THE PLANNING ACT 2008

THE INFRASTRUCTURE PLANNING (EXAMINATION PROCEDURE) RULES

2010

East Anglia TWO Offshore Wind Farm

Appendix A25 to the Natural England Deadline 13 Submission

Final Ornithological Monitoring Report for London Array Offshore Windfarm 2021

For:

The construction and operation of East Anglia TWO Offshore Wind Farm, a 900MW wind farm which could consist of up to 75 turbines, generators and associated infrastructure, located 37km from Lowestoft and 32km from Southwold.

Planning Inspectorate Reference: EN010078

5th July 2021

Final Ornithological Monitoring Report for London Array Offshore Windfarm 2021

This document is applicable to both the East Anglia ONE North (EA1N) and East Anglia TWO (EA2) applications, and therefore is endorsed with the yellow and blue icon used to identify materially identical documentation in accordance with the Examining Authority's (ExA) procedural decisions on document management of 23rd December 2019. Whilst for completeness of the record this document has been submitted to both Examinations, if it is read for one project submission there is no need to read it again for the other project.

Introduction

Natural England is submitting the Final Ornithological Monitoring Report for London Array Offshore Windfarm 2021 which the MMO formally consulted Natural England on early this year. We consider this will assist the Examining Authority and interested parties as this report is referred to from Natural England's comments at Deadline 11 in Appendix A23 [REP11-122] and at Deadline 13 within Appendix A24, Section 7.

London Array

Final Ornithological Monitoring Report for London Array Offshore Wind Farm – 2021

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Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
1.0	02.11.17	1-3	All	‘Front End’: Creation	BG / LJ
1.1	15.11.17	1-3	All	‘Front End’: Internal review	RB
1.2	15.11.17	1-3	All	‘Front End’: Revision internal review	BG
1.2	17.11.17	1-4	All	‘Front End’: Ørsted & NIRAS review	TN / KL
1.0	21.11.17	4, 7	All	Barrier Effect: Creation	BG / LJ
1.0	23.11.17	5, 7	All	Collision Risk: Creation	BG / LJ
1.1	24.11.17	4, 7	All	Barrier Effect: Internal Review	MR
1.1	24.11.17	5, 7	All	Collision Risk: Internal Review	RB
1.3	29.11.17	1-4	All	‘Front End’: Revision external review	RB
1.2	05.12.17	4, 7	All	Barrier Effect: Revision internal review:	MR
1.2	06.12.17	4, 7	All	Barrier Effect: Ørsted & NIRAS review	TN / KL
1.0	06.12.17	6, 7	All	Displacement: Creation	BG / LSH / LJ
1.1	06.12.17	6, 7	All	Displacement: Internal Review	RB / SM
1.2	07.12.17	5, 7	All	Collision Risk: Revision internal review	RB
1.3	07.12.17	5,7	All	Barrier Effect: Revision external review	MR
1.2	07.12.17	6, 7	All	Displacement: Revision internal review	RB / SM
1.2	14.12.17	6, 7	All	Displacement: Ørsted & NIRAS review	TN / KL
1.3	04.01.18	6, 7	All	Displacement: Revision external review	RB / SM
1.4	04.01.18	All	All	Compilation of sections: ‘Front End’, Barrier Effect, Collision Risk, Displacement	RB / SM
1.5	12.01.18	All	All	Internal review of compiled report	MR
1.6	05.02.18	All	All	Ørsted (KL) & NIRAS (TN) review II	RB
2.0	03.10.19	All	All	Updated following MMO & Natural England Response 1	SM

3.0	28.02.20	All	All	Updated following Natural England Response 2	TC
4.0	20.01.21	All	All	Updated following Natural England Response 3	LJ

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1. Executive Summary

- This report provides a summary of the results of surveys undertaken from 2009 until 2016, evaluating them against the requirements of the Marine Licence and its stated objectives in order to determine whether these requirements have been discharged.
- A process, informed by the conclusions of the Environmental Statement (ES) and consultation with the Marine Management Organisation (MMO), Natural England and the Royal Society for the Protection of Birds (RSPB; organised through the Ornithological Review Panel [ORP]), determined the key species in relation to each monitoring objective. This report primarily presents analysis and conclusions with respect to the following effects and key species:
    - Barrier effects on divers;
    - Collision risk in relation to divers, gannet, large gulls, and small gulls; and
    - Displacement of divers and auks.
- Since 2009 APEM, on behalf of London Array Ltd., has conducted digital aerial surveys over the London Array Offshore Wind Farm (LAW) and associated control zones over the winter months November to February.
- The monitoring period began in November 2010 and concluded in February 2016. Zone 1 (which contained the LAW) and Zone 2 (surveyed as the 'reference' site), were consistently surveyed from 2010 until 2016.
- The period 2010 until 2016 was classified as the monitoring period with three phases: pre-construction (2010 to 2011), during construction (2011 to 2013), and post-construction (2013 to 2016). Annual monitoring reports were produced for the programme of surveys conducted each winter across this period.
- The survey months were selected to coincide with the key season for the occurrence of non-breeding red-throated divers, as agreed as part of the ORP process.
- The most abundant species group recorded was divers (peak density: 15.86 birds km^{-2} recorded for red-throated divers) and the second most abundant was auks (peak density: 5.58 birds km^{-2} recorded for guillemot / razorbills).
- Non-parametric analysis was undertaken for gannets, small gulls and large gulls to investigate if there was any significant difference in densities between the development phases for Zone 1 and Zone 2. A significant difference was observed for common gull (P=0.01) in Zone 1 and herring gull in Zone 2 (P=0.01).
- Analysis was not undertaken for species recorded sporadically (scaup, common scoter, unidentified seaduck species, fulmar, shearwater, grebes, waders and skuas) during the monitoring period (2010 to 2016) as too few individuals were recorded to provide a meaningful result.

1.1 Assessment of Barrier Effect Summary

- To assess barrier effects, the relative bearing of each diver to the closest turbine was estimated. Directions were subdivided in to four quadrants: towards, away, and two for flying parallel in relation to the nearest turbine based on the relative angle.
- Two approaches were used to test the relative direction of flying divers in relation to the nearest turbine of the LAW. The null hypothesis that divers were likely to fly in all directions was tested using first a chi-squared (χ^2) test and second a randomisation approach.
- The first analysis found no significant difference in the proportion of divers flying towards the nearest turbine of the LAW between two regions: the LAW to 4 km region and greater than 4 km region (P >0.05). However, the number of flying divers recorded was low, especially in the buffer regions nearest to the LAW.

- To further investigate, additional analysis of flight directions was undertaken based on data bootstrapping. The results of this analysis showed that in the 2 to 4 km buffer region, significantly fewer divers than expected by chance were recorded flying toward the wind farm ($P < 0.05$). For the remaining buffer regions, LAW to 2 km and greater than 4 km, no significant difference was found between the number of divers flying towards the OWF and in other directions
- No flying divers within the footprint and a trend for increasing densities of flying divers away from the LAW post-construction suggest avoidance that could be in part brought about by a possible barrier effect. The evidence that divers avoided flying towards the LAW when between 2 km and 4 km of it provides stronger evidence of a possible barrier effect created by the LAW.
- This analysis was specifically conducted in relation to individual flight direction relative to the nearest turbine, rather than in relation to areas of suitable habitat (e.g. within the Outer Thames Estuary Special Protection Area [OTE SPA]). The area covered by the OTE SPA consists of large areas of favourable habitat for divers and any effect on energy expenditure created by a barrier would be expected to be negligible as rather than flying around any obstruction the divers may be able to utilise other feeding or roosting areas in other directions.

1.2 Assessment of Collision Risk Summary

- The density of flying individuals within the LAW was calculated for each species for each survey month based on the number of individuals in flight and the area surveyed. The peak density estimates per development phase of each key species were identified and qualitatively compared between pre-construction and post-construction.
- The expected number of collisions in the LAW was extrapolated from the estimated number of collisions in the ES. Assuming that the flight behaviour of each species did not change between the pre- and post-construction phases, and that comparable survey data have been gathered for the two phases the change in the estimated number of collisions for each species in the LAW from that predicted in the ES would be directly proportional to (1) the change in the species' densities used for the ES and those recorded post-construction, and (2) the ratio of the total rotor swept zones used in the built wind farm to that estimated in the ES. If these assumptions are correct the following should be exact.
- Red-throated divers were not recorded in flight during the post-construction phase of the LAW and therefore the species is not expected to be at collision risk from the turbines. For gannet, lesser black-backed, herring gull, and great black-backed gull the estimated number of collisions is lower than that predicted in the ES primarily due to the reduced number of turbines installed at LAW compared to the number used in the ES predictions. The lower flying bird densities measured in the post-construction surveys compared to that included in the ES predictions also contributes to lower collisions estimates for all but great black-backed gull. These results do not support the need for further collision monitoring.

1.3 Assessment of Displacement Summary

- APEM Ltd was commissioned by Natural England in 2016 with permission from London Array Ltd to undertake spatial modelling of diver and auk density based on relevant environmental variables following the first year of post-construction surveys.

- The purpose of the modelling was to identify any potential displacement impacts and to set up a suitable model framework for any subsequent analysis of the data collected at the LAW.
- Using the same spatial modelling approach but including the final two years of post-construction surveys, the Centre for Research into Ecological and Environmental Modelling (CREEM) repeated the assessment of displacement using the MRSea package in the R statistical program. The modelling outputs were summarised and presented graphically according to distance from the LAW.
- The density profile of divers increased gradually throughout the buffer regions with a peak at 9 km pre-construction. Year-to-year fluctuations in diver numbers and distribution should be an important consideration when interpreting the results. The displacement distance estimated for divers was up to approximately 12 km based on changes in the modelled absolute densities of divers between pre- and post-construction survey periods..
- Complete displacement was not detected at any distance, but the area of influence on diver densities was greater than what was originally predicted in the ES. This was primarily due to the limited evidence for potential effect distances available in the literature at the time the ES was issued
- The modelling showed that an estimated 1,111 divers (approximately 6% of the population which is approximately twice the percentage assumed in the ES) have been displaced from an area within the OTE SPA centred around the LAW.
- A decreasing proportion of auks were estimated to be displaced up to approximately 5 km from the LAW but, as for divers, complete displacement was not detected at any distance.
- The modelling showed that an estimated 536 auks were displaced from an area within the OTE SPA centred around the LAW, with an area of influence of up to approximately 5 km.
- The areas surveyed, Zone 1 and Zone 2, formed an irregular buffer around the LAW. This means only the smaller buffer regions were completely surveyed and larger buffer distances would have been incompletely surveyed. It is not possible to state with any certainty what the displacement effects would be for the surrounding areas that were not surveyed.

2. Introduction

2.1 Background

London Array Ltd commissioned APEM Ltd (APEM) to undertake the analysis of the aerial survey data that APEM has acquired to demonstrate that the monitoring requirements of the Marine Licence, including the achievement of the objectives set out in its Annex 2, have been fully discharged following completion of the programme of ornithological monitoring for the London Array Windfarm (LAW).[1]

Since 2009 APEM, on behalf of London Array Ltd. has conducted digital aerial surveys over the LAW and associated control zones over the winter months November to February. These survey months were selected to coincide with the key season for the occurrence of non-breeding red-throated divers agreed as part of the Ornithological Review Panel[2] (ORP) process.

Previous analysis has provided information on the abundance and distribution of divers, and other species recorded, within Zone 1 and associated control zones, with that information summarised within survey reports (APEM, 2010; 2011a; 2012; 2013a; 2014; 2015a; 2017). In addition to these annual reports, an additional analysis report was provided as an addendum to the first year of post-construction aerial surveys (APEM, 2015b). The scope and analysis of that report was agreed with Natural England and the RSPB as part of the ORP process. The primary objective of that report was to provide additional information regarding the density profile of divers (predominantly, but not exclusively red-throated divers) pre-, during, and the first-year post-construction of the LAW.

There are now sufficient data available (following the completion of the full three years of post-construction surveys) to conduct more detailed analysis to assess the magnitude of any reduction in diver density with increasing distance from the LAW. Part of the analysis presented herein follows on from analysis carried out by APEM on behalf of NE to assess the density of divers and auks in relation to the LAW following the first year of post-construction surveys (APEM, 2016). That analysis has been updated following completion of the further two years of post-construction surveys.

The purpose of this report is to provide a complete summary of the methods and results of pre-, during- and post-construction monitoring surveys and to evaluate those results against the objectives in the Marine Licence in order to discharge the requirements. Specifically, this report presents analysis and conclusions with respect to:

- Barrier effects;
- Collision risk; and
- Displacement effects.

[1] Predominantly red-throated diver (*Gavia stellata*) but also including black-throated diver (*G. arctica*) and great northern diver (*G. immer*).
[2] The ORP was a formal process established to oversee the monitoring and decisions about the development of Phase 2 (the plan for which was subsequently terminated in 2014 due to potential impact on the red-throated diver population in the vicinity combined with technical challenges).

2.2 London Array Offshore Wind Farm

The London Array Windfarm (LAW) is a 630 MW offshore wind farm located in the outer part of the Thames Estuary. The wind farm comprises 175 3.6 MW wind turbine generators (WTG) and occupies approximately 100 km^2 of the Outer Thames Estuary Special Protection Area (OTE SPA). The offshore components of the project were constructed and installed between March 2011 and December 2012.

Located off the coast of Kent, Essex, Suffolk and Norfolk is an area of sea that supports an internationally important wintering population of red-throated diver (Stroud *et al*., 2001; Musgrove *et al*., 2011). Protection for this population has been given by the classification of an area as the OTE SPA in 2010 (Figure 1). The OTE SPA has been identified by Natural England using data collected from aerial surveys during the period from January 1989 to winters of 2005 / 06 and 2006 / 07 and analysed by the Joint Nature Conservation Committee (JNCC) Seabirds and Cetaceans Team. These data show that the OTE SPA regularly supports numbers of wintering red-throated diver that are of European importance, exceeding 1% of the Great Britain (GB) population of 17,000 birds. The red-throated diver is listed under Annex I of the European Union (EU) Birds Directive (79/409/EEC) as being a rare or vulnerable species, meaning that EU member states are obligated to identify and designate key areas of habitat used by the species as SPAs. Sites supporting 1% or more of the GB population of an Annex I species are automatically considered for SPA designation (Stroud *et al*., 2001). Visual aerial survey estimates for the OTE SPA place the wintering total at 6,466 individuals or 38% of the GB estimate (O'Brien *et al*., 2008). The SPA covers over 379,268 ha of offshore habitat between Kent and Norfolk. Over the wider Greater Thames area, estimates of 8,130 red-throated divers have been made, representing 47% of the national estimate (O'Brien *et al*., 2008). In the winter of 2012 / 13 the peak estimate of the population in the SPA was 14,161 (Goodship *et al*., 2015). A recent survey of the OTE SPA estimated the population size to be 22,280 individuals (Irwin *et al.,*2019).

The potential impact of LAW on the red-throated diver interest feature of the OTE SPA was a key consideration in the determination of the consent for the wind farm. As a result, a requirement for ornithological monitoring was included as part of the consented development's Marine Licence (L/2011/00152) and Environmental Monitoring Plan (EMP).

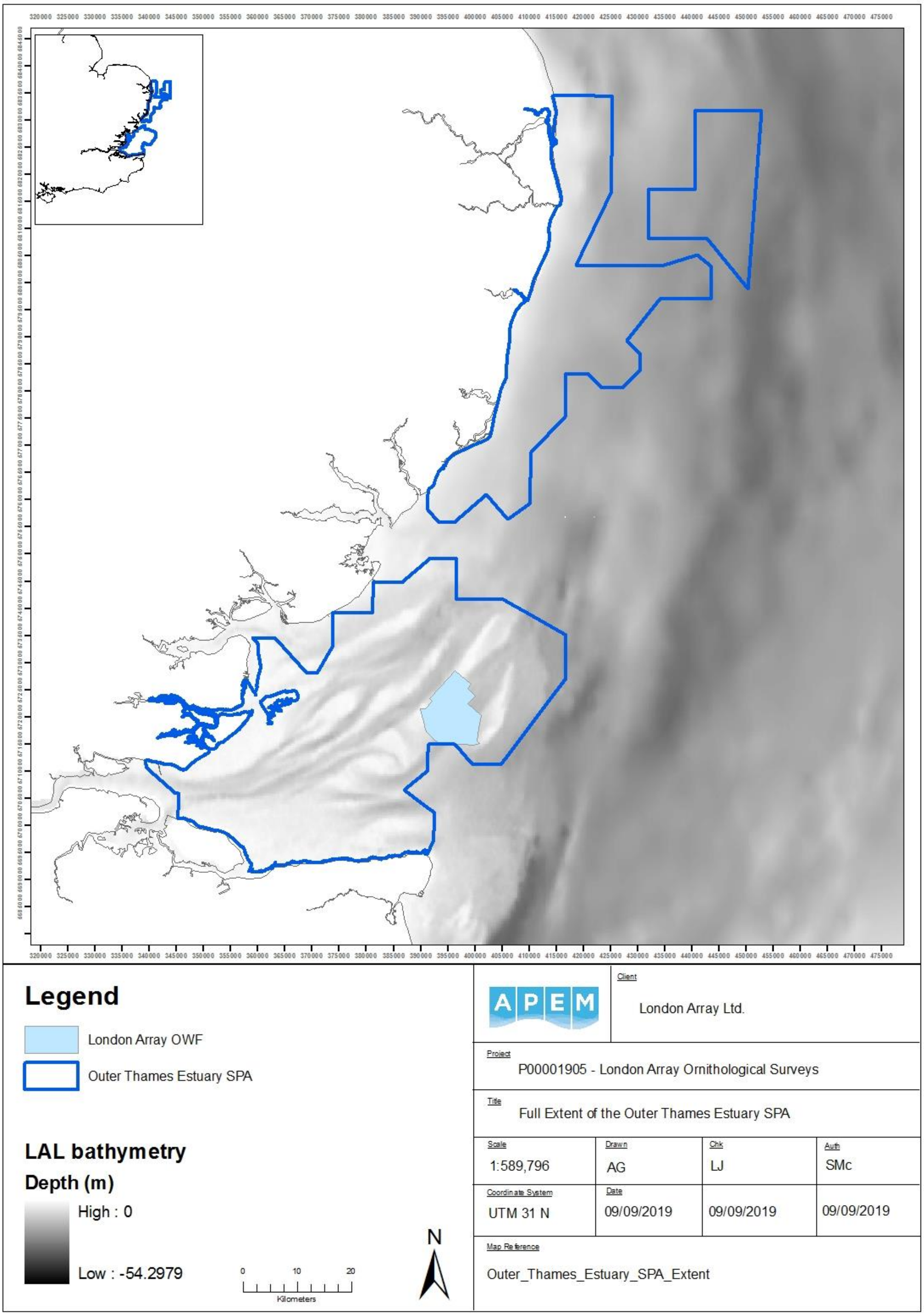

Figure 1 Full extent of the Outer Thames Estuary Special Protection Area.

2.2.1 Monitoring requirements

Annex 2 of Marine Licence (L/2011/00152/34) indicates that the objectives of the ornithological monitoring are to:

1. *Determine whether there is change in bird use and passage, measured by species (with particular reference to red-throated diver), abundance and behaviour, of the wind farm site, 1 km and 2-4 km buffer zones and the reference site.*

2. *Determine whether there is a barrier effect to movement of birds through the wind farm site and the 1 km and 2-4 km buffer zones.*

3. *Continue to determine the distribution of wildfowl and divers in the Greater Thames estuary, covering the London Array windfarm site, 1 km and 2-4 km buffer zones and the reference site.*

4. *If objectives 1 or 2 reveal significant change of use of the wind farm site and 1 km and 2-4 km buffer zones by populations of conservation concern, at heights that could incur collision, a programme of collision monitoring will be implemented.*

As part of the monitoring requirements, annual reports were submitted following the completion of each year of surveys: pre-construction: 2010 / 11, during construction: 2011 / 12, 2012 / 13, and post-construction: 2013 / 14, 2014 / 15, and 2015 16 (APEM, 2011a; 2012; 2013a; 2014; 2015a; 2017). An addendum to the first year of post-construction surveys was provided to summarise the density profile of divers, predominantly red-throated divers, in relation to varying buffer distances from the LAW. This was an initial, interim analysis to determine whether any displacement effects were identifiable (APEM, 2015b). Further to this analysis APEM undertook a more complex, detailed analysis on behalf of NE to determine if any displacement effects were identifiable for divers and auks (APEM, 2016).

As part of demonstrating that the ornithology monitoring requirements of the Marine Licence (including the achievement of the objectives in Annex 2) have been fully discharged, this Final Monitoring Report (FMR) will test the key predictions made in the Environmental Statement (ES) (London Array Limited, 2005) concerning key ornithological interests of relevance to the consented scheme.

The approach to the analyses was constrained by the monitoring survey design and available data. As agreed through the ORP process, monitoring surveys were focused on obtaining data on red-throated diver distribution and abundance. Consequently, the timing of the surveys focused on the periods when divers are present in peak numbers in the OTE SPA(i.e. winter: November to February) and the methods were focused on detecting changes related to displacement effects. These characteristics imposed some constraints on the analyses that were undertaken on species other than divers, particularly those that are present during non-winter months, and for potential impacts such as barrier effects and collision risk.

The scope and approach to analysis in this FMR is to provide a final update to the previous complex analysis undertaken for the first year of post-construction surveys (APEM, 2016) by including the further two years of post-construction surveys to determine whether there are any identifiable effects of displacement to divers and auks (the two most numerous species / groups) due to the construction and operation of the LAW. In general, other species / groups such as gulls, terns, and cormorants have been shown to not be displaced, and aggregate at some OWFs or show little to no change in distribution by the construction activities and presence of an OWF (Furness *et al.,* 2013). In addition, in order to discharge the Marine Licence requirements, where possible analyses were completed for barrier effect and collision risk using the data available, noting the constraints on these analyses resulting from the agreed decisions made that the monitoring program should focus on measuring any potential effect of displacement of divers and the consequent seasonality of surveys.

2.3 Potential wind farm effects and the identification of key species

2.3.1 Overview

The evaluation and assessment of the LAW, as set out in the ES (London Array Limited, 2005), identified three types of effect, detailed below, as those with the greatest potential to affect marine birds. Based on the evidence from surveys of bird populations in the area of the proposed wind farm, the ES identified the 'key species' to be assessed against each type of potential effect. Set out below is a summary of that identification of key species.

2.3.2 Barrier effect

Barrier effects on divers and other seabirds are generally poorly understood, especially outside of the migration period. Furthermore, it can be difficult to separate the possible consequences of a barrier effect on bird distributions from what could be the more frequently described displacement of birds (Drewitt & Langston 2006). For the purposes of this assessment it has thus had to be assumed that study species could potentially be affected by LAW acting as a barrier to daily movements (London Array Limited, 2005). A likely significant effect of the LAW acting as a barrier to divers was predicted in the ES (London Array Limited, 2005), stating this would result in either reduced utilisation of an ecological resource (through birds no longer being able to reach it through the barrier) or significantly increased energy expenditure by the birds in flying around the barrier. The assessment in the ES concluded that given the large extent of the proposed London Array site and the important numbers of divers present in the area, there is the potential for both of these points to give rise to a potentially significant effect, adding further to the likely significant effect on these species (London Array Limited, 2005).

Annex 2 of the Marine Licence identifies barrier effect as an issue to be addressed in the monitoring programme but does not highlight any key species or species groups:

- *Determine whether there is a barrier effect to movement of birds through the wind farm site and the 1 km and 2-4 km buffer zones.*

Based on the evaluation and assessment in the ES, the key identified species of concern for barrier effect as a result of the LAW are:

- Red throated diver / black-throated diver

2.3.3 Collision risk

Bird populations could be impacted through increased mortality as a result of bird collisions with wind turbines. Collision risk modelling was undertaken to determine whether there may be any significant effect of collision for the key species at the LAW. Table 1 summarises the overall collision risks predicted in the ES that would be likely to result from the LAW for the key species of concern. It is important to note however that on the basis of the low numbers of these species observed during the baseline surveys and the lack of any features that would be likely to concentrate large numbers of birds through the wind farm site, it was concluded in the ES that the magnitude of any effects on these birds would not be likely to be sufficient to result in any likely significant effect (London Array Limited, 2005).

Table 1 Summary of collision risks from the London Array Offshore Wind Farm (London Array Limited, 2005).

Species	Sensitivity of local population at risk	Magnitude of effect	Significance	Significant impact?
Red-throated diver	Very high	Low/medium	Medium/very high	Yes*
Black-throated diver	Very high	Low/medium	Medium/very high	Yes*
Herring gull	Medium	Medium	Medium	Possible
Lesser black-backed gull	Medium	Medium	Medium	Possible
Great black-backed gull	Medium	Medium	Medium	Possible
Gannet	Medium	Medium	Medium	Possible
Other seabirds	Medium	Medium	Low/very low	N/A**

*The impact on divers is considered significant when assessing collision risk in isolation. However, when considered in connection with displacement it is expected that high levels of displacement would indicate avoidance rates of 99.9% or higher at which point the magnitude of collision impacts on diver becomes negligible, resulting in a low significance of the impact.
** Detailed collision risk modelling was not undertaken. It was however possible on the basis of the low numbers observed during the baseline surveys and the lack of any features that would be likely to concentrate large numbers of birds through the wind farm site, to conclude that the magnitude of any effects on these birds would not be likely to be sufficient to result in any likely significant effect.

Annex 2 of the Marine Licence identifies collision risk as a potential issue to be included in the monitoring programme but does not name any key species or species groups, referring to 'populations of conservation concern' instead:

- *If objectives 1 or 2 reveal significant change of use of the wind farm site and 1 km and 2-4 km buffer zones by populations of conservation concern, at heights that could incur collision, a programme of collision monitoring will be implemented.*

Based on the evaluation and assessment in the ES, the key identified species of concern for collision mortality impact are:

- Red-throated / black-throated diver
- Large gull species (herring gull, lesser black-backed gull, great black-backed gull)
- Small gulls
- Gannet

2.3.4 Displacement effects

The wind farm could potentially affect the local bird populations by disturbing them and displacing them from an area around the turbines. Such disturbing activities are likely to be greatest during construction but may continue through the operational phase as well (London Array Limited, 2005).

Annex 2 of the Marine Licence highlights two key species groups to be considered when assessing displacement impacts of the LAW:

- *Determine whether there is change in bird use and passage, measured by species (with particular reference to Red-Throated Diver), abundance and behaviour, of the windfarm site, 1 km and 2-4 km buffer zones and the reference site.*
- *Continue to determine the distribution of wildfowl and divers in the Greater Thames estuary, covering the London Array windfarm site, 1 km and 2-4 km buffer zones and the reference site.*

NE requested that auk displacement also be assessed as these birds were also present in numbers sufficient to warrant such an analysis (APEM, 2016).

Based on the evaluation and assessment in the ES and the additional post-consent studies, the key identified species of concern for displacement are:

- Divers
- Wildfowl
- Auks

Table 2 summarises the predictions of the ES in relation to displacement for the key species of concern. Spatial modelling was limited to the two most numerous staging species groups i.e. divers and auks.

Table 2 Summary of displacement impact assessment from the London Array Offshore Wind Farm (London Array Limited, 2005).

Species	Peak no. in WF + 1 km	Sensitivity of local population	Magnitude of effect	Significance	Significant impact?
Red-throated diver	6,700	Very high	Medium/high	Very high	Yes*
Black-throated diver	50	Very high	Medium/high	Very high	Yes*
Common scoter	73	Medium	Low	Low	No**
Guillemot	2,400	Medium	Low	Low	No**
Razorbill	250	Medium	Low	Low	No**

* While birds may be displaced this does not imply a population impact of similar magnitude as the likelihood is that these birds will not be limited by the availability of winter resources. This would reduce the potential for a significant impact of the London Array wind farm through habitat loss caused by displacement.

** The ES, published in 2005, noted that information based on wind farm disturbance to birds has been the subject of several studies on land, and that the maximum distance to which birds have been displaced is 800 m, though in many cases no effect was found (SGS Environment 1996; Gill *et al.,* 1996; Percival, 2000).

3. Survey Methods

3.1 Overview

The proposed site of the LAW (for the baseline EIA) and the site pre-, during-, and post-construction (for the monitoring period) has been surveyed by three methods, with decisions taken on changing the method used being driven by advances in survey techniques. The three methods used have been:

- Boat-based observers (undertaken by RPS; the method was used to collect baseline data to inform the EIA);
- Aerial visual (undertaken by aircraft-based observers from the Wildfowl and Wetlands Trust (WWT) and the National Environmental Research Institute (NERI); the method was used to collect baseline date to inform the EIA); and
- Aerial digital (undertaken by aircraft fitted with cameras operated by APEM; the method was used to collect data post-consent based on the requirements of the Marine Licence monitoring program).

The following section identifies when the surveys of each type took place; the areas surveyed and the design of sampling within those areas; and the analysis of the bird occurrence information obtained. Table 3 provides a summary of this information.

Table 3 Timeline of surveys and events of the London Array Offshore Wind Farm (LAW).

<table>
<tr><th>Nomenclature in FMR</th><th>Survey Type / Event Description</th><th>Date(s)</th></tr>
<tr><td rowspan="4">Baseline EIA</td><td>Pre-consent boat-based surveys</td><td>2002-2004</td></tr>
<tr><td>Pre-consent aerial visual surveys</td><td>2003-2006</td></tr>
<tr><td>Planning consent process</td><td>2005-2007[1]</td></tr>
<tr><td>Offshore works granted consent for the LAW comprising of Phase 1 (630 MW) and Phase 2 (370 MW)</td><td>2006</td></tr>
<tr><td>Pilot Study</td><td>Report to inform method and design of the monitoring period</td><td>2009-2010</td></tr>
<tr><td rowspan="7">Monitoring Period</td><td>Pre-construction aerial digital surveys</td><td>2010-2011</td></tr>
<tr><td rowspan="2">During construction aerial digital surveys</td><td>2011-2012</td></tr>
<tr><td>2012-2013</td></tr>
<tr><td>LAW fully commissioned</td><td>2013</td></tr>
<tr><td rowspan="3">Post-construction aerial digital surveys</td><td>2013-2014[2]</td></tr>
<tr><td>2014-2015</td></tr>
<tr><td>2015-2016</td></tr>
</table>

[1] Planning permission for onshore application was August 2007
[2] Plans for Phase 2 (370 MW) were terminated in 2014

3.2 Survey timings, design, and locations

Information is provided below for all surveys undertaken of the LAW from baseline EIA to post-construction. However, it is important to note that due to differences in the survey methods used, and in the temporal and spatial overlap, it was not possible to incorporate the baseline EIA information in the analysis of barrier effect, collision risk, and displacement in this report. This is because for the results to be comparable a calibration exercise would need to be undertaken to determine if there are any platform effects in the numbers recorded. Žydelis *et al.* (2019) showed that quantitative (count) data from visual and digital aerial surveys may differ significantly, with generally more individuals identified to species level in digital surveys for the majority of taxonomic groups.

3.2.1 Boat-based and aerial visual surveys undertaken to characterise the EIA baseline

Baseline EIA boat-based surveys were conducted between 2002 and 2004, providing baseline data for the impact assessment. Table 4 lists the boat-based survey dates.

Table 4 Information on survey dates for baseline EIA boat-based surveys.

Survey	Date
October 2002	01/10/02
	03/10/02
November 2002	01/11/02
	03/11/02
	30/11/02
December 2002	28/12/02
February 2003	05/02/03
	06/02/03
March 2003	16/03/03
	17/03/03
October 2003	27/10/03
	28/10/03
November 2003	19/11/03
	20/11/03
December 2003	09/12/03
	10/12/03
January 2004	20/01/04
	21/01/04
February 2004	16/02/04
	17/02/04
March 2004	08/03/04
	09/03/04
October 2004	17/10/04
	18/10/04
November 2004	08/11/04
	09/11/04
December 2004	08/12/04
	09/12/04

Baseline EIA aerial visual surveys of the LAW were conducted between 2003 and 2006, providing baseline data for the impact assessment. Table 5 lists the aerial visual survey dates.

Table 5 Information on survey dates for baseline EIA aerial visual surveys.

Survey	Date
January 2003	18/01/03
February 2003	15/02/03
November 2003	27/11/03
December 2003	17/12/03
February 2004	15/02/04
	16/02/04
October 2004	30/10/04
November 2004	25/11/04
December 2004	04/12/04
February 2005	14/01/05
	15/01/05
March 2005	07/03/05
	13/03/05
	15/03/05
November 2005	16/11/05
December 2005	06/12/05
	11/12/05
January 2006	13/01/06
March 2006	02/03/06

Baseline EIA boat-based and aerial visual surveys conducted between 2002 and 2006 followed a line transect method with bird observations recorded in distance bands to allow abundance and density estimates to be calculated (Camphuysen *et al*., 2004). During aerial visual surveys birds were identified to at least group level, enumerated, and their spatial position approximated by comparing the time of recording to the position of the aircraft at the nearest GPS log point. During boat-based surveys birds were frequently identified to species. Figure 2 shows the wind farm area and buffer zone surveyed during the 2002 to 2006 aerial and boat-based surveys.

The aerial visual approach depends on conventional distance sampling (CDS) from aircraft. The aerial CDS approach involves flying transects within the area of interest, with trained observers identifying bird species and estimating abundance across four pre-defined 'distance' bands. These extend laterally from either side of the aircraft so that one observer covers port and one starboard. Distance bands ranged from 44 to 1000 m to the aircraft, and as transects are separated by 2 km approximately 95.6% of the area is assessed. The 4.4% of the area not covered is not visible to the observers as it is underneath the aircraft, from the flight line out to 44 m. CDS uses several parameters including the size of the region, the number of flocks (detections), the effort (length of transect searched), search region half-width (i.e. 1 km) and the expected flock size to form a framework for a detection function model. When fitted to those parameters, the expected flock size in the region is estimated from a regression of probability of detection considering the difficulty of seeing either small flocks or single birds.

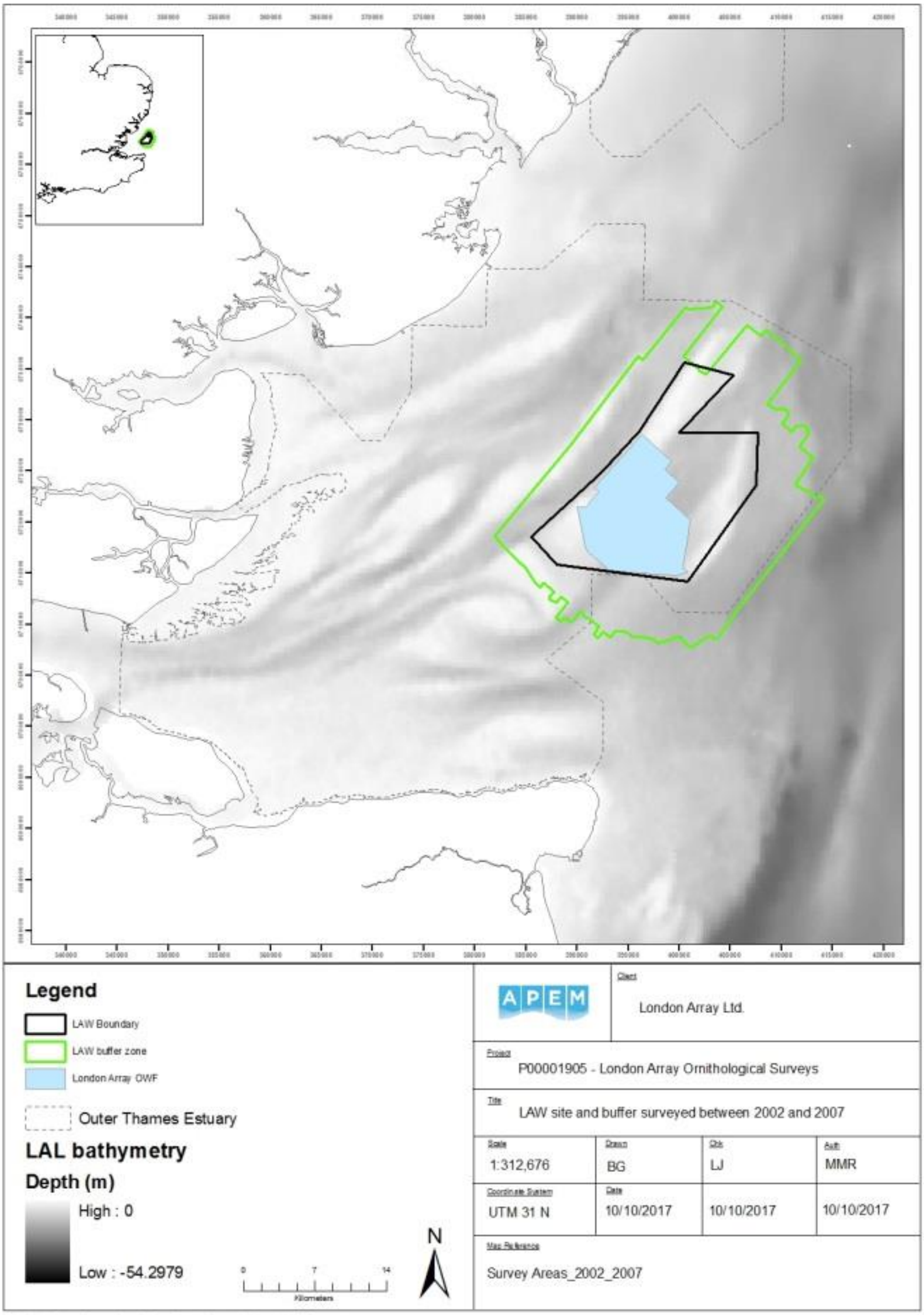

Figure 2 London Array offshore wind farm site (black outline was the planned wind farm extent, blue is the extent of Phase 1 as constructed) and buffer zone surveyed during the aerial and boat-based surveys (green outline) conducted between 2002 and 2007.

3.2.2 Aerial digital monitoring survey timings

During the 2009 / 10 winter pre-construction period, a pilot study was carried out comprising four digital aerial surveys flown in December 2009, January, February and April 2010. The pilot study is described in Section 3.2.2.1.

Pre-, during- and post-construction surveys were conducted during the 2010 / 11 to 2015 / 16 winters. In each winter four monthly surveys were conducted from November to February.

Details of the digital aerial survey timings and zones surveyed (the locations of these zones are described in the next section) for each construction phase are presented in Table 6.

Table 6 Information on survey dates and zones surveyed during pre-, during- and post-construction surveys.

Construction period	Survey	Date	Zones Surveyed						
			1	2	3	4	5	6	7
Pre-Construction (Pilot Study)	December 2009	21/12/2009			✓				
		23/12/2009		✓					
	January 2010	24/01/2010	✓						
		26/01/2010		✓					
		27/01/2010			✓				
	February 2010	10/02/2010		✓					
		12/02/2010	✓						
	April 2010	06/04/2010 – 08/04/2010	✓						
		09/04/2010		✓					
Pre-Construction Baseline Surveys	November 2010	23/11/2010	✓						
		24/11/2010		✓	✓	✓			
		25/11/2010					✓	✓	✓
	December 2010	08/12/2010			✓		✓	✓	✓
		09/12/2010	✓	✓					
	January 2011	10/01/2011	✓		✓				
		11/01/2011							✓
		17/01/2011					✓		
		18/01/2011		✓				✓	
	February 2011	14/02/2011	✓						
		15/02/2011		✓	✓				
		16/02/2011					✓	✓	✓
First Year Construction Surveys	November 2011	02/11/2011 – 03/11/2011		✓					
		03/11/2011			✓				✓
		04/11/2011	✓						

Construction period	Survey	Date	Zones Surveyed						
			1	2	3	4	5	6	7
		10/11/2011						✓	
		17/11/2011					✓		
	December 2011	01/12/2011			✓		✓	✓	✓
		02/12/2011	✓						
		03/12/2011		✓					
	January 2012	13/01/2012					✓	✓	
		16/01/2012		✓					✓
		17/01/2012	✓						
		19/01/2012			✓				
	February 2012	07/02/2012		✓	✓				
		08/02/2012	✓						
		09/02/2012					✓	✓	✓
Second Year Construction Surveys	November 2012	13/11/2012					✓		
		14/11/2012			✓				
		18/11/2012	✓	✓				✓	✓
	December 2012	04/12/2012			✓		✓		✓
		05/12/2012		✓				✓	
		06/12/2012	✓						
	January 2013	02/01/2013		✓			✓		
		03/01/2013						✓	
		04/01/2013			✓				✓
		08/01/2013	✓						
	February 2013	02/02/2013	✓		✓		✓		✓
		03/02/2013		✓				✓	
First Year Post-Construction Surveys	November 2013	09/11/2013		✓					
		10/11/2013	✓						
	December 2013	09/12/2013		✓					
		11/12/2013	✓						
	February 2014	10/01/2014	✓						
		11/01/2014		✓					
		02/02/2014		✓					
		03/02/2014	✓						
Second Year Post-Construction Surveys	November 2014	24/11/2014		✓					
		24/11/2014 – 25/11/2014	✓						
	December 2014	13/12/2014		✓					
		19/12/2014	✓						
	January 2015	02/01/2015	✓						

Construction period	Survey	Date	Zones Surveyed						
			1	2	3	4	5	6	7
		07/01/2015		✓					
	February 2015	02/02/2015		✓					
		03/02/2015	✓						
Third Year Post-Construction Surveys	November 2015	12/11/2015	✓						
		13/11/2015		✓					
	December 2015	02/12/2015 and 04/12/2015		✓					
		03/12/2015	✓						
	January 2016	06/01/2016 and 08/01/2016	✓						
		18/01/2016 – 19/01/2016		✓					
	February 2016	03/02/2016		✓					
		03/02/2016 – 04/02/2016	✓						

3.2.2.1 The pilot study (2009-2010)

A pilot study was undertaken during the 2009 / 10 winter, in consultation with the ORP, to explore and develop a methodology to be delivered in the post-consent monitoring period (APEM, 2010). It was agreed during the ORP discussions that displacement impact on red-throated diver was the key issue to be monitored and this decision informed the choice of technique, survey design, and timing and extent of the subsequent post-consent surveys. The pilot study was carried out to provide confidence in the aerial digital methodology because at that time it was a new approach for monitoring seabirds. Comparisons were made with the aerial visual surveys previously conducted in order to provide confidence in the aerial digital methodology and a suitable survey design was proposed for the pre-, during- and post-construction monitoring of divers.

The initial pilot study aerial digital survey in November 2009 used a grid size of 750 m and images were collected at 3 cm resolution from one of three zones. This survey was undertaken to provide an initial assessment of the coarseness (spacing) of grid required to achieve a pre-defined level of confidence or coefficient of variation (CV) of < 0.16. A doubling or halving of the numbers recorded by two surveys each with a CV of 0.16 or less can be detected with statistical certainty ($P < 0.05$). The pilot study suggested that collecting images using a 750 m grid was likely to generate sufficiently precise mean population estimates of red-throated diver in the outer Thames Estuary region to detect a halving or doubling of populations between surveys. In fact, it was considered that the number of images could be reduced whilst retaining an acceptable level of precision of 0.14 around the mean estimate based on total birds recorded. The agreed reduction in image number led to an increase in grid coarseness from 750 m to 1000 m. This grid spacing was adopted for the remaining pilot study surveys (December 2009 to February 2010). For the April 2010 survey, however, the grid was reduced to 670 m as low numbers of birds were expected in the area at that time of the year.

3.2.2.2 The pre-, during-, and post-construction programme of aerial digital surveys

For the pre-, during- and post-construction surveys a survey design based on a 500 m by 500 m grid of images taken at 3 cm Ground Sampling Resolution (GSD) was chosen. An example of the 500 m grid image nodes captured within Zone 1 can be seen in Figure 3. The total area of images collected in each survey as a proportion of the survey area (the 'coverage') has ranged from approximately 10% to 18% through the period 2010 / 11 to 2015 / 16 due to different camera system arrangements.

3.2.3 Locations surveyed by the pilot study and the pre-, during- and post-construction programme of aerial digital surveys

The survey areas have changed between the pilot study and subsequent surveys. The 2009 / 10 'pilot study' boundaries consisted of a 'London Array OWF boundary' and 'Control Zone' (Figure 4). In 2010 / 11, the survey areas differed to those surveyed in the 'pilot study' and included seven Zones (Figure 5). Aerial surveys of Zone 4 ceased after November 2010 due to an overlapping danger zone making flying dangerous. Thereafter Zones 1 to 3 and Zone 5 to 7 inclusive were surveyed until February 2013 (Figure 5). Aerial surveys of Zones 3, 5, 6 and 7 ceased after February 2013. From November 2013 until February 2016 (post-construction) it was decided to only survey Zones 1 and 2 (Figure 6). Zone 1 contains the LAW, and Zone 2 is considered the reference site. The decision was made to only survey Zones 1 and 2 post-construction to create a spatially consistent data set comprising of the two zones that had been surveyed consistently from the first pre-construction aerial digital surveys delivered during the 2009 / 10 winter to the last post-construction surveys flown during the 2015 / 16 winter.

