Preliminary report on the distribution and abundance of harbour seals (*Phoca vitulina*) during the 2018 breeding season in The Wash

Dr David Thompson
NERC Sea Mammal Research Unit
Scottish Oceans Institute
University of St Andrews.
KY16 8LB

Table of Contents

1. Summary

This report presents preliminary results of a breeding season aerial survey of the harbour seal population along the English east coast between The Wash in Lincolnshire and Scroby Sands off the Suffolk coast on 29th June and 2nd July 2018.

Results suggest that:

- The pup count for the Wash was 1498, which was 18% higher than the 2017 peak and similar to the average of the peak counts for the preceding 5 years.
- Although the counts appear highly variable, a simple exponential growth curve fitted to the counts suggests an average increase of 5.6% p.a. since 2001.
- The ratio of pup counts to the all age population index has remained high, at around 0.4. The ratio was 2.7 times higher in 2018 than in 2001 suggesting that the large increase in apparent fecundity after 2001 has been maintained.

2. Background

The Wash is the largest estuary in England, and holds the majority of the English harbour seal (*Phoca vitulina*) population (Vaughan, 1978). This population 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.

In the summer of 1988 an epidemic of phocine distemper virus (PDV) spread through the European harbour seal population. More than 18000 seal carcasses were washed ashore over a 5 month period, many of them in areas with high levels of human activity (Dietz, Heide-Jorgensen & Härkönen, 1989). Mortality in the worst affected populations, in the Kattegat-Skagerrak, was estimated to be around 60% (Heide-Jorgensen & Härkönen, 1992). After the end of 1988, no more cases of the disease were observed until the summer of 2002, when another epidemic broke out (Harding *et al.*, 2002). Mortality in the European population during the 2002 epidemic was 47%, similar to that seen in 1988 (Harkonnen et al. submitted). However, on the English East coast the mortality rate estimated from pre and post epidemic air survey counts was much lower, approximately 22% (Thompson, Lonergan & Duck, 2005). The pre-epidemic population in 2002 was similar in size to the pre-epidemic population in 1988 and the disease hit the English population at the same time of year, so to date there is no clear explanation for the lower mortality rate.

In general, harbour seal population monitoring programmes have been designed to track and detect medium to long-term changes in population size. As it is difficult to estimate absolute abundance, monitoring programmes have usually been directed towards obtaining indices of population size. If consistent, such time series are sufficient to describe populations' dynamics and have been used to track the long-term status of the English harbour seal population. However, these indices are based on the numbers of individuals observed hauled out, so their utility depends on this being constant over time and unaffected by any changes in population density or structure.

Counts are usually carried out during the annual moult, when the highest and most stable numbers of seals haulout. Unfortunately such counts do not provide a sensitive index of current population health. It is generally accepted that breeding success is a more sensitive index. The breeding season is also the time when disturbance of seal haulout groups is likely to have direct effects. E.g. disturbance of mother/pup pairs will lead to temporary separation which may have direct effects on pup survival, especially if the disturbance is repeated.

Most of the UK harbour seal population breeds on rocky shore habitats, where identifying and counting pups is both difficult and expensive. However, on the English east coast harbour seals breed on open sand banks where pups are relatively easy to observe and count. As a first step towards improving the monitoring program (to increase its sensitivity to short term changes), we identified a need for a baseline survey to map the distribution of breeding harbour seals. In June 2001 Fenland District Council commissioned Sea Mammal Research Unit to conduct an aerial survey 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 as well as 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. In 2008, 2010, 2015 and 2016 additional funds were provided to obtain time series' of counts within single breeding seasons to estimate the parameters of the pupping curve. In addition to confirming the date of the peak number of pups ashore and available to be counted, these results were expected to provide an estimate of the ratio between peak pup counts and pup production and provide an indication of the likely error on estimates of pup production. Large inter-annual differences in the temporal pattern of the pup counts have so far prevented fitting a standard birth curve. However, the data have allowed estimation of the timing of the peak number of pups ashore (Thompson et al, 2016) which confirm that the peak count occurs during the first week in July.

In addition to the pup counts, routine annual moult surveys cover the coast from Donna Nook in Lincolnshire to Scroby Sands off Great Yarmouth in Suffolk. There are known to be smaller groups of seals at various sites along the Essex and the north and east Kent coasts. These sites have been surveyed sporadically during the moult since 2002.

3. Historical data

One or two complete aerial photographic surveys of the Wash were carried out during the moult, in the first half of August in each year from 1988 to present. Surveys were carried out using a twin engine, fixed wing aircraft (Piper Aztec (PA 57)). A fixed route is flown each survey, and all previously occupied sites are inspected. The distribution of occupied sites means that almost the entire coastline and most tidal creeks are overflown and searched each year. In addition, more remote tidal creeks, in previously unoccupied areas, are inspected occasionally so that new groups are detected within one or two years of formation. The results of these surveys, combined with counts at the same time of year from the period 1968-1982 are shown in Figure. 1 (SCOS, 2017). The counts increased between the late 1960s and 1988, at an average of 3.4% pa (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 as a result of an epidemic of Phocine Distemper Virus (PDV). 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)).

Post epidemic counts were also obtained at the other major east coast haulouts outside the Wash, at Blakeney (45km east) and Donna Nook (40km north). At both sites the counts fell after 1988, reaching a minimum in 1990 (Figure 2). 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 2).

In 2002 there was another outbreak of PDV. The timing of the epidemic and the population size immediately prior to the epidemic were similar to that in the 1988 outbreak. 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 in the moult counts for the English east coast population in the three or four years following the 2002 epidemic. Overall, the combined count during the moult for the English East coast population in 2006 was approximately 50% lower than the mean count in 2002. After 2006 the counts increased such that by 2010 and 2011 the numbers were similar to the pre epidemic counts. The 2017 count of 3203 was close to the average since 2010 suggesting little change. The initial failure to recover from the 2002 epidemic is unexplained but is similar to the apparent lack of recovery in the years immediately following the 1988 PDV epidemic. The apparent lack of recovery or continued decline immediately after the epidemic contrasts with the rapid recovery of the Wadden Sea population that increased at around 12% p.a. from 2002 to 2011 (Galatius et al., 2017). Since 2014 the Wadden Sea population has shown clear signs of a slow-down in growth.

4. Previous breeding season surveys 2004 to 2017

Based on a preliminary assumption that the peak number of pups would be encountered at the end of June or beginning of July the breeding population has been surveyed between 27th June and 4th July in each year from 2004 to 2017. In addition in 2008, 2010, 2015 and 2016 four additional surveys were carried out 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 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.

