/2017	Skye	M	Adult	D081	Urine	<LOD
12/03/2017	Skye	M	Adult	D080	Urine	2,057
13/03/2017	Skye	M	Adult	D085	Urine	<LOD
13/03/2017	Skye	M	Adult	D084	Urine	4,566
13/03/2017	Skye	M	Adult	D086	Urine	2,754
15/03/2017	Skye	M	Adult	D088	Urine	<LOD
15/03/2017	Skye	M	Adult	D089	Urine	2,058
15/03/2017	Skye	M	Juvenile	D090	Urine	47,350
16/03/2017	Skye	M	Adult	D092	Urine	3,210
16/03/2017	Skye	M	Adult	D091	Urine	5,518
17/03/2017	Skye	F	Adult	D094	Urine	1,937
18/03/2017	Skye	M	Adult	D095	Urine	5,759
18/03/2017	Skye	F	Adult	D096	Urine	25,855
19/03/2017	Skye	M	Adult	D099	Urine	<LOD
19/03/2017	Skye	M	Adult	D100	Urine	1,038
19/03/2017	Skye	F	Adult	D097	Urine	4,195
19/03/2017	Skye	M	Juvenile	D101	Urine	21,316
19/03/2017	Skye	F	Adult	D098	Urine	3,304
22/03/2017	Skye	M	Adult	D105	Urine	1,343
22/03/2017	Skye	F	Adult	D104	Urine	813,920
22/03/2017	Skye	F	Adult	D106	Urine	2,119
23/03/2017	Skye	F	Adult	D107	Urine	5,314
23/03/2017	Skye	F	Adult	D108	Urine	1,737
23/03/2017	Skye	F	Adult	D109	Urine	4,682

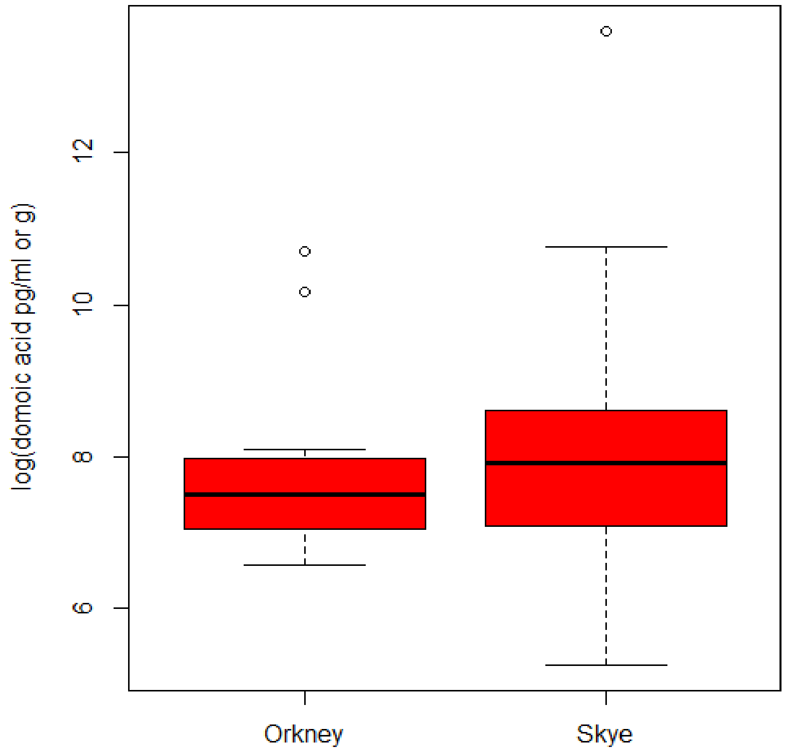

Figure 16. Concentrations of domoic acid in faeces and urine collected from live captured harbour seals and in faeces from the study haulout sites, March, April and May 2017.

4.2.2 Movements

4.2.2.1 GSM/GPS tags

Fourteen GSM/GPS deployed in Orkney and Skye in 2017 functioned well and transmitted data for 56 to 130 days, whilst two tags (numbers 14362 and 14425) had very short transmission durations of only 18 and 2 days respectively (Table 8). All tracks from Orkney and Skye are plotted in Figures 17 and 18, respectively, and detailed individual tracks can be seen in Figures 19 and 20. The seals showed a variety of movement patterns as well as individual preferences for certain areas. Some seals showed very restricted movements (e.g. female 14435 in Orkney) while others travelled greater distances (e.g. females 14120 in Orkney and 14498 in Skye).

Additionally, two GPS/GSM tags deployed in Orkney in 2016 (numbers 14263 and 14264) were recovered after they had fallen off. The tags were recovered from South Burray (where the photo-identification effort occurs) and from the Sands of Wright in Widewall Bay (near the sites where seals were captured). This will allow the download a much more detailed dataset of locations (one every 4 seconds) towards analysis.

Table 8. Summary of tag duration, start and end dates and number of locations transmitted from the GSM/GPS telemetry tags deployed in Orkney and Skye in 2017.

Telemetry tag	Region	Start date	End date	Duration	No. locations
14152	Skye	2017-03-22	2017-06-30	100 days	13359
14211	Skye	2017-03-22	2017-07-27	127 days	21430
14362	Skye	2017-03-16	2017-04-03	18 days	863
14425	Skye	2017-03-24	2017-03-26	2 days	134
14497	Skye	2017-03-18	2017-06-28	102 days	13320
14498	Skye	2017-03-19	2017-07-27	130 days	15558
14506	Skye	2017-03-17	2017-07-16	121 days	20240
14507	Skye	2017-03-19	2017-07-16	119 days	19824
14120	Orkney	2017-04-26	2017-07-19	84 days	11619
14150	Orkney	2017-04-30	2017-07-09	70 days	10104
14151	Orkney	2017-05-02	2017-07-08	67 days	8493
14435	Orkney	2017-05-03	2017-07-25	83 days	9330
14465	Orkney	2017-04-28	2017-07-01	64 days	9370
14469	Orkney	2017-05-02	2017-07-29	88 days	10543
14475	Orkney	2017-05-21	2017-07-16	56 days	5417
14476	Orkney	2017-04-26	2017-07-10	75 days	10758

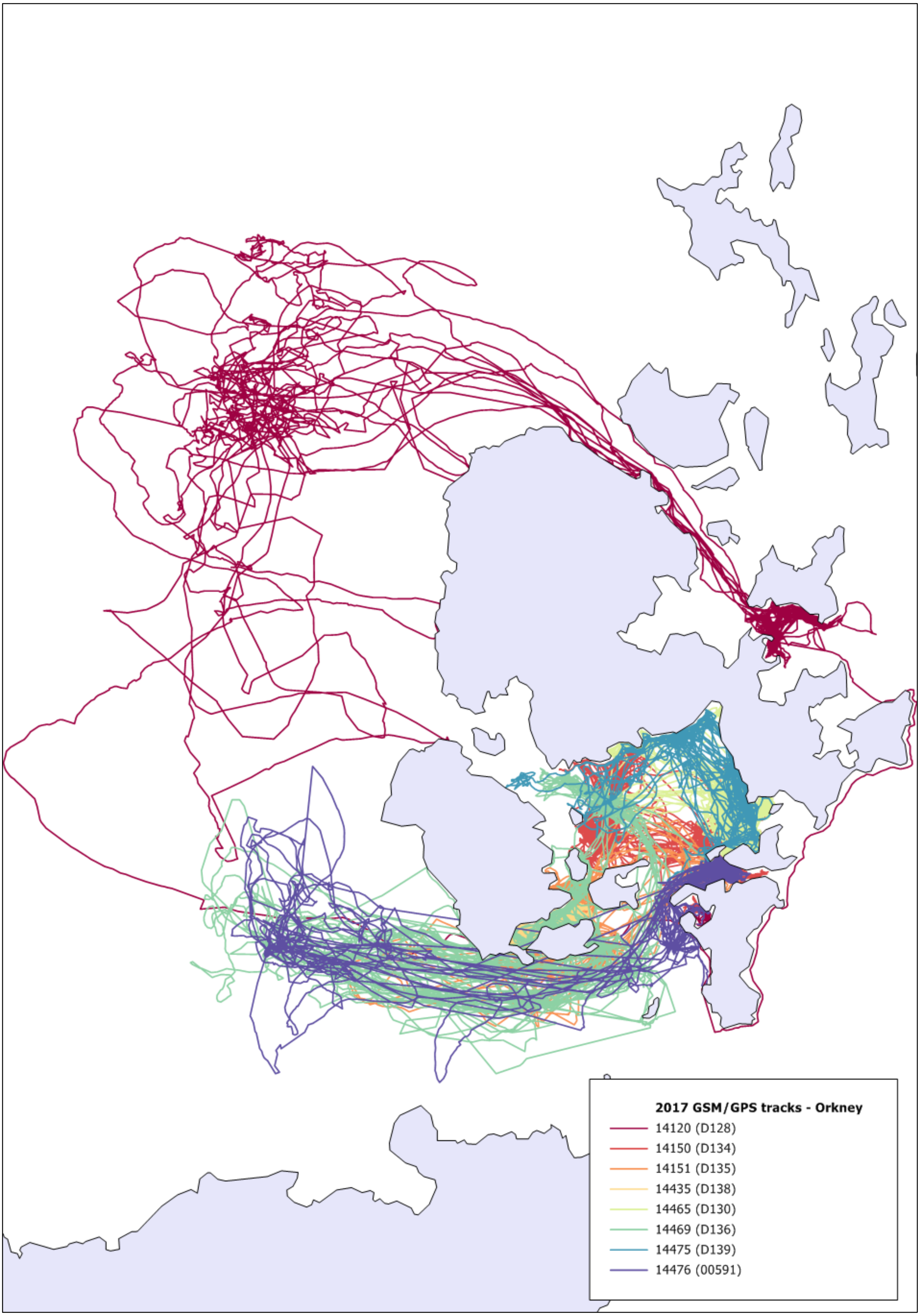

Figure 17. Tracks of eight harbour seals fitted with SMRU GPS/GSM tags in Orkney, April 2017.

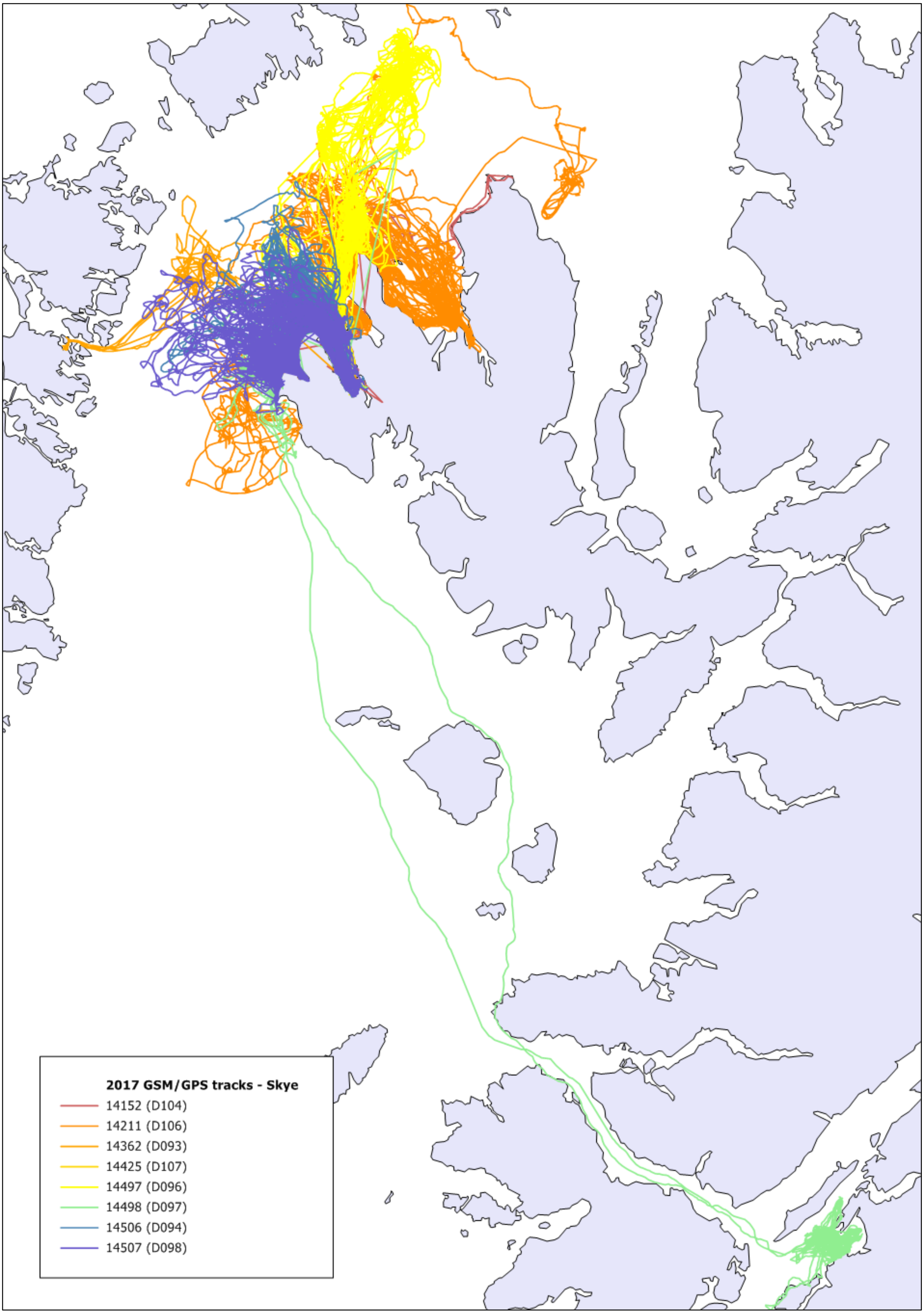

Figure 18. Tracks of eight harbour seals fitted with SMRU GPS/GSM tags on Isle of Skye, March 2017.

