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Report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2015 and 2016 breeding seasons in The Wash

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1 Executive Summary

This report presents the results of a series of aerial surveys of the harbour seal population along the English east coast between Donna Nook in Lincolnshire and Scroby Sands off the Suffolk coast during the breeding seasons from 16th June to 17th July 2015 and 19th June to 16th July 2016.

- Five surveys were completed on the 16th, 21st and 27th June and 3rd and 17th July 2015.
- Five surveys were completed on the 19th, 24th June and 2nd, 8th and 16th July 2016.
- As usual, flights were restricted to weekends because of RAF range activity. Poor weather conditions on the weekend of 10th July 2015 prevented flying and delayed the final flight to the 17th July 2015. This had no negative effects on the results.
- The highest count obtained in 2015 was 1351 on 27th June and in 2016 the highest count was 1580 on 2nd July. Examination of the series of counts suggests that this is close to the actual maximum number of pups for the season. Examination of the five survey counts in each year suggests that these are close to the actual maximum number of pups in each year.
- The 2015 count was substantially lower (22%) than the 2014 equivalent count, but the 2016 peak count was 17% higher than in 2015. These wide fluctuations are not unusual in the long term time series.
- Despite the apparently wide inter-annual variation, the pup production has increased at around 7.4% p.a. since surveys began in 2001.
- The distribution of pup counts within The Wash has changed with more pups in the sheltered South East corner, and more along the banks of the main river channels. These changes appear to have happened between 2001 and 2010.
- Pup productivity has apparently increased relative to the independent estimates of the total population size.

2 Introduction

Dudgeon Offshore Wind Limited (DOWL) is required to carry out marine mammal monitoring at DOW. This requirement is imposed via Marine Licence L/2012/00218/5 Condition 5.2.16. The main focus of marine mammal monitoring at DOW relates to the potential disturbance to harbour seals during the construction phase as a result of pile driving noise. Recent high resolution tracking data from telemetry tagged harbour seals during piling operations close to the Wash indicates avoidance behaviour at substantial ranges and suggests that there is the potential for hearing damage despite this avoidance (Gordon et al 2015; Russel et al 2016 (in review)).

The potential implications of disturbance to harbour seals could include reductions in fecundity (birth rate) and disruption/disturbance of breeding. These potential population scale impacts cannot be detected by observing the behaviour of tagged seals at sea during pile driving activities. In addition, the timing of the planned pile driving at DOW precludes tracking studies because harbour seals undergo an annual moult which leads to tag loss in July – August. Seals are then not available for tagging until late September or October.

As such, despite the details in Annex 1.5 in the Marine Licence, DOWL has agreed with the MMO and its advisors, Natural England, that tagging of harbour seal is not the most effective way to monitor the potential impacts at DOW, and that an alternative approach should be taken. The alternative approach focuses on additional monitoring of The Wash and North Norfolk Special Area of Conservation (SAC) harbour seal population during the breeding season (June/July) with a specific aim of providing robust estimates of pup production using established methods employed by the Sea Mammal Research Unit (SMRU). The survey approach proposed by DOWL supports the current annual pup production monitoring program funded by Natural England and the Natural Environment Research.

The harbour seal (*Phoca vitulina*) is widely distributed around the coasts of Scotland and Ireland, but in England it is largely restricted to the major estuaries on the east and south-east coasts. The Wash holds the majority of the English harbour seal population (Thompson et al 2005) and is designated as a Special Area of Conservation for harbour seals. The population in the Wash has been monitored since the 1960s, using counts of animals hauled out as indices of population size. The initial impetus for monitoring this population was to investigate the effects of intensive pup hunting. When this hunt ceased in 1973 the monitoring program was reduced. Monitoring began again in 1988 and has continued and expanded to include the rest of the East Anglian coast since.

2.1 Survey rationale

Until recently, harbour seal monitoring programmes have been designed to track and detect medium to long-term changes in population size. Historically it was difficult to estimate absolute abundance because an unknown proportion of the population was likely to be at sea and uncountable on any survey. The monitoring programme for the Wash and East Anglia were therefore designed to obtain consistent indices of population size to track

the status of the population. The problem has been alleviated to some extent by the availability of telemetry data from seals, allowing the counts to be converted to a total population index.

The population monitoring counts are usually carried out during the annual moult, in early August, when the highest and most stable numbers of seals are present on haulout sites (Thompson et al. 2005). Unfortunately such counts provide a rather damped index of population size that does not provide information on productivity or the current status of the population. The numbers of pups produced each year provides a direct measure of the productivity which is a better indicator of the current population status. Conversely, pup production alone is not a reliable index of total population size as it is sensitive to short term fluctuations in fecundity. Reliably estimating total population size from pup production requires accurate estimates of fecundity. At present there are no independent estimates of fecundity for the English harbour seal population. Estimates have been obtained for a small portion of the Moray Firth population, but these can not be applied to the Wash because fecundity is likely to vary between years and between sites within years. A comprehensive assessment of both short term status and long term population trends therefore requires both types of census data.

The breeding season is also the time when disturbance of seal haulout groups is likely to have direct effects. For example, disturbance of mother/pup pairs will lead to temporary separation which may have direct effects on pup survival, especially if the disturbance is repeated. Series of surveys during the breeding season should provide early indications of such problems if they arise.

On the English east coast harbour seals breed on open sand banks where pups are relatively easy to observe and count. The majority of the population haulout within The Wash, but there are significant haulout sites on the Lincolnshire coast at Donna Nook, on the Norfolk coast at Blakeney and Scroby Sands (Figure 1).

Since 2001 the Sea Mammal Research Unit have carried out pup counts of the entire breeding population in the Wash. Since 2004 Natural England have commissioned single annual breeding season surveys to develop a time series of pup counts as an adjunct to the annual moult surveys, to obtain a more sensitive index of current status and to monitor the distribution of breeding seals. These counts are conducted at the end of June or beginning of July when the peak counts are expected. Periodically an additional series of surveys are needed within a breeding season to re-estimate the date of the peak number of pups ashore. In addition, the repeat surveys provide information on the ratio between peak pup counts and pup production and can provide information on the likely error on estimates of pup production. Sequences of five surveys spread across the breeding season were carried out in 2008 and 2010.

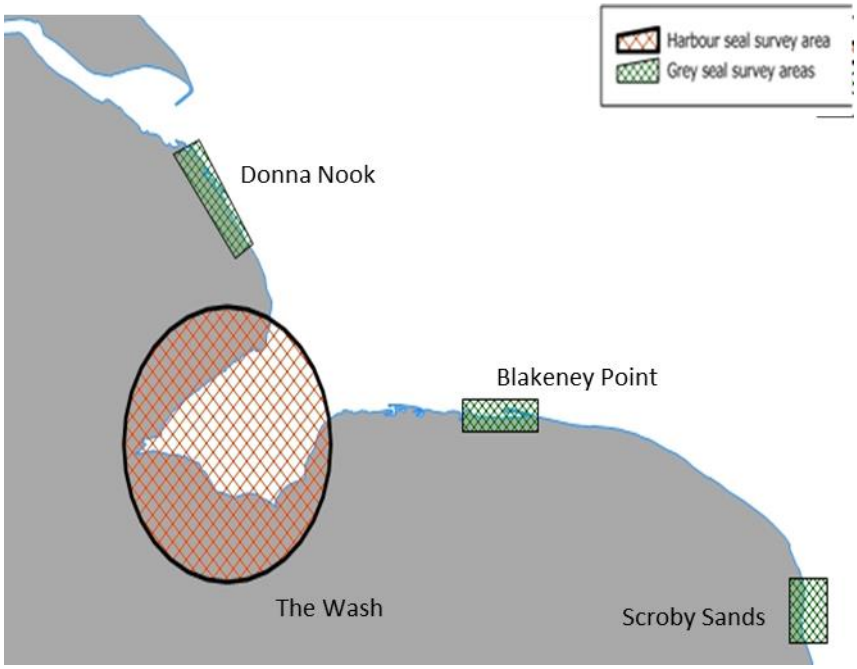

Figure 1 Survey areas of the Lincolnshire and Norfolk coast. Mixed species haulout groups occur in all four areas, but grey seals predominate at Donna Nook; Blakeney and Scroby Sands and harbour seals predominate in The Wash.

2.2 Historical data

One or two complete surveys of the Wash were carried out during the moult, in the first half of August in each year from 1988 to present. The results, combined with counts at the same time of year from the period 1968-1982 are shown in Figure 2. The counts increased between the late 1960s and 1988, at an average of 3.4% p.a. (R^2=0.62, p<<0.0001). The 1988 count was obtained approximately one week before the first reports of sick and dead seals being washed up on the UK coast. The number hauling out fell by approximately 50% between 1988 and 1989, coincident with the PDV epidemic. After 1989 the number increased again, at an average of 5.9% pa (R^2=0.77, p<<0.0001). The post epidemic rate of increase was significantly higher than the pre epidemic rate (t=2.87, df=20, p<0.01 - Comparison of regression coefficients for small samples with unequal residual variances (Bailey 1972)).

Wherever possible, synoptic surveys of the entire coast of Lincolnshire and Norfolk are completed within a single survey day. Weather, tide time and human disturbance means that surveys outside the core area of The Wash are more sporadic and little or no useful information is available on haulout numbers prior to the 1988 PDV epidemic. Figure 3 shows the results of aerial survey counts of harbour seals at the other major east coast haulouts outside the Wash, at Blakeney (45 km east of The Wash) and Donna Nook (40 km north of The Wash). At both sites the counts fell after 1988, reaching a minimum in 1990 (Figure 3). Between 1990 and 2001 Blakeney counts increased by an average of 14.4% pa. (R^2=0.47, p<0.01), and Donna Nook counts by 18% pa (R^2=0.35,

p<0.03). The total for all three east coast sites increased at an average rate of 7.2% pa. (R^2=0.87, p<<0.0001) (Figure 3).

In 2002 there was another outbreak of PDV. The timing of the epidemic and the population size were similar to 1988. The population in the Wash declined by an estimated 22%, based on results of surveys in 2003 and on a fitted population growth model (Thompson, Duck & Lonergan, 2005). There appears to have been a continued decline or at least a failure to recover in the moult counts for the English east coast population in the three or four years following the 2002 epidemic (Figure 2 and Figure 3). Overall, the combined count during the moult for the English east coast population in 2006 was approximately 50% lower than the pre-epidemic mean count in 2001. Since 2006 the counts in The Wash have increased such that by 2010 and 2011 the numbers were similar to the pre-epidemic counts. This apparent lack of recovery or continued decline immediately after the epidemic contrasts with the rapid recovery of the other major harbour seal population in the southern North Sea, the Wadden Sea population, that has been increasing at around 12% p.a. since 2002. The initial failure of the East Anglian population to recover from the 2002 PDV epidemic is unexplained.

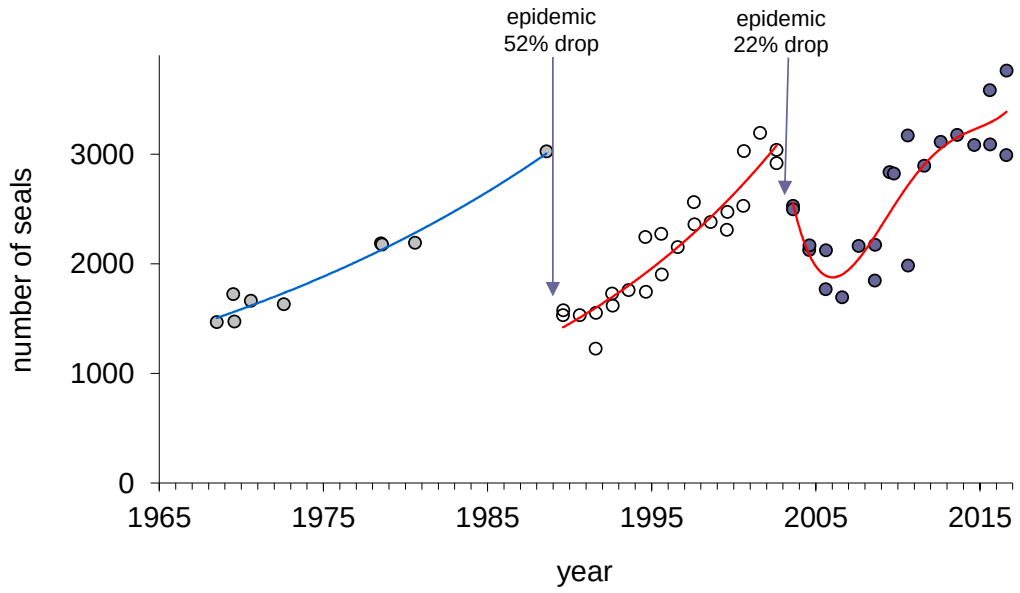

Figure 2 Aerial survey counts of harbour seals in the Wash during the annual moult in August for the period 1968 to 2014. Dramatic declines in 1988 and 2002 were the result of epidemics of Phocine Distemper Virus.

