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
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V5

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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.

Previous work by Matthiopoulos *et al.* (2014) and Caillat and Smout (2015) developed and fitted an age-structured population model to data from the well-studied subpopulation of harbour seals in Loch Fleet (Moray Firth), to evaluate the contributions of different potential proximate causes to the observed decline. Work has continued to build on the original Moray Firth study, re-coding a simplified version of the population model in JAGS language. A decision support tool (DST) has also been developed to include a biologically realistic simulation model and a model-fitting step that attempts to recover the parameters used in the simulation. A simple population model was successfully fitted to historical data for Scapa Flow (Orkney), with the Markov chain Monte Carlo (MCMC) converging and estimating reasonable-seeming parameter values. The DST was used to explore fitting limited data sets. The simulation/fitting approach showed that the fitting software was able to estimate parameters from the data even when the data set was ‘thinned’ (data not available for every year) and when no pup count data were available.

Live capture-release studies were conducted in Orkney in April and May 2016 under 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 on adult seals, primarily on females, to direct the photo-identification effort prior to and during the pupping season. Pregnancy status was determined from progesterone concentrations in the plasma and in blubber, and from 17 beta-oestradiol concentration in plasma. Results show the blubber concentrations of progesterone may be a much more reliable indicator of pregnancy than levels in plasma. The proportion of the live-captured adult females that were pregnant was 61.5% (95% CI 35% - 88%), which is lower than would have been expected. However, 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. Two animals had levels below the limit of detection, but the majority (88%) were above this level, indicating some low level exposure. Additionally, a further six scats collected at the capture haulout sites during May and June were also analysed. Of these, three were positive for DA but the remainder were below the limit of detection or samples were too small for analysis. Two fishing trips to collect prey samples were undertaken in the waters off Scapa Flow on the west coast of Orkney mainland. A total of 85 fish guts were sampled: 35 cod samples, 12 haddock, 36 ling and two torsk. All fish viscera were analysed for domoic acid content, using the same method as for the seal samples. All samples were positive for domoic acid at or above the limit of detection, although, in general, concentrations in all fish sampled were at low levels.

Moult aerial helicopter surveys were conducted in August 2016 in Orkney as part of the annual surveys conducted by SMRU. Breeding aerial surveys were also conducted in 2016 in Scapa Flow (Orkney), Kintyre and Isle of Arran, and Loch Dunvegan, using a fix-wing aircraft and digital photography. The difficulty of locating seals at haulouts from the aircraft and the impossibility of identifying age classes in the digital photographs led to the decision of excluding such data from the population model.

A summary of all seal carcasses reported to SMASS within and nearby the study sites between June 2016 and March 2017 is provided, with details on species, age class and proximate cause of death when available.

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1 Introduction

The UK is home to around 30% of Europe's harbour (or common) seals (*Phoca vitulina*), with Scotland holding 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, 2015).

In Scotland, the Marine (Scotland) Act (2010) prohibits the taking of seals except under licence granted by the Scottish Government for the explicit protection of fisheries or aquaculture activities, or for scientific and welfare reasons. Harbour seals are also 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 by around 95% in the Tay estuary (east coast), 75% in Orkney and 30% in Shetland, compared to counts in 2000. In contrast, populations on the west coast and in the Western Isles are either stable or increasing (SCOS, 2015). More importantly, the decline in seal counts is likely to represent 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 in the abundance of harbour seals in Scotland 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). Therefore, 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 were 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 natural and/or anthropogenic 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. Thus 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 subpopulation 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 2016 to March 2017 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 2 under each approach are detailed in Appendix 1.

This report includes progress on each of the approaches within the Task for Year 2, except for approach two, which will not start until Year 3 of the project.

1 Approach 1. Integrated population model

In Year 2 of the project, work continued to build on the original Moray Firth study of local harbour seal population dynamics and subsequent developments of that model (Matthiopoulos *et al*., 2014; Caillat & Smout, 2015). In these studies, an age-structured population model was fitted to large and diverse data sets using Bayesian hidden-process methodology. This approach allows for uncertainties in observations, such as variations in haulout probability, and in the demographic birth/death processes themselves (Newman *et al*., 2006).

For the three study sites monitored within the HSD project, the existing data sets are more limited. For example, historical time series counts are available for the moult, but not for the breeding season at these sites. Therefore, an important focus for the modelling work was to explore what can be learned from such limited data. A decision support tool (DST) was developed, including a biologically realistic simulation model to produce simulated data, and a model-fitting step that attempts to recover the parameters used in the simulation (Figure 1).

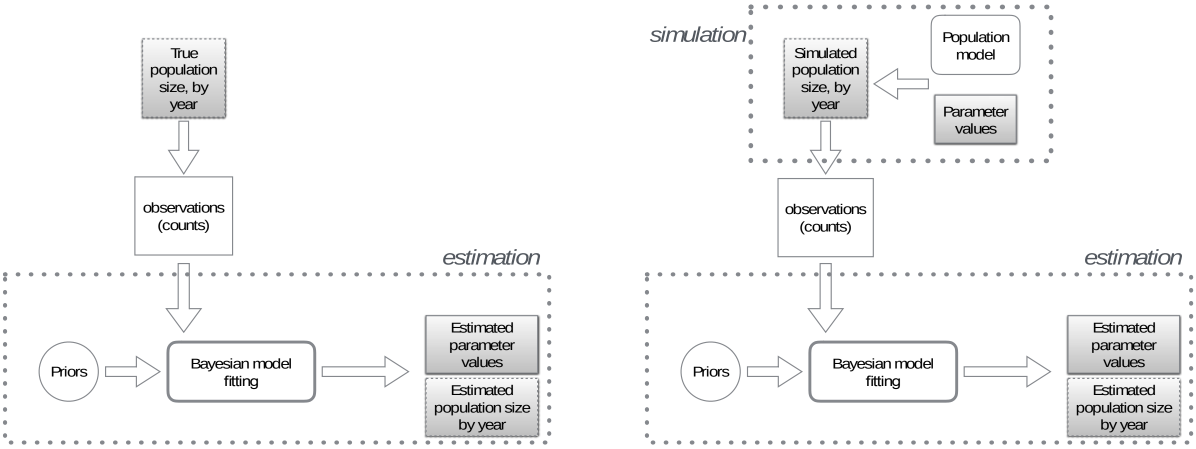

Figure 1. Left panel shows the concept of fitting a model to data using Bayesian methods with prior distributions to inform the estimation of parameter values from a data set. Right panel shows the use of a simulation step to produce 'fake data' to fit a model, for which the 'true' values of parameters and underlying population states are known. The model's estimates can then be compared with the parameter and population size estimates that are known from the original simulation.

By 'thinning' the data used to fit the model, the effects of fitting sparse data can be explored. This work was motivated in part by the limited availability of the historical data and the wish to make use of such data to support population modelling within the project, and also by the need to make decisions about priorities for data collection within the project.

Originally, the model fitting for the Moray Firth was carried out using the freely-available software OpenBUGS (Lunn *et al*., 2009). This framework was chosen because it is well suited to the treatment of hidden-process models, and had the great advantage that models can be developed and shared by different users using a common language and a supporting literature of textbooks and papers. Recently, JAGS software has gained in popularity and is actively maintained, and has a strong user community (Plummer, 2003). It was decided that the JAGS framework would now provide better support for long-term maintenance and sharing of population modelling software for the current project. The Moray Firth model was re-coded in JAGS, and JAGS was also used to fit models from simulations within the DST. Simple population dynamics models were also fitted for the three main study sites within the HSD project.

1.1 Methods

1.1.1 Decision Support Tool

First, an age-structured population model was coded in R to simulate changes in harbour seal population size and pup production at a study site over time, with survival and fecundity rates to be adjusted by the user. These were given realistic values based on those used in the Moray Firth model (Caillat & Smout, 2015). In addition to these baseline rates, additional features could be included, such as effects of environmental drivers on vital rates (coded using a logistic model as in the Moray Firth work) or density dependence. The simulation was designed to output 'observations' such as those that would be collected during the HSD study, e.g. moult counts. Realistic errors were associated with these observations, e.g. variability in the number of animals sighted from one day to the next due to random variation in hauling-out by individual animals.

Second, code was written to use the JAGs package from R, to fit a population model to the simulated data, using the Bayesian hidden-process modelling approach (Newman *et al*., 2006). The simulation could be followed by a fitting step using this code, to find out how far parameters could be recovered from simulated data.

One example of the use of the DST, with simulation followed by fitting, is presented here. In this example the underlying population model includes fixed vital rates except for (a) external mortality, analogous to the shooting that was included in the original Moray Firth model: this was implemented in our example as a step-change, and (b) density dependence which was included as a driver of first-year pup survival according to a Beverton-Holt type formula.

$$s_{pup,year} = \frac{s_{max}}{\beta + n_{total}}$$

In which $s_{pup,year}$ represents pup survival in a given year, s_{max} and β are constant parameters, and n_{total} is the total population size in that year.

The effect of fitting pupping and moult-count data was investigated using the DST simulation/fitting tool. After this, the procedure was repeated using only moult-count data. The aim was to explore the 'needs' of the population model for data, to suggest how much can be learned from relatively sparse data sets including those with only moult count data. For the model fitted to moult-only data, it was considered unrealistic to attempt to separately estimate first-year pup survival and female fecundity, so instead a single value representing pup recruitment was calculated: this is effectively the product of female fecundity with first year survival and represents the average number of yearling seals produced in year *t+1* by female pupping in year *t.* For ease of comparison between models, this is the quantity that has been estimated for all results reported here.

1.1.2 Fitting to historical data

Building on the fitting code developed as part of the DST, a short feasibility study based on fitting a population model to data from the Scapa Flow study site (Orkney) demonstrated that this modelling approach would be suitable for these limited data sets. Code written for the DST module was modified to fit such a population model to data, again using the Bayesian hidden-process modelling approach. Based in part on the results of the DST runs, the fitted model was modified by including the change in 'external' mortality as a logistic function of time rather than as a step function. The model was also simplified: density dependent processes were not included, male survival rate was calculated within the model as a simple multiplier (*0.9 X female survival*), female fecundity was assumed fixed at 0.9. As before, pup recruitment, rather than separate fecundity and first-year-survival parameters, was monitored during the MCMC to estimate its posterior distribution.

1.2 Results

1.2.1 Decision support tool and the use of moult-only data

Data sub-sampled from a 30 year time interval were fitted in about 15 minutes using 100,000 MCMC iterations on a standard I7 laptop, using JAGS.

The marginal posterior distributions of parameters estimated by the fitting process (black curves) compared with priors (red curves) are shown in Figure 2. When MCMC is used for Bayesian estimation, the output is a Markov Chain. This takes the form of a long list, typically 1000 lines, with each line in the list containing a value for each of the parameters. The density plots in Figure 2 (and also in Figures 4 and 6) represent the marginal posterior distributions of the parameter values: the plot for each parameter is effectively a smoothed histogram, based on a sample of 1000 values (one column of the long list). The most probable estimate of the parameter corresponds to the location (on the x axis) of the peak of the curve. The range and variance of the estimate are visualised by the spread of the frequency plot. Where the prior appears 'flat' compared with the posterior distribution, this implies that the fitting process has 'refined' our prior knowledge about that parameter. If the prior and posterior are similar in shape, then the fitting process has not added much information. For this example, the 'recovered' values of the parameters are fairly close to the 'known' values.

Pup recruitment is the product of female fecundity with first year survival and represents the average number of yearling seals produced in year *t+1* by female pupping in year *t*.

The estimated population trajectory based on the fitted model (black curve) is shown in Figure 3 and this can be compared with the 'known' trajectory (red curve) because the values from the simulated data set are available to us. The red curve lies within the 95% confidence intervals (dashed curves) of the model's predictions. The black and red points represent the survey 'data' that the model was fitted to. The fitted model recovers the 'known' population trajectory well, and approximates the change point year. Survey counts are lower than total population size for two reasons: (i) total population size includes both pups and adults, so pup counts will always be lower than this, and (ii) the probability that a given animal is hauled out during a survey is less than 1.

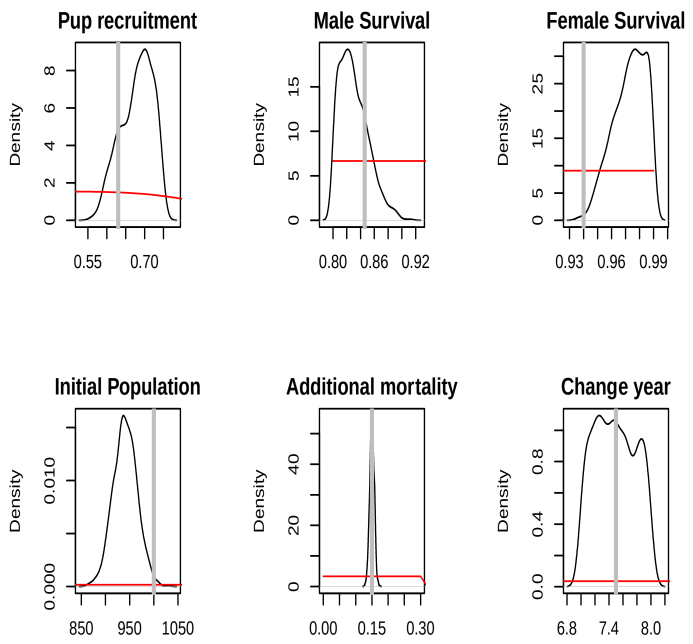

Figure 2. Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the DST run with simulated pup and moult count data both included for model fitting. The vertical grey lines represent the 'true' values of the parameters i.e. those that were used in the simulations that produced the simulated data.