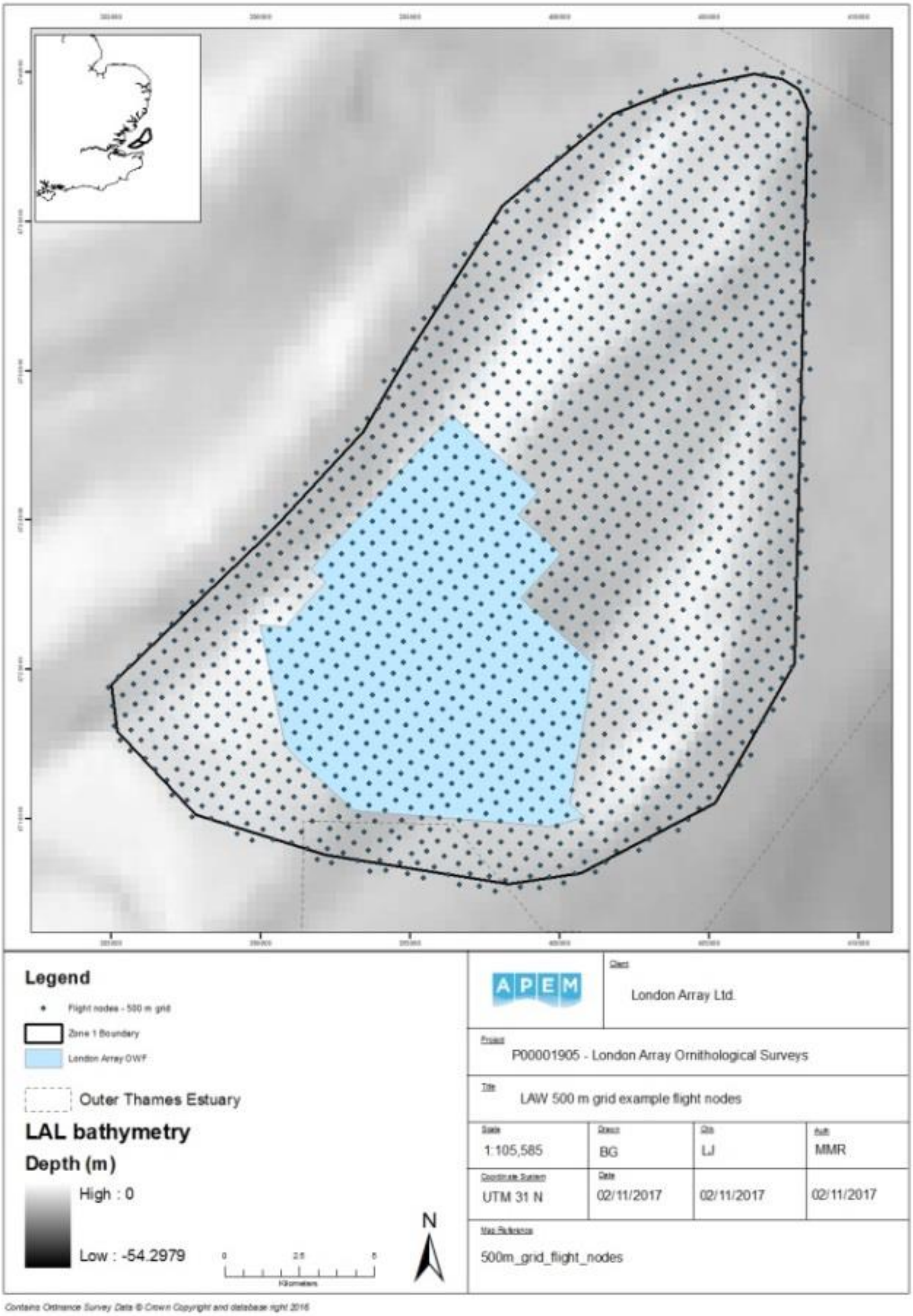

Figure 3 Example of 500 m grid survey image nodes in Zone 1 used since the 2010 / 11 surveys.

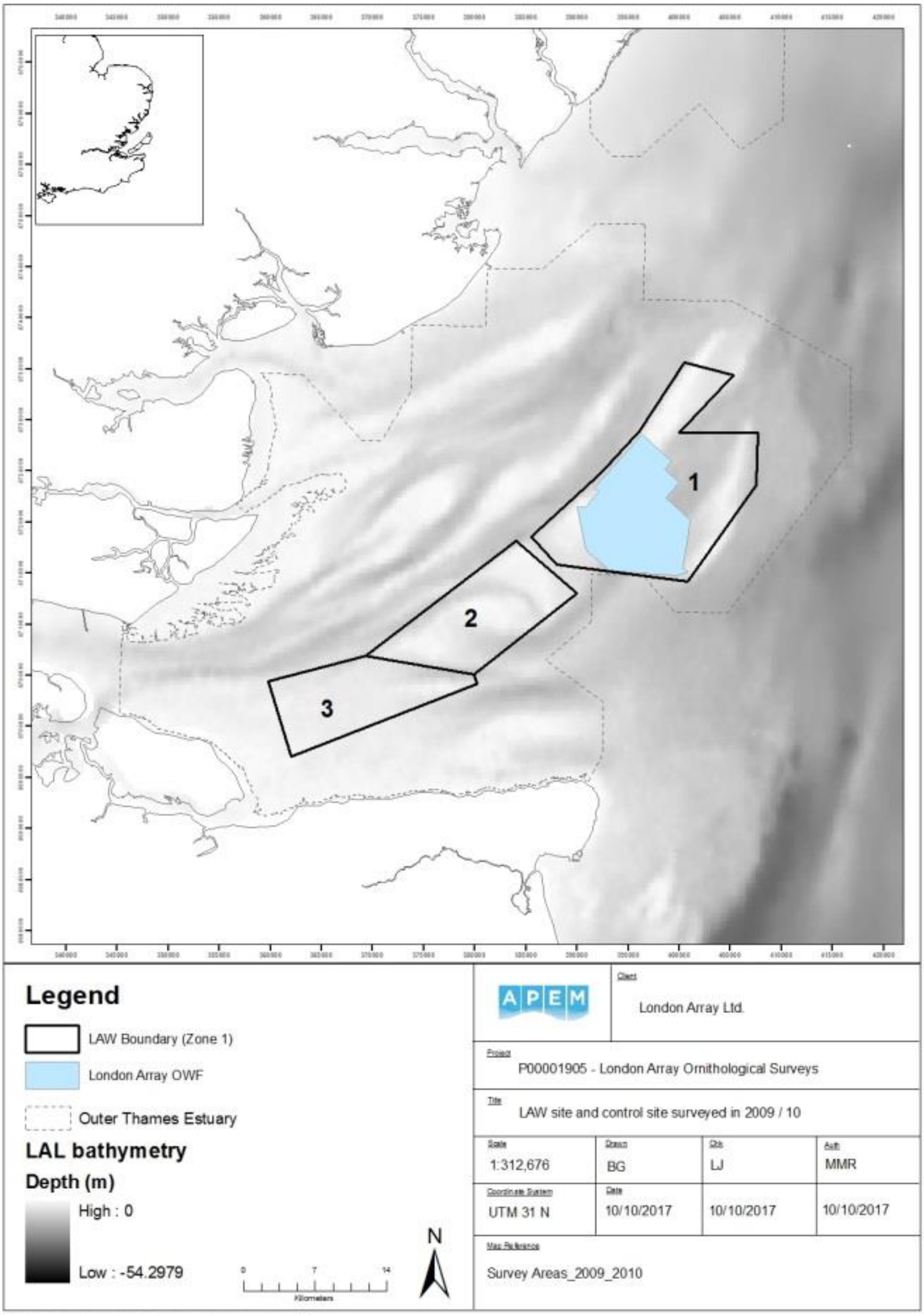

Figure 4 **London Array offshore wind farm site (Zone 1) and control zone (Zones 2 and 3) surveyed during the 'pilot study' conducted in 2009 / 10.**

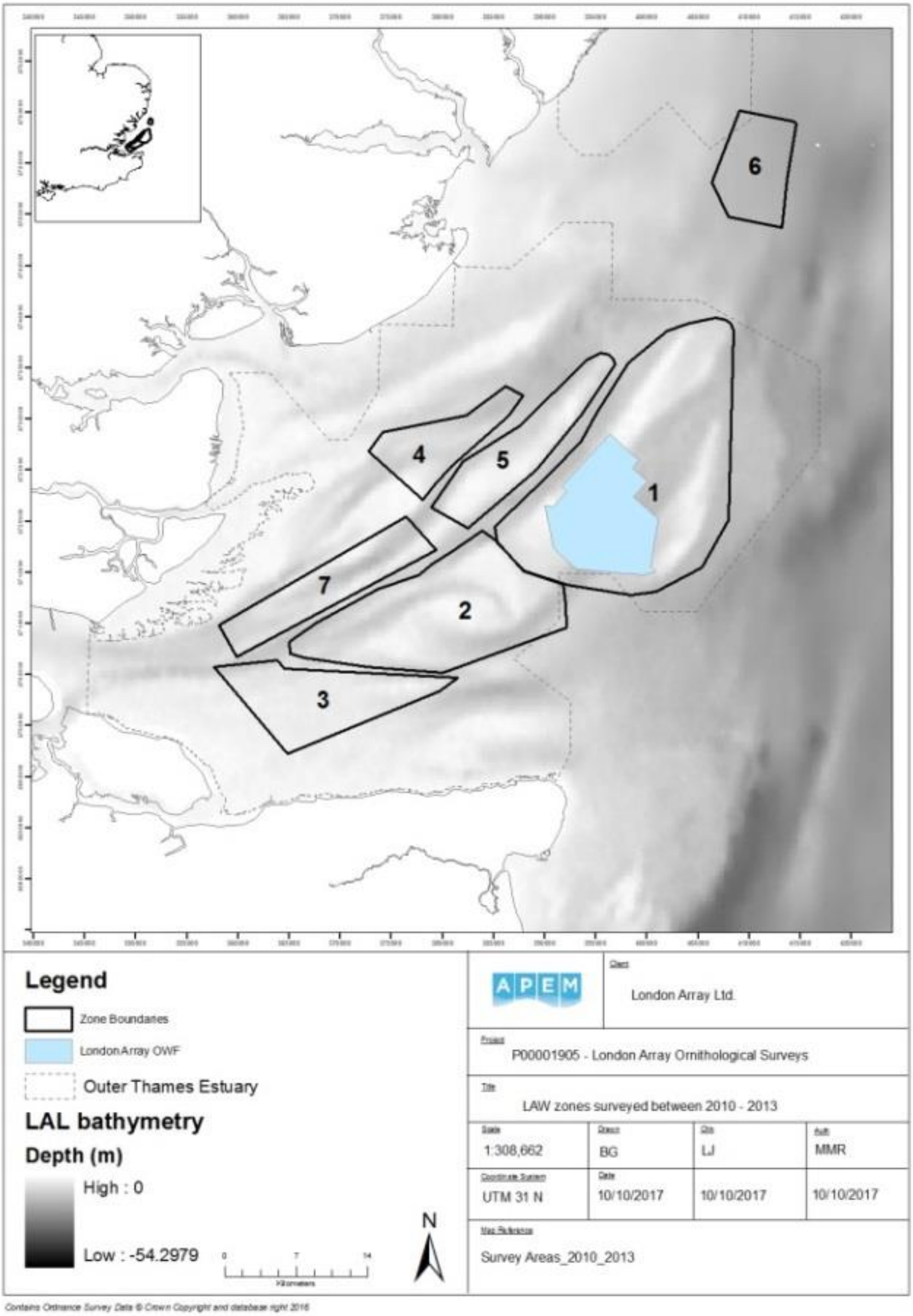

Figure 5 **Zones 1-7 surveyed during the period November 2010 – February 2013. Zone 4 was only flown in November 2010 due to overlapping danger areas (D138, 138A and 138B).**

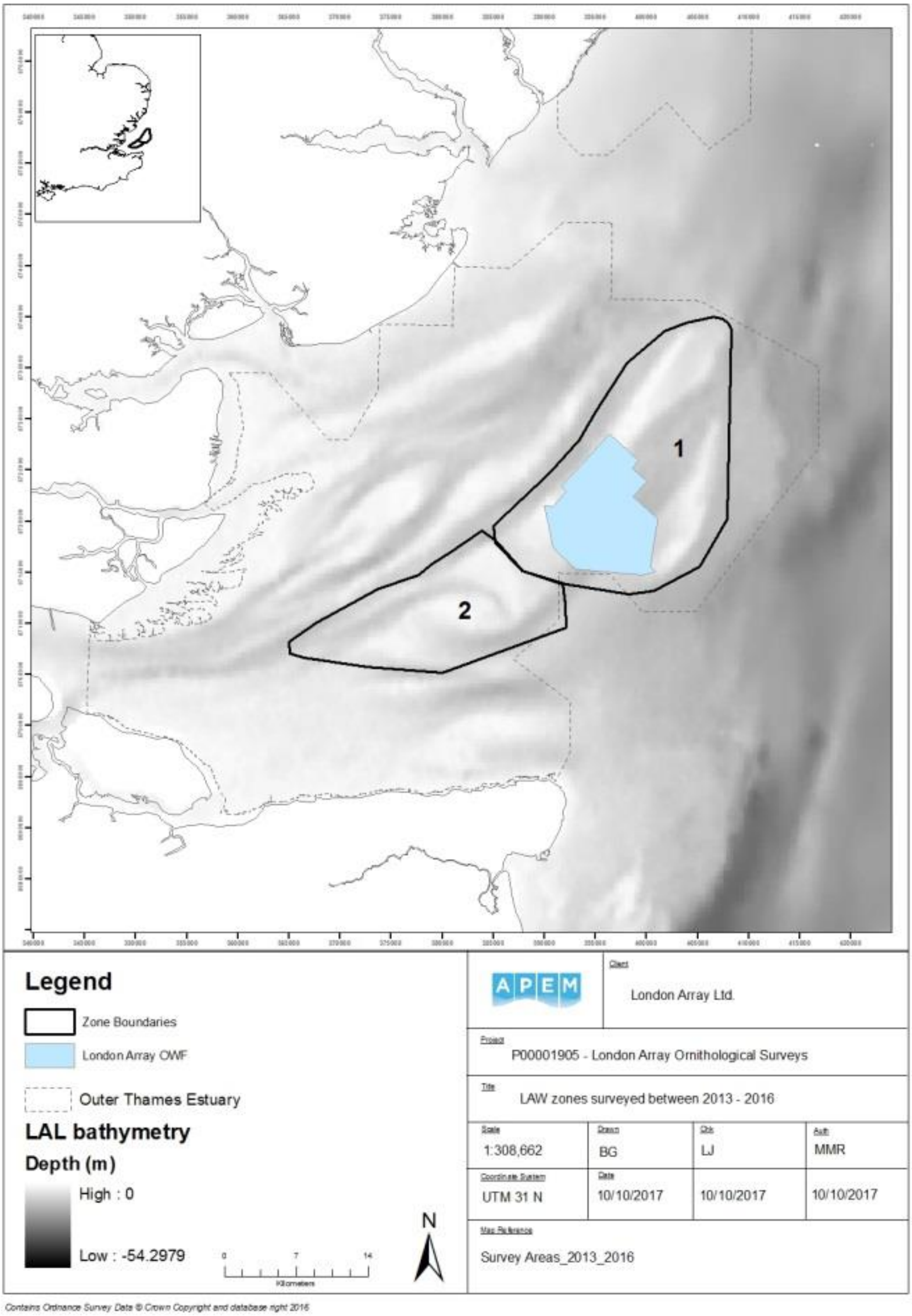

Figure 6 Post-construction survey areas of Zone 1 and Zone 2.

4. Survey Results

This section provides a summary of the survey results. Appendix 1 describes the analysis undertaken for the processing of the raw survey data. Methods of analysis for investigating barrier effect, collision risk, and displacement are described in Sections 5, 6, and 7.

4.1 Overview

The following tables present peak counts, abundance estimates, precision and confidence limits for each species recorded during the pre-consent (baseline) and the pre-, during- and post-construction surveys of the LAW.

Raw counts of all species recorded per month for each year of surveys are detailed in the survey reports (APEM, 2010; 2011a; 2012; 2013a; 2014; 2015a; 2017). Please note that due to minor refinement of the data set (e.g. as our knowledge and experience of image processing and bird identification has improved it has been possible to apply some of those improvements retrospectively through the data QA process) a small number of the values will not match the data presented in the annual reports. A summary of the data refinements is provided in Appendix 2, Table 1 for clarity. The extent of the changes is minor and do not have any significant effect on the outcome of the analyses for this report nor do they alter the conclusions of the relevant annual reports.

4.2 EIA boat-based survey abundance estimates

Table 7 and Table 8 present the results collated from the baseline EIA boat-based surveys for red-throated divers conducted between 2002 and 2004.

Table 7 Percival (2009) and distance analysis peak abundance estimates and density values of red-throated divers for each winter from baseline EIA boat-based surveys. CL: 95% Confidence Limits.

Date	Percival (2009) Analysis		Distance Analysis					
	Estimated total	Density (birds per km^2)	Estimated total			Density (birds per km^2)		
	Wind Farm	Wind Farm	Wind Farm	-CL	+CL	Wind Farm	-CL	+CL
Nov-02	-	-	2,179	830	5,722	3.79	1.44	9.95
Feb-03	2,470	4.3	-	-	-	-	-	-
Feb-04	11,117	19.33	4,334	1,953	9,616	7.54	3.4	16.72
Dec-04	2,716	4.72	1,846	840	4,056	3.21	1.46	7.05

Table 8 Peak total population estimates and densities comprising distance estimates plus scaled up 'in flight' counts of red-throated divers for each winter from baseline EIA boat-based surveys.

Date	Distance Analysis					
	Estimated total			Density (birds per km^2)		
	Wind Farm	Birds in Flight	Total	Wind Farm	Birds in Flight	Total
Nov-02	2,179	598	2,777	3.79	1.04	4.83
Feb-03	-	-	-	-	-	-
Feb-04	4,334	7077	11,411	7.54	12.31	19.85
Dec-04	1,846	1353	3,199	3.21	2.35	5.56

4.3 EIA aerial visual survey abundance estimates

Table 9 presents the results collated from the baseline EIA aerial visual surveys for red-throated divers conducted between 2003 and 2006.

Table 9 Peak distance analysis estimates and density values of red-throated divers for each winter from the baseline EIA aerial visual surveys.

Date	Distance Analysis					
	Estimated total			Density (birds per km^2)		
	Wind Farm	-CL	+CL	Wind Farm	-CL	+CL
Jan-03	2,596	2,093	3,219	4.51	3.64	5.6
Feb-04	3,821	3,127	4,668	6.64	5.44	8.12
Mar-05	1,541	1,138	2,086	2.68	1.98	3.63
Jan-06	1,759	1,280	2,419	3.06	2.23	4.21

4.4 Post-consent (2009-2016) aerial digital survey report summary

There has been a long series of reports issued to describe the ornithological monitoring following the consent of the LAW. The following reports were provided by APEM:

- The Pilot Study: Aerial Survey Methods, Data Collection and Statistical Analysis (APEM, 2010);
- Red-throated Divers & Offshore Windfarms in the Outer Thames: Historic Data Review (APEM, 2011b);
- Six Ornithology Aerial Survey Reports: 2010 / 11, 2011 / 12, 2012 / 13, 2013 / 14, 2014 / 15, 2015 / 16 (APEM 2011a, 2012, 2013a, 2014, 2015a, 2017); and
- London Array Additional Analysis (APEM, 2015b).

The pilot study aimed to demonstrate the appropriateness of the aerial digital survey method for offshore surveys, and to provide data describing the distribution and association of birds within and around the proposed wind farm site with focus on red-throated diver (APEM, 2010). The report described the methodology for monitoring the pre-construction distribution of birds, with focus on red-throated diver. The report was not a baseline report and did not present abundance or distribution of birds by species. A comparison of aerial digital and aerial visual methods was undertaken because at that time the aerial digital method was a relatively novel technique in comparison to boat-based or aerial visual techniques. The report concluded that 3 cm digital still resolution was the most suitable of the then possible approaches. The exact survey design was determined after further analysis and with discussions with the ORP. The report stated that the grid size would be in the region of 750 m. The final survey design, as agreed with the ORP, was based on a 3 cm resolution 500 m grid.

The historic data review was commissioned to evaluate the historical boat and aerial bird survey data relating to red-throated divers for five offshore wind farm areas: Greater Gabbard, Gunfleet Sands, Kentish Flats, Thanet, and London Array (APEM, 2011b). Additionally, it compared historical estimates with new data collected during the pilot study (2009 / 10) by aerial digital methods. The data covered aerial and boat-based surveys spanning 2001 until 2010. The timings of the surveys were inconsistent in that aerial or boat-based data existed for one wind farm in one month but not in another. For data analysis, only data collected between the months of October and March were included, since outside of this period red-throated divers are predominantly on or travelling to or from their breeding territories and not found offshore in the southern North Sea. The report concluded that abundance estimates from boat surveys varied according to month, winter and wind farm area, and that probably as a result of this variation abundance estimates from aerial surveys did not show consistent patterns with boat survey data. An index of change in red-throated diver numbers over time in the outer Thames Estuary region was produced based on distance estimates calibrated against aerial digital data. The calibrated trends suggested that in the London Array area, red-throated divers fluctuated each winter, with estimates for the latest year like those in the earliest year of the survey.

The six annual reports provided species-specific abundance estimates generated for each month of survey, and species-specific distribution maps (APEM, 2011a, 2012, 2013a, 2014, 2015a, 2017). The timing and weather conditions of each survey were provided. The 'Discussion' sections in the reports focussed on the red-throated diver abundance and distribution changes over time. A separate section of 'other species' was also included. These reports spanned the pre-construction period 2010 / 11 until the final, third year of post-construction monitoring in 2015 / 16. It is the data contained in these reports which were considered to cover the monitoring period and that were reviewed by the MMO. All six of the annual reports have been formally signed off by the MMO.

An additional analysis report was commissioned to analyse the red-throated diver density profile following the first year of post-construction surveys (APEM, 2015b). The scope of the analysis was agreed with NE and RSPB as part of the ORP process. The report presented the density profile of divers in Zone 1 in concentric 500 m buffers surrounding the LAW footprint. A repeated measures ANOVA (analysis of variance) was used to investigate if there was any significant change between the densities of divers during the different construction periods. The repeated measures ANOVA showed a significant effect of construction, which suggested a significant decrease pre- and during construction, and a significant increase between during and post-construction. There was no significant difference between the pre- and post-construction diver densities. Whilst the distribution of divers was similar pre- and post-construction within 2 km of the LAW, the distribution of diver density increased within 4 km of the LAW (APEM, 2015b).

In addition to the reports referenced above, a further report was completed which was funded by NE with permission from London Array Ltd to complete complex statistical analysis of the displacement of divers and auks following the first year of post-construction surveys (APEM, 2016). A literature review was undertaken to determine the relevant environmental variables that were needed for modelling the distribution of divers and auks in the outer Thames Estuary region. All available data were considered for inclusion, including boat-based and aerial visual. However due to the lack of spatial and temporal overlap between different methods it was agreed the most robust approach was to only use data derived from aerial digital surveys. Aerial digital data included surveys conducted of the LAW and its associated Zones as well as surveys of the OTE SPA undertaken by APEM in 2013 (APEM, 2013b). The results were focussed on the pre-construction and during construction phases because these phases were fully completed. The post-construction phase had two remaining years to be completed at the time that the modelling was undertaken. The results indicated that both divers and auks showed a reduction in numbers during construction compared to pre-construction. The results suggested divers avoided to a degree, but not absolutely, the areas within approximately 9 km of the LAW whilst auks avoided to a degree, but not absolutely, the areas approximately 4 km from the LAW during construction (APEM, 2016). Initial results of the post-construction phase suggested that one year after construction numbers returned to pre-construction levels for auks and divers; however, the distribution of auks especially was altered as there were still fewer auks proportionally in the wind farm and surrounding areas. It is important to note that the results of the analysis were preliminary pending the further two years of post-construction data. The results in this FMR for the displacement of divers and auks provide an update to the modelling that was undertaken for NE, and it is based on the addition of the final two years of post-construction surveys.

4.5 Monitoring period (2010-2016) aerial digital results species overview

This section presents an overview of the results of the monitoring period (2010 to 2016). It is important to note that the monitoring period included only the winter period, November to February. This was in order to capture the key information regarding red-throated divers, the focus on this species being agreed through the ORP process. Surveys were not carried out and hence data do not exist for the remaining months of the relevant years.

The level of analysis applied to each species that was recorded during the monitoring programme was determined primarily from the relevant monitoring objectives in the requirements and conditions of the Marine Licence. The monitoring objectives determined the key species and these species were subject to a greater level of analysis than others. This process was informed by consultation with the MMO, Natural England and the RSPB and agreed through the ORP.

A summary of species occurrence and a comparison of bird densities across the development phases, set out within species groupings, are presented in this section. For the detailed analysis of the key species, refer to:

- Section 5: Assessment for Barrier Effect (divers);
- Section 6: Assessment for Collision Risk (gannet, small gulls, and large gulls); and
- Section 7: Assessment for Displacement (divers and auks).

In addition, cumulative density distribution maps for the key groups are presented in Appendix 3, monthly distribution maps for the key species and groups are presented in Appendix 4 and peak densities per year are presented in Appendix 5.

For each species recorded in the surveys, the mean density per development phase, separated by survey zone, is presented in Table 10.

Kruskal-Wallis tests were undertaken on the density estimates of key species in Zone 1 and Zone 2 to investigate if there was any significant difference between different development phases. A Kruskal-Wallis test allows for differences between populations to be investigated without requiring normally distributed data. If the Kruskal-Wallis test showed a significant result, further analysis was undertaken using a Dunn Test for multiple comparisons (using the 'FSA' package in R).

Species that were tested using the Kruskal-Wallis test included: gannet, great black-backed gull, herring gull, lesser black-backed gull, black-headed gull, common gull and kittiwake between each development phase in Zone 1 (the 'impact' zone) and Zone 2 (the 'reference' zone). The results are included within the relevant species or species group accounts below. It must be noted that undertaking the analysis in this manner by comparing Zone 1 and Zone 2, it is unlikely to detect small effects of displacement or attraction given the size of the areas being compared. As such, a non-significant result should not be interpreted as a sign of no displacement effect.

The associated raw counts, population estimates, confidence intervals, and precision can be found in the annual monitoring reports (APEM 2011a, 2012, 2013a, 2014, 2015a, 2017).

Table 10 **Mean density per species per Zone (1, 2, 3, 4, 5, 6 and 7) per development phase: pre-construction, during construction, and post-construction.**

Species / group	Pre-construction							Construction						Post-construction	
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 1	Zone 2	Zone 3	Zone 5	Zone 6	Zone 7	Zone 1	Zone 2
Scaup	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00
Common scoter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.25	0.00	0.00	0.00	0.27	0.00	0.00
Seaduck species	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red-throated diver	0.23	0.02	0.00	0.00	0.00	0.00	0.02	1.98	2.17	1.32	1.13	0.44	0.78	4.02	4.88
Black-throated diver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.02	0.02	0.02	0.03	0.00
Great northern diver	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.01	0.00	0.03	0.00	0.03	0.00
Diver species	6.32	1.39	0.64	0.03	1.53	0.22	1.73	0.15	0.76	0.25	0.22	0.05	0.27	0.00	0.00
Fulmar	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.04	0.02	0.04	0.00	0.03	0.01	0.00	0.00
Shearwater species	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gannet	0.38	0.05	0.00	0.00	0.00	0.00	0.04	0.25	0.00	0.00	0.02	0.03	0.00	0.13	0.04
Cormorant	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.25	0.98	0.00	0.00	0.13	0.02	0.51
Shag	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cormorant shag	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.05	0.00	0.00	0.03	0.00	0.18
Great crested grebe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.04	0.00	0.00
Grebe species	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Oystercatcher	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Pomarine skua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Great skua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Kittiwake	0.18	0.33	0.26	0.00	0.24	0.11	0.73	0.34	0.24	0.36	0.13	0.21	0.48	0.52	0.25
Black-headed gull	0.03	0.08	0.30	0.00	0.04	0.02	0.09	0.01	0.03	0.10	0.01	0.00	0.01	0.01	0.03
Common gull	0.02	0.16	2.00	0.00	0.27	0.18	1.03	0.04	0.10	0.22	0.04	0.03	0.14	0.10	0.14
Little gull	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.00	0.00	0.00
Small gull species	0.52	1.00	3.48	0.00	1.89	3.43	2.07	0.02	0.02	0.03	0.02	0.01	0.08	0.02	0.02
Lesser black-backed gull	0.05	0.02	0.05	0.00	0.00	0.03	0.23	0.04	0.03	0.13	0.01	0.02	0.10	0.06	0.04
Herring gull	0.03	0.04	0.50	0.00	0.29	0.17	0.38	0.08	0.65	1.28	0.22	0.03	0.63	0.08	0.37
Great black-backed gull	0.04	0.12	0.10	0.00	0.18	0.00	0.30	0.26	0.29	0.31	0.17	0.05	0.16	0.26	0.55
Black backed-gull species	0.04	0.00	0.02	0.00	0.14	0.00	0.09	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Large gull species	0.04	0.15	0.37	0.00	0.26	0.14	0.11	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01
Guillemot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.02	0.06	0.02	0.00	0.00
Razorbill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Guillemot/Razorbill	0.08	0.05	0.00	0.00	0.02	0.02	0.05	0.81	0.61	0.36	0.48	1.14	0.46	0.89	1.28
Puffin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.02	0.01	0.00	0.03	0.00	0.00
Little auk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Auk species	0.51	0.22	0.07	0.03	0.27	0.73	0.07	0.01	0.02	0.00	0.00	0.00	0.04	0.00	0.00

4.5.1 Wildfowl

Wildfowl were recorded sporadically throughout the monitoring period; too few individuals were recorded to warrant analysis. A qualitative summary is provided here.

Scaup were recorded in Zone 3 and 7 during construction (see Appendix 4, Figure 1: November 2012) with a peak density of 0.13 birds km^{-2} in Zone 3 (Appendix 5, Table 3).

Common scoter were recorded in Zone 1, 2, and 7 during construction and post construction (see Appendix 4, Figure 1: November 2011, November 2012, January 2013, February 2013, and January 2015) with a peak density of 2.14 birds km^{-2} recorded in Zone 7 in November 2011 (Appendix 5, Table 7).

Unidentified seaduck species were recorded in Zone 1 pre-construction (see Appendix 4, Figure 1: January 2011 and February 2011) with a peak density of 0.05 birds km^{-2} in January 2011 (Appendix 5, Table 1).

4.5.2 Divers

Divers were the most abundant species group recorded during the monitoring surveys. Detailed analyses have been undertaken with respect to the assessment of barrier effect (Section 5) and displacement (Section 7) monitoring objectives. Due to the earlier years containing limited information regarding species identification, divers as a species group were combined for these assessments. Refer to the Sections 5 and 7 for information on the detailed analyses.

Red-throated divers were recorded in Zones 1 and 2 pre-construction, Zones 1, 2, 3, 5, 6 and 7 during construction and in Zones 1 and 2 post construction (see Appendix 4, Figure 2: February 2011, January 2012, February 2012, November 2012, December 2012, January 2013, February 2013, November 2013, December 2013, January 2014, February 2014, November 2014, December 2014, January 2015, February 2015, November 2015, December 2015, January 2016, and February 2016) with a peak density of 15.86 birds km^{-2} recorded in Zone 2 in February 2015 (Appendix 5, Table 2).

Black-throated divers were recorded in Zones 1, 2, 3, 5, 6, and 7 during construction and Zones 1 and 2 post construction (see Appendix 4, Figure 2: November 2012, December 2012, January 2013, February 2013, December 2013, January 2014, and February 2014) with a peak density of 0.29 birds km^{-2} recorded in Zone 1 in December 2013 (Appendix 5, Table 1).

Great northern divers were recorded in Zones 1, 2, 3, and 6 during construction and in Zone 1 post construction (see Appendix 4, Figure 2: February 2012, November 2012, December 2012, January 2013, February 2013, November 2013, December 2013, January 2014, February 2016) with a peak density of 0.64 birds km^{-2} recorded in Zone 2 in February 2012 (Appendix 5, Table 2).

Unidentified diver species were recorded in Zones 1, 2, 3, 4, 5, 6, and 7 pre-construction and Zones 1, 2, 3, 5, 6 and 7 during construction (see Appendix 4, Figure 2: November 2010, December 2010, January 2011, February 2011, November 2011, December 2011, January 2012, February 2012, November 2012, December 2012) with a peak density of 19.25 birds km^{-2} recorded in Zone 1 in February 2011 (Appendix 5, Table 1).

4.5.3 Fulmar

Fulmars were recorded in low numbers throughout the monitoring period; too few were recorded to warrant analysis. A qualitative summary is provided here.

Fulmars were recorded in Zones 1 and 3 pre-construction, Zones 1, 2, 3, 6, and 7 during construction, and Zone 1 post construction (see Appendix 4, Figure 8: January 2011, November 2011, January 2012, February 2012, November 2013, December 2013, and January 2014) with a peak density of 0.23 birds km^{-2} recorded in Zone 3 in January 2012 (Appendix 5, Table 3).

A single individual was recorded in the LAW pre-construction (2010-2011), during the second year of construction (2012-2013), and post construction (2013-2014). Three individuals were recorded in the LAW during the first year of construction (2011-2012). Relatively greater numbers of fulmars were recorded throughout all the Zones (particularly Zones 1, 2, and 3) during the construction years (Appendix 3, Figure 3). Due to the small number of fulmars recorded, it is difficult to state with any certainty whether the slight increases recorded during construction would be caused by the development of the LAW or other environmental factors.

4.5.4 Shearwaters

Unidentified shearwater species were recorded sporadically throughout the monitoring period; too few were recorded to warrant analysis. They were recorded in Zone 1 in pre-construction, January 2011 with a density of 0.28 birds km^{-2} (Appendix 5, Table 1).

4.5.5 Gannet

Gannets were recorded in Zones 1, 2 and 7 pre-construction, Zones 1, 2, 5 and 6 during construction, and Zones 1 and 2 post construction (see Appendix 4, Figure 4: January 2010, January 2011, February 2011, December 2011, November 2012, January 2013, February 2013, November 2013, December 2013, February 2014, November 2014, December 2014, February 2015, November 2015, December 2015, December 2015, January 2016 and February 2016) with a peak density of 1.90 birds $km-^{2}$ recorded in Zone 1 in February 2013 (Appendix 5, Table 1).

Overall, gannet mean density decreased in Zone 1 across development phases from 0.38 birds $km-^{2}$ pre-construction to 0.13 birds $km-^{2}$ post construction (Table 10; Figure 7). Mean densities were relatively low in Zone 2 with no birds recorded during construction (Table 10; Figure 7).

The Kruskal-Wallis test showed that the density of gannets in Zone 1 was not significantly different (H_2=3.15, P =0.20) between each of the development phases. Density in Zone 2 was not significantly different (H_2=2.01, P =0.37) between each of the development phases.

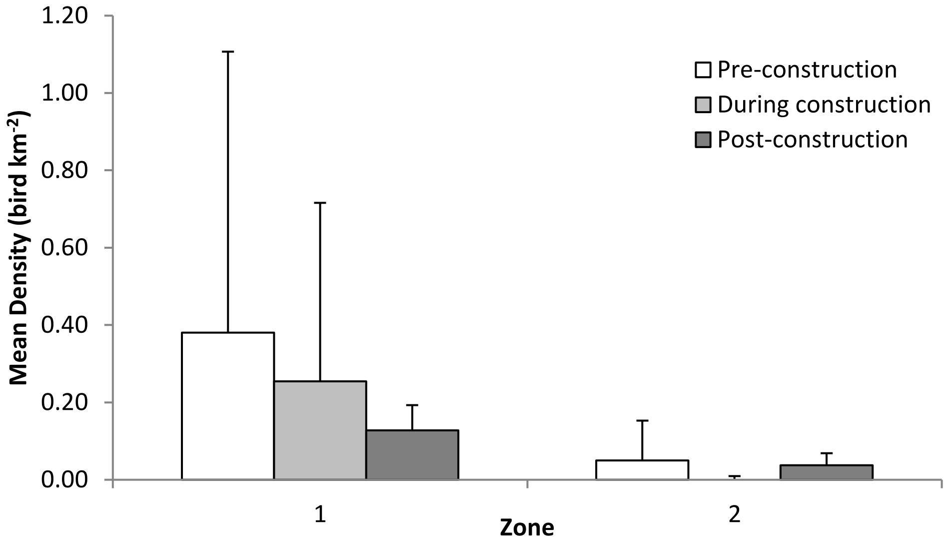

Figure 7 Mean densities per development phase of gannets recorded in Zone 1 and Zone 2.

4.5.6 Cormorants and shags

Cormorants and shags were recorded in relatively low numbers and exhibited a clustered distribution throughout the Zones surveyed. A qualitative summary has been provided here because too few were recorded to give meaningful results using non-parametric statistics.

Cormorants were recorded in Zones 1, 2, 3, and 7 during construction and Zones 1 and 2 post construction (see Appendix 4, Figure 1: December 2011, January 2012, February 2012, December 2012, January 2013, February 2013, November 2013, January 2014, November 2014, January 2015, February 2015, November 2015, January 2016, and February 2016) with a peak density of 4.45 birds km^{-2} recorded in Zone 3 in January 2012 (Appendix 5, Table 3).

Shags were recorded in Zone 1 pre-construction and during construction (see Appendix 4, Figure 1: November 2010, December 2010, and December 2012) with a peak density of 0.05 birds km^{-2} recorded in Zone 1 in November and December 2012 (Appendix 5, Table 1).

Cormorant / shag (i.e. unidentified individuals that were classified as either cormorant or shag) were recorded in Zone 1 pre-construction, Zones 1, 2, 3, and 7 during construction and Zone 2 post construction (see Appendix 4, Figure 1: November 2010, January 2011, February 2011, November 2011, January 2012, February 2012, January 2013, and December 2013) with a peak density of 2.17 birds km^{-2} in Zone 2 in December 2013 (Appendix 5, Table 2).

Overall (when combining all individuals recorded as cormorant, shag, and cormorant / shag), two individuals were recorded within the LAW footprint during the pre-construction phase. In total, three individuals were recorded in Zone 1 pre-construction. During the first year of construction, in comparison to the pre-construction phase, relatively large clusters of individuals were recorded throughout many of the Zones (in particular Zones 1, 2, 3, and 7) with a cluster recorded within the LAW footprint (four individuals in total). In the post-construction years, the number of individuals recorded in the LAW foot ranged from one to two per year. A greater number was recorded in Zone 1 in the second year of post-construction in comparison to the other two years of post-construction.

Due to the small numbers recorded it is difficult to state with any certainty whether the changes in numbers and distribution of cormorants and shags relate to the development activities of the LAW, or to other environmental factors.

4.5.7 Grebes

Grebes were recorded in low numbers throughout the monitoring period; too few were recorded to warrant analysis. A qualitative summary is provided here.

Great crested grebes were recorded in Zones 1, 2, and 7 during construction (see Appendix 4, Figure 1: January 2012, February 2012, November 2012, January 2013, February 2013) with a peak density of 0.28 birds km^{-2} recorded in Zone 7 in January 2013 (Appendix 5, Table 7).

Unidentified grebe species were recorded in Zones 1, 2, and 7 in pre-, during, and post-construction (see Appendix 4, Figure 1: November 2010, December 2010, February 2011, December 2012, and February 2014) with a peak density of 0.08 birds km^{-2} recorded in Zone 1 in December 2010 (Appendix 5, Table 1).

A single grebe was recorded in the LAW pre-construction (2010-2011) and during construction (2011-2012), classified as unidentified grebe species and great crested grebe respectively. In the post-construction phase, no grebes were recorded in the LAW although two individuals were recorded within approximately 2 km from the wind farm boundary in February 2014 and January 2013 (Appendix 4: Figure 1). Overall, the mean density of grebes in Zone 1 was greater in the pre-construction than during, or post-construction. However due to the small numbers recorded, it is difficult to state with any certainty whether these slight differences can be attributed to the development of the LAW, or whether they are due to other environmental factors.

4.5.8 Waders

Waders were recorded sporadically throughout the monitoring period; too few were recorded to warrant analysis. Oystercatchers were recorded in Zone 3 during construction, in January 2013 with a density of 0.05 birds km^{-2} (Appendix 5, Table 3).

4.5.9 Skuas

Skuas were recorded sporadically throughout the monitoring period; too few were recorded to warrant analysis.

Pomarine skuas were recorded in Zone 1 during and post construction (November 2012 and November 2013) with a density of 0.02 birds km^{-2} (Appendix 5, Table 1).

Great skuas were recorded in Zones 1 and 2 during and post construction (November 2011 and February 2013, November 2014, December 2014 and December 2015) with a peak density of 0.03 birds km^{-2} in Zone 2 in November 2014 and December 2015 (Appendix 5, Table 2).

4.5.10 Small gulls

Small gulls were an abundant species group during the monitoring surveys. Detailed analyses have been undertaken with respect to the assessment of collision risk (Section 6).

An overview of the survey results is provided here. Refer to the Section 6 for information on the detailed analysis.

Kittiwakes were recorded in Zones 1, 2, 3, 5, 6 and 7 during the majority of the pre-, during-, and post-construction monitoring surveys with exception to December 2009, January 2010, February 2010, April 2010, November 2010 and December 2010 (see Appendix 4, Figure 6), with a peak density of 2.90 birds km^{-2} recorded in Zone 7 in February 2011 (Appendix 5, Table 7).

Kittiwake mean density increased in Zone 1 across development phases from 0.18 birds km^{-2} pre-construction to 0.52 birds km-^{2} post construction (Table 10; Figure 8). In Zone 2, mean kittiwake density was highest in pre-construction and remained almost constant between construction and post-construction phases (0.24 and 0.25 birds km-^{2} respectively) (Table 10; Figure 8).

The Kruskal-Wallis test showed that density was not significantly different for kittiwake (H_2=5.26, P=0.07) in Zone 1 between each of the development phases. Density was not significantly different for kittiwake (H_2=0.86, P=0.65) in Zone 2 between each of the development phases.

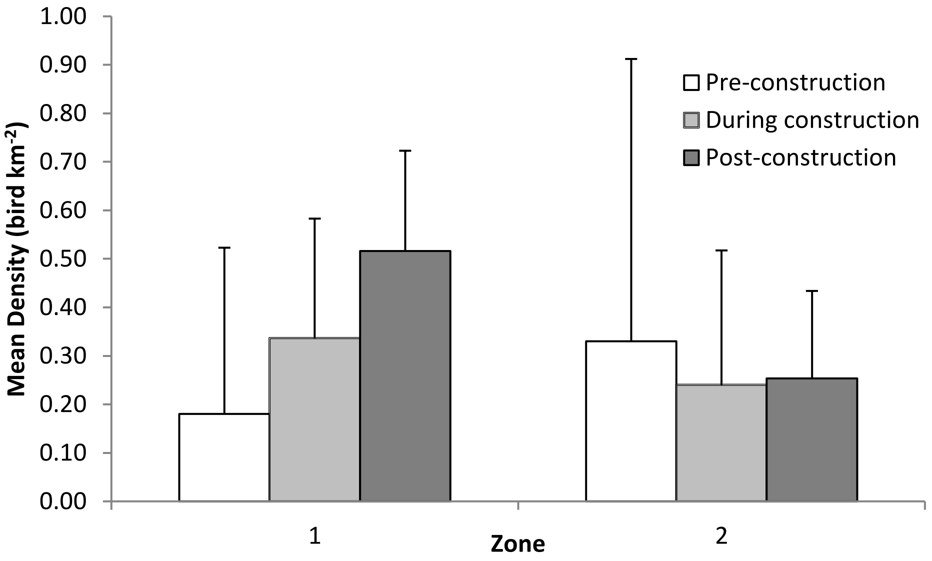

Figure 8 Mean densities per development phase of kittiwakes recorded in Zone 1 and Zone 2.

Black-headed gulls were recorded in Zones 1, 2, 3, 5, 6 and 7 pre-construction, Zones 1,2,3,5 and 7 during construction and Zones 1 and 2 post construction (see Appendix 4, Figure 6: January 2011, February 2011, December 2011, November 2012, December 2012, January 2013, February 2013, November 2013, November 2014 and February 2015) with a peak density of 0.87 birds km-^{2} recorded in Zone 3 in February 2011 (Appendix 5, Table 3).

In Zone 1 and Zone 2, black-headed gull mean densities were higher pre construction (0.03 and 0.08 birds km-^{2} respectively) (Table 10; Figure 9). Mean densities decreased during construction and increased slightly post construction in Zone 1 and Zone 2, however post-construction mean densities remained lower than those recorded pre construction (0.01 and 0.03 birds km-^{2} respectively) (Table 10; Figure 9).

The Kruskal-Wallis test showed that density was not significantly different for black-headed gull (H_2=0.48, P =0.79) in Zone 1 between each of the development phases. Density was not significantly different for black-headed gull (H_2=1.42, P =0.49) in Zone 2 between each of the development phases.