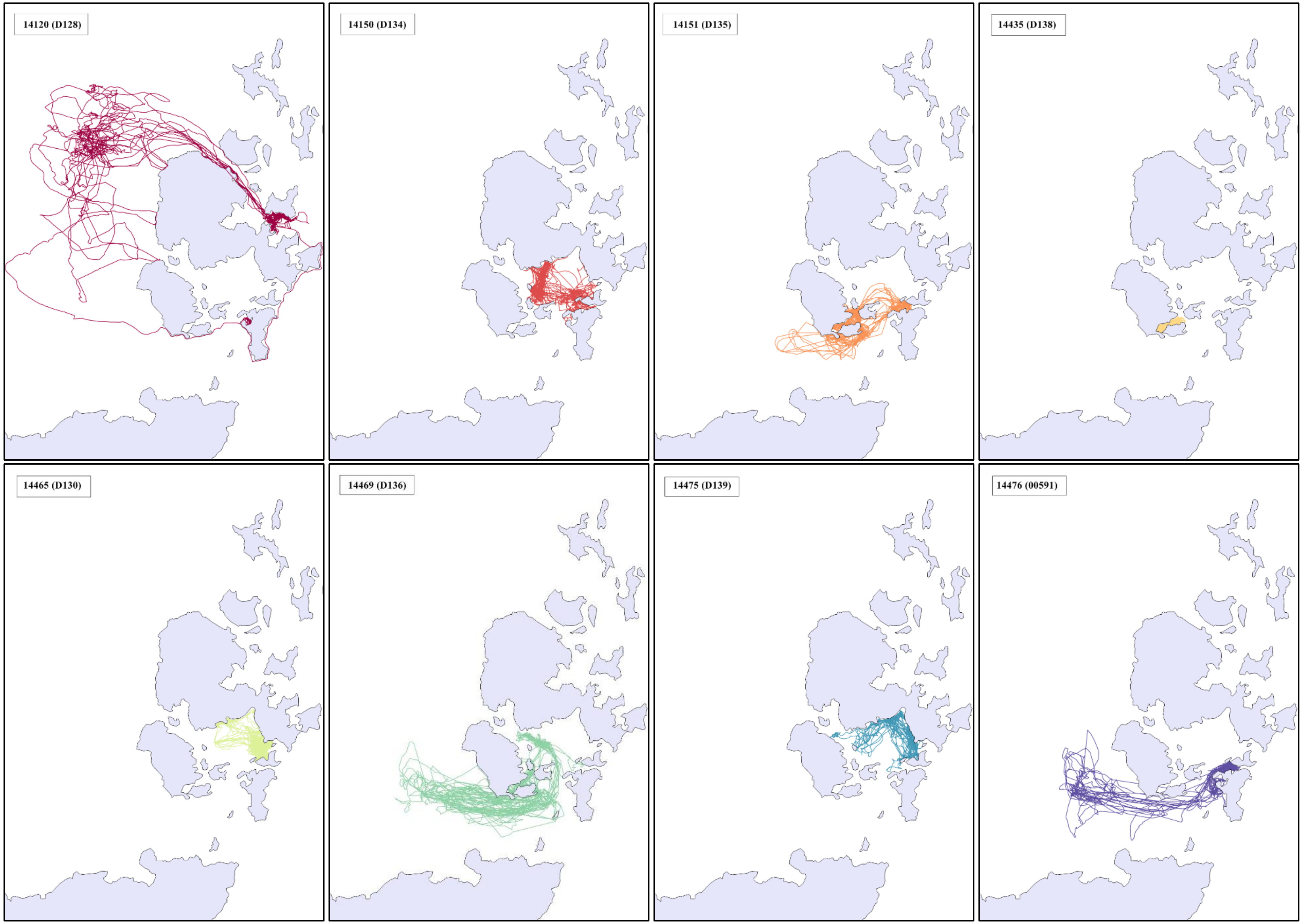

Figure 19. Individual tracks from eight adult harbour seal females tagged in Orkney in April/May 2017 with GSM/GPS telemetry devices.

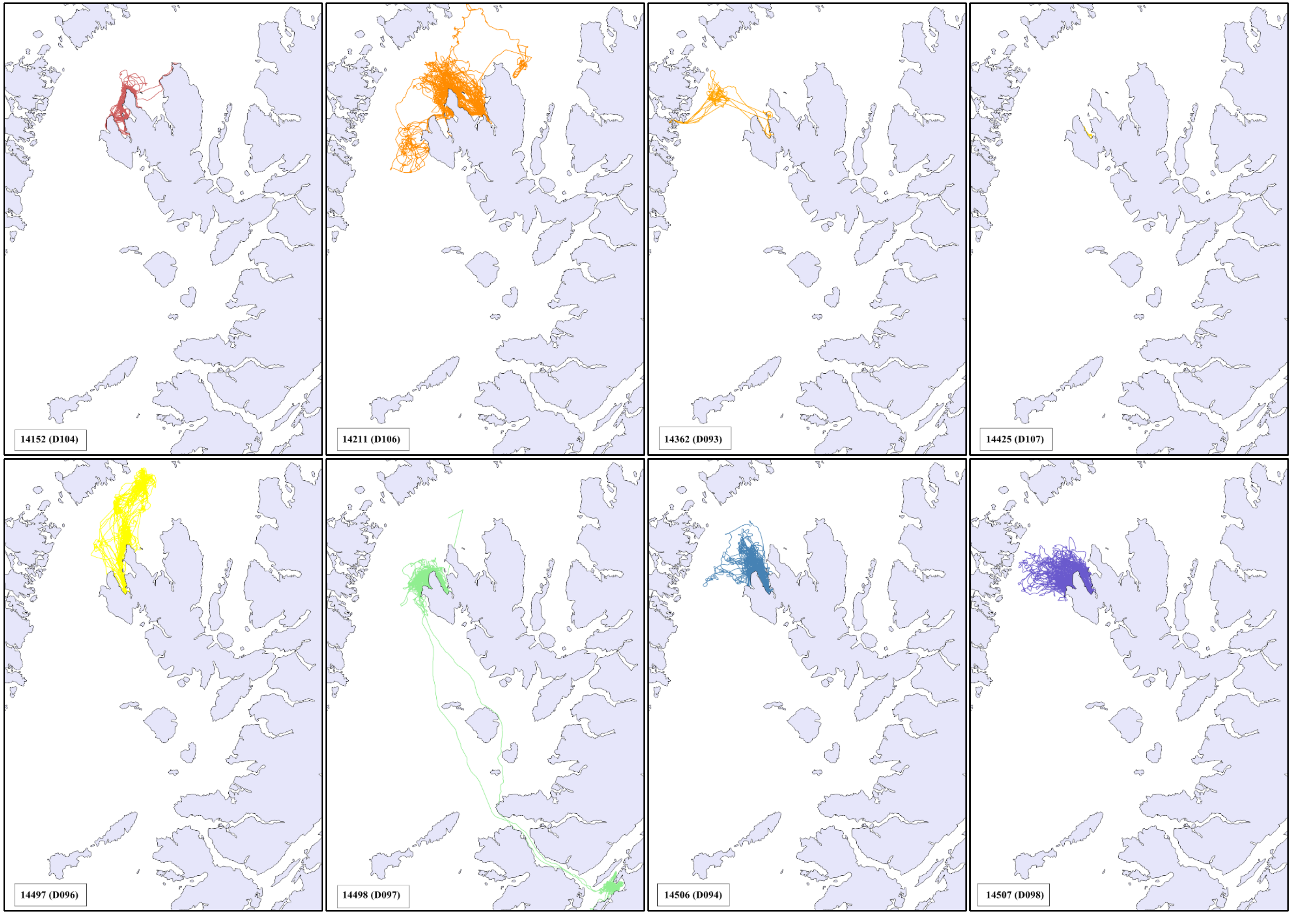

Figure 20. Individual tracks from eight adult harbour seal females tagged in Skye in March 2017 with GSM/GPS telemetry devices.

4.2.2.2 Location Only (LO) tags

The three LO tags deployed on the Isle of Skye (ST01, ST02 and ST09) did not transmit after their deployment. All tags sent initial messages when activated prior to deployment. After deployment, ST01 sent a second GPS position 7 hours after being activated and ST02 sent a GPS position two days after being deployed. It is suspected the general poor phone signal coverage in the area is likely to be the cause of this failure. Two LO tags deployed in Orkney have been regularly transmitting their positions (ST05 and ST12) (Figure 21). The third deployed tag, ST14, did not transmit at all after deployment and the cause remains unknown.

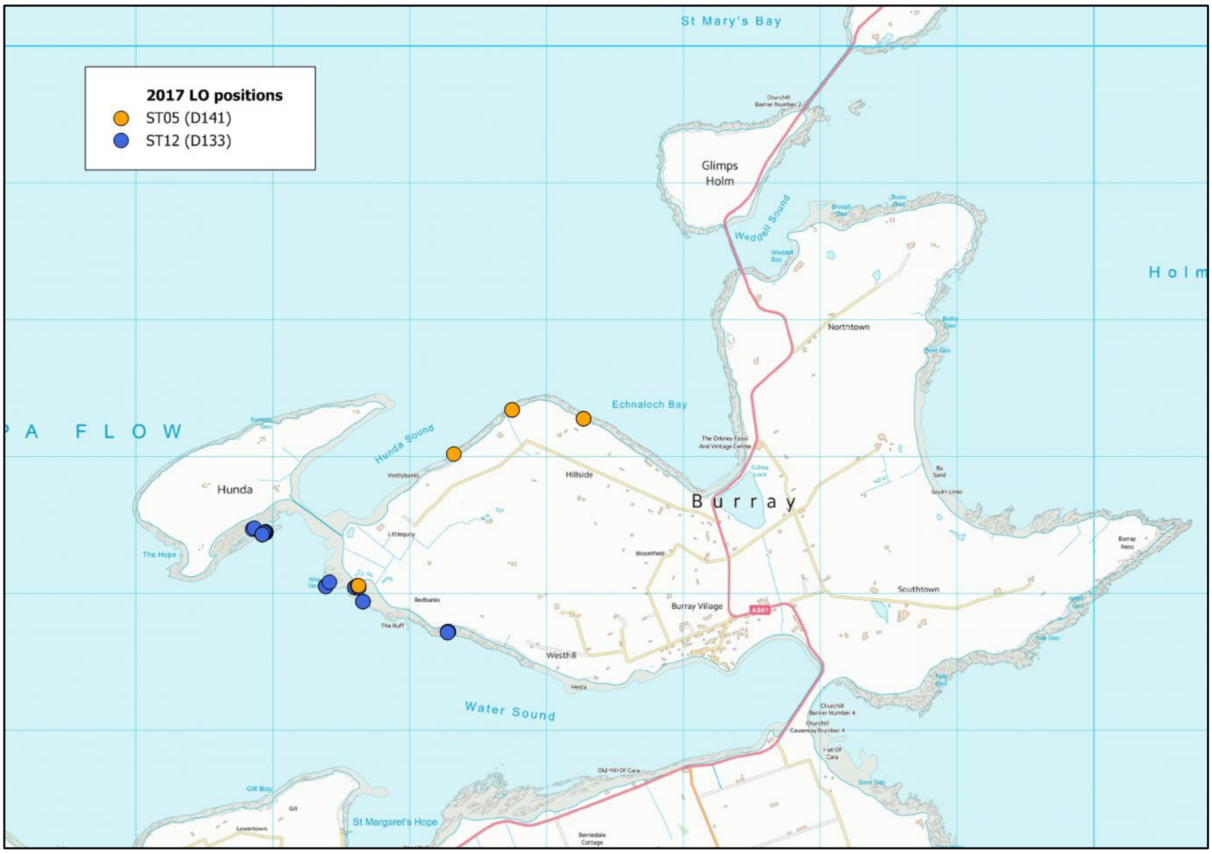

Figure 21. Positions transmitted by LO tags ST05 and ST12 in Orkney in 2017.