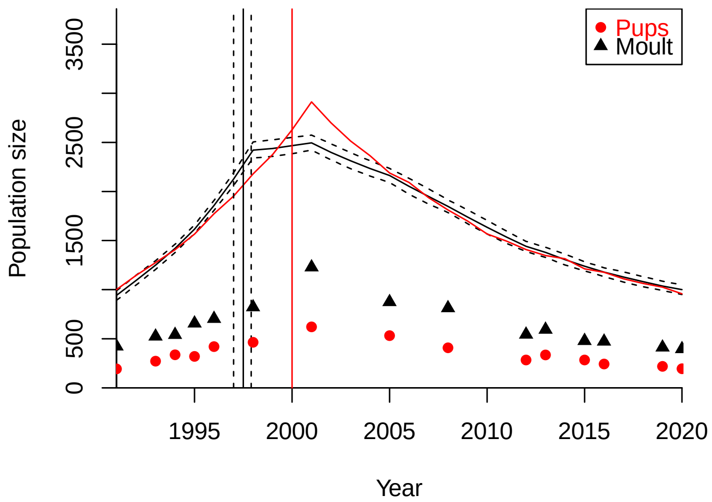

Figure 3. Estimated population trajectory (black curve) compared with known population trajectory (red curve) and simulated data for pup counts during breeding, and seals hauled out during moult (which are mainly adults). The estimated change-point year is shown as a vertical black line and confidence intervals around it are shown with dashed lines. The 'true' value for this change-point is represented by the red vertical line.

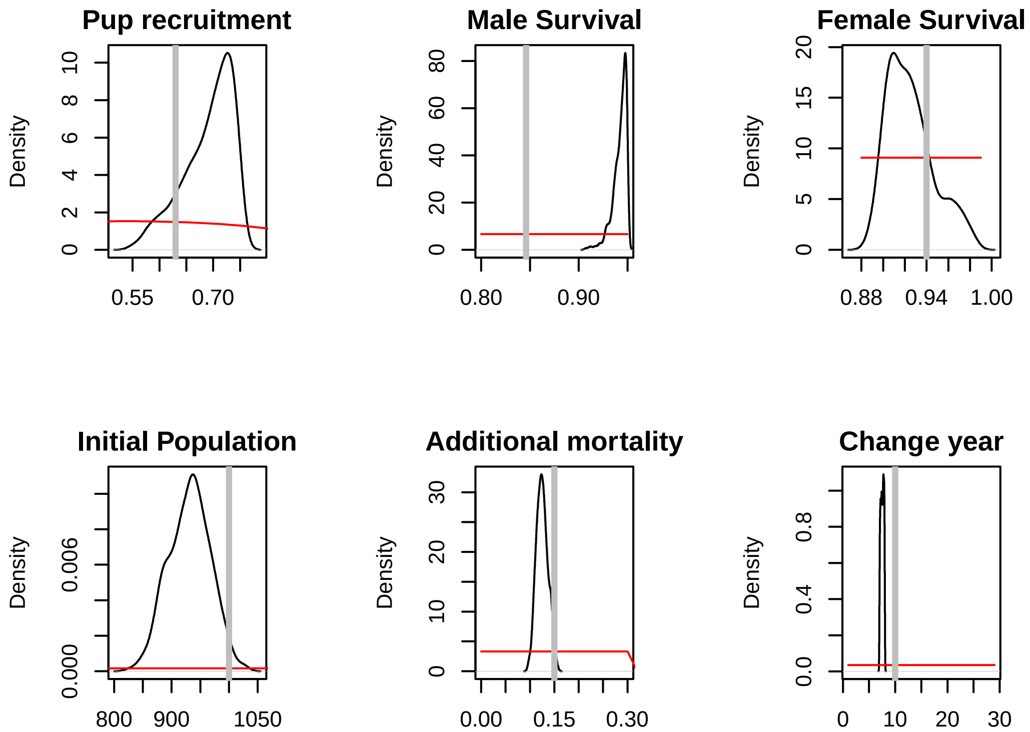

Figure 4. Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the DST run with moult count data only included for model fitting. The vertical grey lines represent the ‘true’ values of the parameters i.e. those that were used in the simulations that produced the simulated data.

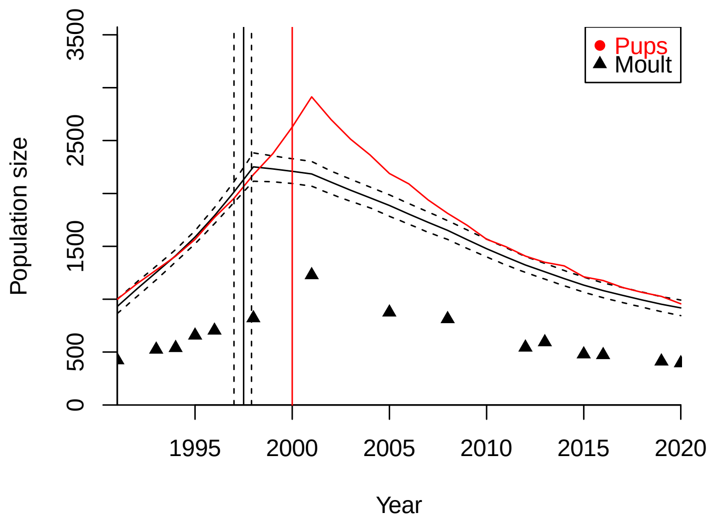

Figure 5. Estimated population trajectory (black curve) compared with known population trajectory (red curve) and counts of seals hauled out during moult (which are mainly adults). There are no pup count data. The estimated change-point year is shown as a vertical black line and confidence intervals around it are shown with dashed lines. The ‘true’ value for this change-point is represented by the dotted vertical line which coincides with the lower confidence limit on the estimate (2000).

Figure 4 and Figure 5 show the results obtained when the underlying simulation was the same as for the previous step, but only moult count data were made available for model fitting. Figure 4 shows the marginal posterior distributions of parameters estimated by the fitting process (black curves) compared with priors (red curves). In this case, the male and female survival rates are refined, compared with the priors, but male survival is not estimated well. This is perhaps not surprising given that there is now not much information in the data to inform the model about the relative numbers of males and females (pup count data perhaps adds important information here because female numbers are more closely linked to pup numbers). The year in which mortality changes is considerably refined from the broad prior and it is close to the true value, but the estimates’

95% confidence intervals do not include the true value i.e. they are too 'tight': the precision of this estimate is over-estimated. Figure 5 shows the estimated population trajectory based on the fitted model (black curve) and this compares fairly closely with the 'known' trajectory (red curve), though there is some deviation associated with imperfect estimation of the change point year. The black points represent the survey 'data' that the model was fitted to (moult counts only).

1.2.2 Fitting a simple model to an historical data set

Figure 6 shows posterior parameter estimates resulting from fitting a simplified population model to the historical data from Scapa Flow. Pup recruitment (the product of female fecundity with first year survival) appears very low compared with results for the previous simulation-based models: this is because the previous models had density-dependence in this quantity so that the reported parameter for those models represents a maximum possible level of pup recruitment, not typically seen except in years of very low population size. For 'typical' years under the density-dependent model, pup recruitment would be reduced well below the level indicated by this parameter, due to intraspecific competition.

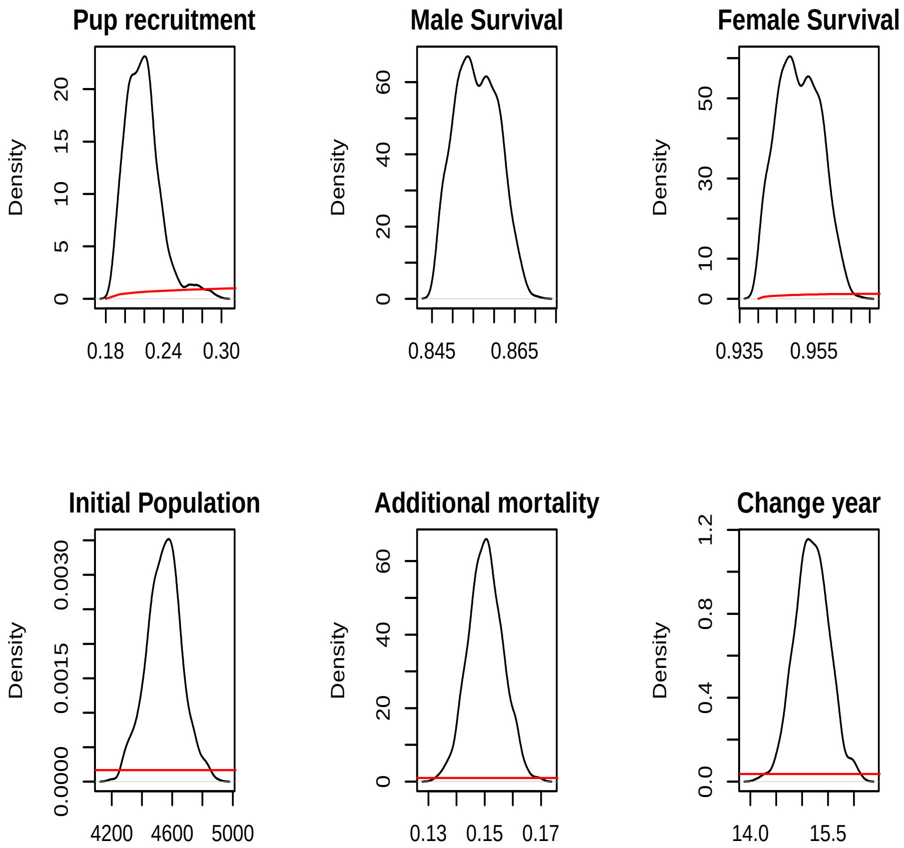

Figure 6. Posterior parameter distributions (black curves) compared with prior distributions (red curves) for the historical moult count data at Scapa Flow. No prior is shown for adult male survival, which was modelled using a simple multiplier on female survival (0.9): the posterior distribution is shown here for information only.

The estimated total population size compared with the moult survey data for Scapa Flow is shown in Figure 7, and the position of the estimated change-point is shown. Model estimates and original data appear consistent, suggesting that some of the observed patterns in the data could be explained by a change in 'externally forced' mortality starting around 1999.

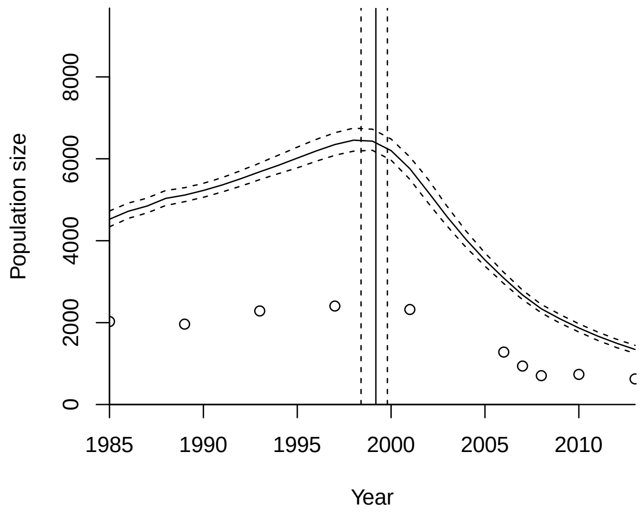

Figure 7. Estimated population trajectory (black curve) compared with counts of seals hauled out during moult (which are mainly adults). The estimated change-point year, when mortality increases across the whole population, is shown as a vertical black line, and confidence intervals around it are shown with dashed lines.

1.3 Discussion

The simulation tool developed for the DST is useful in itself as a way to test out hypotheses about possible impacts on local common seal populations, such as the imposition of 'external' sources of mortality (these could include shooting, toxic algal blooms, or predation by grey seals for example). The simulation can show the effects of changes that may affect all the population or only certain age/sex classes. Such a framework therefore provides an arena for exploration of possible hypothesis about population decline.

In combination with the fitting module, the simulation approach can also suggest how well model-fitting will inform our understanding of local seal populations, including where data are limited. The simulation/fitting approach showed that the fitting software was able to estimate parameters from the data even when the data set was 'thinned' (data not available for every year) and even when no pup count data were available. However, the original 'true' values of parameters were not always recovered precisely. While the timing of changes in mortality rate was estimated to within a few years, the estimate had inaccurately high precision i.e. the estimate's 95% confidence intervals were too small, and the 'true' value of the change point lay outside them – this therefore might be misleading, giving artificial confidence in an estimated result. This may be due to poor mixing within the MCMC for this parameter, a technical issue which should be further explored. Estimating male survival was another point of difficulty, perhaps not surprisingly as the survey data do not distinguish adult males from females. Where pupping season data are available this may put some constraints on numbers of breeding females and inform estimates of female numbers overall, thus indirectly informing estimates of male numbers and survival rates. However, without pupping season data, this route to estimating male survival may become even more indirect and difficult. It is recommended that in all future model-fitting, the approach used in the original Moray Firth model is adopted, and male survival is assumed to be (*0.9 X female survival*).