5. 2018 survey results

In 2018 a survey was attempted on 29th June, but was curtailed because of low cloud covering the open coast between Donna Nook and Scroby Sands. The cloud moved west to cover most of the Wash during the survey. As a consequence only around 1/3 of the sites could be surveyed. The rest of the Wash and the haulout at Blakeney Point were surveyed during the late afternoon on 2nd July after the RAF ranges closed. The late timing of the survey dictated by military restrictions meant that Donna Nook was not surveyed. However, given the absence of pups in the previous surveys it is unlikely that any pups were missed.

A total of 1498 pups and 3747 older seals (1+ age classes) were counted in the Wash. As in 2017, only 1 pup was seen at Blakeney point. The 2018 pup count for the Wash was 18% higher than the 2017 count but similar to the average of the peak counts for the preceding 5 years (1463). The non-pup count, i.e. all 1+ age classes, was 7% higher than the 2017 count, but close to the average count during the previous five year's breeding season survey counts. The 18% difference between the estimated peak pup counts in the 2018 and 2017 surveys continues the pattern of high inter-annual variability (Table 2 and Figure 3). Accounting for the variability there has been little change in the peak count over the past 5 years suggesting that the increase in pup production may have slowed and may be approaching an asymptote after a period of exponential growth since the Phocine Distemper outbreak in 2002 (Figure 3). Both logistic and exponential growth curves were fitted to the pup count data since 2004, i.e. after the last PDV epidemic. The two models fit the data equally well (Exponential AIC = 74.9; Logistic model AIC = 73.6), so it is not possible to conclude that the population growth rate is slowing. Based on a simple exponential model the pup production is estimated to have increased at an average rate of 5.6% p.a. since the 2002 PDV epidemic.

Pups were recorded in 34 separate haulout groups in the Wash, although the number of sites is to some extent a function of the arbitrary division or pooling of groups (see below). This is the

same as in the previous 3 years, indicating no contraction or expansion in number of pupping sites. Figure 4 shows the distribution of haulout sites in the Wash. Figure 5 shows the flight path for the standard East Anglian surveys and Figure 6 shows the detailed track of survey flights over the Wash carried out on 29/06/2018 and 2/07/2018. The GPS track in combination with the photographs and the observers' knowledge of locations of seals on the beach have been used to confirm the positions of all the sites given in Table 1. In some areas, e.g. along the banks of the Lynn channel and the River Nene the groups are highly variable in size and location between surveys. In those cases the counts are pooled and a single count is given at an arbitrary point in the approximate centre of the distribution of observed groups. Figure 7 shows the counts of pups at each site obtained during the 2018 breeding season survey. Table 1 presents the data for 2015 to 2018. All the raw pup count data from 2004 to 2018 are presented in the appended Excel spreadsheet along with similar data from a survey carried out in 2001 for Fenland District Council and additional counts carried out in 2015 and 2016 for Statoil.

In 2018 pups were present at all bar five of the sites occupied by harbour seals. The fine scale distribution was similar to that observed in previous years. Most sites that held more than one pup per year over the previous three years also had pups in 2018. Each of the eight sites where this was not the case were within 2 km of a site with pups. Inter-annual movement at that scale is not unusual for harbour seals. The proportion of pups in the counts at sites on the inner banks and in tidal creeks in the southern end of the Wash was generally high indicating the importance of these sites during the pupping season (Figure 8).

The time series indicates that there was no evidence of a major decline in pup production after the 2002 PDV epidemic and the peak counts increased at around 9% p.a. during the 10 years following the PDV epidemic. This continued increase in pup production contrasted with the apparent decrease in the moult counts between 2003 and 2006 (Figure 1). The moult count increased between 2006 and 2010-2011, but the overall rate of increase for pup counts initially exceeded that of the moult population index counts (Figure 9). Since 2011 there has been little apparent increase in either the pup or moult counts. The different trajectories of the pup counts and the independent index of population size represented by the moult count since the 2002 PDV epidemic means that the apparent productivity or apparent population fecundity has changed over the period (Figure 10). An index of productivity, i.e. the maximum pup count in each year divided by the moult count in that year shows a major increase from approximately 0.25 at the start of the series between 2001 and 2005 up to an average of 0.45 since 2006. The productivity index for 2018 is based on the moult count for 2017 and will be updated when the counts for 2018 are available.

6. Discussion

The 2018 breeding season survey counts for both pups and associated 1+ age classes at the estimated peak of the breeding season were similar to the average counts from surveys during the previous five years. This suggests that the apparent continuous increase in pup production since the first survey in 2001 is slowing or stopping. However, the high degree of variability in the pup counts and the inconsistencies in the shapes of the pupping curves seen in 2008, 2010, 2015 and 2016 means that it is still too early to confirm this apparent slow down. At present, the fitted exponential growth curve indicating an average increase of 5.6% p.a. should be seen as the best descriptor of the pup production trajectory. The increase in the counts during the annual moult, which are regarded as a more stable indicator of population size, also appears to have slowed after a period of growth since 2005. Again, the variability in these counts means it is too early to confirm this slow down.

Both the population and pup production estimates are high relative to the pre-epidemic counts obtained in 2001. Numbers over the last five years represent the highest populations and the highest pup production recorded in the Wash. A reduction in growth rate of the population is therefore unlikely to indicate any problem for the 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 5.6% p.a. increase in pup count should be a reliable indication of the rate of increase of pup production.

The recent low intensity 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 and a continued decline in the moult counts resulting in a 50% decrease by 2006, 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. Alternatively any decrease in adult female population could have been masked by variations in fecundity.

Although the moult counts in Wash continued to decline after the 2002 epidemic they had clearly stabilised around 2005 or 2006 and then increased rapidly until around 2012. Interestingly, although the moult counts in recent years, 2012 to 2017 have been similar to the 2001 pre-epidemic count, the estimated peak pup count in 2018 was 2.7 times greater than in 2001 and the number of 1+age class animals counted in the breeding season was approximately double

the 2001 estimate. 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 2.5 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. Telemetry data from both the English and Netherlands populations suggests that there is limited movement between the two areas that is unlikely to be sufficient to account for these changes. However, to date the telemetry studies have been primarily targeted on seals in the early spring or post moult, so there are few data on movements of female seals in the period immediately before pupping and none during the post pupping period. These studies therefore have little power to detect such movements.

The observed large increase in pup production relative to the moult count index 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. Targeted studies of survival and fecundity in Wash harbour seals would be needed to identify the likely causes of these changes.

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 2004 and 2005 distribution was similar to the 2001 distribution, suggesting that there has been a real shift in distribution 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 2017 and 2018 indicate that the relative importance of the SE corner of the Wash is still increasing.

7. References

BOWEN, W.D., BONESS, D.J., & IVERSON, S.J. (1999) Diving behaviour of lactating harbour seals and their pups during maternal foraging trips. *Canadian Journal of Zoology - Revue Canadienne de Zoologie*, **77**, 978-988.

