APPENDIX SIX: MODELLING THE EFFECT PILE DRIVING PROJECT ALPHA AND PROJECT BRAVO ON FIRTH OF TAY AND EDEN ESTUARY SAC HARBOUR SEAL POPULATION

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1. INTRODUCTION

In order to quantify the potential impacts of pile driving during the construction phase of Project Alpha and Project Bravo at the SAC population level a simple population viability analysis (PVA) model has been constructed. PVA allows the predicted rate of population change over time to be modelled and compared between a no-impact scenario, and considering the potential impacts from pile driving.

A number of assumptions have been used in the model to allow exploration of the potential magnitude of impacts that may occur due to pile driving, which may affect both the hearing ability of an individual (though a Permanent Threshold Shift (PTS)) and behaviour due to disturbance.

The consequences of these two impacts at an individual and population level are not well understood, and no empirical data exist to link either of these impacts to changes in the ability of an individual harbour seal to either breed or survive. Despite this, there is acknowledgment that some fitness effects may occur, and within the Moray Firth Framework (MFF) (Thompson *et al.*, 2012), a number of assumptions have been made about the fitness effects of PTS and disturbance in harbour seal. The approach to PVA presented here uses many of the MFF assumptions, along with some adaptations, to investigate the impacts of pile driving during the construction of Project Alpha and Project Bravo on the SAC population.

Details of assumptions and the approach to modelling are provided below. The use of PVA in examining the long term-trends in the Firth of Tay and Eden Estuary SAC has been discussed through consultation with Marine Scotland (MS) during the preparation of the Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA) (PVA HRA consultation per. comms. 18 January 2013 with Dr Ian Davies, Marine Renewable Energy Programme Manager, MS Science).

2. THE FIRTH OF TAY AND EDEN ESTUARY SAC POPULATION

The number of harbour seals counted in the Firth of Tay and Eden Estuary SAC has been rapidly declining over recent years (Thompson *et al.,* 2010; Seagreen Phase 1 Offshore Project Environmental Statement (ES) (Seagreen, 2012) Chapter 13, Appendix H5). Declining harbour seal populations have been observed across Scotland (Lonergan *et al*., 2007), but the rate of decline within this SAC is far greater than other observed declines (Lonergan & Thompson, 2012).

Lonergan & Thompson (2012) undertook an investigation of recent trends in this SAC population, and extrapolated the trends to extinction. Using counts of seals within the SAC made between 1988 and 2011 they concluded that, following a sudden change in trajectory in 2000, the population has been undergoing a rate of decline of 18% per annum (95% Confidence Interval (CI) 14.9% – 21.2%). This would lead to the effective loss of this species from the SAC within the next 20 years.

Lonergan & Thompson (2012) conclude that a reduction in adult survival beyond levels estimated in other populations (e.g. Härkönen & Heide-Jørgensen, 1990) would be required to lead to such a decline. They constructed a simple stochastic model for the female component of the population, which assumed: 92% annual survival of non-pups; 40% survival of pups; 90% of females older than 3 years pup; and that half of the pups are female. This modelled a growth rate of 5% per annum. Though subsequent introduction of an additional 25% mortality affecting adults and non-pup juveniles, Lonergan & Thompson (2012) modelled a rate of change of 18% per annum decline; this mirrors the trend observed in the haul out counts.

3. HARBOUR SEAL POPULATION MODEL – POPULATION TRAJECTORY WITH NO IMPACT

In order to undertake an investigation of the potential effect of increased mortality (the additional 25% implied by Lonergan & Thompson (2012)) on the harbour seal population of the Tay and Eden Estuary SAC, a simple six-stage population model based on that presented in Thompson *et al.*, (2007) was constructed. Figure 1 shows the life cycle graph for this model, where probabilities P_i represent survival at each stage, G_i represent growth into the next stage, and F_i show the fecundity probabilities (based only on the female segment of the population). The model was originally used to describe the harbour seal population in the Moray Firth, considering the impacts of shooting of seals (Thompson *et al.,* 2007). The population model used life history data published by Härkönen & Heide-Jørgensen (1990) and Heide-Jørgensen *et al.*, (1992) as shown in Table 1. Further details of the model structure can be found in Thompson *et al.* (2007) and Mackey (2004). The six-stage structured model used in Thomson *et al*. (2007) and for the SAC population modelled here is described by the population projection matrix **A**, below (Leslie, 1945; Caswell, 1989):

$$\mathbf{A} = \begin{bmatrix} P_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & F_3 & F_4 & F_5 & F_6 \\ G_1 & P_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_2 & P_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_5 & P_6 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & P_1 & 0 & F_3 & F_4 & F_5 & F_6 \\ 0 & 0 & 0 & 0 & 0 & 0 & G_1 & P_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_2 & P_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_3 & P_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_4 & P_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & G_5 & P_6 \end{bmatrix}$$