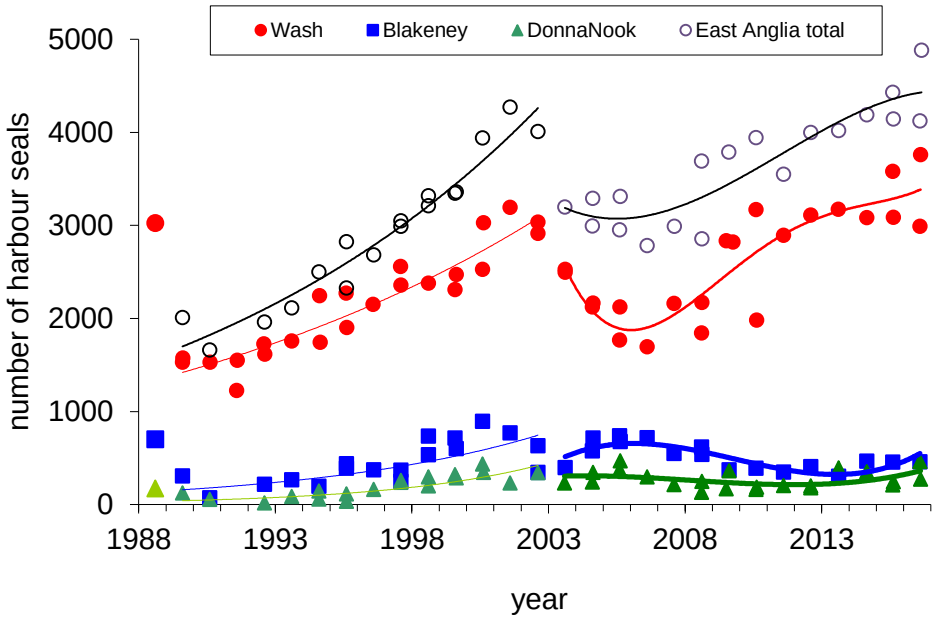

Figure 3 Aerial survey counts of harbour seals at major sites in East Anglia during recovery from the 1988 and 2002 PDV epidemics. Exponential increases were seen in all three sub populations before the 2002 PDV epidemic.

2.3 Previous breeding season surveys 2004 to 2014

Based on pup surveys during the hunting in the 1960s and early 1970s and anecdotal observations in recent years suggesting similar birth patterns, we estimated that the peak number of pups would be encountered at the end of June or beginning of July. Intense military aircraft activity at The Wash precludes surveys between sunrise on Monday and midday on Friday so survey flights are restricted to the weekends. We have surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2014. In addition, in both 2008 and 2010 we carried out four additional surveys between 12th June and 13th July to establish the form of the pups ashore curve. Surveys were carried out over the period 1.5 hours before to 2 hours after low water. All tidal sand banks and all creeks accessible to seals were examined visually. Small groups were counted by eye and all groups of more than 5 animals were photographed using either colour reversal film in a vertically mounted 5X4" format, image motion compensated camera in 2001, 2004 & 2005 or with a hand held digital SLR camera since. The equipment and techniques are described in detail in Hiby, Thompson & Ward (1986) and Thompson et al. (2005). Photographs were processed and all seals were identified to species. Harbour seals were then classified as either pups or 1+ age class. No attempt was made to further differentiate the 1+ age class.

3 2015 & 2016 surveys

3.1 Survey timing

Five aerial surveys were conducted along the Lincolnshire and Norfolk coast during the harbour seal breeding season in 2015 and again in 2016. Surveys were conducted between 16th June and 17th July 2015 and again between 19th June and 16th July 2016. Surveys were planned on a weekly basis to estimate usage of the area by breeding harbour seals and provide an estimate of pup production over the peak of the pupping season. Adverse weather prevented us from flying the final survey on the planned date in 2015. The delayed flight resulted in a 2 week interval between surveys 4 and 5. This is not expected to have any adverse effects on the production estimate. As in previous years, surveys were carried out at weekends as a large portion of the planned flight route is in military controlled air space which is closed to low flying aircraft during working hours.

In addition to the harbour seal surveys which focussed on The Wash, surveys also covered the mixed harbour and grey seal (*Halichoerus grypus*) haulout sites at Donna Nook, Blakeney and Scroby Sands (Figure 1).

3.2 Flight plans and tracks

Flights were planned to arrive at the first survey site (Donna Nook) approximately 1.5 hours before low tide to ensure that the entire survey could be completed within 2 hours of local low tide when the maximum number of seals are expected to be ashore (Thompson et al., 2005).

All flights started from the aircraft's base in Kent. Survey effort began at Donna Nook and continued south, tracking the coastline around The Wash and continued east along the Norfolk coast to Blakeney and then travelled over-land to complete the survey at Scroby Sands (Figure 4 and Figure 5). Time constraints due to tides precluded survey at Donna Nook on three days: 21st June 2015, 24th June and 16th July 2016 and a large rain shower prevented surveying of Blakeney and Scroby on the 24th June 2016. The low numbers of pups recorded at Donna Nook, Blakeney and Scroby means that this will have little or no effect on the production estimate for The Wash. The flight-tracks presented in Figure 4 and Figure 5 indicate the intense turning activity required during the surveys and clearly demonstrate the need for an experienced team with intimate knowledge of the seal distribution.

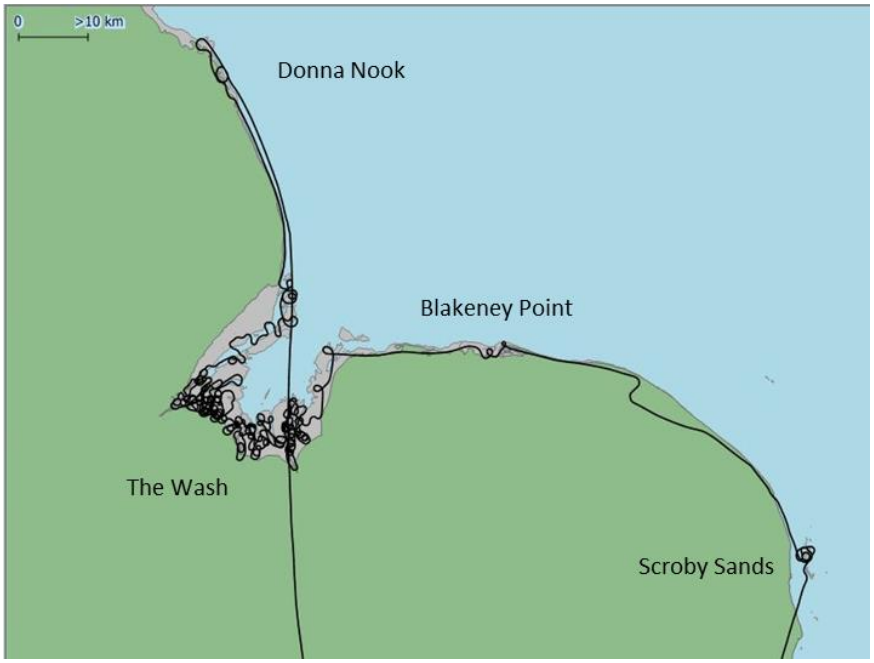

Figure 4 Example harbour seal breeding survey flight path on 01/07/2016.

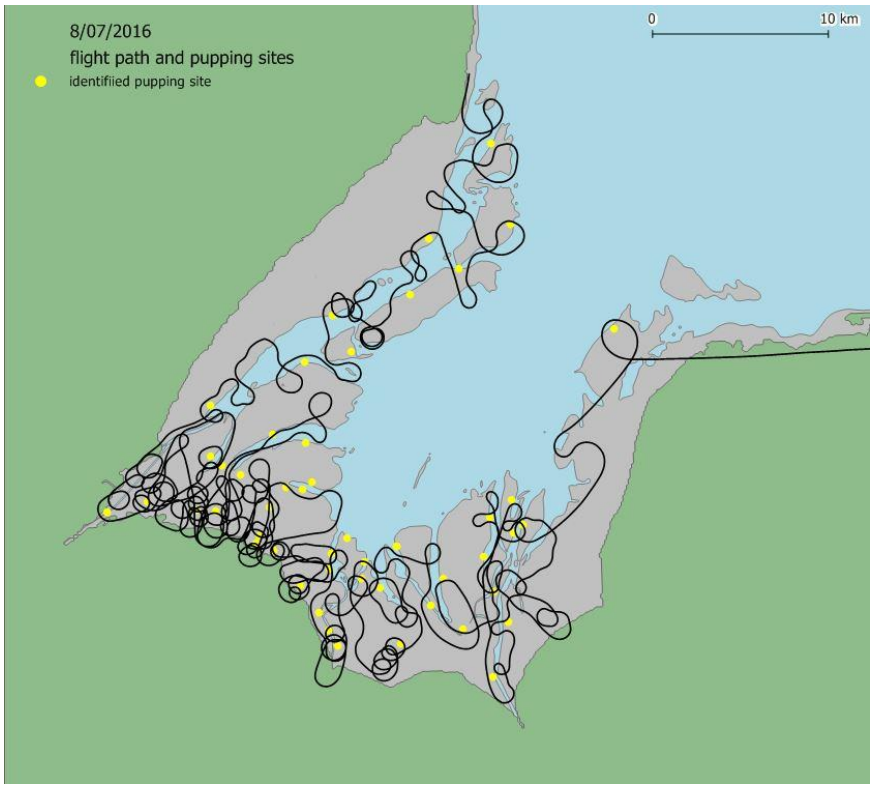

Figure 5 Example survey route over the haulout sites in The Wash, 8/07/2016.

3.3 Survey methodology

Essentially the survey method is a continuous visual inspection of all potential haulout sites around the coast on off-shore tidal banks. When groups of more than two or thee seals are spotted they are photographed. High resolution, large images are required because of the difficulty in differentiating harbour seal pups from similar sized juveniles and differentiating juvenile grey seals from adult harbour seals. As a consequence large numbers of photographs are required to cover large groups.

All photography was conducted obliquely using a CANON EOS SLR camera with 18 to 270mm zoom lens. All surveys followed standard SMRU survey methods and routes and were flown in a twin engine Piper PA-23, 'Aztec' based in Kent. The entire coast is searched from a variable height of 180 to 400m. When groups of seals are sighted the aircraft either flies parallel with the shore for groups of seals spread along open stretches of beach, or performs one or more tight turns to circle smaller or more evenly dispersed groups. Groups hauled out along creeks or dispersed in the salt marsh areas were first identified during intensive visual searches by the 3 man crew and then photographed.

This method produces extremely convoluted survey tracks making it difficult to keep track of which groups and sites have been covered. To avoid missing or over-counting groups we maintain three separate records of the survey track. GPS tracks were recorded from the aircraft's on-board GPS logger sampling at 5 second intervals and a GARMIN FORETREX 401 GPS logger sampling at 3 second intervals. The timestamp of the loggers were synched with the time on the camera. Discrete haul-outs can therefore be associated with precise locations and temporal and spatial haul-out patterns can be analysed. Both the cameraman and the observer/tracker recorded the locations and frame numbers directly onto maps and maintained a separate written log of the flight.

The number of discrete groups of harbour seals ranged from 44-60 and few were observed at sites other than those previously recorded in the survey area, during the pupping surveys (Figure 6). Additional, solitary animals were counted but not photographed. Example photographs of a range of group sizes are presented in Figure 7 and Figure 8.

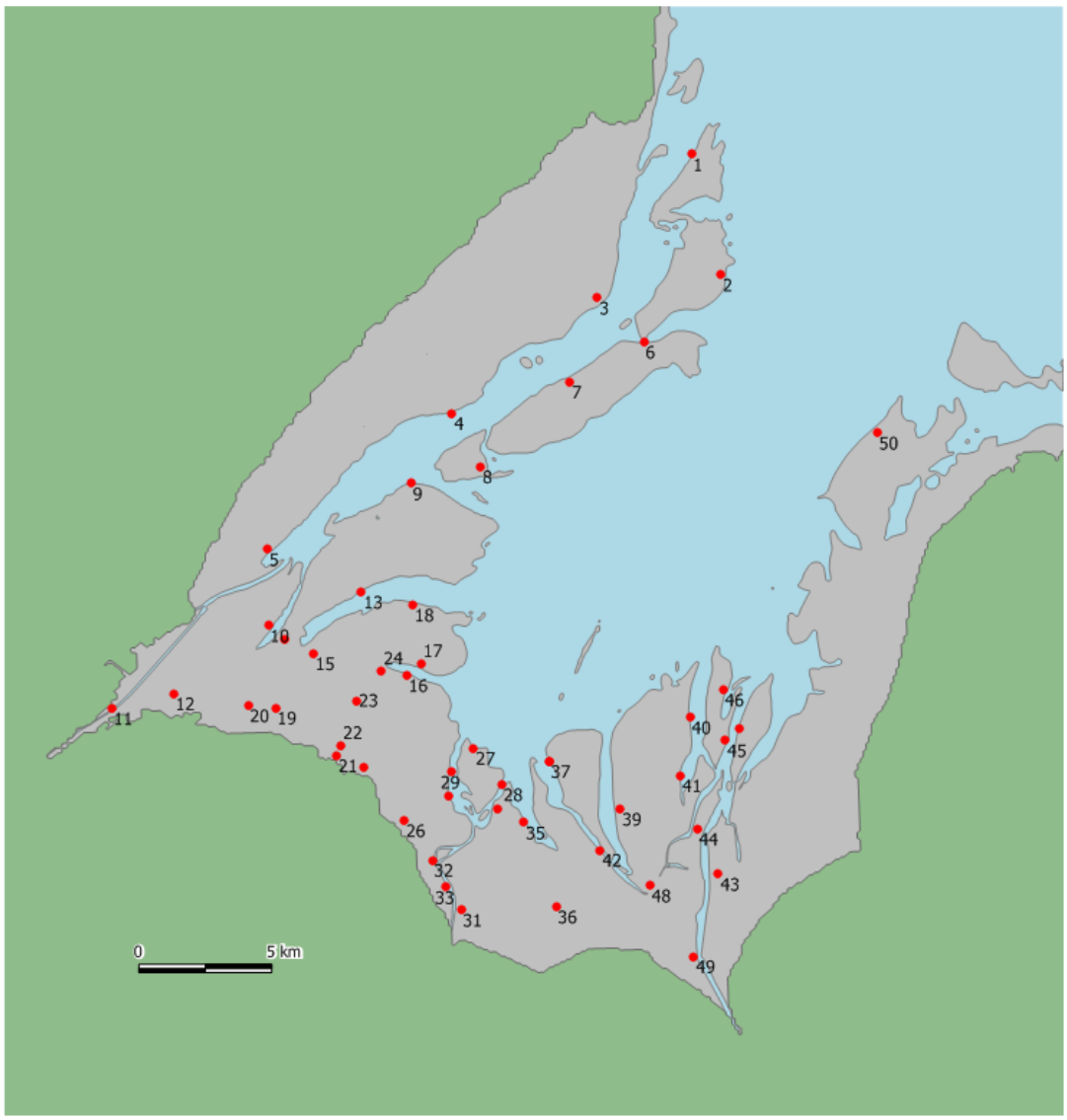

Figure 6 Locations of seal haulout sites during the pupping season in the Wash. Numbers correspond to counts in Table 1 & 2 in the Appendix.