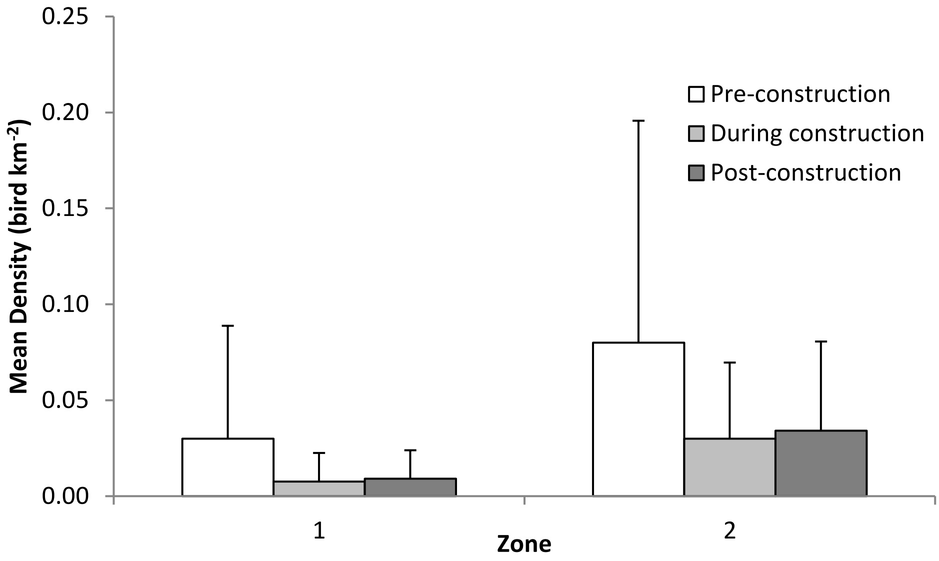

Figure 9 Mean densities per development phase of black-headed gulls recorded in Zone 1 and Zone 2.

Common gulls were recorded in Zones 1, 2, 3, 5, 6 and 7 pre and during construction, and in Zones 1 and 2 post construction (see Appendix 4, Figure 6: January 2010, November 2010, December 2010, January 2011, February 2011, December 2011, January 2012, February 2012, November 2012, December 2012, January 2013, February 2013, November 2013, December 2013, January 2014,February 2014, November 2014, December 2014, January 2015, February 2015, November 2015, December 2015, January 2016 and February 2016) with a peak density of 4.03 birds km-^{2} recorded in Zone 7 in February 2011 (Appendix 5, Table 7).

In Zone 1, common gull mean density increased across development phases from 0.02 birds km-^{2} pre-construction to 0.10 birds km-^{2} post construction (Table 10; Figure 10). In Zone 2, mean density decreased during construction and increased post construction, however post-construction mean density remained slightly lower than that recorded pre construction (0.14 and 0.16 birds km-^{2} respectively) (Table 10; Figure 10).

The Kruskal-Wallis test showed that the density of common gull was significantly different in Zone 1 between development phases (H_2=9.00, P=0.01). A Dunn Test identified that the densities during- versus post-construction (Z = -2.37, P=0.03) and pre- versus post-construction (Z = 2.49, P=0.04) were significantly different. This suggests that common gull density was similar pre versus during construction but was significantly higher post construction. Density was not significantly different for common gull (H_2=1.65, P =0.44) in Zone 2 between each of the development phases.

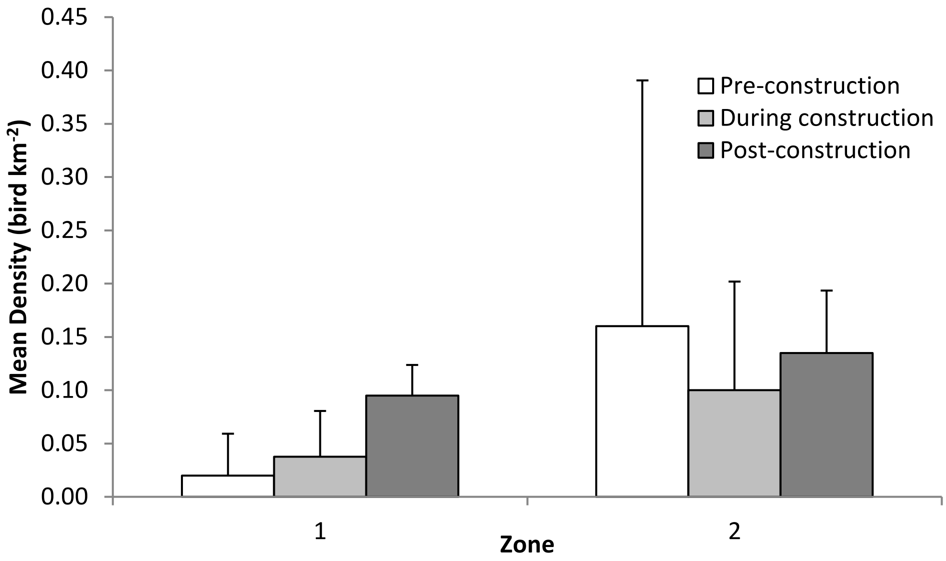

Figure 10 Mean densities per development phase of common gulls recorded in Zone 1 and Zone 2.

Little gull was a sporadic species throughout the monitoring period; too few were recorded to warrant analysis. They were recorded in Zone 1, 2, and 6 during construction (see Appendix 4, Figure 6: November 2012 and December 2012) with a peak density of 0.21 birds km^{-2} recorded in Zone 6 in November 2012 (Appendix 5, Tables 1, 2 and 6).

Unidentified small gulls were recorded in Zones 1, 2, 3, 5, 6 and 7 during the majority of the pre-, during-, and post-construction monitoring surveys with exception to February 2012, November 2013, January 2014, November 2014, January 2015, and January 2016 (see Appendix 4, Figure 6), with a peak density of 22.8 birds km^{-2} recorded in Zone 3 in January 2011 (Appendix 5, Table 3).

Mean density of unidentified small gulls was highest pre construction for Zone 1 and Zone 2 (0.52 and 1.00 birds km-^{2} respectively) (Table 10; Figure 11). In both Zone 1 and Zone 2, mean density decreased during construction to 0.02 birds km-^{2} and remained constant post construction (Table 10; Figure 11).

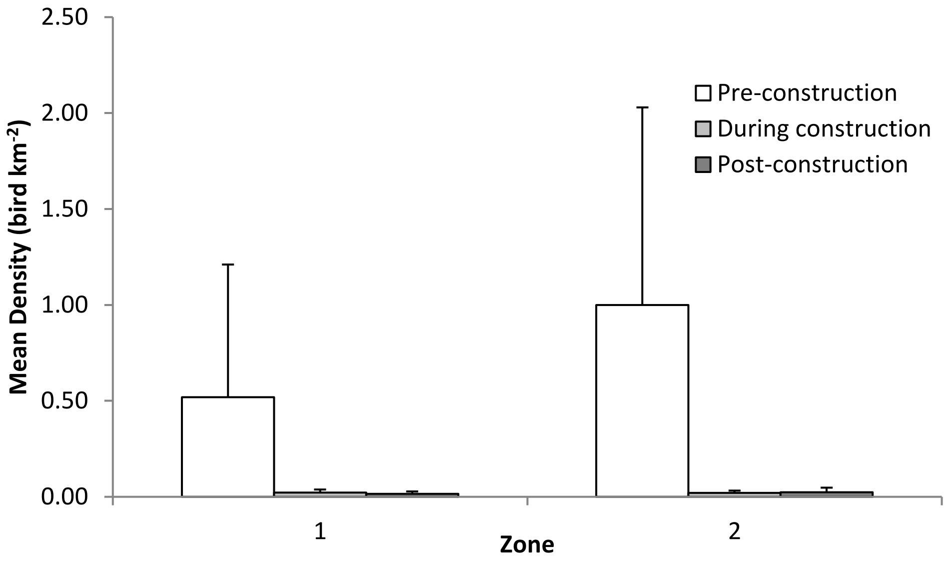

Figure 11 Mean densities per development phase of small gull species recorded in Zone 1 and Zone 2.

4.5.11 Large gulls

Lesser black-backed gulls were recorded in Zones 1, 2, 3, 6 and 7 pre and during construction and in Zones 1 and 2 post construction. They were recorded in most survey months except January 2011, January 2015, February 2015, and December 2015 (see Appendix 4, Figure 7). A peak density of 0.92 birds km^{-2} in Zone 7 was recorded in February 2011 (Appendix 5, Table 7).

In Zone 1, lesser black-backed gull mean density decreased during construction and was highest post construction (Figure 12). In Zone 2, mean density increased across development phases from 0.02 birds $km\text{-}^2$ pre-construction to 0.04 birds $km\text{-}^2$ post construction (Table 10; Figure 12).

The Kruskal-Wallis test showed that density was not significantly different for lesser black-backed gull (H_2=2.98, P=0.86) in Zone 1 between each of the development phases. Density was not significantly different for lesser black-backed gull (H_2=1.16, P=0.56) in Zone 2 between each of the development phases.

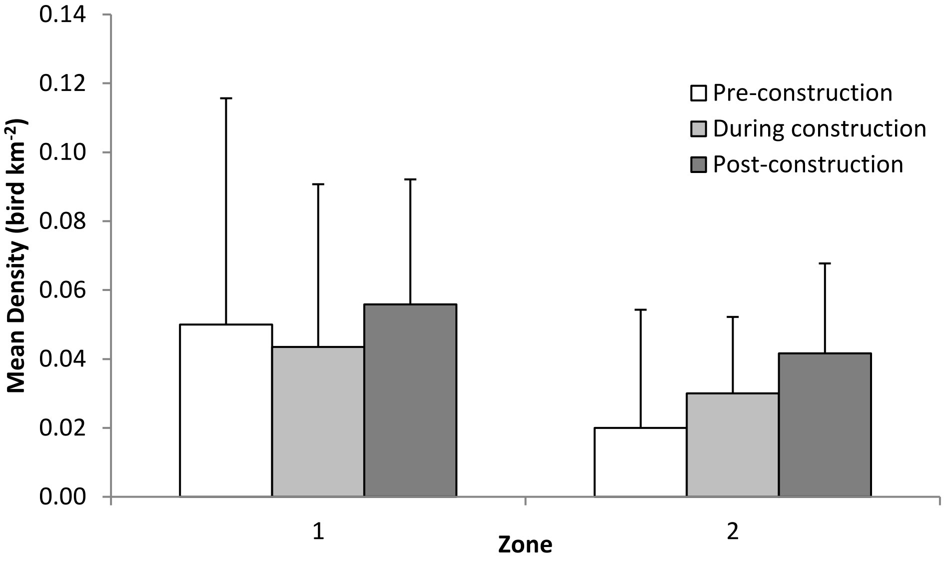

Figure 12 Mean densities per development phase of lesser black-backed gulls recorded in Zone 1 and Zone 2.

Herring gulls were recorded in Zones 1, 2, 3, 5, 6, and 7 pre and during construction, and Zones 1 and 2 post construction. They were recorded in every survey month (see Appendix 4, Figure 7). A peak density of 3.73 birds km^{-2} in Zone 3 was recorded in January 2012 (Appendix 5, Table 3).

Mean density of herring gulls was lowest pre construction in both Zone 1 and Zone 2 (0.03 and 0.04 birds km^{-2} respectively). A small increase in mean density from 0.03 birds km^{-2} pre-construction to 0.08 birds km^{-2} during construction occurred in Zone 1 and mean density remained constant post construction (Table 10; Figure 13). A large increase in mean density from 0.04 birds km^{-2} pre-construction to 0.65 during construction occurred in Zone 2 followed by a decrease post construction to 0.37 birds km^{-2} (Table 10; Figure 13).

The Kruskal-Wallis test showed that density was not significantly different for herring gull (H_2=5.12, P =0.08) in Zone 1 between each of the development phases. Density of herring gull was significantly different in Zone 2 between development phases (H_2=9.02, P =0.01). A Dunn Test identified that the density pre versus during construction (Z = 3.00, P=0.01) was significantly different. This suggests that herring gull density was similar pre versus post construction and had significantly greater density during construction. However, the pre- versus post-construction densities were similar.

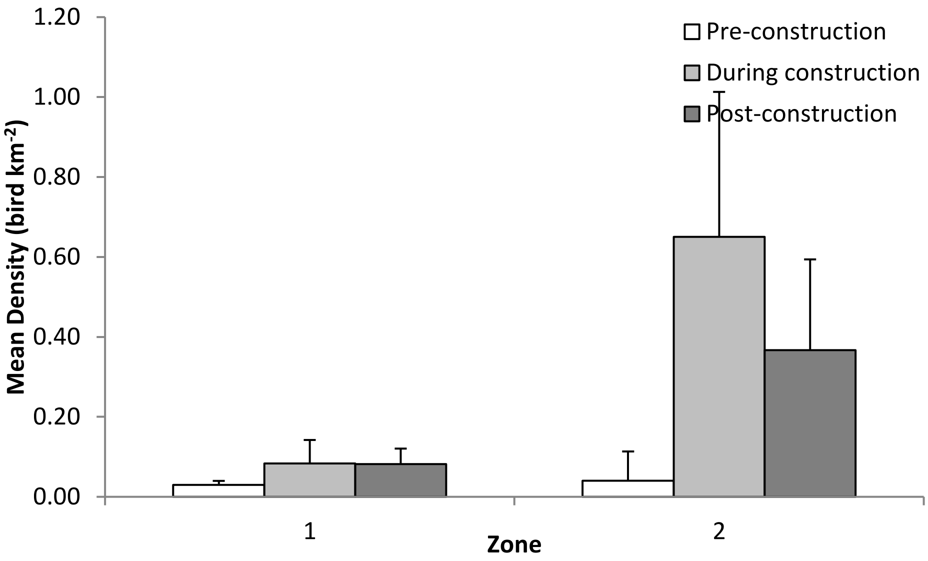

Figure 13 Mean densities per development phase of herring gulls recorded in Zone 1 and Zone 2.

Great black-backed gulls were recorded in Zones 1, 2, 3, 5, and 7 pre-construction, Zones 1, 2, 3, 5, 6 and 7 during construction, and Zones 1 and 2 post-construction. They were recorded in every survey month (see Appendix 4, Figure 7). A peak density of 1.69 birds km^{-2} in Zone 2 was recorded in November 2013 (Appendix 5, Table 2).

Great black-backed gull mean density increased in Zone 1 from pre-construction to construction (0.04 to 0.26 birds km-^{2} respectively) (Table 10; Figure 14). Mean density remained constant between construction and post-construction in Zone 1 (Figure 14). In Zone 2, mean great black-backed gull density increased across development phases from 0.12 birds km-^{2} pre-construction to 0.55 birds km-^{2} post-construction (Table 10; Figure 14).

The Kruskal-Wallis test showed that density was close to showing a significant difference for great black-backed gull (H_2=5.68, P =0.06) in Zone 1 between each of the development phases. Density was not significantly different for great black-backed gull (H_2=4.39, P =0.11) in Zone 2 between each of the development phases.

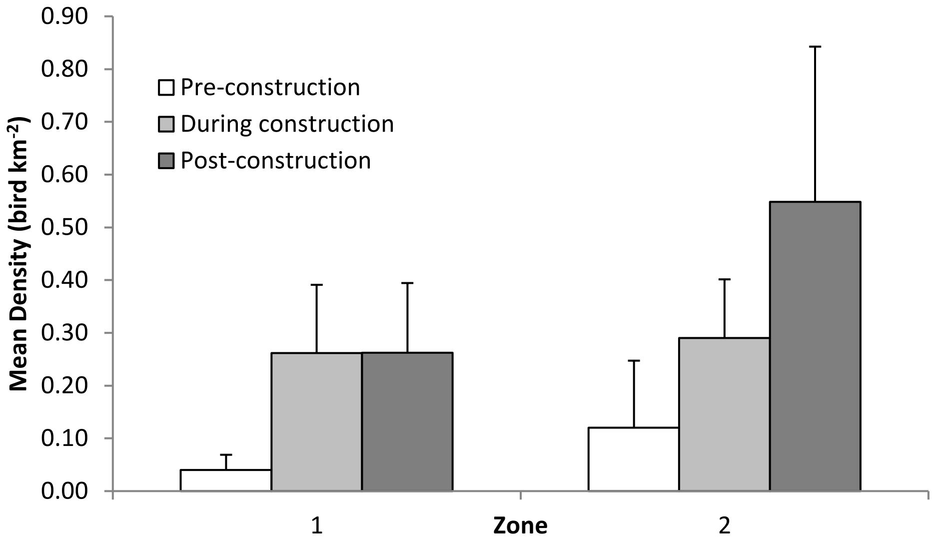

Figure 14 Mean densities per development phase of great black-backed gulls recorded in Zone 1 and Zone 2.

Unidentified black-backed gulls were recorded in Zones 1, 3, 5, and 7 pre-construction, Zones 1, 3 and 5 during construction (see Appendix 4, Figure 7: November 2010, January 2011, February 2011, November 2011, December 2011, and February 2012) with a peak density of 0.42 birds km^{-2} recorded in Zone 5 in January 2011 (Appendix 5, Table 5).

In Zone 1, mean density of black-backed gull species was highest pre construction (0.04 birds km-^{2}). Mean density decreased during construction and no birds were recorded post construction (Table 10; Figure 15). No black-backed gull species were recorded in Zone 2 (Table 10; Figure 15).

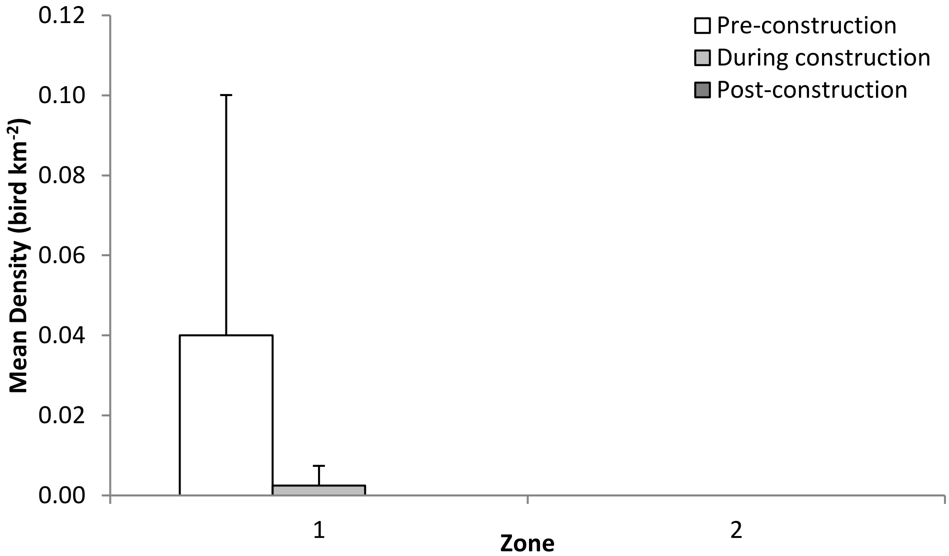

Figure 15 Mean densities per development phase of black-backed gull species recorded in Zone 1 and Zone 2.

Unidentified large gulls were recorded in Zones 1, 2, 3, 5, 6, and 7 presconstruction, Zones 1, 2, 3, 6 and 7 during construction, and Zones 1 and 2 post construction (see Appendix 4,

Figure 7: November 2010, December 2010, January 2011, February 2011, November 2011, January 2012, February 2012, November 2012, December 2013, February 2014, December 2014, January 2016) with a peak density of 0.94 birds km^{-2} recorded in Zone 5 in February 2011 (Appendix 5, Table 5).

Mean density of unidentified large gulls was highest pre construction in Zone 1 and Zone 2 (0.04 and 0.15 birds km-^{2} respectively) (Table 10; Figure 16). In Zone 1, mean density decreased during construction to 0.01 birds km-^{2} and remained constant post construction (Table X; Figure 16). In Zone 2, no unidentified large gulls were recorded in construction and mean density increased post construction to 0.01 birds km-^{2},however, post-construction mean density remained lower than that recorded pre construction (Table 10; Figure 16).

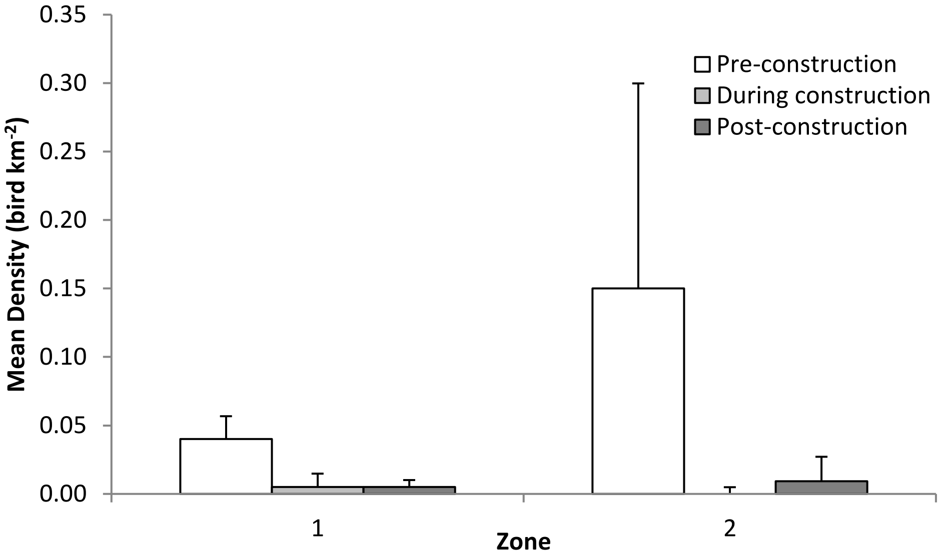

Figure 16 Mean densities per development phase of large gull species recorded in Zone 1 and Zone 2.

4.5.12 Auks

Auks were the second most abundant species group recorded (after divers) during the monitoring surveys. Detailed analysis has been undertaken with respect to the assessment of displacement (Section 7). Due to the earlier years containing limited information regarding species identification, auks as a species group were combined for further detailed analysis for this assessment. An overview of the survey results is provided here. Refer to Section 7 for information on the detailed analysis.

Guillemots were recorded in Zones 1, 2, 5, 6, and 7 during construction (see Appendix 4, Figure 8: December 2011, January 2012, February 2012, and November 2012) with a peak density of 0.49 birds km^{-2} recorded in Zone 6 in November 2012 (Appendix 5, Table 6).

Razorbills were recorded in Zones 1, 2, and 3 during construction (see Appendix 4, Figure 8: December 2011, November 2012, December 2012) with a peak density of 0.22 birds km^{-2} recorded in Zone 1 in November 2012 (Appendix 5, Table 1).

Guillemot / razorbills (i.e. unidentified individuals that were classified as either guillemot or razorbill) were recorded in Zones 1, 2, 5, 6, and 7 pre-construction, Zones 1, 2, 3, 5, 6 and 7 during construction, and Zones 1 and 2 post construction (see Appendix 4, Figure 8: February 2011, November 2011, December 2011, January 2012, February 2012, November

2012, December 2012, January 2013, February 2013, November 2013, December 2013, January 2014, February 2014, November 2014, December 2014, January 2015, February 2015, November 2015, December 2015, January 2016, and February 2016), with a peak density of 5.58 birds km^{-2} recorded in Zone 2 in February 2014 (Appendix 5, Table 2).

Puffins were recorded in Zones 1, 2, 3, 5, and 7 during construction and Zone 1 post construction (see Appendix 4, Figure 8: December 2011, January 2012, November 2012, December 2012, January 2013, February 2013, and February 2016), with a peak density of 0.19 birds km^{-2} recorded in Zone 7 in January 2012 (Appendix 5, Table 7).

Little auks were recorded in Zone 1, 2, and 5 during construction (see Appendix 4, Figure 8: January 2012, November 2012, December 2012, January 2013, February 2013), with a peak density of 0.08 birds km^{-2} recorded in Zone 1 in November 2012 (Appendix 5, Table 1).

Unidentified auks were recorded in Zone 1, 2, 3, 4, 5, 6, and 7 pre-construction and Zones 1, 2, and 7 during construction (see Appendix 4, Figure 8: November 2010, December 2010, January 2011, February 2011, December 2011, January 2012, February 2012), with a peak density of 1.59 birds km^{-2} recorded in Zone 6 in November 2010 (Appendix 5, Table 6).

5. Assessment for Barrier Effect

5.1 Introduction

The ES predicted that in order for a barrier effect to be potentially significant it would need to result in either reduced utilisation of an ecological resource (through birds no longer being able to reach it through the barrier) or significantly increased energy expenditure by the birds having to fly around the barrier. Divers were assumed to be most at risk to any barrier effect given the large extent of the wind farm and the large number of divers present in the area. No barrier effect was anticipated for any other species.

Objective 2 of the Marine Licence is as follows:

- *Determine whether there is a barrier effect to the movement of birds through the wind farm site, 1 km and 2-4 km buffer zones.*

To meet Objective 2 of the Marine Licence, analysis was undertaken to determine whether the LAW acts as a barrier to the movement of birds through the wind farm. In this case a barrier effect is taken to mean that a wind farm obstructs the movement of birds causing them to fly around it rather than through the turbines, or neither fly around nor through the wind farm, i.e. creating inaccessible areas.

The approach to testing for a barrier effect is to hypothesise that if the LAW were to act as a barrier, then it could be expected that a smaller proportion of flying bird trajectories would be towards the wind farm than in other directions, and that as a result of any barrier effect, lower densities of divers would be present near the wind farm than elsewhere in broadly similar habitats. This latter effect of detecting lower densities, but in this case of flying birds, can also be considered as displacement. Drewitt & Langston (2006) suggest that "the effect of birds altering their migration flyways or local flight paths to avoid a wind farm is also a form of displacement." The distribution of all divers (and auks) are analysed for potential displacement effects in Section 7. This displacement analysis could potentially also identify whether any areas have become inaccessible (i.e. are sited behind a barrier) following the construction activities of the LAW.

5.2 Methods

5.2.1 Data preparation

Barrier effect analysis was undertaken for all diver species recorded throughout the monitoring phase. Although a large proportion of the divers identified to species were red-throated divers, the analysis considered all divers as a single group. Raw count data were used to determine whether there was a barrier effect. These data from the digital aerial surveys collected during the construction and post-construction phases included identification to diver species or species group, diver behaviour and flight trajectory.

The densities of flying divers within Zone 1 were calculated separately for each construction phase for the wind farm, and its 1 km and 2 to 4 km buffer zones, as per reference to the buffer zones in the Marine Licence Objective. The densities were calculated by dividing the number of birds recorded in each zone by the area of the images collected.

As the direction of flight of individual birds was only recorded from November 2011 onwards, no analysis of flight direction was carried out during the pre-construction phase, including the pilot study period of 2009 / 10. For the construction and post-construction phases, the flight trajectory of the divers was recorded from digital still images by measuring the axis of bill to tail, within bespoke image analysis software, taking the bearing relative to the bird's head. This bearing is linked to the geo-referenced image and thus provides an accurate representation of bird orientation at the time of image capture.

The divers, during the pre-construction phase of 2010 / 11, for which it was not possible to estimate flight trajectory, are represented as dots in the figure (see Figure 18). The divers recorded in the pilot study year of 2009 / 10 were not plotted due to the difference in survey areas and timings in comparison to the subsequent surveys undertaken for the monitoring period 2010 to 2016. For the remaining divers for which it was possible to estimate flight trajectory, the direction of movement during the construction and post-construction phases was plotted using arrows corresponding to their flight direction.

The most appropriate method to analyse barrier effect based on the data available was to first plot individual directions of flight; a descriptive method for analysing directional behaviour. Bird flight trajectory (bearing) was obtained from the geo-referenced images and presented spatially (see Figure 19 and Figure 20 – the direction of the arrows indicates each diver's bearing). As the trajectory data are spread across the survey area and as the LAW is centred within the survey area, each diver's bearing does not indicate a trajectory relative to the wind farm when pooled because the flight bearing obtained from geo-referenced images was relative to north. For example, consider two birds each with a bearing of 360^{o} thus they are both flying in a northerly direction, however depending on where they are located each could be flying either toward the wind farm (if they were recorded to the south of the survey area), or away from the wind farm (if they were recorded to the north of the survey area). Thus, a calculation was undertaken to obtain an additional bearing for each diver in relation to the nearest turbine of the LAW. The relative bearing of each diver to the closest turbine was estimated by calculating the distance of each individual and the relative angle. The difference between a diver's bearing and a turbine's location was calculated to reveal the flight direction relative to the nearest point of the wind farm. The calculation to obtain an additional bearing for each diver relative to the nearest turbine of the LAW allowed for further analysis. See Figure 20 for the post-construction period: the arrows show the bearings as obtained from the geo-referenced imagery whilst the colour denotes each individual as being ascribed to one of four directional quadrants relative to the wind farm (towards, away, and two for flying parallel to the wind farm), based on the bearing relative to the nearest turbine.

Directions were subjectively subdivided into four quadrants: towards, away, and two for flying parallel in relation to the nearest turbine based on the relative angle (Figure 17). The divers were deemed to be flying towards the turbines if their bearing relative to the nearest turbine was between 135-225°, otherwise the divers were taken to be either flying away from or broadly parallel to the wind farm. Thus, if the divers were equally likely to fly in all directions one would expect 25% of them to be flying towards the turbines (i.e. four quadrants of 90° making up the complete 360° possible in all directions which is 25%; see Figure 17). This split was deemed to be precautionary on the basis that some individuals at a greater distance from the nearest turbine are likely to alter their trajectory the closer they get to the LAW.

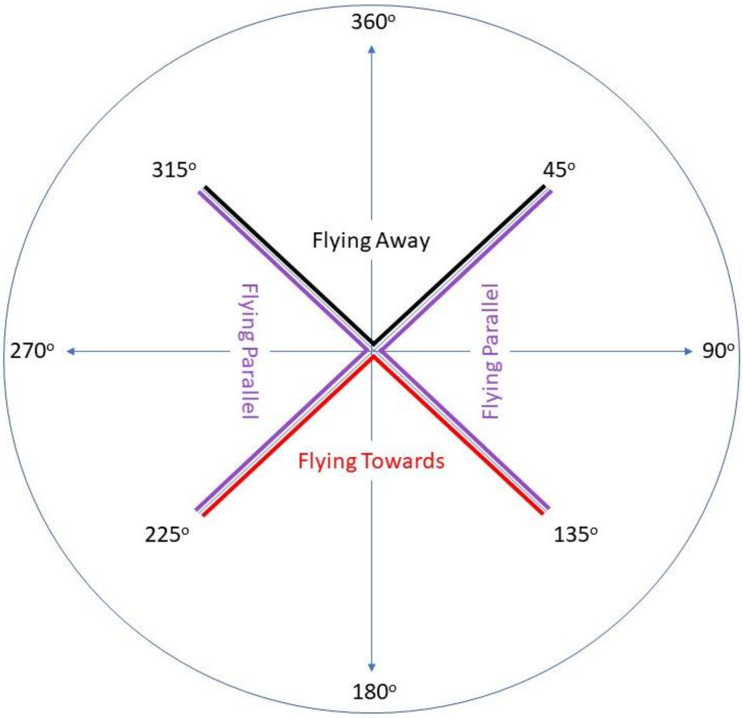

Figure 17 Schematic delineation of quadrants for flying towards, away, or parallel to the nearest turbine of the London Array Offshore Wind Farm.

The high resolution digital aerial surveys were based on a grid design, and the regular and even samples gathered across the survey area meant that it was possible to examine flight direction for sub-sets of samples. Bird records that fell within the wind farm (and associated buffers) could be selected in GIS, and their flight directions analysed separately.

5.2.2 Analysis

The diver trajectory data from each survey were analysed in two stages detailed below.

This analysis was not considered to be subject to bias by sampling flying birds at a non-random time in relation to tidal state. Figure 1 Appendix 6 illustrates how flying birds were detected across a wide range of dates and times of the day and consequently across a range of tidal states.

Stage 1: Distribution of Birds

For this descriptive stage, flying birds in the wind farm and associated buffers (1 km, 2 km, and 4 km), as well as in Zone 1 and Zone 2 were selected in ArcGIS. Data from all nine surveys of the post-construction phase were pooled for the key species group divers. The distributions and directions of the flying birds were mapped, and their numbers tabulated according to each of the development phases. Flying individuals were coloured according to whether their relative direction was toward, away, or parallel to the nearest turbine for the post-construction period. The densities of the flying divers in each of the three development phases are represented graphically.

Stage 2: Analysis of flight directions

The flight trajectory data were analysed to assess whether there was any evidence that the divers avoided the turbines. The number of flying divers recorded throughout each development phase was limited which posed an issue for statistical testing as the critical values of test statistics generally increase with small samples sizes, resulting in statistically significant results being less likely to arise. Therefore, two approaches were used to test the relative direction of flying divers in relation to the nearest turbine of the LAW. Due to the small number of flying divers recorded in certain buffer regions it was necessary to sum data from several buffers to ensure that samples were large enough.

The null hypothesis that the proportion of divers flying towards the nearest turbine was the same between different regions was tested using a chi-squared (χ^2) test and a randomisation approach. The χ^2 test is suitable for count data which can be separated categorically. In this case the count data are based on the relative direction of flying divers in relation to the nearest turbine, and distance to the LAW using buffer regions. The randomisation approach is based on the number of flying divers per buffer and their relative direction. These data were resampled 999 times per buffer region providing a larger data set with the characteristics of the original data. This approach is especially useful for small data sets.

If the statistical testing provided a less than 5% probability ($P \leq 0.05$) then the null hypothesis is rejected. If the null hypothesis is rejected, the data suggest that divers do not fly in all directions randomly, but rather trend towards a specific direction in relation to the nearest turbine. However, rejection of the null hypothesis does not necessarily mean that the flight direction in relation to the turbine is significant, further analysis of the data would be required to prove this.

The technical details of the two approaches are provided in Appendix 4.

5.3 Results

Stage 1 Distribution of birds

Figure 18, Figure 19, and Figure 20 present the distributions of flying divers recorded in Zones 1 and 2 for the pre-, during- and post-construction phases, respectively.

During the pre-construction and construction phases, flying divers were present within the wind farm, 1 km and 2-4 km buffer zones, and Zones 1 and 2 (Figure 18 and Figure 19). No divers were present within the LAW during the post-construction phase surveys (Figure 20). The highest densities of flying divers were observed in the north-eastern region of Zone 1 during all construction phases (Figure 18 to Figure 20).

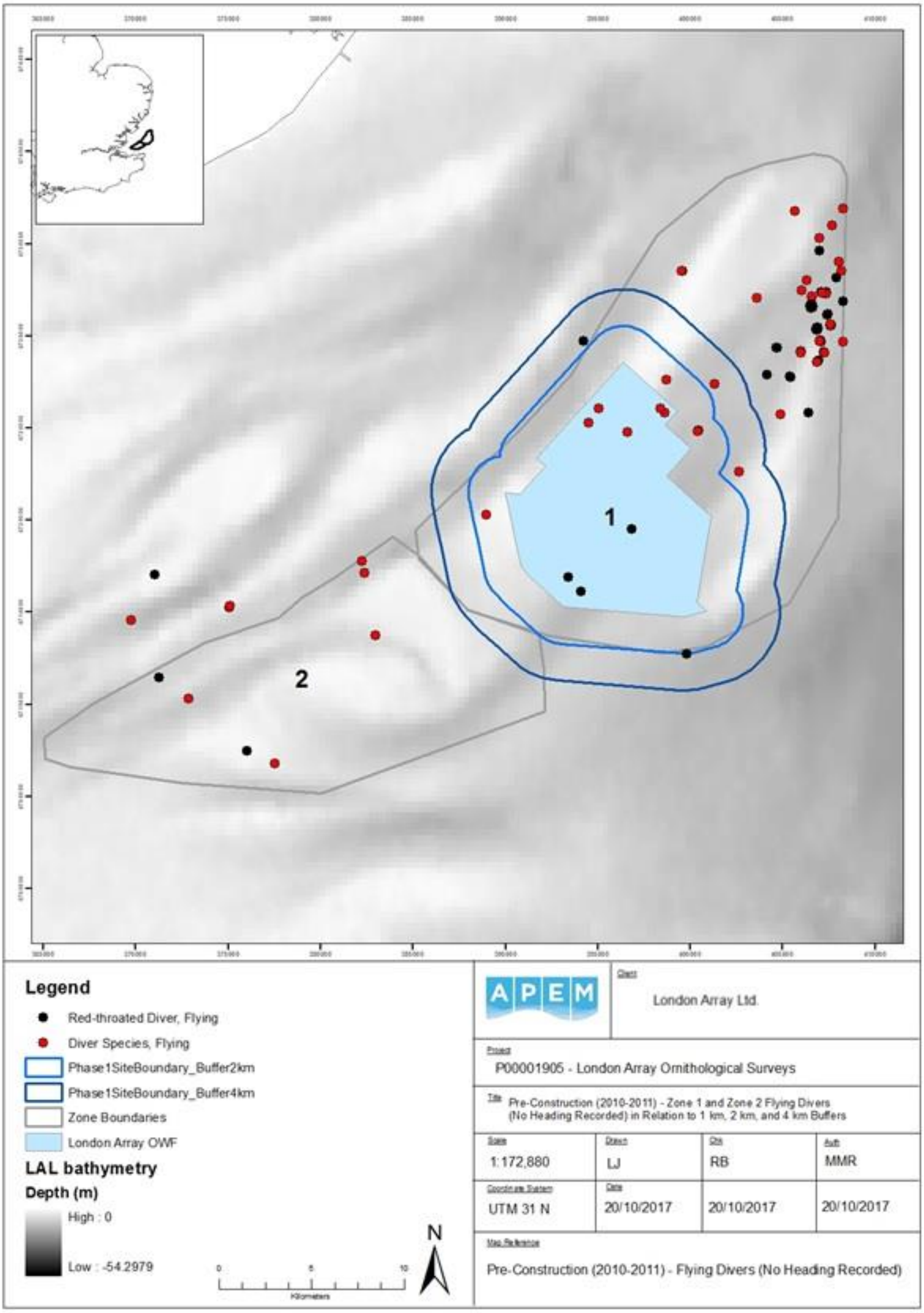

Figure 18 Distribution of flying divers recorded during the pre-construction phase digital aerial surveys (November 2010 to February 2011).

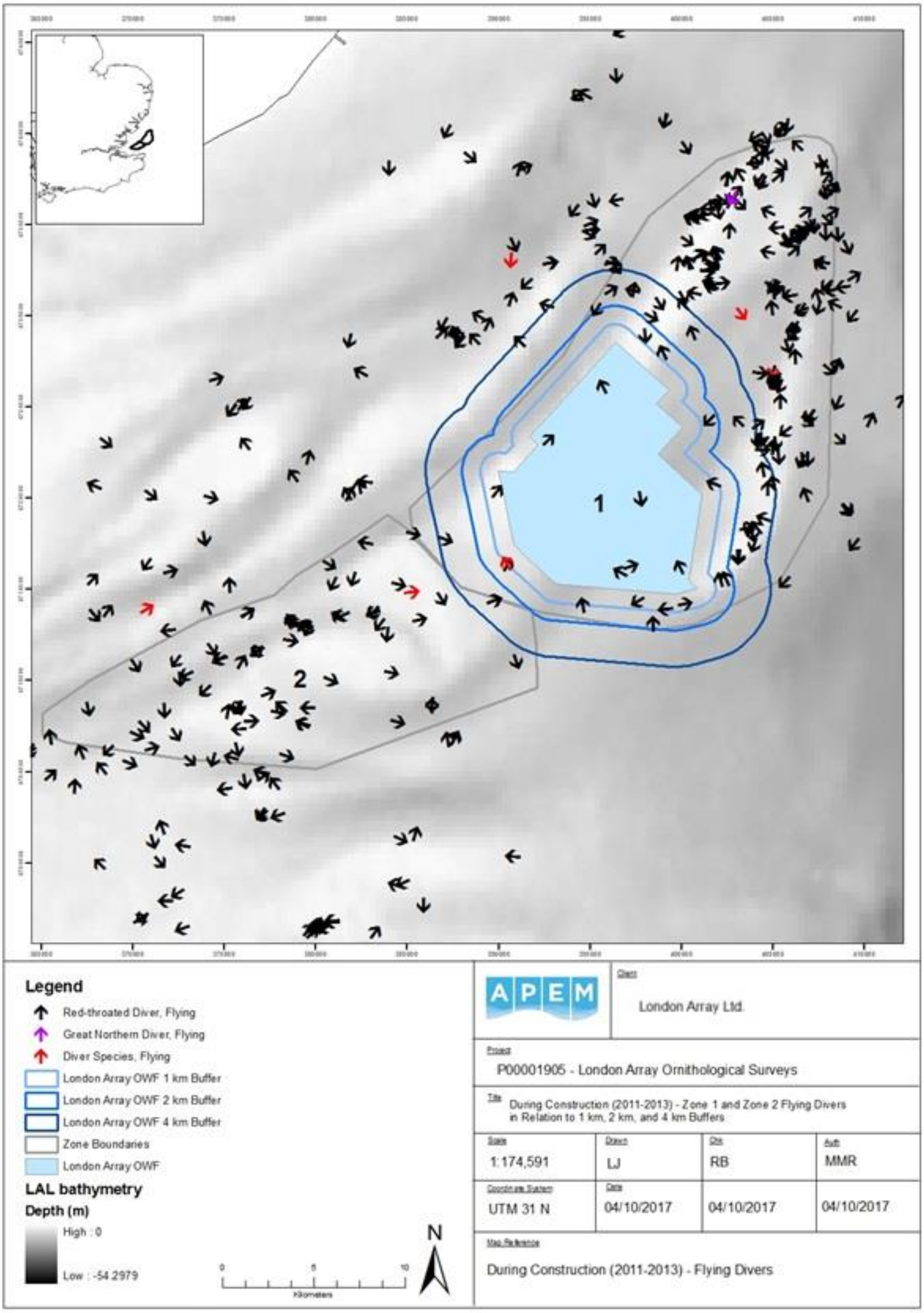

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Figure 19 Distribution of flying divers recorded during the construction phase digital aerial surveys (November 2011 to February 2013).

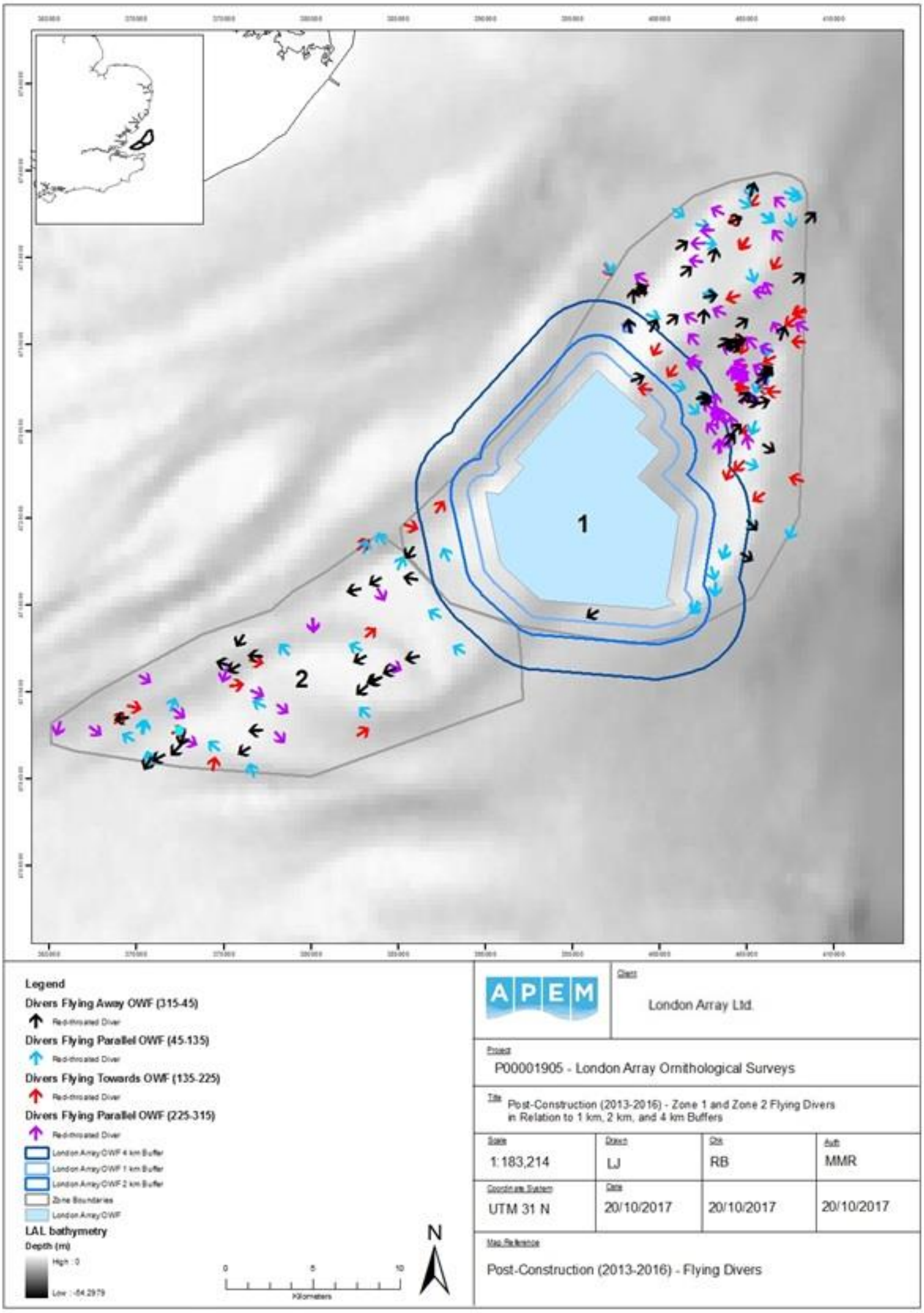

Figure 20 **Distribution of flying divers recorded during the post-construction phase digital aerial surveys (November 2013 to February 2016).**

The total number of flying divers recorded in the different buffer regions during each construction phase is summarised in Table 11.