A simple population model was successfully fitted to historical data for Scapa Flow: the MCMC converged and reasonable-seeming parameter values were estimated. The timing of the 'changepoint' estimated by a simple model assuming step-change mortality also appears reasonable, i.e. the timing of the change is consistent with visual inspection of the survey data. This is encouraging, **but these results should be interpreted with every possible caution at present**. In the DST approach, the correct 'structure' for the biological model of the population was known, e.g. it was known that the 'virtual population' being modelled was subject to density dependent effects on pup survival, and the model to be fitted included such effects on that particular life-history stage. In fitting the 'real' data sets, it was not clear *a priori* what effects should be included and what parts of the population may be responding, and for this reason the initial model fitted to the historical data was 'minimal' i.e. it was very simple. Results suggest that the observed patterns in the data could be explained by a change in 'externally forced' mortality starting around 1999, but other explanations for the observed patterns, such as a change in pup recruitment, might be equally good. Future work could include investigations into population changes at all the monitored sites. Fitted models should also include a wider range of different possible mechanisms for population change e.g. including density dependence, or changes in vital rates over time that apply only to parts of the population such as only to first year animals. The DST modules can be used to check whether, realistically, the parameters of more complex models can be recovered from limited data. If this seems plausible, then by fitting a range of different models to the historical data, formal comparison and evaluation of the models could be used to choose the most appropriate model (or subset of models) from a set of candidate models. Such work is also expected to incorporate results from other parts of the HSD project where causes of decline and change in the population may be suggested by field observations, and new priors, based on the results of new empirical science, can inform the fitting process.

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

The calculation of vital rates and movements will not start until year three, following the collection of field data.

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

3.1 Methods

3.1.1 Live captures at Orkney in 2016

Two separate trips to carry out live capture-release studies of harbour seals in Orkney in April (1st to 23rd) and May (7th to 14th) were conducted under the SMRU Animal (Scientific Procedures) Act, 1986, (Home Office Licence No. 192CBD9F). Both trips were focused on capturing adult females where possible, using the West Burray haulout site where the photo-ID studies were to be carried during the breeding season. However, adjacent sites located in Widewall Bay (South Ronaldsay) were also targeted when the numbers of seals using the West Burray site was low. The locations where the animals were captured are shown in Figure 8 (namely West Burray, Widewall Bay by Quindry and Widewall Bay by Oyce of Herston).

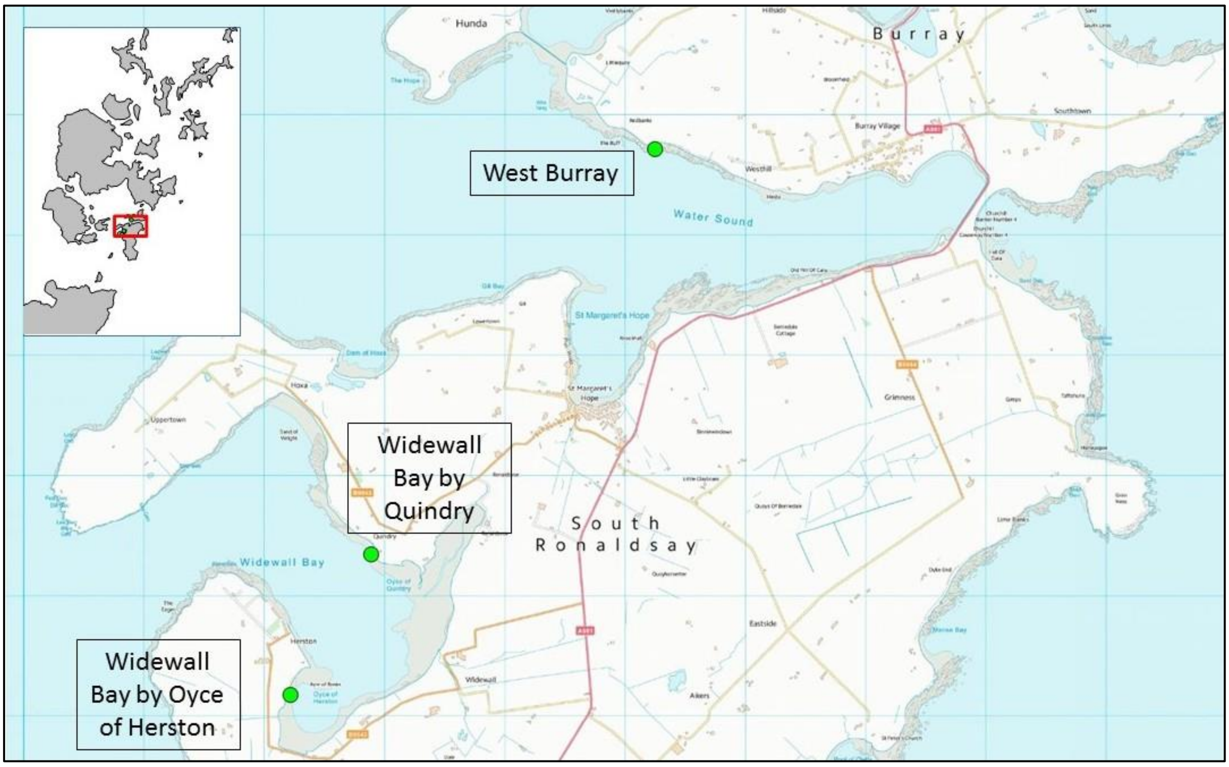

Figure 8. Map of Burray and South Ronaldsay in Orkney showing the locations of live captures in 2016.

During both 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. Pictures 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),
- small incisor tooth (for aging, except from juveniles),
- urine (for harmful algal toxin exposure) and
- faeces (for harmful algal toxin exposure and diet assessment).

Ten adult harbour seals (7 females and 3 males) were equipped with GSM/GPS telemetry tags (GSM) during the April trip. These tags were funded by Vodafone UK, and their support is gratefully acknowledged.

During the May trip, a further five adult females were equipped with low-cost, GPS haulout site location-only (LO) tags. These tags were designed at SMRU to provide low-cost tracking of the haulout sites visited. Their purpose was to provide a location when a seal was hauled out via the mobile phone GSM system. These tags were designed to attempt to send a GPS location once every four hours, using conventional consumer grade GPS units rather than the Fastloc GPS units used in the GSM tags. It was assumed that this methodology would be unsuccessful when a seal was at sea. The LO tag was based on an Itrack Mini Basic GPS Tracker[1] which was enclosed in a 3-D printed pressure-resistant epoxy shell. It was controlled externally by a microprocessor that mimicked the manual pressing of the ‘off/on’ and ‘send message’ buttons. The information sent by the tags on the seals’ movements was used to direct the photo-ID effort conducted in Orkney.

A summary of all captured seals, with details on the location, date, sex, morphometrics, samples collected and whether each individual was provided with either a GSM or a LO tag is given in Table 1. A total of 24 seals were captured, of which 14 were females and 10 were males. Based on their mass and length, 21 of the seals were adults (13 females and 8 males), and the other three were juveniles (1 female and 2 males). One of the seals captured, an adult male with flipper tag 73349, was a recaptured animal from 2012 (also sampled in Orkney on Stronsay).

Urine and faecal samples were analysed for domoic acid concentrations using the validated and published ELISA method (Hall & Frame, 2010). The growth layer groups in the collected teeth were counted to determine the age of the individuals (Dietz *et al*., 1991). Blood samples were analysed for progesterone and 17 beta-oestradiol 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 will in future be analysed for specific clinical chemistry parameters to determine health condition. Samples will be analysed in batches to minimise inter-assay variability.

[1] http://www.itrack-uk.co.uk/shop/4589068898/itrack-tk102b-mini-gps-tracker/9639765

Table 1. Summary of live captured harbour seals in Orkney during April and May, 2016.

Date	Location	Sex	Age class	Flipper tag	Tag type	Tag body number	Tag Label	Mass (kg)	Length (cm)	Girth (cm)	Blood	Blubber	Urine	Skin	Faeces	Tooth
08-Apr-16	West Burray	M	Adult	00583				85.8	154	107	✓	✓	✓	✓	x	x
11-Apr-16	West Burray	F	Adult	00584	GSM	14259	vf01-259-16	93	148	110	✓	✓	x	✓	x	✓
14-Apr-16	Widewall Bay, Oyce of Herston	M	Adult	55126	GSM	14260	vf01-260-16	78.2	143	98	✓	✓	✓	✓	x	✓
14-Apr-16	Widewall Bay, Oyce of Herston	M	Adult	00586	GSM	14261	vf01-261-16	99.4	156	116	✓	✓	✓	✓	x	✓
14-Apr-16	Widewall Bay, Quindry	F	Adult	00585	GSM	14263	vf01-263-16	77.6	143	106	✓	✓	✓	✓	x	✓
15-Apr-16	Widewall Bay, Oyce of Herston	M	Adult	55128	GSM	14258	vf01-258-16	78.8	147	110	✓	✓	✓	✓	x	✓
15-Apr-16	Widewall Bay, Oyce of Herston	F	Adult	55127	GSM	14257	vf01-257-16	86.6	142	111	✓	✓	✓	✓	✓	✓
17-Apr-16	Widewall Bay, Oyce of Herston	M	Adult	55129				106.4	157	121	✓	✓	✓	✓	✓	✓
19-Apr-16	West Burray	M	Juvenile	55193				51.2	132	90	✓	✓	✓	✓	x	✓
19-Apr-16	West Burray	F	Adult	55197				89.2	145	109	✓	✓	✓	✓	✓	✓
19-Apr-16	West Burray	F	Adult	55196	GSM	14256	vf01-256-16	96.8	148	108	✓	✓	✓	✓	x	✓
19-Apr-16	West Burray	F	Adult	55192	GSM	14262	vf01-262-16	80.4	148	107	✓	✓	✓	✓	✓	✓
19-Apr-16	Widewall Bay, Oyce of Herston	F	Adult	55191	GSM	14265	vf01-265-16	86.4	146	109	✓	✓	x	✓	x	✓
19-Apr-16	Widewall Bay, Oyce of Herston	F	Adult	55189	GSM	14264	vf01-264-16	83.8	149	104	✓	✓	✓	✓	x	✓
09-May-16	West Burray	F	Juvenile	55188				40.4	119	82	✓	✓	x	✓	x	x
09-May-16	West Burray	F	Adult	55187	LO	B1927	FA-B-389	98.4	145	110	✓	✓	✓	✓	x	✓
09-May-16	West Burray	F	Adult	55186	LO	F1638	FA-B-155	77.6	142	104	✓	✓	x	✓	x	✓
09-May-16	West Burray	M	Adult	55199				91.8	150	114	✓	✓	✓	✓	x	✓
09-May-16	West Burray	M	Adult	55198				87	150	111	✓	✓	✓	✓	x	✓
09-May-16	West Burray	M	Juvenile	55190				45.4	124	87	✓	✓	✓	✓	x	x
12-May-16	West Burray	M	Adult	73349				90.4	148	111	✓	✓	✓	x	x	x
13-May-16	West Burray	F	Adult	00600	LO	E2610	FA-B-128	106.6	146	111	✓	✓	✓	✓	x	✓
13-May-16	West Burray	F	Adult	00590	LO	D5294	FA-B-666	78.8	136	105	✓	✓	x	✓	x	✓
13-May-16	West Burray	F	Adult	00591	LO	A2497	FA-B-787	67.0	141	97	✓	✓	✓	✓	x	✓

3.2 Results and Conclusions

3.2.1 Individual covariates

3.2.1.1 Age from growth layer groups in teeth

The ages estimated from the growth layer groups in the teeth are given in Table 2. Unfortunately, some of the teeth could not be aged because of 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 2). Teeth were not taken from juveniles (marked with a ‘-’ in Table 2). There was no significant difference in the mean age of the males compared to the females (males = 8.6 y, females = 9.3 y, $p>0.05$). In addition there was no significant difference in the age of the pregnant compared to the non-pregnant females (see below for pregnancy determination method, Figure 10, not-pregnant = 10.8, pregnant = 8.3, $p>0.05$).

3.2.1.2 Pregnancy status

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). Circulating progesterone in pregnant female harbour seals is elevated throughout gestation (following implantation), but the closer to parturition that blood samples are collected, the more reliable the estimate of pregnancy status. Gardiner *et al*. (1996) estimated that concentrations above 18.9 ng ml^{-1} (60 nmol l^{-1}) are indicative of pregnancy but Greig (2002) found that female harbour seals in San Francisco Bay with progesterone concentrations above 8.2 ng ml^{-1} (>26 nmol l^{-1}) had a 95% probability of being pregnant. Concentrations of plasma progesterone and 17 beta-oestradiol are shown in Table 2, together with assignment of their pregnancy status based on the progesterone concentrations (n=13, see Table 2) and using the threshold established by Gardiner *et al*. (1996) of 18.9 ng ml^{-1}. Concentrations of plasma 17 beta-oestradiol showed considerable overlap between pregnant and non-pregnant animals ($p=0.09$, non-pregnant 117.8 pg ml^{-1}, pregnant 297.5 pg ml^{-1}). The male plasma samples were also analysed as control samples and all were very low, at or around the lowest level of detection (n=10, mean=1.44 ng ml^{-1}, SD=0.45, SE=0.14). One female was immature (length < 133 cm) and had a circulating progesterone concentration of 2.07 ng ml^{-1}.

Comparing the pregnancy assignments with the photo-ID observations (i.e. whether females were obviously in the last stages of pregnancy from their body shape or whether they were seen with or suckling a pup), two had low circulating progesterone (and assays were repeated to ensure this was not due to a laboratory error) and had been assigned as not pregnant from their blood results (highlighted in green in Table 2). It should be noted that the thresholds used are based on previously published estimates for harbour seals and specific thresholds do need to be established for the assay currently being used. Nonetheless, the levels in these two females were not borderline.

