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Report

Changes in at-sea foraging trips of harbour seals and grey seals in south-east Scotland

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Editorial Trail

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Contents

1 Executive summary

In many areas of Scotland including Orkney, Shetland and south-east Scotland, the harbour seal (*Phoca vitulina*) population is in rapid decline. Although the reasons for this decline are not known, nutritional stress has been postulated as a potential key factor. In south-east Scotland, telemetry data are available for multiple years for both harbour and grey (*Halichoerus grypus*) seals, allowing a pilot study to be conducted to investigate whether putative symptoms of nutritional stress are present in the behaviour of harbour seals. Specifically, it was hypothesised that the duration and extent of harbour seal foraging trips would have increased since the decline started. Contrary to the hypothesis, while controlling for day of year and sex, it was found that, since the start of the decline, harbour seal trip extent and duration has significantly decreased. In contrast, grey seal trip duration and extent has significantly increased, despite the grey seal population in south-east Scotland not appearing to be in decline. Although changes in the environment are likely to have driven these changes in apparent foraging effort, the underlying drivers remain unknown. Further work should focus on how robust the results are to (1) changes in how foraging trips are defined and (2) changes in the metric of foraging effort considered.

2 Introduction

Since the turn of the century, the harbour seal population within the Firth of Tay and Eden Estuary Special Area of Conservation has declined dramatically (Figure 1a) and at its current rate of decrease will be extinct within 20 years (Lonergan & Thompson, 2012). The concurrent summer grey seal counts, which are highly variable, do not show a clear trend (Figure 1b). For such a dramatic harbour seal decline to occur, decreased adult survival must play a role (Lonergan & Thompson, 2012). Between 2008 and 2012, 25 harbour seal carcasses were recovered which died as a result of severe trauma (spiral lacerations; Lonergan & Thompson, 2012) but the proportion of carcasses with such injuries that were recovered is unknown therefore it is not clear to what degree these deaths have contributed to the population decline. Levels of mortality due to other potential contributors to the declines, such as toxins and nutritional stress resulting in starvation, are unknown.

Many central place foragers show a degree of flexibility in their time budgets which can buffer, to some extent, against decreased food availability. If increased nutritional stress is a driver of the population decline, any spare time in harbour seal activity budgets would have been diminished. Specifically, longer and possibly more distant forging trips would be expected. Such changes would not be expected for grey seals, for which there was not a discernible decrease in population size.

Telemetry data are available for multiple years for both species. For harbour seals, during the first period of telemetry data (2001-2003), the mean moult count was 700; the rapid decline started within this period (Figure 1a; Duck *et al*., 2014). During the second period (2008-2013) the count had dropped to 222 (Figure 1a). For grey seals, telemetry data were available for two distinct periods: 1997-1998 and 2005-2008. Although the mean grey seal count for the second period (843) was much lower than the mean count for the first period (1891), this did not appear to represent a significant decreasing population trend (Figure 1b; Duck *et al*., 2014).