Table 11 Counts of flying divers per construction phase and per buffer region (LAW = London Array Offshore Wind Farm).

Region	Pre-Construction[1]	During Construction[2]	Post-Construction[3]
LAW	8	6	0
LAW - 1 km	3	7	1
1 km - 2 km	1	7	4
2 km - 4 km	2	23	31
Zone 1 Total	100	186	150
Zone 2 Total	7	71	60

[1] 2010-2011 - One year of London Array surveys (Nov-Feb). The pre-construction year 2009/2010 was not included.
[2] 2011-2013 - Two years of London Array surveys (Nov-Feb) and two Outer Thames surveys (Jan-Feb).
[3] 2013-2016 - Three years of London Array surveys (Nov-Feb).

The counts of flying individuals (Table 11) were weighted by the total surveyed coverage for each phase per buffer to make it possible to assess how the density of flying birds varied with distance to the wind farm (Figure 21).

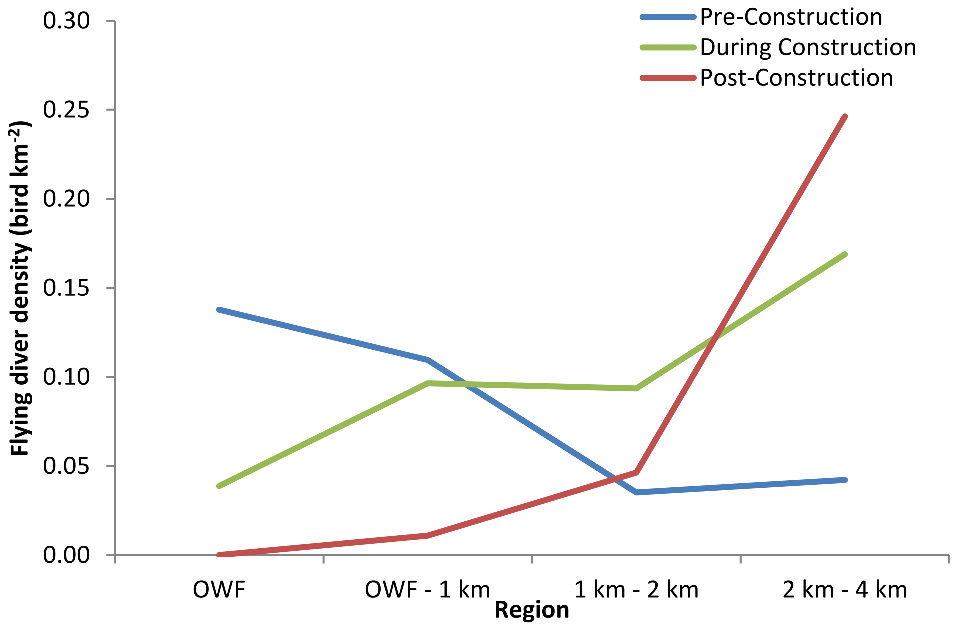

Figure 21 Differences in flying diver densities between the pre-, during-, and post-construction phases.

Figure 21 shows that in the pre-construction phase the density of flying divers is high within the proposed footprint of the wind farm and falls to lower levels with increasing distance from the proposed footprint of the wind farm. Opposite trends in flying diver densities are observed in the during- and post-construction phases with low (during construction) and no (post-construction) flying divers within the footprint of the wind farm and rising densities of flying birds with increasing distance from the footprint of the wind farm.

Stage 2 Analysis of flight directions

Table 12 summarises the flight directions of the flying divers used for the χ^2 test, with two regions included for analysis: LAW to 4 km, and greater than 4 km within Zone 1. Due to the limited number of flying divers recorded in the wind farm and the 1 km buffer, it was necessary to combine the buffer regions to ensure that the assumptions of the χ^2 statistic were met. Specifically, that no more than 20% of the expected counts are less than five and that all individual expected counts are one or greater (Yates, Moore & McCabe, 1999). Typically, a minimum of five observed values per group is required to run a χ^2 test without violating the statistical assumptions.

Table 12 Counts of flying divers during the post-construction phase per buffer region. Directions are relative to the nearest turbine of the London Array Wind Farm.

Region	Flying towards wind farm (135-225°)	All other trajectories (225-135°)	Total
LAW to 4 km	5	31	36
> 4 km in Zone 1	24	90	114
Total	29	121	150

There would be evidence of a barrier effect if the proportion heading toward the wind farm (the 135-225° quadrant) was significantly different between the two regions. A χ^2 test indicates how likely it is that flight direction and region are completely independent; in other words, the test indicates how likely it is that the distribution of individuals by region for each flight category occurred due to chance. There was no evidence to suggest that fewer (or more) divers were flying towards the nearest turbine between the two regions ($\chi^2_1 = 0.900$, n = 150, $P > 0.05$; based on the observed numbers presented in Table 12).

To further investigate the flight direction by buffer region, due to the small number of divers in flight, an additional method using bootstrapping was applied. The full dataset (e.g. the relative bearing to the nearest turbine for each diver in the '> 4 km in Zone 1' region; n = 114) was resampled 999 times, using only the values in the original dataset, which resulted in 999 quadrant directions (towards, away, or parallel) for each flying diver recorded during the surveys. The proportion of birds flying towards the nearest turbine in each of the 999 resampled datasets was calculated (see Table 13).

Table 13 Example dataset of flying red-throated divers, their original quadrant direction relative to nearest turbine, and the resampled quadrant direction (X1 to X999), with the number of individuals flying toward the nearest turbine calculated as a proportion of the total dataset.

Bird No.	Easting	Northing	Common Name	Quadrant Direction	Resampled No.					
					X1	X2	X3	X4		X999
1	400740	5731457	Red-throated Diver	A	P	A	T	T	…	A
2	404250	5729879	Red-throated Diver	T	T	A	A	T		T
3	407991	5733820	Red-throated Diver	P	P	P	P	P		A
4	401514	5734234	Red-throated Diver	A	A	A	A	P		P
5	405888	5726709	Red-throated Diver	P	P	T	A	T		T
6	404718	5731249	Red-throated Diver	A	A	P	A	A		P
No. of T/(A+P+T)				0.17	0.17	0.17	0.17	0.50		0.33

Table 14 presents the number of the 999 bootstrapped samples of diver flight directions that have 25% or less (equal to or less than 1 in 4) flying individuals flying towards the LAW. The probability values were calculated by dividing the number of occurrences that each bootstrap had more or less than 25% of flying divers towards the LAW by the total number of bootstraps (n = 999) for each region in question: LAW to 2 km, 2 km to 4 km, > 4 km in Zone 1 (Table 14). For example:

43 ÷ 999 = 0.043 (see Table 14)

The five divers observed in flight within 2 km of the LAW, resampled to provide 999 bootstrapped samples, did not provide evidence that the divers tended to fly away from the wind farm ($P > 0.05$). Resampling of the 31 divers in flight between the 2 to 4 km buffer region of the LAW, produced 956 of 999 samples that had 25% or more of the divers flying away or parallel to the wind farm, thus the null hypothesis that the divers are as likely to fly towards the wind farm as in other directions can be rejected ($P < 0.05$). The 114 divers observed in Zone 1 in flight beyond 4 km of the LAW, resampled to provide 999 bootstrapped samples, did not provide evidence that the divers tended to fly away from the wind farm ($P > 0.05$).

Table 14 Raw counts and proportion of bootstrapped samples of flying divers present in each buffer region during the post-construction phase and the probability that such a proportion of bootstraps would occur by chance.

Region	Raw Counts		999 Bootstraps		Probability value *P < 0.05
	Towards LAW (135-225°)	All other trajectories (225-135°)	≤ 25% Towards LAW (135-225°)	>25% Towards LAW (135-225°)	
LAW to 2 km	1	4	730	269	0.269
2 km to 4 km	4	27	956	43	0.043*
> 4 km in Zone 1	24	90	851	148	0.148

5.4 Discussion

Objective 2 of the Marine Licence is as follows:

- *Determine whether there is a barrier effect to the movement of birds through the wind farm site, 1 km and 2-4 km buffer zones.*

The effect of LAW acting as a barrier to divers was predicted in the ES to result in either a reduced utilisation of ecological resources (through birds no longer being able to reach them as a result of the “barrier”) or a significantly increased energy expenditure by the birds as a result of having to fly around the barrier (London Array Limited, 2005).

To meet Objective 2 of the Marine Licence a two-stage data interpretation was undertaken to determine whether the LAW creates a barrier effect to the movement of diver species through the wind farm.

Stage 1 Distribution of birds

A greater number of flying divers were observed in the north-eastern region of Zone 1 during all construction phases (Figure 18 to Figure 20) than in the pre-construction phase. This is unsurprising as the overall highest densities of divers; both sitting and flying, occurred in the northern area and eastern edge of Zone 1 (see Divers in Section 4.2). A combination of water depths of less than 20 m and the presence of sand banks makes this area a preferred habitat for divers (Skov & Prins, 2001).

Unlike during the pre-construction period, during the post-construction phase no flying divers were recorded within the LAW footprint. As there is some evidence that divers may be sensitive to shipping disturbance (Camphuysen *et al*., 2004; Schwemmer *et al*., 2011, Burger *et al.,* 2019), it is possible that shipping may be disturbing the divers. However, any effect of disturbance could also be due to other operational activities inside the wind farm boundary or by the turbines themselves. It is also not possible to discount the changes in local environmental conditions, or diver population size in some years (Maclean *et al*., 2013) could fully or partly explain the observed changes in observed diver numbers in the area.

Flying diver densities were found to have increased 1 to 4 km away from the LAW during the post-construction phase in comparison to the pre-construction phase (Figure 18 and Figure 20). This would be consistent with divers displaced from the LAW footprint and near environs, utilising adjacent airspace.

Interpretation of this information is not straightforward as there can be large variations in seabird numbers between years even in areas unaffected by developments (Maclean *et al*., 2013), and divers in particular have been known to vary considerably in numbers within the OTE SPA (Goodship *et al*., 2015). Such variation may be explained by a range of factors including environmental variables such as weather patterns (e.g. changing conditions on wintering or breeding grounds), tide, food availability, diurnal variation in diver movements affecting the number of individuals present at the time of each survey, possible (combined) effects following construction in the area or a combination of these factors (Goodship *et al*., 2015), as well as the overall population size of the species.

The observed changes in diver flight numbers suggest a possible barrier effect created by the LAW but this is unproven. The observed effects of no flying birds within the footprint post-construction and an increasing density of flying birds away from the wind farm are consistent with displacement (see Section 6) and do not necessarily infer a barrier effect.

Stage 2 Analysis of flight directions

Using the trajectories of flying birds recorded from the LAW to 4 km buffer, and greater than 4 km in Zone 1, a χ^2 test was carried out to determine whether there was any evidence that divers were less likely to fly towards the LAW, if so suggesting that the birds may be avoiding the wind farm and thus that it could be acting as a barrier to their movements. This analysis indicates that there was no significant difference in the proportion of divers flying towards the nearest turbine of the LAW (Table 12) between the two regions ($\chi^2_1 = 0.900$, n = 150, $P > 0.05$). On this basis there appeared to be no difference in the proportion of divers flying toward the nearest turbine within 4 km of the LAW versus greater than 4 km of the LAW, suggesting that divers did not alter their flight trajectory between the two regions. However, the number of flying divers recorded was low, especially in the buffer regions nearest to the LAW.

To further investigate flight trajectories, additional analysis of flight directions was undertaken based on data bootstrapping. The results of this analysis showed that in the

2 km to 4 km buffer region, significantly fewer divers than expected by chance were recorded flying toward the wind farm ($P < 0.05$). For the remaining buffer regions, LAW to 2 km and greater than 4 km, no significant difference was found between the number of divers flying towards the OWF and in other directions. Only five divers being recorded in flight from the LAW to 2 km buffer region makes the power of any test very weak, and therefore, little weight can be placed on its outcome for this region.

Unfortunately, as the flight directions of divers before construction of the LAW are unknown; it is not possible to test whether diver behaviour (flight direction in relation to the wind farm) has changed with wind farm construction. The present tendency of divers to avoid flying towards the OWF may reflect a flight preference of the birds unrelated to the LAW. The large majority of the divers in the 2 to 4 km buffer being east of the LAW (Figure 3), it is possible that the divers prefer to avoid flying in a broadly east-west direction which would explain the apparent tendency of the birds to avoid flying towards the LAW for reasons unrelated to the wind farm. Why the birds would have such a preference is uncertain, but it could relate to any predominant wind directions which would increase the energy requirements of birds flying into the wind. The average wind direction for the days surveyed during the post-construction period was south-westerly (SSW; 212°, n=9) based on Met Office data from an observation site at Shoeburyness on the coast. Assuming that the wind direction is similar offshore, and given that the majority of divers were recorded in the north east region of Zone 1, it is conceivable that the apparent avoidance of LAW by the divers is a result of these birds avoiding to fly into the wind (and therefore the LAW). However, if this were so one would expect to observe a similar avoidance of south-westerly flight by divers in the more than 4 km buffer region, but no such avoidance was identified.

The flight trajectory and distribution of flying birds across the buffer regions observed during all surveys including the post-construction surveys is likely to reflect changing abundances and distributions of prey with tidal state (Kaiser *et al*., 2006; Skov & Prins, 2001) which could lead to a predominant direction of flight that, although unrelated to the LAW, suggests that the LAW could act as barrier to diver movements. This analysis designed to detect the possible presence of a barrier effect does not take habitat preferences and tidal states into account. However, as flying divers were captured at different times and dates throughout the post-construction period (Appendix 4: Figure 1) and each survey took several hours to complete, it is most likely that the flying divers were captured at a range of different tidal states making the outcome of the analysis defensible.

Barrier effects are less likely to be an issue for migrating divers as the energetic costs associated with diverting around a wind farm are likely to be relatively small in the context of total distance travelled (Masden *et al*., 2009). Modelling the foraging flights of breeding seabirds has revealed that any prolonged flights brought about by the need to circumvent OWFs acting as barriers are likely to have less effect on breeding seabirds than low food abundance or adverse weather (Masden *et al*., 2010). Barrier effects could be of greater importance to resident wintering divers as any barrier effect could stop them making most use of food resources that are on both sides of an obstruction for the duration of their time in the area, or making them have to fly around the obstruction on a regular basis to access these resources. When facing an obstruction, Masden *et al*. (2010) indicated that of the seabird species with contrasting morphologies, species with high wing-loading ratios, such as divers, would incur the greatest energetic costs associated with additional foraging distances. However, as the area covered by the OTE SPA consists of large areas of favourable feeding habitat for divers the effect on energy expenditure would be expected to be negligible. Any potential loss of habitat is not included in the barrier effect assessment and would specifically relate to the LAW (see Section 7).

Overall, there is a suggestion that the LAW may be providing a barrier to movement; with very few divers being found very close to the LAW and evidence of the divers avoiding flying towards the LAW when within 4 km of it. The displacement modelling (see Section 7 Assessment for Displacement) showed that proportionally fewer divers were recorded post-construction in comparison to pre-construction up to 11 km of the LAW, although interpretation is complicated by the significantly higher densities of divers estimated to be present post-construction than during construction. The results of the modelling also suggested that divers were redistributed with significantly greater densities in the southern region of Zone 2 and a small pocket in the northern corner of Zone 1. As flying divers were recorded within the LAW footprint during its construction, this suggests that it does not provide a complete barrier to diver movement during this phase but it is not known if those few flying divers were in a section of the part-constructed wind farm where turbines were erected. However, no flying divers were recorded during post-construction in the LAW footprint (Figure 20) suggesting a complete local barrier effect.

It was not possible to determine whether the LAW was acting as a barrier to movement to other areas of habitat outside of the LAW due to the large extent of the OTE SPA. Thus, even if the LAW were to be acting as a barrier to flying divers in particular regions in the OTE SPA, it is unlikely that slight deviations in flight trajectories to avoid the LAW would have detrimental energetic consequences in a species that moves over larger geographic scales. Since the analysis was of diver flying directions relative to the nearest turbine, any loss of habitat for the divers would be specifically in relation to the proximity to the LAW. This form of barrier effect is better considered to be the result of a displacement effect.

5.5 Summary

No flying birds within the footprint and a trend for increasing densities of flying divers away from the LAW post construction suggest a possible barrier effect. However, it is difficult to discount that these observations are a result of displacement.

The evidence that divers avoid flying towards the LAW when within 4 km of it provides stronger evidence of a possible barrier effect created by the LAW. Although displacement could explain the relatively small number of divers observed flying in the vicinity of the LAW, the few detected individuals did seem to actively avoid flying towards the LAW. For foraging flights of breeding seabirds modelling has revealed that any prolonged flights brought about by the need to circumvent OWFs acting as barriers have less effect on breeding seabirds than low food abundance or adverse weather (Masden *et al*., 2010). The area covered by the OTE SPA consists of large areas of favourable habitat for divers. If the LAW were to be acting as a localised barrier to wintering diver movement, the extra energy expenditure of the divers is expected to be negligible.

Since the analysis was based on diver flying directions relative to the nearest turbine, any loss of habitat for the divers would be specifically in relation to the proximity to the LAW. This form of barrier effect, i.e. potential loss of habitat relating to areas within the LAW, is defined as displacement (refer to Section 7).

6. Assessment for Collision Risk

6.1 Introduction

Objective 4 of the Marine Licence relates to the potential of LAW to elevate the risk of bird collision mortality through changes in bird use of, and behaviour at, the wind farm site:

- *If objectives 1 or 2 reveal significant change of use of the wind farm site and 1 km and 2-4 km buffer zones by populations of conservation concern, at heights that could incur collision, a programme of collision monitoring will be implemented.*

The purpose of the analysis set out in this section is to determine whether there has been a change in use of the wind farm by flying birds - that behaviour placing them at risk of collision. It will also test whether the predictions made in the ES in relation to the number of birds at potential collision risk are consistent with the as-built situation.

Objective 4 focuses attention on bird "populations of conservation concern". The ES identified the species of concern with respect to potential collision mortality as:

- Red-throated / black-throated diver;
- Large gull species (herring gull, lesser black-backed gull, great black-backed gull);
- Small gulls (kittiwake, common gull, black-headed gull); and
- Gannet.

The ES assessed the likelihood of a significant impact arising from collision mortality and identified a likely significant effect for divers. As divers were anticipated to be displaced by the wind farm it can be expected that the risk of collision can be reduced to non-significant levels. Section 7.3 describes the outcome of diver displacement at LAW.

The ES also assessed the likelihood of a significant impact arising from collision mortality to large gulls, small gulls and gannets. The potential impact was identified as possibly significant for large gulls and gannets and not significant for small gulls. These species are included in the analysis for any change in use of the site by flying birds.

Two approaches were used to investigate changes in flight behaviour using the data available. The first approach was to undertake a comparison of flying bird density using the post-consent aerial digital still monitoring data: pre-construction (2010 / 11) versus post-construction (2013 to 2016). The second approach was to investigate possible change in the collision risk of flying birds by comparing the post-construction data against the baseline data originally assessed in the ES.

6.2 Methods

For the first approach, the datasets used in the analysis are those obtained from the aerial digital surveys conducted in the periods of pre-construction (2010/11) and post-construction (2013-2016). These two datasets are compared to determine whether there has been any change in the use of space and the behaviour of birds at the wind farm site.

As we do not have flight height information for the birds, this assessment assumes that collision risk for a species is directly proportional to the number of individuals present in the LAW footprint and environs. The assessment is predicated on the premise that there would be more collisions if more birds are present. This assumption would be at best simplistic and at worst wrong if the birds changed their flying behaviour (height and speed) in response to the turbines.

Pre-construction data from 2009 / 10 (the pilot study period) were not included in the dataset of flying bird densities for numerous reasons. The months the surveys took place (December, January, February and April) did not fully coincide with subsequent survey months for the monitoring period 2010 to 2016 (November, December, January, February); the survey coverage of Zone 1 was incomplete for the third survey February 2010, meaning it was not easily comparable to other surveys; behaviour was not recorded during the first survey of the pilot study (December 2009); and there was only a single unidentified large flying gull in the LAW in January 2009.

The post-consent monitoring surveys were specifically aimed at recording red-throated diver information. This means that the aerial surveys were confined to the winter season (November to February inclusive). As such, data do not exist for any analysis that would cover the remainder of the year, including the breeding season.

The data of flying birds used in the analysis consist of raw counts contained within ArcGIS files obtained from the monitoring period of pre-construction (2010/11) and post-construction aerial digital surveys (2013 to 2016). Flying bird density data are also provided for Zone 1 and Zone 2 for the purposes of context.

The datasets contained unidentified specimens, placed into species group categories (e.g. large gull species). If unidentified specimens were 5% or greater across the year of the total of each group recorded, an apportionment exercise was undertaken to divide these individuals into the relevant positively identified species that were recorded within the same month. In months where no positively identified individuals were recorded, an apportioning exercise of the unidentified individuals was not undertaken. Unidentified individuals are often those that are sitting on the water and less often those that are in flight because more features are visible in flying birds enabling species identification. As such there were very few unidentified individuals that were recorded in flight within the LAW. Although it would have been possible to apportion these individuals using species' ratios from other months, that could have led to large errors in the numbers of each species present as the proportion of species present can vary a significantly between months. In the pre-construction period, an apportioning exercise was undertaken to account for individuals classified as small gulls and divers. In the post-construction period, the number of unidentified individuals did not meet the 5% threshold and as such no apportionment was undertaken. In total two individuals recorded in flight within the LAW classified as small gulls in the post-construction period were not included in the results, which was an average density of 0.01 birds km^{-2}.

The density of flying individuals within LAW was calculated for each species for each survey month based on the number of individuals in flight and the area surveyed. The peak density estimates per development phase of each key species were identified (accounting for unidentified individuals) and qualitatively compared between pre-construction and post-construction (Table 16), meaning these values are not an underestimate and account for a worst-case scenario.

For the second approach, the predicted numbers of collisions in the ES was assessed for the proposed LAW to determine whether they are realistic. The expected number of collisions in the LAW is extrapolated from the estimated number of collisions in the ES. For each species, the change in the number of collisions in the LAW from that predicted in the ES will be proportional to changes in the density of the species in the wind farm footprint, the number of turbines in the footprint, the rotor swept zone of each turbine, and species' specific parameters such as its flight speed and flight height. This project did not have flight height information for the surveyed birds and it was assumed that the birds' flight heights did not change from those used in the ES. The same assumption is made about the species' flight speeds. Avian flight speed appears to be a species-specific feature that varies within certain physiologically determined bandwidths (Alerstam *et al.,* 2007). Furthermore Ainley *et al.* (2015) presented evidence for how morphological and environmental (wind speed) factors influenced the height at which seabirds flew and therefore their relative sensitivity to OWFs. For flight height, this is likely to necessitate accurate and precise longitudinal measurements to ensure that differences are detectable (Cook *et al.,* 2018).

Based on these assumptions the change in the estimated number of collisions for each species in the LAW from that predicted in the ES will be directly proportional to the change in the species' densities used for the ES and those recorded post-construction, and the ratio of the total rotor swept zones used in the built wind farm to that estimated in the ES. Applying that ratio of 0.6458 (Table 15) to the ES collision estimates corrects them to allow for the smaller than planned number of turbines in the built wind farm. Applying this ratio will always lower the expected number of collisions. Then, these new expected numbers of collisions are finalised for the built wind farm by multiplying them by the change in each species' density used in the ES and observed in the built LAW.

Table 15 Turbine parameters used to generate the ratio between the total turbine rotor swept zones used for the ES collision calculations and as exists in the LAW.

Parameters	Method	ES	LAW	Ratio LAW:ES
Turbine diameter (2r)		150 m	150 m	
Number of turbines		271	175	
Turbine model		3.6 MW Siemens	3.6 MW Siemens	
Total rotor swept area (m^2)	No turbines $\times \pi r^2$, where r = turbine radius	$=271 \times \pi \times (150/2)^2$ m^2 $=4{,}788{,}965.30$ m^2 $=4.789$ km^2	$=175 \times \pi \times (150/2)^2$ m^2 $=3{,}092{,}505.27$ m^2 $=3.093$ km^2	0.6458

6.3 Results

6.3.1 Comparison of pre-construction and post-construction post-consent data

The peak flying densities of each key species recorded in flight in the LAW footprint during the monitoring aerial digital still surveys are presented in Table 16. The pre-construction year comprised of 2010/11 data and the post-construction years comprised of 2013 to 2016 data. No other species of diver, small or large gulls were identified in flight during the two phases.

Table 16 Peak flying bird densities within the wind farm footprint pre- and post-construction of LAW (winter 2010/11 vs 2013-16). Numbers in bold represent the peak value recorded during the pre- and post-construction periods. Numbers in italics contain apportioned individuals.

Species	Peak Flying Density (bird km^{-2})		Difference (bird km^{-2})
	Pre-Construction	Post-Construction	
Red-throated diver	***0.33***	0.00	-0.33
Gannet	0.07	**0.13**	+0.07
Lesser black-backed gull	0.00	**0.13**	+0.13
Herring gull	0.00	**0.07**	+0.07
Great black-backed gull	0.00	**0.40**	+0.40
Kittiwake	*0.57*	**0.72**	+0.16
Common gull	*0.08*	**0.33**	+0.25
Black-headed gull	*0.08*	**0.13**	+0.05

There was a reduction in the density of flying divers in the footprint recorded post-construction compared to pre-construction. No flying divers were recorded in the LAW footprint during the post-construction phase. There were increases in the densities of flying gannets, and all large and small gulls recorded during the post-construction phase in the footprint.

The changes in density must be considered in the context of the relatively small bird counts that these densities represent. Some of the changes are so small that they could just represent chance events, strongly depending on detection probabilities and species identification rates varying among different years with different survey conditions. These changes in density in the LAW footprint between the pre- and post-construction phases equate to the following numbers of birds:

- Red-throated diver five versus zero;
- Gannet one versus two;
- Lesser black-backed gull zero versus two;
- Herring gull zero versus one;
- Great black-backed gull zero versus six;
- Kittiwake seven versus eleven;
- Common gull one versus five; and
- Black-headed gull one versus two.

Figure 22 demonstrates the absolute change in peak flying density between the pre-construction and post-construction phases for each of the key species recorded within the LAW footprint, Zone 1 and Zone 2.

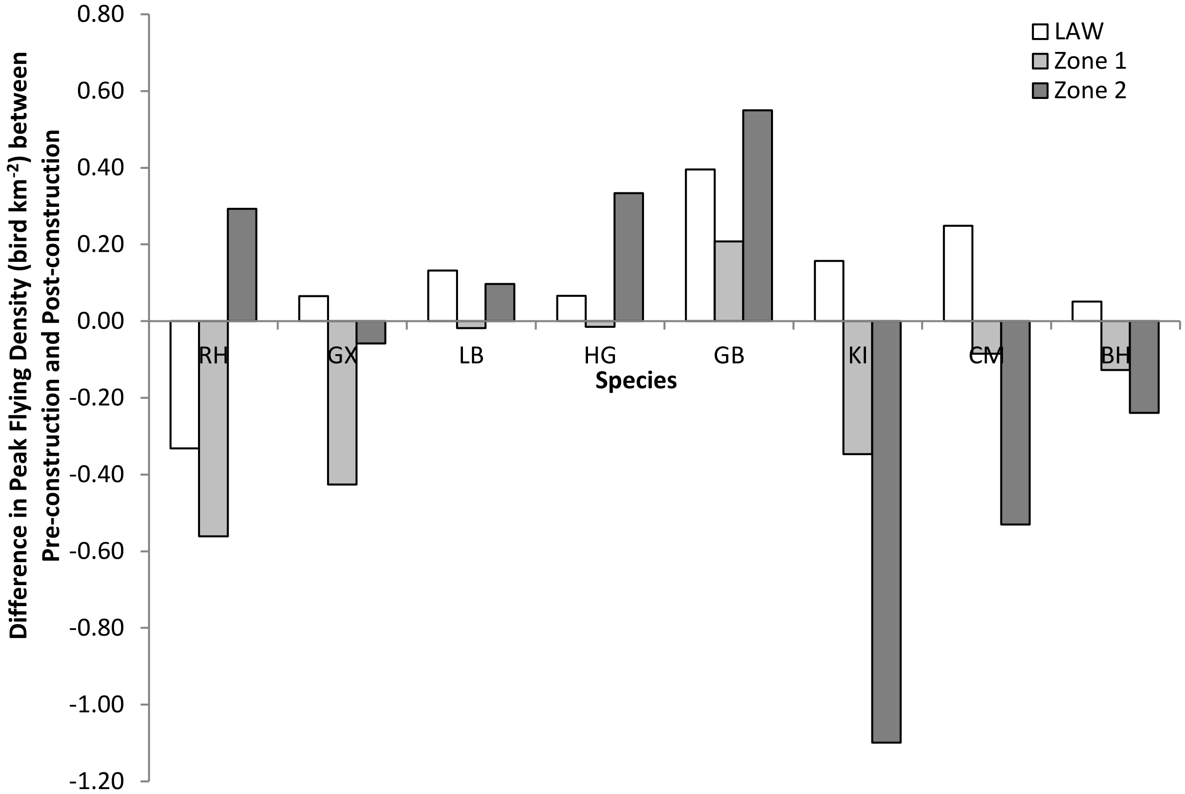

Figure 22 Difference in peak density of flying birds between the pre- and post-construction phases (winter 2010/11 vs 2013-2016) within the LAW footprint, Zone 1, and Zone 2 for each of the key species.

Figure Notes: Species key - red throated diver (RH), gannet (GX), lesser black-backed gull (LB), herring gull (HG), great black-backed gull (GB), kittiwake (KI), common gull (CM), and black-headed gull (BH). A value greater than zero indicates an increase in density post-construction.

No red-throated divers were recorded in flight during the post-construction phase in the LAW footprint. Whereas flying red-throated diver densities reduced in Zone 1 post construction they increased in Zone 2 (Figure 22).

Gannet, kittiwake, common gull, and black-headed gull flying densities were lower post construction than pre construction in Zones 1 and 2, but their flying densities in the LAW footprint were higher post-construction than pre-construction (Figure 22). It is important to note that the changes in the LAW relate to very few individuals e.g. from one to two gannets.

Great black-backed gull flying density increased in Zones 1 and 2 and the LAW footprint post construction (Figure 22). Lesser black-backed gull and herring gull flying densities increased post construction in the LAW footprint and Zone 2 but decreased in Zone 1 (Figure 22).

6.3.2 Comparison of post-construction data against Environmental Statement (ES)

The numbers of collisions estimated to occur in the LAW were lower than those predicted in the ES for red-throated diver, gannet, lesser black-backed gull, herring gull, and great black-backed gull (Tables 16 and 17). Kittiwake, common gull and black-headed gull were not assessed for collision risk in the ES. It is important to note that the mean flying density and collisions obtained from the ES are assumed to be per annum estimated from January to December (Table 17, column A in Table 18). However, the values presented for the post-construction period are mean monthly densities based on data collected November to February due to the timing of the surveys in the monitoring period (Table 17). It is not possible to convert these mean monthly densities from the post-construction period to an estimated per annum figure as sea bird densities change from month to month. Therefore caution is required when interpreting these differences.

Table 17 Mean flying bird densities used in the ES (assumed to be per annum) to estimate collisions and within the LAW footprint post-construction (based on flying densities captured November to February in 2013-2016). No small gull densities are provided in the ES.

Species	Mean Flying Density (bird km^{-2})		Proportion of birds flying in LAW footprint compared to ES
	ES (based on 303.7 km^2 – old LAW + 1 km buffer)	LAW Post-Construction (100.8 km^2)	
Red-throated diver	0.16	0.00	0.00
Gannet	0.07	0.02	0.23
Lesser black-backed gull	0.67	0.02	0.03
Herring gull	0.55	0.05	0.10
Great black-backed gull	0.09	0.10	1.06
Kittiwake	n / a	0.32	n / a
Common gull	n / a	0.12	n / a
Black-headed gull	n / a	0.01	n / a

Table 18 Predicted change in the numbers of collisions in built LAW (based on flying densities captured November to February in 2013-2016) from the numbers predicted in ES (assumed to be per annum). No change is presented for small gulls as they were not included in the ES.

Species	Predicted Collisions in ES A	Ratio turbines LAW:ES B	Proportion of birds flying in LAW footprint compared to ES C	Predicted Collisions in LAW (A × B × C)
Red-throated diver	20	0.6458	0.00	0
Gannet	12	0.6458	0.23	2
Lesser black-backed gull	115	0.6458	0.03	2
Herring gull	110	0.6458	0.10	7
Great black-backed gull	15	0.6458	1.06	10
Kittiwake	n / a	n / a	n / a	n / a
Common gull	n / a	n / a	n / a	n / a
Black-headed gull	n / a	n / a	n / a	n / a

6.4 Discussion

The results of this analysis of collision risk based on the peak densities of various species recorded during the pre- and post-construction phases of LAW indicate that the collision risk for red-throated divers is likely to be minimal as the flying diver density in the footprint, where the divers could encounter turbines, dropped to zero. This is likely to be due to the species showing significant avoidance (e.g. Garthe & Hüppop, 2004) and displacement (Section 7 of this report) in response to manmade structures.

The densities of the other key species increased within the LAW footprint post-construction. This potentially presents an increase in the risk of collision mortality, but the numbers of birds concerned are very low. The increase in collision mortality, however small, may be fully or partly counteracted by the built wind farm comprising fewer turbines than used as a basis for the ES predictions (see below).

Gannets, large gulls, and small gulls are known to be attracted to vessels and their density and abundance are known to vary based on the availability of local food resources (Mitchell *et al*., 2004). Built wind farms tend to weakly attract great black-backed, herring, lesser black-backed, common and black-headed gulls, have little effect on black-legged kittiwake abundance, and be strongly or almost completely avoided by red- and black-throated divers (Dierschke *et al*., 2016). With several factors that could be attracting or repelling the birds to be considered as well as the presence of the LAW, it is impossible to determine with any certainty what has led to the observed increase in the numbers of these species.

The numbers of collisions estimated to occur in the LAW were lower than those predicted in the ES for red-throated diver, gannet, lesser black-backed, herring gull, and great black-backed gull (Tables 16 and 17). A similar analysis was not possible for the smaller gulls as no densities were provided for them in the ES. It is important to note that the mean densities and collision estimates in the ES were assumed to be per annum, whereas the mean densities presented for the post-construction period were calculated from the estimates November to February. Due to species behaviour varying throughout each season, it was not possible to convert the monthly densities collected from November to February into per annum figures or vice versa. In addition, it is important to note that the LAW densities presented here are based on a mean of November to February (except lesser black-backed gulls) which is when seabird densities on The Thames tends to be at their highest of the year. Thus, if the assumption is correct that the ES collision figures are based on mean monthly densities per annum, then the analysis presented here will have rather over-estimated the collisions that could occur within the LAW relative to the estimates in the ES. However, no red-throated diver collisions were estimated to occur in the LAW. This is lower than that predicted in the ES for the species that the Marine Licence focuses on most.

6.5 Summary

Red-throated divers were not recorded in flight during the post-construction phase of the LAW and therefore the species is not expected to collide with the turbines. For gannet, lesser black-backed, herring gull, and great black-backed gull the estimated number of collisions is lower than that predicted in the ES primarily due to the reduced number of turbines installed at LAW compared to the number used in the ES predictions. The lower flying bird densities measured in the post-construction surveys compared to that included in the ES predictions also contributes to lower collisions estimates for all but great black-backed gull.

7. Assessment for Displacement

7.1 Introduction

The key species of concern for assessing the potential for displacement effects arising from the construction of the LAW were identified as divers during the ORP process. The survey design and seasonality were developed specifically for quantifying any potential change in diver abundance and distribution. It was agreed with the MMO and NE during the ORP process that auks would also be assessed for displacement using the same analytical techniques as for divers. Wildfowl species (a key species group of concern for displacement identified in the ES) were detected in such low numbers (Tables 10) that they were not included in this analysis for potential displacement effects. The ES assumed high levels of displacement would occur for divers.

Annex 2 of the Marine Licence contains two points relevant to the assessment of displacement:

- *Determine whether there is change in bird use and passage, measured by species (with particular reference to Red-Throated Diver), abundance and behaviour, of the windfarm site, 1km and 2-4 km buffer zones and the reference site.*
- *Continue to determine the distribution of wildfowl and divers in the Greater Thames estuary, covering the London Array windfarm site, 1km and 2-4 km buffer zones and the reference site.*

The aim of the displacement analysis of divers and auks is to quantify the likely magnitude of displacement at different distances (buffers) from the LAW.

7.2 Methods overview

APEM was commissioned by NE in 2016 with permission from London Array Ltd to undertake spatial modelling of diver and auk density based on relevant environmental variables following the first year of post-construction surveys. The purpose of the modelling was to identify any potential displacement impacts and to set up a suitable model framework for any subsequent analysis of the data collected at the LAW. The modelling presented in this report includes data following the final two years of post-construction surveys.

As part of the NE funded report a review of the environmental variables (including anthropogenic activities) which might influence the distribution of red-throated divers (and other species) was conducted. These were considered as factors to be accounted for in the analysis. APEM (2016) provides details of environmental data used in the analysis (selected based on the literature review conducted by APEM) and availability of the selected environmental variables. The same environmental variables have been included in the analysis presented in this report.

7.2.1 Modelling approach overview

In order to compare the effects of the LAW construction or operation on the abundance and distribution of divers and auks, it was necessary to utilise only the data that was available in a consistent manner in each of the three construction phases, namely, pre-construction, during construction and post-construction. All aerial digital still data (2009 to 2016) were used to build the initial model (see Table 6). However due to only Zone 1 and Zone 2 being surveyed throughout all three construction phases, only these areas could be compared for displacement analysis.

The following comparisons were undertaken between each of the development phases:

- Pre-construction versus during construction;
- During construction versus post-construction; and
- Pre-construction versus post-construction.

The bird data available for modelling comprised aerial digital data collected during ornithological monitoring surveys between 2009 and 2016, however earlier years (e.g. the pilot study of 2009/10) contained limited information on species identification (identification was to species group level only). Other available datasets were considered and investigated (APEM, 2016) but several factors precluded their use. The bird data from the aerial visual surveys and the boat surveys differs in a number of ways from the digital aerial stills data and there was insufficient overlap between the different survey platforms to be able to investigate if there were any significant differences in the numbers of birds recorded. This meant therefore that the modelling work proceeded using the digital aerial stills data from 2009 to 2016, by combining species into two groups: divers and auks to account for the limited number of individuals identified to species level in the pilot study period of 2009 / 10.

The data were analysed using a statistical package in R called MRSea (Marine Renewables Strategic Environmental Assessment). This statistical package was specifically developed to quantify any change in the density and/or distribution of animals in and around marine renewables development sites. This modelling technique is suitable for seabird and marine mammal distributions that are potentially very complex and uneven in the marine environment (Mackenzie *et al*., 2013). This method is currently the recommended guidance for analyses of this type (Mackenzie *et al*., 2013).

The methodological information presented in the following sections has been simplified to aid understanding to readers with no statistical knowledge. However due to the nature of the approach used and the specific terminology required for describing statistical methods, the information provided assumes some understanding of modelling techniques. Additional detail for the modelling approach is provided in Appendix 6.

7.2.2 Modelling approach in-detail

APEM collated diver and auk abundance data from the final two years of post-construction surveys and appended them to the previous dataset for the modelling undertaken on behalf of Natural England (APEM, 2016). Shipping data were also obtained and collated accordingly. APEM provided these data to The Centre for Research into Ecological and Environmental Modelling (CREEM), the developers of the MRSea statistical package in R, to undertake the modelling of divers and auks to investigate displacement effects.

The MRSea package uses ‘Complex Region Spatial Smoother’ spatial modelling techniques with a ‘Spatially Adaptive Local Smoothing Algorithm’ (CReSS-SALSA) to estimate bird (or mammal) distribution in a GAM (Generalised Additive Model) framework (Scott-Hayward *et al*., 2013). GAMs are used to account for the non-linear relationship between variables. Generalised Estimating Equations (GEEs) are additionally used in the ‘CReSS-SALSA’ modelling framework to provide coefficients and estimates of precision. GEEs are specifically designed to estimate and incorporate autocorrelation, which is a violation of spatial distribution modelling. Autocorrelation in data collected from offshore survey methods is likely due to data having a time-series element. Autocorrelation is the similarity between observations as a function of the time lag between them. For offshore survey methods, observations are more likely to be similar especially for data collected along the track lines. The ‘CReSS-SALSA’ method generates predictions of bird numbers across the study area (Scott-Hayward *et al*., 2013). The relevant environmental information was selected using a 10-fold cross-validation technique to inform the models for divers and auks based on all environmental data included in the dataset (see APEM, 2016 for further details about the relevant environmental data and a literature review). Cross-validation is a technique used to protect against overfitting in a predictive model. Overfitting is the production of a model that corresponds too closely to a set of data and may therefore fail to predict other observations reliably. In cross-validation, a fixed number of partitions (folds) of the data are created e.g. in a dataset of 100 observations, data can be partitioned into four separate folds of 25; the analysis is run for each fold; and then the average overall error is estimated.

The modelling approach of this report differed slightly to the modelling undertaken previously as described in APEM (2016). The different approach included the use of cross-validation to select covariates instead of probability which was previously used. In addition, amendments to the MRSea package have been undertaken since the previous modelling was completed [Scott-Hayward *pers. comm*.].

This analysis does not consider that there can be major differences in diver or auk densities between years; therefore, a lower density in a year does not necessarily mean that a local event in that year is the cause of that lower density. Local events can, however, be indicated, since MRSea identifies areas in which increases, and decreases occur. Should a decrease occur around the windfarm, whereas increases occur elsewhere, then this may indicate (but cannot causally explain) local events (cf. Mendel *et al*., 2019).

7.2.3 Prediction grid

The relevant environmental information based on the 10-fold cross-validation technique was used to generate the best model for divers and auks to predict the bird density and distribution across all development phases in Zone 1 and Zone 2. All the data from the relevant zones were used to inform the models. Bird density predictions were completed on Zone 1 and Zone 2 because these data spanned all development phases: pre-, during-, and post-construction.

The prediction grid was constructed by clipping a grid of 1 km² grid cells to the shapefile of Zones 1 and 2. This resulted in a final grid of 700 cells. Each grid cell was associated with each of the environmental variables listed in APEM (2016): Table 3. The results and buffer distances presented in this report relate only to the distances within the extent of the survey areas i.e. some of the buffers may not have been completely surveyed due to the irregularity in extent of Zone 1 and Zone 2 in relation to the LAW.

7.2.4 Spatially explicit inference

Spatially explicit inference is the process of predicting density estimates based on the best model fit. A parametric ‘bootstrap’ which was based on the robust standard errors was used to incorporate the autocorrelation. ‘Bootstrapping’ is a statistical term used to describe the technique of resampling from the dataset. For example, all observations are in a bag, one observation is drawn from the bag at random and recorded, the observation is put back into the bag (termed resampling with replacement), and this process is repeated for as many observations as originally recorded. This example would provide one iteration of resampled data. The analysis to be completed is then run on these resampled data. This can create thousands of predicted datasets which is used to generate the errors associated with a mean. This technique is considered a robust method for determining the 95 percentile intervals for predictions. In the case of the modelling presented here, 1000 iterations were used to determine upper and lower 95-percentile intervals for the predictions of divers and auks.

Following the prediction of diver or auk densities, spatially explicit maps of differences were used for assessment of changes in animal numbers between each of the development phases. The null hypothesis was that there was no difference between development phases in each grid cell. Grid cells with significant differences (where the probability was less than 0.05 i.e. 95%) were highlighted on the maps using ‘o’ for significantly negative, and ‘+’ for significantly positive. Significantly negative indicates a significant decrease in the density of divers or auks, and likewise significantly positive indicates a significant increase in the density of divers or auks (Figure 28, Figure 29, Figure 30, Figure 39, Figure 40, and Figure 41).

7.3 Results: Divers

Not all divers were identified to species level, especially in the earlier years of surveys. As red-throated divers are the predominant species in the Outer Thames Estuary, it was assumed that unidentified divers were red-throated divers and the modelling was carried out on the total of red-throated divers and unidentified divers.