However, when the blubber samples were analysed for progesterone concentration, the degree of agreement with the observations carried out during the photo-ID study were entirely consistent with the assignments from the blubber hormones. The females that were assigned as not-pregnant from the blood were assigned as pregnant from the blubber results (highlighted in red in Table 2). Concentrations were significantly different between the two groups ($p=0.0012$, mean concentration in non-pregnant females = 17.16 ng g^{-1}, mean concentration in pregnant females = 198.11 ng g^{-1} in, Figure 9). It appears therefore that the blubber concentrations may be a much more reliable indicator of pregnancy than plasma levels.

Using these final assignments, the proportion of the live-captured adult females that were pregnant was 61.5% (95% CI 35% - 88%). This is lower than would have been expected as other studies in harbour seals (including those carried out in the Moray Firth in the early 1990s) reported between 79% (95% CI 60% - 89%, Gardiner *et al*. (1996)) and 82% (95% CI 67% – 91%, Greig (2002)) of live captured animals as being pregnant (using the above respective concentrations as thresholds). However, the sample size was small, leading to wide confidence intervals compared to the other studies.

How important this finding may be for understanding the drivers of the population decline in Orkney is unclear and further investigations must 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 the data collected from the Loch Fleet study being carried out by the University of Aberdeen, will also be used to construct a predictive model, with confidence limits, for estimating pregnancy status using these reproductive hormones in plasma and blubber.

3.2.1.3 Domoic acid concentrations

Domoic acid concentrations in the urine and faecal samples collected from the live capture-release animals are shown in Table 2. Two animals had levels below the limit of detection but the majority (88%) were above this level, indicating some low level exposure. Only one pregnant female had a reasonably high level of DA in her urine (>60,000 pg ml^{-1}). Unfortunately, it was not possible to collect samples from all individuals. There was no difference in concentrations between pregnant and non-pregnant females ($p=0.9$) or between males and females ($p=0.5$). It should be noted that it is not possible to say whether the concentrations measured in the excreta are due to low level, recent exposure or previous higher level exposure. Nevertheless, these animals have been consuming fish contaminated with DA and since the half-life of DA is short, the levels represent a minimum exposure. Further analyses to estimate the levels of exposure, incorporating the results from the fish collected from the region (see Approach 5), and determine likely thresholds for effects based on published data from laboratory animal models and using the method developed for California sea lions (Bejarano *et al*., 2007) will be carried out in future.

3.2.2 Movements

3.2.2.1 GSM/GPS tags

Ten GSM/GPS tags deployed on 11th April (n=1), 14th April (n=3), 15th April (n=2) and 19th April (n=4) transmitted for 43 to 106 days. The tracks coloured in yellow, orange and red in Figure 11 correspond to three adult males (vf01-258-16, vf01-260-16 and vf01-261-16) while the other seven tracks are from adult females. Detailed individual tracks can be seen in Figure 12. The seals showed a variety of movement patterns as well as individual preferences for certain areas. Some seals showed very restricted movements (e.g. females 263 and 265) while others travelled greater distances (e.g. females 256, 259, 264). The updates on the location of each seal were used to direct the photo-identification data collection effort during the pupping season in the months of June and July.

Table 2. Summary of results from the analysis of samples collected in Orkney in 2016.

Flipper tag	Tag label	Age	Tooth Age (y)	Sex	Progesterone Blood (ng/ml)	17 beta oestradiol (pg/ml)	Pregnant-Blood	Progesterone Blubber (ng/mg)	Pregnant-Blubber	With Pup	Seen Pregnant	Agreement in pregnancy from blubber progesterone	Urinary Domoic Acid pg/ml	Faecal Domoic Acid pg/g
55187	FA-B-389	Adult	-	F	141.70	569.40	Pregnant	223.02	Pregnant	yes		yes	62937	
55189	vf01-264-16	Adult	11	F	3.94	790.70	Not Pregnant	61.24	Pregnant	yes		yes	1227	
00590	FA-B-666	Adult	4	F	3.05	73.90	Not Pregnant	352.78	Pregnant	yes		yes		
55196	vf01-256-16	Adult	x	F	55.57	293.90	Pregnant	225.46	Pregnant	yes		yes		
00584	vf01-259-16	Adult	5	F	85.51	225.60	Pregnant	113.34	Pregnant		yes	yes		
00600	FA-B-128	Adult	8	F	152.25	232.50	Pregnant	117.01	Pregnant				27557	
55127	vf01-257-16	Adult	12.5	F	99.81	77.90	Pregnant	196.28	Pregnant				<LOD	
55197		Adult	9.5	F	73.47	115.80	Pregnant	295.74	Pregnant	yes				18728
00591	FA-B-787	Adult	14	F	45.52	132.10	Possibly Pregnant	8.91	Not Pregnant				27352	
00585	vf01-263-16	Adult	x	F	1.40	82.50	Not Pregnant	15.73	Not Pregnant	no		yes	2803	
55192	vf01-262-16	Adult	12	F	2.39	241.90	Not Pregnant	23.13	Not Pregnant	no	no	yes	2297	
55186	FA-B-155	Adult	9	F	2.00	90.70	Not Pregnant	23.21	Not Pregnant					
55191	vf01-265-16	Adult	8	F	1.33	41.70	Not Pregnant	14.82	Not Pregnant					
55188		Juvenile	-	F	2.07									
00583		Adult	-	M	1.21								5184	
00586	vf01-261-16	Adult	x	M	1.79								1695	
55126	vf01-260-16	Adult	5.5	M	1.08								3453	
55128	vf01-258-16	Adult	7.5	M	1.14								<LOD	
55129		Adult	9.5	M	1.06								2083	
55190		Juvenile	-	M	1.17								16596	
55193		Juvenile	x	M	1.61									28191
55198		Adult	4.5	M	2.37								6977	
55199		Adult	5	M	1.09								15566	
73349		Adult	19.5	M	1.86								4134	

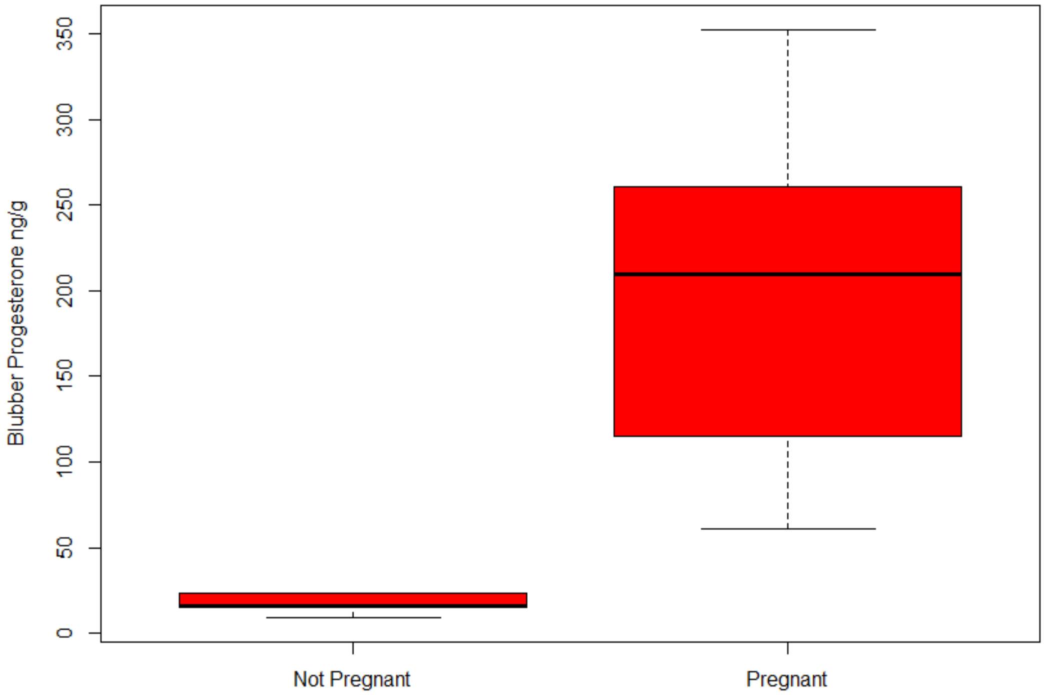

Figure 9. Pregnancy status in relation to blubber progesterone concentrations in live captured female harbour seals.

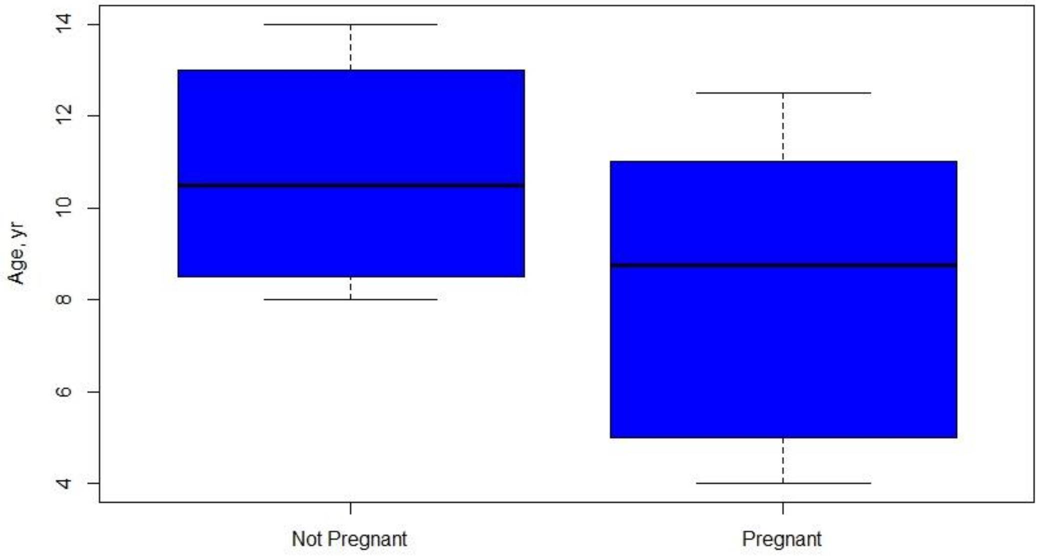

Figure 10. Estimated age, from growth layer groups in the teeth, compared to pregnancy status in live captured female harbour seals.

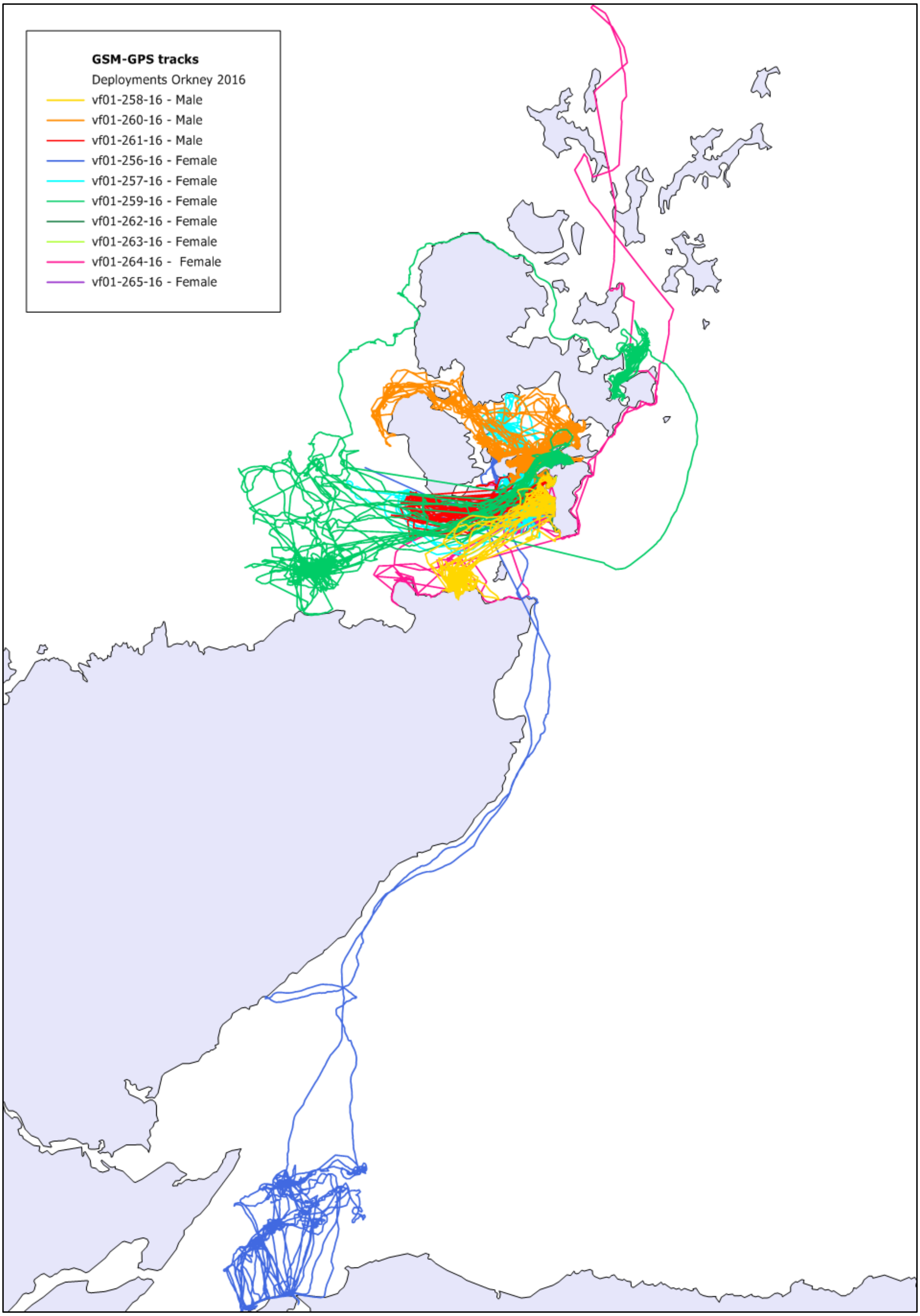

Figure 11. Tracks of all ten GSM-GPS telemetry devices deployed on adult harbour seals in Orkney in 2016.