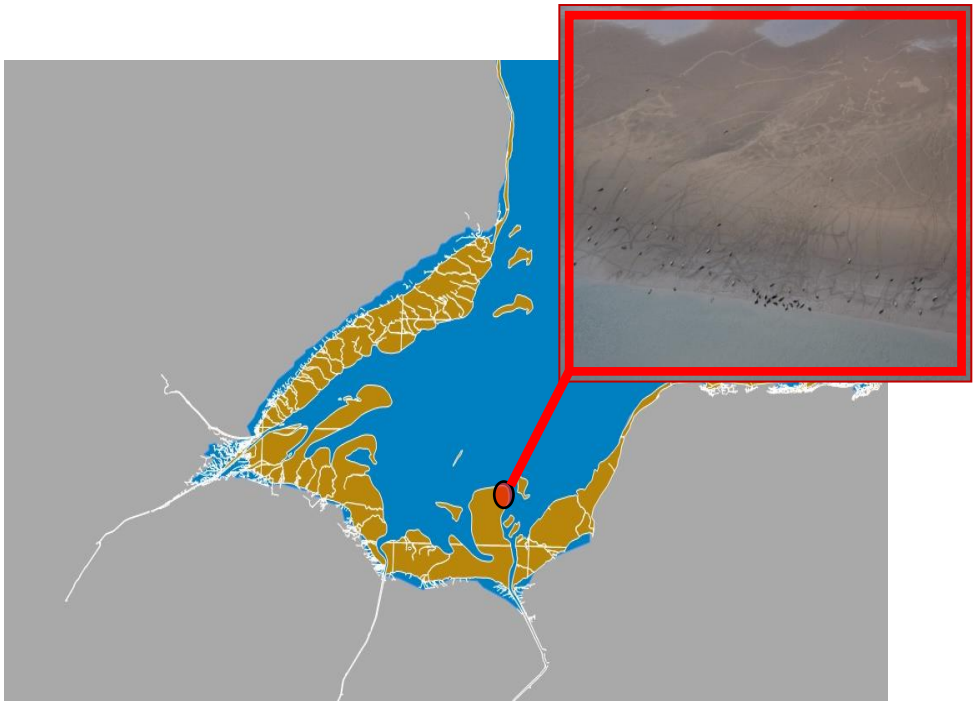

Figure 7 Haul-out on the north-east side of 'Seal Sand' in the south-east section of The Wash. Photograph taken at 14:35 on 16th June 2015, approximately 16 minutes after low water.

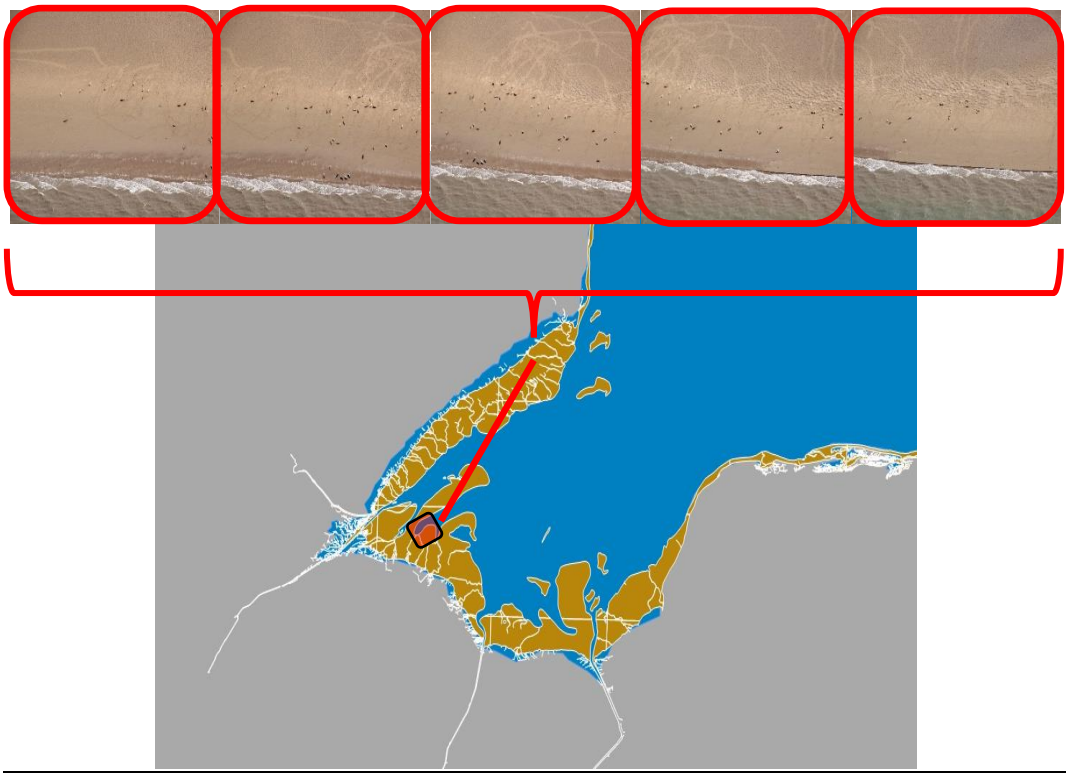

Figure 8 Sequence of photographs showing the entire haul-out on the north side of 'Gat Sand' in the Western section of The Wash. These photographs were taken at 15:18 on 3rd July 2015, approximately 36 minutes before low water.

4 Survey results

4.1 2015

Counts for The Wash were obtained for the five surveys. Counts for each haulout site are presented in Table 1 of Appendix 1. The maximum pup count was 1351 pups on 27th June together with 4238 older seals (1+ age classes). The highest count of 1+ age classes was 4539 on 3rd July. Only seven pups were counted on the 27th June at Donna Nook and 4 at Blakeney point.

The maximum count was 25% lower than the previous highest peak count of 1802 pups during the single survey during the 2014 breeding season. The 2014 survey produced the highest pup count ever in the Wash; 22% greater than the previous highest count in 2012.

4.2 2016

Counts for The Wash were obtained for the five surveys in 2016. Counts for each haulout site are presented in Table 2 of Appendix 1. The maximum pup count was 1586 pups on 2nd July together with 3760 older seals (1+ age classes). The highest count of 1+ age classes was 3905 on 24th June.

The 2016 peak count was 17% higher than the peak count in 2015, but was still 12% lower than the previous highest peak count of 1802 pups during the 2014 breeding season survey.

4.3 Trends

Peak pup count for the Wash in each survey year between 2001 and 2016 are presented in Table 1. Figure 9 indicates that there are large inter-annual fluctuations in pup counts but despite the large variations, the trend in the counts can be approximated by an exponential increase at an annual rate of increase of approximately 7.5% p.a. since 2001.

The maximum pup count from the 2015 breeding season surveys was 25% lower than the previous year, but the 2016 peak count was 17% higher, so overall these fluctuations have had little impact on the fitted trend since 2001. The fitted trend suggests a continual upward trend in pup production of the Wash harbour seal population. At present we do not have a direct conversion from peak count to pup production, but there is no reason to suspect a systematic change in that ratio. Therefore the observed 7.5% p.a. increase in pup count should be a reliable indication of the rate of increase of pup production.

Table 1 Peak counts of harbour seal pups and 1+ ages in The Wash for all surveys from 2001 to 2016.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586
1+ ages	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905

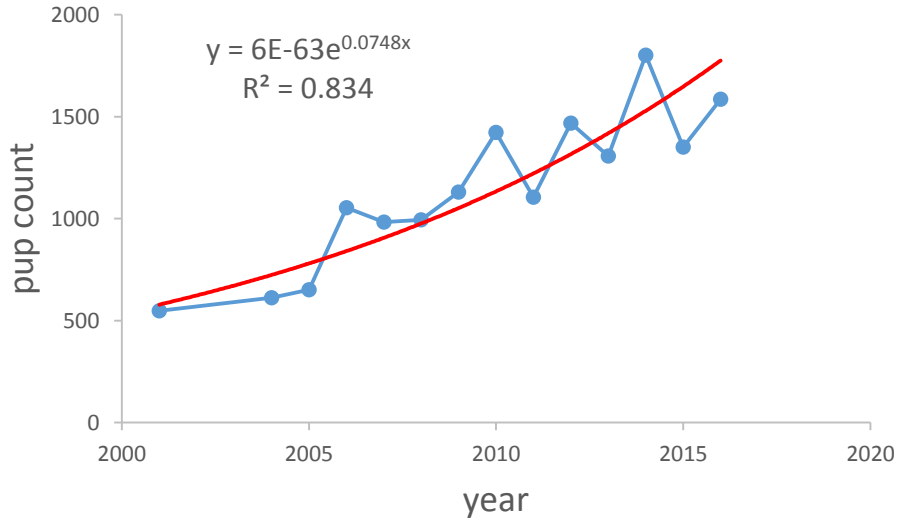

Figure 9 Maximum pup counts for The Wash population between 2001 and 2016. Fitted line is a simple exponential which fits reasonably well to the counts (R^2= 0.83) and produces an estimated average growth rate of 7.5% p.a since 2001.

4.4 Distribution

The pups in the Wash were distributed over approximately 50 separate haulout groups, although the number of sites is to some extent a function of the arbitrary division or pooling of groups. Over the course of the five surveys in each of 2015 and 2016, pups were present on most of the occupied sites on all flights (Tables A1 and A2 in Appendix 1). There is no information in the survey data to indicate where pups were born, but clearly all or most sites are used breeding females. Figure 6 showed the distribution of all haulout sites in the Wash where pups have been seen in previous surveys. Figure 10 shows the counts of pups at each site obtained during the 3/7/2015 and the 2/7/2016 breeding season surveys.

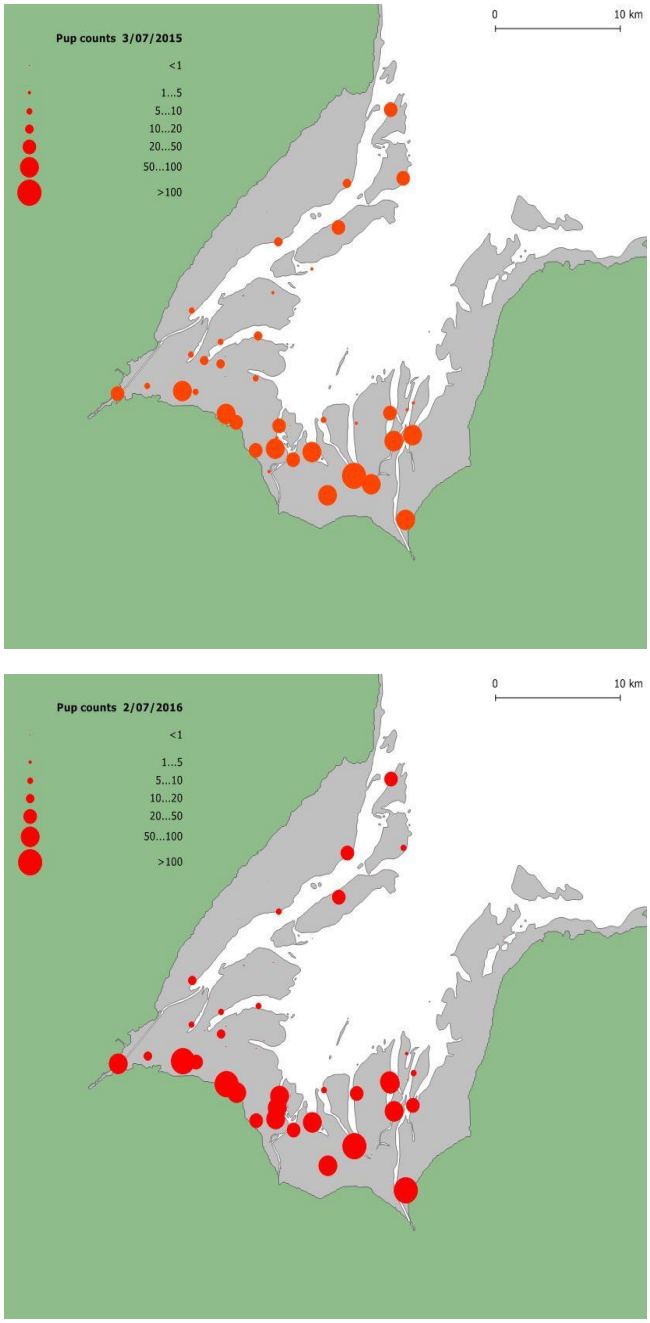

Figure 10 Distribution of pups in the Wash on 3rd July 2015 and 2nd July 2016. Numbers of pups are represented by the areas of the circles on each site. Locations given to nearest 50m.