The final diver model (the model that has the greatest explanatory power) is provided below. The final model covariates are provided in Table 19.

Additive predictor = construction phase(df=2) + s(chlorophyll, df=3) + s(sea surface temp, df=5) + s(thermal front probability, df=3) + s(x, y, df=9) + s(x, y):construction phase

Model dispersion parameter for the final diver model was 23.05. Model dispersion greater than 1 suggests that there is over dispersion and a large amount of noise (high variance in the count data) present in the underlying data. This supports the decision to fit an over dispersed model. Model diagnostics are shown in Figures 2 to 9 in Appendix 7.

Table 19 Final diver model covariates.

Covariate	Df	*P*-value
Construction Phase	2	<0.0001
s (Chlorophyll)	3	0.017
s (sea surface temperature)	5	<0.0001
s (thermal front probability)	3	<0.0001
s (x, y)	9	<0.0001
s (x, y): construction phase	18	<0.0001

Table notes: The ‘s’ before a covariate in brackets indicates that a smoothed term has been applied because the relationship with density is non-linear. ‘Df’ is Degrees of Freedom, and ‘*P*-value’ is the probability value where less than 0.05 indicates a significant relationship with density.

Observed values across the years within each of the development phases were plotted to give a visual indication of any change. This provided an average value across the surveys within Zone 1 and Zone 2 within the years classified to each construction phase. Figure 23, Figure 24, Figure 25, and Figure 26 provide the observed density of divers with associated lower and upper confidence intervals.

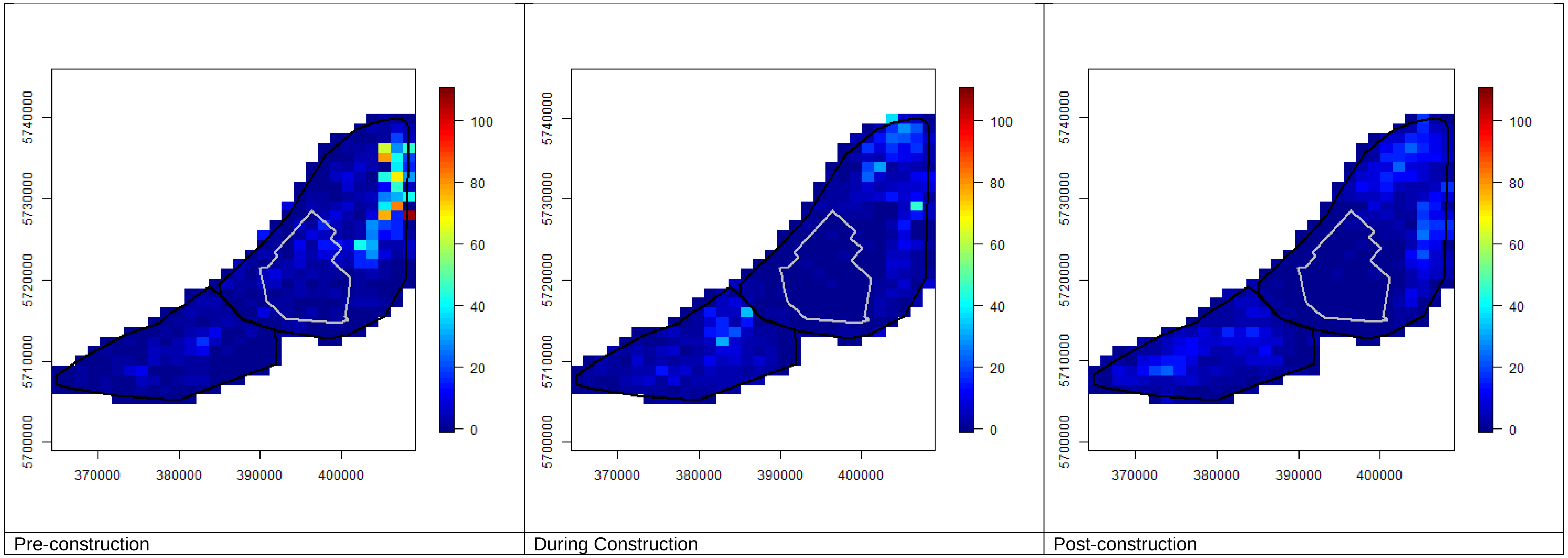

Figure 23 **Pre-construction, during construction, and post-construction mean observed diver density (birds km^{-2}).**

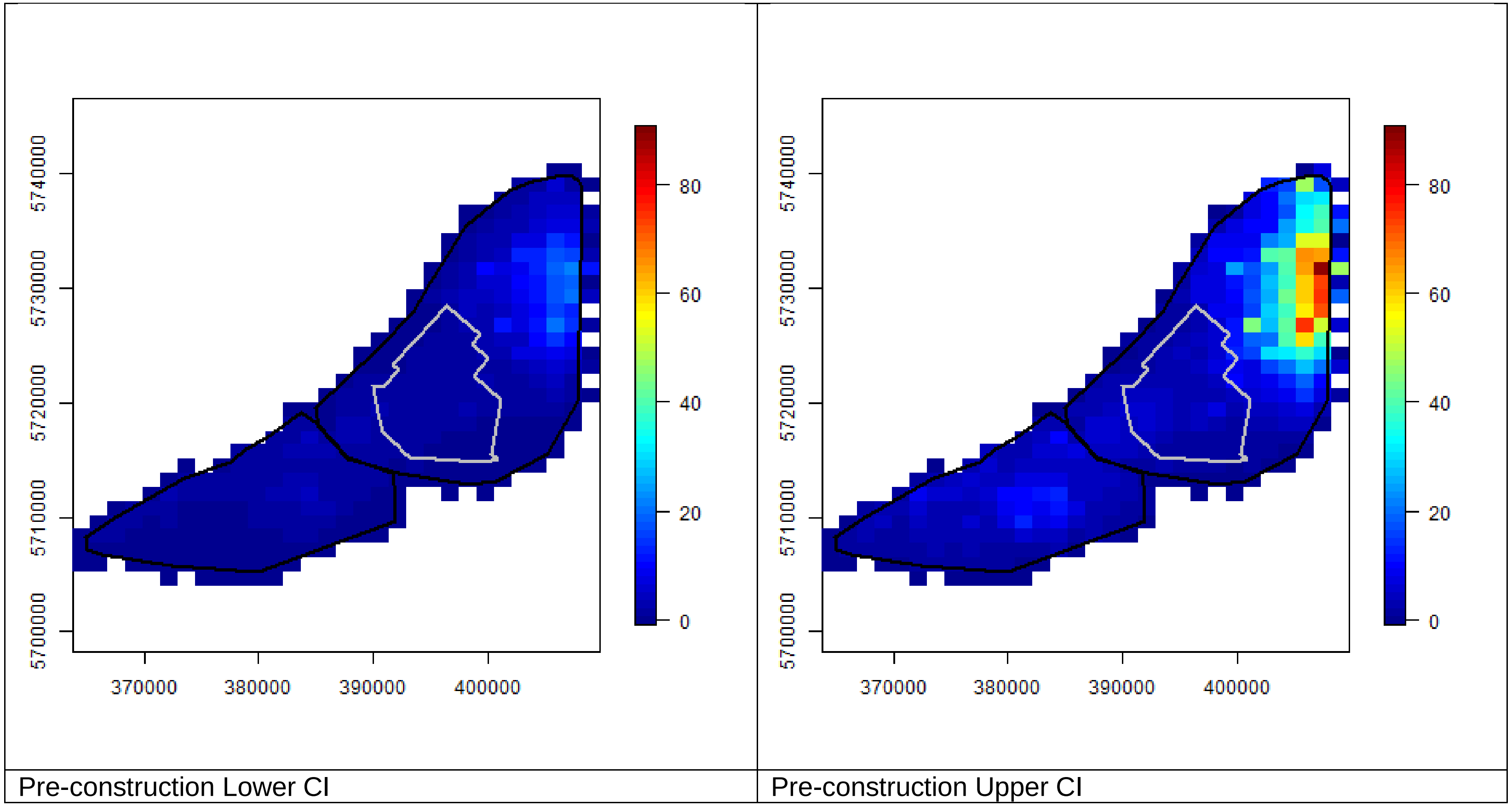

Figure 24 **Pre-construction diver density (birds km^{-2}) lower and upper confidence limits.**

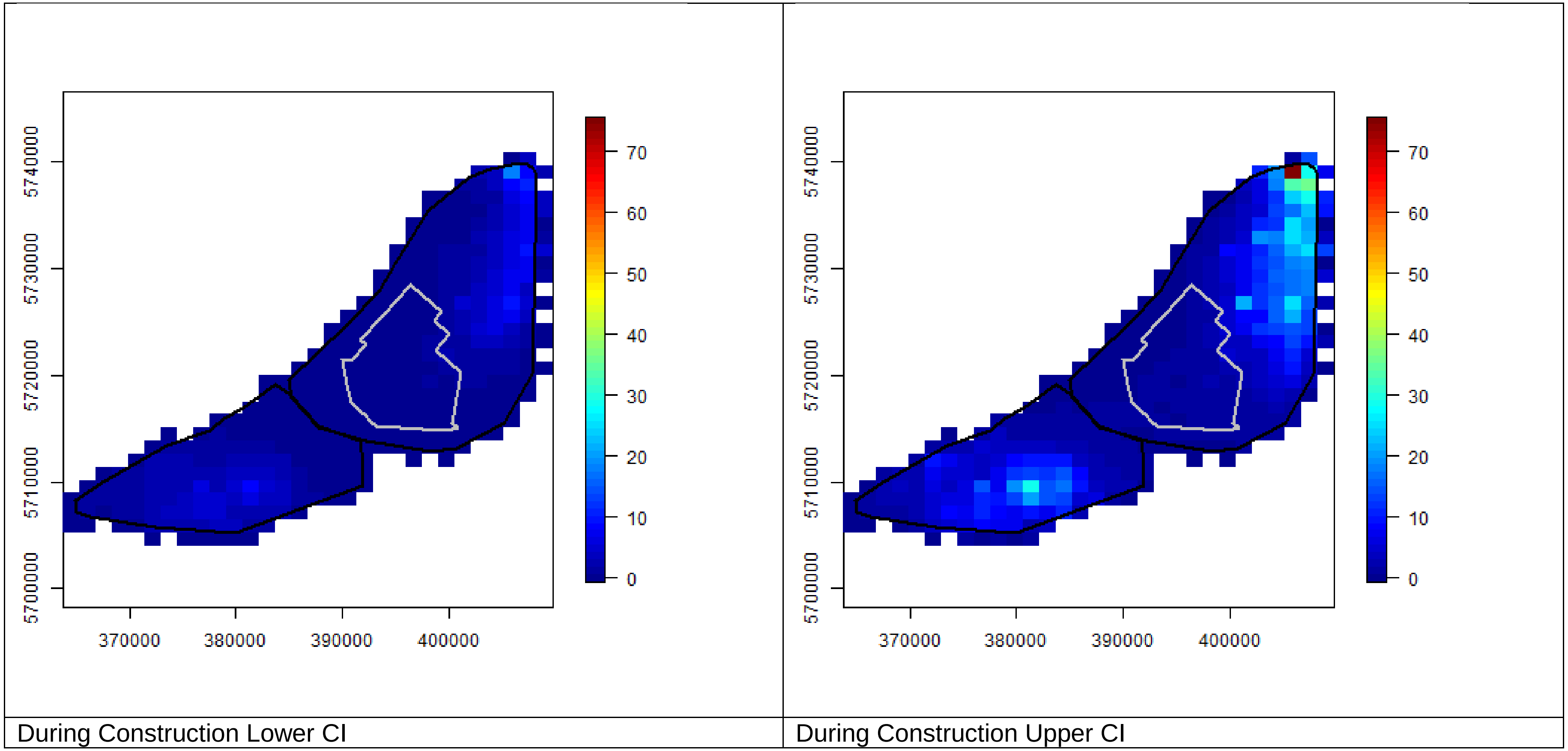

Figure 25 During construction diver density (birds km^{-2}) lower and upper confidence limits.

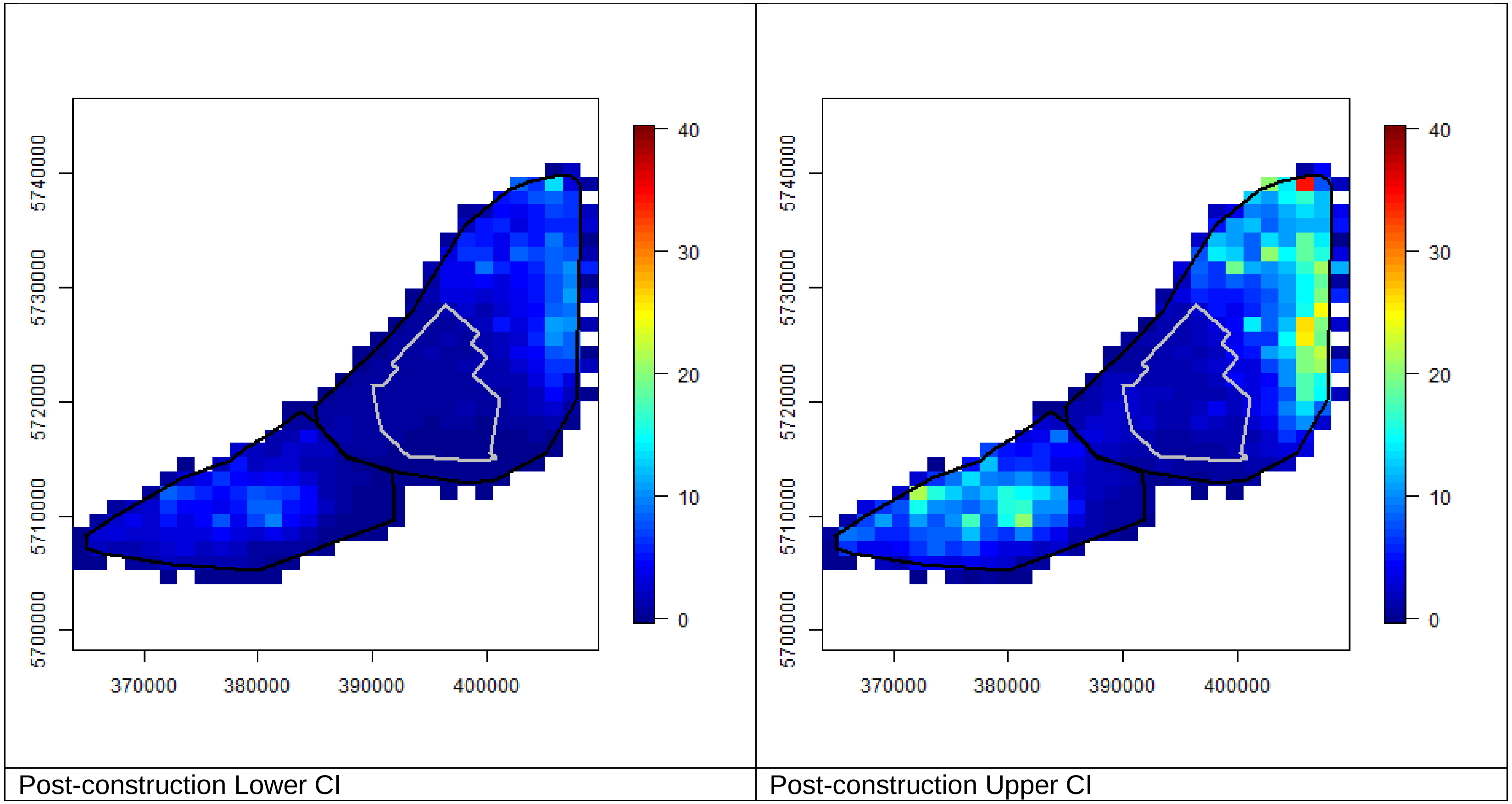

Figure 26 **Post-construction diver density (birds km^{-2}) lower and upper confidence limits.**

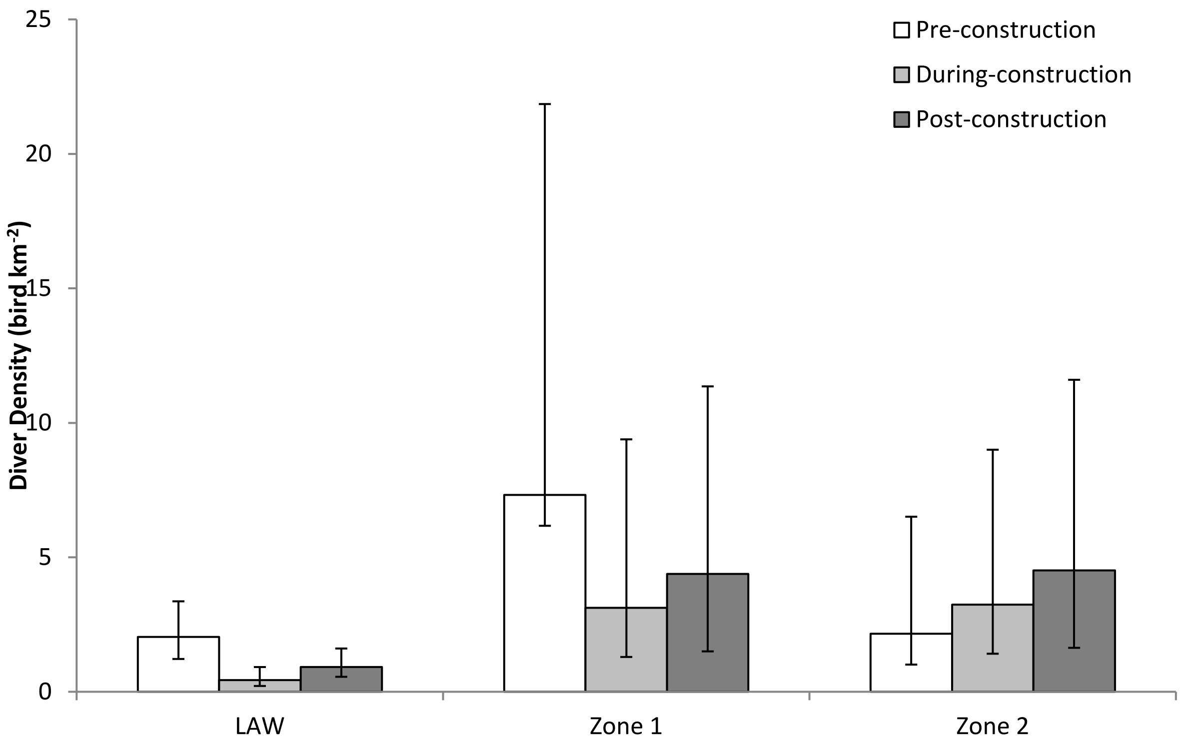

Figure 27 Mean diver density (+ 95% confidence intervals generated during the modelling process) within the London Array Wind Farm (LAW), Zone 1, and Zone 2 per development phase.

Figure 27 presents the average densities of divers and associated confidence intervals (based on those generated during the modelling) across each construction phase within Zone 1 and Zone 2, and the LAW. Pre-construction densities were greater in the LAW and Zone 1, with decreases in the during construction phase. Densities increased slightly for the post-construction phase but remained lower than those recorded in the pre-construction phase. For Zone 2 the density of divers was estimated to be lower in the pre-construction phase with increases during and post construction.

There was a significant decrease in diver numbers across most of Zone 1, and significant increase in the southern area of Zone 2 between the pre-construction and during construction phases (Figure 28). The greatest decline was seen in the areas of highest density in Zone 1 along the eastern boundary. Whilst this area of reduction was outside of the LAW, it cannot be excluded that the activities associated with the development caused or influenced this reduction.

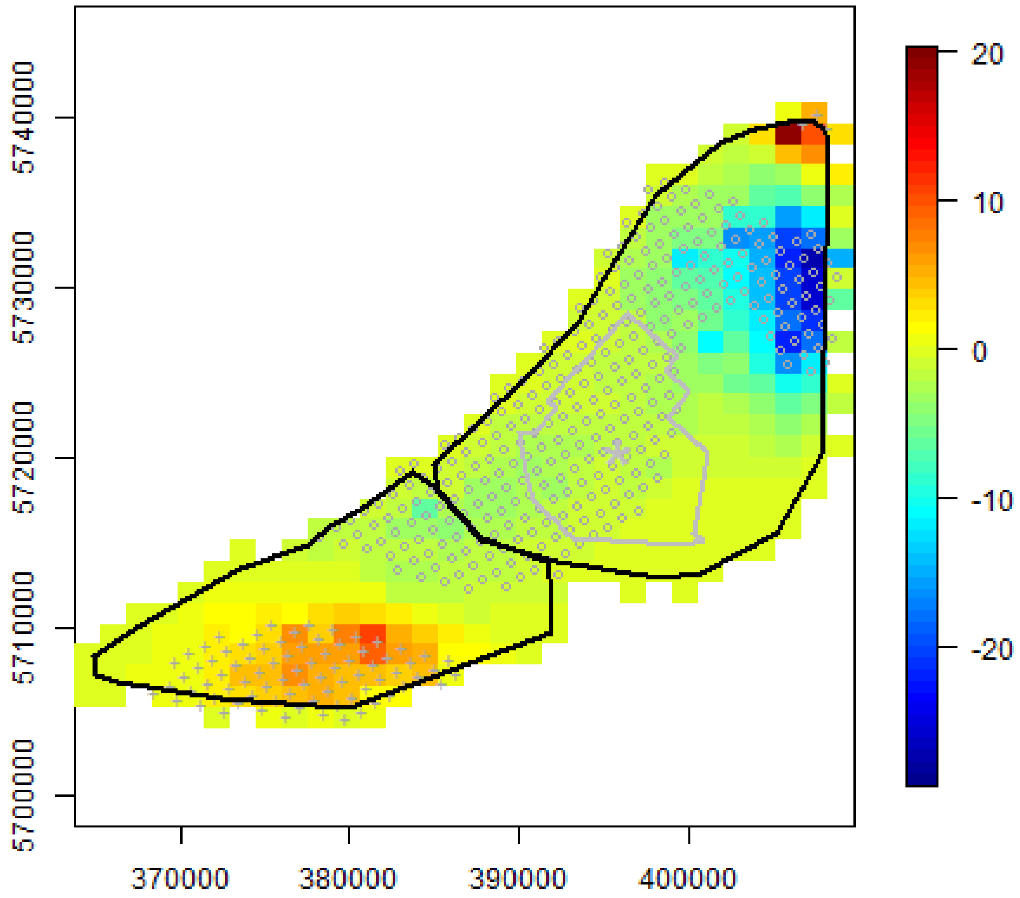

Figure 28 Predicted differences in average diver numbers per 1 km x 1 km square comparing pre- and during construction. Statistically significant increases are indicated using '+', and statistically significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '*'.

There appears to have been a redistribution of divers across Zone 1 and Zone 2 between the pre-construction and post-construction phases (Figure 29). Numbers remained to be significantly lower in the north east corner post-construction than they were in the pre-construction reference period (Figure 27). There was a significant increase in diver numbers to the north of the LAW in Zone 1 and in the south west corner of Zone 2.

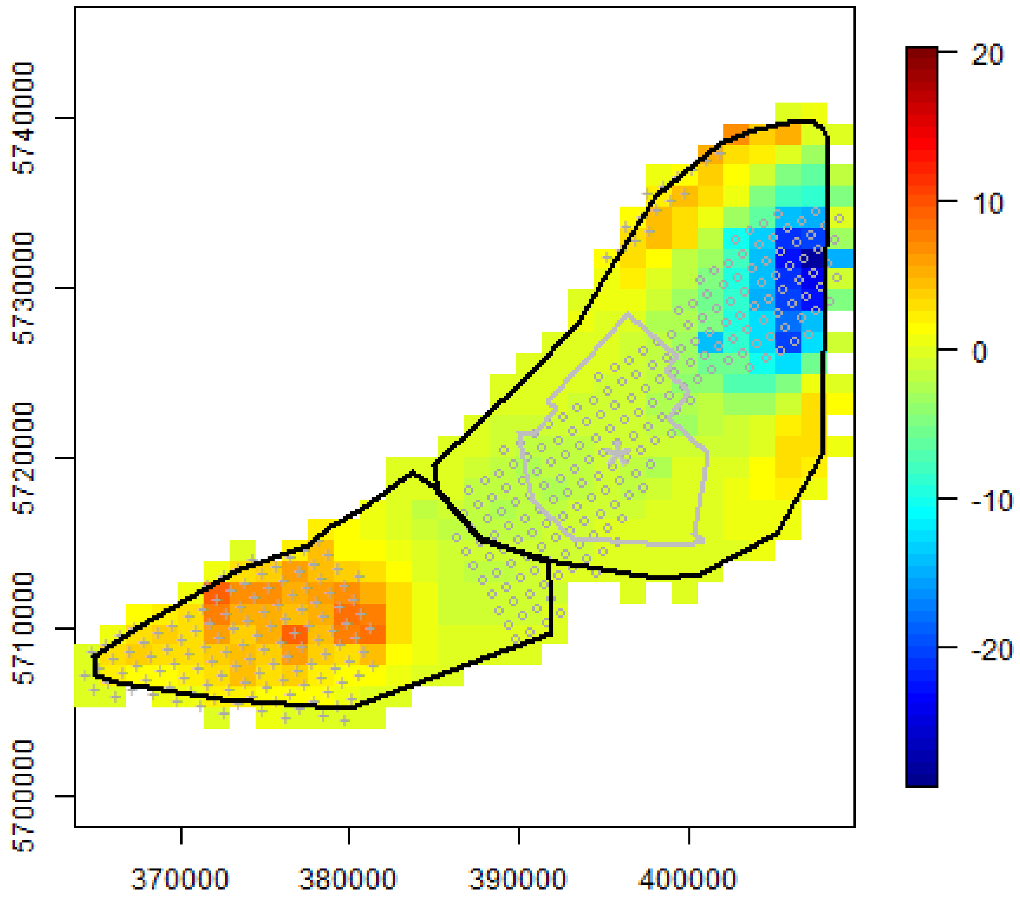

Figure 29 Predicted differences in average diver numbers per 1 km x 1 km square comparing pre- and post-construction. Statistically significant increases are indicated using '+', and statistically significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '*'.

There was a significant increase in diver numbers post-construction compared to the construction period within both Zones 1 and 2 (Figure 30). Diver density across both sites has increased along the northern boundary, although there is a greater increase in density to the northern region and a small pocket in the south of Zone 1, and the northern region of Zone 2 respectively. Significant decreases in diver density are evident in the north eastern corner of Zone 1 and the southern region of Zone 2.

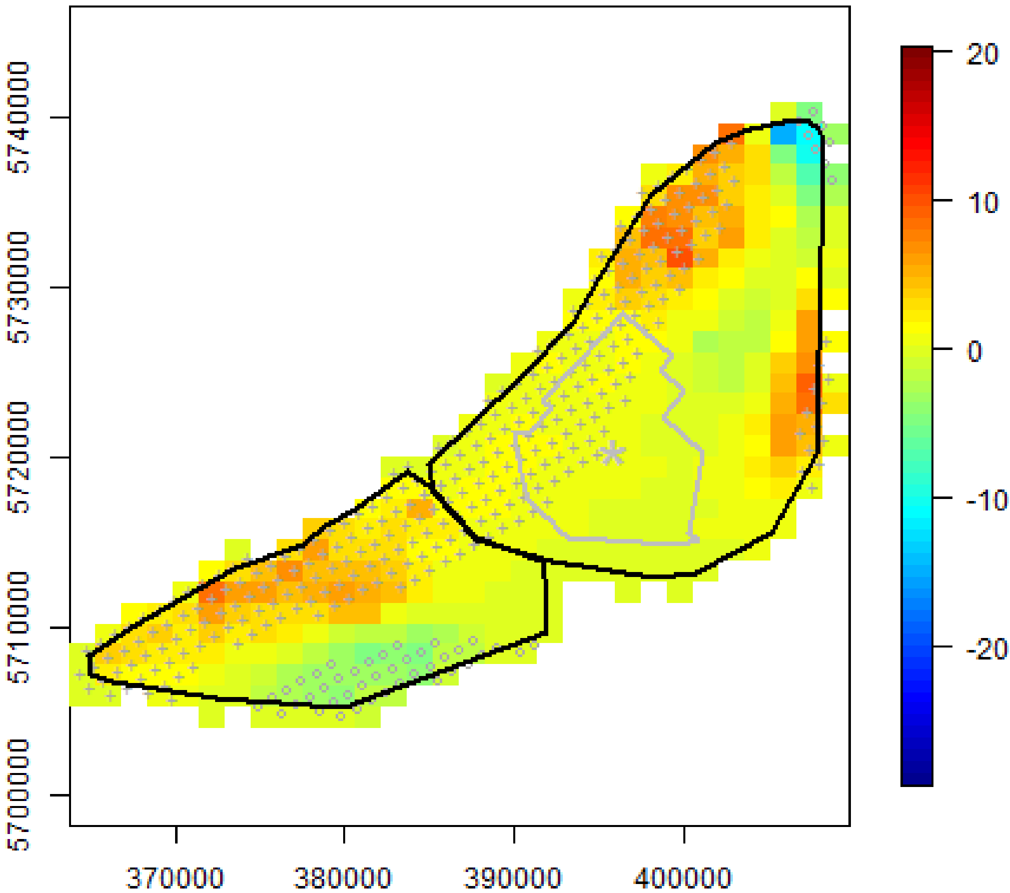

Figure 30 Predicted differences in average diver numbers per 1 km x 1 km square comparing during and post-construction. Statistically significant increases are indicated using '+', and statistically significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '*'.

To investigate whether there was an effect of the wind farm on diver density, average diver densities as predicted from the model were summarized for the wind farm, and for 1 km buffers extending around the wind farm up to 15 km distance in ArcGIS (Figure 31). The density of divers was calculated for each buffer and compared to that of the wind farm footprint. Confidence intervals calculated as part of the modelling process for each predicted value have been provided to demonstrate the variance in the modelled estimates.

The density of divers varied with distance to the LAW (Figure 31). There was a decrease in density close to the wind farm during construction years when compared to the pre-construction reference period. During construction years, the density of divers decreased compared to the pre-construction reference period up to 12 km from the wind farm. Post-construction, diver density is more like that of the pre-construction reference period and is slightly greater from 12 km of the wind farm footprint. This does not account for any changes in abundance that could have occurred between the periods. It is worth noting that the greatest density of divers during the pre-construction phase is estimated approximately 9 km from the LAW. This means that whilst densities were lower during and post construction compared to the pre-construction phase within 12 km, the greatest relative change occurs at the 9 km distance.

To assess how the distribution of divers between construction periods has changed, the proportion of diver density at each distance from the wind farm was calculated (Figure 32).

Figure 32 shows that whilst there appears to be a redistribution of divers across the site between the years in each construction period, these differences are unlikely to be significant. There are fewer divers predicted to be present within 11 km of the wind farm during construction, with an increase in the proportion of divers present outside of this distance. Post construction, an increase in the proportion of divers is seen from approximately 11 km away from the wind farm, when compared to the pre-construction reference period, with a decrease inside of this distance. A greater increase is seen when comparing the during-construction values within 10.5 km of the wind farm to those of the post-construction period. These changes are highlighted when looking at the percentage change between these proportions in Figure 33. However, as previously stated, the density of divers pre construction varied throughout the buffer distances, with the greatest peak occurring at 9 km from the LAW.

Appendix 8 provides supplementary information to Figure 31, Figure 32, and Figure 33.

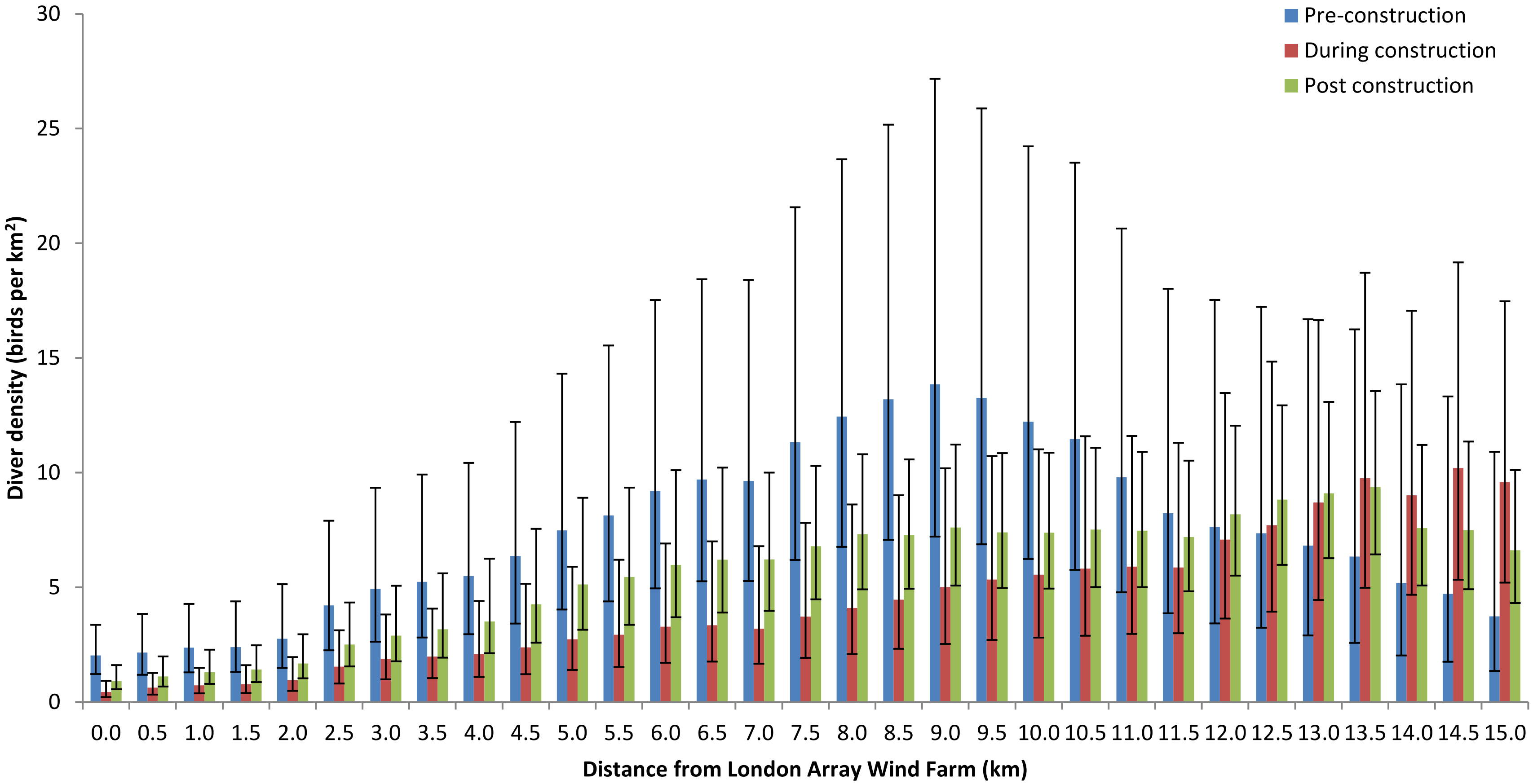

Figure 31 **Diver density (± 95% confidence intervals generated during the modelling process) at different distances from the London Array Wind Farm.**

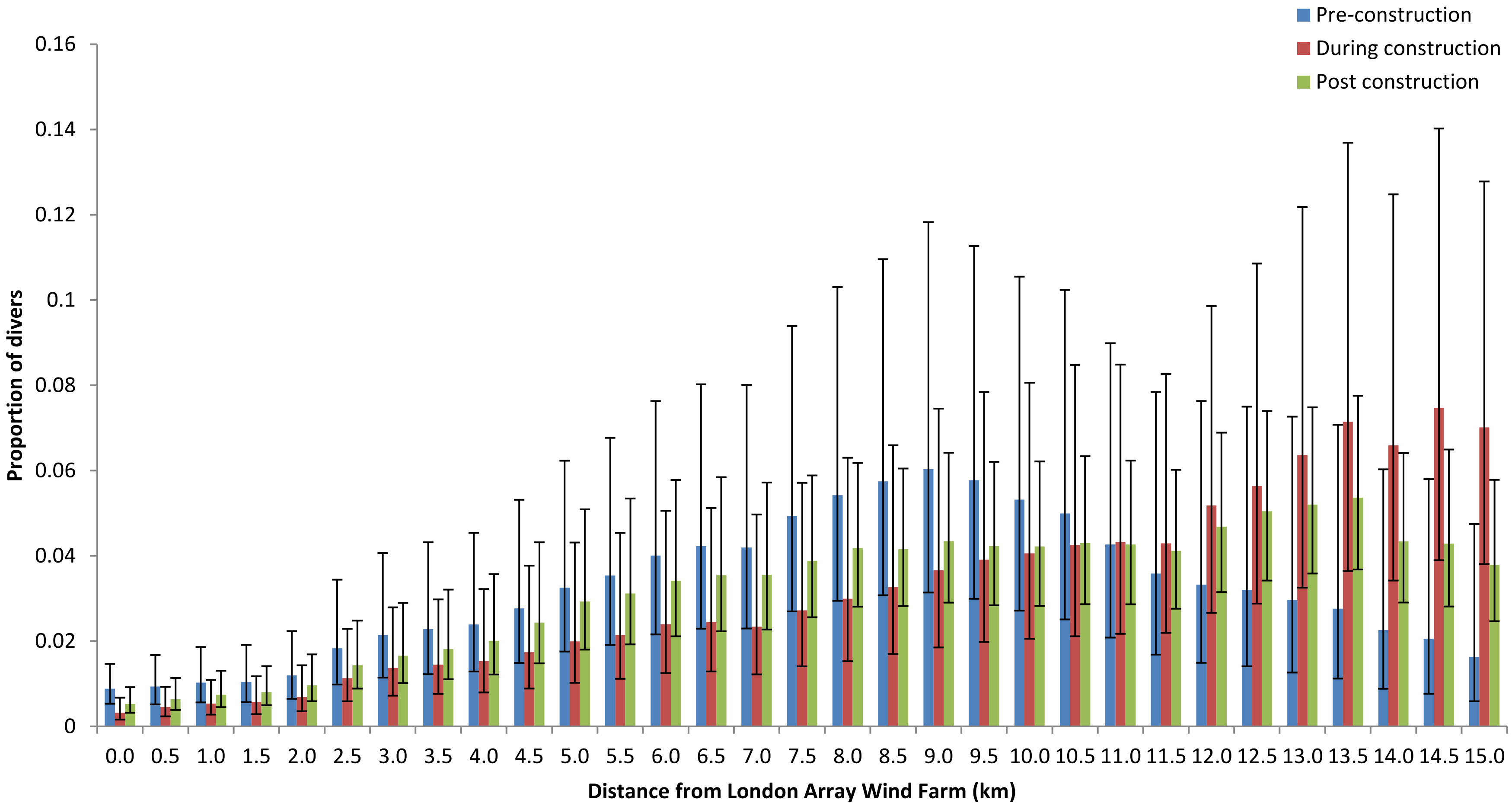

Figure 32 **Proportion of divers (± 95% confidence intervals generated during the modelling process) by distance to the London Array Wind Farm.**

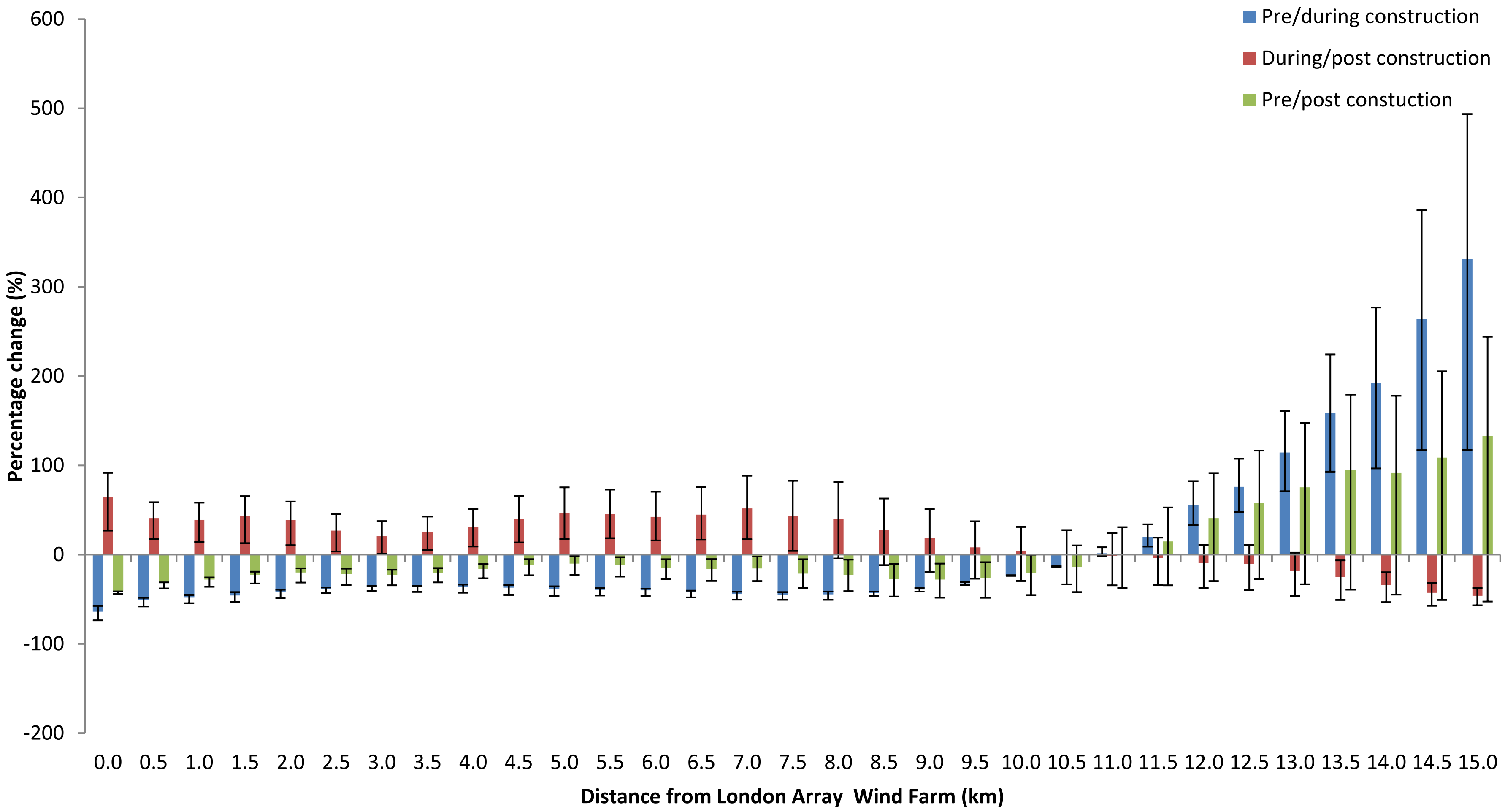

Figure 33 **Percentage change in proportion (± 95% confidence intervals generated during the modelling process) of divers between construction periods.**

7.4 Results: Auks

Final auk model (the model with the greatest explanatory power) is provided below. The final model covariates are provided in Table 20.

Additive predictor = construction phase (df=2) + s(sea surface temp, df=5) + s(tidal force, df=3) + s(x, y, df=6) + s(x, y):construction phase

Model dispersion parameter for the final auk model was 16.86. Model dispersion greater than 1 suggests that there is over dispersion and a large amount of noise (high variance in the count data) present in the underlying data. This supports the decision to fit an over-dispersed model. Model diagnostics are shown in Figures 10 to 15 in Appendix 7.

Table 20 Final auk model covariates.