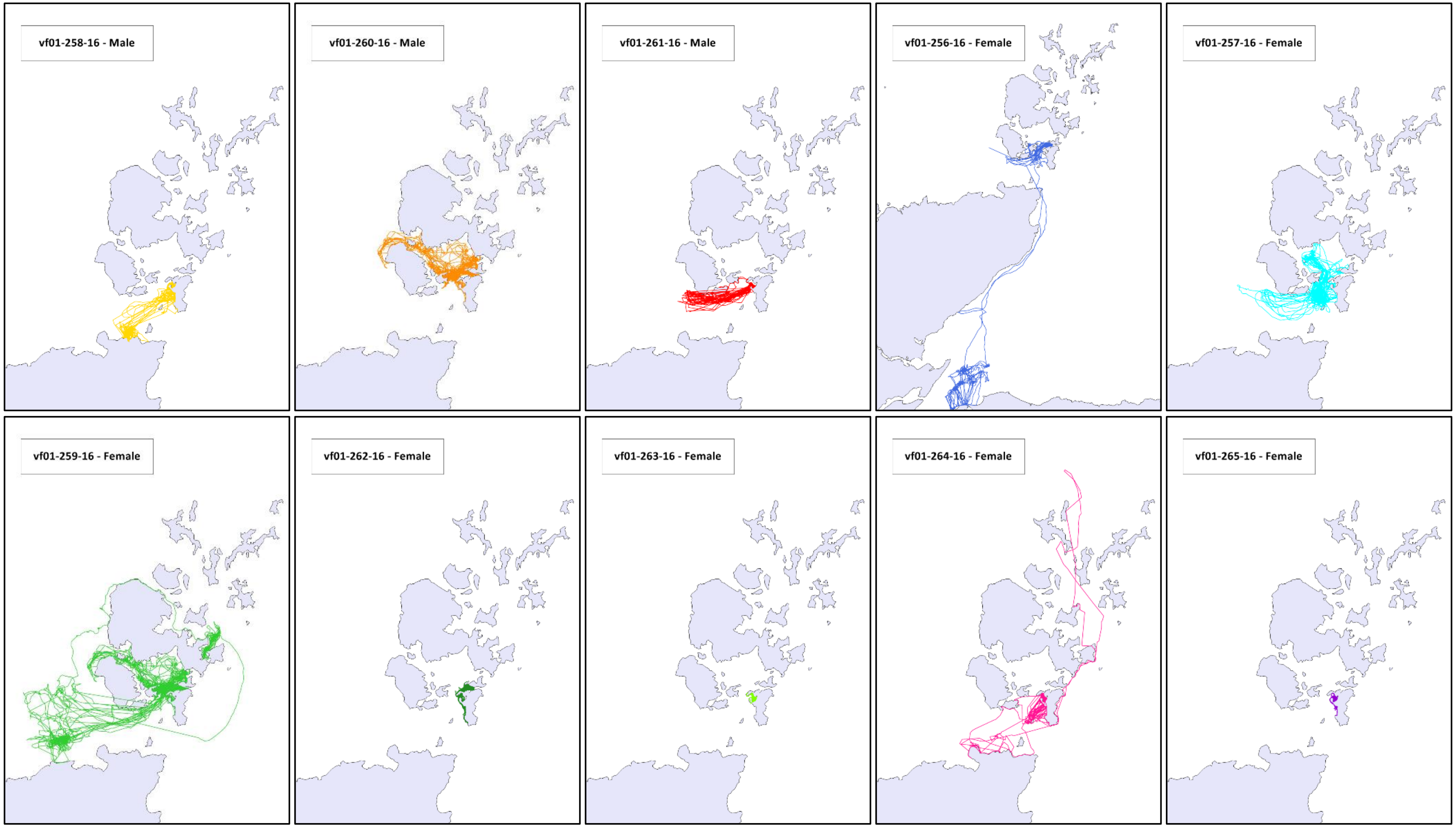

Figure 12. Individual tracks from adult harbour seals tagged in Orkney in 2016 with GSM-GPS telemetry devices.

3.2.2.2 LO tags

The design life for the SMRU LO tags was initially three months, but this was foreshortened due to a programming error that made the tags attempt a GPS location fix once every hour, rather than once every four hours. The durations of the five tags were thus only 6, 13, 18, 21 and 21 days (Figure 13). Whilst the LO tag longevity was disappointing, proof of concept for a cheap tagging system has been demonstrated and with a little refinement, they will provide a cost effective method of tracking seals during their terrestrial (haul-out) activity.

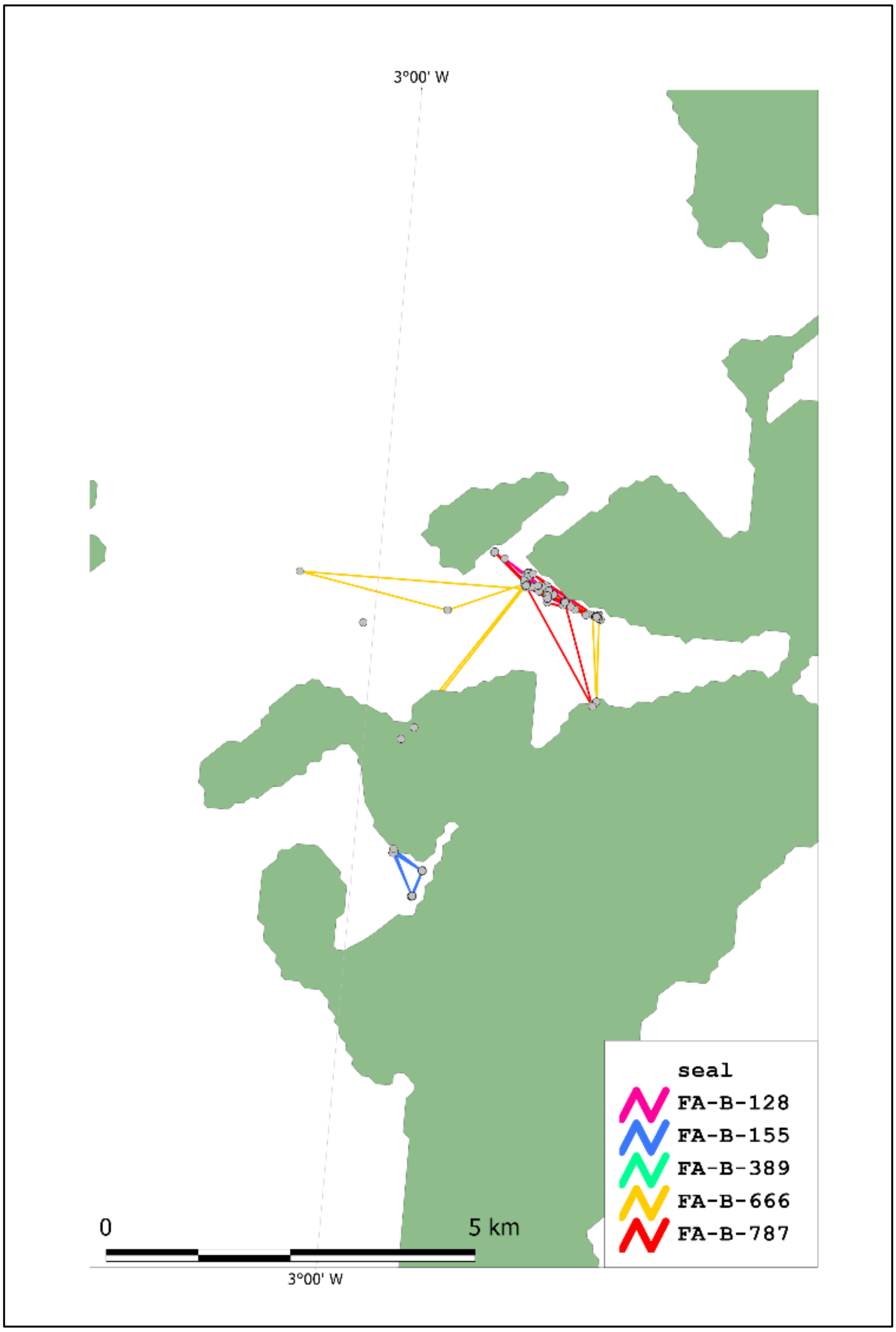

Figure 13. Locations derived from the five location only tagged harbour seals. The connecting lines are colour coded by seal.

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

4.1 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, 2015). 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 3 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 (2015).

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 and Scapa Flow (Orkney) were surveyed in August 2015 and 2016, respectively, as part of the SMRU annual moult counts. Counts of harbour and grey seals for Kintyre study site in 2015 will be available later in the year in the Special Committee of Seals (SCOS) annual report (2017). Photographs taken in Orkney in 2016 and resulting counts are currently being processed.

4.2 Breeding air surveys

Breeding aerial surveys were conducted in Scapa Flow (Orkney) on 3rd July 2016, in Kintyre and Isle of Arran on 16th August and in Loch Dunvegan (Isle of Skye) on the 17th August 2016 (Figure 14, Figure 15 and Figure 16, respectively). Flights were conducted using a small fixed-wing aircraft (Figure 17) and after being identified by eye, digital photographs of groups of seals were taken at haulout sites along the coast.

In Kintyre and Loch Dunvegan, the entire coast as defined for each study area could be surveyed within one low tide cycle. In Scapa Flow, however, given the extent and complexity of the coast line, the west end of the study area could not be surveyed. Part of the GPS track was not recorded during the survey, but the missing track was manually reconstructed afterwards (Figure 14).

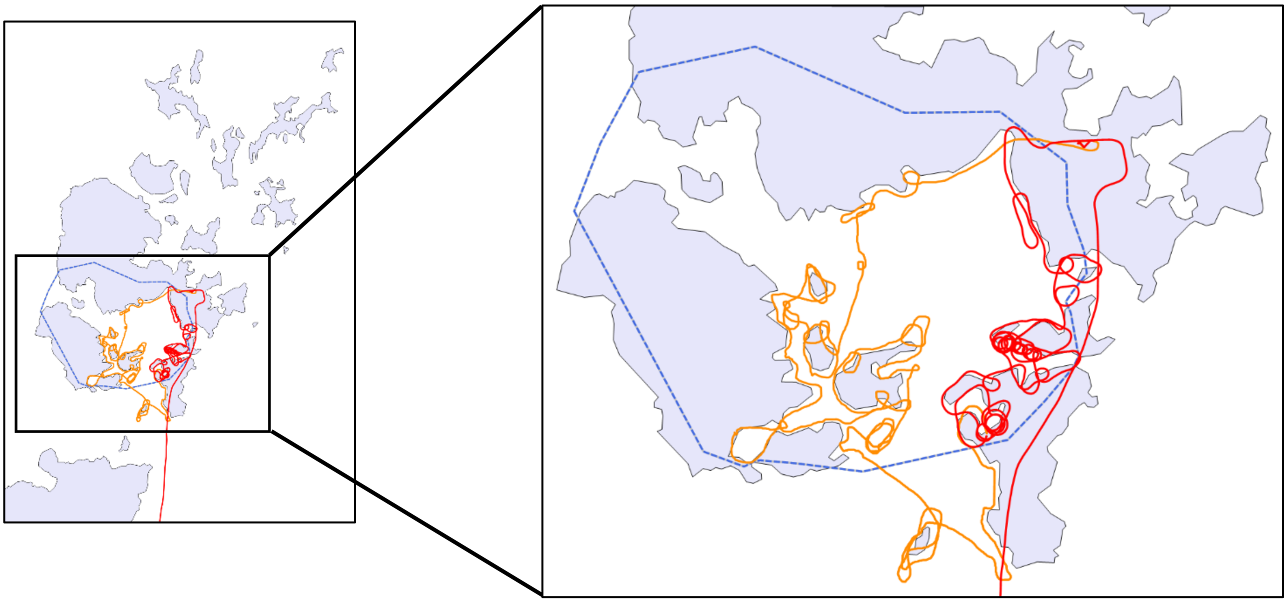

Figure 14. Aerial survey track followed on July 3rd, 2016, in Scapa Flow, Orkney. The red line denotes the track downloaded from the GPS device, and the orange line denotes the manually reconstructed track. The blue dashed line delimits the regional extent of the study area.