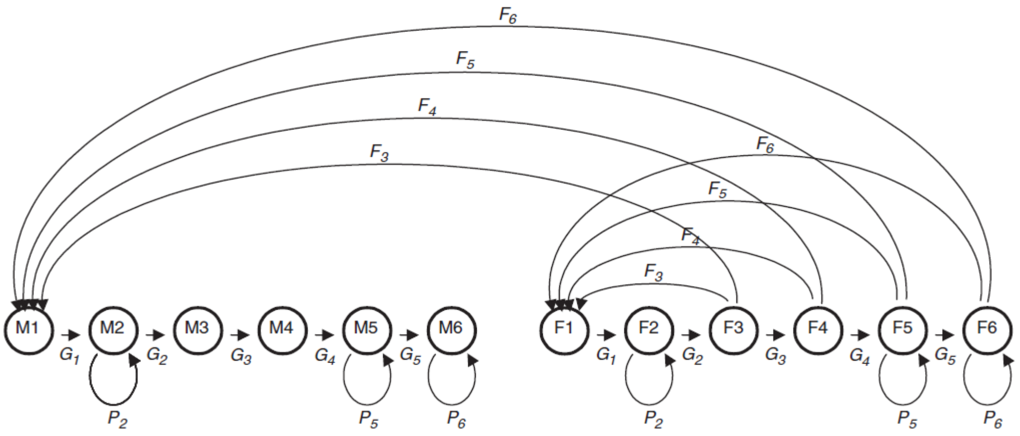

Figure 1: Life cycle graph for the six-stage two-sex classified model. M1-M6 and F1-F6 represent the six stage classes for males and females respectively. The values for F_i represent the per capita fertility of stage class i, G_i the probability of survival in each stage and P_i the probability of growing into the next stage.

Table 1: Age and sex - specific per capita fertility and survival probabilities. After Härkönen & Heide-Jørgensen (1990) and Heide-Jørgensen et al. (1992)

Age class	**0**	**1-3**	**4**	**5**	**6-26**	**27-37**
Females	0	0	0.17	0.33	0.48	0.35
	0.75	0	0	0	0	0
	0	0.91	0	0	0	0
	0	0	0.91	0	0	0
	0	0	0	0.95	0	0
	0	0	0	0	0.95	0.95
Males	0	0	0.17	0.33	0.48	0.35
	0.75	0	0	0	0	0
	0	0.91	0	0	0	0
	0	0	0.91	0	0	0
	0	0	0	0.91	0	0
	0	0	0	0	0.91	0.91

The stage durations in the model are calculated following methods outlined in Caswell (1989) and Mackey (2004). This population model, when unperturbed, leads to a growth rate at close to the theoretical maximum for this species (an increase of approximately 10.5% per annum). In order to predict the observed rate of decline in the SAC population (18% per annum), Lonergan & Thomson (2012) suggested that a 25% increase in mortality, affecting adults and non-pup juveniles, would lead to the decline, as observed in the haul out counts.

Within the six-stage model used in this investigation, a 28% reduction in survival probability across each stage class led to a modelled decline of 18% percent per year. The 28% reduction across all stages was determined by sensitivity analysis. The reduction in survival produced the population projection matrix **A**, shown below:

$$\mathbf{A} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.17 & 0.33 & 0.48 & 0.35 \\
0.54 & 0.4536 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.2016 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.6552 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.6552 & 0.648 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0072 & 0.6552 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.17 & 0.33 & 0.48 & 0.35 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.54 & 0.4536 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2016 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6552 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.684 & 0.6624 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.00216 & 0.684
\end{bmatrix}$$

It is assumed that the survival probabilities in matrix **A** (above) provide a representation of the current vital rates of this population. It should be noted that within this model survival probabilities incorporate immigration and emigration, as well as direct mortality. Numbers of harbour seals in the east coast management area (ECMA) are not exhibiting the same trend as within the SAC. They have also probably been declining since 2000, but the annual rate of change was in the range -0.024 to +0.03 (Lonergan & Thompson, 2012). Therefore the vital rates applied here (to the Tay and Eden Estuary SAC population) will not be applicable across the entire ECMA.

It should also be noted that Lonergan & Thompson (2012) report relatively low numbers of pups recorded in the SAC compared to other harbour seal populations. In the SAC, one pup was observed for every ten animals counted, and in 2010 the ratio was 1:13. This may reflect lower stage-specific fecundity rates in the SAC, or a highly skewed stage- and sex-structure, where the population is composed of either a large number of young animals, or old animals whose reproductive rates are low. In the absence of empirical data to refine the stage- or sex-structure of the population, a stable distribution is assumed. In order to model the population trajectory of the SAC, the stable starting stage- and sex-structure was determined by running the model for 100 years to allow a stable distribution to develop. Although it is unlikely that the stage- and sex-structure of the current SAC population is stable, this approach has been chosen to establish the number of seals in each stage- and sex-class prior to modelling the population trajectory post-impacts.

It should be noted that other combinations of reductions in survival and fecundity rates as presented in Table 1 could also lead to the observed annual rate of change. However, the approach used here was taken to provide an initially simplistic but realistic approach to the modelling.