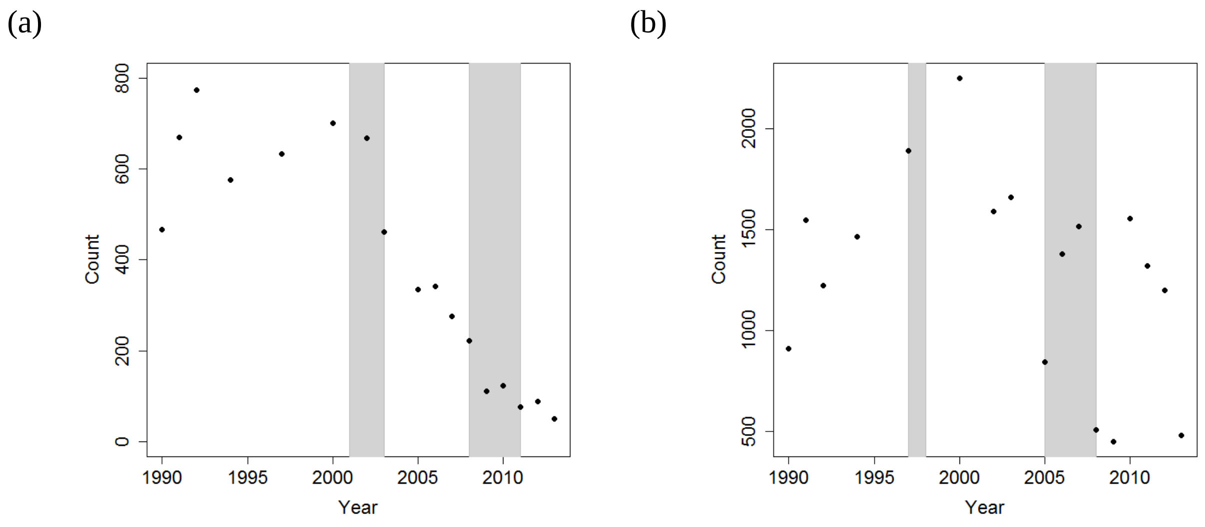

Figure 1. The summer haul-out counts of (a) harbour and (b) grey seals within the Firth of Tay and Eden Estuary Special Area of Conservation (reproduced from Tables 5 and 6 in Duck *et al*. 2014). The grey rectangles represent the periods for which telemetry data were used.

3 Methods

3.1 Data preparation

The telemetry data available are a mixture of ARGOS (period 1) and GPS (period 2). Positions from ARGOS tags were less frequent and had greater error, ranging from 50m to > 2.5km (Vincent *et al*., 2002). To correct for positional error in ARGOS data, locations were filtered by an algorithm that used a 'maximum speed parameter' of $2ms^{-1}$ (Mcconnell *et al*., 1992), and the remaining locations were processed through a Kalman filter (Royer & Lutcavage, 2008). Occasional erroneous GPS locations were removed using thresholds of residual error and number of satellites; tests on land showed 95% of the remaining locations had a distance error of < 50m.

The first seven days of data were excluded because capture or anaesthesia may have affected the subsequent trip extent and/or duration. The start and end time of all haul-out events were recorded on board the tag and the events numbered. The majority of haul-out events were then successfully transmitted by the tag. The estimated location of these events was the mean of the observed locations during the event if available. If no locations were recorded during the event, the estimated haul-out location was interpolated using the two observed locations surrounding the haul-out event. Due to the lower frequency of locations transmitted through the ARGOS system (<12 per day compared to the GSP system (>50 per day)), observed locations within haul-out events were often not available. Due to location error and interpolation, haul-out events that occurred on land could appear to be at sea. Furthermore, because haul-out events are defined using the on board wet/dry sensor, haul-out events can occur at sea when the seal is at the surface for a prolonged period.

Using knowledge of swim speed, haul-out events which could not have been on land, were flagged as “offshore” and removed. Haul-out events which were located within a 5km buffer of the St Andrews Bay (which includes the Eden and Tentsmuir) and Firth of Tay haul-out sites were included as valid haul-out events. Haul-out events outwith this buffer were flagged as non-valid haul-out events and trips starting or ending in such events were excluded. Although this process may have resulted in the exclusion of some terrestrial haul-out events whose true location was within St Andrews Bay or the Firth of Tay, it was more important not to include false haul-out events which if truly at sea would cause apparent trip lengths to be effectively halved. Because not all haul-out events were transmitted, trips were also excluded if there was a missing numbered haul-out event during the trip.

3.2 Trip definition

Almost all seals were tagged in St Andrews Bay and the remaining ones were tagged in the Firth of Tay. Haul-out location may effect trip duration and distance so to allow comparisons between years, only trips to these haul-out areas were included. A trip started at the end of a haul-out event and ended at the start of the next haul-out event. However, for this analysis some of these “trips” were deemed invalid. Because the haul-out sites at St Andrews Bay and the Firth of Tay are tidal, seals spend time in shallow water near the sites while waiting for them to become exposed. During this time they often sleep on the surface or on the sea bed (Thompson 1989) and this inter-haul-out behaviour should not be considered a foraging trip. Typically the haul-out sites are exposed within two hours of low tide and this is the tidal period when aerial surveys are conducted. Thus there is typically a maximum of eight hours when such haul-out sites may not be available, so all “trips” which were under eight hours were excluded. For both ARGOS and GPS data, trips for which the maximum extent was less than 5km were also excluded because the error in the ARGOS data meant that apparent trips with extents of under 5km may have been simply ARGOS error. Finally any apparent trips, for which there was only one location, were excluded because erroneous locations do occur and these could result in inaccurate estimates of trip extent.

Trips during the breeding season (harbour seals: June and July; grey seals October to December) were also excluded to remove behaviour related specifically to breeding. During the annual moult, telemetry tags fall off and thus few data are available for this period. For grey seals, the data used extended from 10th May to 30th September and for harbour seals data extended from 7^{th} November to 31^{st} May.