Local, small scale re-distributions within The Wash are not unusual and are known to occur over small time intervals, even between successive tidal cycles. However Figure 10 suggests that the general distribution of pups in 2015 and 2016 were very similar. Most pups (94%) are counted on the inner sand banks and on the banks of creeks in the mudflats along the bottom (inner) edge of The Wash (Figure 10), more than 15 km from the open sea.

On a longer timescale there is clear evidence of a redistribution or change in the relative importance of sites within The Wash. Figure 11 shows the distribution of pups at the peak count in 2004 and 2016. The number of pups in 2016 was greater, but groups were also more widespread, with areas in the south east corner of the Wash now holding large breeding groups. There have also been large increases along the banks of the main rivers draining into the Wash. Interestingly, these channels also represent the main areas of concentrated vessel traffic in The Wash.

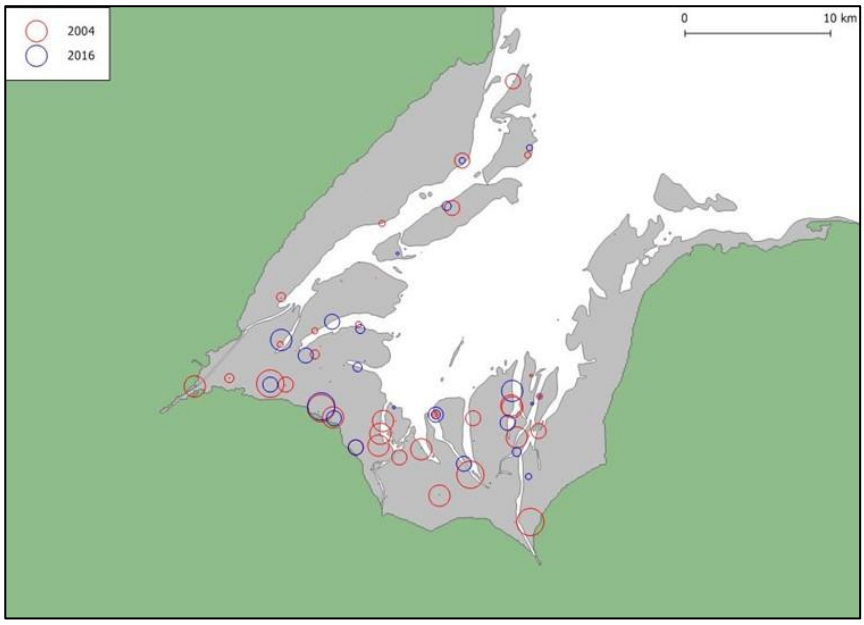

Figure 11 Distribution of pups in the Wash on 4th July 2004 and 2nd July 2016. Numbers of pups are represented by the areas of the circles on each site.

Figure 12 shows the counts of pups divided into four sub-areas within the Wash. The areas were chosen by researchers in the 1970s on the basis that they held roughly equal proportions of the moult population estimates of harbour seals (Vaughan 1978). The sites included in the sub-areas and the pup counts at those sites are given in Tables A1 and A2 in Appendix 1. In the time series shown in Figure 12 the numbers in the south east sector have increased in both absolute and relative terms. The four areas, North West, South West, Creeks and South east held 5%, 25, 38% and 32% of pups respectively in 2004. These proportions changed to 6%, 9%, 24% and 61% respectively by 2016. Most of this change happened during the period 2004 to 2010 and the proportion in the South east has remained relatively stable since 2010.

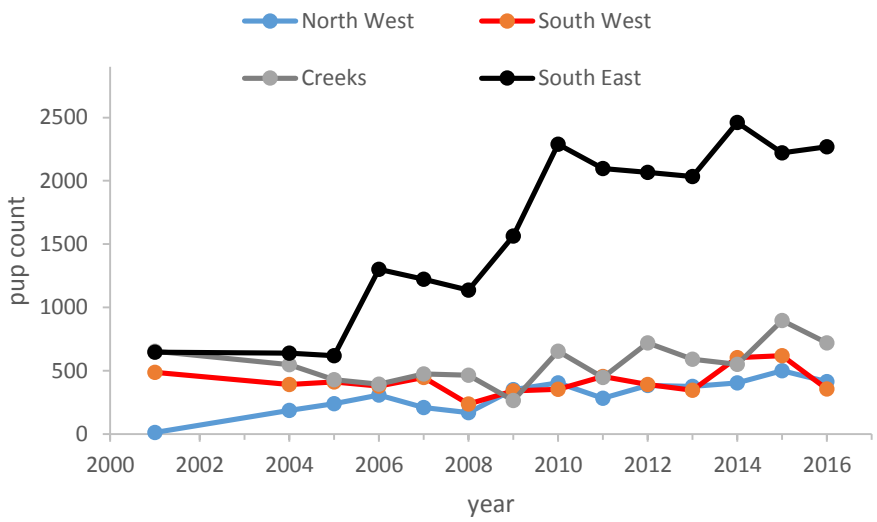

Figure 12 Counts of pups in four sub areas within The Wash. The sites included in each sub area and the counts of pups in those areas are given in Tables 1 & 2 in Appendix 1.

4.5 Converting pup counts to pup production

Five repeat surveys were carried out over the entire Wash breeding population in 20015 and 2016. The counts form these surveys are presented along with similar data from 2008 and 2010 in Figure 13.

The trajectories of the pup counts in 2008, 2015 and 2016 are similar, but the 2010 time series is significantly different. As a result it has not been possible to develop a simple pup production estimation model that can be applied in all four years that will provide a reliable estimate of the total pup production. The consequences and possible solution to this are presented in the discussion below.

In most years only one count is possible, so it is important that this single count provides a consistent index of pup production. The time series in each year can be used to estimate the peak date. A cubic polynomial fitted to each set of counts is shown in Figure 13 and used to estimate the date of the peak number of pups ashore. The estimated peak dates were 26th June in 2015, 28th June in 2016 and 2nd July in 2010.

Surveys are restricted to weekends because of flight restrictions as described above. The estimated peak dates suggest that the current policy of flying single surveys during the weekend nearest to the end of June will consistently produce the closest count to the expected peak.

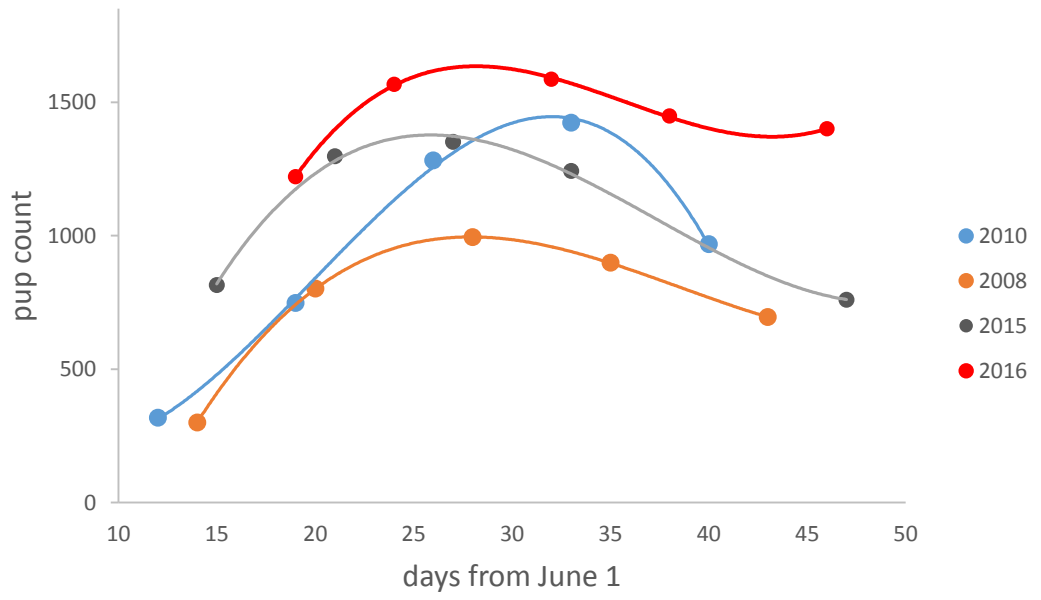

Figure 13 Counts of pups on each survey of the Wash during 2008, 2010, 2015 and 2016. Curves fitted to the Counts are cubic polynomials. Count data are given in Tables A1 & A2 in Appendix1.

4.6 Apparent productivity

The evolving time series indicates that there was no evidence of a major decline in pup production after the 2002 PDV epidemic. This continued increase in pup production contrasts with the apparent decrease in the moult counts between 2002 and 2005 (Figure 2). The moult count appears to have been increasing since around 2005 or 2006, but the overall increase in pup counts exceeds that of the moult population index counts.

We do not have independent data on fecundity for this seal population, but we can derive an index of productivity by dividing the peak pup count (an index of pup production) by the peak moult count (an index of overall population size). The different trajectories of the pup counts and the independent index of population size represented by the moult count means that this apparent productivity or apparent population fecundity has changed over the period (Figure 14); increasing from less than 0.2 at the start of the series up to an average of 0.44 over the last 10 years.

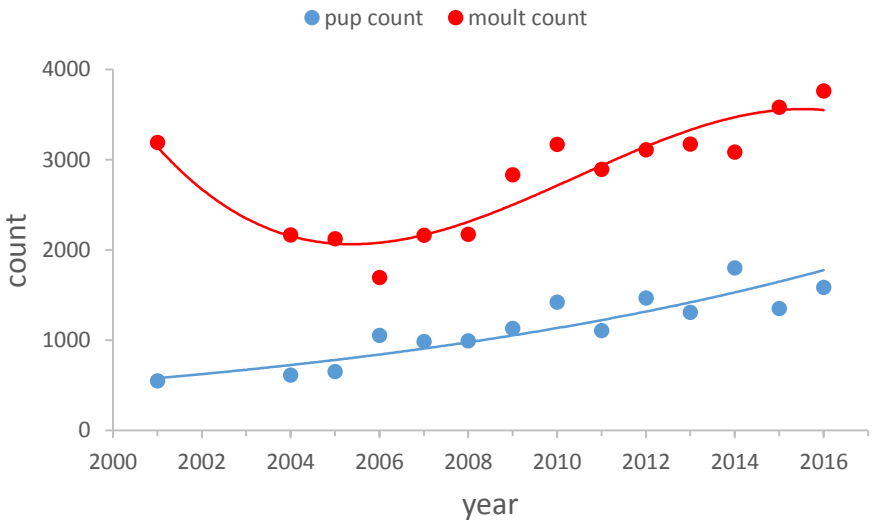

Figure 14 Maximum counts of pups in The Wash between 2001 and 2016 alongside the annual moult count over the same period.

Coincident with this apparent change in productivity/apparent fecundity, there has also been a significant increase in the numbers of 1+ age class seals counted in the breeding season (Table A1, Appendix 1) in both absolute number and relative to the moult count index of total population. In 2001 the 1+ age class count in the breeding season was 1802, equivalent to 56% of the moult population count. In 2015 and 2016 the 1+ age class counts in the breeding season were 4539 and 3905, equivalent to 127% and 104% of the moult population counts.

5 Discussion

The 2015 and 2016 breeding season surveys confirm the continued upward trend in pup production of the Wash harbour seal population. At present we do not have a direct conversion from peak pup count to pup production, but there is no reason to suspect a systematic change in that ratio. Therefore the observed 7.5% p.a. average rate of increase in pup count should be a reliable indication of the average rate of increase of pup production.

The recent pup survey effort has produced two interesting results that highlight the advantage of a two pronged approach to seal monitoring. Although there was a well-documented decline of over 20% in the population as a result of the 2002 PDV epidemic, there was no apparent decrease in pup production between the pre and post epidemic counts. There are several potential explanations for the lack of a decline. If there was differential mortality, the number of adult females lost to the epidemic may have been small (compared to males, juvenile or pups). Alternatively any decrease in adult female population could have been masked by variations in fecundity. Alternative scenarios involving temporary immigration are thought to be less likely.