The haul out count from 2010 (of 124 seals), has been corrected for the proportion of seals hauled out during the Sea Mammal Research Unit (SMRU) air survey (assumed to be 0.72 following Lonergan *et al*., 2011). This provides an estimate for the SAC population of 172 seals in 2010. The stable distribution from the model allows the number of seals in each stage- and sex-class to be calculated, as show in Table 2. This structure provides a ratio of one pup for every 3.5 non-pup seal counted. This is clearly higher than the observed ratio presented in Lonergan & Thompson (2012).

Table 2: Simulated numbers of individuals within each stage class for the SAC population in 2010 (assuming a stable stage distribution).

Stage (age) class	Number of males	Number of females
1 (0)	19	19
2 (1-3)	29	29
3 (4)	7	7
4 (5)	6	6
5 (6-26)	21	24
6 (27-37)	1	4
Total	**83**	**89**

The unperturbed (without pile driving) population growth trajectory was modelled from 2010 until 2030 using the population projection matrix **A**, and the starting stage structure in Table 2. The projection resulting from this modelling is representative of the predicted rate of change in the population, and is analogous to the rate of decline predicted by Lonergan & Thompson (2012). The modelled trajectory is shown in Figure 2 (solid black line), and Table 3 provides a summary of the demographics used in the model. This model gives an estimated SAC population of 78 seals in 2014; prior to any impact from pile driving at Project Alpha and Project Bravo being assessed.

Table 3: Summary of parameters used in the SAC population model.

Parameter	**Values used**	**Source**
Starting population size (2010)	172	Estimate based upon corrected count from SMRU 2010 surveys.
Starting population size pre construction (2014)	78	Unperturbed (without pile driving) population growth trajectory model.
Age at first reproduction	4	Härkönen & Heide-Jørgensen (1990)
Reproductive rate of females	Age 4: 34% Age 5: 66% Age 6 to 26: 96% Age 27 to 37: 70%	Härkönen & Heide-Jørgensen (1990)
Sex ratio	0.5	Boulva & McLaren (1979)
Pup mortality	Age 0: 46%	28% reduction in survival from values in Härkönen & Heide-Jørgensen (1990).
Non-pup mortality - males	Age 1-3: 34.5% Age 4: 34.5% Age 5: 34.5% Age 6 - 26: 34.5% Age 27-37: 34.5%	28% reduction in survival from values in Härkönen & Heide-Jørgensen (1990).
Adult	Age 1-3: 34.5% Age 4:34.5% Age 5:31.6% Age 6 -26:31.6% Age 27-37:31.6%	28% reduction in survival from values in Härkönen & Heide-Jørgensen (1990).