3.3 Metrics

Two metrics were considered: trip extent and trip duration. Trip extent was the maximum distance between any observed location on a trip and the mid-point of the St Andrews Bay and Firth of Tay haul-out sites. This single point was chosen so trip distance was not affected by the accuracy of the observed or interpolated haul-out location which could be up to 5 km offshore.

3.4 Data

After the above mentioned process, data from 32 grey and 16 harbour seals (aged one year and over) remained (Table 1).

Table 1. The harbour and grey seal telemetry data used in the study.

	Harbour seal		**Grey seal**	
	Period 1	**Period 2**	**Period 1**	**Period 2**
Years	2001, 2002, 2003	2008, 2011	1997, 1998	2005, 2008
Number individuals	24	8	7	9
Number of trips	200	157	11	66

3.5 Analysis

Even outwith the breeding season, both day of year (DOY) and sex may affect trip extent and duration (Sharples *et al*. 2012) and thus needed to be controlled for in the analyses. Furthermore, the effect of sex and period may depend on DOY so the full model comprised an interaction both between sex and DOY, and between period and DOY. Both sex and period were input as factors and DOY was input as a smooth term with one knot at the median value of the data. The modelling framework used needed to account for individual seal and any correlation within individuals; short trips may follow short trips (positively correlated) or alternatively short trips may be followed by longer trips (negatively correlated). A typical auto-regressive correlation structure within individual was not appropriate because of the missing trips (due to missing haul-out events). Thus the data were analysed within a generalised estimating equation (GEE) framework using package geepack (Højsgaard *et al*., 2006) within R (R Development Team 2012). By using robust sandwich-based estimates of variance (Pirotta *et al*., 2011) the uncertainty about the parameter estimates returned were robust to the presence of serial autocorrelation within individuals whilst not explicitly modelling this correlation using a specified working correlation structure. A Poisson distribution with log link was used and the dispersion parameter was estimated within the geeglm function. Backwards selection based on P values was used. The models (four in total) examined trip extent and duration for both species.

4 Results

4.1 Harbour seal

4.1.1 Trip extent

The final model included period (X^2_2=21.8, P<0.00001) and DOY (X^2_4=20.4, P<0.001) only. Trip extent was highest in winter and lowest in spring. Compared to the first period, trips of a significantly shorter extent were exhibited in the second period (Figure 2a). Qualitatively similar results were found when model selection was repeated (1) without two trips which were outliers in terms of their long extents, and (2) when one individual was excluded which post analysis diagnostics showed to be highly influential in the model, likely because it performed 59 of the trips in the data used.

4.1.2 Trip duration

The final model included period (X^2_1=10.4, P< 0.01) and DOY (X^2_4=28.0, P< 0.0001) with trip duration higher in winter compared to spring. Trips of a significantly shorter duration were exhibited in the second period (Figure 2b) compared to the first period. Qualitatively similar results were found when model selection was repeated as above (1) without seven trips which showed particularly long durations, and (2) when one individual was excluded as post analysis diagnostics had shown it to be highly influential in the model.

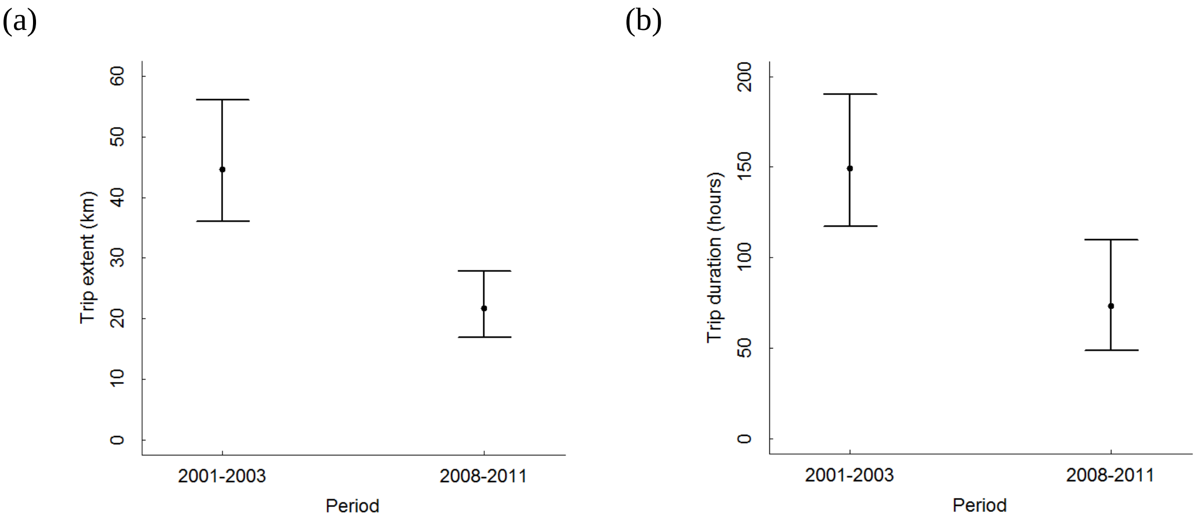

Figure 2. Harbour seal (a) trip extent and (b) duration in both periods for which there was telemetry data. Point estimates are shown along with 95% confidence intervals represented as whiskers.