GALATIUS, A., BRASSEUR, S., CZECK, R., JEß,A., KÖRBER, P., PUND, R., SIEBERT, U., TEILMANN, J. & KLÖPPER, S. (2017) Aerial surveys of Harbour Seals in the Wadden Sea in 2017:Population counts still in stagnation, but more pups than ever. http://www.waddensea-secretariat.org/ sites/default/files/downloads/TMAP_downloads/Seals/17-1109_harboursealreport2017.pdf

HIBY, A. R., THOMPSON, D. & WARD, A. J. (1987). Improved census by aerial photography - an inexpensive system based on non-specialist equipment. *Wildl. Soc. Bull.* **15**, 438-43.

LONERGAN, M., DUCK, C.D., THOMPSON, D., MACKEY,B.L., CUNNINGHAM,L. & I L BOYD (2007) Using sparse survey data to investigate the declining abundance of British harbour seals."; *Journal of Zoology*; 271(3):261-269

REIJNDERS, P.J.H. & FRANSZ, H.G. 1978. Estimation of birth rate and juvenile mortality from numbers of juveniles in a seal population with normally dispersed reproduction. I.C.E.S. C.M. 1978/N:7

REIJNDERS, P.J.H. (1978) Recruitment in the harbour seal (*Phoca vitulina*) population in the Dutch Wadden Sea. Neth. J. Sea. Res. **12(2)**: 164-179

SCOS (2017) Scientific advice on matters related to the management of seal populations. Natural Environment Research Council, 144pp.
http://www.smru.st-andrews.ac.uk/files/2018/01/SCOS-2017.pdf

THOMPSON, D, LONERGAN, M & DUCK, C.D. (2005) Population dynamics of harbour seals (*Phoca vitulina*) in England: growth and catastrophic declines. *J. Appl. Ecol*. 42 (4): 638-648

THOMPSON, D., ONOUFRIOU, J., & PATTERSON, W. (2016) REPORT ON THE distribution and abundance of harbour seals (phoca vitulina) during the 2015 and 2016 breeding seasons in The Wash. Report number: SMRUC-DOW-2016-016, DECEMBER 2016 (UNPUBLISHED).

VAUGHAN, R. W. (1978). A study of common seals in the Wash. *Mammal Rev.* **8**, 25-34.

Table 1. Counts of harbour seal pups and 1+ age classes in the Wash from 2001 to 2018.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Pups	548	613	651	1054	984	994	1130	1432	1106	1469	1308	1802	1351	1586	1289	1498
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561	3345	4020	4539	3905	3443	3747

Table 2. Counts of harbour seal pups and 1+ ages at haulout sites in the Wash, 2016-2018.

			2-July 2018		4-July 2017		2-July 2016	
			harbour seals		harbour seals		harbour seals	
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups
Inner & Outer Knock	53.082	0.364	195	24	81	15	157	31
Inner Dogs Head	53.036	0.376	45		24	3	44	7
Friskney	53.034	0.309	68	16	69	15	81	20
Friskney Middle	52.997	0.225	8	4	32	17	8	7
Friskney South	52.953	0.119	38	16	9	2	22	15
Long Sand N/E End	53.019	0.334						
Long Sand Middle	53.005	0.297	97	25	59	15	101	22
Ants	52.978	0.264	1	1	0	0	1	0
Rodger	52.963	0.217	7		5	0	1	0
NW total			459	86	279	67	415	102
Black Buoy	52.924	0.117	26		34	1	41	8
Boston Channel	52.900	0.029	210	104	143	35	180	88
Herring Shoal	52.904	0.064	66	31	49	4	43	12
Toft East	52.932	0.153	28	5	16	3	19	6
Toft West	52.920	0.133	52	41	15	0		
Mare Tail	52.917	0.152	26	10			28	11
Main End	52.907	0.193						
Gat End	52.912	0.203	9	9				
Gat Sand	52.935	0.198	70	13	53	5	44	8
SW total			487	213	310	48	355	133

			2-July	2018	4-July	2017	2-July	2016
			harbour	seals	harbour	seals	harbour	seals
site name	lat	long	1+ages	pups	1+ages	pups	1+ages	pups
Puff	52.899	0.121	57	24	32	9	55	20
Kenzies Creek	52.900	0.106	143	94	148	93	159	110
Fleet Haven Marsh	52.877	0.152						
Fleet Haven Middle	52.884	0.157	234	114	173	114	295	156
Fleet Haven Lower	52.909	0.157						
Fleet Haven Mouth	52.922	0.158	25	25	48	26		
Evans Creek	52.878	0.169	137	56	182	89	101	58
Dawesmere Creek	52.859	0.191	167	49	46	28	110	35
Creeks total			763	362	629	359	720	379
OWMK 1	52.875	0.233	74	36	24	12		
OWMK 2	52.867	0.250	27	12	7	2		
Nene Channel 1	52.875	0.220	78	46			104	64
Nene Channel 2	52.867	0.216	165	44	198	60	223	68
Nene Channel 3	52.860	0.214	25	6	47	16	88	55
Nene Channel 4	52.845	0.206	96	56	83	37		
Nene Channel 5	52.827	0.219						
IWMK	52.852	0.235			40	19	28	20
Scalmans Sled	52.857	0.258	145	68	74	43	159	87
Breast Sand	52.828	0.275	174	84	78	58	137	71
Thief West	52.878	0.273	25	2	19	1	37	5
Thief East	52.878	0.273	2		6	1	5	1
Seal Sand (W)/Black Shore	52.875	0.312			113	42	51	22
Seal sand (E)	52.881	0.352	128	26	148	23	245	60
Seal Sand/Daseleys	52.882	0.351			79	31	138	68
Hull Sand	52.840	0.307	369	144	719	193	563	232
Bull Dog Sand	52.866	0.378	64	35	222	49	38	29
Pandora	52.862	0.355	86	23	87	23	235	60
Black Guard	52.883	0.372	4		3	0		
Old Bell	52.900	0.372					22	2
Stylemans Middle	52.887	0.380	13	3	8	0	15	7
Pie Corner	52.834	0.327			30	7		
Lynn Channel	52.810	0.367	563	252	276	177	176	121
Sunk Sand	52.975	0.493			5	0	6	0
East total			2038	837	2266	794	2270	972
Wash Total			3747	1498	3484	1268	3760	1586