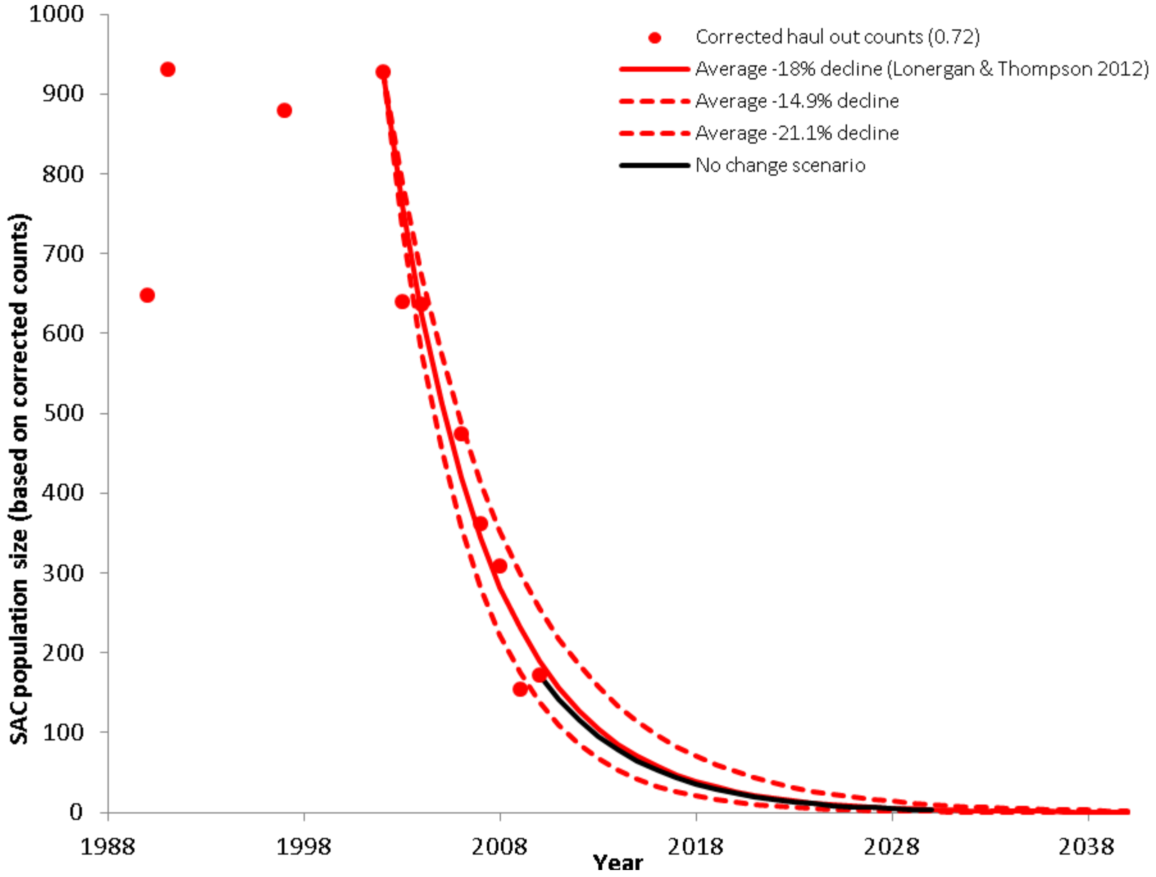

Figure 2: Corrected haul out counts from within the SAC; projected rate of decline (18%); 95% confidence intervals (14.9% to 21.1%) based on Lonergan & Thompson (2012); and projected rate of decline from 2010, based on the stage structured model used in this investigation (no change scenario).

4. IMPACT OF PILE DRIVING

An investigation was carried out to determine the population level effects arising from predicted pile driving impacts. The aim was to determine if the impacts of PTS and behavioural disturbance would lead to a significant increase in the projected rate of decline in the SAC population. This exercise only models the impacts from pile driving on the SAC population.

Assumptions

A number of assumptions were used in the model: these are briefly outlined in the following section, and summarised at the end of the section in Table 5. A number of these assumptions are the same as those used in the MFF. There are also a number of assumptions outlined in Seagreen ES Volume I Chapter 13 (Section Impact Assessment – Construction Phase) that have been used in the calculation of impacts; these assumptions are not repeated in this report.

The impact ranges for PTS were estimated using the Sound Exposure Level (SEL) injury criteria: 186dB re 1 $\mu Pa^2.s^{-1}$ (M-weighted; Southall *et al*., 2007) for multiple pulses and the proportion of the population impacted was calculated using Statistical Algorithms For Estimating the Sonar Influence of Marine Megafauna (SAFESIMM) (see ES Volume I Chapter 13 for details of methods and data used in the assessment of impact, and Chapter 13 Table 13.17, 13.26 and 13.34). The number of harbour seals exposed to disturbance has been calculated using the spatial overlay method, as presented in the ES Volume I Chapter 13 (Chapter 13 Table 13.21, 13.30 and 13.35 provide details for behavioural impact magnitudes). Table 4 summarises the number of seals estimated to develop PTS and be disturbed due to pile driving, as well as the percent of the ECMA population this equates to from the data presented in the ES Volume I Chapter 13. The most recent corrected haul out count provides an estimate of 540 (95% CI 442-720) seals in the ECMA; the SAC represents approximately 32% percent of this population.

There is mixing of seals between the SAC and the rest of the ECMA, as shown by telemetry data (ES Volume III Appendix H5). It is therefore not appropriate to assume that impacted seals are only from the SAC population. The potential impacts from pile driving on the SAC population are therefore considered to be at the same proportion as in the wider ECMA population.

Table 4: Number of seals from the ECMA (and percentage of ECMA population) predicted to be impacted by SAFESIMM (PTS) and spatial overlay method (disturbance) from pile driving, as summarised from ES Volume I Chapter 13.

Project	Worst case PTS	Most Likely PTS	Worst Case Disturbance	Most Likely Disturbance
Alpha	16 (2.96%)	9 (1.67%)	51 (9%)	44 (8%)
Bravo	10 (1.85%)	5 (0.95%)	38 (7%)	28 (5%)
Alpha and Bravo concurrent	21 (3.88%)	12 (2.22%)	56 (10%)	50 (9%)

It is acknowledged that the PTS thresholds in pinnipeds may be higher than 186dB (e.g. 198dB, as argued by Thompson & Hastie, 2011) but no data currently exist to revise this. It is likely that the PTS threshold may lie somewhere between these two values, and, therefore, the magnitude of potential impacts will also lie somewhere between the two. In the case of pile driving at Project Alpha and Project Bravo, potential impacts of PTS at the 198dB threshold will be mitigated (ES Volume I Chapter 13). Therefore, in this assessment, as a precautionary approach, we investigate impacts based on the predictions of SAFESIMM at the 186dB threshold as being the worst case.

It is assumed that individuals predicted to develop PTS will also have an additional 25% increase in their mortality risk (based on the assumption of the MFF). This increased risk of mortality (expressed as a reduced survival probability in the model) will continue throughout the lifetime of the individual. In addition, individuals who have PTS are assumed to experience a 100% reduction in fecundity, which also persists throughout their life. This latter assumption is in addition to the MFF assumptions: it is considered here that animals exposed to PTS thresholds will also experience disturbance, and therefore an impact on fecundity is also assumed, at least in the years of pile driving. The perpetuation of this impact is assumed to continue for the lifetime of the individual for simplicity of modelling, but also provides a precautionary approach to assessment of the impacts of PTS on fecundity; with harbour seal using acoustic cues (among other methods) during mating (Thompson *et al*., 2012).