5 Approach 4. Counts of harbour and grey seals at and adjacent to the study sites from air surveys

5.1 Moult air surveys

SMRU carries out annual moult surveys in August to count the number of harbour and grey seals along the Scottish coastline (SCOS, 2017). Seals are well camouflaged when hauled out on rocky or seaweed covered shores and are difficult to detect. Surveys are carried out from a helicopter using a thermal-imaging camera, enabling the detection of groups of seals at a distance of up to three km, and groups of seals are photographed using a digital camera equipped with an image-stabilised zoom lens. Further details on how the surveys are conducted can be found in SCOS (2017).

Existing counts of harbour and grey seals conducted between 1985 and 2014 during the August moult were reported in the first year annual report (Arso Civil *et al*., 2016). The study sites of Kintyre, Scapa Flow (Orkney), and Loch Dunvegan (Isle of Skye) were surveyed in August 2015, 2016 and 2017, respectively, as part of the SMRU annual moult counts. Photographs taken in Skye in 2017 and resulting counts are currently being processed. These will be reported in the annual report for Year four, and compared to previous counts for the same area.

A total of 733 harbour seals and 158 grey seals were counted in the Kintyre study site (included within the Southwest Scotland management unit; see SCOS, 2016) during the August moult counts in 2015 (Figure 22). The last count in that same area was conducted in 2007, when 650 harbour seals and 208 grey seals were counted (see Arso Civil *et al*., 2016 for a summary of counts in the different study areas). In Orkney, moult surveys conducted in 2016 counted 398 harbour seals and 949 grey seals within the area of Scapa Flow (Figure 22). The harbour seal count in 2016 is lower than the previous count in 2013, in which 624 harbour seals and 858 grey seals were counted. Over the last 15 years, SMRU moult surveys have documented a continuing decline of more than 75% in counts of harbour seals in Orkney. The total harbour seal count for Orkney in 2016 was 1,240, the lowest count recorded since the mid-1980s, and is lower compared with 1,865 counted in 2013 and 8,522 counted in 1997 (Figure 23). The lowest count was recorded in 14 out of the 21 sub-regions comprising Orkney (Duck and Morris, 2017).

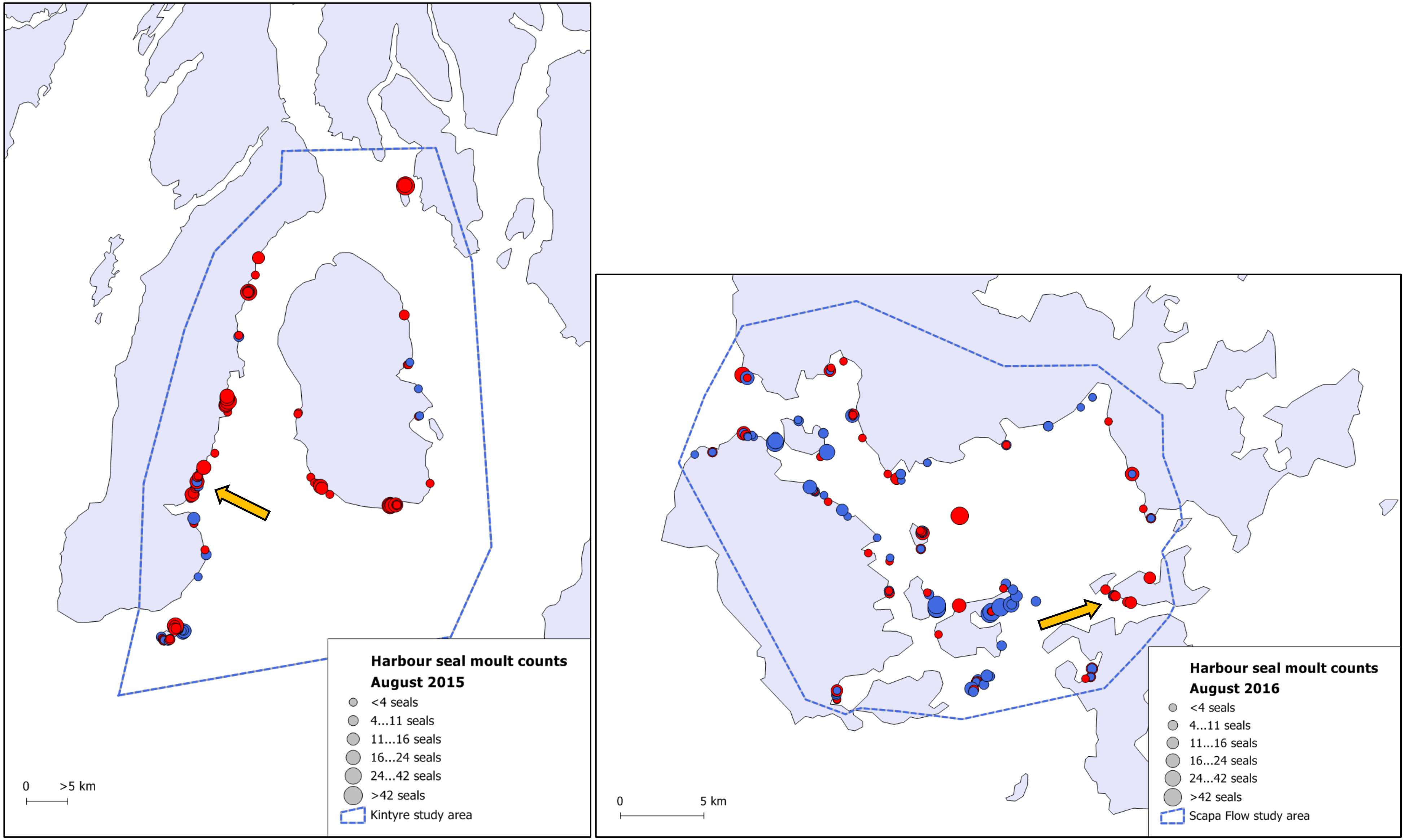

Figure 22. August moult harbour (red) and grey (blue) seals in the Kintyre (left) and Scapa Flow (Orkney) (right) study areas conducted in 2015 and 2016, respectively. The yellow arrows point to the location of the main photo-identification study sites in each region. Note: the scaling is different between the maps to accommodate the difference between the size of the study areas.

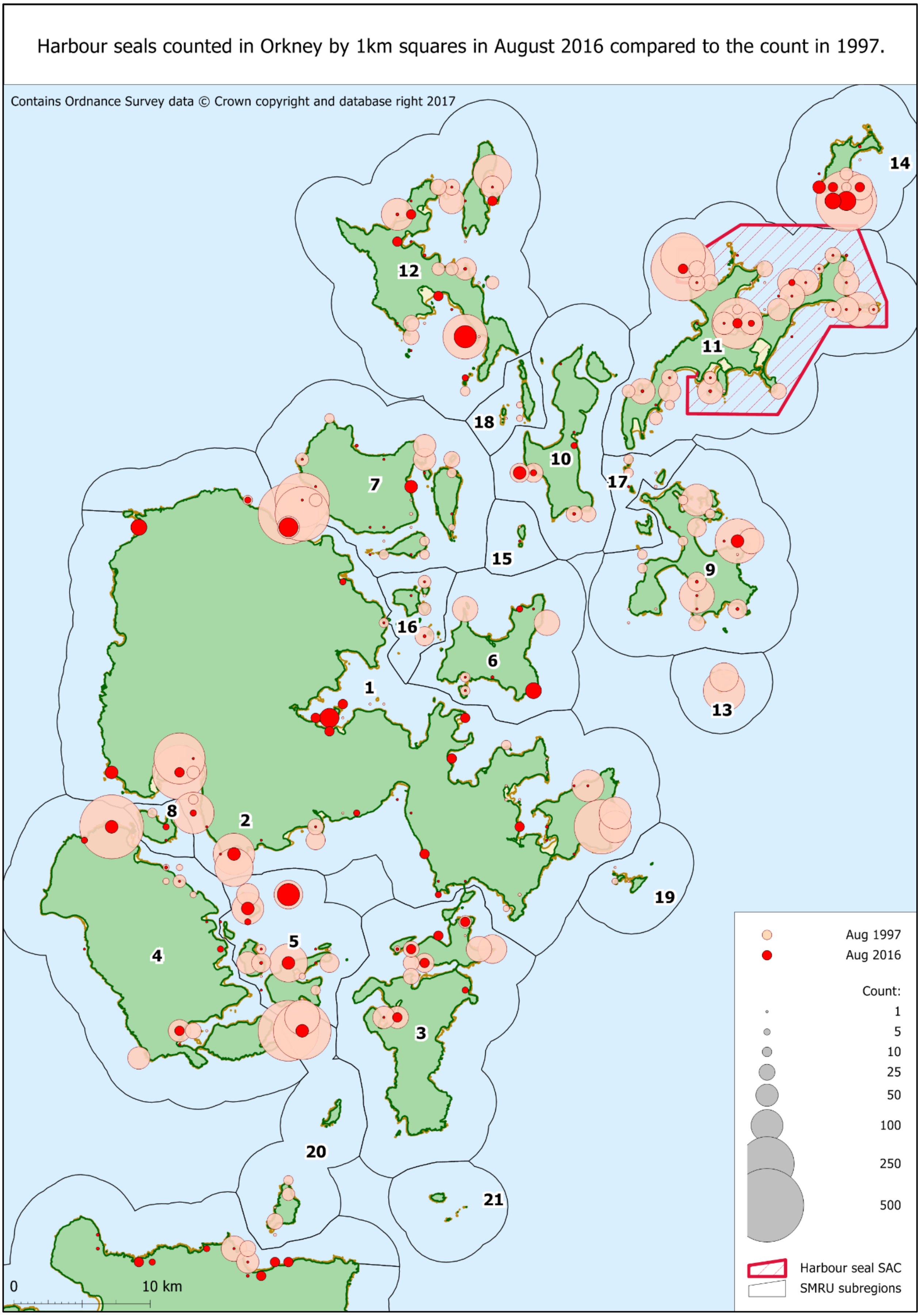

Figure 23. Harbour seals counted in Orkney by 1km square in August 2016 compared to the count in 1997 (from Duck and Morris, 2017).

6 Approach 5. Improving understanding of potential drivers of population change

6.1 Toxin uptake of harbour seals in regions with different population abundance trajectories

The results of the analysis of urine and faeces from the live captured seal in Orkney and Skye to determine the presence of domoic acid are reported under Approach 3 (Table 7).

6.1.1 Comparisons between the levels of toxins in the prey species at sites with different population abundance trajectories

6.1.1.1 Fish sampling

Prey sampling and survey at Scapa Flow

There is no commercial white fishery in Scapa Flow, and the effort by angling clubs did not coincide with putative harbour seals foraging sites therefore, a set of dedicated boat surveys were initiated. These were targeted at feeding spots within Scapa Flow, and had the following aims:

1. obtain fish guts for DA analysis,
2. qualitative exploration of fish species occurrence in putative feeding hot spots,
3. assess the practicalities of small-boat surveys for future work.

The work was carried out from the Swordsman, a 7.4m MCA coded (Category 4) work boat owned by the Scottish Oceans Institute (Figure 24 a). Rod and line fishing used both mackerel/cod flies and flatfish tackle (Figure 24 b). Video survey was carried out with a towed sledge or from a static lander (Figure 24 c).

Figure 24. Swordsman moored in Stromness (a). Video camera mounted on tripod lander (b). Rod and line fishing (c).

Foraging hotspots were identified visually from the 2016 and 2017 phone tag data. Those occurring within Scapa Flow are shown in Figure 25.