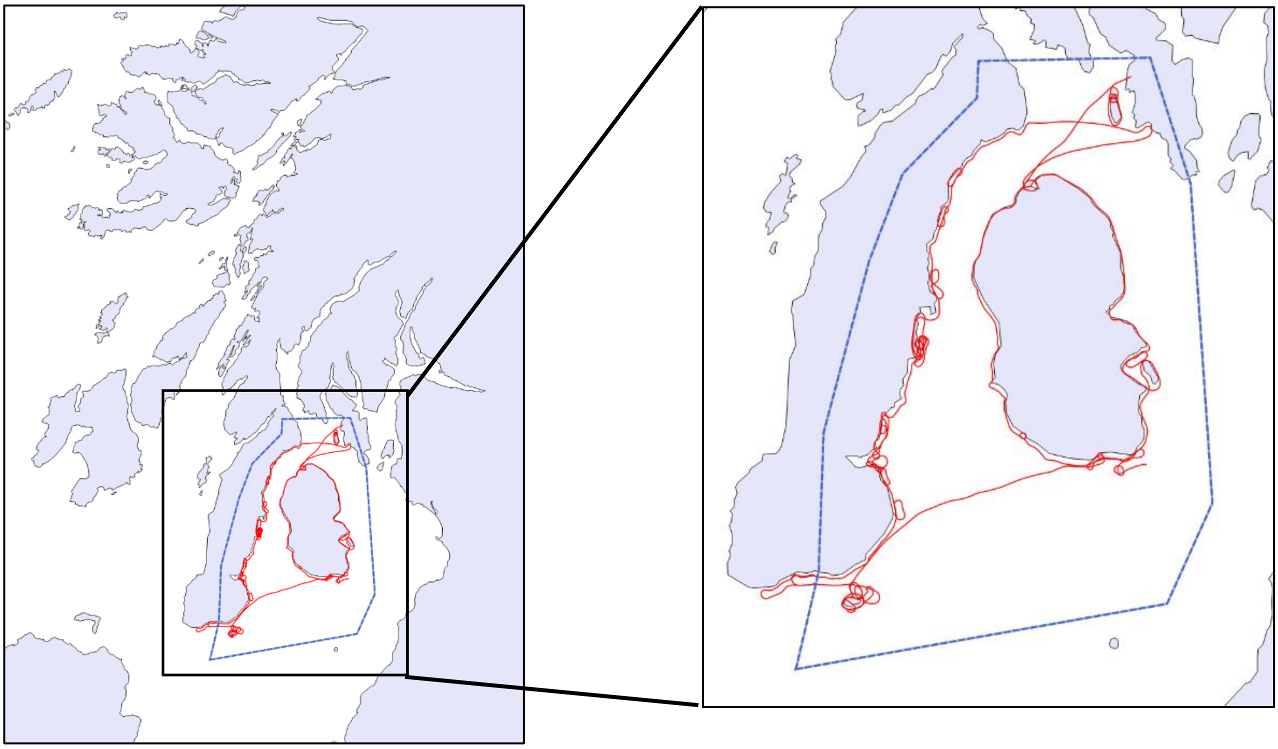

Figure 15. Aerial survey track (in red) followed on August 16th, 2016, in Kintyre and Isle of Arran, West Coast. The blue dashed line delimits the regional extent of the study area.

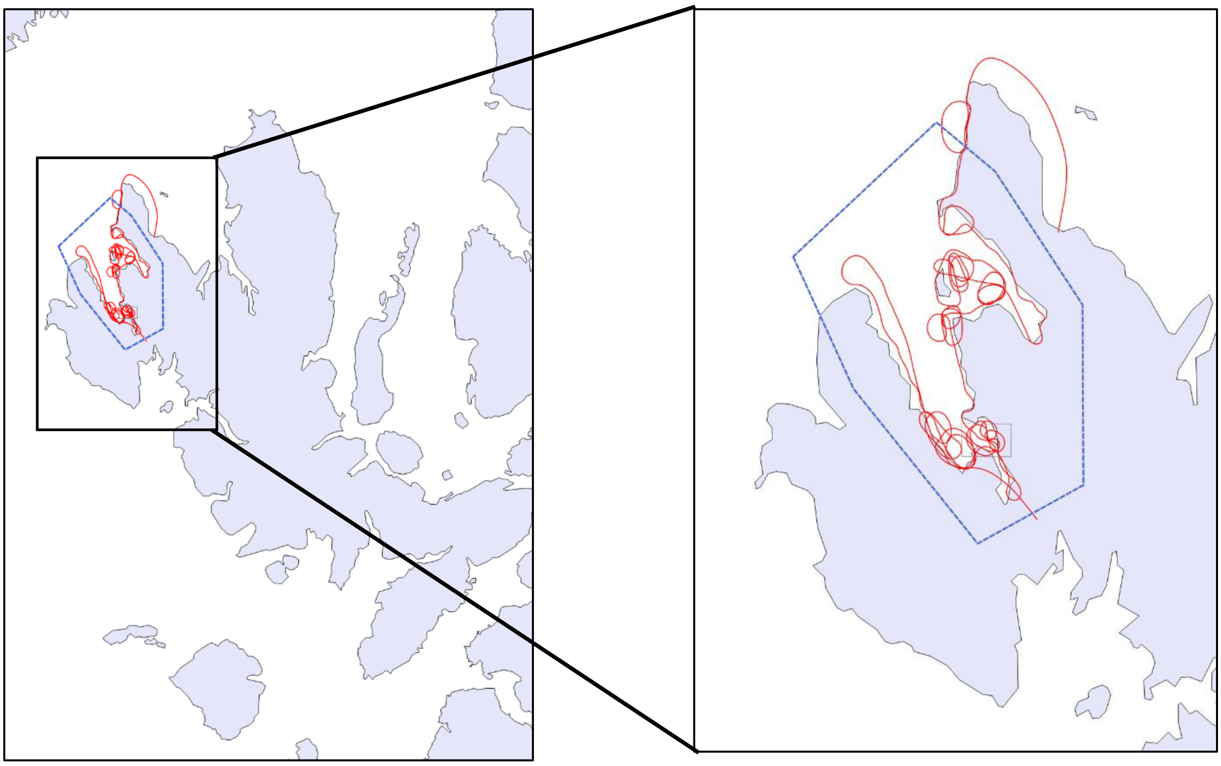

Figure 16. Aerial survey track (in red) followed on August 17th, 2016, in Dunvegan Loch, Isle of Skye. The blue dashed line delimits the regional extent of the study area.

Figure 17. Fix-wing aircraft used during the breeding aerial surveys at all three study sites.

The search for haulouts along the coast was guided by previous knowledge from the historical data collected during August moult aerial surveys. Despite this, it was difficult to detect all seals hauled out as they were well camouflaged among the rocky and seaweed-covered shores, meaning some might not have been photographed. A total of 1001 photographs were taken in all three areas (312 photographs in Scapa Flow, 424 in Kintyre and 265 in Loch Dunvegan). Photographs from each area were analysed to count the number of harbour and grey seals, as well as the number of harbour seal pups. During the processing of photographs it became obvious that it was impossible to distinguish age classes (e.g. harbour seal pup versus yearling or juvenile) from the digital photographs taken, even in the best quality photographs. Figure 18 shows an example of the difficulty of identifying species and age classes in a good quality digital photograph taken during the surveys in Scapa Flow.

Figure 18. Example of a good quality photograph of a haulout using digital photography during the breeding surveys.

The difficulty of locating seals at haul out sites from the aircraft and the impossibility of identifying age classes in the digital photographs led to discussions within the project about the use of these data for the population model. Given the quality of the resulting pup count data and the ability of the population model to perform without these data, it was decided that harbour seal pup counts would be excluded from the population model. Details on the implications of not including pup counts in the population model are discussed in Approach 1.

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

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

In addition to the excreta samples collected during the live captures in April and May (see Approach 3), a further six scats were collected at the capture haulout sites in Widewall Bay (n=5 scats) and West Burray (n=2 scats, n=13 in total) during May and June. One scat was also collected at Rubh nan Sgarbh, in Kintyre, west coast of mainland. No scat were collected at the Isle of Skye study site as it was not possible to land during the photo-ID trips.

Three samples from Orkney (two from West Burray and one from Widewall Bay) were positive for DA (12,600 – 23,500 pg g^{-1}) but the remainder were either below the limit of detection or the samples were too small for analysis.

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

Two fishing trips to collect prey samples were undertaken in the waters off Scapa Flow on the west coast of Orkney mainland, with the Orkney Sea Angling Association during their sea angling competitions. The trips were conducted on May 22nd and June 4th (Figure 19). The guts, including stomach contents, of the captured specimens were sampled and stored for future toxin analysis.

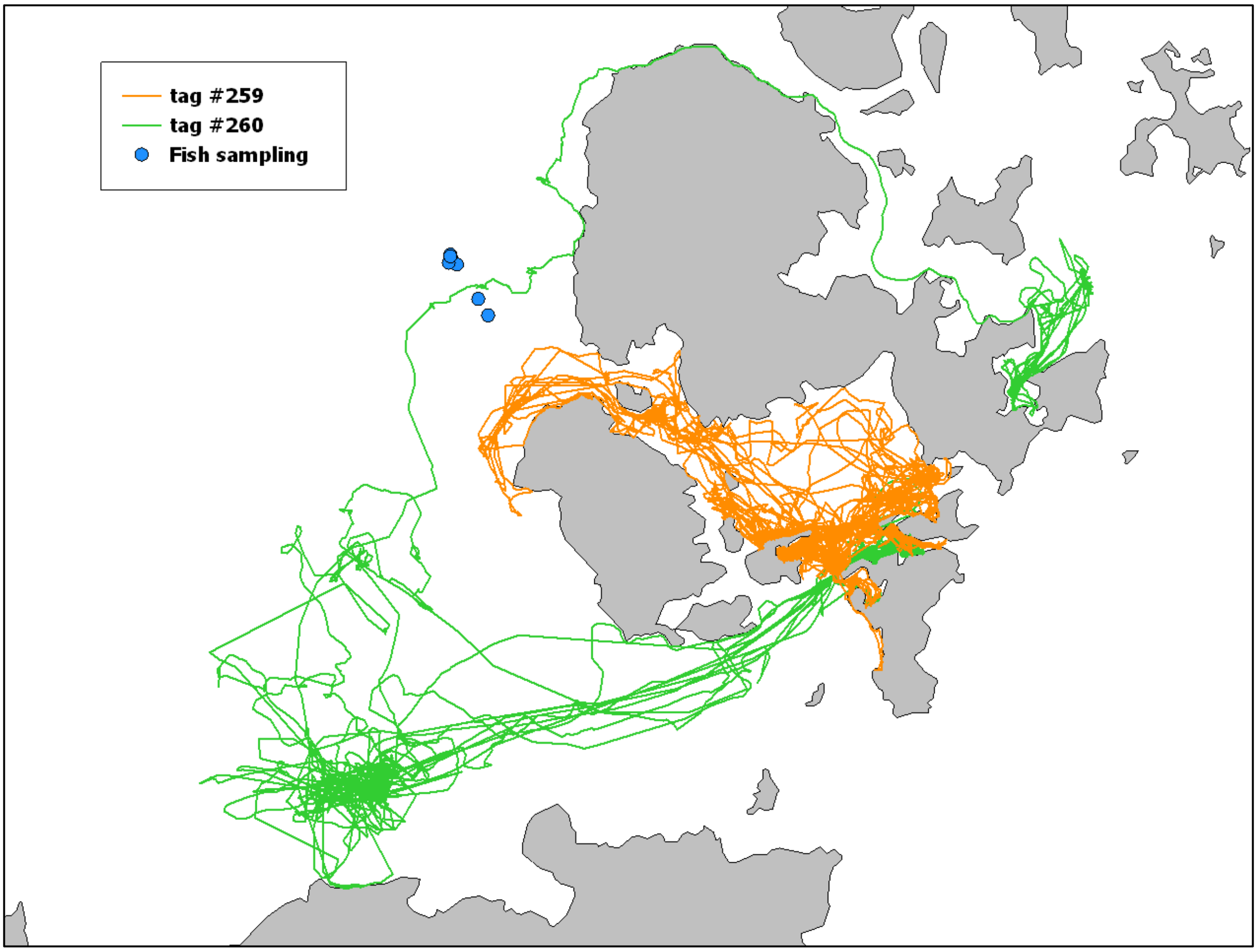

Figure 19. Locations where fish guts were sampled (blue dots) and tracks of two of the tagged seals that have travelled close to such locations before the prey sampling was conducted. The tracks are shown for 11th April to 12th June 2016 for tags #259, and 14th April to 18th June 2016 for tag #260.

Four different species of fish were taken on both fishing trips: cod, haddock, ling and torsk. A total of 85 fish guts were sampled: 35 cod samples, 12 haddock, 36 ling and two torsk. All sampled fish were measured except for 11 where the fish were cleaned by members of the crew before it was possible for them to be measured. Cod specimens ranged 37.8 to 69 cm in length, haddock specimens ranged 32.8 to 43.6 cm, ling specimens ranged 30 to 92 cm, and torsk specimens measured 49.5 and 50 cm. Samples were classified by species and stored in bags containing between 1 and 7 guts, with details on the length of the sampled fish contained in each bag. All samples were frozen on the same day as sampling.

All fish viscera collected in Orkney in 2016 have been analysed for domoic acid content, using the same method as for the seal samples. The fish samples were put into batches of up to five for processing and analysis and the resulting concentrations of domoic acid (pg g^{-1}) are shown in Figure 20. All samples were positive for domoic acid at or above the limit of detection. Interestingly, all the levels in the samples of ling were very low (at the limit of detection). However, in general, concentrations in all fish sampled were at low levels. These results will be used to estimate the dose of domoic acid consumed by harbour seals assuming they are consuming prey with similar concentrations and require an average daily calorie requirement.

Samples of fish viscera are also being analysed for the presence of PSP toxins (saxitoxin and its derivatives) at the Marine Scotland Science Laboratory in Aberdeen. Results will be reported as soon as they are available.