Following the MFF, it is assumed that behavioural disturbance will lead to reduced fecundity (through a reduction in the overall energy balance of a seal). The scale of the reduction in fecundity will be in direct proportion to duration of disturbance (i.e. exclusion for 10% of the year will lead to a 10% reduction in fecundity in that year). The MFF assumes that there will be continuous pile driving within each year of construction, therefore, there is the potential for

PTS only once per year, and the behavioural disturbance is assumed to be for 100% of the time. In the case of Project Alpha and Project Bravo the worst case fully driven pile will take approximately 55 minutes to install, and the most likely (drive, drill, drive) will only have 33 minutes of pile driving. There will be an average break of 12.5 hours between each of the worst case pile driving events, and an average break of 38.5 hours between the most likely pile driving events. Across Project Alpha and Project Bravo, approximately 20% of the foundations will be worst case, and 80% will be most likely. As only one vessel will be operating in Project Alpha and one in Project Bravo at any one time, there is the potential for significant proportions of the year during which there will be no pile driving. Breaks in pile driving provide the potential for animals to return to the area and thus have reduced periods of disturbance or exclusion, but there is also the potential for exposure of new animals to PTS. The number of breaks in pile driving and potential exposure to PTS across the population is hard to quantify, as little is known about the duration of behavioural exclusion in harbour seals.

Table 5: Summary of precautionary assumptions

Assumption	**Reason**
PTS threshold is 186dB	The use of 186dB as the threshold for PTS onset is considered to be precautionary (Thompson & Hastie, 2011, Thompson et al., 2012).
The consequences of PTS are a 25% increase in risk of mortality and a 100% reduction in fecundity – sustained through that individual's life.	The MMF assumes individuals predicted to develop PTS experience an additional 25% increase in mortality risk. This is accepted as being precautionary, in the absence of empirical data. In the modelling here an additional permanent effect on fecundity is also considered as a further precautionary approach to the impacts of PTS.
There can be breaks in pile driving which allow PTS exposure to the population more than once per year	The MFF assumes continuous pile driving and single PTS exposure. Exposure to the population one more than once occasion is modelled as a scenario in this assessment to explore the potential of individuals retuning to the area of impact due to breaks in pile driving.
Following breaks in pile driving, seal densities return to levels pre- piling	There is a large amount of uncertainty as to the temporal duration of any behavioural disturbance from pile driving. In addition, during breaks in pile driving construction vessels may remain in the area, which may lead to some behavioural exclusion. However, seals may be habituated to vessel noise, and behavioural disturbance may be limited from this, and animals could return. Despite this, assuming that numbers of seals in the vicinity of the development return to pre-piling levels is still considered a precautionary approach.
After breaks in pile driving which allow the exposure of new individuals to PTS thresholds, it is assumed that the number that develop PTS (as modelled by SAFESIMM) will be the same as on the initial exposure.	This is precautionary as it is possible that some of the seals exposed to noise above PTS thresholds could have already developed PTS. Therefore, the proportion of those seal that will develop PTS following exposure may be less than on the first pile driving event. The probability of developing PTS at the threshold in SAFESIMM is approximately 0.18.

Modelling Scenarios

Two simplistic scenarios have been modelling in order to explore the potential impacts from pile driving during construction at Project Alpha and Project Bravo. These are provided as an illustration of the potential impacts based on a range of assumptions, and will not necessarily be indicative of the actual approach to construction. They aim to provide a realistic worst case scenario. In each scenario it is assumed that impacts will be evenly distributed across the stage- and sex-classes of the population, in direct proportion to the size of each class.

The modelling takes no account of changes in the survival or reproductive rates that may occur in the SAC population other than the impacts from pile driving at Project Alpha and Project Bravo. It therefore does not consider pile driving from other offshore wind farm developments in the Firth and Tay.

Scenario A:

This scenario assumes that during construction PTS exposure only occurs once per year, and there is behavioural disturbance for 100% of the year. This scenario follows the assumptions of the MFF. Disturbance footprints and numbers impacted are based on the modelling of a single concurrent (worst case) pile driving event at Project Alpha and Project Bravo, with 3.88% (3 seals) of the SAC assumed to develop PTS each year, and 10.4% (8.2 seals) assumed to be disturbed (Table 4). Pile driving occurs for two years at each project; in 2015 and 2016. Table 6 summarises this construction scenario in terms of exposure to and magnitude of impacts.

Table 6: Summary of construction Scenario A, number of seals impacts is based on the project starting SAC population size in 2014 of 78.