Although the moult counts in Wash continued to decline after the 2002 epidemic, they had clearly stabilised around 2005 or 2007 and have increased rapidly since then. Interestingly, although the moult counts in recent years have been similar to the 2001 pre-epidemic count, the estimated peak pup counts in 2015 and 2016 were 2.4 and 2.9 times greater than in 2001. If the moult count is a consistent index of the total population size then the apparent fecundity of the Wash population has increased by a factor of 2.4 to 2.9 since 2001. The fact that pup production varies much more than the moult population index and more rapidly than could be accounted for by changes in adult female numbers, means that there must be wide fluctuations in fecundity and/or short term immigration and emigration. At present we do not have information on pregnancy rates in any UK harbour seal population. However, the numbers of pups as a proportion of the number of seals hauled out during the peak of the breeding season has shown little change over the same period, averaging 0.28 over the entire period with no trend.

Concomitant with this apparent change in productivity/apparent fecundity, there has also been a significant increase in the numbers of 1+ age class seals counted in the breeding season compared to the independent population index from the moult counts. These changes must be the result of either a change in the fecundity of the Wash seal population, a change in the spatial distribution of moulting or breeding seals or a change in the proportion of time spent on haulouts during the moult or breeding season or some combination. Telemetry data on haulout patterns in adult harbour seals in Scotland (Lonergan et al 2012) suggests that changes in the proportion of time spent hauled out are unlikely to account for these patterns. Telemetry data from both the English and Dutch populations suggests that movement between the two areas is unlikely to be sufficient to account for these changes, however there is little telemetry data available for the relevant period.

The initial decision to base the monitoring programme on moult counts was based on the fact that moult counts in the 1970s and early 1980s were much higher than during the breeding season. This is no longer the case, again suggesting that some undocumented but potentially large change in the temporal distribution of seals has occurred.

As we are conducting only single counts in most years there is a potential danger of confusing timing effects with actual changes. Therefore, before attempting to draw conclusions about the causes or implications of changes in pup production it is important that we are able to discount the possibility that the difference in counts were artefact of the changes in timing of the surveys.

The series of pup counts from 2008, 2010, 2015 and 2016 confirms the timing of the peak count. Based on a simple polynomial fit to the pup count series in 2008, 2010, 2015 and 2016 the peak number ashore occurred between on or about the 26th June and 2nd July. With the exception of 2001 and 2004, all counts would have been within this window and counts would be expected to be close to the peak number ashore, within 4% of the peak if the timing in each year was similar to the 2008 or 2010 patterns. The largest under-estimation would have been in 2001 when the count would have represented 90% of the peak if the timing was the same as in 2008.

This confirms that a pup-production monitoring program based on single annual counts with occasional more intensive surveys, (e.g. every 5 years a series of 4 or 5 surveys to re-estimate birth curve parameters) will provide data to be combined with the annual total population index surveys in August to allow more responsive and sensitive management of the harbour seal population.

However, a major aim of this survey programme is to develop a robust method for converting peak pup counts to pup production estimates. Unfortunately the fitted pup curve for 2008, 2015 and 2016 did not fit well to the 2010 data. At present we do not know if this is a problem with the 2010 survey data or if there is a greater than expected level of inter annual variation in the behaviour of breeding females and pups. Initial investigations of the 2010 data do not indicate any inconsistency in the survey or counting process. A complete re-count of the 2010 data is beyond the scope of this project, but will be completed by SMRU personnel in spring 2017 and will be reported to the NERC Special Committee on Seals and Natural England by summer 2017. Further attempts to generate a robust method of converting counts to pup production estimates will be reported at the same time.

The observed large increase in pup production in the absence of an equivalent increase in the moult counts is unexplained at present. It could be generated in various ways:

1. Immigration of a large number of adult females. The absence of any substantial populations on the east coast means that the source of seals would have to be either the Wadden Sea or the Scottish East coast. Data on seal movements suggest that immigration from Scotland is unlikely and that movement between the English and European populations is unlikely to be frequent enough to explain these changes.

2. A continual increase in fecundity. This seems unlikely given the scale of the increase since 2005, although rapid changes in both directions may suggest wide variation in fecundity rates.

At present we have no information to allow us to differentiate clearly between these options and it is likely that a combination of some or all could be operating. However, in each case the explanation would represent a major change in harbour seal demographics.

The results of the 2001 pup survey suggested that there had been a significant shift in spatial distribution of breeding seals over the preceding 30 years. The distribution of pups in The Wash has continued to change since 2001 with a much higher proportion of pups being found in the south eastern corner of the Wash. At present we do not know why this distributional change is occurring but the results through to 2016 indicate that the relative importance of the SE corner of the Wash is still increasing. The majority of the re-distribution appears to have pre-dated any of the activity associated with wind farm construction. This, combined with the apparent large increase in the use of the banks of the main shipping channels in the inner reaches of The Wash, means that there are as yet no clear indications that shipping or construction activities have altered seal haulout usage patterns.

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7 Appendix 1

Table 2 Counts of harbour seal pups and 1+ ages at haulout sites in the Wash during the 2015 surveys.

			16/06/2015		21/06/2015		27/06/2015		03/07/2015		17/07/2015	
	decimal	decimal	harbour	seals	harbour	seals	harbour	seals	harbour	seals	harbour	seals
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups
Inner & Outer Knock	53.082	0.364	146	11	97	15	193	22	163	36	166	36
Inner Dogs Head	53.036	0.376	44	1	52	3	37	2	73	24	60	29
Friskney	53.034	0.309	48	3	56	11	81	18	53	17	44	15
Friskney Middle	52.997	0.225	27	12	33	18	79	26	32	14	9	6
Friskney South	52.953	0.119			27	12	23	8	42	8	36	7
Long Sand N/E End	53.019	0.334										
Long Sand Middle	53.005	0.297	173	6	92	16	84	15	124	27	78	18
Ants	52.978	0.264	9	1	24	8			26	3	4	2
Rodger	52.963	0.217					4	1	9	3		
NW total			447	34	381	83	501	92	522	132	397	113
Black Buoy	52.924	0.117	212	19	167	73	51	8	28	5	109	4

Boston Channel	52.900	0.029	173	46	233	102	319	65	162	37	135	40
Herring Shoal	52.904	0.064	310	97	12	5	100	14	80	8	41	12
Toft East	52.932	0.153	34	3	69	15	32	2	49	5	41	3
Toft West	52.920	0.133			3	0	3	0	43	19	10	3
Mare Tail	52.917	0.152			161	72	5	4	37	15	5	4
Main End	52.907	0.193			42	21	70	22	34	5		
Gat End	52.912	0.203			22	10						
Gat Sand	52.935	0.198	59	6	35	27	40	7	80	16	50	12
SW total			788	171	744	325	620	122	513	110	391	78
Puff	52.899	0.121	79	28	83	15	50	22	15	6	8	8
Kenzies Creek	52.900	0.106	101	22	43	13	185	97	190	53	193	30
Fleet Haven Marsh	52.877	0.152										
Fleet Haven Middle	52.884	0.157	192	62	128	70	396	139	296	95	284	91
Fleet Haven Lower	52.909	0.157										
Fleet Haven Mouth	52.922	0.158										
Evans Creek	52.878	0.169					104	58	126	34	127	13
Dawesmere Creek	52.859	0.191	100	40	111	41	162	46	300	36	114	27

Creeks total			472	152	365	139	897	362	927	224	726	169
OWMK 1	52.875	0.233	37	16	5	6					6	9
OWMK 2	52.867	0.250										
Nene Channel 1(or pooled)	52.875	0.220	75	14	163	41	169	20	146	23	15	22
Nene Channel 2	52.867	0.216			16	10	65	24	17	2	37	11
Nene Channel 3 Barge	52.860	0.214	142	27	63	33	28	8	99	52	51	14
Nene Channel 4	52.845	0.206			7	6	2	1	21	3	54	17
Nene Channel 5	52.827	0.219					127	26			14	11
IWMK	52.852	0.235	54	15			135	56	123	36	9	10
Salman's Sled	52.857	0.258	128	61	214	105			132	75	87	79
Breast Sand	52.828	0.275	218	87	112	56	174	98	209	58		
Thief West	52.878	0.273	49	10	35	5	23	2	58	6	32	1
Thief East	52.878	0.273			4	0	3	2	6	1		
Seal Sand (West)/Black Shore	52.875	0.312							12	3	24	10
Seal sand (East)	52.881	0.352	214	40	140	34	178	56	180	36	164	18
Seal Sand/Daseleys	52.882	0.351			24	14			14	3		

Hull Sand	52.840	0.307	401	112			558	198	647	196	338	76
Bull Dog Sand	52.866	0.378	42	6	17	8	133	73	148	64	199	34
Pandora	52.862	0.355	287	43	227	45	17	0	371	95	220	54
Black Guard	52.883	0.372							3	3	24	11
Old Bell	52.900	0.372										
Styleman's Middle	52.887	0.380	6	2	37	25			12	3	9	2
Pie Corner	52.834	0.327					78	47	170	62		
Lynn Channel	52.810	0.367	94	25	394	202	521	164	171	55	191	19
Sunk Sand	52.975	0.493	20	0	34	2	9	0	38	0	83	2
East total			1767	458	1945	750	2220	775	2577	776	1557	400
Wash Total			3474	815	3435	1297	4238	1351	4539	1242	3071	760

Table 3 Counts of harbour seal pups and 1+ ages at haulout sites in the Wash during the 2016 surveys.

			19/06/2016		24/06/2016		2/07/2016		8/07/2016		16/07/2016	
	decimal	decimal	harbour	seals	harbour	seals	harbour	seals	harbour	seals	harbour	seals
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups	1+ages	pups
Inner & Outer Knock	53.082	0.364	133	6	120	13	157	31	151	26	190	30
Inner Dogs Head	53.036	0.376	31	0	32	0	44	7	68	9	53	19
Friskney	53.034	0.309	66	4	65	16	81	20	105	19	75	16
Friskney Middle	52.997	0.225	4	2	10	4	8	7	95	39	0	
Friskney South	52.953	0.119	34	15	7	3	22	15	12	3	34	3
Long Sand N/E End	53.019	0.334	26	11								
Long Sand Middle	53.005	0.297	101	4	94	17	101	22	89	13	71	7
Ants	52.978	0.264	6	1	5	2	1	0	3	1	1	0
Rodger	52.963	0.217	8	1	5	1	1	0	5	0	7	1
NW total			409	44	338	56	415	102	528	110	431	76
Black Buoy	52.924	0.117	90	8	104	42	41	8	77	12	205	7