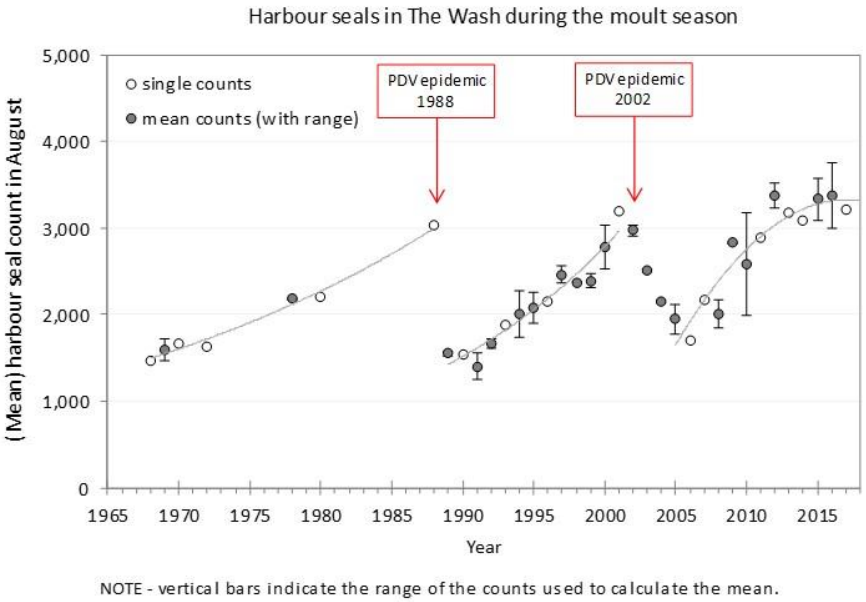

Figure 1. *Aerial survey counts of harbour seals in the Wash during the annual moult in August for the period 1968 to 2017. Dramatic declines in 1988 and 2002 were the result of epidemics of Phocine Distemper Virus. Fitted lines are exponential growth curves between 1968 and 1988 and between 1989 and 2002. A simple polynomial is fitted to the counts from 2005.*

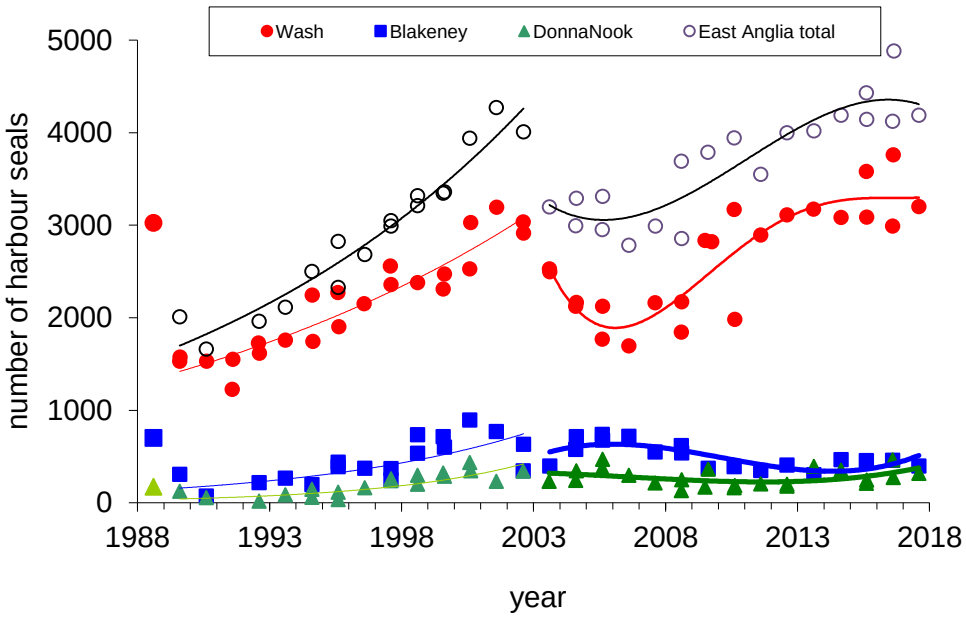

Figure 2. *Aerial survey counts of harbour seals at major sites in East Anglia during recovery from the 1988 and 2002 PDV epidemics. 1989 to 2002 fitted line is a simple exponential. The fitted polynomial from 2003 is included simply for illustration.*