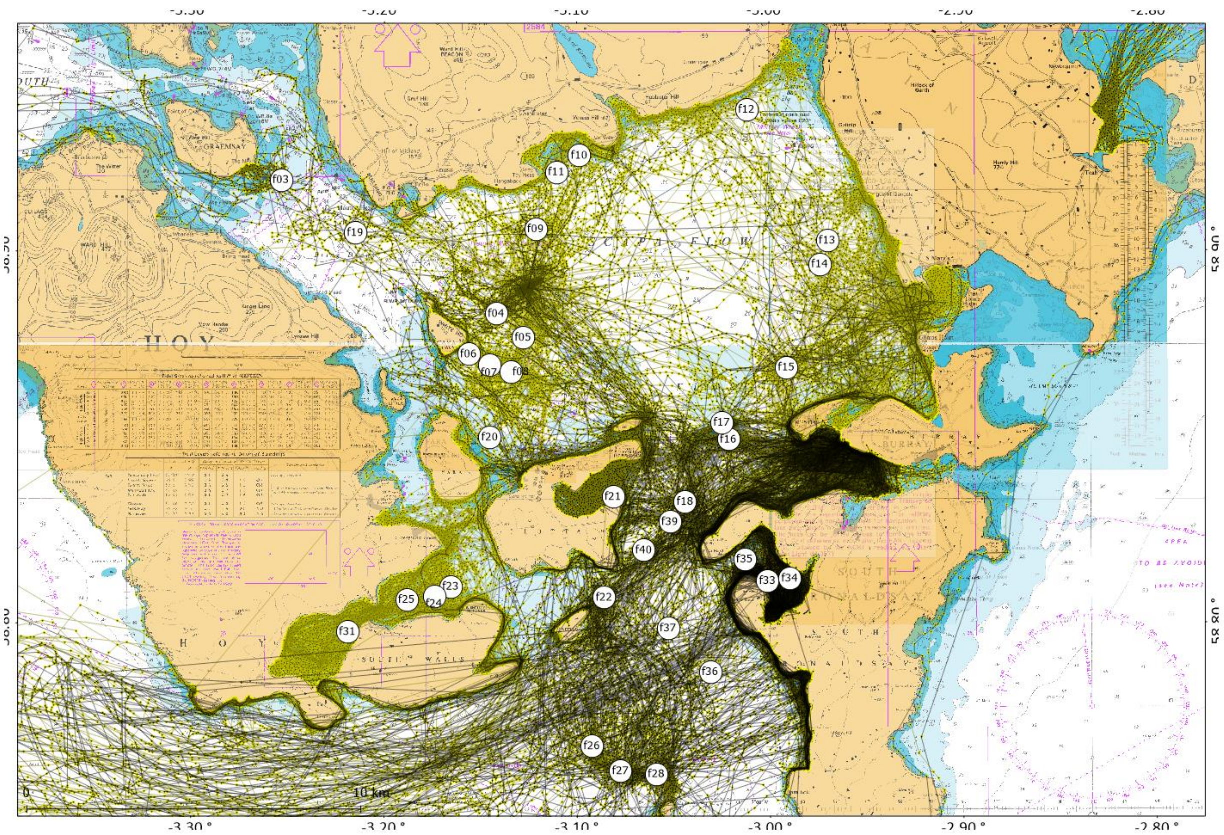

Figure 25. Map showing tracks of seals tagged in 2016 and 2017. The putative foraging locations are shown as white circles.

Two surveys were carried out. The first took place between 25 and 28 July 2017 and covered all the putative foraging sites shown in Figure 25. The second took place in November 2017, but bad weather resulted in only three days at sea and only at one site off Graemsay (F03). Table 9 shows the fish that were sampled in the two surveys.

Table 9. Number of fish samples collected in Orkney in July and November 2017.

survey	**species**	**No**
July	cod	6
	mackerel	48
	saithe	5
November	dogfish	2
	saithe	8
	dab	3

Fish were successfully sampled for biotoxin analysis (see below). Whilst rod and line (including bottom-set long lines) fishing is selective (albeit with a variety of ground tackle), and does not provide a quantitative assessment of fish abundance, it does offer the potential to qualitatively assess potential prey items. It is noteworthy that dogfish were caught at one foraging site (F03), and that a skate was photographed at another (F35). Neither of these cartilaginous species are identifiable in seal scat as they do not contain hard parts.

Working from the Swordsman proved to be valuable in assessing the practicalities of small-boat surveys for future work. It is MCA-coded to work up to 20 miles from a ‘safe haven’ and so can reach most harbour seals foraging grounds. The development of appropriate fishing techniques and the development of two underwater photographic landers were challenging, but have proved worthwhile.

Work is currently underway to assess the value of recording sonar logs over proscribed paths, during fishing surveys, with the aim of matching foraging locations to areas of increased fish biomass. Funding has been received from the Marine Alliance for Science and Technology Scotland (MASTS) to fit the Swordsman with a Humminbird Helix echosounder to collect echogram records at 83 kHz and 200 kHz, in addition to side scan sonar at 1.2 MHz. The latter will allow better micro-targeting of fruitful fishing grounds by identifying local physical features of sea bed that may correlate with increased fish abundance.

Having developed an efficient method of working, it is planned to repeat these surveys in 2018 at both Orkney (including offshore foraging grounds outside Scapa Flow) and off Skye (a contrasting site with a different population trend). For these surveys, foraging location determination will be formalised, rather than relying upon visual inspection.

Opportunistic prey sampling in North Ronaldsay

Samples of fish from North Ronaldsay (Orkney) recovered from black guillemots returning from foraging trips as part of a PhD project at the Environmental Research Institute at the University of Highlands and Islands were made available. A total of nine samples were collected between 17 June and 10 July 2017, including six butterfish (*Pholis gunnellus*), one sculpin and one Yarrell's blenny (*Chirolophis ascanii*).

6.1.1.2 Domoic acid

The results of the analysis of the fish samples collected in July and November 2017 for domoic acid are shown in Table 10. All samples were above the limit of detection except the bullrout. Mackerel caught in the summer showed the highest concentrations. Mackerel are abundant pelagic planktivores that feed on calanoid copepods. Copepods have been shown to concentrate domoic acid and are key vectors for the transfer of toxins through the food chain. Dab caught in the autumn were also found to be vectors for domoic acid.

Table 10. Samples of fish collected in Scapa Flow and North Ronaldsay analysed for domoic acid concentrations. Numbers prefixed 'F' refer to the foraging areas identified from the harbour seal telemetry data (Figure 25). All samples were fish viscera except the bullrout and butterfish where analyses were carried out on whole fish. (LOD = limit of detection).

Fish species	Mass (g)	Location	Date	DA (pg/g)
Bullrout	11.6	North Ronaldsay	5/7/17	<LOD
Butterfish (4)	42.3	North Ronaldsay	6/7/17	19,284
Mackerel	40.9	Orkney (F19)	27/7/17	56,670
Mackerel	119.9	Flotta (F40)	27/7/17	64,113
Mackerel	144.1	Hunda Sound	27/7/17	143,277
Mackerel	30.4	Churchill Bay	27/7/17	72,432
Saithe	61.9	The Grinds (F17)	27/7/17	88,753
Cod	57.1	Orkney (F22)	28/7/17	6,503
Cod	57.1	Orkney (F22)	28/7/17	2,669
Cod	48.1	Orkney (F22)	28/7/17	6,004
Mackerel	130.3	Triton Bank (F27)	28/7/17	46,347
Mackerel	117.0	Barrel of Butter	28/7/17	107,195
Mackerel	119.2	Orkney (F22 #2)	28/7/17	22,577
Dogfish	208.6	Graemsay	8/11/17	7,827
Saithe	46.0	Graemsay (F03)	8/11/17	4,194
Dab (3)	15.4	Orkney (F03)	11/11/17	78,085
Saithe (4)	66.2	Orkney (F03)	11/11/17	1,044

6.1.1.3 Saxitoxin

Guts were removed from various fish species collected in June 2017 (Sinclair Bay, Caithness) and pooled (three or four individuals from the same species). The pooled tissues (14 samples in total) alongside a number of fish gut samples (nine) collected in Orkney in July 2017 were homogenised using a blender prior to acetic acid extraction which followed the AOAC Official Method 2005.06 protocol (Lawrence *et al.*, 2005) (Table 11).

Table 11. Fish guts analysed for presence of PSP toxins from samples collected in Orkney and Sinclair Bay in 2017.

Species	Tissue type	Site	Date	Reference	Comments
Dab	Guts	Sinclair bay	02-Jun	N/A	Pool of 5 fish
Mackerel	Guts	Haul 8	02-Jun	58 12 218/02 46 826	Pool of 5 fish
Mackerel	Guts	Haul 11	02-Jun	57 48 725/02 46 973	Pool of 5 fish
Mackerel	Guts	SI 7004	02-Jun	N/A	1 fish
Mackerel	Guts	Haul 12	02-Jun	57 47 41/02 07 82	Pool of 5 fish
Cod	Guts	Sinclair bay	02-Jun	N/A	1 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 4 fish
Mackerel	Guts	Sinclair bay	02-Jun	N/A	Pool of 4 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Mackerel	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Haddock	Guts	Sinclair bay	02-Jun	N/A	Pool of 3 fish
Saithe	Guts	Orkney - F7	27-Jul	5	NA
Cod	Guts	Orkney - F19	27-Jul	6	NA
Cod	Guts	Orkney - F22	28-Jul	7	NA
Cod	Guts	Orkney - F22	28-Jul	8	NA
Mackerel	Guts	Orkney - F40	27-Jul	9	NA
Mackerel	Guts	Orkney - F27	28-Jul	10	NA
Mackerel	Guts	Orkney - F19	27-Jul	11	NA
Mackerel	Guts	Orkney - F23	28-Jul	12	NA
Mackerel	guts	Orkney - F17	27-Jul	13	NA
Mackerel	guts	Orkney - F13	27-Jul	14	NA
Mackerel	guts	Orkney - F22	28-Jul	15	NA

The gut extracts were cleaned using C18 solid phase cartridges. After periodate oxidation, the cleaned extracts were analysed for Paralytic Shellfish Poisoning (PSP) toxins by liquid chromatography with fluorescence detection (LC-FLD). The extracts were screened for PSP toxins by comparing and matching the retention times of specific target chromatographic peaks with those derived from oxidised PSP calibration standards. The certified reference materials (CRMs), purchased from the Institute of Biotoxin Metrology, NRCC, Halifax, Canada, used to prepare the standards, included: saxitoxin (STX), Neosaxitoxin (NEO), decarbamoyl saxitoxin (dcSTX), gonyautoxins 1 to 5 (GTX1-5), decarbamoyl gonyautoxins 2 and 3 (dcGTX2,3) and C toxins 1 and 2 (C1,2).

PSP analysis was performed using a Shimadzu Prominence LC-FLD system (Milton Keynes, UK). The PSP toxins were separated in a 15 minute run using a Supelcosil LC-18 analytical column (150 x 4.6 mm, 5 µm particle size). Gut extracts without periodate oxidation were also analysed to check for the presence of naturally fluorescent coextractives.

The 25 periodate-oxidised gut cleaned extracts which were analysed did not contain any detectable PSP toxins. The chromatograms were easy to interpret as the C18 clean-up removed any interference.

7 Approach 6. Carcass collection

A total of 92 seal carcasses were reported to the Scottish Marine Animal Strandings Scheme (SMASS) between March 2017 and February 2018 in the three study areas (Orkney, Isle of Skye and Kintyre and the Clyde). No carcasses were reported for these areas in May 2017. Figure 26 shows the locations of all reported carcasses during the time period in all study areas, and Figure 27 shows a detail of the locations for Orkney. Tables 4.A, 4.B, and 4.C in Appendix 4 summarize details on species, age class and proximate cause of death, when available.

Most of the reported seal carcasses were found in Orkney (n=44) and Strathclyde (where Kintyre and the Clyde are included) (n=43) (Tables 4.A and 4.B in Appendix 4). In Orkney, 25 grey seals (one adult and 24 unknown age), four harbour seals (two pups, one juvenile and one unknown age) and 15 carcasses that could not be identified to the species level were reported. Proximate cause of death could only be established for one carcass of unknown species as a case of possible grey seal predation. For the remaining carcasses, proximate cause of death could not be determined due to advance autolysis and damage to the carcasses. Tissue samples were taken from the two harbour seal pups.