4.2 Grey seal

4.2.1 Trip extent

The final model included period and an interaction between DOY and sex. However, once an extreme outlier from an individual tagged in 2008 which had a trip extent of 261 km was removed, no interactions were significant: trips of significantly greater extent were made by males (X^2_1= 8.4, P<0.01), in the second period (X^2_1= 6.6 , P= 0.01; Figure 3a) and towards the breeding season (X^2_4= 181.6, P< 0.00001).

4.2.2 Trip duration

The final model included period (X^2_1= 14.1, P< 0.001) an interaction between DOY and sex (X^2_4= 32.5, P< 0.00001). Trip duration was generally shorter in females except towards the breeding season when trip duration increased in females. Seals tagged in the second period exhibited trips of significantly longer duration than those tagged in the first period (Figure 3b). Qualitatively similar results were found once the extreme outlier was removed.

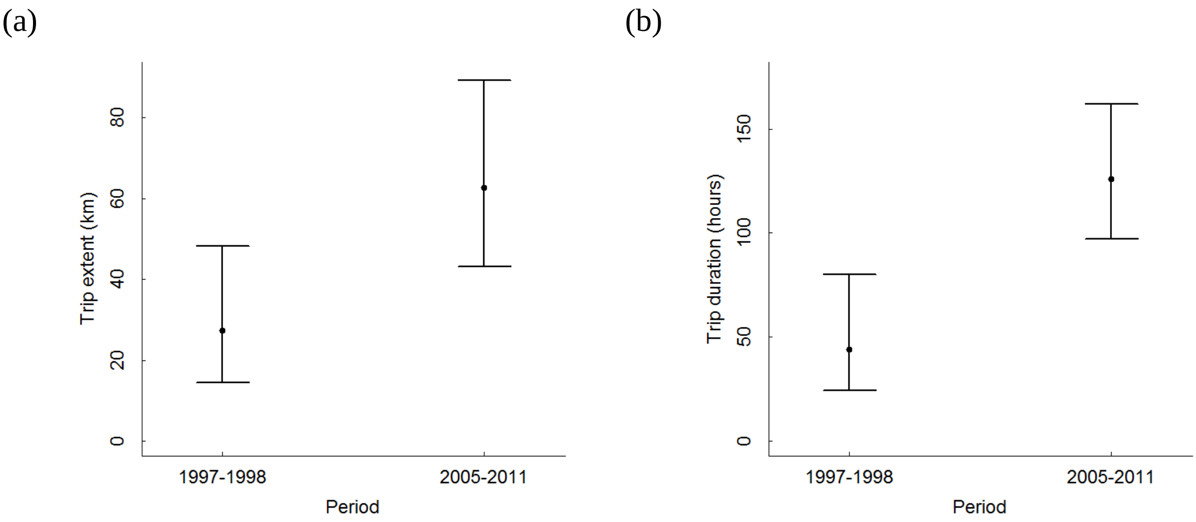

Figure 3. Grey seal trip extent (a) and duration (b) in both periods for which there was telemetry data. Point estimates are shown along with 95% confidence intervals represented as whiskers.

5 Discussion

Contrary to the starting hypothesis, harbour seals exhibited shorter trips in both extent and duration in the second period compared to the first period. Grey seals, which have not shown such a population decline, and thus were hypothesised not to show increased trip duration, did in fact show such a pattern. The change in behaviour of both species suggests that there has been some kind of change in the environment in the last 20 years.

5.1 Caveats

There were some data and methodological limitations that should be considered when assessing these results. Tag type also changed with period: ARGOS tags were used exclusively in the earlier period and GPS tags in the latter period. GPS tags transmit a higher proportion of haul-out events and locations are transmitted more frequently and are more accurate. Therefore, for the most part, haul-out locations can be accurately assigned to a haul-out site on land or as being at sea and so, in comparison to the ARGOS data, fewer haul-out events are flagged as unknown and so fewer trips have to be excluded. While this would have resulted in a relatively low sample size of trips for the individuals for which there were ARGOS data, it should not have biased the results.