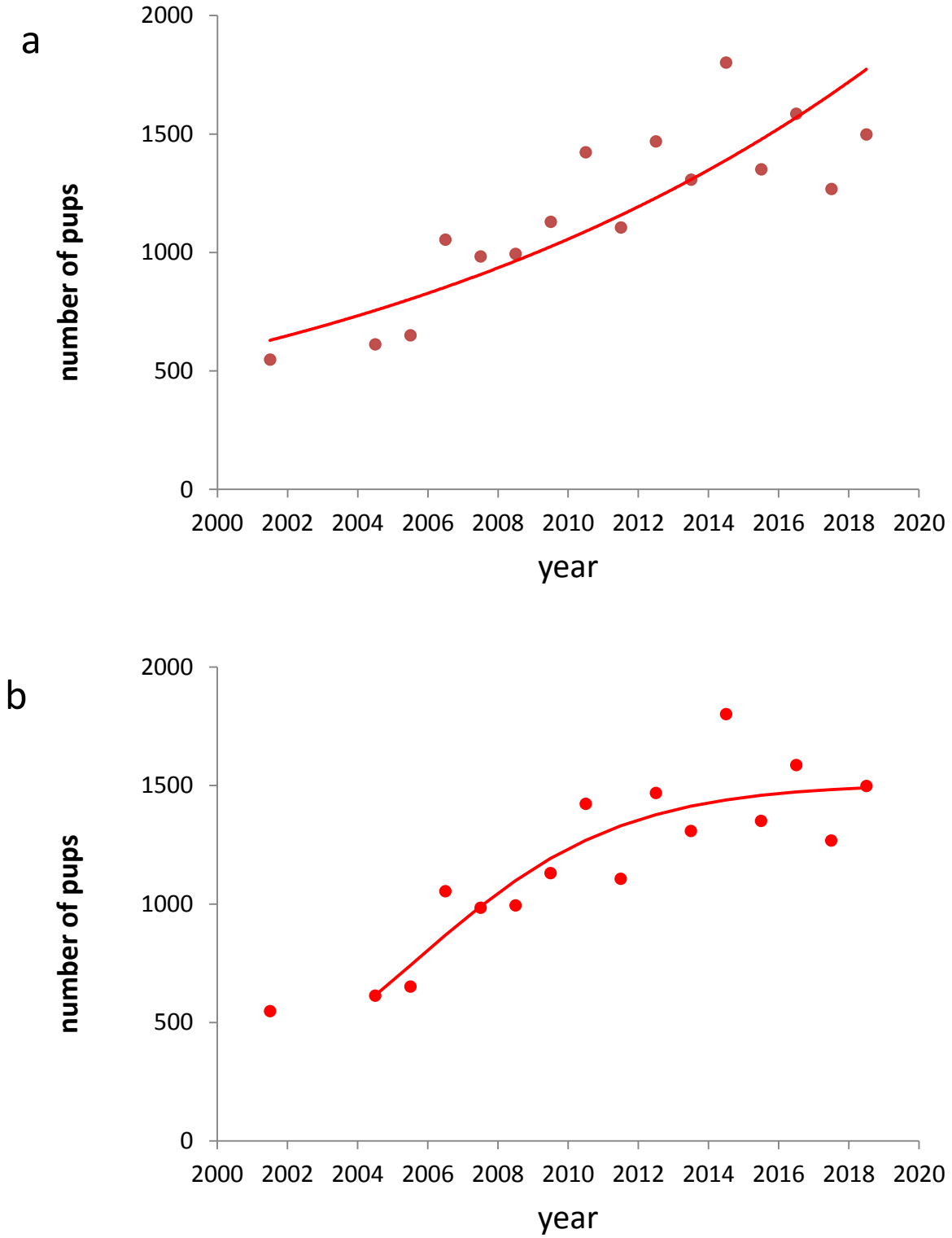

Figure 3. *Maximum counts of pups in The Wash between 2001 and 2018. The fitted line in* a *is a simple exponential which suggests that pup counts have increased at an average rate of approximately 5.6% p.a. since the 2002 PDV epidemic. The fitted line in* b *is a logistic growth curve indicating a slowdown in the rate of increase in recent years. Both models have equal weight based on AIC model selection criterion.*

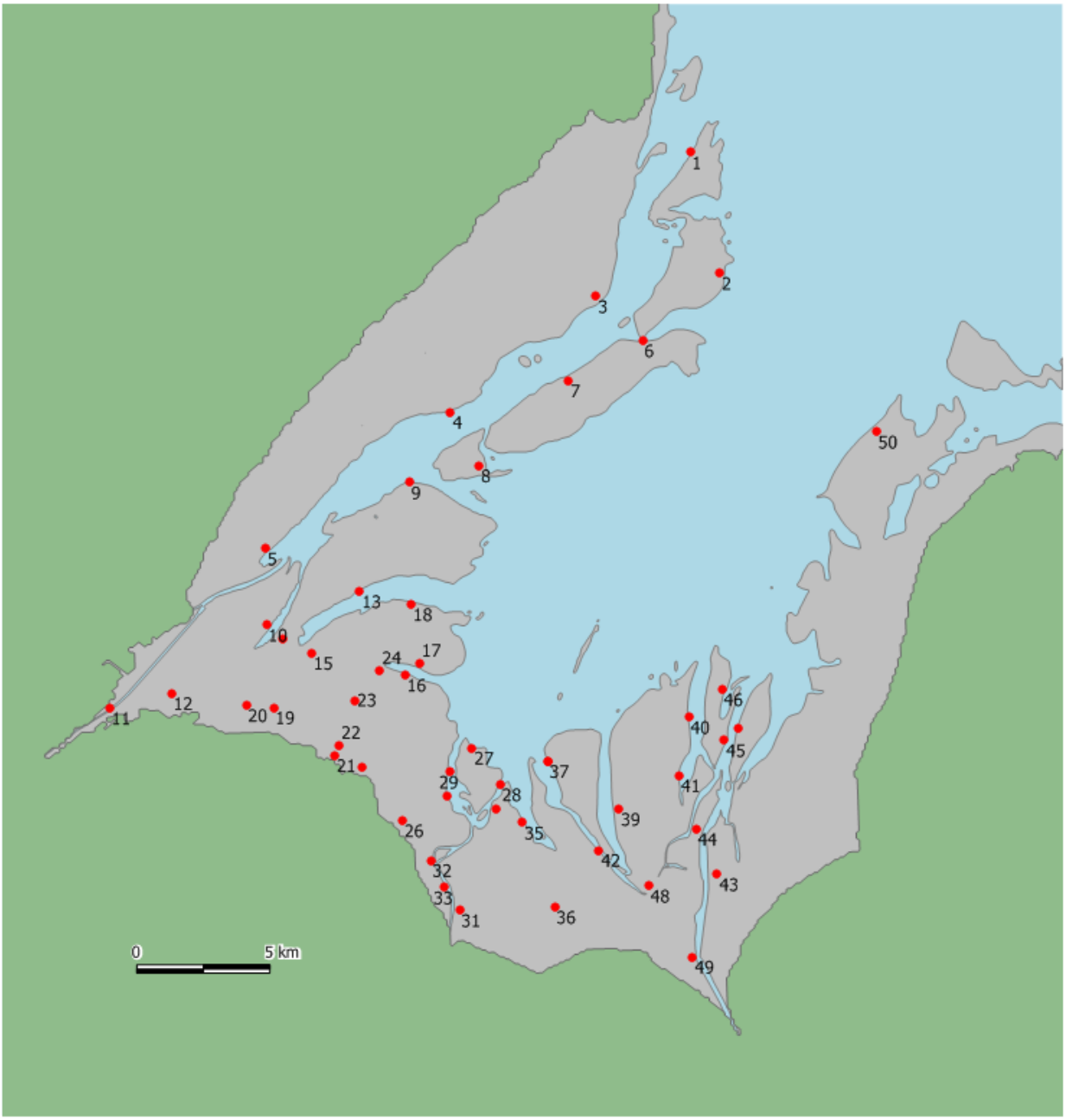

Figure 4. *Locations of seal haulout sites during the pupping season in the Wash. Numbers correspond to counts in Table 1. Sites 11 and 49 are composites of several groups that haulout within the lower tidal reaches of the Rivers Welland and Great Ouse respectively. The exact locations and sizes of groups vary widely between surveys so a single composite count is marked at the approximate centre of the distribution of sites.*