In the Kintyre and Clyde area, the reported 43 seal carcasses included ten grey seals (two adults and eight seals of unknown age), 15 harbour seals (one adult, three juveniles and eleven of unknown age) and 18 carcasses that could not be identified to the species level (Table 4.B in Appendix 4). Only one harbour seal carcass was recovered and is pending a post-mortem examination. For the remaining harbour and grey seal carcasses, proximate cause of death could not be determined due to advanced autolysis and damage to the carcass, except for one harbour seal, for which seal predation was determined as the proximate cause of death.

A total of five harbour seal carcasses were reported in Isle of Skye (Table 4.C in Appendix 4), comprising one pup, two juveniles and two seals of unknown age. Of these, one juvenile was recovered for a post-mortem (results pending) and one juvenile had samples taken. A proximate cause of death could only be determined for one seal of unknown age as possible grey seal predation; for the remaining carcasses, cause of death could not be determined due to advance autolysis and damage to the carcasses.

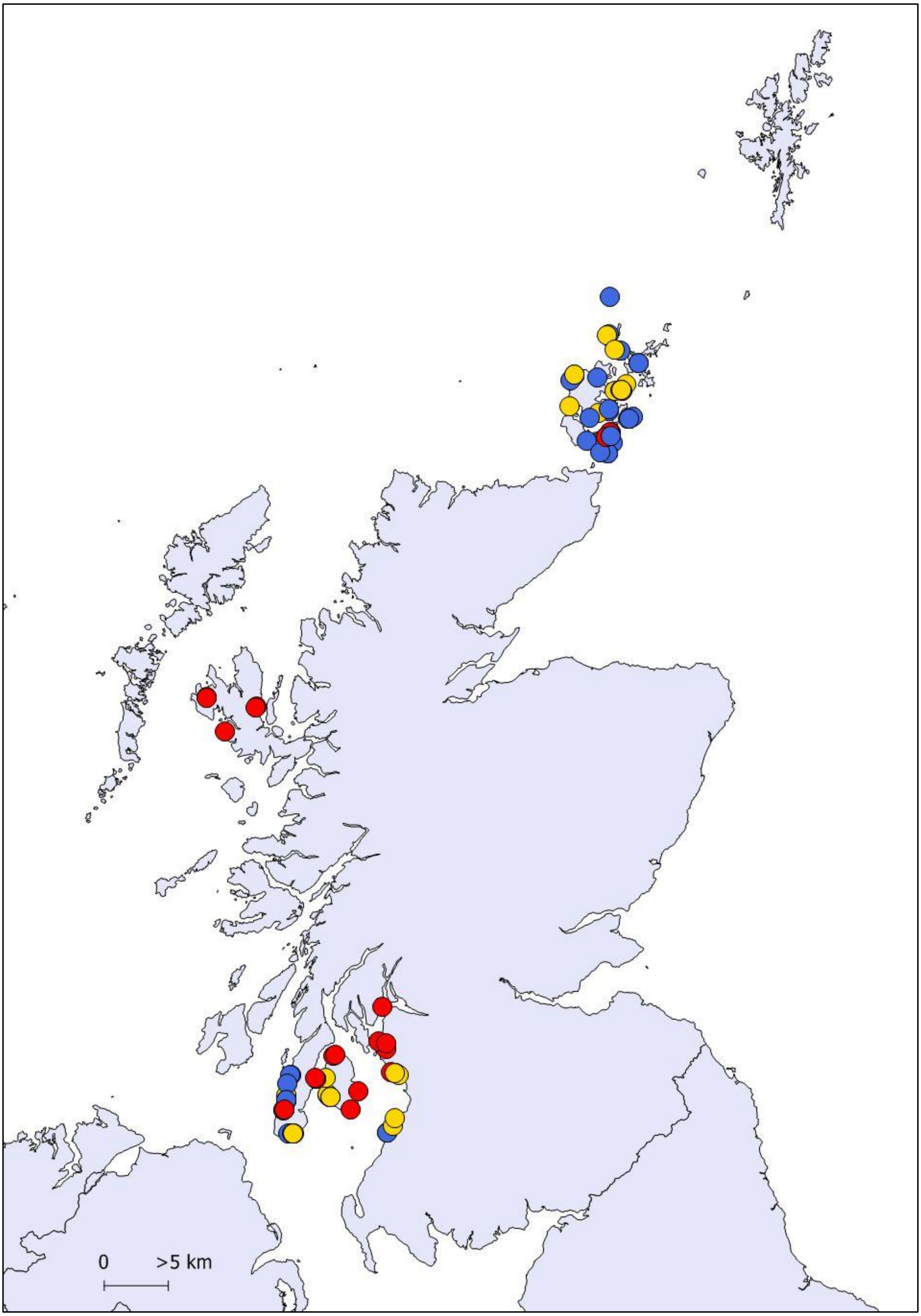

Figure 1. Location of all seal carcasses reported to SMASS between March 2017 and February 2018 within the vicinity of the study areas. Red = grey seal, blue = harbour seal, yellow = pinniped, species unknown.

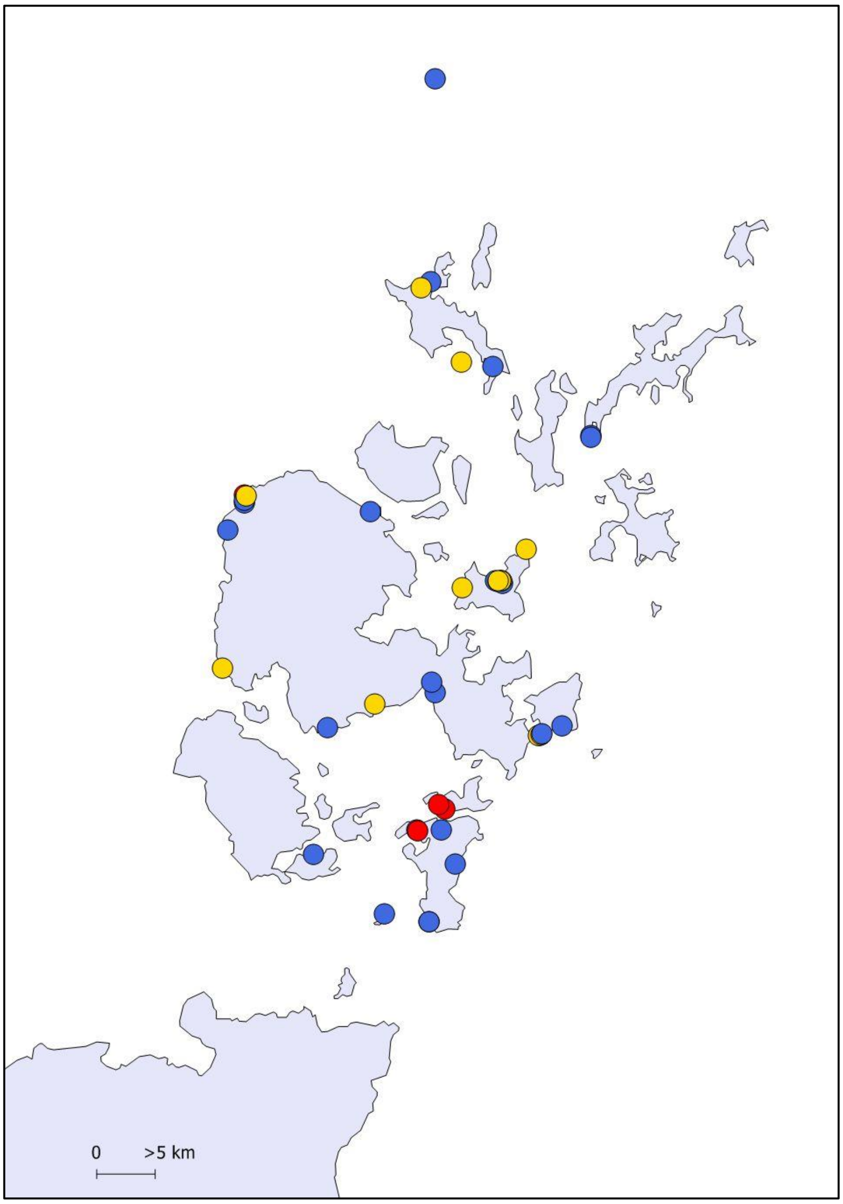

Figure 2. Location of all seal carcasses reported to SMASS between March 2017 and February 2018 in Orkney. Red = grey seal, blue = harbour seal, yellow = pinniped, species unknown.

8 Appendices

8.1 Appendix 1: Deliverables for Year 3 (HSD 2)

Approach 1. Integrated population model.

1. A decision-support tool coded in R consisting of

(i) a simulation that predicts harbour seal population size and pup production at a study site, given realistic values for survival and fecundity rates (these can be set by the user). This simulation will output 'observations' that will be collected during the HSD study. Realistic errors can be associated with these observations.

(ii) a 'fitting' module will take the simulated data set, and fit a population model to it using the methodology that we aim ultimately to use to fit the real data we will collect during the harbour seal fieldwork.

The simulation module will provide a useful tool that can be used directly to explore the sensitivity of harbour seal populations to changes in population parameters such as survival or fecundity rates. The fitting module will allow us to explore the feasibility of fitting population models to limited data sets (e.g. adult moult counts only) and the importance of obtaining parameter estimates that can be used as priors in the modelling process, such as fecundity rates.

Approach 2. Investigate harbour seal vital rates and movement using capture-mark-recapture and telemetry.

The calculation of vital rates will not start until year five, following the collection of field data for four consecutive pupping seasons (2016 to 2019)

1. Catalogue of individually photographed seals in 2016 with information, when available, on approximate age class, sex, pregnancy (from visual observation) and presence of associated pup.

2. Summary of photo-identification data collected in 2017 across the study sites

Approach 3. Live Captures.

1. Data on the movements of harbour seals between haulout sites within the time period of the photo ID study to be used to inform the photo ID field effort and data analysis.

2. Estimates of pregnancy and natality for a subset of harbour seals using the study site.

3. Comparisons between the age, condition, pregnancy, toxin exposure and health status among individuals captured at study sites in regions with different abundance trajectories.

Approach 4. Counts of harbour and grey seals at and adjacent to the study sites from air surveys.

1. Moult season counts of harbour seals for parameterisation of the integrated population model.

2. Abundance of grey seals using the study sites and adjacent haulout sites to provide covariates for assessing the spatial overlap between grey seals and harbour seals.

3. If feasible, size structure (at the scale of small, medium and large animals) of seals at the haulout sites in regions with different population abundance trajectories.

Approach 5. Improving understanding of potential drivers of population change

1. Comparisons between the toxin up-take of harbour seals in regions with different population abundance trajectories.

2. Comparisons between the prey available to harbour and grey seals in the vicinity of the haulout sites and the levels of toxins in the prey species at sites with different population abundance trajectories.

Approach 6. Carcass collection

1. Full necropsy reports on any dead seals found and collected within the regions of the study sites (in collaboration with Scottish Marine Animal Stranding Scheme)