Year	**Activity**	**Exposure to impact**	**Number of seals (percent of SAC population exposed)**
2015	Concurrent worst case pile driving at Alpha and Bravo	Single PTS	3 seals (3.88%)
		Continuous disturbance (100% of the year)	8 seals (10.4%)
Break in pile driving			
2016	Concurrent worst case pile driving at Alpha and Bravo	Single PTS	2.4 seals (3.88%)
		Continuous disturbance (100% of the year)	6.5 seals (10.4%)

Scenario B:

This scenario is more complicated as it allows more than one opportunity for exposing animals within the population to PTS. It is based on the assumption that with only two vessels in total operating across Project Alpha and Project Bravo there is a high probability of breaks in pile driving. These breaks allow seals to return to the area to forage, and thus new individuals could be exposed to the potential for PTS. This scenario is summarised in Table 7.

In year 1 it is assumed that there will be construction at Project Alpha and Project Bravo. At Project Alpha there will be exposure to noise from the worst case scenario while fully driven piles are installed; there will then be a break before the fully driven piles are installed at Project Bravo (using the same vessel). Therefore, at each site seals will be exposed to the worst case impact footprint (fully driven piles) for Project Alpha, and then Project Bravo. In addition, drive drill drive installation is assumed to take place at Project Bravo initially, and then move to Project Alpha (using the same vessel), thus exposing seals to the most likely impact footprints at each project site once per year. This approach also assumes that there is no overlap between periods of disturbance at Project Alpha and Project Bravo in year 1, and the impacts of PTS are additive, as new seals are exposed each time. Therefore, in year 1, a total of 5.8 seals, or 7.4% of the SAC develop PTS, and 22.7 seals or 29.1% of the SAC are behaviourally excluded for some proportion of the year.

By year 2 it is assumed that only drive drill drive installation (most likely) will be required. This is due to the short amount of time (and average of 12.5 hours between piles) required to fully pile drive foundations (worst case), and the planned maximum of 20% of the foundations installed by this approach.

Table 7: Summary of construction Scenario B.

Year	**Activity**	**Exposure to impact**	**Number of seals (and percent of SAC population exposed)**
2015	Single worst case pile driving at Alpha	Single PTS Disturbance for 10% of the year	2.3 seals (2.96%) 7 seals (9%)
	Break in pile driving		
	Single worst case pile driving at Bravo	Single PTS Disturbance for 10% of the year	1.5 seals (1.85%) 5.5 seals (7%)
	Break in pile driving		
	Single most likely pile driving at Alpha	Single PTS Disturbance for 90% of the year	1.3 seals (1.67%) 6.3 seals (8%)
	Break in pile driving		
	Single most likely pile driving at Alpha	Single PTS Disturbance for 90% of the year	0.7 seals (0.95%) 3.9 seals (5%)
Break in pile driving			
2016	Concurrent most likely pile driving at Alpha and Bravo	Single PTS Continuous disturbance (100% of the year)	1.4 seals (2.22%) 5.6 seals (9.26%)

5. RESULTS

Figure 3 shows the results of modelling the SAC population growth over time given the impact magnitudes described for each scenario. As can be seen from the figure, the difference between the growth rates when there is no impact and when there is an impact is small in absolute terms. In both cases, the theoretical SAC population from the model continues decline at a rapid rate over time, and this decline is within the bounds of the 95% confidence limits for the current rate of decline. This means that it is unlikely that the change in SAC population trajectory as a result of the modelled impacts could be detected. However, it should be noted that the impacts are based on the SAC population parameters that lead to an 18% decline per annum, and not the greater 21.1% decline which is the lower bound of the confidence interval for projected decline from Lonergan & Thompson (2012). If the SAC population were declining at this faster rate, the underlying life history parameters would be different from those used in the model presented here, and modelling the potential impacts from pile driving could lead to detectable change in the rate of decline from the predicted average.

Although small perturbations are seen in the SAC population trajectory (Figure 3) following the impacts as described, it is harder to discern whether these changes constitute a significant change in the rate of decline. Impacts are also presented as a percentage reduction in the SAC population size compared to the no change scenario (Figure 4). The impacts approach a 17% reduction in the SAC population size in Scenario B. Impacts are also presented as projected date at which less than ten seals are within the SAC population, as an indication of potential 'extinction' of the SAC (Table 8).