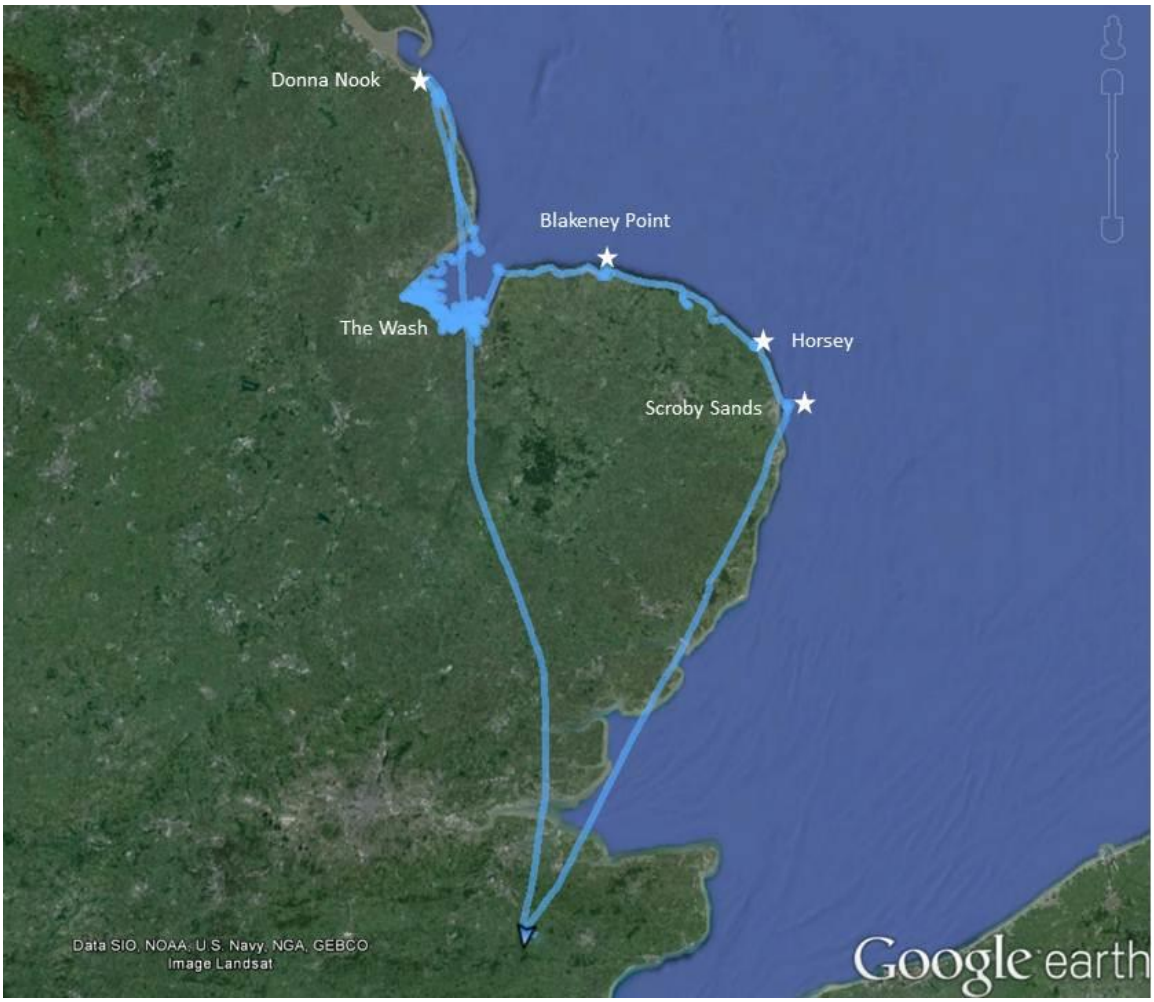

Figure 5. *Survey flight path from aircraft base in Kent to Donna Nook, The Wash, Blakeney Point and Scroby Sands.*

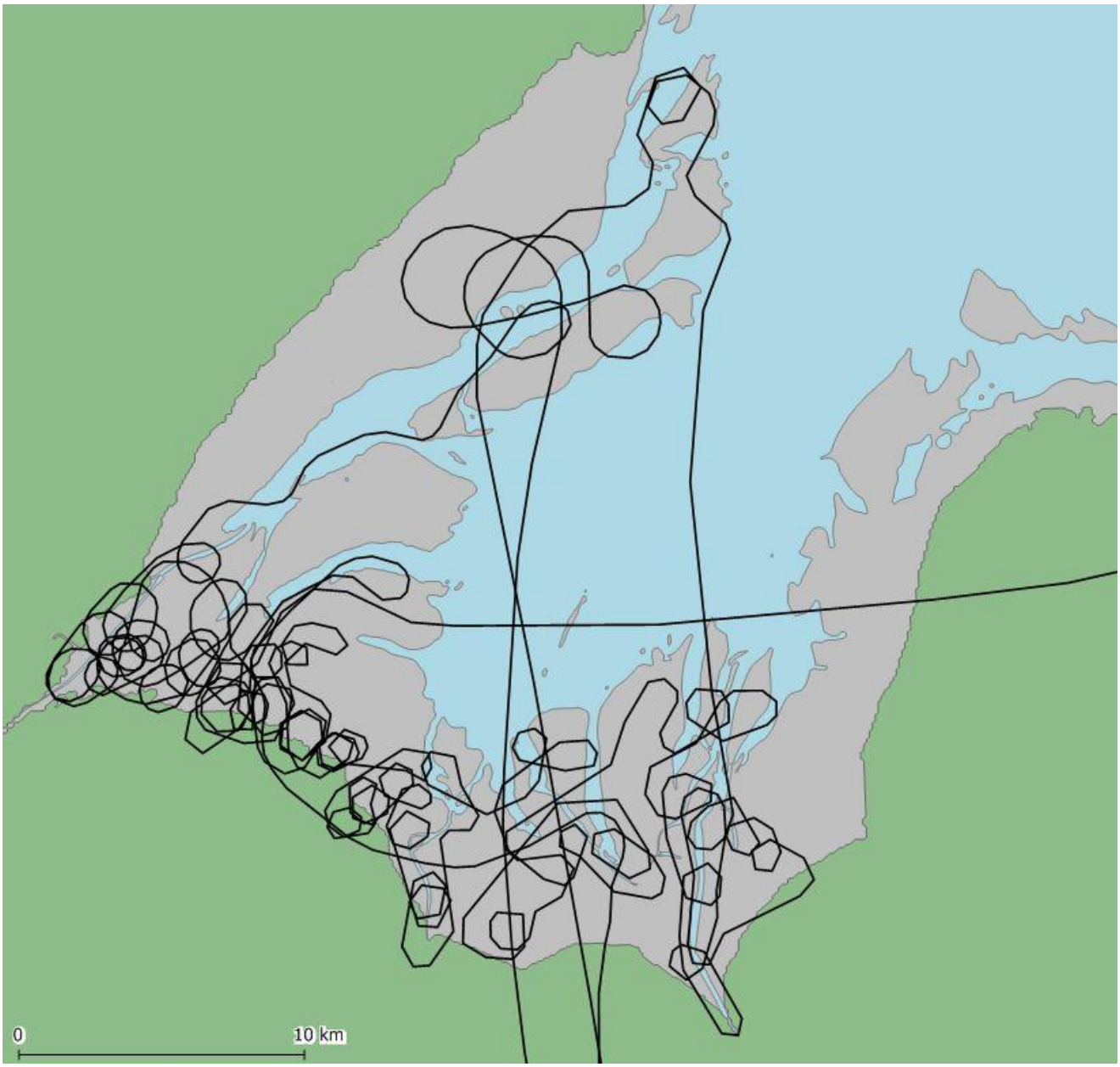

Figure 6. *Survey flight paths over the Wash during the breeding season survey (29/6/2018 & 2/7/2018). The approximate locations of the groups are derived from a combination of the positions of the tight turns and our observations of the location of seals within the turn.*