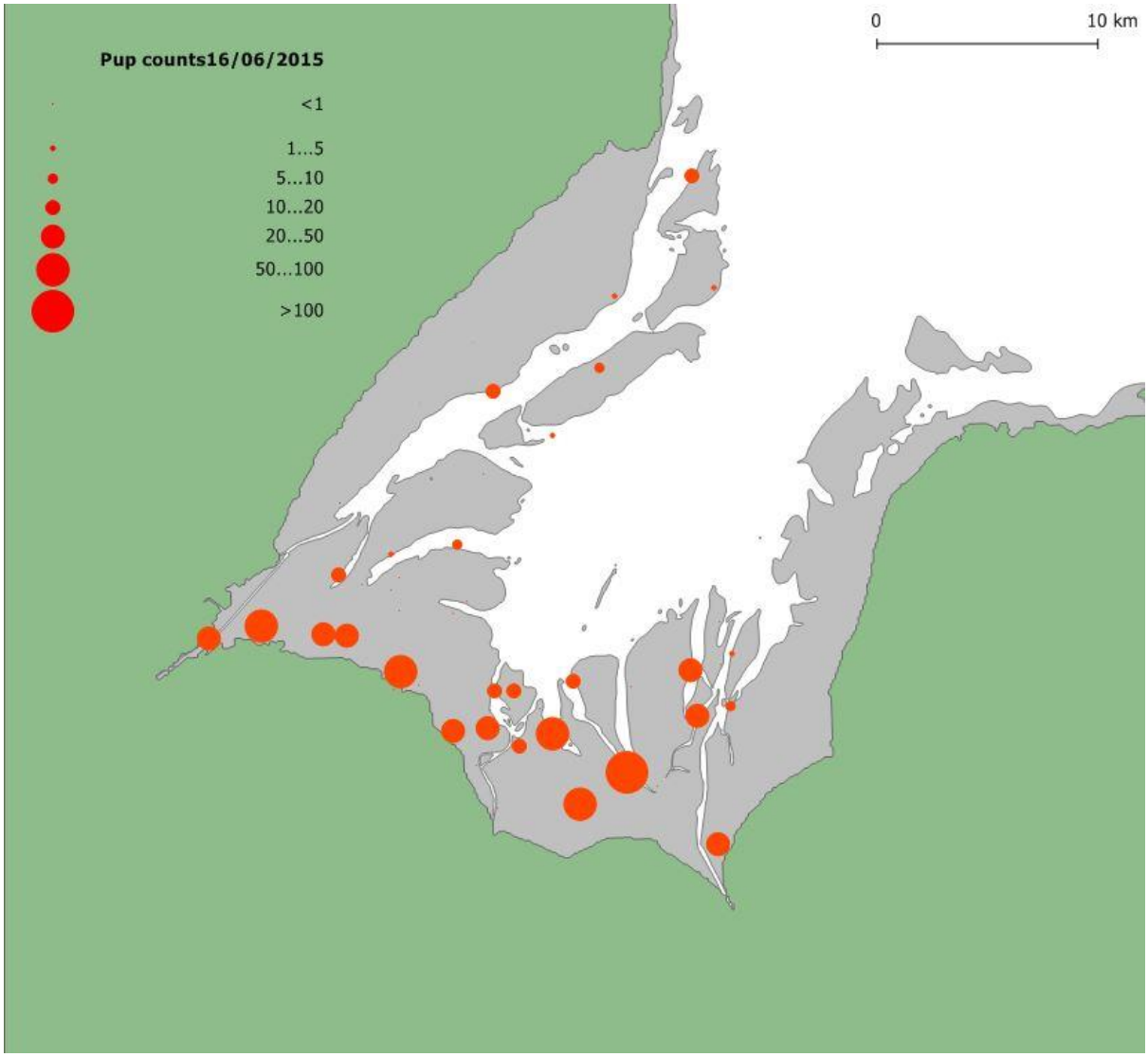
Boston Channel	52.900	0.029	166	71	210	71	180	88	146	55	128	51
Herring Shoal	52.904	0.064	61	17	6	4	43	12	78	34	129	45
Toft East	52.932	0.153	3	3			19	6	29	9	12	2
Toft West	52.920	0.133	26	1	27	5			44	8	53	3
Mare Tail	52.917	0.152	12	9	14	14	28	11	6	5		
Main End	52.907	0.193			3	1			1	1		
Gat End	52.912	0.203	17	7								
Gat Sand	52.935	0.198	91	6	64	3	44	8	61	6		
SW total			466	122	428	140	355	133	442	130	527	108
Puff	52.899	0.121	22	12	76	25	55	20	22	34	48	15
Kenzies Creek	52.900	0.106	139	88	172	96	159	110	71	49	146	27
Fleet Haven Marsh	52.877	0.152										
Fleet Haven Middle	52.884	0.157	311	122	290	138	295	156	220	149	142	163
Fleet Haven Lower	52.909	0.157										
Fleet Haven Mouth	52.922	0.158	10	7	31	18						
Evans Creek	52.878	0.169	204	139	116	70	101	58	123	48	80	22

Dawesmere Creek	52.859	0.191	63	23	81	29	110	35	131	61	153	114
Creeks total			749	391	766	376	720	379	567	341	569	341
OWMK 1	52.875	0.233	32	9	11	11			18	9		
OWMK 2	52.867	0.250							31	15		
Nene Channel 1(or pooled)	52.875	0.220	4	3	17	10	104	64	59	41	52	70
Nene Channel 2	52.867	0.216	169	12	291	52	223	68	39	46	6	8
Nene Channel 3 Barge	52.860	0.214	28	6	23	5	88	55	143	92	106	88
Nene Channel 4	52.845	0.206	32	20	40	26			9	13	105	48
Nene Channel 5	52.827	0.219	11	2					5	4		
IWMK	52.852	0.235	42	22	37	23	28	20	35	18	6	6
Salman's Sled	52.857	0.258	123	74	134	84	159	87	77	94	12	52
Breast Sand	52.828	0.275	144	82	168	84	137	71	136	93	95	50
Thief West	52.878	0.273	2	0	32	4	37	5	28	2		
Thief East	52.878	0.273	7	0	6	0	5	1	6	2	15	1
Seal Sand (West)/Black Shore	52.875	0.312	101	34	92	58	51	22	41	19	5	3
Seal sand (East)	52.881	0.352	188	23	189	51	245	60	238	58	214	89

Seal Sand/Daseleys	52.882	0.351			113	67	138	68	97	25	2	2
Hull Sand	52.840	0.307	459	180	471	201	563	232	442	165	358	147
Bull Dog Sand	52.866	0.378	270	56	236	49	38	29	18	11	34	17
Pandora	52.862	0.355	105	48	73	43	235	60	226	42	64	47
Black Guard	52.883	0.372							18	0	38	25
Old Bell	52.900	0.372			4	1	22	2				
Styleman's Middle	52.887	0.380	47	2	26	2	15	7	51	20	15	8
Pie Corner	52.834	0.327										
Lynn Channel	52.810	0.367	191	88	365	221	176	121	196	98	429	214
Sunk Sand	52.975	0.493	42	2	45	3	6	0	36	0		
East total			1997	663	2373	995	2270	972	1949	867	1556	875
Wash Total			3621	1220	3905	1567	3760	1586	3486	1448	3083	1400

8 Appendix 2

Distributions of harbour seal pups on all 10 surveys carried out in 2015 (a-e) and 2016 (f-j).



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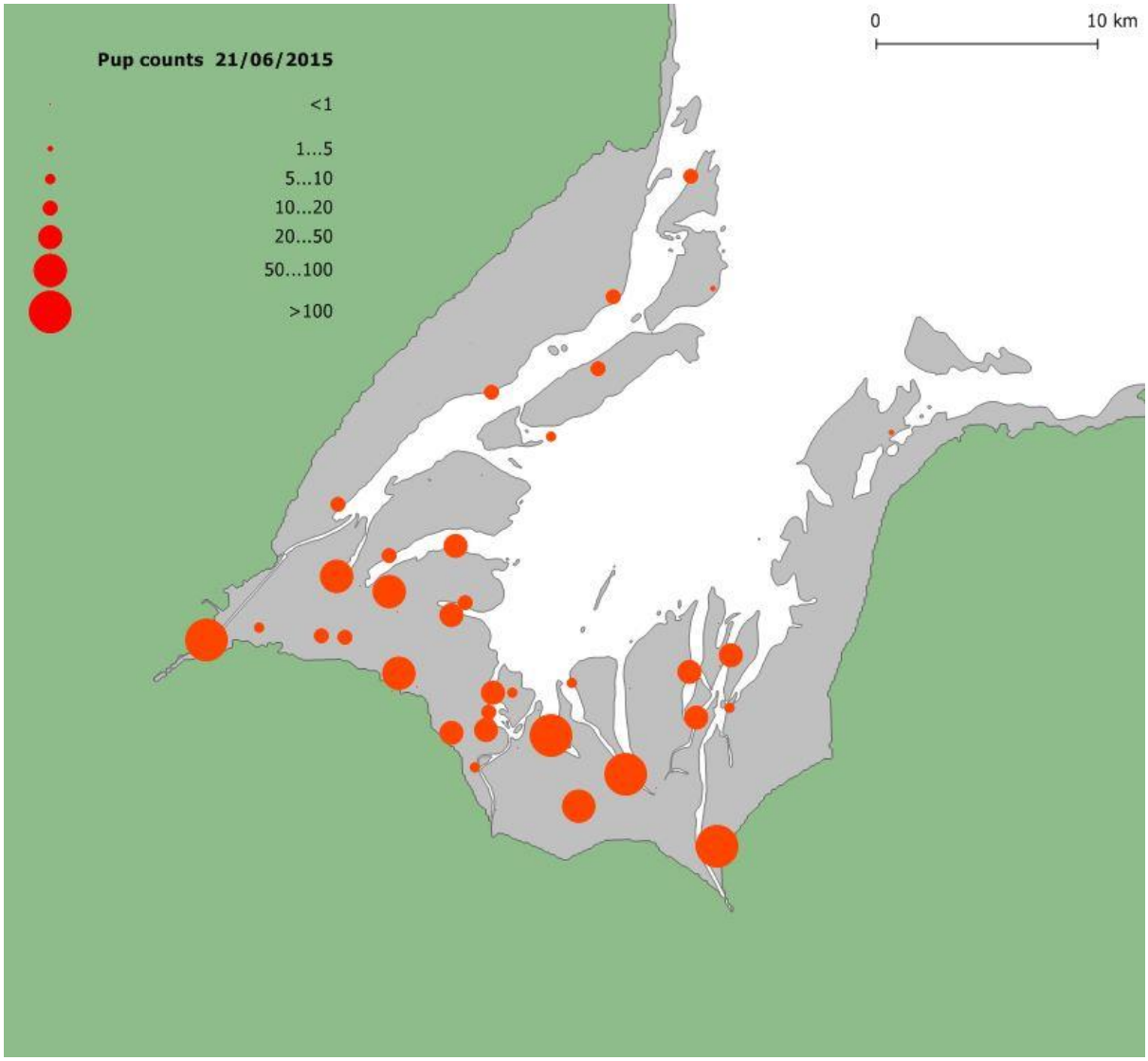

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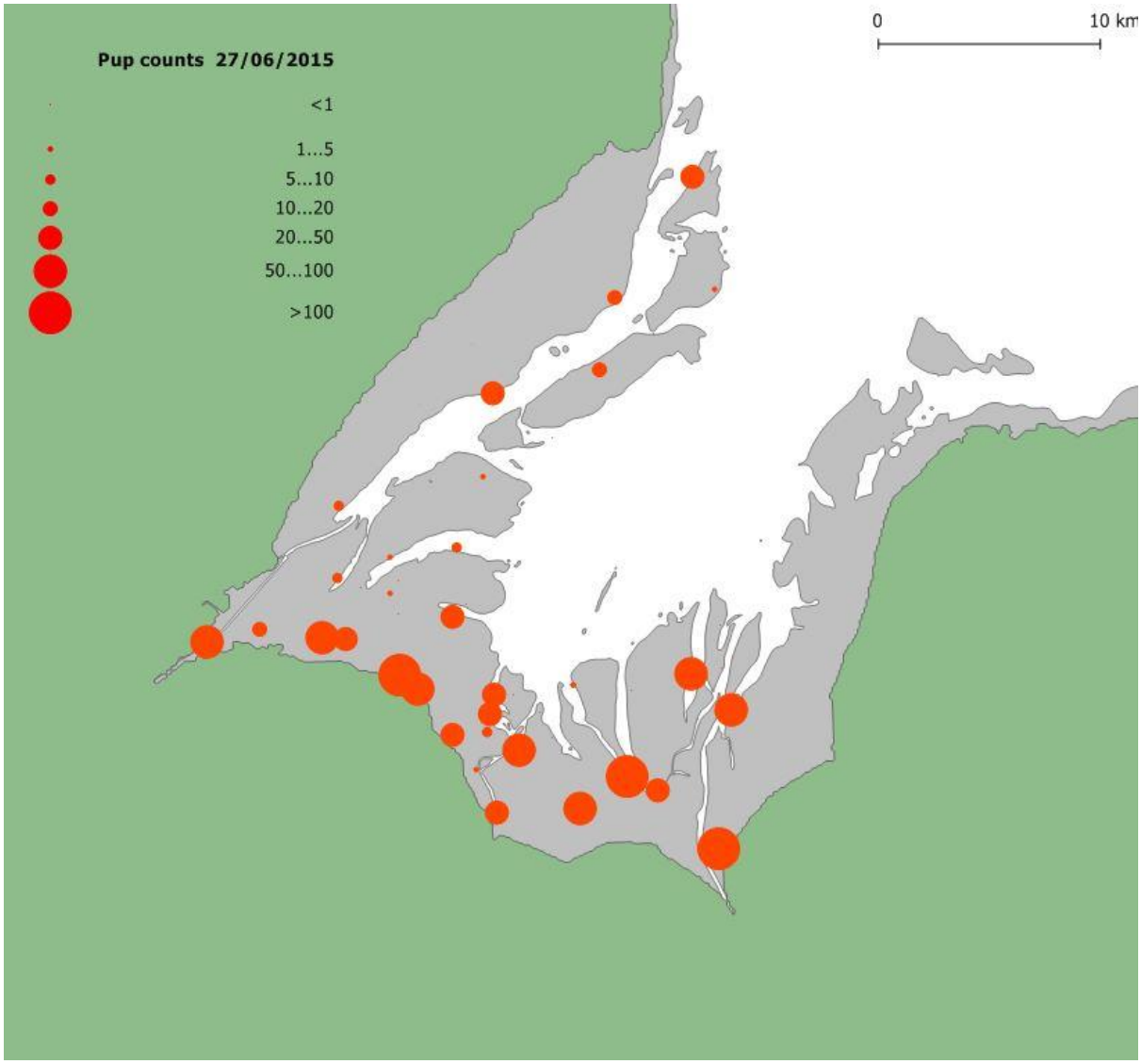