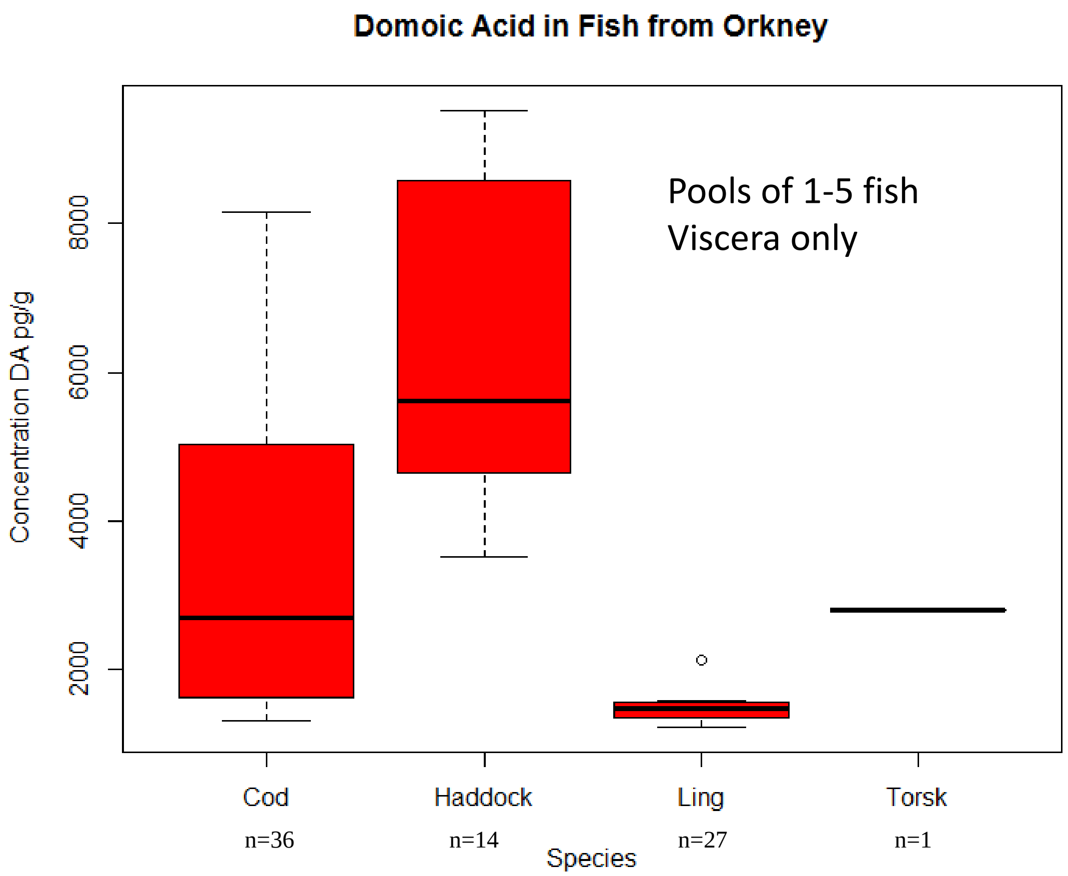

Figure 20. Concentration of DA (pg/g) in viscera by species of fish sampled off Scapa Flow in Orkney in 2016. Each data sample contained between 1 and 5 viscera. The black lines show the median, the red boxes the interquartile range and the dashed lines the value range of concentrations of DA.

6 Approach 6. Carcass collection

A total of 92 seal carcasses were reported to SMASS between June 2016 and March 2017 in the three study areas (Orkney, Isle of Skye and Kintyre and the Clyde). No carcasses were reported for these areas in April and May 2016. Figure 21 shows the locations of all reported carcasses during the time period, and Table 3, Table 4 and Table 5 summarize details on species, age class and proximate cause of death. Age class is not yet available for those seals collected in 2017.

Most of the reported seal carcasses were found in Orkney (n=72) and on the North Coast (n=1) (Table 3). Of these, 53 were grey seals (6 adults, 7 juveniles, 17 pups, 7 unknown age, and 16 to be determined), 10 were harbour seals (2 adults, 3 juveniles, 3 pups, 2 unknown age) and nine carcasses could not be identified to the species level. Proximate causes of death for harbour seals in Orkney included entanglement (n=2), possible grey seal predation (n=2) and starvation/hypothermia (n=2). For the remaining four carcasses proximate cause of death could not be determined as there were insufficient data or the carcasses had advanced autolysis preventing any determination. For grey seals, proximate cause of death could only be determined for nine of the carcasses, all of which had physical trauma in the form of possible spiral 'corkscrew' lesions.

A total of seven seal carcasses were reported in Isle of Skye (Table 4), of which five were harbour seals (2 juveniles and 3 pups) and two were grey seals. Of these, six do not have an associated cause of death as they could not be examined, and one harbour seal pup was frozen for a future post-mortem examination.

In the Kintyre and Clyde area, 12 seal carcasses were reported (Table 5), of which five were harbour seals (1 adult, 3 juveniles and 1 pup), six were grey seals (3 juveniles and 3 unknown age) and one carcass could not be identified to the species level. Only two of the carcasses were recovered (2 juvenile harbour seals) and are pending a post-mortem examination.

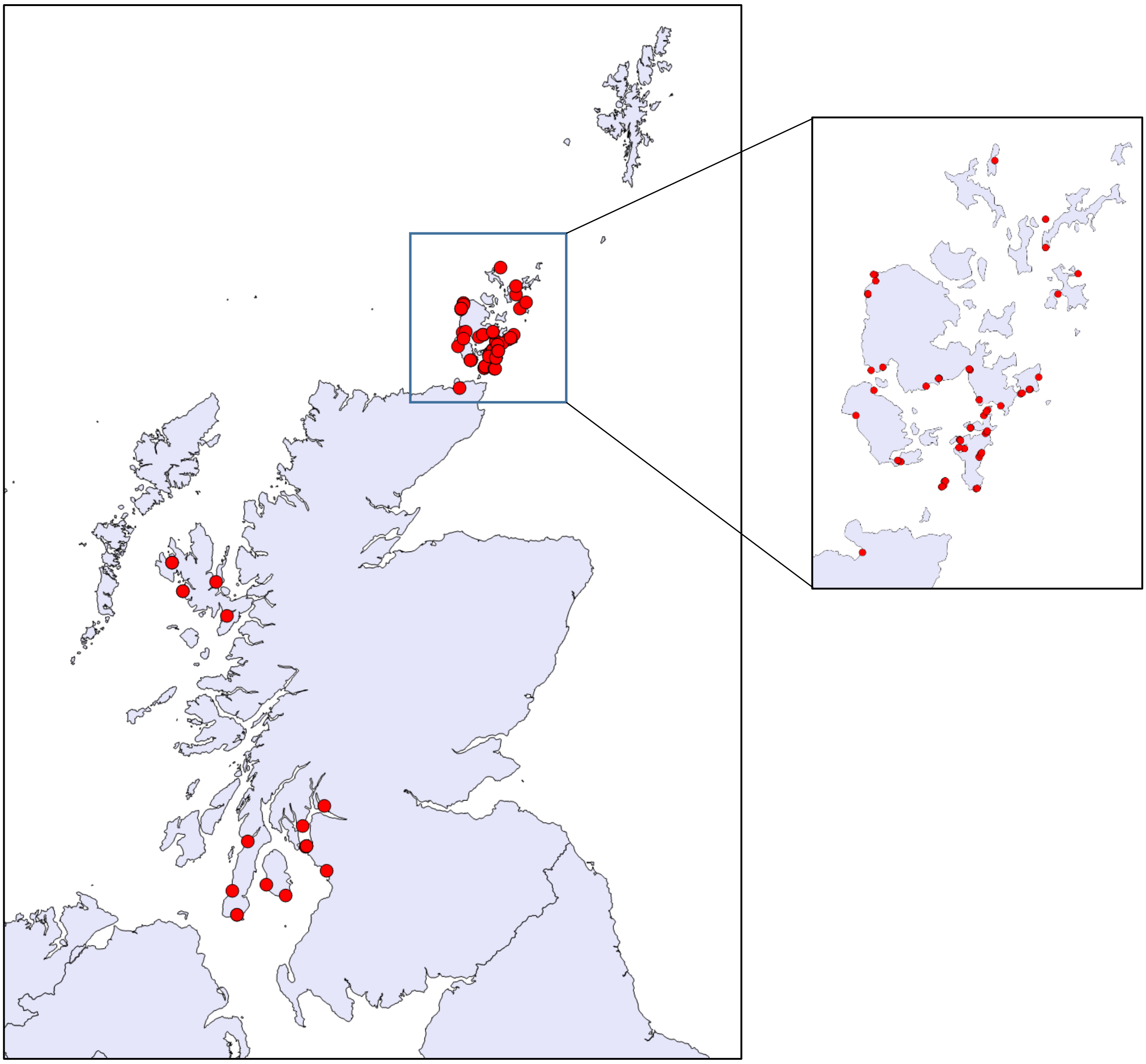

Figure 21. Location of all seal carcasses reported to SMASS between June 2016 and March 2017 within and in the vicinity of the study sites.

Table 3. Summary of seal carcasses reported to SMASS between April 2016 and March 2017 in Orkney and the North coast. Pv = Harbour seal, Hg = Grey seal, Unk = unknown seal species (continues in the next two pages).

Species	Date	Location	Area	Latitude	Longitude	Sex	Post mortem	Age Group	Findings (as recorded by person undertaking the post mortem)
Unk	15/06/2016	Papa Westray	Orkney	59.35611	-2.88722	U	FALSE	Pup	Not Examined: Insufficient Data
Unk	10/07/2016	Taracliff bay	Orkney	58.91611	-2.77694	U	FALSE	Unknown	Not Examined: Carcase Incomplete/Scavenger Damage
Unk	06/12/2016	Near Liddel loch South Ronaldsay.	Orkney	58.73389	-2.94028	U	FALSE	Adult	Not Examined: Advanced Autolysis
Unk	06/12/2016	Near Liddel loch South Ronaldsay.	Orkney	58.73472	-2.93611	U	FALSE	Pup	Not Examined: Insufficient Data
Unk	29/12/2016	Marwick Beach Mainland	Orkney	59.1	-3.34833	U	FALSE	Unknown	Not Examined: Insufficient Data
Unk	29/12/2016	Marwick Beach Mainland	Orkney	59.09861	-3.34667	U	FALSE	Unknown	Not Examined: Insufficient Data
Unk	29/12/2016	Marwick Beach Mainland	Orkney	59.09944	-3.34778	U	FALSE	Unknown	Not Examined: Insufficient Data
Unk	01/01/2017	Churchill barrier	Orkney	58.88306	-2.9025	U	FALSE		
Unk	05/02/2017	Sands of Wright Hoxa	Orkney	58.82472	-2.99833	U	FALSE		
Pv	08/06/2016	Brough of Birsay	Orkney	59.13611	-3.32361	U	FALSE	Juvenile	Physical Trauma: Possible grey seal predation
Pv	23/06/2016	Burray	Orkney	58.84861	-2.96361	M	TRUE	Pup	Starvation/hypothermia
Pv	23/06/2016	Burray.	Orkney	58.84972	-2.96361	F	TRUE	Pup	Starvation/hypothermia
Pv	25/06/2016	Stromness	Orkney	58.95472	-3.32972	U	FALSE	Unknown	Not Examined: Insufficient Data
Pv	03/07/2016	Wideweall Bay South Ronaldsay.	Orkney	58.80944	-2.98417	F	FALSE	Juvenile	Physical Trauma: Entanglement
Pv	03/07/2016	Widewell bay South Ronaldsay.	Orkney	58.80944	-2.98417	M	TRUE	Juvenile	Physical Trauma: Entanglement
Pv	11/07/2016	Wha Taing West Burray	Orkney	58.84917	-2.96444	U	FALSE	Pup	Not Examined: Advanced Autolysis
Pv	18/07/2016	Brough of Birsay	Orkney	59.13639	-3.32861	U	FALSE	Adult	Not Examined: Advanced Autolysis
Pv	10/12/2016		Orkney	59.12444	-3.31972	U	FALSE	Unknown	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Pv	18/12/2016	Swanbister Orphir	Orkney	58.92667	-3.12778	U	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	01/07/2016	Stromness	Orkney	58.96111	-3.28778	U	FALSE	Juvenile	Not Examined: Advanced Autolysis
Hg	10/07/2016	Dingieshowe Bay.	Orkney	58.915	-2.78222	U	FALSE	Unknown	Not Examined: Carcase Incomplete/Scavenger Damage
Hg	14/10/2016	Charlie's point Whitehall Stronsay	Orkney	59.14333	-2.57583	M	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	23/10/2016	Island of Swona	Orkney	58.74667	-3.05611	U	FALSE	Pup	Not Examined: Not Priority