2. Comparison between the causes of death in regions of decline compared to those of stability or increase

8.2 Appendix 2. Deterministic simulation model

```
## Deterministic simulation model
######################################################################
Sim.fn<-function(spupmax,smale,sfemale,fec,mort2,nyear,firstseals,bk)
######################################################################
{
  ####### PARAMETERS ###########
  ### matrix to represent the seal population structure each year
  # males are 1:5; female are 6:10; final absorbing age class (aged 5) is "mature animals" for both sexes
  n<-matrix(nrow=10,ncol=nyear,data=0)
  ## vector to store time series of total population size
  ntot<-rep(0,nyear)
  ntot[1]<-firstseals
  # survival and related matrices
  s<-matrix(nrow=10,ncol=nyear,data=0)     # survival
  f<-rep(fec,nyear)                        # fecundity
  spup<-rep(0,(nyear-1))                   # pup survival
  bbeta<-1/bk   # density dependence parameter (here set to 0 : no DD)
  k<-5          # shape parameter (not used here, no DD is operating)
  spup[1]<-spupmax/(1+(bbeta*firstseals)^k)   # pup survival, first year
  s[1,1]<-spup[1]
  s[6,1]<-spup[1]
  s[1,2:nyear]<-NA
  s[6,2:nyear]<-NA
  s[2:5,1:nyear]<-smale
  s[7:10,1:nyear]<-sfemale
  s[,1]<-s[,1]*(1-mort2)
  f[1:nyear]<-fec
  # set fecundity for year 1
  fec1<-f[1]
  ## Leslie matrix for year 1 age sructure using eigenvector
  les<-matrix(nrow=10,ncol=10,data=0)
  les[1,10]<-s[10,1]*fec1/2
  les[2,1]<-s[1,1]
  les[3,2]<-s[2,1]
  les[4,3]<-s[3,1]
  les[5,4]<-s[4,1]
  les[5,5]<-s[5,1]
  les[6,10]<-s[10,1]*fec1/2
  les[7,6]<-s[6,1]
  les[8,7]<-s[7,1]
```

```
les[9,8]<-s[8,1]
les[10,9]<-s[9,1]
les[10,10]<-s[10,1]
first.evector<-Re(eigen(les)$vectors[,1])
agestructure<-first.evector/(sum(first.evector))
## multiply up by the initial number of seals in the population
n1<-1*(firstseals*agestructure)
n[,1]<-n1

################# POPULATION DYNAMICS ##########################

for(t in 1:(nyear-1)){
  # total population size in year t
    ntot[t]<-sum(n[1:5,t])+sum(n[6:10,t])
  # pup survival for this year
    spup[t]<-spupmax/(1+(bbeta*ntot[t])^k)  ## DD in pup survival
    s[1,t]<-spup[t]
    s[6,t]<-spup[t]
  # apply additional mortality to all ages
    s[,t]<-s[,t]*(1-mort2)
  # pups, juveniles and adults survive from year t to t+1
    n[2,t+1]<-1*(n[1,t]*s[1,t])
    n[3,t+1]<-1*(n[2,t]*s[2,t])
    n[4,t+1]<-1*(n[3,t]*s[3,t])
    n[5,t+1]<-1*(n[4,t]*s[4,t])+1*(n[5,t]*s[5,t])
    n[7,t+1]<-1*(n[6,t]*s[6,t])
    n[8,t+1]<-1*(n[7,t]*s[7,t])
    n[9,t+1]<-1*(n[8,t]*s[8,t])
    n[10,t+1]<-1*(n[9,t]*s[9,t])+1*(n[10,t]*s[10,t])
  # Birth probability
  # the surviving adult females may pup in year t+1
    pups <- n[10,t+1]*f[t]
    # 50% of the pups are female (random, binomial)
          n[1,t+1] <- 1*(pups/2)
          n[6,t+1] <- 1*(pups/2)
} # end of main loop
# total population size in final year
    ntot[t+1]<-sum(n[1:10,t+1])
# calculate the average rate of population change and return this
    results<-list(rate=(ntot[nyear]/ntot[1])^(1/(nyear-1)))
    return(results)
}
```

8.3 Appendix 3: List of identified seals in Orkney in 2016 at the main haulout sites

The table below summarises all identified seals for which photo-identification data were collected in 2016 at the main monitored haulout sites in Orkney. L, R, F = top quality photographs available for left-, right-, and front- sides; Firstseen = first time photographed (this includes capture-release events); Firstseen_Q34 = first time photographed with quality 3 or 4 according to the grading criteria; Agethen = estimated ageclass based on size; Sex = Male, Female, Unknown; Pup_2016, Preg_2016, Suckle_2016 = information on whether the females were seen with a pup, pregnant or suckling a pup.

Note that pups's IDNO is made up of the mother's IDNO and _P16 to define it as a pup born in 2016.

IDNO	L	R	F	Firstseen	Firstseen_Q34	Agethen	Sex	Pup_2016	Preg_2016	Suckle_2016
Or001	4	4	3	06/04/2016	06/04/2016	Adult	F	No	Yes	
Or002	4	4	3	31/03/2016	31/03/2016	Adult	F	No	No	
Or003	3	4	3	23/05/2016	23/05/2016	Adult	M			
Or004	4	4	2	31/03/2016	31/03/2016	Adult	M			
Or005	1	2	1	23/06/2016	NA	Adult	F	Yes	No	Yes
Or005_P16	2	2	0	23/06/2016	NA	Pup	U			
Or006	3	4	0	30/06/2016	30/06/2016	Adult	M			
Or007	3	3	2	31/03/2016	31/03/2016	Adult	F	Yes	No	Yes
Or007_030_P16[6]	4	4	2	12/06/2016	15/06/2016	Pup	M			
Or008	3	3	2	28/06/2016	28/06/2016	Adult	F	No	No	
Or009	4	4	3	20/05/2016	20/05/2016	Adult	F	No	No	
Or010	4	4	2	06/04/2016	06/04/2016	Adult	F	Yes	Yes	Yes
Or010_P16	3	4	0	15/06/2016	15/06/2016	Pup	M			
Or011	0	3	0	25/05/2016	25/05/2016	Adult	M			
Or012	4	3	3	31/03/2016	31/03/2016	Juvenile	F	No	No	
Or013	4	4	2	25/05/2016	25/05/2016	Juvenile	M			
Or015	3	3	2	20/05/2016	20/05/2016	Adult	F	Yes	No	Yes
Or015_P16	3	2	2	03/07/2016	17/07/2016	Pup	U			
Or016	4	4	3	31/03/2016	31/03/2016	Adult	M			
Or018	0	3	0	28/05/2016	28/05/2016	Adult	M			
Or020	4	4	2	06/04/2016	06/04/2016	Adult	F	Yes	Yes	Yes
Or020_P16	3	4	2	25/06/2016	08/07/2016	Pup	U			
Or021	3	3	2	09/06/2016	09/06/2016	Adult	F	No	No	
Or022	4	4	3	06/04/2016	06/04/2016	Adult	F	No	Maybe	
Or023	3	3	0	23/05/2016	23/05/2016	Adult	F	No	No	
Or024	4	4	2	20/05/2016	20/05/2016	Adult	F	Yes	Yes	Yes
Or024_P16	2	2	0	26/06/2016	NA	Pup	U			
Or025	4	4	3	06/04/2016	06/04/2016	Adult	F	No	Yes	
Or026	4	4	3	13/06/2016	13/06/2016	Adult	F	Yes	Yes	Yes
Or026_P16	3	3	0	04/07/2016	07/07/2016	Pup	U			
Or027	4	4	2	31/03/2016	31/03/2016	Adult	U	No	No	
Or028	4	3	3	31/03/2016	31/03/2016	Adult	M			
Or029	4	4	2	31/03/2016	31/03/2016	Adult	M			
Or030	4	4	3	31/03/2016	31/03/2016	Adult	F	Yes	No	Yes
Or031	4	4	3	02/04/2016	02/04/2016	Adult	U			
Or032	2	3	2	31/03/2016	31/03/2016	Adult	M			
Or033	4	3	2	31/03/2016	31/03/2016	Adult	F	Yes	No	Yes

[6] This pup was first seen associated and suckling from female Or030 and later on suckling from female Or007. Consequently the pup has been named with both females' names.

Or033_P16	3	3	3	29/06/2016	13/07/2016	Pup	M			
Or034	0	3	0	02/04/2016	02/04/2016	Adult	U			
Or035	0	3	2	02/04/2016	02/04/2016	Adult	U			
Or038	4	4	3	06/04/2016	06/04/2016	Adult	F	Yes	Yes	Yes
Or038_P16	3	3	2	23/06/2016	24/07/2016	Pup	U			
Or040	4	0	3	06/04/2016	06/04/2016	Adult	M			
Or041	4	4	3	06/04/2016	06/04/2016	Adult	F	No	No	
Or042	4	4	3	18/05/2016	18/05/2016	Adult	M			
Or043	3	3	3	18/05/2016	18/05/2016	Adult	F	No	Yes	
Or044	4	4	2	18/05/2016	18/05/2016	Adult	F	Yes	Yes	Yes
Or044_P16	2	2	0	15/06/2016	NA	Pup	U			
Or045	4	4	3	19/05/2016	19/05/2016	Adult	F	Yes	Yes	Yes
Or045_P16	0	1	0	18/06/2016	NA	Pup	U			
Or047	1	3	0	31/03/2016	31/03/2016	Adult	M			
Or048	3	0	0	02/04/2016	02/04/2016	Adult	U			
Or049	4	3	1	18/05/2016	18/05/2016	Adult	U			
Or050	0	2	0	20/05/2016	NA	Adult	U			
Or051	0	3	3	20/05/2016	20/05/2016	Adult	F	No	No	
Or052	1	3	3	20/05/2016	20/05/2016	Adult	U			
Or053	0	3	0	20/05/2016	20/05/2016	Adult	F	No	No	
Or054	0	4	3	20/05/2016	20/05/2016	Adult	F	Yes	Yes	Yes
Or055	0	3	0	20/05/2016	20/05/2016	Adult	U			
Or056	0	3	0	20/05/2016	20/05/2016	Adult	U			
Or057	4	4	3	20/05/2016	20/05/2016	Adult	F	Yes	Yes	Yes
Or057_P16	3	3	1	20/06/2016	20/06/2016	Pup	U			
Or058	3	3	0	20/05/2016	20/05/2016	Juvenile	F			
Or059	4	4	3	20/05/2016	20/05/2016	Adult	F	Yes	Yes	Yes
Or059_P16	3	3	0	18/06/2016	21/06/2016	Pup	U			
Or060	4	4	3	20/05/2016	20/05/2016	Adult	M			
Or062	4	4	3	20/05/2016	20/05/2016	Adult	F	Yes	Yes	Yes
Or062_P16	3	2	0	14/06/2016	06/07/2016	Pup	U			
Or063	0	3	0	23/05/2016	23/05/2016	Adult	M			
Or064	4	4	3	23/05/2016	23/05/2016	Adult	M			
Or065	4	4	3	23/05/2016	23/05/2016	Juvenile	F			
Or066	0	3	0	23/05/2016	23/05/2016	Adult	M			
Or067	2	3	0	23/05/2016	23/05/2016	Adult	F		Yes	
Or068	4	4	2	23/05/2016	23/05/2016	Juvenile	U			
Or069	4	4	3	25/05/2016	25/05/2016	Adult	F	Yes	Yes	Yes
Or069_P16	3	3	0	13/06/2016	16/06/2016	Pup	U			
Or070	3	3	2	25/05/2016	25/05/2016	Juvenile	U			
Or071	4	4	3	25/05/2016	25/05/2016	Juvenile	F			
Or072	3	3	3	18/05/2016	18/05/2016	Juvenile	M			
Or073	4	4	0	25/05/2016	25/05/2016	Juvenile	M			
Or074	4	4	3	25/05/2016	25/05/2016	Adult	M			
Or075	3	2	3	25/05/2016	25/05/2016	Adult	F			
Or076	3	3	1	25/05/2016	25/05/2016	Juvenile	M			
Or079	4	0	0	26/05/2016	26/05/2016	Adult	M			
Or080	3	0	2	26/05/2016	26/05/2016	Adult	U			