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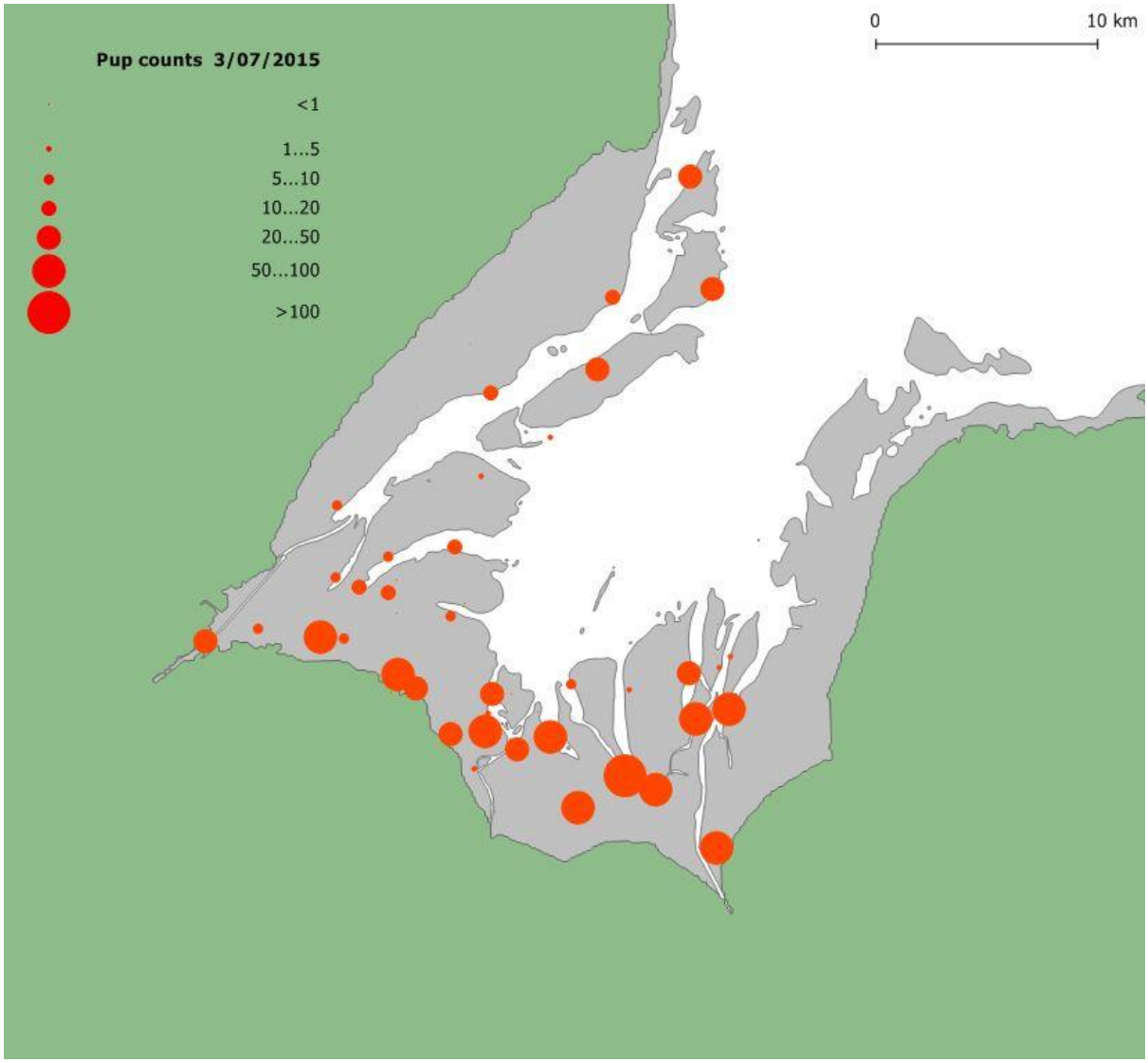

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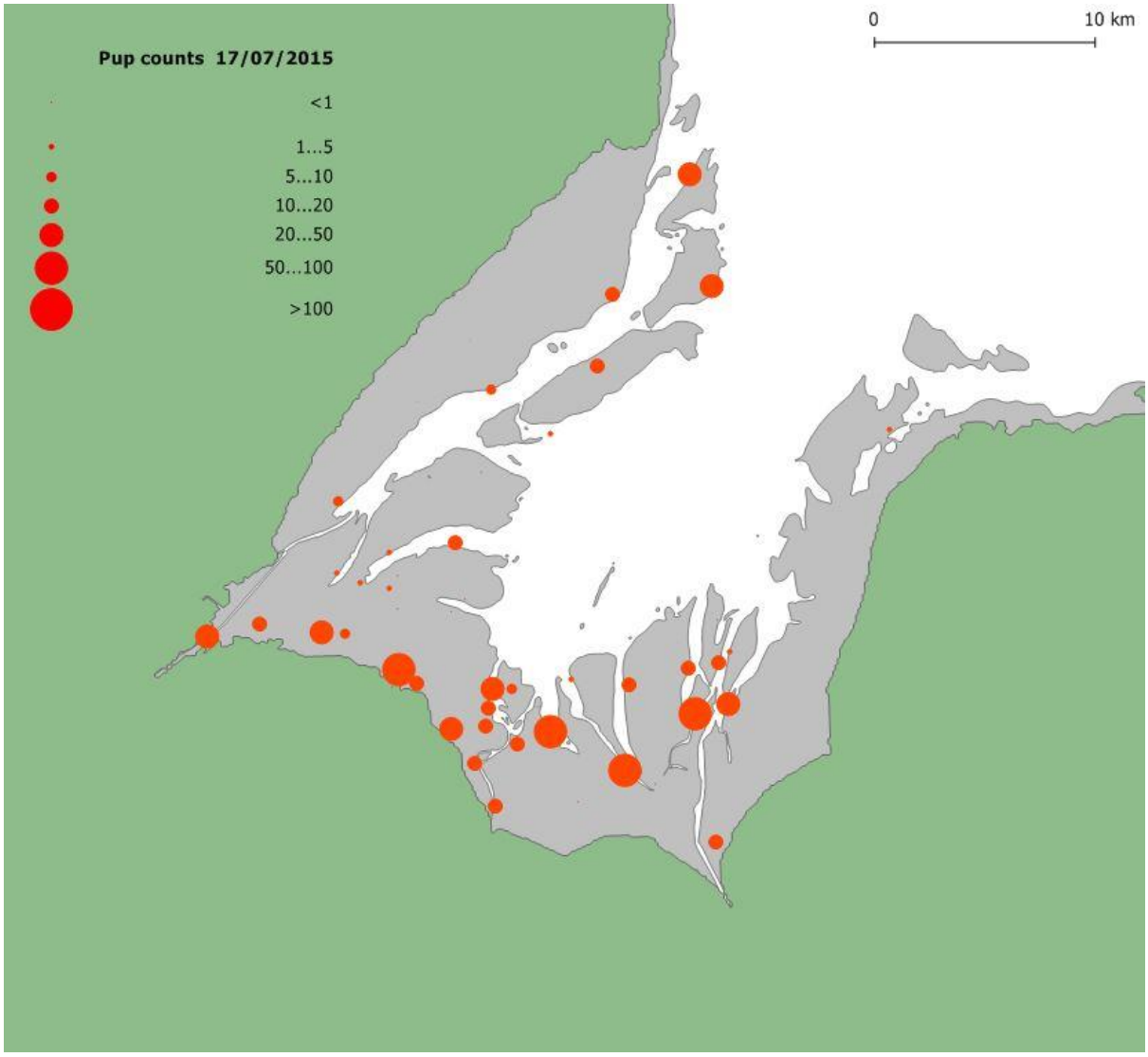

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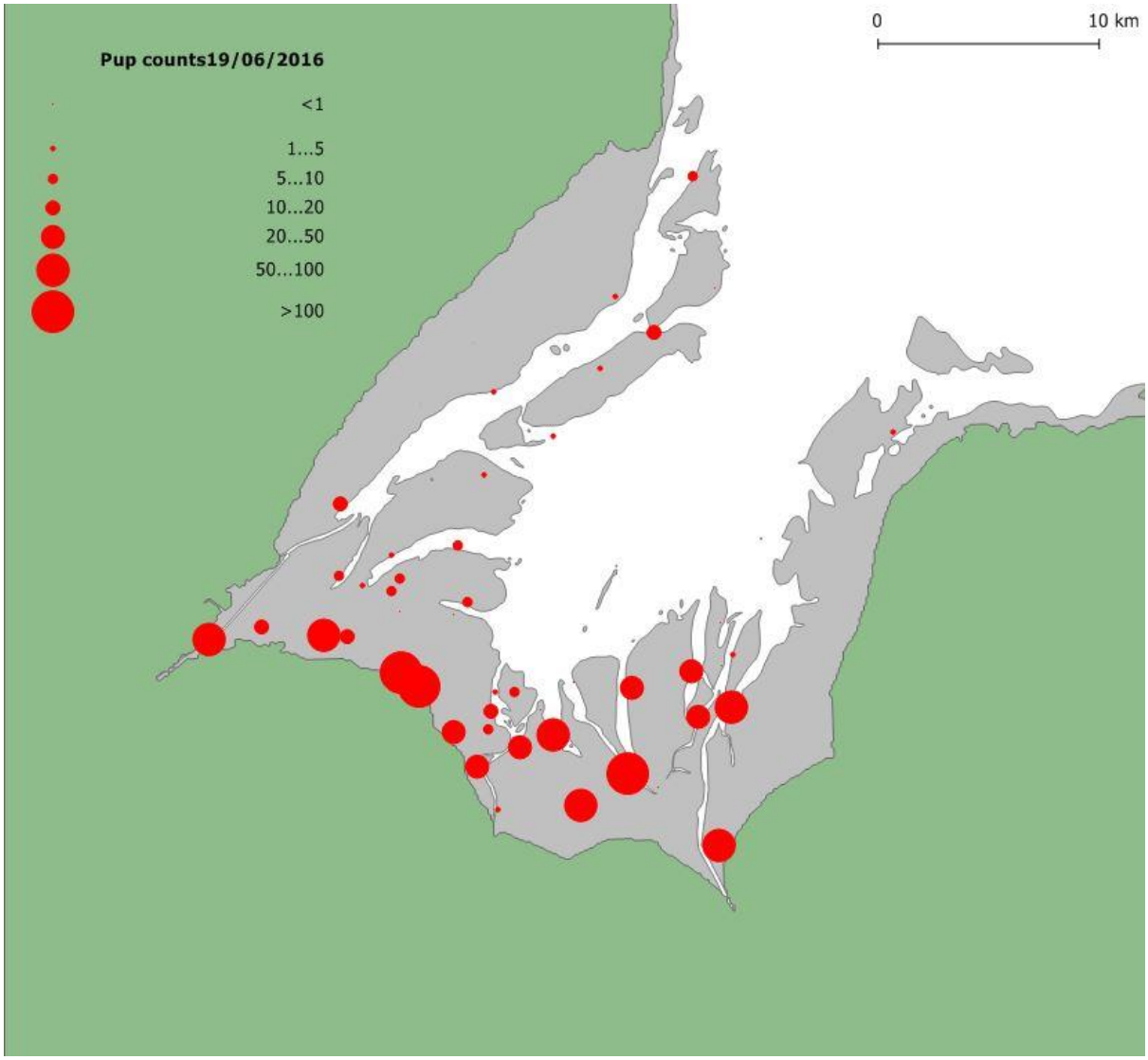
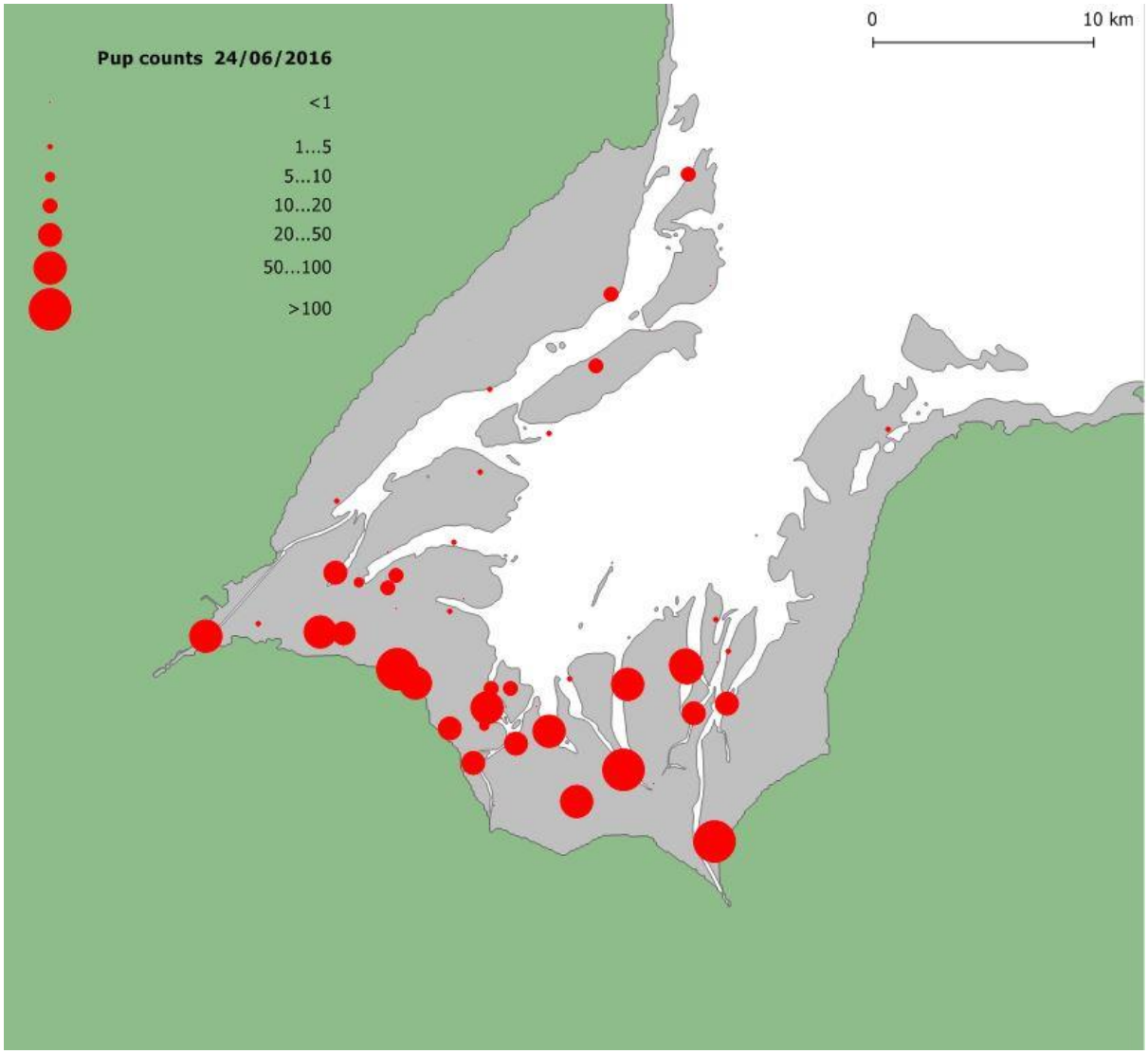