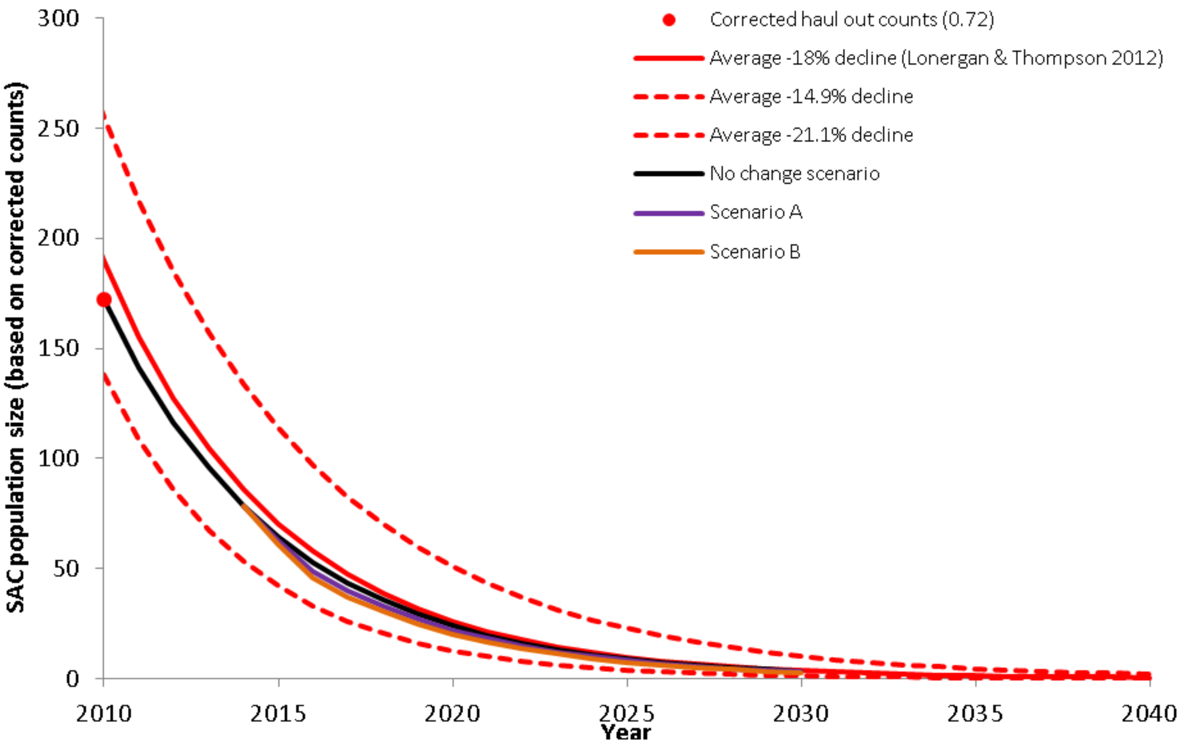

Figure 3: Corrected haul out counts from within the SAC, projected rate of decline (18%) as well as 95% confidence intervals (14.9% to 21.1%) based on Lonergan & Thompson 2012, as well as projected rate of decline from 2010 in the no impact scenario, as well as impacts based on Scenario A and B (see text for details).

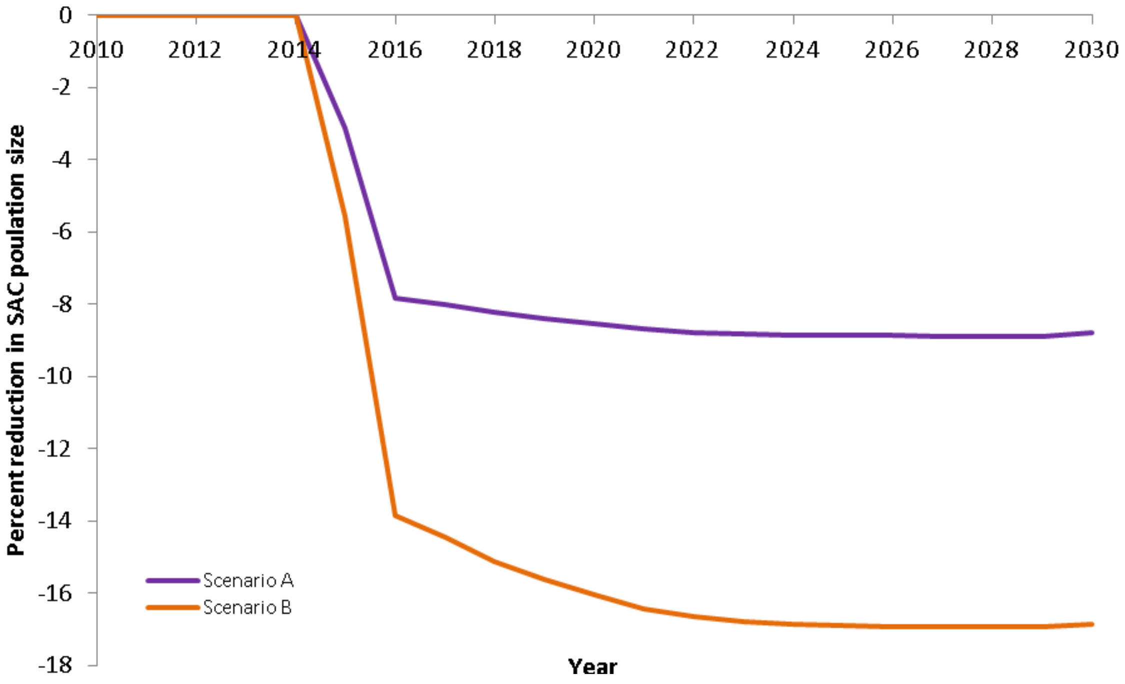

Figure 4: Percentage reduction is SAC population size for each scenario as compared to the no impact scenario.