Or081	4	4	2	26/05/2016	26/05/2016	Adult	M			
Or083	3	0	0	26/05/2016	26/05/2016	Adult	U			
Or084	3	3	2	26/05/2016	26/05/2016	Adult	M			
Or085	3	3	2	26/05/2016	26/05/2016	Juvenile	F	No	No	
Or086	4	4	3	27/05/2016	27/05/2016	Adult	F			
Or087	4	4	2	27/05/2016	27/05/2016	Adult	F	Yes	Yes	Yes
Or087_P16	3	3	3	27/06/2016	28/06/2016	Pup	U			
Or088	4	4	2	27/05/2016	27/05/2016	Adult	M			
Or089	4	3	3	28/05/2016	28/05/2016	Adult	F	Yes	Yes	Yes
Or089_P16	4	3	0	01/07/2016	01/07/2016	Pup	U			
Or090	3	3	3	27/05/2016	27/05/2016	Juvenile	F	No	No	
Or091	4	4	3	26/05/2016	26/05/2016	Adult	F	Yes	Yes	Yes
Or091_P16	3	4	2	15/06/2016	15/06/2016	Pup	U			
Or092	3	4	3	28/05/2016	28/05/2016	Adult	F	Yes	No	
Or092_P16	2	2	0	21/06/2016	NA	Pup	U			
Or093	3	3	2	29/05/2016	29/05/2016	Adult	F	No	No	
Or094	4	4	2	29/05/2016	29/05/2016	Adult	F	Yes	Yes	Yes
Or094_P16	3	3	0	23/06/2016	17/07/2016	Pup	U			
Or095	0	3	0	31/05/2016	31/05/2016	Adult	U			
Or096	3	4	2	20/05/2016	20/05/2016	Adult	F	No	Yes	
Or097	0	3	0	31/05/2016	31/05/2016	Adult	F			
Or098	4	3	2	31/05/2016	31/05/2016	Adult	F	Yes	Yes	Yes
Or098_P16	3	3	1	19/06/2016	26/06/2016	Pup	U			
Or101	3	0	0	01/06/2016	01/06/2016	Adult	U			
Or103	3	3	0	08/06/2016	08/06/2016	Adult	F		Yes	
Or104	4	4	2	03/06/2016	03/06/2016	Adult	F	No	Yes	
Or108	4	4	2	08/06/2016	08/06/2016	Adult	F	Yes	Yes	Yes
Or108_P16	3	3	0	14/06/2016	21/06/2016	Pup	U			
Or109	0	3	0	08/06/2016	08/06/2016	Adult	F			
Or110	3	2	2	01/06/2016	01/06/2016	Adult	F	Yes	Yes	
Or110_P16	2	0	0	04/07/2016	NA	Pup	U			
Or112	4	3	2	09/06/2016	09/06/2016	Adult	F	Yes	Yes	
Or112_P16	3	3	1	17/06/2016	27/06/2016	Pup	U			
Or113	3	3	2	09/06/2016	20/06/2016	Juvenile	M			
Or116	0	4	0	10/06/2016	10/06/2016	Juvenile	U			
Or117	3	3	0	10/06/2016	10/06/2016	Adult	F			
Or118	4	4	3	10/06/2016	10/06/2016	Adult	F	Yes	Yes	Yes
Or118_P16	3	3	0	20/06/2016	20/06/2016	Pup	U			
Or121	4	4	3	13/06/2016	13/06/2016	Adult	F	Yes	Yes	Yes
Or121_P16	3	2	0	21/06/2016	21/06/2016	Pup	U			
Or123	4	4	3	14/06/2016	14/06/2016	Adult	F	Yes	No	Yes
Or123_P16	3	3	0	15/06/2016	15/06/2016	Pup	U			
Or124	4	4	3	15/06/2016	15/06/2016	Adult	F	Yes		Yes
Or124_P16	2	2	0	20/06/2016	NA	Pup	U			
Or125	3	4	3	26/05/2016	26/05/2016	Adult	F	Yes	No	Yes
Or126	0	4	0	21/06/2016	21/06/2016	Adult	U			
Or127	3	3	0	15/06/2016	15/06/2016	Adult	F	Yes	Yes	Yes
Or127_P16	1	1	0	14/07/2016	NA	Pup	F			

Or128	0	3	0	16/06/2016	16/06/2016	Adult	U			
Or129	4	4	3	16/06/2016	16/06/2016	Adult	F	Yes	Yes	
Or129_P16	0	1	0	17/06/2016	NA	Pup	U			
Or130	4	4	3	16/06/2016	16/06/2016	Adult	F	Yes	Yes	Yes
Or130_P16	1	2	0	20/06/2016	NA	Pup	U			
Or132	3	4	2	17/06/2016	17/06/2016	Adult	F	Yes	No	Yes
Or132_P16	3	3	1	17/06/2016	20/06/2016	Pup	U			
Or133	4	4	3	18/06/2016	18/06/2016	Adult	F	Yes	Yes	Yes
Or133_P16	3	3	0	18/06/2016	19/06/2016	Pup	U			
Or134	4	3	2	18/06/2016	18/06/2016	Adult	F	Yes		Yes
Or134_P16	3	3	2	18/06/2016	18/06/2016	Pup	U			
Or135	4	3	2	19/06/2016	19/06/2016	Adult	U			
Or136	4	0	0	20/06/2016	20/06/2016	Adult	M			
Or137	4	4	2	20/06/2016	20/06/2016	Adult	F	Yes		Yes
Or137_P16	1	3	0	20/06/2016	20/06/2016	Pup	U			
Or138	4	3	2	20/06/2016	20/06/2016	Adult	F	Yes		
Or138_P16	3	3	0	20/06/2016	04/07/2016	Pup	U			
Or139	3	2	2	20/06/2016	20/06/2016	Adult	F	Yes	No	Yes
Or139_P16	0	2	0	20/06/2016	NA	Pup	U			
Or141	3	4	2	21/06/2016	21/06/2016	Adult	F	Yes	No	Yes
Or141_P16	0	3	0	25/06/2016	25/06/2016	Pup	U			
Or142	4	4	2	21/06/2016	21/06/2016	Adult	F	Yes		Yes
Or142_P16	3	4	0	21/06/2016	21/06/2016	Pup	U			
Or144	4	4	3	21/06/2016	21/06/2016	Adult	F	Yes		Yes
Or144_P16	4	4	3	21/06/2016	21/06/2016	Pup	U			
Or145	0	3	0	21/06/2016	21/06/2016	Adult	M			
Or146	3	2	3	26/06/2016	26/06/2016	Adult	F	Yes		
Or146_P16	0	0	2	26/06/2016	NA	Pup	U			
Or150	4	0	0	27/06/2016	27/06/2016	Adult	M			
Or151	3	3	2	27/06/2016	27/06/2016	Adult	F	Yes		Yes
Or151_P16	3	3	0	27/06/2016	27/06/2016	Pup	U			
Or153	3	4	0	27/06/2016	27/06/2016	Adult	F	No		
Or157	0	2	0	20/06/2016	NA	Pup	U			
Or157_P16	2	2	0	20/06/2016	NA	Pup	U			
Or161	3	0	0	03/07/2016	03/07/2016	Adult	F	Yes	No	
Or161_P16	3	2	0	03/07/2016	03/07/2016	Pup	U			
Or166	3	4	3	06/07/2016	06/07/2016	Adult	U			
Or169	2	3	0	08/07/2016	08/07/2016	Adult	U			
Or170	3	3	3	08/07/2016	08/07/2016	Adult	F	No	No	
Or171	3	2	2	09/07/2016	09/07/2016	Juvenile	U			
Or172	3	4	3	12/07/2016	12/07/2016	Adult	M			
Or173	4	4	0	14/07/2016	14/07/2016	Adult	F	No	No	
Or182	4	0	0	21/07/2016	21/07/2016	Adult	U			
Or185	3	4	1	28/06/2016	28/06/2016	Juvenile	U			
Or186	3	0	0	23/07/2016	23/07/2016	Juvenile	U			
Or189	3	3	1	23/07/2016	23/07/2016	Adult	U			
Or191	4	3	2	24/07/2016	24/07/2016	Juvenile	U			
Or192	4	3	4	24/07/2016	24/07/2016	Adult	M			

Or224	3	0	0	26/07/2016	26/07/2016	Adult	U
Or231	3	4	0	31/05/2016	31/05/2016	Adult	U
Or232	3	3	0	12/07/2016	12/07/2016	Adult	U
Or233	3	0	0	17/07/2016	17/07/2016	Juvenile	U
Orpup1_P16[7]	4	4	0	26/06/2016	26/06/2016	Pup	U
Orpup2_P16	2	0	0	09/07/2016	NA	Pup	U
Orpup3_P16	2	0	0	21/06/2016	NA	Pup	U
Orpup4_P16	3	3	3	20/06/2016	16/07/2016	Pup	U
Orpup5_P16	3	3	0	16/07/2016	16/07/2016	Pup	U
Orpup6_P16	3	1	0	26/07/2016	26/07/2016	Pup	U

[7] The last six entries in the table are pups that could not be associated with a known female, i.e. were observed alone when photographed.

8.4 Appendix 4. Summary of all seal carcasses reported to SMASS

Table 4.A. Summary of seal carcasses reported to SMASS between March 2017 and February 2018 in Orkney. Pv = Harbour seal, Hg = Grey seal, Unk = unknown seal species (continues in the next page).

Species	Date	Location	Area	Latitude	Longitude	Sex	Post-mortem	Age Group	Findings
Unk	20/07/2017	Billia Croo Mainland	Orkney	58.97194	-3.35194	U	No	Unknown	Physical Trauma: Possible grey seal predation
Unk	23/10/2017	Floating off Vasa point Shapinsay	Orkney	59.05028	-2.92556	U	No		
Unk	28/12/2017	Viantro bay Shapinsay	Orkney	59.05639	-2.85806	U	No		
Unk	28/12/2017	Viantro bay Shapinsay	Orkney	59.05667	-2.85667	U	No		
Unk	29/12/2017	Grobost beach Westray	Orkney	59.32694	-3.00667	U	No		
Unk	02/01/2018	Below Sholtisquoy Shapinsay	Orkney	59.08611	-2.81194	U	No		
Unk	13/01/2018	Waulkmill bay	Orkney	58.94167	-3.07861	U	No		
Unk	15/01/2018	Dingieshowe beach Deerness	Orkney	58.91472	-2.78389	U	No		
Unk	15/01/2018	Dingieshowe beach Deerness	Orkney	58.91417	-2.78611	U	No		
Unk	15/01/2018	Dingieshowe beach Deerness	Orkney	58.91556	-2.78083	U	No		
Unk	27/01/2018	Shapinsay	Orkney	59.05667	-2.85528	U	No		
Unk	27/01/2018	Shapinsay	Orkney	59.05667	-2.85611	U	No		
Unk	27/01/2018	Shapinsay	Orkney	59.05667	-2.86111	U	No		
Unk	02/02/2018	Birsay lower palace	Orkney	59.13167	-3.31667	U	No		
Unk	02/02/2018	Westray	Orkney	59.25889	-2.93222	U	No		
Pv	16/06/2017	South Burray	Orkney	58.84556	-2.95111	M	No	Pup	Not Examined: Samples Taken
Pv	06/07/2017	Wha Taing Burray	Orkney	58.84889	-2.96250	M	No	Pup	Not Examined: Samples Taken
Pv	26/08/2017	Birsay beach	Orkney	59.13250	-3.31833	U	No	Juvenile	Not Examined: Advanced Autolysis
Pv	18/02/2018	Sands of Wright	Orkney	58.82500	-2.99917	F	No		
Hg	06/03/2017	Eastside beach Newark Bay.	Orkney	58.79472	-2.93000	U	No		
Hg	31/03/2017	Longhope Hoy	Orkney	58.80139	-3.18389	M	No		
Hg	06/09/2017	Dingieshowe	Orkney	58.91500	-2.78111	U	No	Adult	Not Examined: Advanced Autolysis
Hg	17/09/2017	Westeray	Orkney	59.33222	-2.99000	U	No	Unknown	Not Examined: Advanced Autolysis
Hg	11/10/2017	Birsay	Orkney	59.12500	-3.31889	U	No		

Hg	04/11/2017	Burwick	Orkney	58.74056	-2.97639	U	No	
Hg	04/11/2017	Burwick	Orkney	58.74056	-2.97639	U	No	
Hg	21/11/2017	Loth Sanday.	Orkney	59.19250	-2.69667	U	No	
Hg	21/11/2017	Loyh Sanday	Orkney	59.19083	-2.69667	U	No	
Hg	24/12/2017	Sands of Wright, South Ronaldsay	Orkney	58.82528	-2.99972	U	No	
Hg	28/12/2017	Viantro bay Shapinsay	Orkney	59.05667	-2.86556	U	No	
Hg	28/12/2017	Viantro bay Shapinsay	Orkney	59.05639	-2.86083	U	No	
Hg	02/01/2018	Scapa bay	Orkney	58.95278	-2.97167	U	No	
Hg	04/01/2018	Birsay	Orkney	59.12750	-3.31917	U	No	
Hg	07/01/2018	Swona	Orkney	58.74750	-3.05583	U	No	
Hg	11/01/2018	Marwick	Orkney	59.09972	-3.34778	U	No	
Hg	11/01/2018	Allerness Evie	Orkney	59.11889	-3.09167	U	No	
Hg	17/01/2018	Newark	Orkney	58.92361	-2.74306	U	No	
Hg	21/01/2018	Westray	Orkney	59.25528	-2.87500	U	No	
Hg	25/01/2018	Lochend Shapinsay	Orkney	59.05500	-2.85306	U	No	
Hg	27/01/2018	Scapa bay	Orkney	59.52000	-2.98694	U	No	
Hg	09/02/2018	Dingieshowe	Orkney	58.91583	-2.77944	U	No	
Hg	19/02/2018	Scapa beach	Orkney	58.96250	-2.97694	U	No	
Hg	25/02/2018	St.Margarets Hope	Orkney	58.82611	-2.95722	U	No	
Hg	26/02/2018	Ophir	Orkney	58.91861	-3.16167	U	No	Physical Trauma: Possible grey seal predation

Table 4.B. Summary of seal carcasses reported to SMASS between March 2017 and February 2018 in Kintyre and Clyde area. Pv = Harbour seal, Hg = Grey seal, Unk = unknown seal species.