Covariate	Df	*P*-value
Construction Phase	2	0.0010
s (sea surface temperature)	5	<0.0001
s (tidal force)	3	0.0022
s (x, y)	6	0.0207
s (x, y): construction phase	12	<0.0001

Table notes: The ‘s’ before a covariate in brackets indicates that a smoothed term has been applied because the relationship with density is non-linear. ‘Df’ is Degrees of Freedom, and ‘*P*-value’ is the probability value where less than 0.05 indicates a significant relationship with density

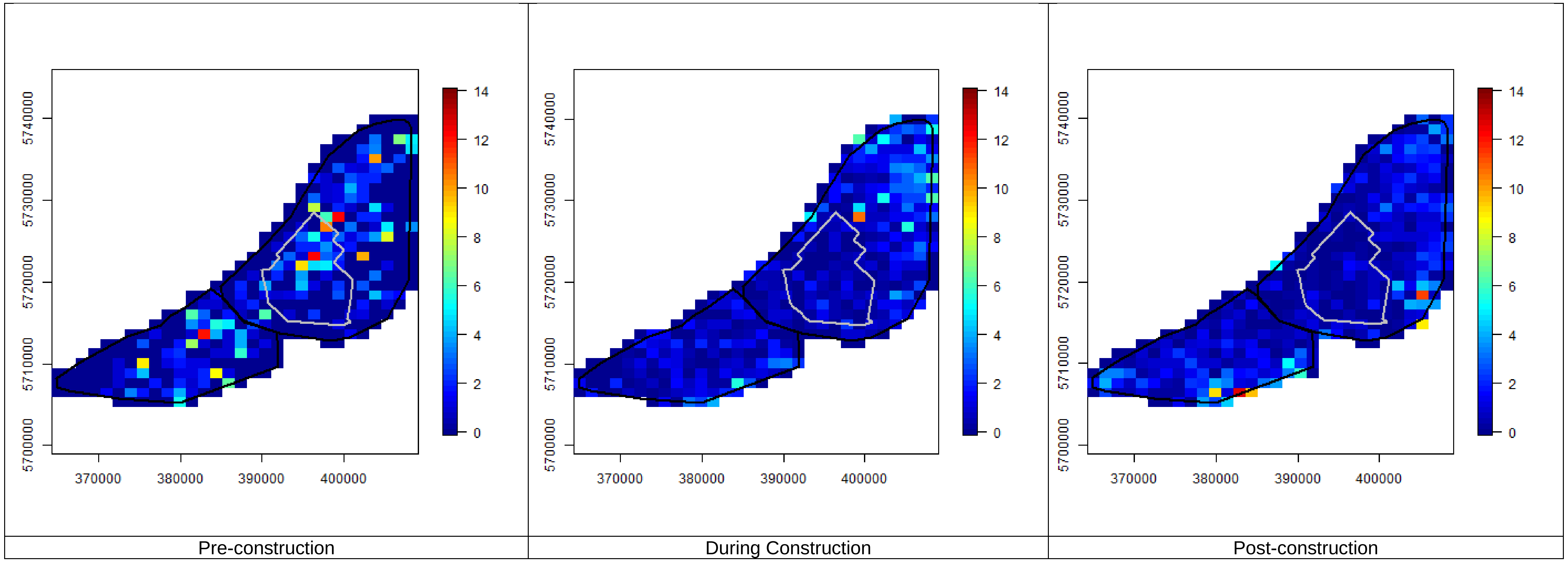

Figure 34 **Pre-construction, during construction, and post-construction mean observed auk density (birds km^{-2}).**

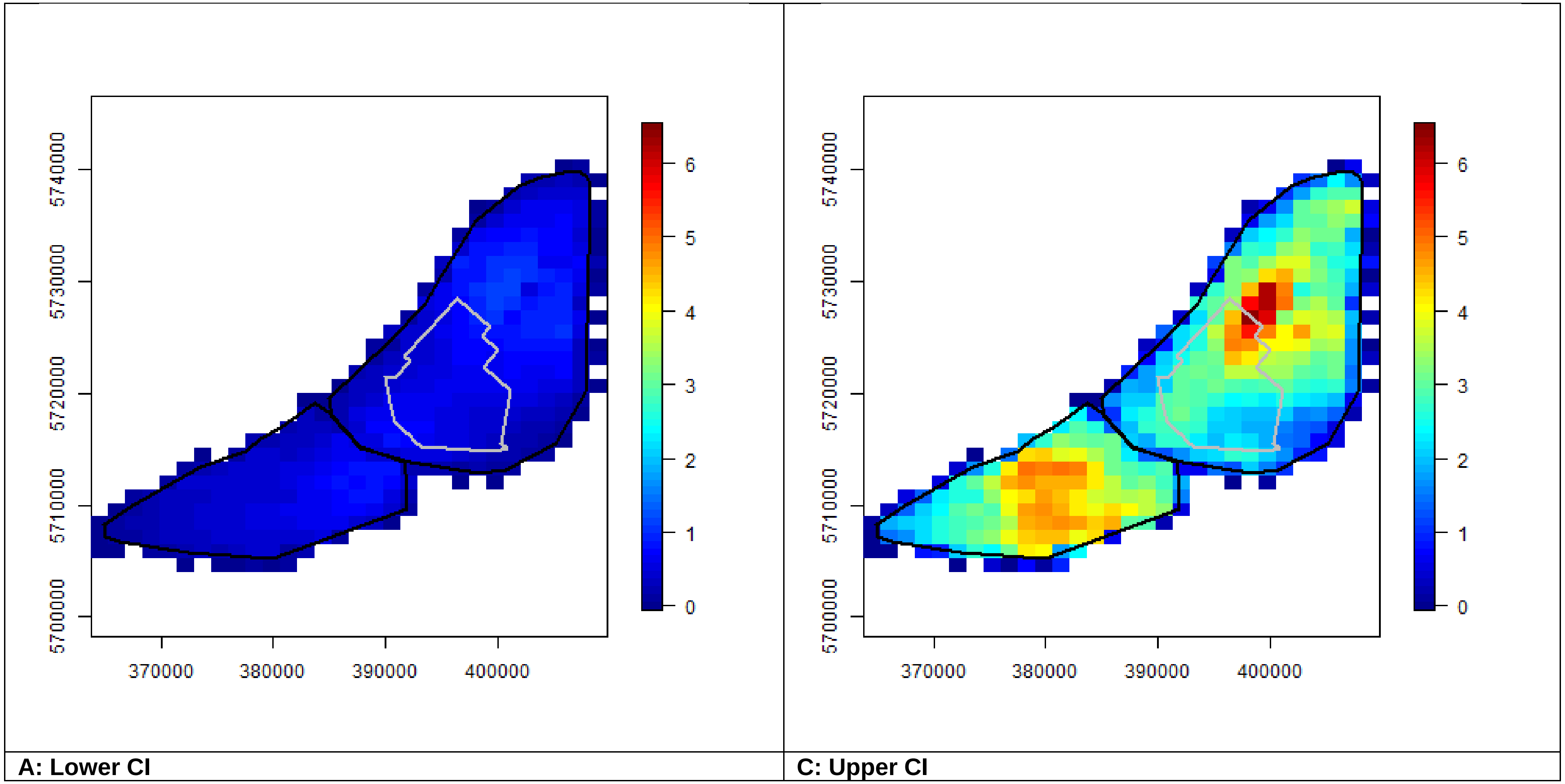

Figure 35 Pre-construction auk density (birds km^{-2}) lower and upper confidence limits.

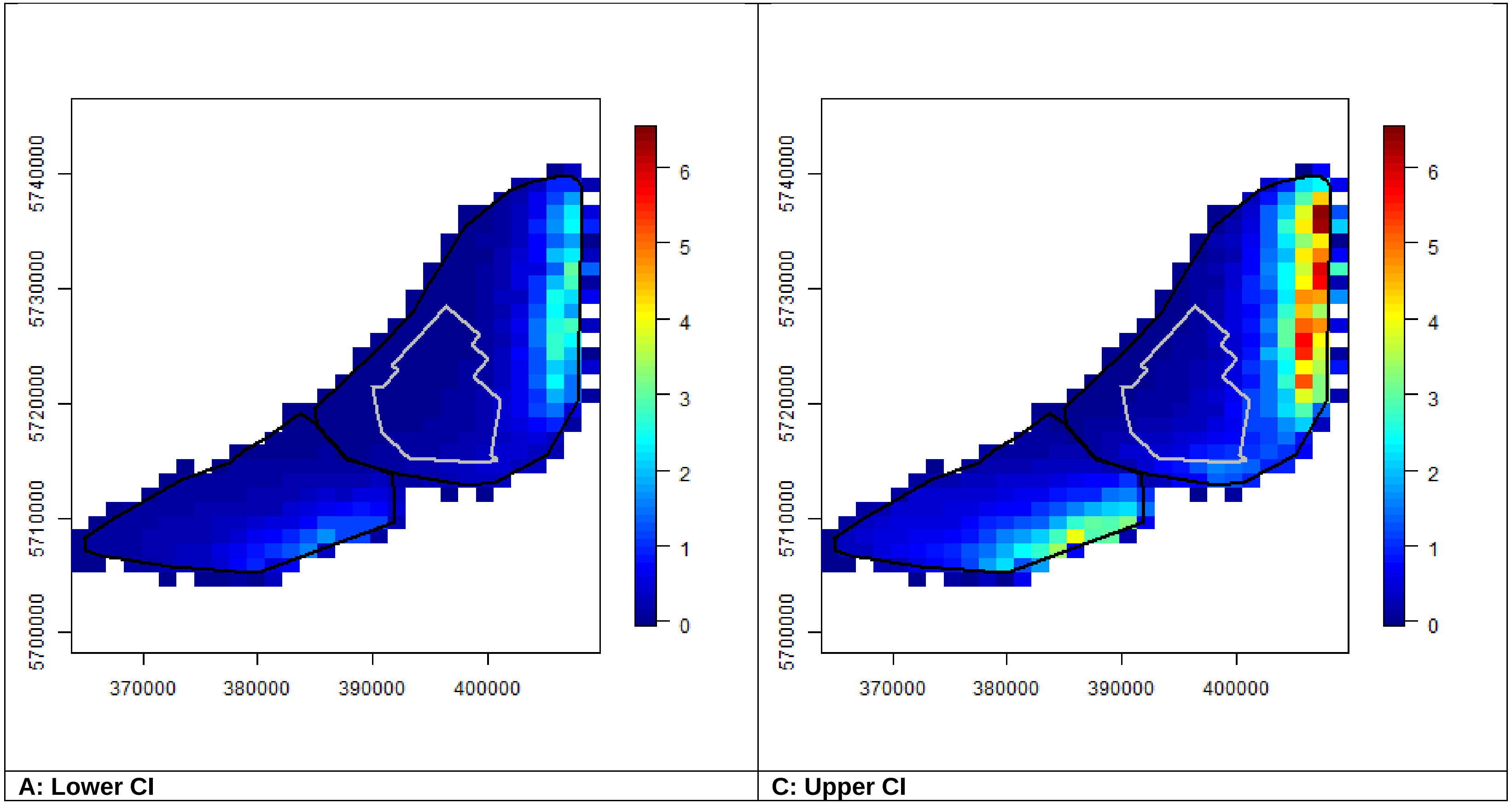

Figure 36 During construction auk density (birds km^{-2}) lower and upper confidence limits.

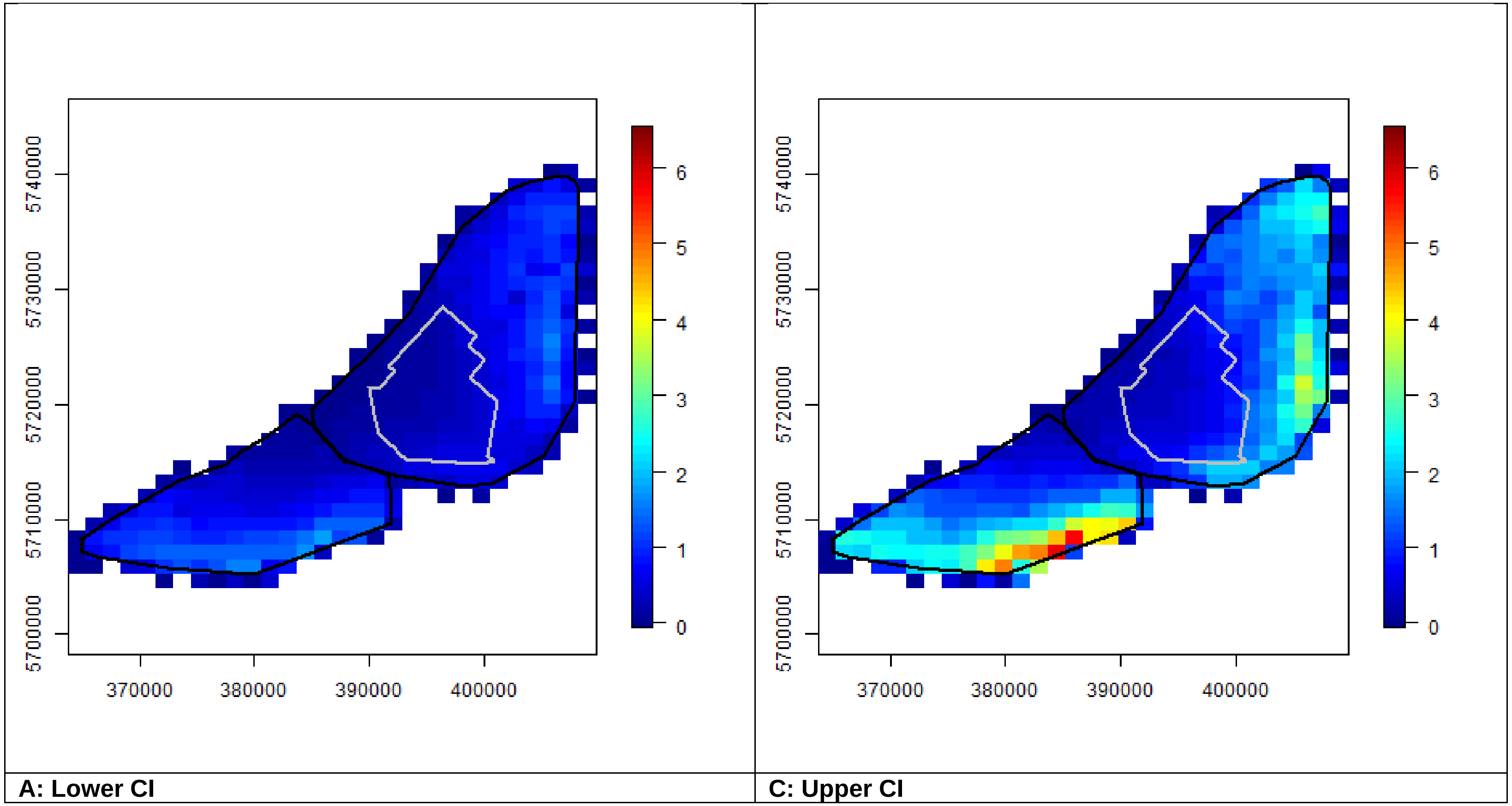

Figure 37 Post-construction auk density (birds km^{-2}) lower and upper confidence limits.

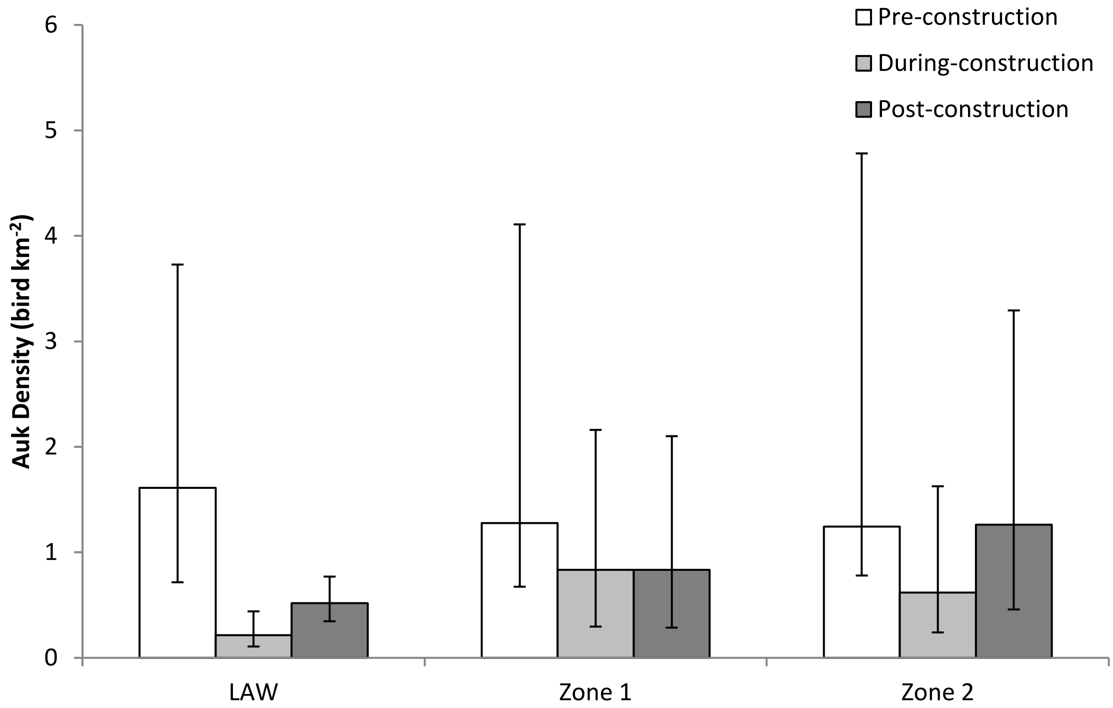

Figure 38 Mean auk density (+ 95% confidence intervals generated during the modelling process) within the London Array Wind Farm (LAW), Zone 1, and Zone 2 per development phase.

Figure 38 presents the average densities of auks and associated confidence intervals (based on those generated from the models) across each construction phase within Zone 1 and Zone 2, and the LAW. Pre-construction densities were greater in all cases, with decreases in the during construction phase. Densities increased slightly for the post-construction phase in Zone 2 but remained lower than recorded in the pre-construction phase in the LAW and Zone 1.

There was a significant decrease in auk numbers across most of Zones 1 and 2 before construction and during construction (Figure 39). There was a significant decline in the density of auks predicted in and around the LAW with a significant increase in auk density predicted along the eastern boundary of Zone 1.

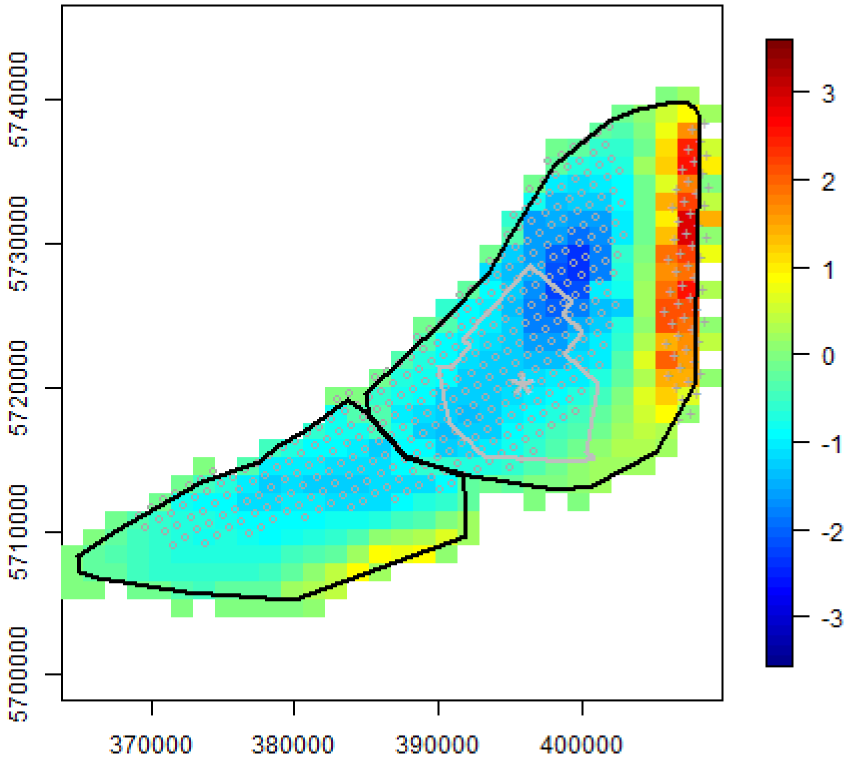

Figure 39 Predicted differences in average auk numbers per 1 km x 1 km square comparing pre- and during construction. Statistically significant increases are indicated using '+', and significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '*'.

There appeared to be a redistribution of auks across the site between the pre-construction and post-construction phases (Figure 40). Numbers remained significantly lower in and around the LAW during the post-construction years than they were in the pre-construction reference period. There was a significant increase in auk density in the south eastern corner of Zone 1.

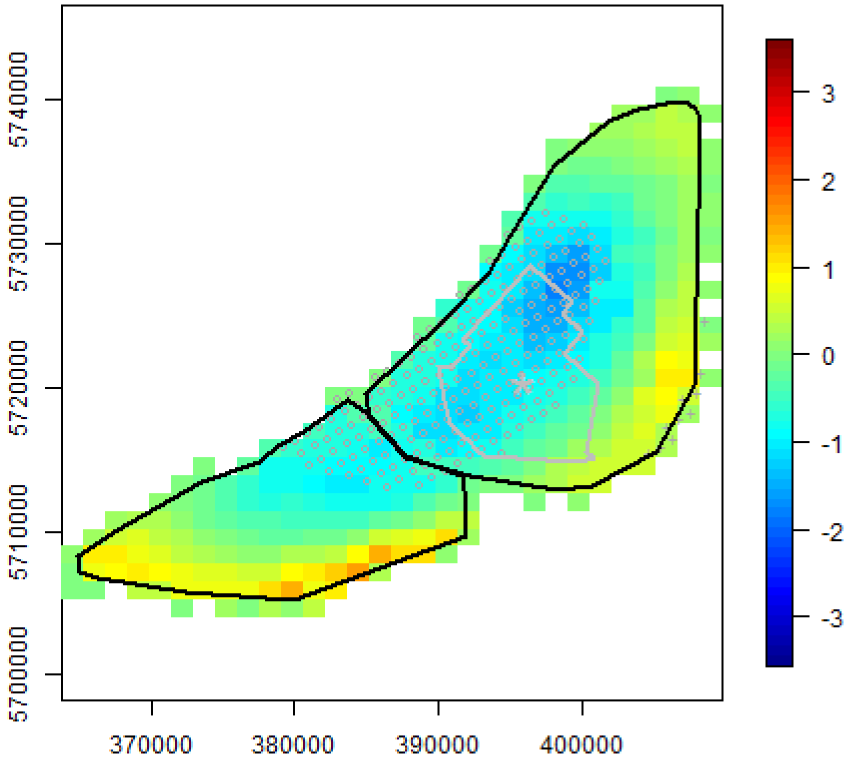

Figure 40 Predicted differences in average auk numbers per 1 km x 1 km square comparing pre- and post-construction. Statistically significant increases are indicated using '+', and significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '*'.

There was a significant increase in auk density post construction when compared to the construction period years across Zone 1 and Zone 2 (Figure 41). There were widespread increases across the site, although significant decreases were shown along the eastern boundary of Zone 1.

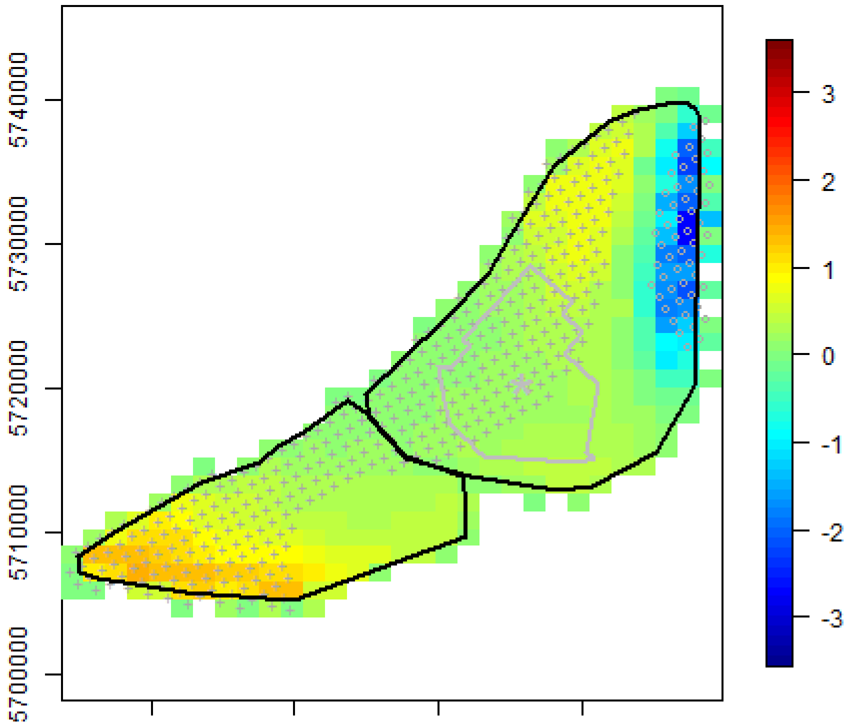

Figure 41 Predicted differences in average auk numbers per 1 km x 1 km square comparing during and post-construction. Statistically significant increases are indicated using '+', and significant decreases are indicated using 'o'. The centre of the London Array Wind Farm is indicated using '∗'.

To investigate if there was an effect of the wind farm on auk density, average auk density was summarised for the wind farm, and for 1 km buffers extending around the wind farm up to 15 km distance (Figure 42). The density of auks was calculated for each buffer and compared.

The density of auks varied with distance to the LAW (Figure 42). There was a decrease in density close to the wind farm in both during and post-construction periods. Post-construction years, the density matches that of the pre-construction reference period at approximately 11 km from the wind farm. However, this does not account for changes in abundance between the development phases.

To assess how the distribution of auks between construction periods has changed, the proportion of auk density at each distance from the wind farm was calculated (Figure 43). Figure 43 indicates there was a redistribution of auks across the site between the development phases. Unlike divers, auk density in the pre-construction period appeared similar across all the buffer distances. There were fewer auks predicted within 5.5 km of the wind farm during construction, with an increase in auk density outside of this distance. Post-construction years, a decrease in the proportion of auks is seen up to 5 km from the wind farm, when compared to the pre-construction reference period, with an increase outside of this distance (Figure 43). These changes are highlighted when looking at the percentage change between these proportions in Figure 44, with a clear gradient evident of negative percentage change during both the construction and post-construction periods, extending to 5 km during construction, and 4.5 km post-construction. Appendix 8 provides supplementary information to Figure 42, Figure 43, and Figure 44.

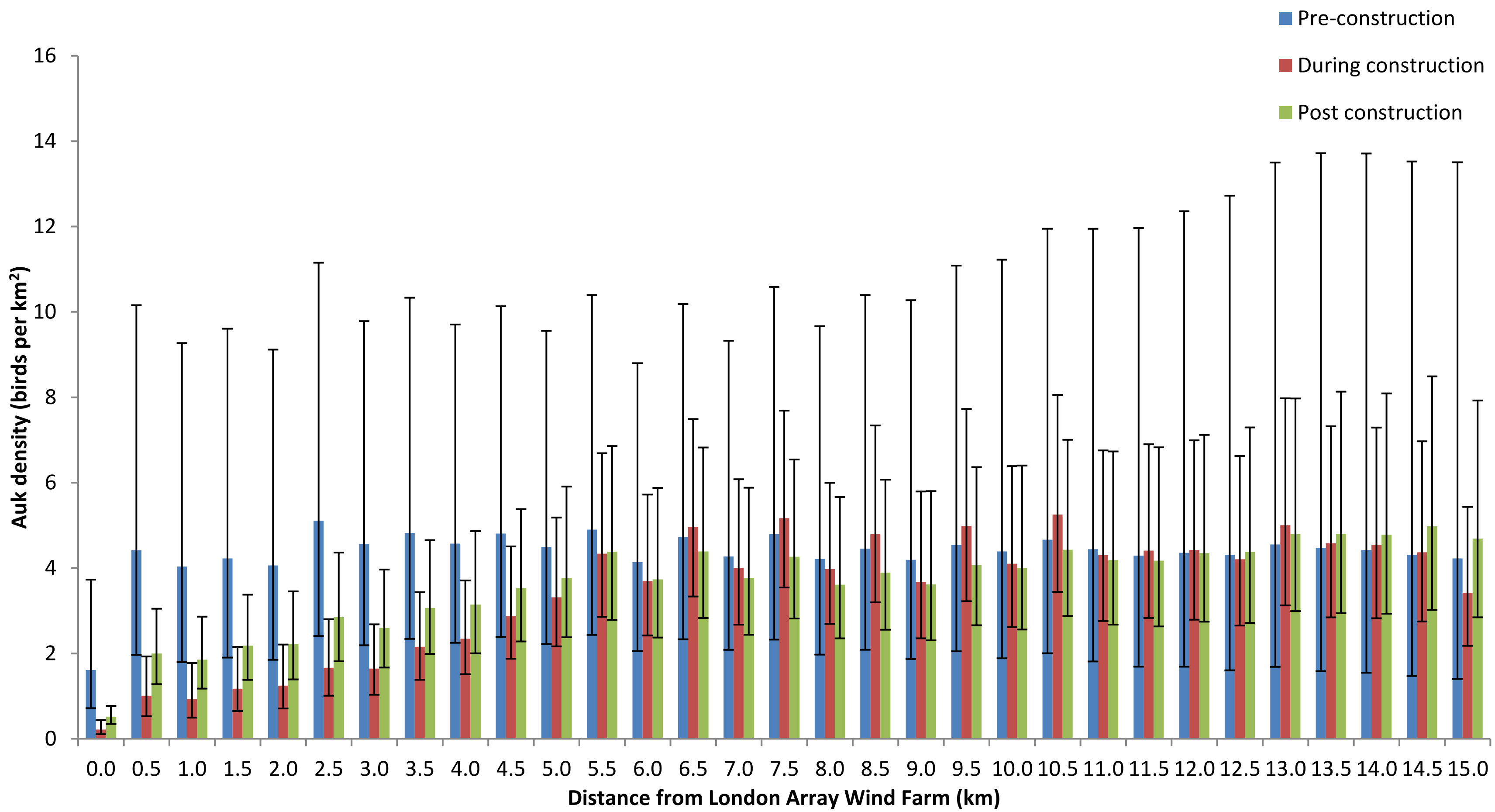

Figure 42 **Auk density (± 95% confidence intervals generated during the modelling process) at different distances from the London Array Wind Farm.**

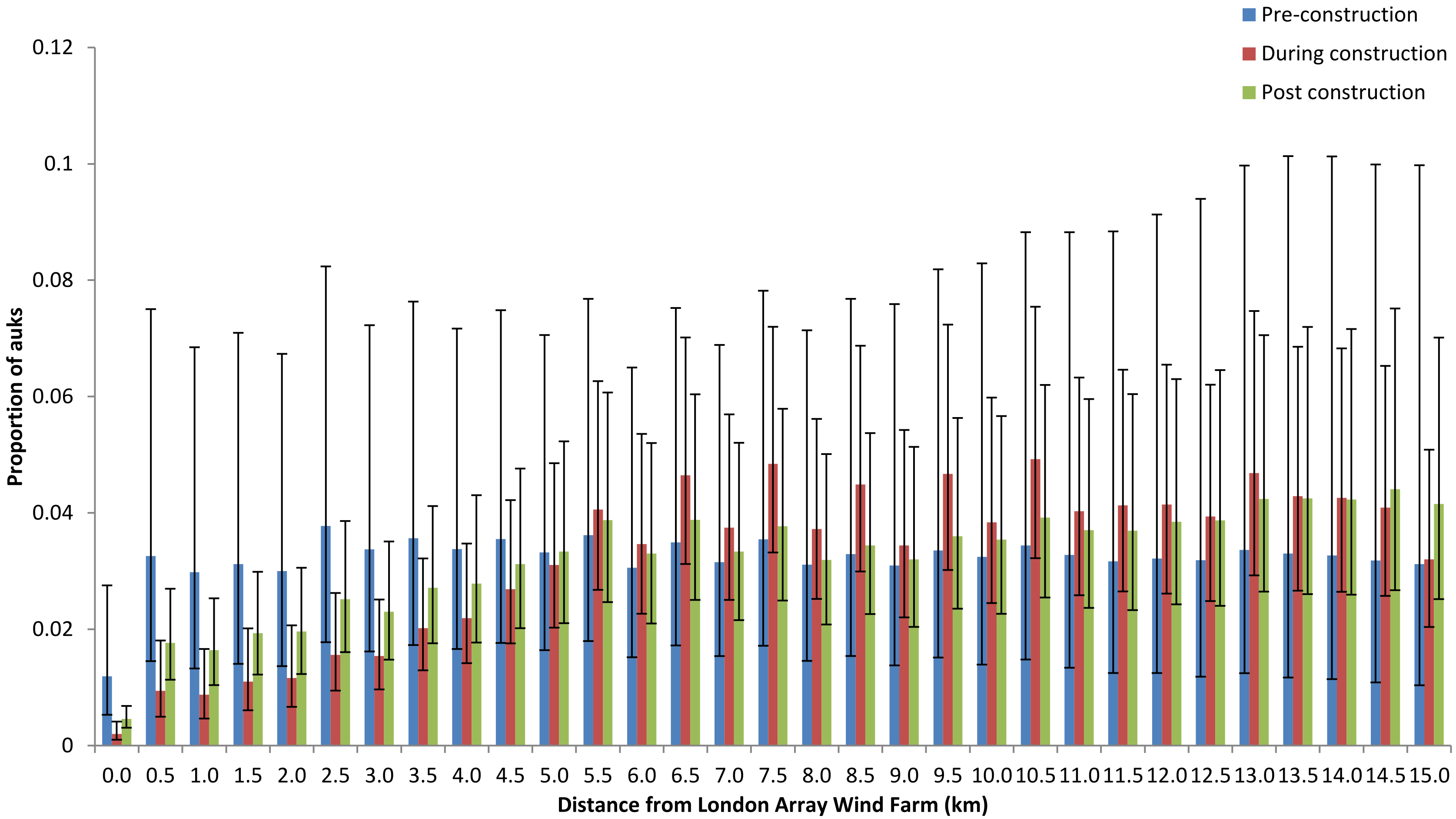

Figure 43 Proportion of auks (+ 95% confidence intervals generated during the modelling process) by distance to the London Array Wind Farm.

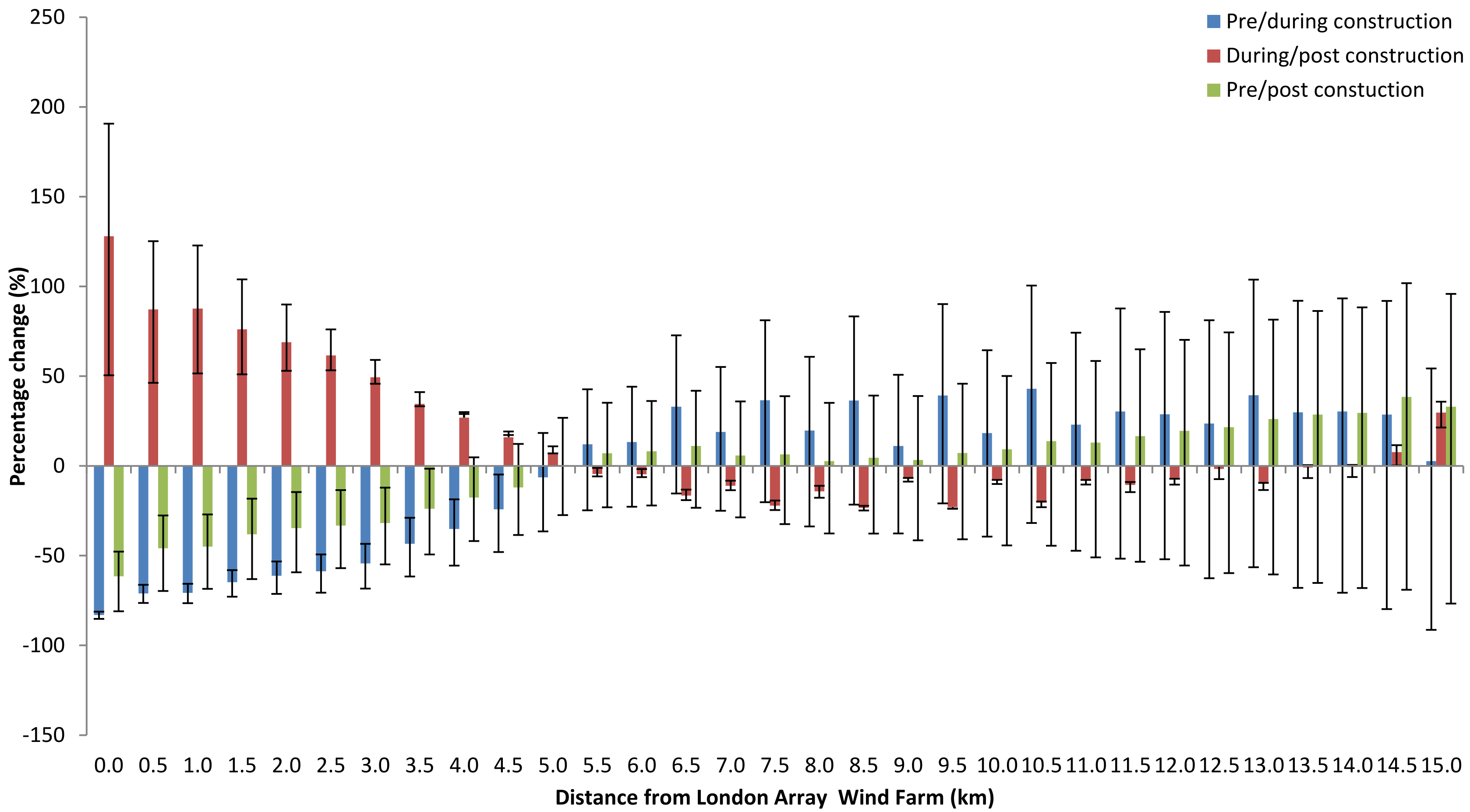

Figure 44 **Percentage change in proportion (± 95% confidence intervals generated during the modelling process) of auks between construction periods.**

7.5 Discussion

Initial 'CReSS-SALSA' models were constructed for divers and auks with a number of continuous variables. The model simplification process determined that development phase, chlorophyll-*a*, sea surface temperature, thermal front probability was retained for divers. For auks, development phase, sea surface temperature, and tidal force were retained. The development phase had a significant effect on the density and distribution for both divers and auks due to the construction activities at the LAW in combination with the presence of the wind turbines as the development phase covariate was retained in the final model. The significant relationships with environmental variables for both divers and auks are perhaps indicative of habitat preferences.

The proportion of auk and diver abundance was calculated by estimating the difference in the predicted modelled abundance within specific buffer regions between pairwise comparisons of pre-construction, during-, and post-construction phases. The proportion of birds at different distances from the wind farm accounts for changes in overall abundance between years. Whereas this is likely to provide a better indication of any effect that construction may have on the distribution of the birds, this analysis will only be valid for the density of birds present in each year. The results are not conclusive across all bird densities as the selection of habitat made by divers or auks will vary with habitat quality but this quality of habitat for foraging birds will vary with the number of birds in it (Fretwell & Lucas 1970, Fretwell 1972). Therefore, in years of low bird densities, the birds may select habitat with sufficient prey and also where real or perceived disturbance is low. Offshore wind farms or the boat traffic associated with the wind farms could be examples of such disturbance. However, in years of high bird density, when competition for food between birds is greater, prey availability may become the key determinant of bird distribution and individual birds may become more tolerant of any real or perceived disturbance. Thus, any differences recorded in the observed proportions of birds with distance to the wind farm footprint should be taken to apply to the density of birds in that particular year, and any generalisation of the results should only be made with great caution. It is also important to note that averaging across grid cells within distance buffers for the pairwise comparisons of each development phase combines grid cells where abundances may have increased or decreased between phases. This means an increase in one direction and a decrease in another could cancel each other out such that the mean change in density is zero (e.g. Figure 31, Figure 32, Figure 33, Figure 42, Figure 43, Figure 44). However overall, for the pre- and post-construction comparisons, there was an average decline in all distance bands of red-throated divers (consistently by 30 to 50%) out to approximately 10 km from the LAW and of auks out to approximately 12 km from the LAW. The gradient for auks varied by 68% in the LAW down to approximately 7% at approximately 6.5 km. This demonstrates that auks had a greater gradient in decline but over a smaller distance in comparison to divers. Divers showed a relatively smaller proportional decline but over a much greater distance. The reasons for this are unknown but may be due to the differing habitat preferences of each species at this location and different environmental response thresholds. Detailed interpretation of the displacement effects should be taken from the maps (Figure 28, Figure 29, and Figure 30 for divers, and Figure 39, Figure 40, and Figure 41 for auks).

The results indicated that diver and auk density significantly decreased in the LAW footprint and surrounding area during the construction phase of the wind farm in comparison to the pre-construction phase. During the post-construction phase, the proportional decrease in diver and auk density between pre- and post-construction was less pronounced than those recorded between pre- and during-construction phases. However, the density in the wind farm and surrounding area significantly increased in comparison to the during construction phase. This significant increase in both divers and auks in and around the LAW from during to post-construction may be due to a reduction in construction activities such as vessel traffic.

7.5.1 Discussion: Divers

The proportion of divers displaced from the LAW footprint was estimated to be approximately 78% and 55% for during and post-construction respectively.

The comparison of diver distribution pre versus during construction indicated that significant increases in density were estimated mainly in the southern region of Zone 2, but also a small pocket in the northern corner of Zone 1. Significant decreases were estimated across Zone 1 and extended into the eastern boundary of Zone 2. During- versus post-construction comparison indicated that significant increases in density were estimated mostly along the northern boundary of Zone 1 and Zone 2. A small pocket of increased density was also estimated in the southern corner of Zone 1. Areas of significant decrease in diver density were evident in the north eastern corner of Zone 1 and the south western corner of Zone 2. The pre- versus post-construction comparison indicated that significant decreases were estimated in a band across the middle of Zone 1 and extending into the eastern boundary of Zone 2. Significant increases in diver density were estimated in the western half of Zone 2.

Based on the summarised density information, a proportion of the divers appeared to avoid areas up to approximately 11 km from the wind farm. It is also important to note that whilst the density of divers during and post construction was lower in comparison to pre-construction up to 11 km, the greatest density of divers pre construction occurred at the 9 km distance from the LAW. This may be indicative that other factors, apart from the construction activities at the LAW, are compounding displacement effects of divers in the Zone. This distance demonstrates the greatest relative change which is outside of the LAW footprint (Figure 29). The pattern recorded pre construction, i.e. diver density increasing with distance from the LAW up to 9 km and then gradually decreasing was similar, although amplified, to the pattern of diver density during and post construction, i.e. a gradual increase in density from the LAW with increasing distance. This pattern in density suggests that preferred habitat for divers occurred outside of the LAW footprint pre construction. The change in peak density between the development phases was estimated by calculating the difference in the peaks of the diver density pre (9 km), during (14.5 km), and post construction (13.5 km). Whilst the pattern was similar during and post construction in comparison to pre-construction, increasing density from the LAW, the peak in density shifted approximately 5.5 km and 4.5 km away from the LAW, respectively. This suggests that divers redistributed to areas away from the LAW, with the overall density remaining lower than estimated pre construction but were not completely displaced at any distance. For the pre- versus post-construction comparison, interpretation from Figure 33 shows that the point at which the CIs first overlap with zero is at 10 km in the case of divers.

Overall, the results indicate that greater numbers of divers were recorded in the pre-construction period with divers redistributing to other areas of Zone 2 and to a lesser extent, Zone 1 during the construction phase. During the post-construction phase, the number of divers significantly increased across Zone 1 and Zone 2, but not to the same level as the densities recorded pre construction in Zone 1.

The results following the analysis of the first year of post-construction surveys indicated that divers appeared to avoid areas within 9 km of the LAW during the construction period with diver numbers appearing like those recorded pre construction (APEM, 2016). The results of this analysis of the final two years of post-construction surveys has indicated that diver density post construction was lower than that estimated pre construction. This suggests that higher densities were recorded in the first year of post-construction surveys, with lower densities recorded in the last two years of post-construction surveys. These apparent year-to-year fluctuations in diver density may be in response to local food and habitat availability and are perhaps indicative of fluctuations in diver numbers across the OTE SPA (O'Brien *et al*., 2008; Goodship *et al*., 2015). However due to the slight amendments to the modelling method, the previous analysis (APEM, 2016) cannot be directly compared with the one presented in this report.

The ES suggested that disturbing activities were likely to be greatest during construction and may continue through the operational phase. A detailed disturbance impact assessment was undertaken using existing bird data taken from aerial surveys in the Thames Estuary which resulted in a predicted significant impact on red-throated diver and black-throated diver and no significant impact on all other species. It was noted however, that red-throated divers generally have a surplus of survival (non-breeding) habitat and population constraints would therefore relate to the conditions in the breeding area. This could therefore reduce the potential for a significant impact of the LAW through habitat loss caused by displacement. The observed redistribution of divers into Zone 1 and Zone 2 during construction supports this statement in that divers appear to utilise surrounding areas of suitable habitat.

The ES predicted that the magnitude of displacement for divers would be no greater than 3.4% of the wintering population of the OTE SPA. The Appropriate Assessment considered that loss was negligibly low in comparison to the large interannual natural fluctuations in the population of divers observed within the Thames Estuary. The total relative difference in the modelled diver abundance within the LAW and up to 11.5 km (noting the irregularity of the Zone 1 and Zone 2 survey areas in relation to the LAW) was estimated to be 1,111 individuals which is 6.1% of the OTE SPA conservation objective population size of 18,079 individuals and based on the digital aerial surveys combined (14,161 individuals: APEM Ltd, 2013, Goodship *et al.,* 2015; 22,280 individuals: Irwin *et al.,*2019). It must be noted that it is not possible to unequivocally causally link this reduction to the development and presence of the LAW across such distances as some of the variation may also be caused by natural fluctuations, however the gradient effect in the results is conclusive evidence suggestive of that causal link. Furthermore, due to the irregularity of Zone 1 in relation to the LAW, only the inner buffer regions fully capture the effect of displacement in all directions. The distance that Zone 1 surrounds the LAW at its minimum is approximately 1.5 km up to a maximum of approximately 16 km. Potential displacement effects outside of the surveyed area cannot be assumed or discounted. Any such displacement effects beyond Zone 1 and Zone 2 have not been extrapolated in the maps generated or been factored into the numbers presented.