However, the inaccuracy of ARGOS locations means that haul-out events could rarely be assigned to individual haul-out sites. Some of the haul-out events located within the 5 km buffer of the haul-out sites, and thus assigned as valid, may have in fact been at sea. The inclusion of such haul-out events would result in trip durations being artificially short. This may, to a small degree, explain the increased duration and extent of trips by grey seals in the second period but is contrary to the decrease in extent and duration observed in harbour seals. The differing direction of results in the two species suggests that the results for both species are unlikely to be caused by changes in tag technology.

It must also be considered that due to differing breeding and moulting seasons, the data available for the two species barely overlapped in terms of time of year. Thus it is possible that the results seen for the two species are not the result of temporal change in differing directions but an effect of considering different seasons. However, it does seem unlikely that between the two periods, such a large decrease in trip extent and duration occurred in winter and spring, and an increase occurred in summer. The data for each species were largely collected in different years and so it should also be considered that there can be substantial inter-annual variation in foraging behaviour as a result of particularly poor or good environmental conditions. For harbour seals, since the start of the decline, the count has fallen every year (Figure 1a) and thus if environmental conditions have driven the decline, it is likely that the years considered in the second period were representative of the environmental conditions during the decline.

5.2 Implications

There are various potential reasons why, between the two periods, harbour seal trips became shorter in duration and extent. If the decline is not driven by nutritional stress, the decreasing population could result in less prey depletion near to haul-out sites and thus the remaining harbour seals do not need to go as far to fulfil their energetic requirements.

However, trip duration and extent do not match up well with time spent foraging or even diving (foraging and travelling) because they do not take time resting into account (Russell *et al*., 2015). It is thus possible that although harbour seals are making shorter trips, they may be working harder: increasing their trip frequency so that their time spent resting is lowered. Although there has not been an increase in the grey seal population between the two periods of harbour seal telemetry data, if prey availability has decreased, there may have been an increase in inter-specific competition for food, forcing harbour seals into shorter trips nearer the coast as grey seals forage further out to sea.

Trip duration and extent, and changes therein, may simply reflect prey distribution or diet. A study in 2010 and 2011 found that in south-east Scotland, harbour seal diet was dominated by flatfish with sandeel and large gadids also being key components (Wilson & Hammond, 2015). An earlier study found fine scale spatial variation in diet; the diet of seals hauling out at St Andrews Bay was dominated by sandeels, whereas the diet of seals hauling out in the Firth of Tay was predominantly salmonids (Sharples *et al*., 2009). Although the majority of seals on which telemetry tags were deployed were caught in St Andrews Bay, haul-outs did occur in the Firth of Tay. If sandeels or other key prey species (gadids and flatfish) are scarce, harbour seals may be more inclined to forage for salmonids in the Firth of Tay. In contrast, there is no evidence that grey seals feed on salmonids in this area (Hammond & Grellier, 2006); in South-east Scotland their main prey species in the seasons for which there is telemetry data (spring/summer) was sandeels (Wilson & Hammond, 2015). The dominance of sandeels in their diet in this area has increased both since 1985 and 2002 (Hammond & Wilson, 2015). Sandeel foraging grounds are associated with a particular substrate type and grey seals may have to go further to obtain sandeels compared to other prey.

5.3 Further work

Further work should be focussed in three areas:

- The robustness of these findings should be explored with regard to differing definitions of a trip. The most appropriate definition of a trip can vary with region and with research question (Sharples *et al*., 2012). It should be examined whether the results are sensitive to excluding the threshold on distance from haul-out and to changes in the temporal threshold of a trip.
- During the first period of harbour seal telemetry data, the diet of harbour seals that hauled out in the Firth of Tay was found to differ from those that hauled out in St Andrews Bay (Sharples *et al*., 2009); harbour seals which hauled out in the Firth of Tay had a diet which is rich in salmonids whereas 70% of the diet of the harbour seals that hauled out in St Andrews Bay was sandeels. Although almost all harbour seals considered in this project were caught in St Andrews Bay, some did haul out in the Firth of Tay. Return trips to the Firth of Tay may be shorter in duration and distance if individuals are foraging on salmonids. For the historical ARGOS data, it is not always possible to pinpoint location to St Andrews Bay or the Firth of Tay. However, in the more recent data whether hauling out within the Firth of Tay was associated with trips of shorter extent and duration could be examined.
- Finally, activity budgets should be defined for all historical and recent data, and the proportion of time resting, foraging and travelling examined through time.

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