Species	Date	Location	Area	Latitude	Longitude	Sex	Post-mortem	Age Group	Findings
Unk	02/04/2017	Ardeer beach near Salcoats	North Ayrshire	55.63222	-4.76778	U	No		
Unk	02/07/2017	Near Tangytavil	Argyll and Bute	55.49833	-5.71278	U	No	Unknown	Not Examined: Insufficient Data
Unk	10/08/2017	Machrihanish	Argyll and Bute	55.42306	-5.73583	U	No	Unknown	Not Examined: Advanced Autolysis
Unk	24/10/2017	Machrihanish	Argyll and Bute	55.42722	-5.72500	U	No		
Unk	06/11/2017	Near Slipway at Dunaverty	Argyll and Bute	55.30778	-5.64472	U	No		
Unk	06/11/2017	Near Slipway at Dunaverty	Argyll and Bute	55.30806	-5.64472	U	No		
Unk	14/11/2017	Drumadoon point Arran	North Ayrshire	55.51222	-5.35111	U	No		
Unk	27/12/2017	Kilpatrick beach Arran	North Ayrshire	55.49889	-5.32861	U	No		
Unk	30/12/2017	Brunerican Southend	Argyll and Bute	55.30889	-5.63139	U	No		
Unk	30/12/2017	Brunerican Southend	Argyll and Bute	55.30889	-5.63472	U	No		
Unk	30/12/2017	Brunerican Southend.	Argyll and Bute	55.30889	-5.63889	U	No		
Unk	01/01/2018	Near Imacher Arran	North Ayrshire	55.59583	-5.37972	U	No		
Unk	07/01/2018	Croy near Culzean Castle	South Ayrshire	55.37222	-4.76917	U	No		
Unk	10/01/2018	Carradale bay	Argyll and Bute	55.58556	-5.46500	U	No		
Unk	10/01/2018	Kilpatrick beach Arran.	North Ayrshire	55.49889	-5.32861	U	No		
Unk	15/01/2018	Dunure	South Ayrshire	55.40778	-4.75778	U	No		
Unk	26/01/2018	Ardeer Stevenston	North Ayrshire	55.62278	-4.73889	U	No		
Unk	10/02/2018	Stevenston	North Ayrshire	55.63222	-4.76889	U	No		
Pv	06/07/2017	Blackwatersfoot Arran	North Ayrshire	55.50000	-5.33222	F	No	adult	Not Examined: Advanced Autolysis
Pv	07/10/2017	Near Lochranza	North Ayrshire	55.70472	-5.31917	U	No	Unknown	Not Examined: Carcase Not Found
Pv	14/11/2017	Drumadoon point Arran	North Ayrshire	55.51000	-5.35306	U	No	Unknown	Not Examined: Carcase Incomplete/Scavenger Damage
Pv	20/11/2017	Westport beach	Argyll and Bute	55.46778	-5.71333	U	No	Unknown	Physical Trauma: Possible grey seal predation
Pv	24/11/2017	Kirn Dunoon	Argyll and Bute	55.96083	-4.91000	U	Yes	juvenile	Pending

Pv	01/12/2017	Fairlie beach	North Ayrshire	55.75222	-4.85833	U	No	juvenile	Not Examined: Advanced Autolysis
Pv	27/12/2017	Near Lochranza	North Ayrshire	55.70778	-5.30611	U	No	juvenile	Not Examined: Advanced Autolysis
Pv	04/01/2018	Holy Isle near Arran	North Ayrshire	55.53222	-5.08750	U	No		
Pv	10/01/2018	Between Skate bay and Stinky bay Cumbrae	North Ayrshire	55.78778	-4.92472	U	No		
Pv	15/01/2018	Porrt Righ near Carradale	Argyll and Bute	55.58556	-5.46472	U	No		
Pv	15/01/2018	Carradale	Argyll and Bute	55.59306	-5.46639	U	No		
Pv	18/01/2018	Machrihanish	Argyll and Bute	55.42611	-5.72750	U	No		
Pv	24/01/2018	Ardrossan	Argyll and Bute	55.63889	-4.80333	U	Yes		
Pv	24/02/2018	Kildonan Arran	North Ayrshire	55.44306	-5.14611	U	No		
Pv	25/02/2018	Largs	North Ayrshire	55.77889	-4.86000	U	Yes		Pending
Hg	07/09/2017	Machrihanish	Argyll and Bute	55.47250	-5.71306	M	No	adult	Not Examined: Samples Taken
Hg	08/09/2017	Muasdale beach	Argyll and Bute	55.59972	-5.68528	U	No	adult	Not Examined: Advanced Autolysis
Hg	04/10/2017	Muasdale	Argyll and Bute	55.59778	-5.68639	F	No		
Hg	27/10/2017	Killegruer beach	Argyll and Bute	55.55556	-5.70806	U	No		
Hg	07/11/2017	Carskey bay Kintyre.	Argyll and Bute	55.30806	-5.68222	U	No		
Hg	28/11/2017	Maidens	South Ayrshire	55.33444	-4.81889	M	No		
Hg	28/11/2017	Maidens	South Ayrshire	55.33444	-4.81889	M	No		
Hg	09/12/2017	Machrihanish	Argyll and Bute	55.42528	-5.72889	U	No		
Hg	11/12/2017	Dunaverty beach	Argyll and Bute	55.30806	-5.64472	U	No		
Hg	20/12/2017	West port beach Machrihanish	Argyll and Bute	55.47361	-5.71194	U	No		

Table 4.C. Summary of seal carcasses reported to SMASS between March 2017 and February 2018 in Isle of Skye. Pv = Harbour seal, Hg = Grey seal, Unk = unknown seal species.

Species	**Date**	**Location**	**Area**	**Latitude**	**Longitude**	**Sex**	**Post-mortem**	**Age Group**	**Findings**
Pv	28/07/2017	Colbost	Skye	57.44778	-6.64500	U	No	Unknown	Physical Trauma: Possible grey seal predation
Pv	28/07/2017	Colbost	Skye	57.44528	-6.64278	U	No	Pup	Not Examined: Advanced Autolysis
Pv	09/11/2017	Scorrybreac Portree	Skye	57.41528	-6.18417	F	No	juvenile	Not Examined: Samples Taken
Pv	11/01/2018	Portree Skye.	Skye	57.41194	-6.19111	F	Yes	juvenile	
Pv	25/02/2018	Talisker Skye	Skye	57.28417	-6.45778	U	No		

9 References

Arso Civil, M., Smout, S., Onoufriou, J., Thompson, D., Brownlow, A., Davison, N., Duck, C., Morris, C., Cummings, C., Pomeroy, P. P., McConnell, B. and Hall, A. 2016. *Harbour Seal Decline - vital rates and drivers. Report to Scottish Government HSD2*. Sea Mammal Research Unit, University of St Andrews, St Andrews. pp 63.

Bowen, W.D., Iverson, S.J., McMillan, J.I. and Boness, D.J. 2003. Reproductive performance in grey seals: age-related improvement and senescence in a capital breeder. *Journal of Animal Ecology*. **75**, 1340-1351.

Bolt, H.E., Harvey, P.V., Mandleberg, L. and Foote, A.D. 2009. Occurrence of killer whales in Scottish inshore waters: temporal and spatial patterns relative to the distribution of declining harbour seal populations. *Aquatic Conservation: Marine and Freshwater Ecosystems.* **19(6)**:671–5.

Brownlow, A., Onoufriou, J., Bishop, A., Davison, N. and Thompson, D. 2016. Corkscrew Seals: Grey Seal (*Halichoerus grypus*) Infanticide and Cannibalism May Indicate the Cause of Spiral Lacerations in Seals. PLOS ONE. **2;11(6)**:e0156464–14.

Caillat, M. and Smout, S. 2015. *Harbour seal decline: Population modelling. CSD4*. St Andrews: Sea Mammal Research Unit, University of St Andrews. pp.29.

Cordes, L.S. and Thompson, P.M. 2013. Mark-recapture modeling accounting for state uncertainty provides concurrent estimates of survival and fecundity in a protected harbor seal population. *Marine Mammal Science.* **30(2)**, 691-705.

Cunningham, L. 2009. Using computer-assisted photo-identification and capture-recapture techniques to monitor the conservation status of harbour seals (*Phoca vitulina*). *Aquatic Mammals.* **35**:319.

Dietz, R., Heide-Jørgensen, M.-P., Härkönen, T., Teilmann, J. and Valentin, N. 1991. Age determination of European harbour seal, *Phoca vitulina* L. *Sarsia*. **76**, 17-21.

Duck, C.D. and Morris, C.D. 2017. Aerial survey of harbour (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) in Orkney and the north coast, the Moray Firth, and part of East Scotland in August 2016. Scottish Natural Heritage Commissioned Report. pp.33.

Gardiner, K., Boyd, I., Racey, P., Reijnders, P. and Thompson, P. 1996. Plasma progesterone concentrations measured using an enzyme-linked immunosorbent assay useful for diagnosing pregnancy in harbor seals (*Phoca vitulina*). *Marine Mammal Science*. **12**, 265-273.

Gentleman, W., Leising, A., Frost, B., Strom, S. and Murray, J. 2003. Functional responses for zooplankton feeding on multiple resources: a review of assumptions and biological dynamics. *Deep Sea Research Part II: Topical Studies in Oceanography*. **50 (22-26)**:2847–75.

Hall, A.J. and Frame, E. 2010. Evidence of domoic acid exposure in harbour seals from Scotland: A potential factor in the decline in abundance? *Harmful Algae*. **9**, 489-493.

Kellar, N.M., Trego, M.L., Marks, C.I. and Dizon, A.E. 2006. Determining pregnancy from blubber in three species of delphinids. *Marine Mammal Science*. **22**, 1-16.

King, R., Morgan, B., Gimenez, O. and Brooks, S. 2009. Bayesian Analysis for Population Ecology. Chapman and Hall/CRC Press, Boca Raton, USA.

Lawrence, J.F., Niedzwiadek, B. and Menard, C. 2005. Quantitative determination of paralytic shellfish poisoning toxins in shellfish using prechromatographic oxidation and liquid chromatography with fluorescence detection: collaborative study. *Journal of AOAC International*. **88.6**: 1714-1732.

Lonergan, M., Duck, C.D., Thompson, D., Mackey, B.L.,Cunningham, L. and Boyd, I.L. 2007. Using sparse survey data to investigate the declining abundance of British harbour seals. *Journal of Zoology*. **271(3)**, 261-269.

Lonergan, M., Duck, C.D., Moss, S., Morris, C. and Thompson, D. 2013. Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation: Marine and Freshwater Ecosystems*. **23(1)**, 135-144.

Mackey, B.L., Durban, J.W., Middlemas, S.J. and Thompson, P.M. 2008. A Bayesian estimate of harbour seal survival using sparse photo-identification data. *Journal of Zoology*. **274**, 18-27.

Matthiopoulos, J., Cordes, L., Mackey, B., Thompson, D., Duck, C., Smout, S., Caillat, M. and Thompson, P. 2014. State-space modelling reveals proximate causes of harbour seal population declines. *Oecologia*. **174**, 151-162.

Plummer, M. 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd international workshop on distributed statistical computing. Technische Universitat Wien, Wien, Austria. pp.10.

SCOS. 2016. *Scientific advice on matters related to the management of seal populations: 2015*. Sea Mammal Research Unit, University of St Andrews, St Andrews. pp. 169.

SCOS. 2017. *Scientific advice on matters related to the management of seal populations: 2016*. Sea Mammal Research Unit, University of St Andrews, St Andrews. pp. 144.

Sinclair, A.R.E., Pech, R.P., Dickman, C.R., Hik, D., Mahon, P. and Newsome, A.E. 1998. Predicting Effects of Predation on Conservation of Endangered Prey. *Conservation Biology*. **12(3)**:564–75.

Smout, S., Asseburg, C., Matthiopoulos, J., Fernández, C., Redpath, S., Thirgood S. and Harwood, J. 2010. The Functional Response of a Generalist Predator. *PLoS One*. **5:5**, e10761. DOI: 10.1371/journal.pone.0010761.

Stenson, G.B., Buren A.D. and Koen-Alonso, M. 2016. The impact of changing climate and abundance on reproduction in an ice-dependent species, the Northwest Atlantic harp seal, *Pagophilus groenlandicus*. *ICES Journal of Marine Science*. **22;73(2):**250–62.

Suryawanshi, K.R., Redpath, S.M., Bhatnagar, Y.V., Ramakrishnan, U., Chaturvedi, V., Smout, S.C. and Mishra, C. 2017. Impact of wild prey availability on livestock predation by snow leopards. *Royal Society Open Science*. **4**: 170026. DOI: 10.1098/rsos.170026