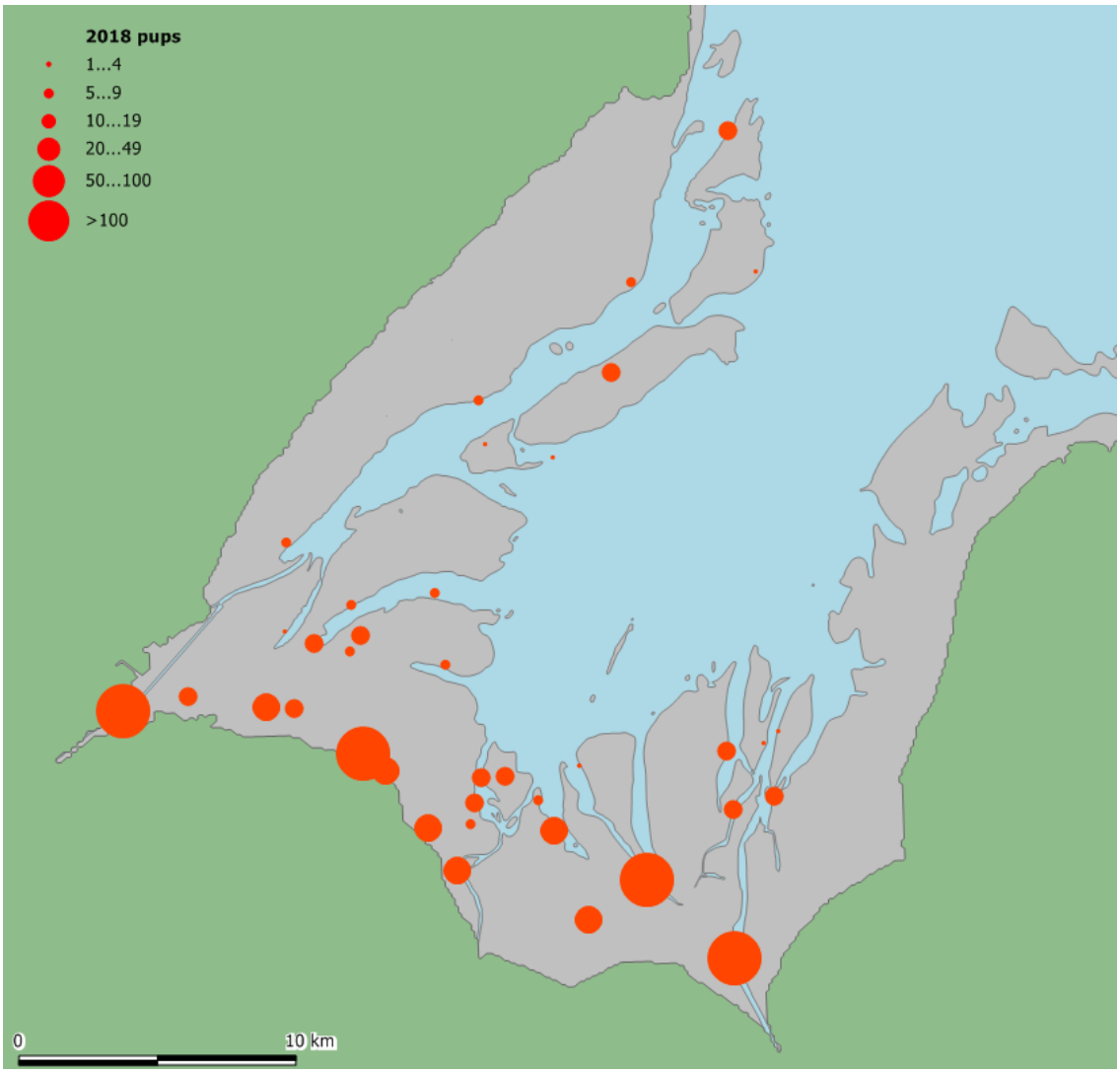

Figure 7. *Distribution of pups in the Wash on 29/6/2018 & 2/7/2018. Numbers of pups are represented by the areas of the circles on each site. Locations given to nearest 50m. Names of haulout sites together with latitudes and longitudes and numbers of seals at each site are given in Table 1 and Figure 3.*