In comparison to the ES, the impact of divers within the LAW and 1 km buffer has been less than what was predicted; a relative reduction of 159 individuals (see Appendix 8) which accounted for 0.87% of the OTE SPA population of 18,079 individuals. However, the displacement effect seems to have occurred over a much larger distance than what was initially predicted; 0% displacement was predicted at distances greater than 1 km, considered to be precautionary, due to the limited information in the literature during that time. The negative effect on divers was apparent out to the distance band 10.5 to 11 km when considering proportions of birds recorded and out to 11.5 to 12 km when considering the absolute densities of divers recorded in each band when comparing pre- versus post-construction. English Nature and the RSPB had accepted that 600 m represented the greatest distance at which reliable studies had shown displacement of birds from around wind turbines (English Nature / RSPB, 2004 cited by London Array Limited, 2005). This means that the overall impact on the diver population is greater than what was predicted in the ES on the basis of the evidence for the effect of offshore windfarms on divers that was available in the literature at that time i.e. approximately twice the SPA population has been found to be subject to displacement in comparison to that assumed in the ES (6.1% vs. 3.4%

and the distance away from the boundary of LAW over which diver densities has been reduced has been found to be far greater (over 11 km vs. 1 km).

7.5.2 Discussion: Auks

The proportion of auks displaced from the LAW footprint was estimated to be approximately 87% and 68% during and post construction, respectively.

The comparison of auk distribution pre versus during construction indicated that significant increases in density were estimated along the eastern boundary of Zone 1. Significant decreases were estimated for areas surrounding the LAW within Zone 1, as well as areas extending into Zone 2. The during- versus post-construction comparison indicated that significant increases in density were estimated in a similar extent to the regions of significant decrease pre versus during but extending slightly into the southern region of Zone 2. Significant decreases in density were estimated along the eastern boundary of Zone 1. The pre- versus post-construction comparison indicated that significant decreases were estimated across the northern half of the LAW and surrounding areas extending into the eastern boundary of Zone 2. Significant increases in auk density was estimated along the south eastern corner of Zone 1.

Based on the summarised density information, a proportion of the auks appeared to avoid areas up to approximately 5 km from the wind farm. The proportional decline in auk density was greater than that of divers near the wind farm. For the pre- versus post-construction comparison, interpretation of Figure 43 shows that the point at which the CIs first overlap with zero is at 4 km in the case of auks.

Overall, the results indicate that greater numbers of auks were recorded in the pre-construction period with auks redistributing to the eastern boundary of Zone 1 during the construction phase. Post construction, the number of auks significantly increased across Zone 1 and Zone 2, but not to the same level as the densities recorded pre construction in Zone 1. Significant decreases in auk density were recorded along the eastern boundary of Zone 1 during versus post construction.

Following the modelling of the first year of post-construction surveys, proportionally fewer auks were recorded in the wind farm and surrounding areas up to approximately 7 km (APEM, 2016). However due to the slight amendments to the modelling method, the previous analysis (APEM, 2016) cannot be directly compared with the one presented in this report.

The ES predicted that guillemots and razorbills would not be significantly impacted by the development of the LAW. The total relative difference in the modelled auk abundance within the LAW and up to 11.5 km (noting the irregularity of the Zone 1 and Zone 2 survey areas in relation to the LAW) was estimated to be 536 individuals. Due to the irregularity of Zone 1 in relation to the LAW, only the inner buffer regions fully capture the effect of displacement in all directions. The distance that Zone 1 surrounds the LAW at its minimum is approximately 1.5 km up to a maximum of approximately 16 km. Potential displacement effects outside of the area surveyed cannot be assumed or discounted. Any such displacement effects beyond Zone 1 and Zone 2 have not been extrapolated in the maps generated or been factored into the numbers presented. It must be noted that it is not possible to unequivocally causally link this reduction to the development and presence of the LAW across such distances as some of the variation may also be caused by natural fluctuations, however the gradient effect in the results is conclusive evidence suggestive of that causal link.

English Nature and the RSPB had accepted that 600 m represented the greatest distance at which reliable studies had shown displacement of birds from around wind turbines (English Nature / RSPB, 2004 cited by London Array Limited, 2005). This means that the overall impact on the auk population is greater than what was predicted in the ES on the basis of the evidence for the effect of offshore windfarms on auks that was available in the literature at that time.

7.6 Summary

Based on the modelling presented in this report, a decreasing proportion of divers were displaced at distances estimated up to approximately 11 km from the LAW, but complete displacement (habitat loss) was not detected at any distance. Table 21 summarises displacement distances estimated for divers and auks at other offshore wind farms, the distances for divers ranged from 1 to 6 km (Welcker & Nehls, 2016).

The density profile of divers increased gradually throughout the 15 km buffer regions with a peak at 9 km pre-construction. This density profile pattern was similar during and post-construction but with the peak in density shifting 5.5 km and 4.5 km away from the LAW respectively. Year-to-year fluctuations in diver numbers and distribution should be an important consideration when interpreting these results. In addition, the greatest decline in absolute diver density occurred outside of the LAW footprint pre- versus during construction, along the eastern boundary of Zone 1. This indicates that other factors may confound any displacement effects in divers in the region. Therefore the displacement distance estimated for divers is estimated to be up to approximately 11 km. Based on the modelling presented in this report, a decreasing proportion of auks were displaced at distances estimated up to approximately 5 km from the LAW but, as for divers, complete displacement was not detected at any distance. Table 21 summarises displacement distances estimated for divers and auks at other offshore wind farms, the distances for auks ranged from 2 to 4 km (Welcker & Nehls, 2016) whereas for divers recent studies have estimated a displacement effect of up to approximately 15 km away from an OWF (Mendel *et al.*, 2019; Heinänen *et al.*, 2020).

Overall, a greater change in the proportion of auks (62-83%, see Appendix 8) than divers (41-64%, see Appendix 8) occurred in the LAW with displacement estimated up to approximately 5 km for auks and up to approximately 11 km for divers. In this case, the results indicate that divers are more sensitive to the effects of an offshore windfarm than auks due to the greater distance at which displacement occurred. However, auks exhibited a larger proportional decline than that of divers near to the LAW.

Table 21 Displacement effects for divers and auks from other offshore wind farms taken from Welcker & Nehls (2016) with the addition of Mendel *et al.* (2019) and Heinänen *et al.* (2020): '-' and '0' indicates statistically significant negative effect on abundance and no effect detected respectively. Symbols in parentheses indicate no significant effect, but response suggested by authors.

Source	Offshore Wind Farm	Diver Displacement Distance (km)	Auk Displacement Distance (km)
Petersen *et al*. 2006 & Petersen & Fox 2007	Horns Rev I / Nysted	2	2
Leopold *et al*. (2011, 2013)	Egmond aan Zee / Princess Amalia	-	-
Percival 2013	Thanet	0	(-)

Source	Offshore Wind Farm	Diver Displacement Distance (km)	Auk Displacement Distance (km)
Walls *et al*. 2013	Robin Rigg	(-)	(-)
Vanermen *et al*. 2013	Thorntonbank	N/A	0
Percival 2014	Kentish Flats	1*	0
Petersen *et al*. 2014	Horns Rev II	5-6**	N/A
Webb *et al*. 2015	Lincs	2-6	4
Vanermen *et al*. 2015	Bligh Bank	-	3
Welcker & Nehls 2016	Alpha Ventus	1.5	2.5
Mendel *et al.* 2019	South Eastern North Sea (Butendiek and 'Helgoland Cluster')	Up to 16	N/A
Heinänen *et al.* 2020	German Bight	Up to 10-15***	N/A

* No statistical effect outside the wind farm - 1 km suggested by author
** Authors suggested up to 13 km but summarised that 5-6 km was more sensible
*** Authors noted a very strong effect up to 5 km away, but significant effect still detected up to 10-15 km

8. Conclusions

Each of the marine licence conditions have been analysed in the preceding sections and the results are summarised below under each of the relevant conditions.

Determine whether there is change in bird use and passage, measured by species (with particular reference to Red-Throated Diver), abundance and behaviour, of the windfarm site, 1 km and 2-4 km buffer zones and the reference site.

The results indicate that divers and auks were not completely displaced during or post construction. During construction it appears that there was a redistribution of divers and auks into Zone 1 and Zone 2 with significant increases in density estimated for divers in the southern region of Zone 2, and along the eastern boundary of Zone 1 for auks.

During the construction phase the proportion of divers present appeared to be reduced up to approximately 11 km from the LAW. However, the diver density profile pre construction, with the greatest diver density occurring at 9 km from the LAW suggests that factors other than the construction activities of the LAW influenced the distribution of divers. The locations of the peak diver densities pre, during and post construction moved 5.5 km and 4.5 km away from the LAW, respectively. This may be indicative that other factors, apart from the construction activities at the LAW, are compounding any displacement effects in divers in the region. Therefore, the displacement distance for divers is estimated to be between10.5 km and 12 km. The displacement effect of divers appeared to be less than predicted within the LAW, as the ES predicted 100% displacement, but a larger effect than predicted occurred over a larger distance from the LAW. Overall, the numbers of divers displaced was almost double what was predicted in the ES: 3.4% versus 6.1% when expressed as a percentage relative to the estimated size of the OTE SPA population (the population size of red-throated divers in the OTE SPA has increased almost threefold during this time).

During the construction phase the proportion of auks present appeared to be reduced up to approximately 5 km from the LAW. Postconstruction diver and auk densities significantly increased from the construction phase in the LAW and surrounding area, although the densities were still proportionally lower than those recorded pre construction. The presence of the operational turbines and other potential activities of the LAW indicate that displacement of these species groups is ongoing within the LAW and immediate surrounding area. The modelling showed that an estimated 1,111 divers (approximately 6% of the population; approx. twice the percentage assumed in the ES) have been displaced from an area within the OTE SPA centred around the LAW. The modelling showed that an estimated 536 auks were displaced from an area within the OTE SPA centred around the LAW, with an area of influence of up to approximately 5 km (see Appendix 8).

Objective 2: Determine whether there is a barrier effect to the movement of birds through the wind farm site, 1 km and 2-4 km buffer zones.

Flying divers were located mainly in the north-east region of Zone 1 during all construction phases, and no flying individuals were recorded within the wind farm footprint during the post-construction surveys. However, birds were recorded within the LAW footprint during construction and within 1 km of the LAW across all construction phases. A first test did not detect any difference in the number of divers flying towards the wind farm compared to all other directions, between the LAW to 4 km and greater than 4 km in Zone 1 ($P > 0.05$), however due to the small sample size this test lacked in power. A more powerful test based on resampling detected that fewer divers tended to fly toward the wind farm in the 2 to 4 km buffer region, than in other directions ($P < 0.05$). This suggests that the wind farm may be acting as a barrier to flying divers up to 4 km from the LAW. The analysis specifically calculated the direction of flying individuals in relation to the nearest turbine and as such the analysis of the potential barrier effect was confined to the LAW footprint and buffer and did not examine effects on connectivity between suitable habitat beyond these boundaries. A barrier effect preventing birds to enter the wind farm footprint and buffer is defined as avoidance leading to displacement. The cross-sectional monitoring programme did not cover areas of the OTE SPA and as such could not be used to assess wider ranging barrier effects on individual flight trajectories and habitat connectivity.

Although displacement could explain the relatively small number of divers observed flying in the vicinity of the LAW, the few observed flying divers do seem to avoid flying towards the LAW. The divers avoiding flights into the predominant south-westerly wind, however, could give the misleading impression that the LAW is acting as a barrier.

Objective 3: If objectives 1 or 2 reveal significant change of use of the wind farm site and 1 km and 2-4 km buffer zones by populations of conservation concern, at heights that could incur collision, a programme of collision monitoring will be implemented.

The absence of flying red-throated divers in the footprint post-construction means that the collision risk is reduced for this species. This displacement of red-throated diver and hence reduction in collision risk is consistent with the predictions of the ES.

Even though the analysis presented in this report is likely to overestimate the number of collisions in the LAW, seven or less herring and lesser black-backed gulls were estimated to collide with the wind farm which is less than the figures predicted by the ES. Gannet and great black-backed gull collisions appear also to have been overestimated in the ES.

These results do not support the need for a programme of collision monitoring for diver species, because divers are considered as having a relatively low sensitivity to collisions as opposed to displacement from habitat (Furness *et al*., 2013) and the post-construction analysis indicates that very few divers enter the London Array OWF footprint.

9. References

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Appendix 1 Methods of Analysis of the Raw Survey Data

Selection of observations to be included in the analysis

For boat survey data, only those divers recorded as 'in transect' and on the water were suitable for analysis (Webb & Durinck, 1992). Birds in flight do not tend to become less detectable with distance in the same way as those on the sea, and so counts of birds in flight were scaled to adjust for coverage, but not detection.

For aerial survey data, all birds recorded were suitable for analysis.

'Percival analysis' of the boat survey data (pre-consent)

For boat survey data, population estimates were generated following the method outlined in Percival (2009). This method adjusts for the effects of detection and coverage to produce population estimates and was used for comparability with results for Kentish Flats OWF from Percival (2009). Estimates presented incorporate counts of birds in transect adjusted for detection and coverage, summed with scaled birds in transect and in flight.

The method was not applied to aerial survey data.

Distance analysis of boat and aerial visual survey data (pre-consent)

For boat and aerial visual survey data, distance sampling was applied to data collected (Buckland *et al*., 2001; Thomas *et al*., 2010), using Distance 6.0. This method models detection of birds as a function of distance from the survey vessel and produces density and population estimates. It is recommended as "the most statistically robust method of estimating bird densities based on the results of aerial [visual] or ship-based survey" (Camphuysen *et al*., 2004).

Global and stratum-level detection functions were applied in order to ascertain best model fit, with density estimates always at the stratum level (in this case, the individual survey or survey month). Detectability of birds was modelled for clusters, as boat and visual aerial survey methods tend to record groups when encountering many birds (for example, a recorder will estimate a flock of 1,000 rather than 1,000 individual records). Conventional Distance Sampling selected between three robust models (half-normal / hermite polynomial; hazard rate / simple polynomial; and uniform / cosine) on the basis of minimum Akaike's Information Criteria (AIC). These model definitions are consistent with Buckland *et al*. (2001). Multiple Covariates Distance sampling was investigated, but a lack of consistent covariate data prevented its use. Variance was assumed to be Poisson distributed with an overdispersion factor.

Separate estimates were produced for wind farm (plus buffer) and control zones where relevant. Scaled counts of birds in transect and in flight are presented alongside distance estimates to provide total estimates (these detections do not typically decrease with distance and are not suitable for distance analysis).

Digital aerial survey data collection and analysis (post-consent)

Data collected

During the monitoring period the understanding of how digital aerial surveys could inform the understanding of the potential effects of offshore wind farms developed and that development is reflected in the information that was recorded and derived from the images. As a result, the earlier surveys may not contain all of the information listed below e.g. for the certain months in the pilot study, available information is restricted to the geo-referenced location and species and / or species grouping.

For each monthly aerial survey geo-referenced locations of birds contained within each individual digital still image were used to generate raw counts. Those bird locations were extracted using ArcGIS. Photographs were imported as geo-referenced images (WGS 84 projection) into ArcGIS.

Data contained within the ArcGIS files for each bird recorded includes information such as (noting that due to the development of the methodology described above, not all this information is available for the earlier years):

- Geo-referenced location (easting, northing)
- Species and / or species grouping
- Behaviour (sitting on the water or flying)
- Age and sex where possible
- Flight direction
- Heading
- Size (body length)
- Date and time stamp of image collection

Data on flight height were not considered essential and was not recorded as the main species of interest was red-throated divers, known typically to fly close to the sea surface (Blomdahl *et al*., 2003).

Quality assurance of image identification

A standard internal and external Quality Assurance (QA) procedure was carried out on each survey.

For the internal QA, images were assessed in batches with a different staff member responsible for each batch. Each bird image was reviewed and checked by APEM’s own dedicated QA manager, ensuring that 100% of birds found in the images were subject to internal QA. The QA manager, an experienced ornithologist, was responsible for maintaining and updating the image library and also provided advice and guidance to the image processing staff. Images containing no birds were removed and kept separately for further QA. Of these ‘blank’ images, 20% were randomly selected for QA by the QA manager. If there was less than 90% agreement, the entire batch of images was re-analysed.

Upon completion of the internal QA, 20% of the birds located in each survey were subject to external QA by an independent organisation. The appointed auditors for seabirds are the British Trust for Ornithology (BTO). The images for external QA were selected at random using a random number generator. The selected images were provided to the BTO along with information on measured body lengths and wingspans of the birds. All identifications were conducted 'blind' by the external analyst. Upon completion, a matrix was created to show the proportion of agreement and identify areas of potential misidentification. It was previously established that at least 90% agreement between BTO and APEM was required. Any disagreements were reviewed and if the 90% threshold was still not reached then a further 20% of images were assessed by the BTO. If 90% agreement was not achieved after secondary assessment, then the entire batch of images would be required to be reassessed and the QA process repeated.

Abundance estimates

Design-based estimates of bird abundance with confidence limits (CL) and associated precision of estimates were calculated for each zone. Abundance estimates were only calculated for red-throated diver species for the 2009/10 surveys. All analysis and data manipulation were conducted in the R programming language (R Development Core Team, 2014) and non-parametric 95% confidence intervals were generated using the 'boot' library of functions (Canty & Ripley, 2010).

To calculate abundance estimates, it is necessary to know the total number of images required to cover the survey area. This was done by calculating the average size of an image footprint. An average image footprint was calculated by dividing the sum of the image areas contained within the survey area by the number of images that were wholly or partially within the survey area. Average coverage recorded during the 2015 / 16 aerial surveys was 15.31%, although coverage of the zones varied between months (lowest coverage 15.00%, highest coverage 15.75%). The variation in coverage was due to the use of camera systems with differing image footprint sizes, and variation in environmental conditions resulting in variation in the number of partial images captured within the tolerance limits of the survey design. The same survey design was flown during each survey resulting in the same number of replicates. A greater coverage does not necessarily lead to an increased encounter rate. Nonetheless, if greater coverage leads to an increased uniform encounter rate, this will be reflected by an improved precision estimate. However, if the variance between images increases due to encountering larger flocks and thereby increasing the variability between images, this will be reflected by a poorer precision estimate. Therefore, the encounter rate and variability are assessed within the calculation of the precision estimate. This provides a measure of which to compare between surveys to assess how well a change in abundance would be detected by each survey.

Population estimates were generated by adding up the raw counts from geo-referenced images and dividing this number by the total number of images to give the mean number of birds per image (i). Population estimates (N) for each survey month were then calculated by multiplying the mean number of birds per image by the total number of images required to cover the entire study area (A). This is analogous to abundance estimation outlined in Borchers *et al*. (2002).

$N = i\ A$

Population estimates were derived from the grid data for all the monthly surveys undertaken. For each monthly aerial survey of each zone, geo-referenced locations of birds contained within each individual digital still image were used to generate raw counts. Bird locations contained within the boundaries of each zone were then extracted using ArcGIS, leaving raw count data for images obtained from each zone. Where an image fell across the survey boundary, only the part of the image that fell within the survey area was included in the analysis.

As the population estimates are derived by scaling counts by size of the area, and not in relation to available habitat, it is possible that the population estimates could either be under- or over-estimated. However, due to the survey design being a 500 m grid each Zone is sampled in a consistent manner and provides a greater probability of sampling patchy habitats in a representative manner than does a survey design of widely spaced transects.

Confidence limits of the abundance estimates

Confidence limits (CL) showing the extent of variability surrounding the relative population estimate were calculated using a non-parametric bootstrap method. APEM routinely use bootstrap methods to calculate CL as this statistical method is considered to be a robust way of assigning measures of accuracy (Borchers *et al*., 2002). For the bootstrap simulation, a sub-sample of images within stratums were re-sampled 999 times with replacement from image data (i.e. 999 subsamples of the raw counts were used to produce 999 new 'total raw count' values). Each of the 999 bootstrap values were then used to produce relative population estimates within each stratum. The upper and lower 95% confidence intervals (+CL and –CL respectively) of all the bootstrapped population estimates was taken as the variability of the statistic over the population (Efron & Tibshirani, 1993).

Precision of the abundance estimates

For every population estimate, APEM calculates a CV' (coefficient of variation) to provide a measure of precision about the mean population estimate, i.e. to provide a measure of how good the estimates are of the relative population. As aerial survey grid data normally contain a high proportion of images with zero counts (as animals are not normally evenly distributed across the survey area), measures of precision were calculated from the raw count data using a negative binomial estimator which is suitable for data that have a pseudo-Poisson over-dispersed distribution caused by a large number of zero counts (Elliott, 1977). This produced a CV' based on the relationship of the standard error (SE) to the mean (μ).

$$CV' = SE / \mu$$

This statistic is used to determine whether the sampling regime is sufficient to estimate the population with a given level of precision. A $CV' \leq 0.16$ relates to a precision level able to detect a doubling or halving of the population (Bohlin, 1990), although at very low densities, it is not always mathematically possible to obtain a CV' of 0.16, even if 99% of the area is covered.

Relative density distribution maps

Bird observations comprised individual points for each recorded individual, geo-referenced to actual spatial location at the time of survey. Relative density distribution maps were produced using ArcGIS (version 9.2) by summing the number of divers recorded in each image and then representing this sum of divers as a dot on a map that was proportional to the number of divers in that image; i.e. large numbers of divers per image were represented by larger dots than smaller numbers of divers per image.

Appendix 2 Data Refinement Summary

Table 1 presents a summary of changes made to the data following final quality assurance checks. The table details original count data which are shown in the annual reports and their corrected values used in the analyses of this report. Please note that the extent of these changes is minor and therefore these changes would not be expected to have any significant effect on the outcome of the analyses for this report, nor would they be expected to alter the conclusions of the relevant annual reports.

Table 1 Summary of changes made to finalised data.

Species	Zone	Date	Original Count	Corrected finalised count	Comment
Great black-backed gull	1	Dec-13	79	78	Birds clipped to zone.
Total large gull species	1	Dec-13	120	119	Birds clipped to zone.
Total diver species	1	Dec-13	1,023	1,021	Birds clipped to zone.
Red-throated diver	1	Dec-13	974	973	Birds clipped to zone.
Black-throated diver	1	Dec-13	27	25	Birds clipped to zone.
Great northern diver	1	Dec-13	22	23	Species ID change.
Puffin	1	Feb-13	12	13	Species ID change.
Guillemot	1	Jan-13	10	0	Not present in final shapefile.
Guillemot / razorbill	1	Jan-13	102	108	Species ID change.
Lesser black-backed gull	3	Feb-13	10	8	Birds clipped to zone.
Total diver species	1	Feb-13	665	664	Birds clipped to zone.
Red-throated diver	1	Feb-13	651	650	Birds clipped to zone.
Common scoter	2	Jan-13	14	14	Species ID changed from scaup to common scoter.
Common scoter	7	Feb-13	58	0	Birds clipped to zone.
Cormorant	2	Jan-13	40	40	Species ID changed from cormorant/shag to cormorant. Peak value for total cormorant/shag has been updated.

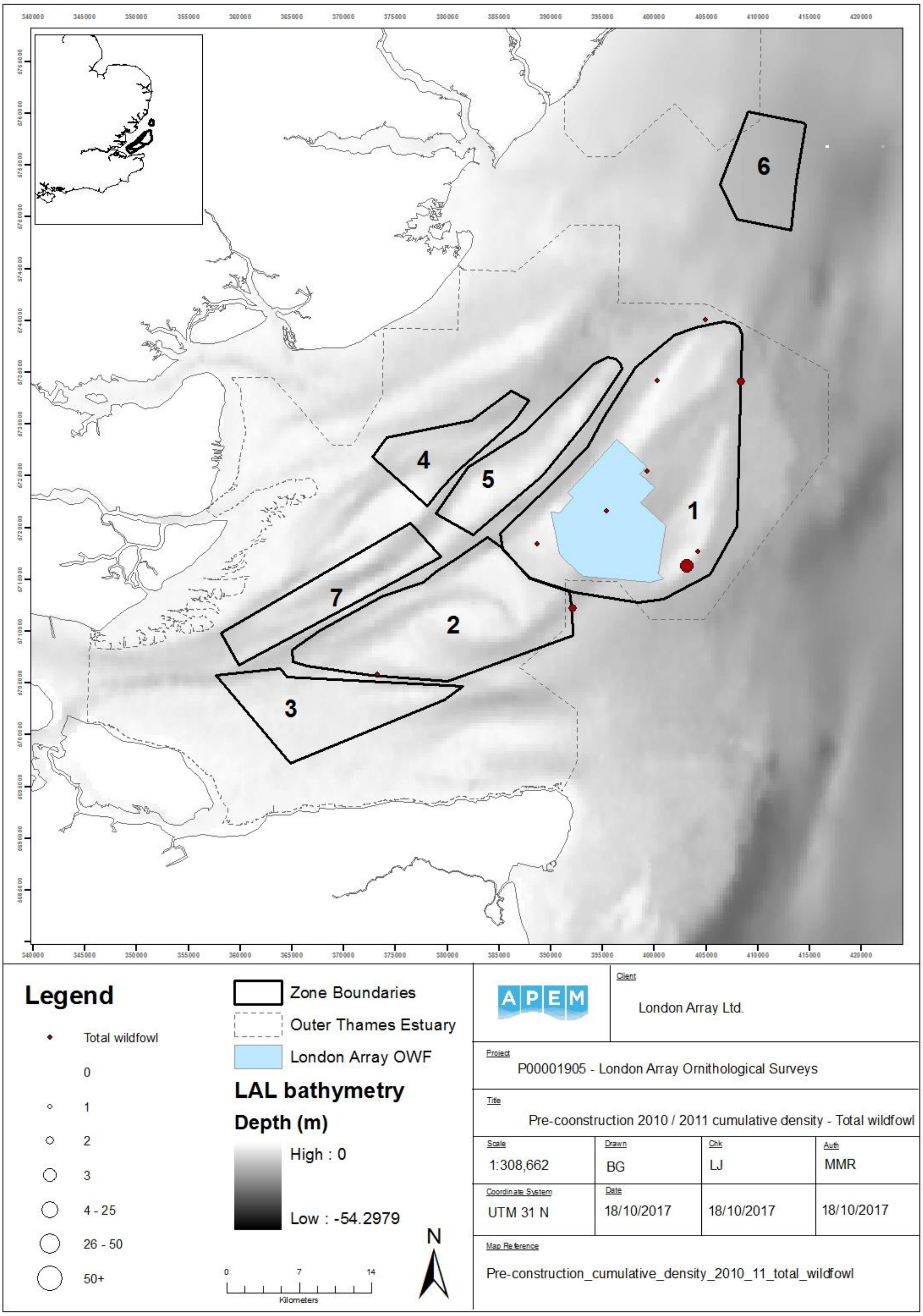
Species	Zone	Date	Original Count	Corrected finalised count	Comment
Great crested grebe	7	Jan-13	3	3	Species ID changed from grebe species to great crested grebe.
Total diver species	2	Feb-12	433	462	Peak counts for diver species, red-throated diver, great northern diver and total diver species have been updated.
Common scoter	2	Nov-11	28	28	Species ID changed from seaduck species to common scoter.
Cormorant	3	Jan-12	56	56	Species ID changed from cormorant/shag to cormorant. Peak value for total cormorant/shag has been updated.
Great crested grebe	1	Jan-12	1	1	Species ID changed from grebe species to great crested grebe.
Great skua	1	Nov-11	1	1	Species ID changed from skua species to great skua.
Kittiwake	2	Feb-12	50	54	Species ID change.
Herring gull	3	Jan-12	50	47	Birds clipped to zone.
Total diver species	1	Feb-11	1,257	1,220	Birds clipped to zone, diver species and red-throated diver peaks updated.
Seaduck species	1	Jan-11	4	3	Birds clipped to zone.
Cormorant / shag	7	Nov-10	1	0	Birds clipped to zone.
Auk species	1	Jan-11	50	49	Birds clipped to zone.
Gannet	1	Feb-11	91	90	Birds clipped to zone.
Great black-backed gull	7	Feb-11	14	13	Birds clipped to zone.
Lesser black-backed gull	7	Feb-11	14	13	Birds clipped to zone.
Small gull species	3	Jan-11	469	418	Birds clipped to zone.
Black-headed gull	3	Feb-11	33	16	Birds clipped to zone.
Common gull	3	Feb-11	92	71	Birds clipped to zone.
Kittiwake	2	Feb-11	46	40	Birds clipped to zone.

Appendix 3 Cumulative Density Maps (2010-2016)

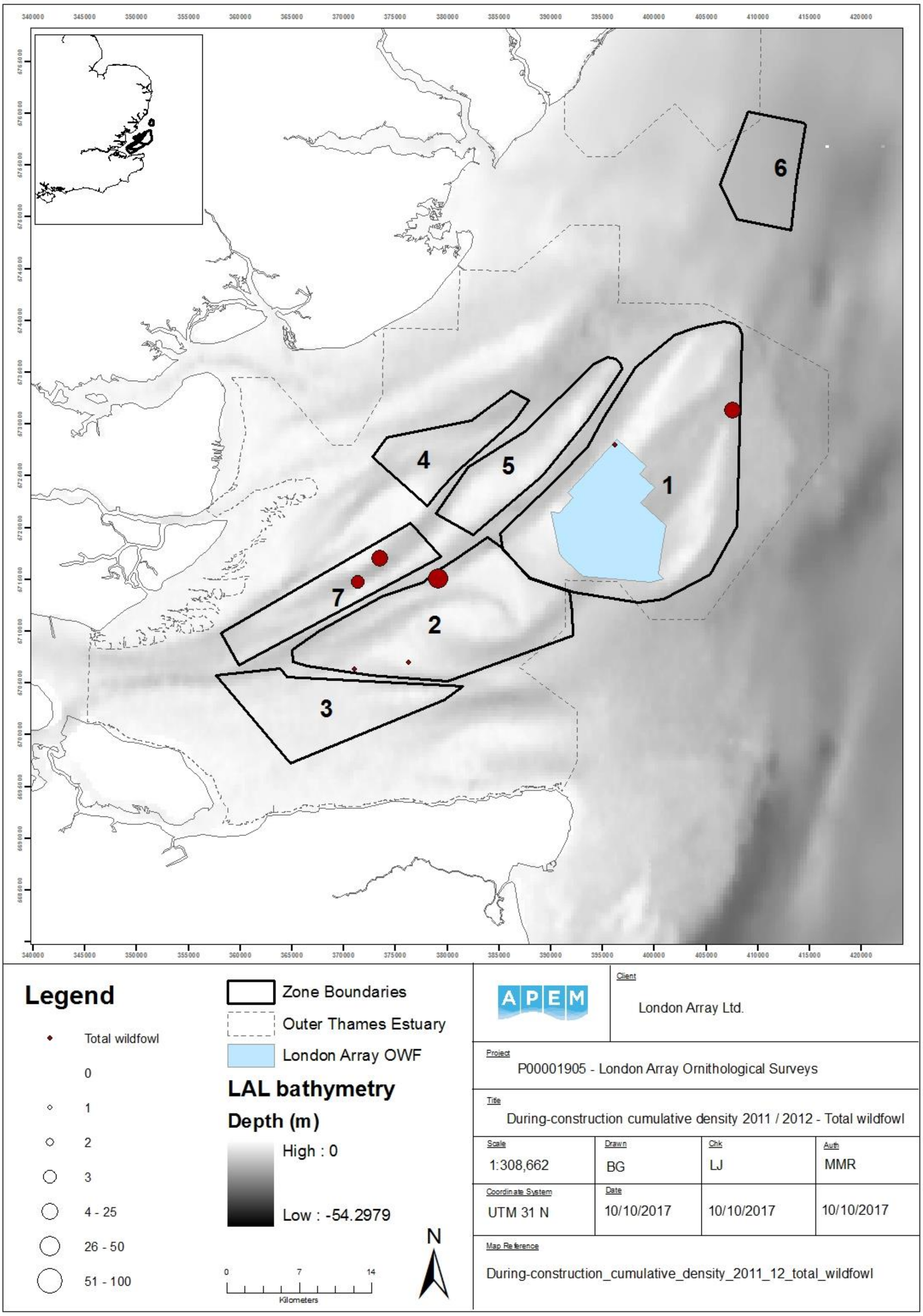
The following figures present the cumulative densities recorded for each species or species group within each digital aerial survey year for the pre-, during-, and post-construction phases (2010-2016). For most of the figures what is presented is the density of the species group in order to account for the variation in identification rates in earlier surveys. Those cumulative density figures for species groups (expressed as 'total [group name]') are derived using the same method as used previously for the annual reports. This method is described in Appendix 1: Relative density distribution estimates. Cumulative values for the numbers of birds present during the pre-, during, and post-construction phases could not be created meaningfully due to the differences in the number of surveys carried out during each phase. Instead, yearly cumulative maps are presented which allow for comparability between each winter. Maps will not be present if the species group was not recorded in that year.

Species-specific monthly maps are provided in Appendix 4.

Total wildfowl



2010 / 11 Pre-construction



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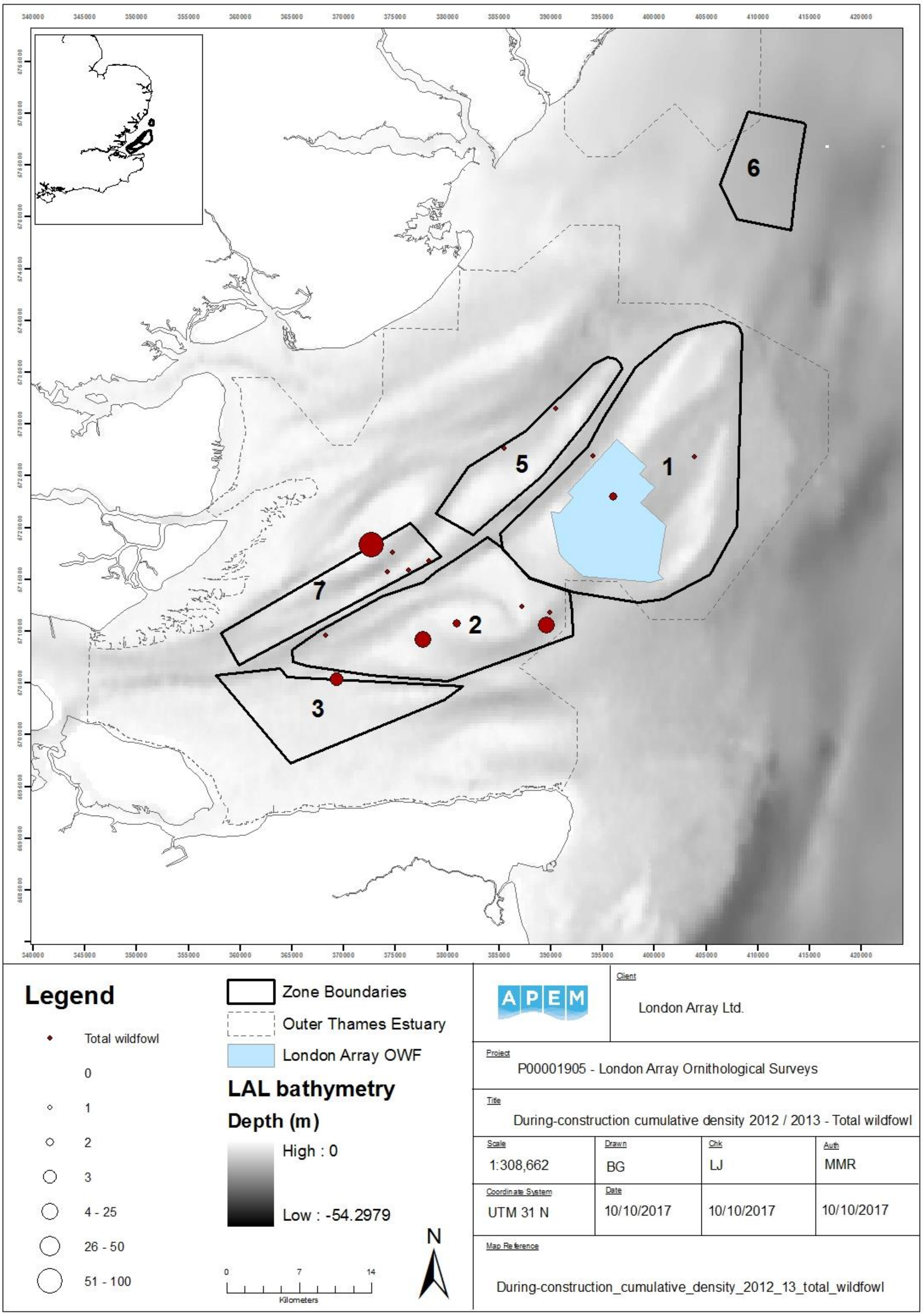
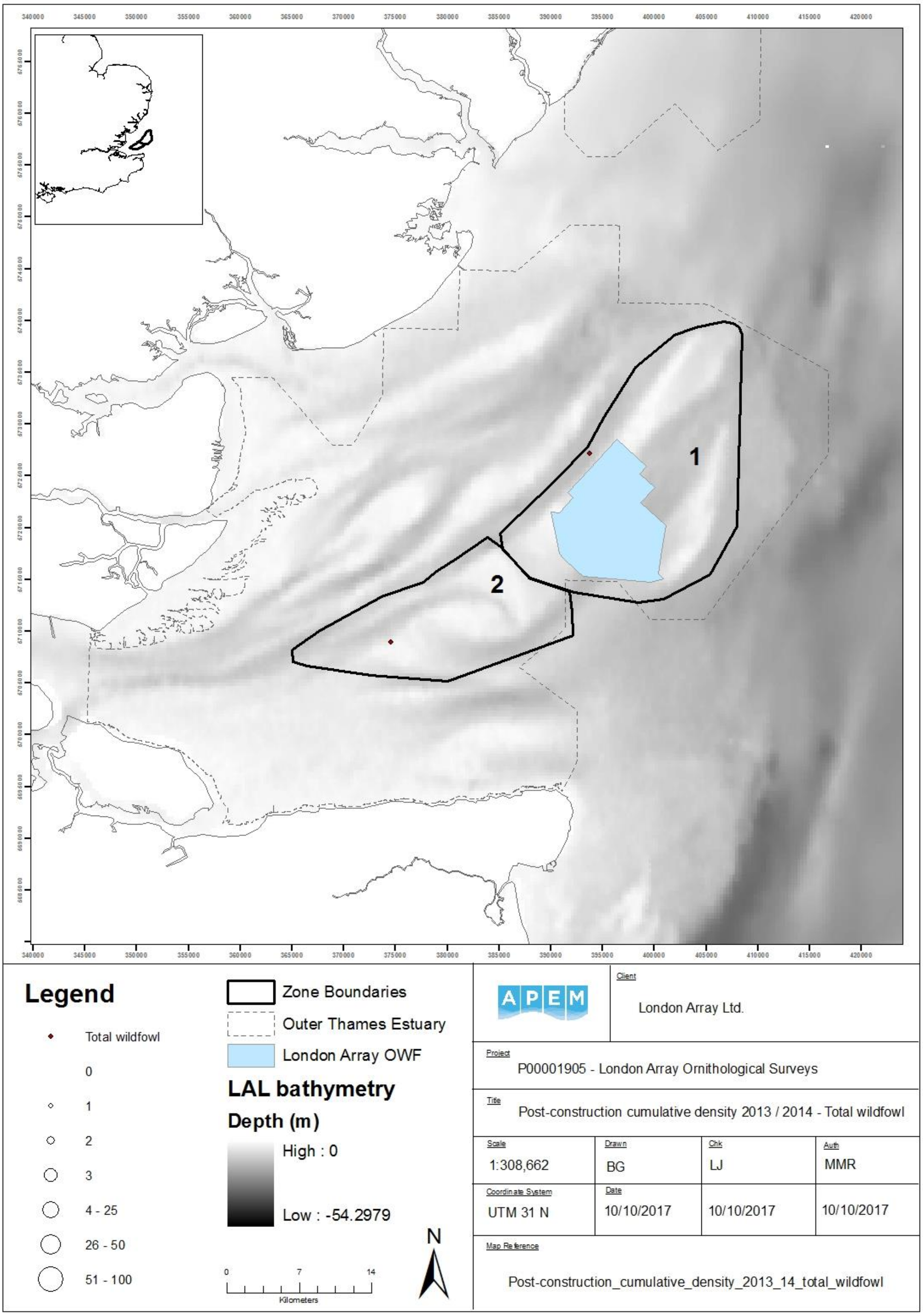
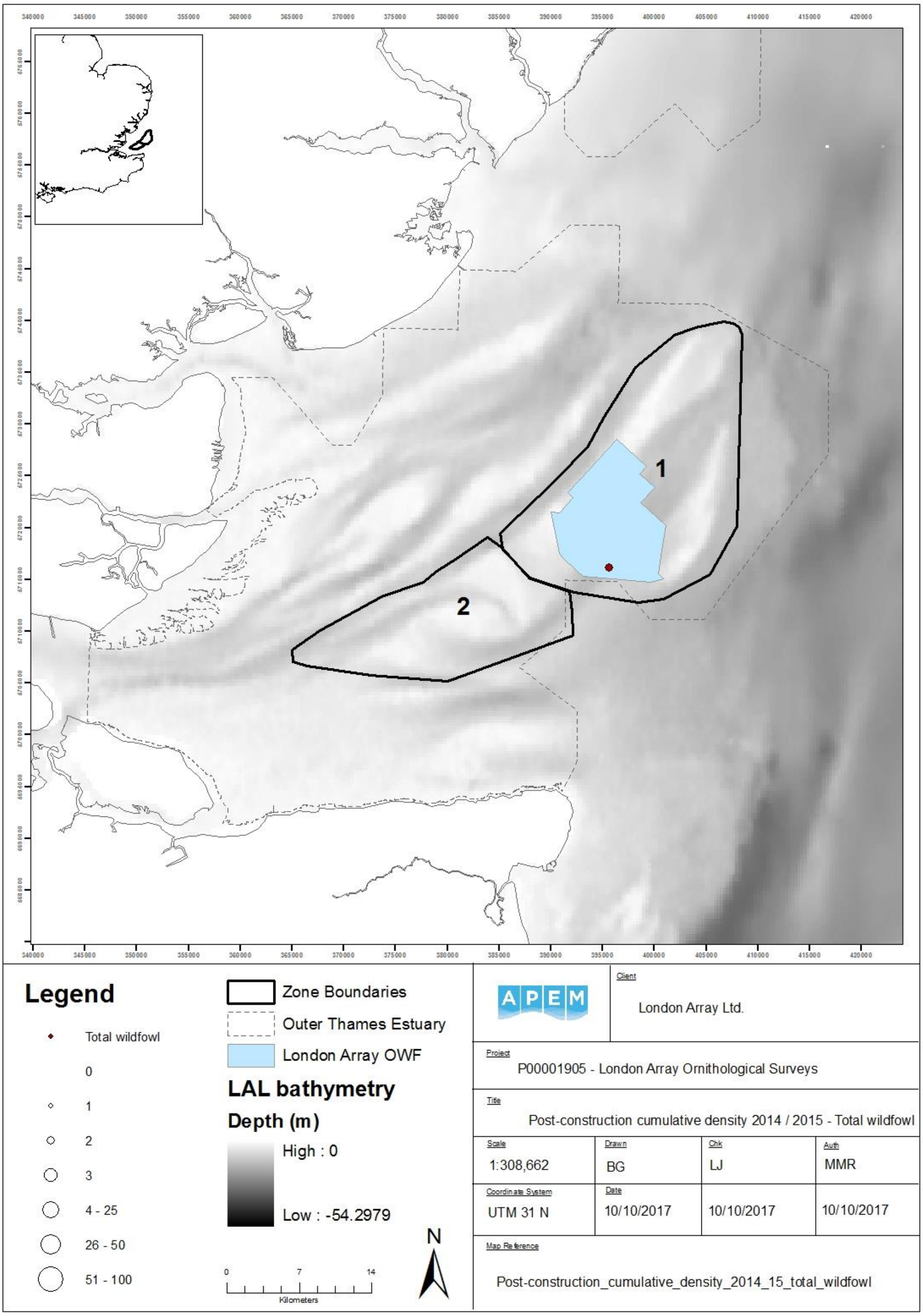
2011 / 12 Construction



2012 / 13 Construction



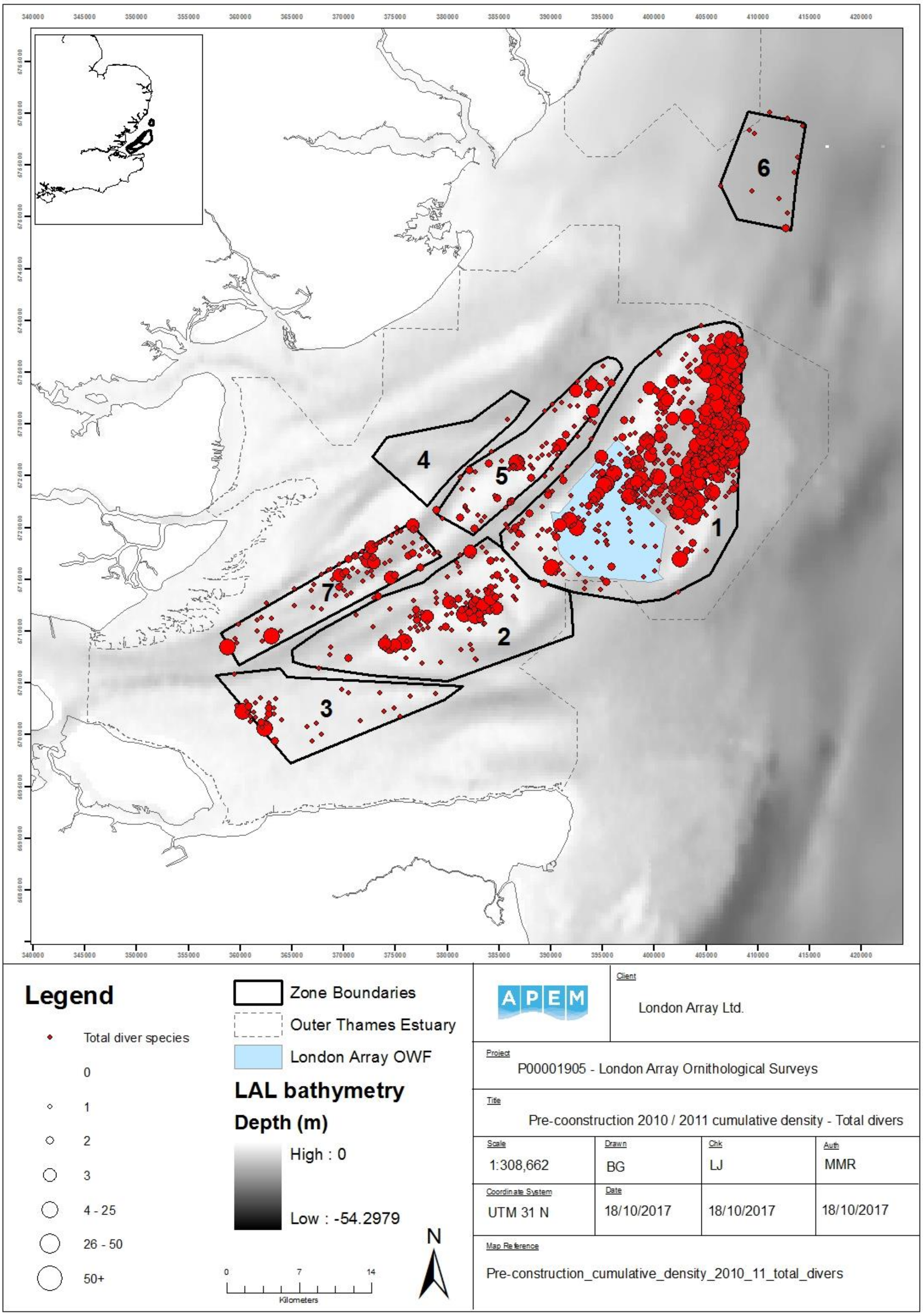
2013 / 14 Post-construction



2014 / 15 Post-construction

Figure 1 Cumulative distribution maps for total wildfowl recorded between the years 2010-2016.