Hg	23/10/2016	Island of Swona	Orkney	58.7475	-3.05444	U	FALSE	Pup	Not Examined: Not Priority
Hg	23/10/2016	Island of Swona.	Orkney	58.73639	-3.06583	U	FALSE	Pup	Not Examined: Not Priority
Hg	24/10/2016	Creekland bay Hoy.	Orkney	58.91694	-3.31889	U	FALSE	Juvenile	Not Examined: Advanced Autolysis
Hg	27/10/2016	Newark bay South Ronaldsay	Orkney	58.80111	-2.92333	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	03/11/2016	Loth Sanday	Orkney	59.19222	-2.69583	U	FALSE	Pup	Not Examined: Not Priority
Hg	03/11/2016	Loth Sanday.	Orkney	59.24611	-2.69694	U	FALSE	Pup	Not Examined: Not Priority
Hg	11/11/2016	Newark Bay South Ronaldsay.	Orkney	58.79361	-2.93	M	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	15/11/2016	Newark Bay South Ronaldsay	Orkney	58.79917	-2.925	U	FALSE	Unknown	Not Examined: Advanced Autolysis
Hg	20/11/2016	Swona	Orkney	58.74694	-3.055	U	FALSE	Pup	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	20/11/2016	Swona	Orkney	58.73889	-3.05806	U	FALSE	Juvenile	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	20/11/2016	Swona	Orkney	58.74694	-3.055	U	FALSE	Pup	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	20/11/2016	Swona	Orkney	58.73694	-3.06333	U	FALSE	Juvenile	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	20/11/2016	Swona	Orkney	58.74778	-3.05139	U	FALSE	Pup	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	20/11/2016	Swona	Orkney	58.74778	-3.05139	U	FALSE	Pup	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	23/11/2016	Holm	Orkney	58.90222	-2.9325	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	02/12/2016	Ayre of Cara South Ronaldsay	Orkney	58.83889	-2.90861	U	FALSE	Unknown	Not Examined: Removed by Tide
Hg	03/12/2016	Wester sand Holm	Orkney	58.89139	-2.85444	U	FALSE	Unknown	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	04/12/2016	Herston South Ronaldsay.	Orkney	58.81111	-3.00417	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	09/12/2016	Scapa Beach	Orkney	58.95917	-2.96889	M	FALSE	Pup	Not Examined: Not Priority
Hg	09/12/2016	Scapa Beach	Orkney	58.95833	-2.96889	F	FALSE	Adult	Not Examined: Not Priority
Hg	10/12/2016	Glimpss Holm	Orkney	58.87972	-2.90722	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	17/12/2016	Eastside beach	Orkney	58.80194	-2.92167	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	18/12/2016	Waulkmill bay	Orkney	58.94194	-3.08222	U	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	18/12/2016	Sandside Deerness	Orkney	58.94639	-2.71639	U	FALSE	Unknown	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	18/12/2016	Newark Bay	Orkney	58.92333	-2.75	U	FALSE	Unknown	Not Examined: Advanced Autolysis

Hg	18/12/2016	Waulkmill bay	Orkney	58.94167	-3.08361	U	FALSE	Unknown	Not Examined: Advanced Autolysis
Hg	19/12/2016	4th Churchill barrier	Orkney	58.84056	-2.90361	U	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	22/12/2016	Scapa beach	Orkney	58.96056	-2.97056	U	FALSE	Juvenile	Not Examined: Not Priority
Hg	25/12/2016	Southwalls	Orkney	58.785	-3.22556	U	FALSE	Pup	Not Examined: Advanced Autolysis
Hg	25/12/2016	Southwalls	Orkney	58.785	-3.22722	U	FALSE	Juvenile	Not Examined: Advanced Autolysis
Hg	27/12/2016	Eastside beach South Ronaldsay	Orkney	58.80194	-2.92167	U	FALSE	Adult	Not Examined: Advanced Autolysis
Hg	29/12/2016	Churchill barriers	Orkney	58.84333	-2.9025	U	FALSE	Juvenile	Not Examined: Not Priority
Hg	29/12/2016	Churchill barriers	Orkney	58.84333	-2.9025	U	FALSE	Pup	Physical Trauma: Possible spiral ""Corkscrew"" Lesions
Hg	02/01/2017	Waulkmill bay Ophir.	Orkney	58.94222	-3.08083	U	FALSE		
Hg	05/01/2017	Rackwick Hoy.	Orkney	58.86833	-3.38194	U	FALSE		
Hg	16/01/2017	Eastside beach South Ronaldsay.	Orkney	58.80083	-2.92389	U	FALSE		
Hg	16/01/2017	Bay of Sandoyne Mainland	Orkney	58.9025	-2.9325	U	FALSE		
Hg	17/01/2017	Glims Holm	Orkney	58.8725	-2.91583	U	FALSE		
Hg	20/01/2017	Sands of Wright Hoxa	Orkney	58.82611	-3.00194	U	FALSE		
Hg	20/01/2017	Sands of Wright Hoxa	Orkney	58.82528	-3	U	FALSE		
Hg	20/01/2017	Sands of Wright Hoxa	Orkney	58.82639	-3.00278	U	FALSE		
Hg	20/01/2017	Sands of Wright Hoxa	Orkney	58.82583	-3.00111	U	FALSE		
Hg	21/01/2017	Sands of Wright Hoxa	Orkney	58.82583	-3.00083	U	FALSE		
Hg	04/02/2017	South Walls	Orkney	58.7825	-3.215	U	FALSE		
Hg	05/02/2017	Rothiesholm Beach Stronsay	Orkney	59.10444	-2.64861	U	FALSE		
Hg	11/02/2017	Newark bay Deerness.	Orkney	58.92333	-2.74778	U	FALSE		
Hg	11/02/2017	Newark Bay Deerness.	Orkney	58.92278	-2.75083	U	FALSE		
Hg	16/02/2017	Glims Holm.	Orkney	58.8725	-2.91583	U	FALSE		
Hg	06/03/2017	Eastside beach Newark Bay.	Orkney	58.79472	-2.93	U	FALSE		
Hg	04/07/2016	Dunnet Bay.	North coast	58.60972	-3.34806	U	FALSE	Pup	Not Examined: Not Priority

Table 4. Summary of seal carcasses reported to SMASS between April 2016 and March 2017 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	05/07/2016	Dunvegan Skye	Skye	57.45583	-6.60083	U	FALSE	Pup	Not Examined: Delay in reporting
Pv	13/07/2016	Ord Skye.	Skye	57.15	-5.94278	F	TRUE	Neonate	Pending
Pv	16/07/2016	Dunvegan Skye	Skye	57.45306	-6.60167	M	SAMPLED	Juvenile	Not Examined: Samples Taken
Pv	16/07/2016	Isle of Raasay.	Skye	57.35222	-6.08361	U	FALSE	Pup	Not Examined: Weather/travel difficulties
Pv	16/07/2016	Dunvegan Skye.	Skye	57.45472	-6.60306	U	SAMPLED	Juvenile	Not Examined: Samples Taken
Hg	31/12/2016	Talisker beach Skye	Skye	57.28361	-6.45806	U	FALSE	Unknown	Not Examined: Advanced Autolysis
Hg	31/12/2016	Talisker beach Skye	Skye	57.28556	-6.45833	U	FALSE	Unknown	Not Examined: Advanced Autolysis

Table 5. Summary of seal carcasses reported to SMASS between April 2016 and March 2017 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	19/10/2016	Millport Great Cumbrae Island	Kintyre	55.74944	-4.93472	U	FALSE	Unknown	Not Examined: Insufficient Data
Pv	06/08/2016	Kildonan Isle of Arran.	Kintyre	55.44306	-5.12528	U	FALSE	Adult	Not Examined: Advanced Autolysis
Pv	14/11/2016	Millport Great Cumbrae	Kintyre	55.75278	-4.92583	U	TRUE	Juvenile	Pending
Pv	16/12/2016	Newton bay Millport Great Cumbrae	Kintyre	55.75278	-4.9275	U	TRUE	Juvenile	Pending
Hg	02/09/2016	Irvine	Kintyre	55.60806	-4.6925	U	FALSE	Unknown	Not Examined: Advanced Autolysis
Hg	16/11/2016	Blackwaterfoot Arran	Kintyre	55.505	-5.34194	U	FALSE	Unknown	Not Examined: Insufficient Data
Pv	30/07/2016	Between Innellan and Toward	Kintyre	55.87806	-4.97444	U	FALSE	Juvenile	Not Examined: Samples Taken
Pv	04/11/2016	Helensburgh	Kintyre	56.005	-4.75139	F	SAMPLED	Pup	Not Examined: Samples Taken
Hg	17/08/2016	Clochkiel beach Machrihanish.	Kintyre	55.45472	-5.71333	U	FALSE	Unknown	Not Examined: Advanced Autolysis
Hg	22/11/2016	Southend Kintyre	Kintyre	55.31028	-5.6475	U	FALSE	Juvenile	Not Examined: Advanced Autolysis
Hg	22/11/2016	Portchoillan	Kintyre	55.76556	-5.57083	U	FALSE	Juvenile	Not Examined: Advanced Autolysis
Hg	22/11/2016	Southend Kintyre	Kintyre	55.30972	-5.64556	U	FALSE	Juvenile	Not Examined: Advanced Autolysis

7 Harbour Seal Decline Project web blog[2]

A WordPress blog (Figure 22) was set up in March 2016 and has been kept updated with news from the field since then. A total of 17 posts were published between January 2016 and July 2016, summarizing the effort expended during the data collection.

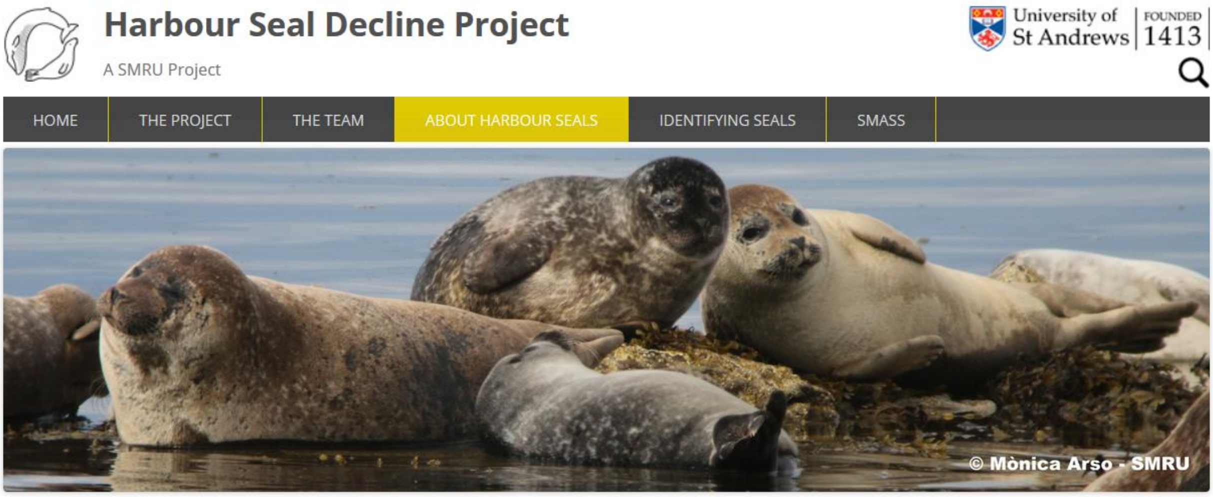

Figure 22. Screen capture of the Harbour Seal Decline Blog.

Since July 2016, the activity of the blog has been monitored by means of the Jetpack plugin[3] within WordPress. Over this time the blog has received 1,247 views from 635 visitors, with an average 5 visits per day, and between 109 and 165 visits per month (Figure 23).

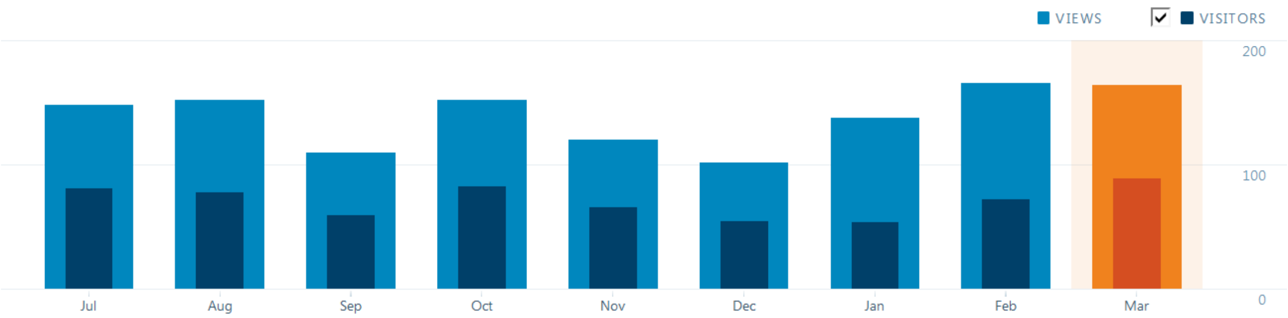

Figure 23. Summary statistics of number of views and visitors per month between July 2016 and March 2017.

[2] https://synergy.st-andrews.ac.uk/harbourseals/
[3] https://en-gb.wordpress.org/plugins/jetpack/

8 Appendices

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

Approach 1. Integrated population model.

1. A decision-support tool coded in R consisting of 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 e.g. pup counts. Realistic errors can be associated with these observations.
2. A decision-support tool coded in R consisting of 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 counts only, with no pup counts) 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 vial rates and movements will not start until year three, following the collection of field data.

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 and breeding season counts of harbour seals for parameterisation of the integrated population model.
2. Abundance of grey seals using the study sites and adjacent haul out sites to provide covariates for assessing the spatial overlap between grey seals and harbour seals.
3. A detailed description of breeding site usage and the numbers of pups observed at study sites with differing population abundance trajectories. This will include an assessment of the accuracy of pup production estimates for the surveyed sites.
4. 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 trial 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

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