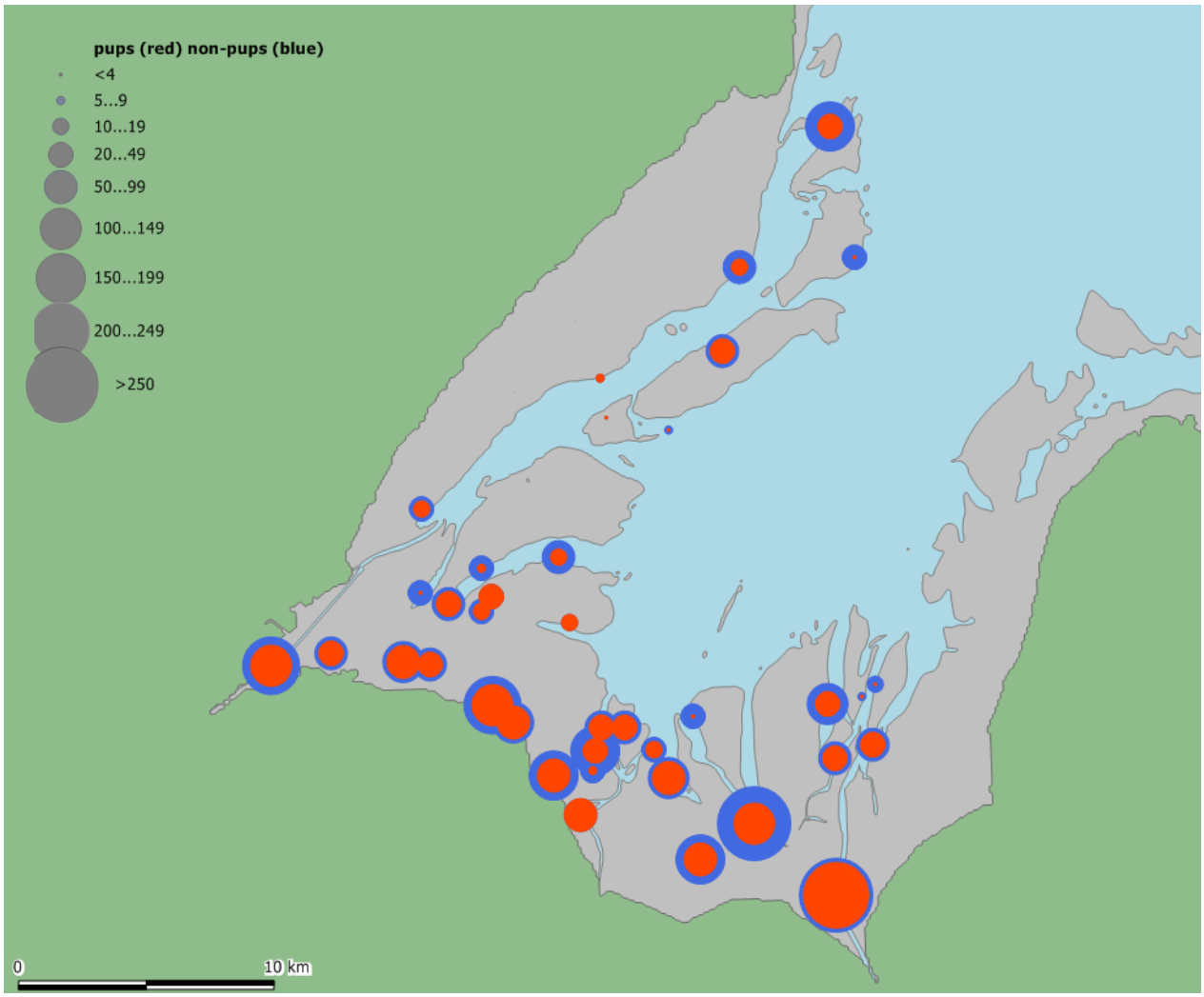

Figure 8. *Distribution of harbour seal pups (RED) and older seals (1+ age classes BLUE) in the Wash on 2/7/2018. Numbers of seals are represented by the areas of the circles on each site. At four sites, shown as simple red dots, the number of pups equalled or slightly exceeded the number of older seals.*

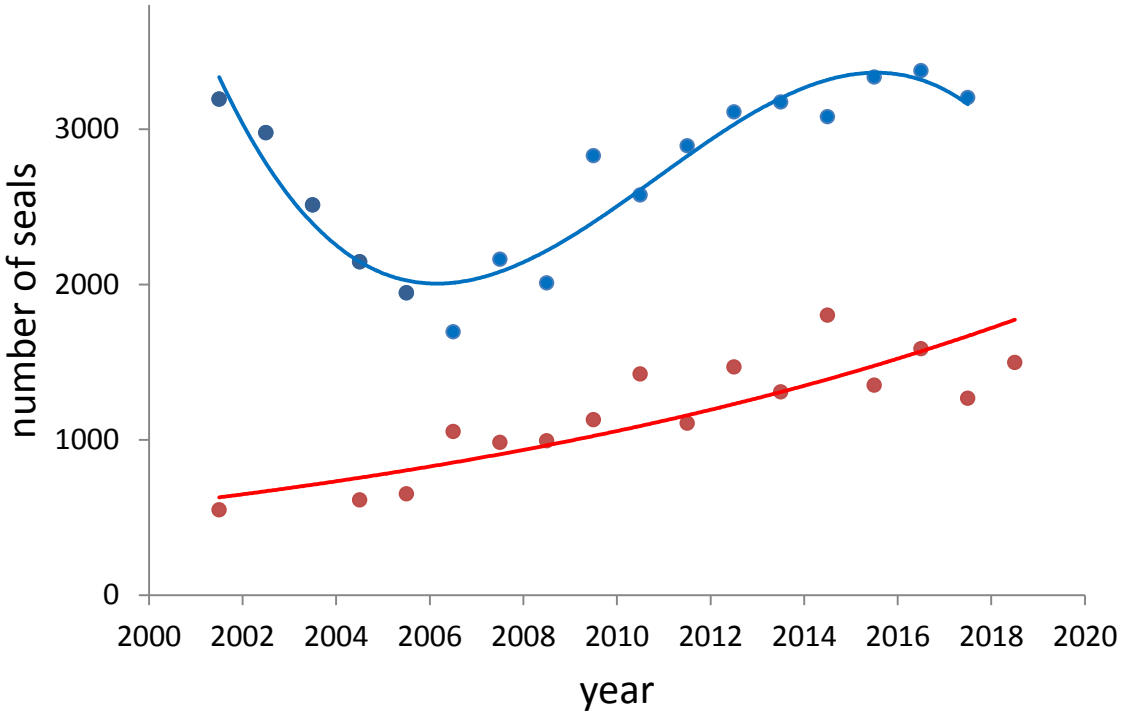

Figure 9. *Maximum counts of pups in The Wash between 2001 and 2018 alongside the annual moult count over the same period.*

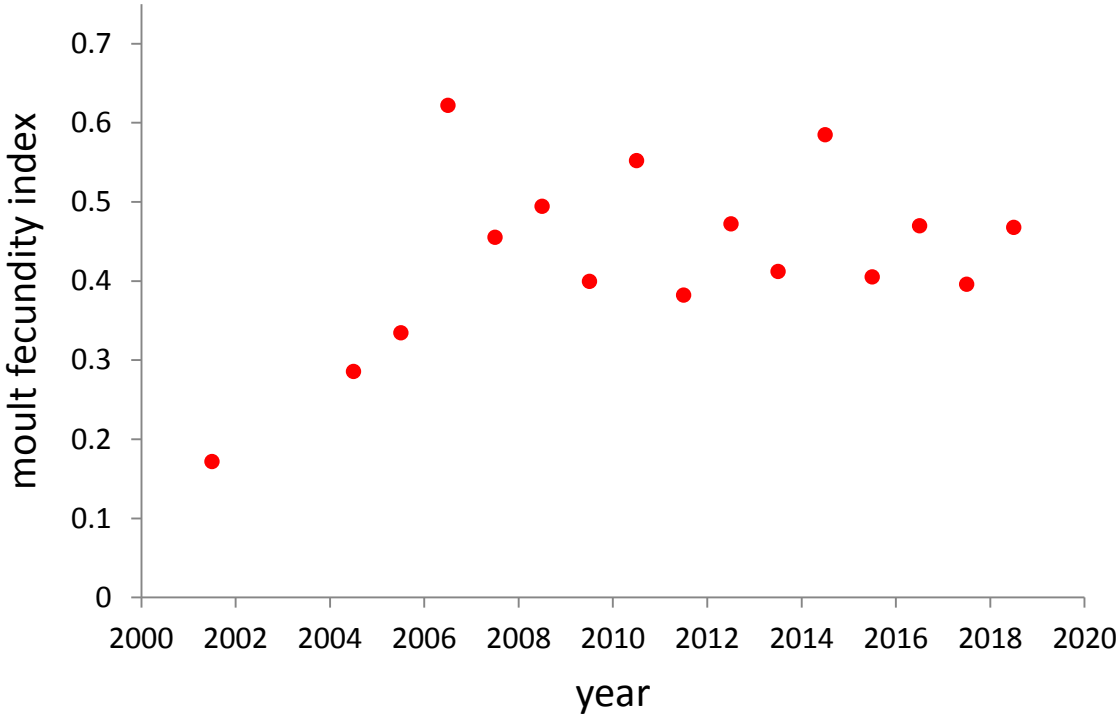

Figure 10. *An index of fecundity, derived as the peak pup count (an index of productivity) divided by the moult count (an index of population size) increased between 2001 and around 2007 after which it appears stable.*