Table 8: Predicted date of extinction (less than 10 seals in the SAC).

Scenario	SAC population projected to drop below 10 seals
No change	2025
A	2025
B	2024

6. SUMMARY

Currently the SAC population of harbour seals in the Firth of Tay and Eden estuary is rapidly declining and likely to become effectively extinct within the next 25 years (Lonergan & Thompson, 2012). The SAC population has suppressed survival rates, and is also likely to have suppressed reproductive rates or a highly skewed stage- or sex-structure (Lonergan & Thompson, 2012). Given these large and unexplained rates of decline, there is a large amount of uncertainty in the future growth rates of this SAC population.

The modelling completed here is used to provide an illustration of possible SAC population level impacts from pile driving at Project Alpha and Project Bravo. A large number of assumptions have been used in the model, as well as in the quantification of the magnitude of potential impacts within the EIA (ES Volume I Chapter 13). In many cases these assumptions can be seen as precautionary due to a lack of empirical data linking pile driving to PTS or behavioural disturbance in harbour seal, or linking PTS or behavioural disturbance to any fitness effects in harbour seal. Given the lack of data and the uncertainties, this assessment has followed many of the assumptions used in the MFF. The discussion surrounding the assumptions used in such assessment is on-going: refinement and adjustment should be anticipated as our understanding of the key issues improves. Assumptions relating to the number of animals that may be exposed to PTS following breaks in pile driving allows a departure from the MFF, and moves towards an approach which provides a precautionary position.

The modelling indicates that, when there is no additional impact from pile driving at Project Alpha and Project Bravo, the population may become effectively extinct (less than 10 seals) by 2025. When considering impacts based on the construction scenarios presented here, extinction occurs by 2024. Immediately following pile driving at Project Alpha and Project Bravo, the SAC population would be approximately 16-17% lower than if there was no impact.

7. REFERENCES

Boulva, J. & McLaren, I.A. 1979. Biology of the harbor seal, *Phoca vitulina*, in Eastern Canada. Bull. Fish. Res. Bd. Canada Bull. 200: 24pp.

Caswell, H. 1989. Matrix population models: Construction, analysis and interpretation. Sinauer Associates Inc., Publishers, Massachusetts.

Härkönen, T. & Heide-Jørgensen,M-P., 1990. Comparative life histories of East Atlantic and other harbour seal populations. Ophelia, 329 (3); 211-235.

Heide-Jørgensen , M-P., Härkönen, T., Åberg, P., 1992. Long-term effects of Epizootic in harbour seals in the Kategat-Skagerrak and adjacent areas. Ambio, 21(8)l 511-516.

Leslie, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika, 33(3) 183-212.

Lonergan, M., Duck, C.D., Thompson, D., Mackey, B.L., Cunningham, L. & Boyd, I.L. 2007. Using sparse survey data to investigate the declining abundance of British harbour seals. J. Zool. (Lond.) 271, 261–269.

Lonergan, M., C. Duck, C. Morris & D. Thompson. 2011. Harbour seal (*Phoca vitulina*) abundance has declined in Orkney: an assessment based on using ARGOS flipper tags to estimate the proportion of animals ashore during aerial surveys in the moult. In SCOS 2011, Scientific Advice on Matters Related to the Management of Seal Populations: 2010.

Lonergan, M. C., and Thompson, D. 2012. Harbour seal (Phoca vitulina) abundance within the Firth of Tay and Eden Estuary Special Area of Conservation: recent trends and extrapolation to Extinction. In SCOS 2012, Scientific Advice on Matters Related to the Management of Seal Populations: 2011.

Mackey, 2004. Population dynamics and Life History of harbour seals. PhD Thesis, University of Aberdeen.

Seagreen (2012). Seagreen Phase 1 Offshore Project Environmental Statement. Document No. A4MR-SEAG-Z-DOC100-SPR-060. Seagreen. September 2012.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene, C. R., Kastak, D., Ketten, D. R., Miller, J. R., Nachtigall, P. E., Richardson, W. J., Thomas, J. A. & Tyack, P. L 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals.

Thompson, D, Duck, CD & Lonergan, ME 2010, ' The status of harbour seals (*Phoca vitulina*) in the United Kingdom ' NAMMCO Scientific Publications , vol 8, pp. 117-128.

Thompson, P.M. & Hastie, G. D. 2011. Proposed revision of noise exposure criteria for auditory injury in pinnipeds 2nd Draft, 11th October 2011

Thompson, P.M., Mackey, B., Barton, T.R., Duck, C. & Butler, J.R.A. 2007 Assessing the potential impact of salmon fisheries management on the conservation status of harbour seals (*Phoca vitulina*) in north-east Scotland. Animal Conservation, 10: 48-56

Thompson, P.M., Hastie G. D., Nedwell, J., Barham, R., Brookes, K., Cordes, L., Bailey, H., & McLean, N 2012. Framework for assessing the impacts of pile-driving noise from offshore wind farm construction on the Moray Firth harbour seal population. Seal assessment Framework Technical Summary, 6th June 2012