f. 19/06/2016



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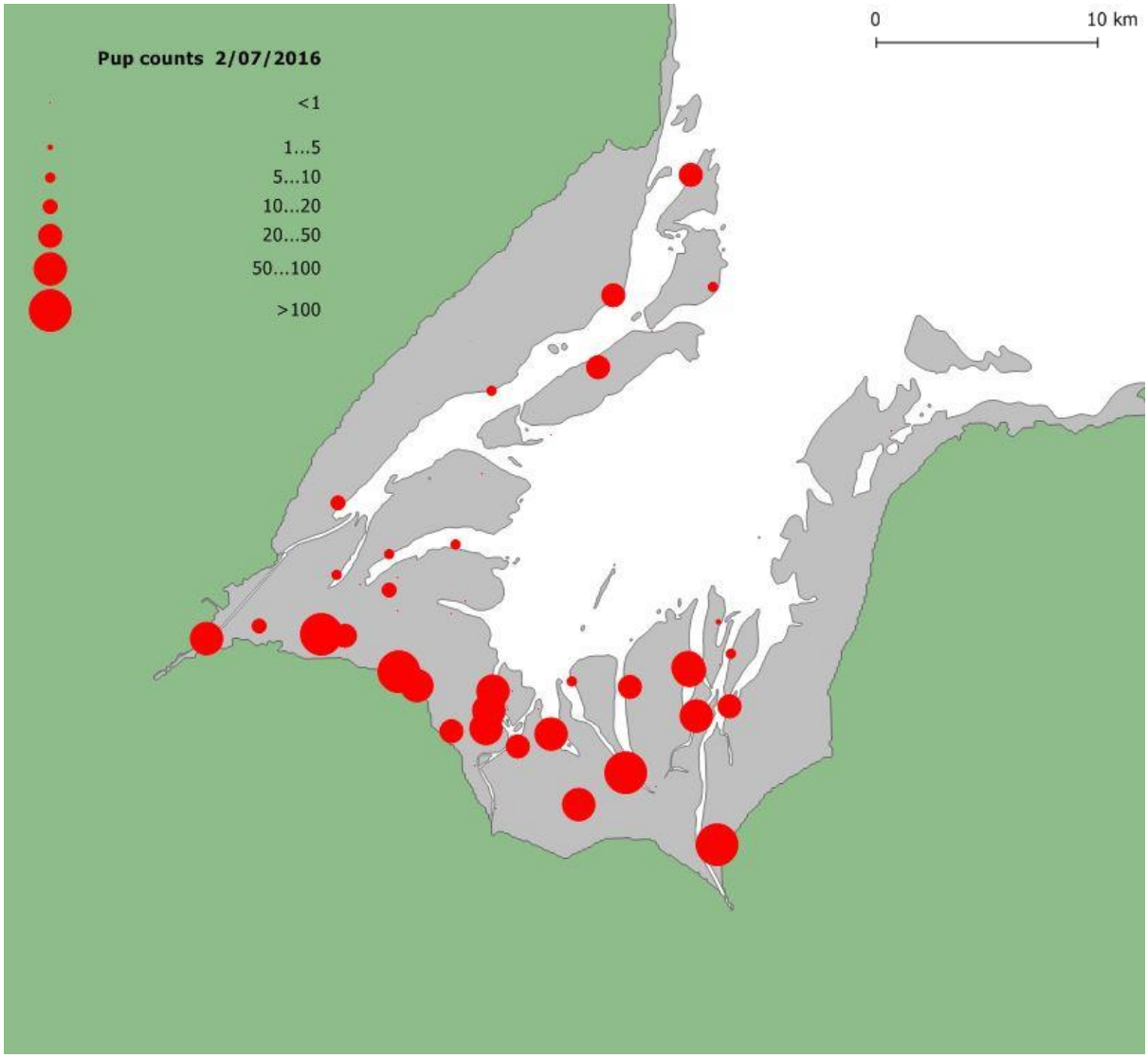

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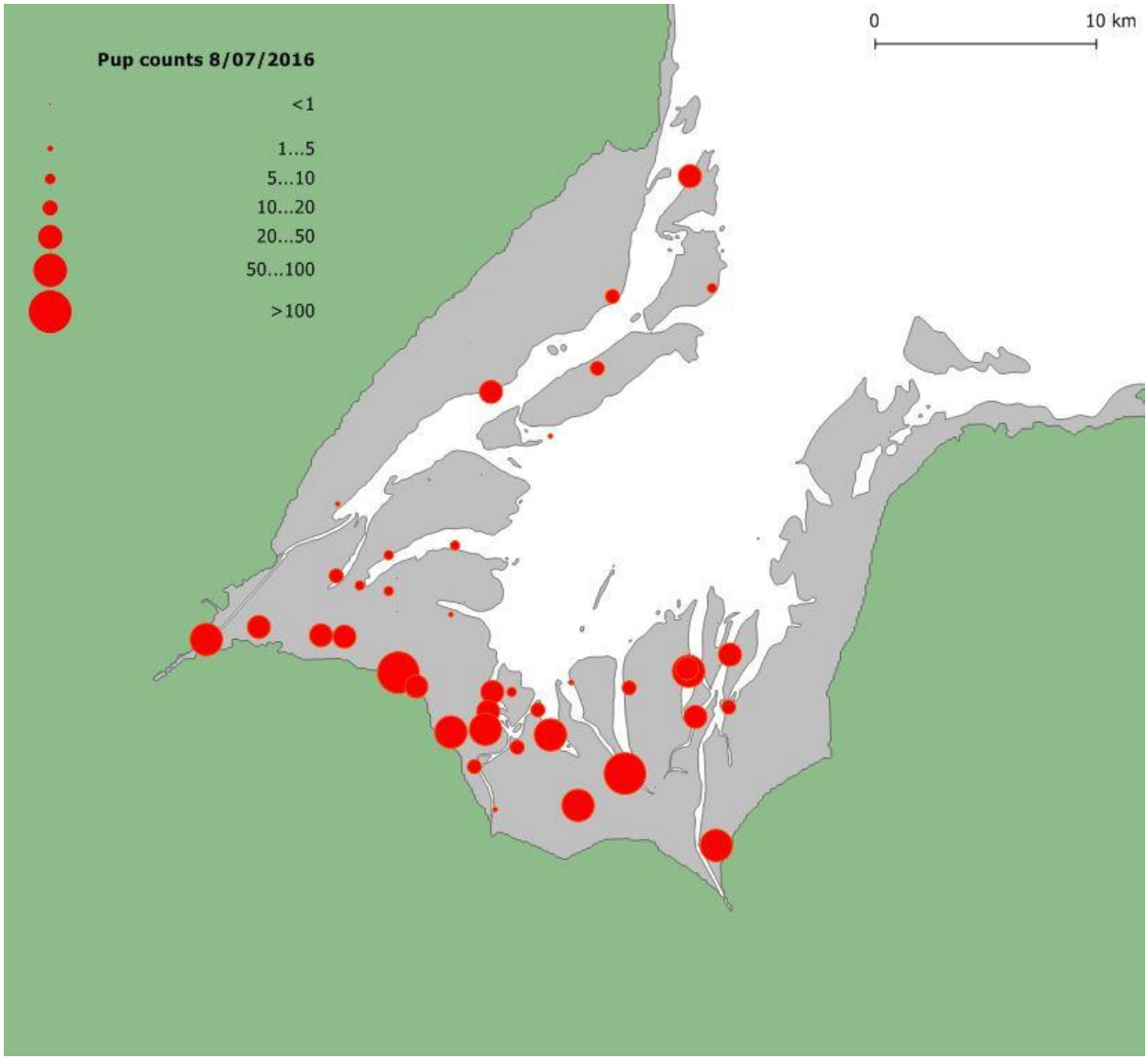
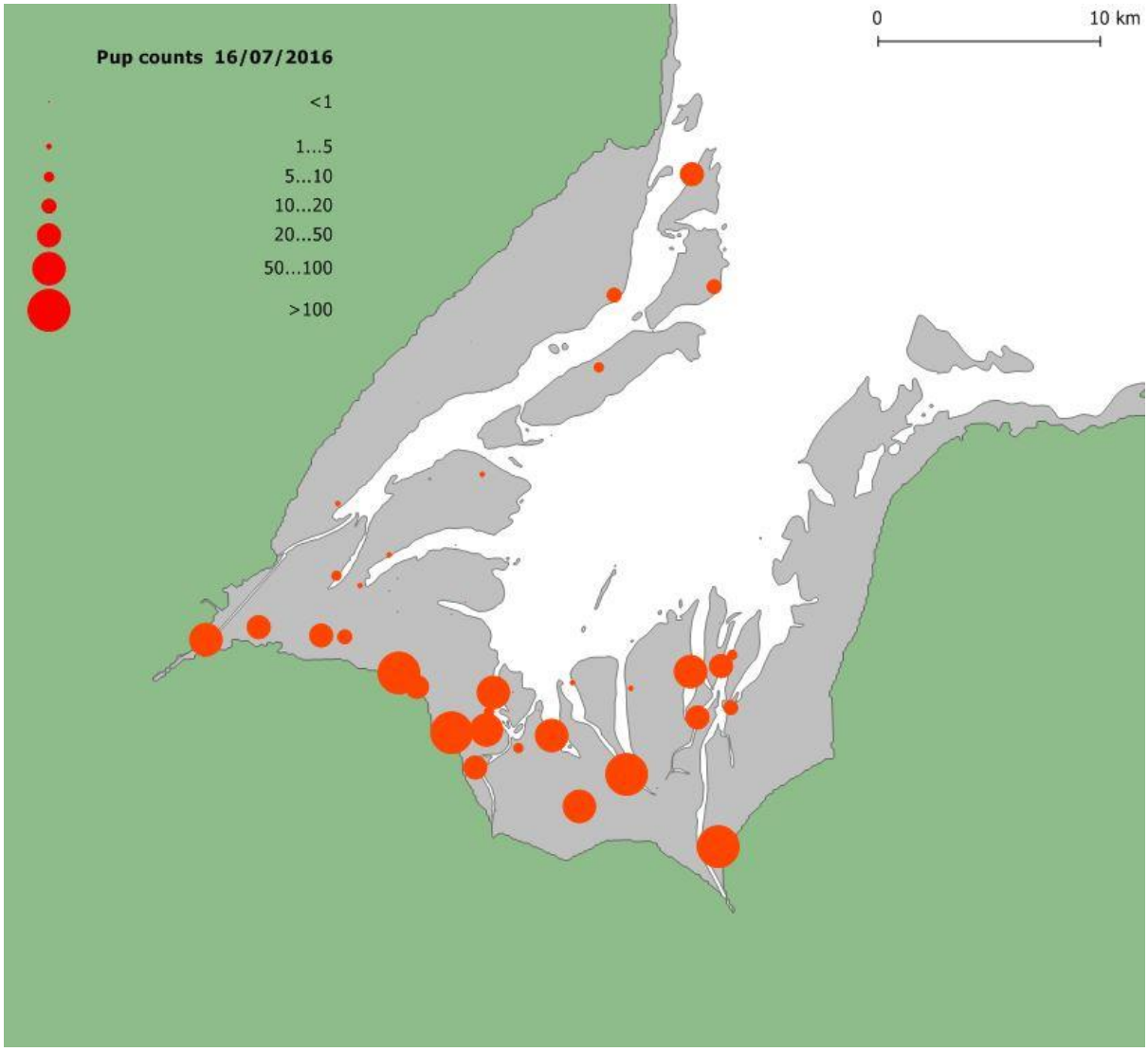


i. 8/07/2016



j. 16/07/2016