Total divers



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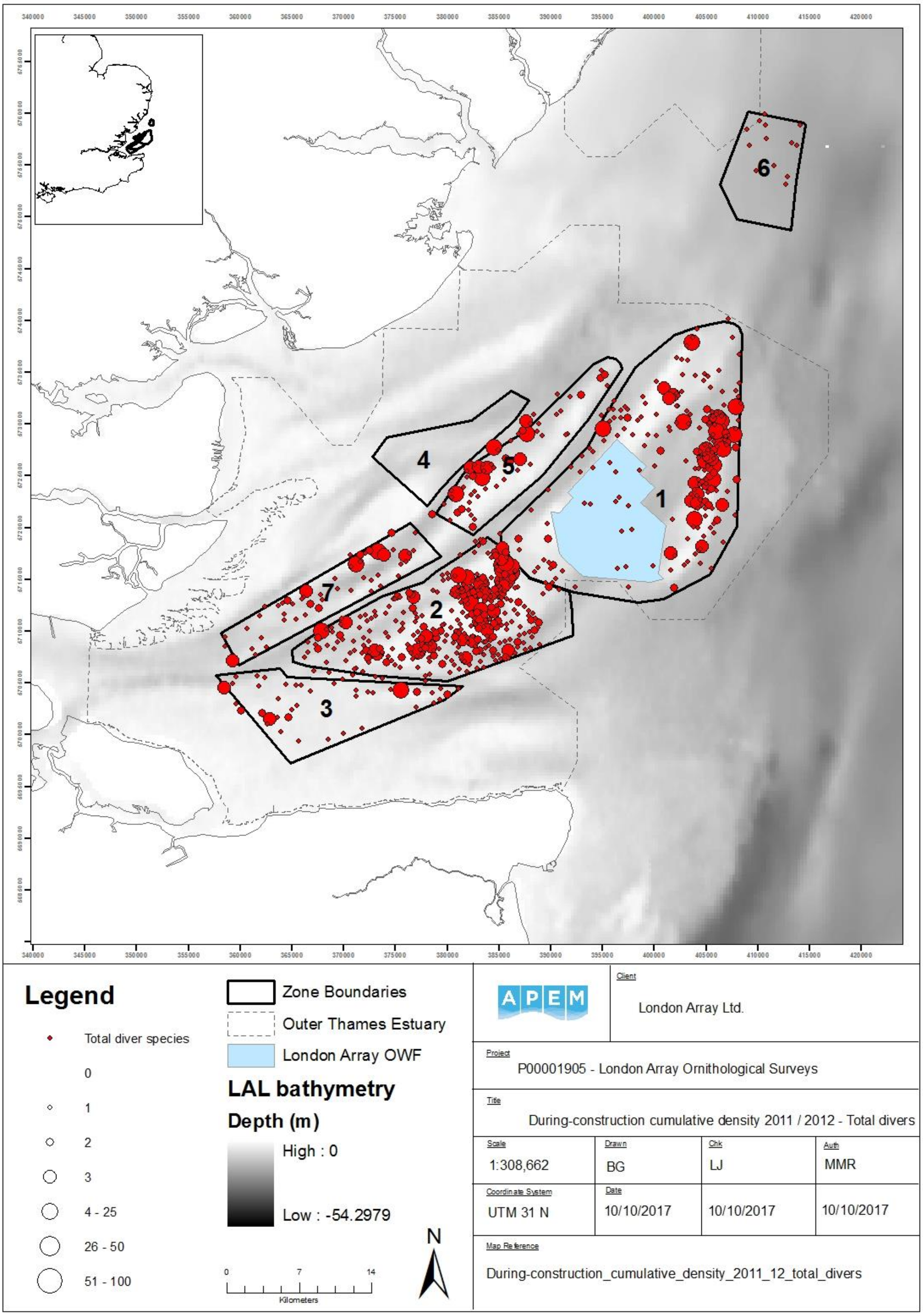
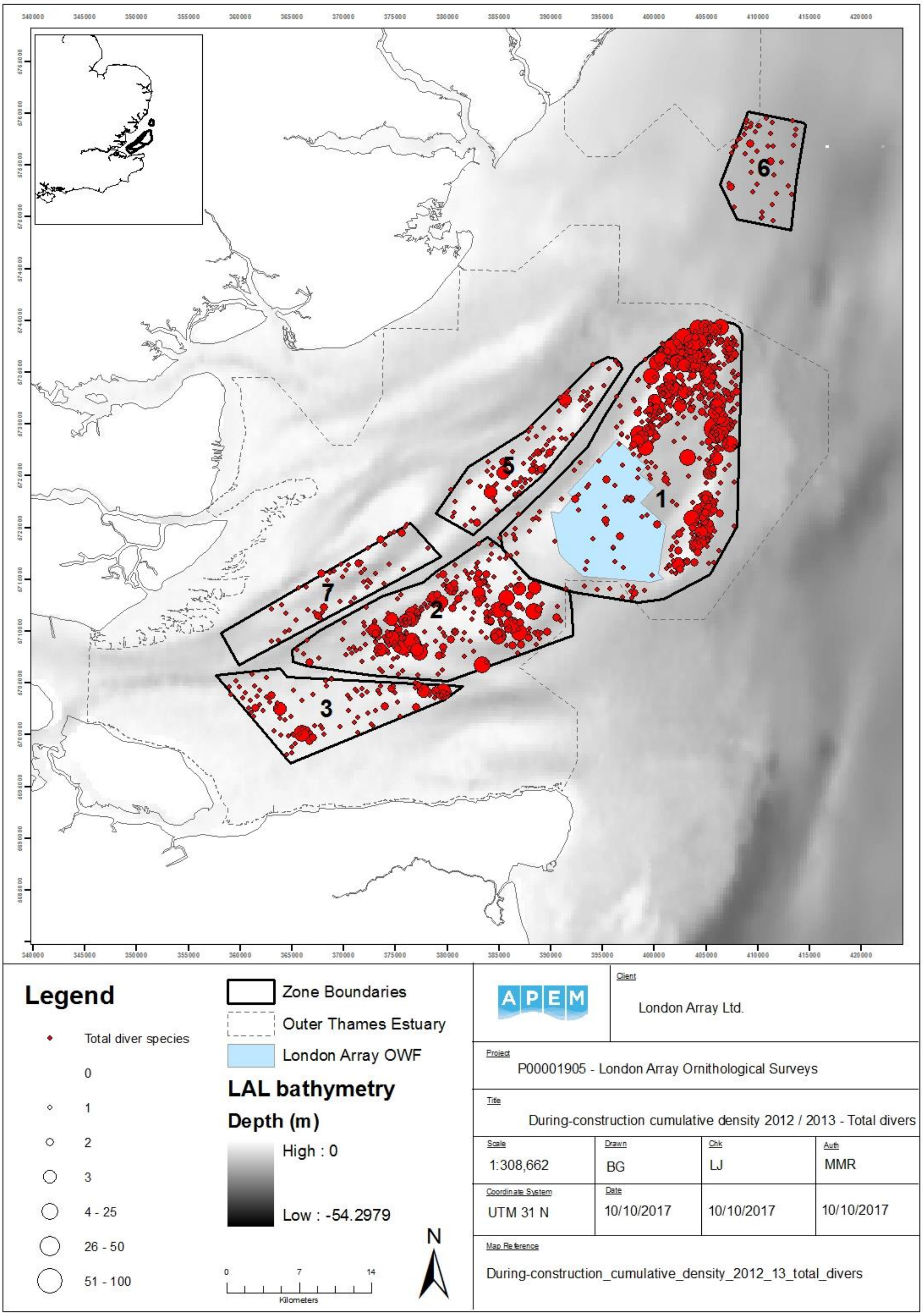
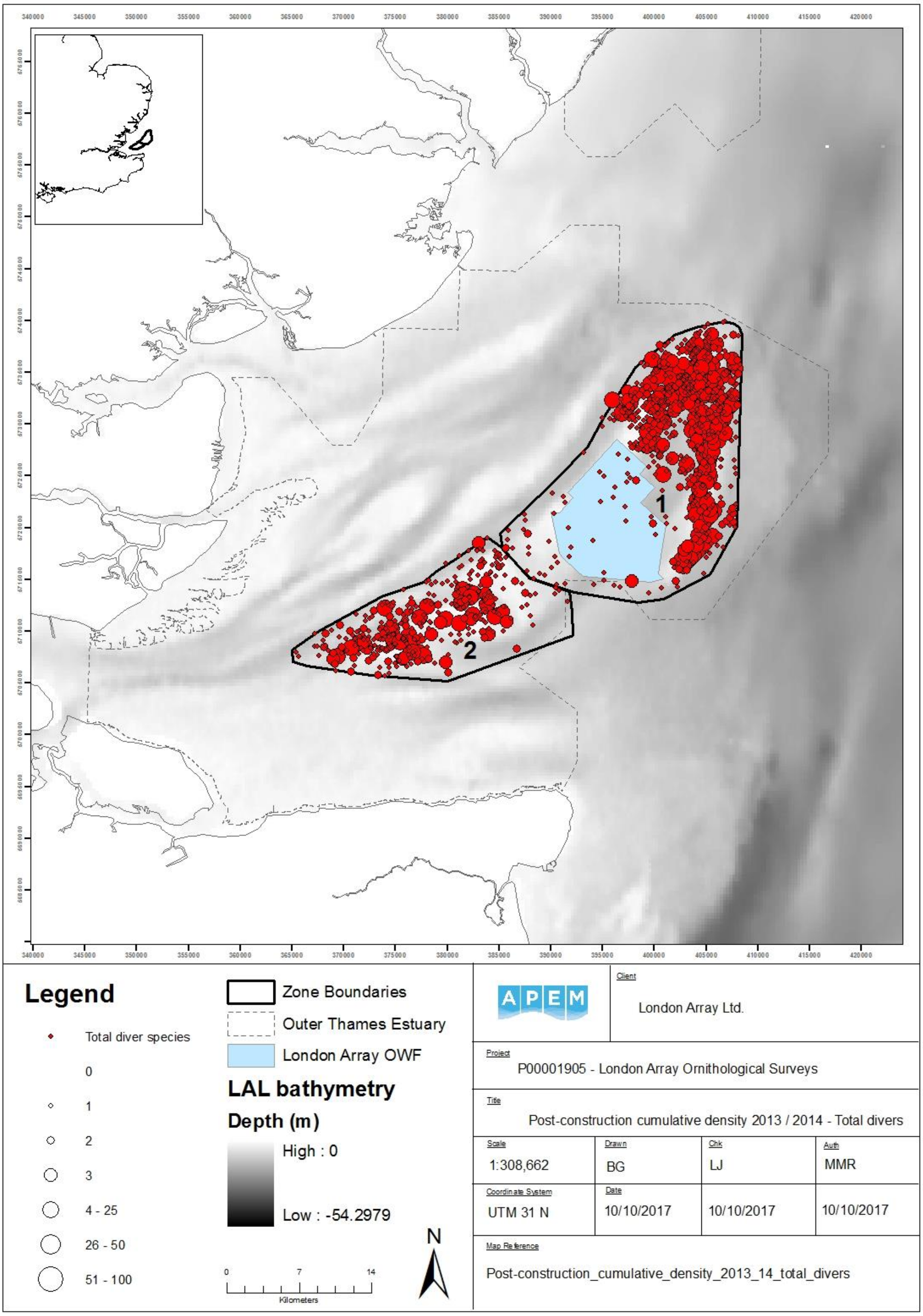
2010 / 11 Pre-construction



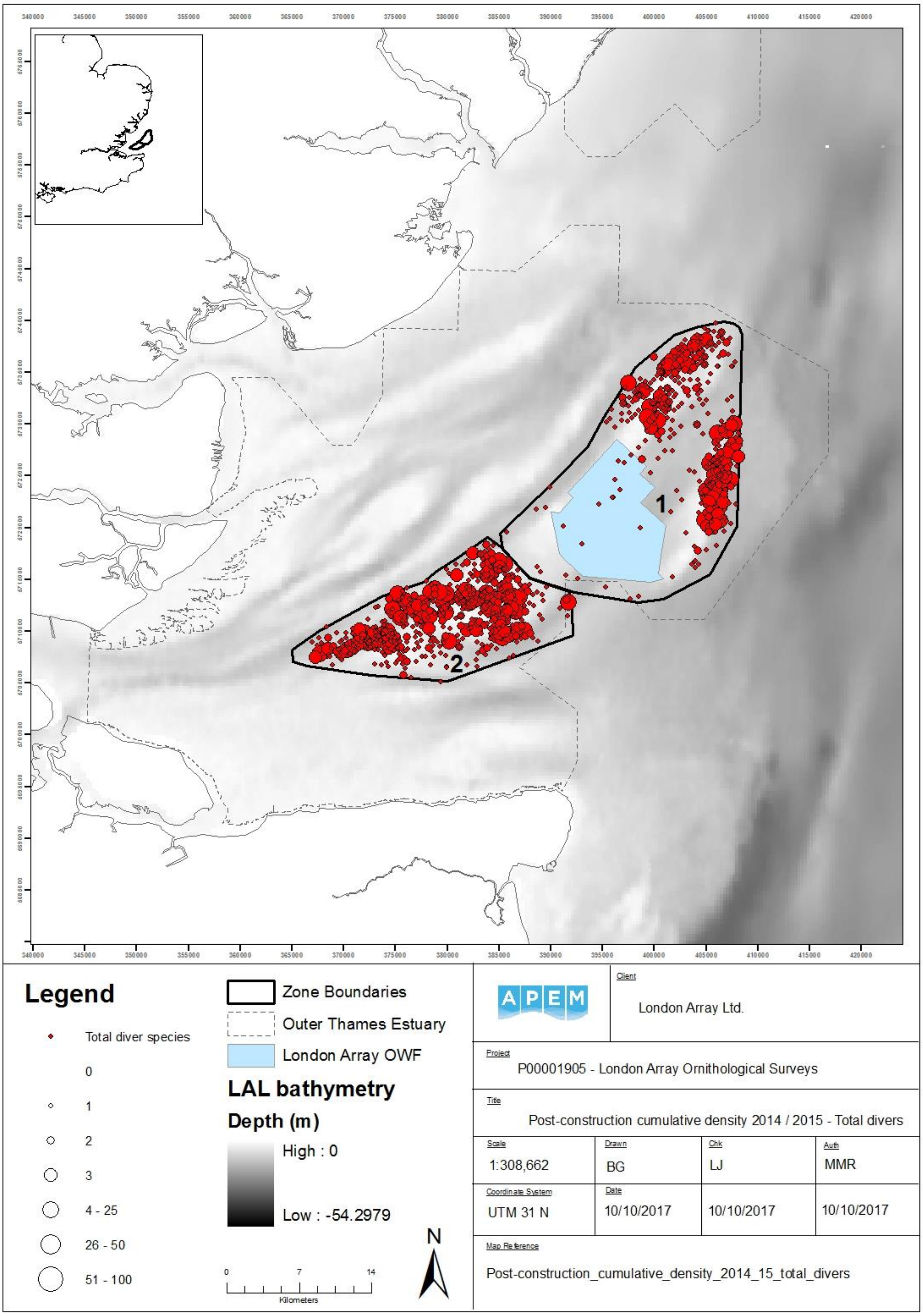
2011 / 12 Construction



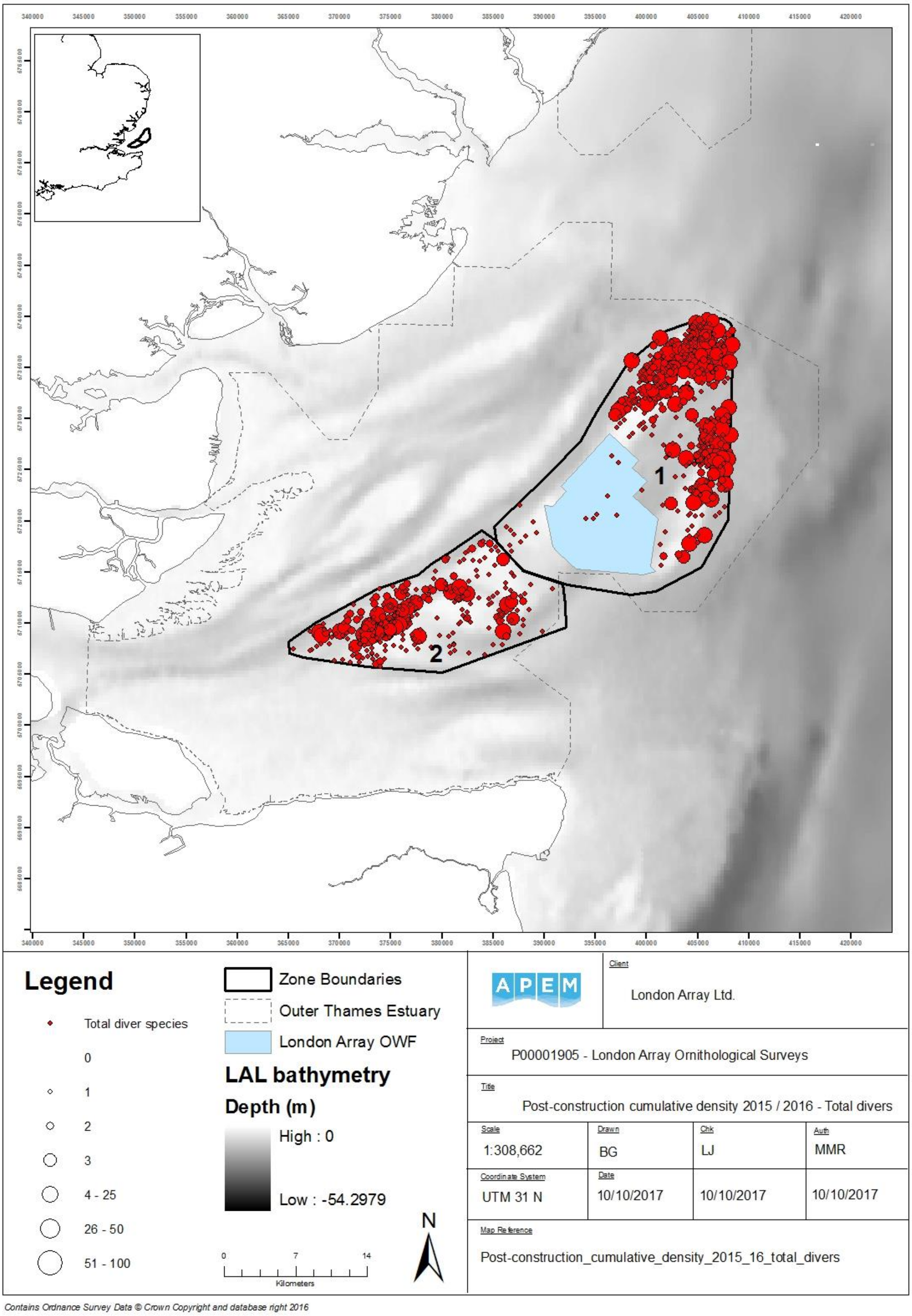
2012 / 13 Construction



2013 / 14 Post-construction



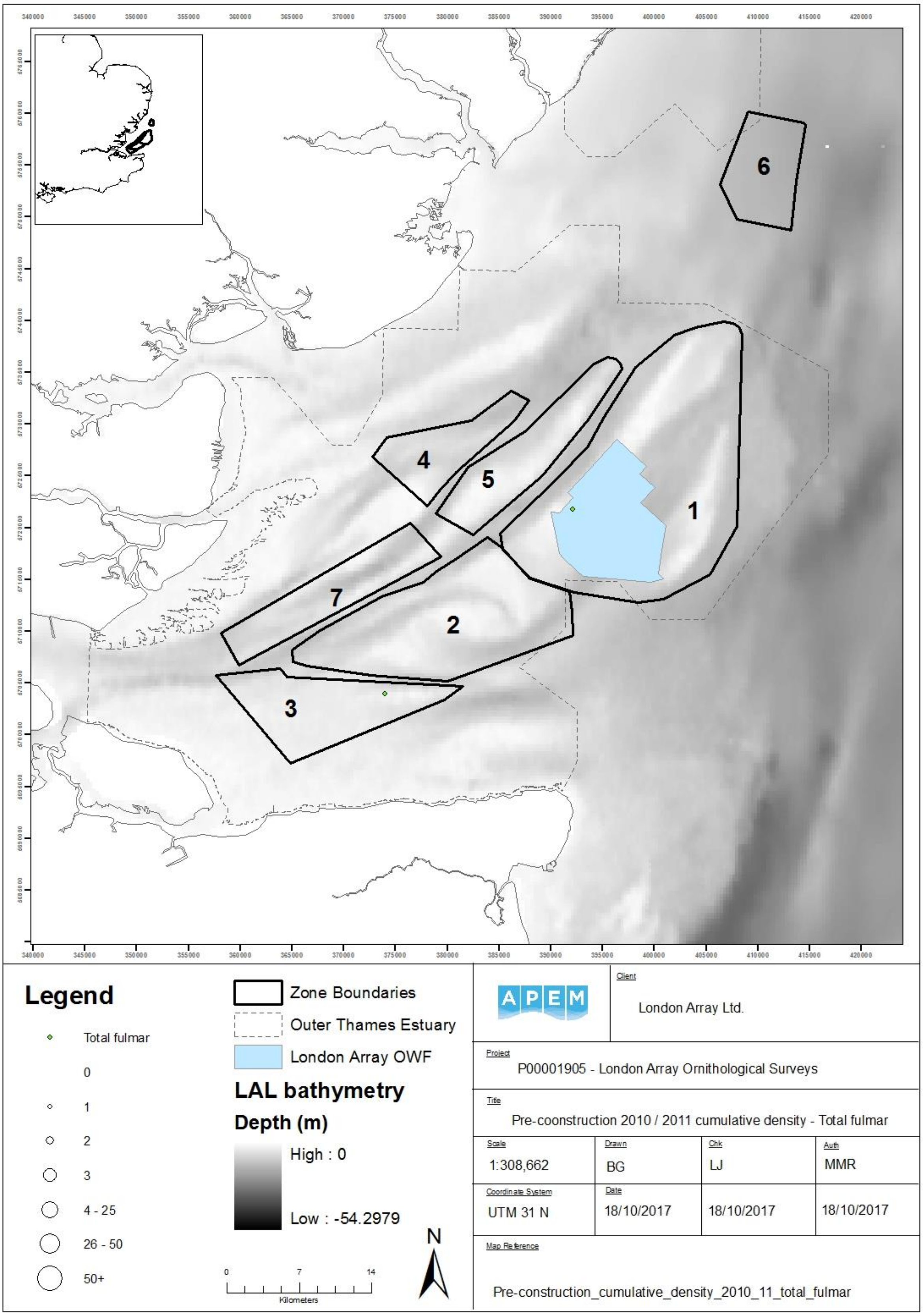
2014 / 15 Post-construction



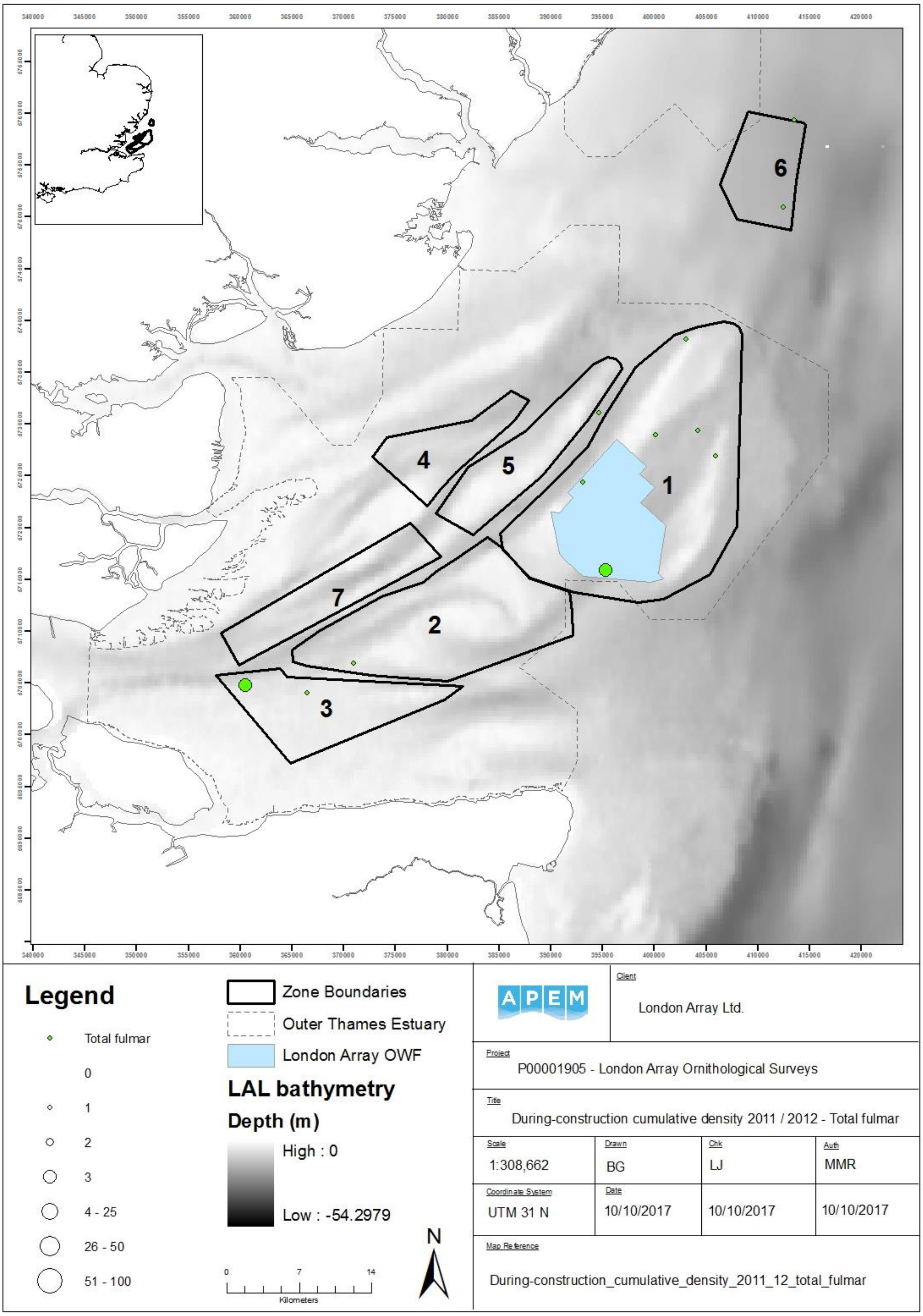
2015 / 16 Post-construction

Figure 2 Cumulative distribution maps for total divers recorded between the years 2010-2016.

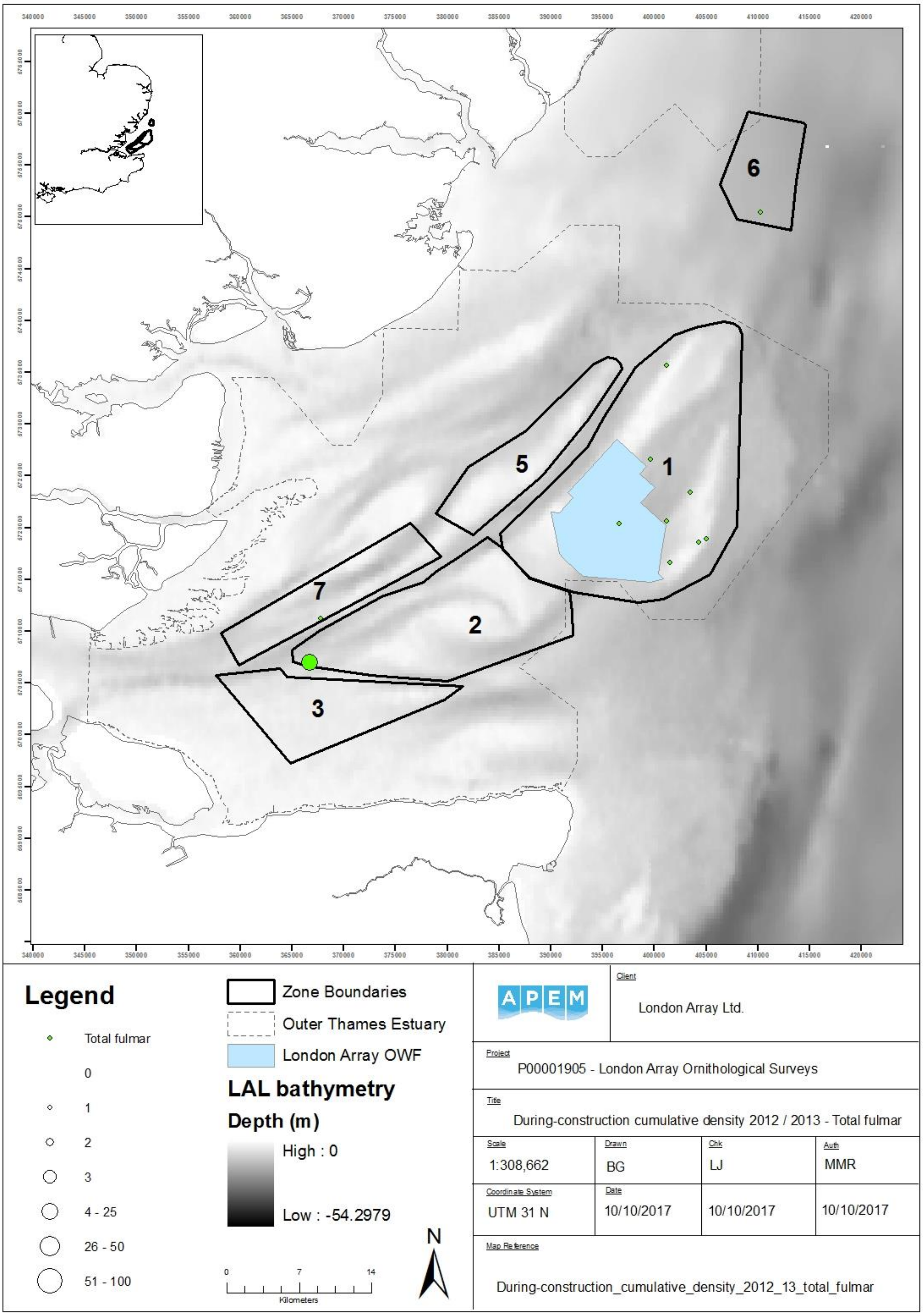
Fulmar



2010 / 11 Pre-construction



2011 / 12 Construction



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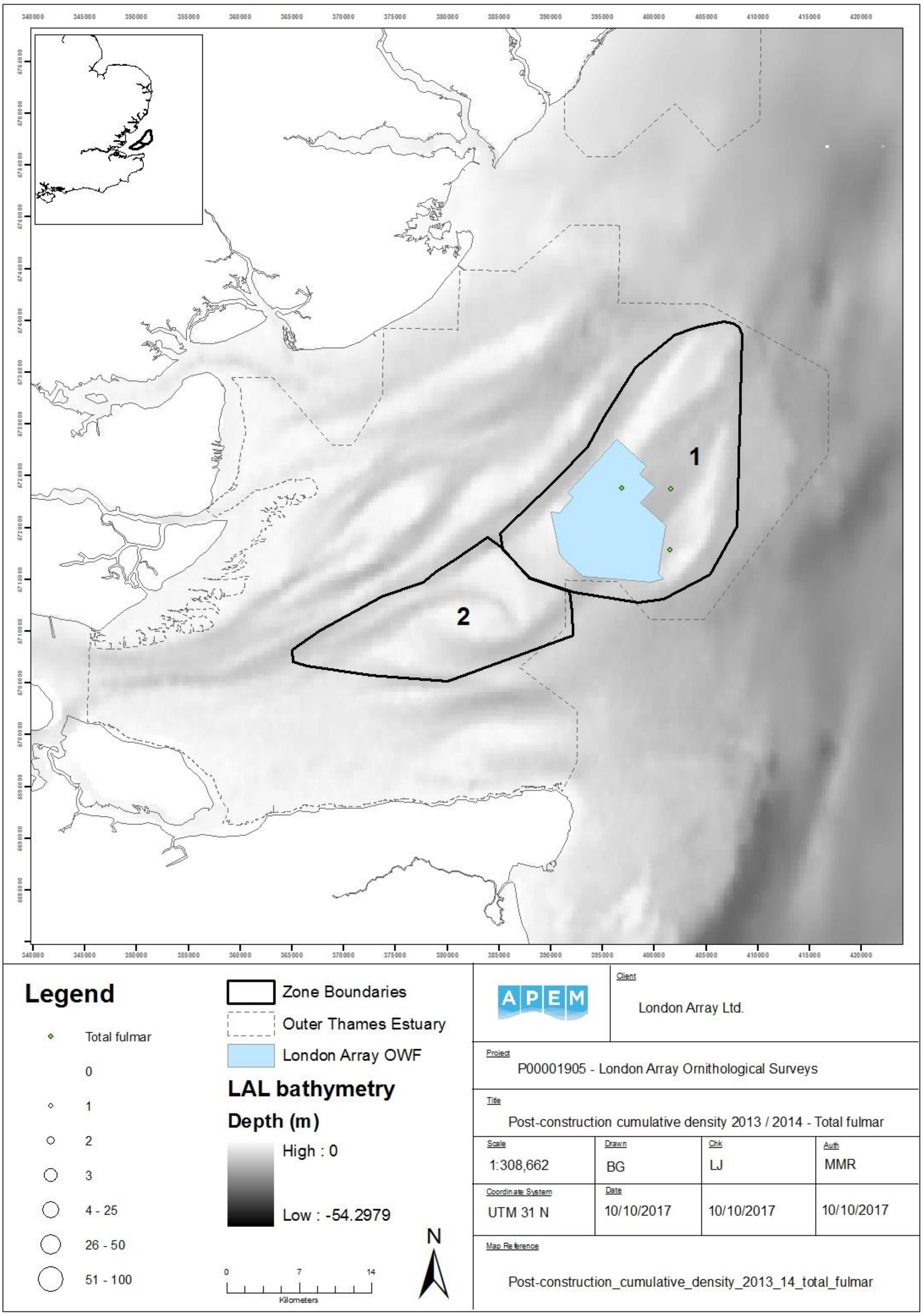
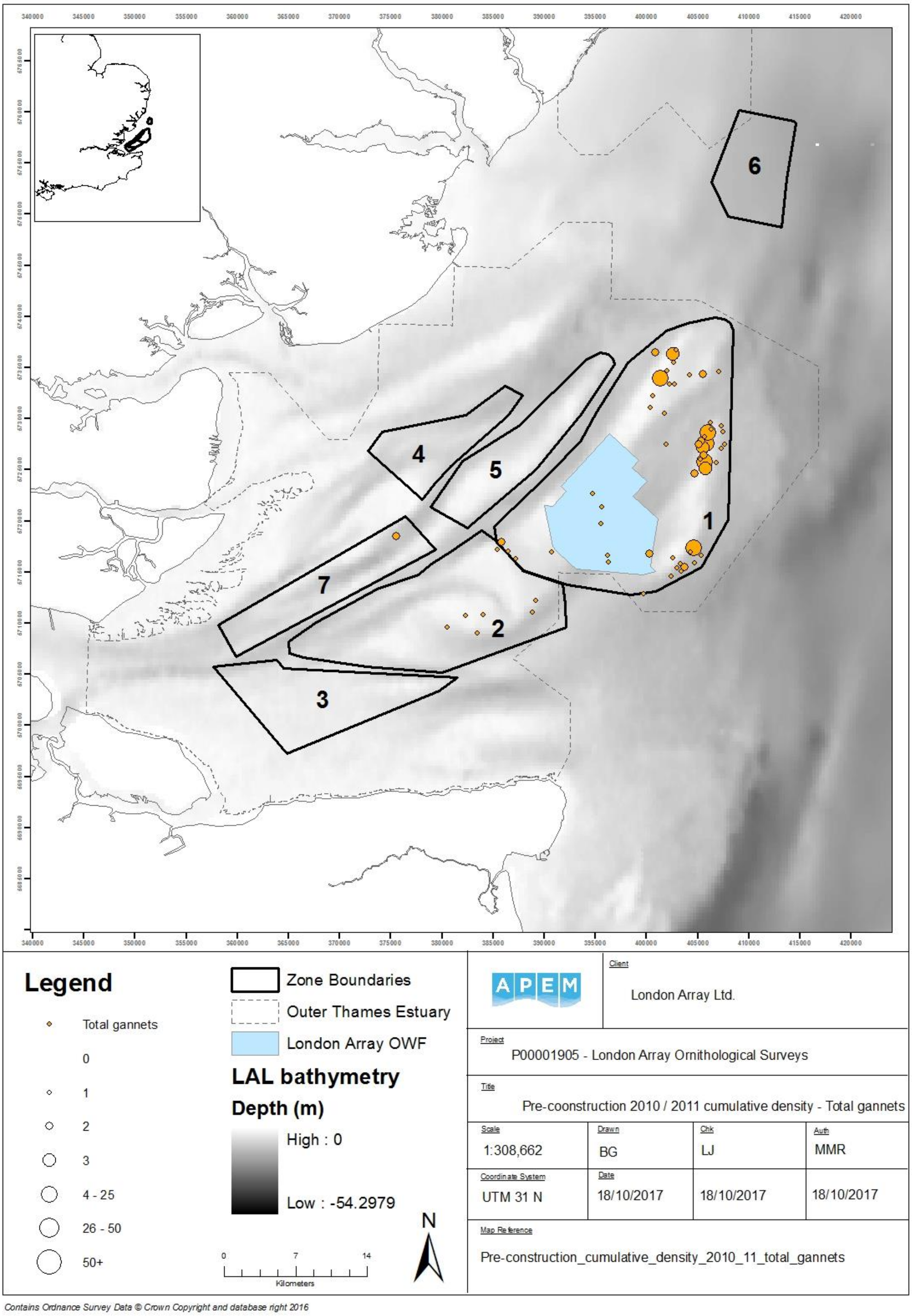
2012 / 13 Construction



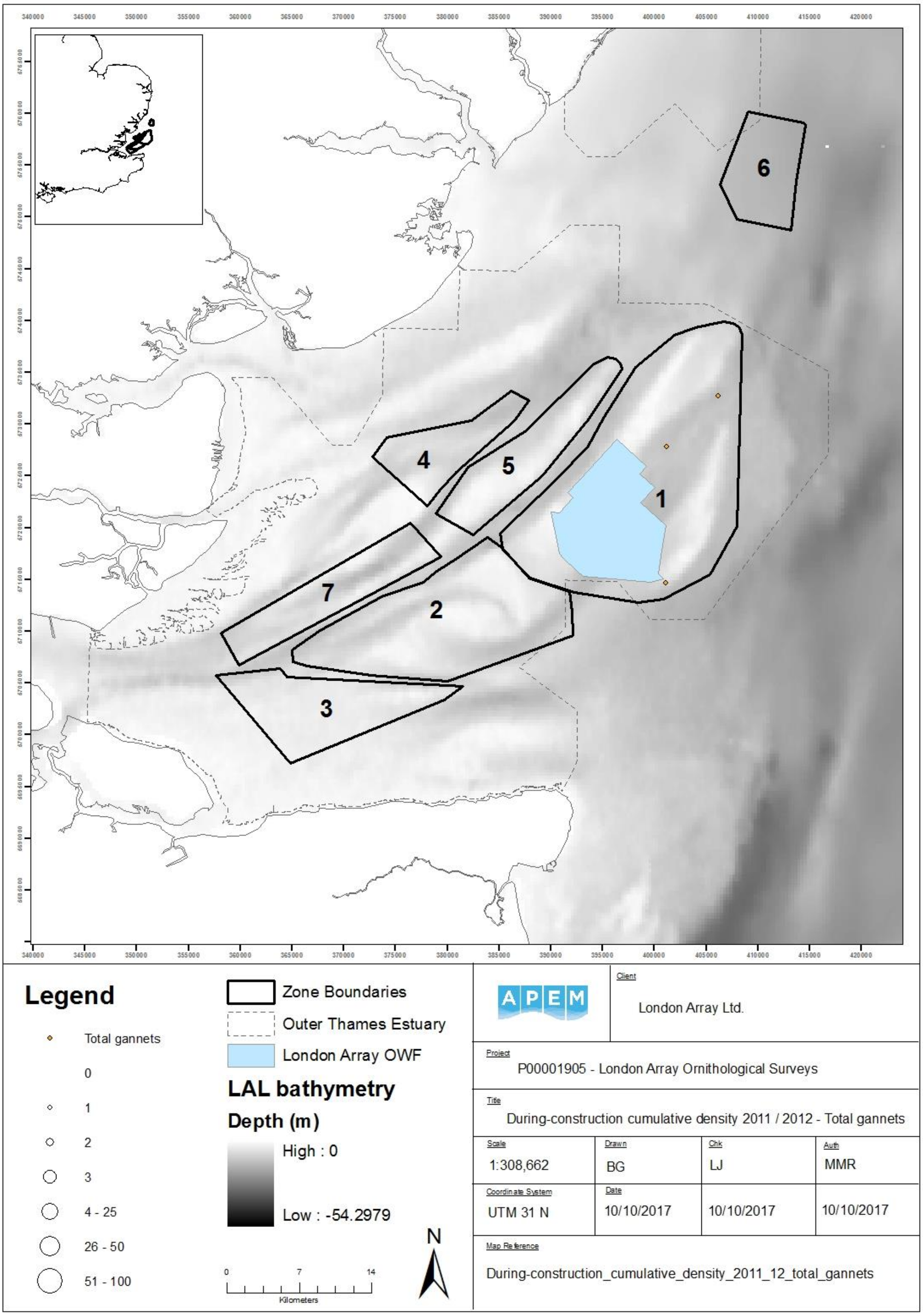
2013 / 14 Post-construction

Figure 3 Cumulative distribution maps for fulmars recorded between the years 2010-2016.

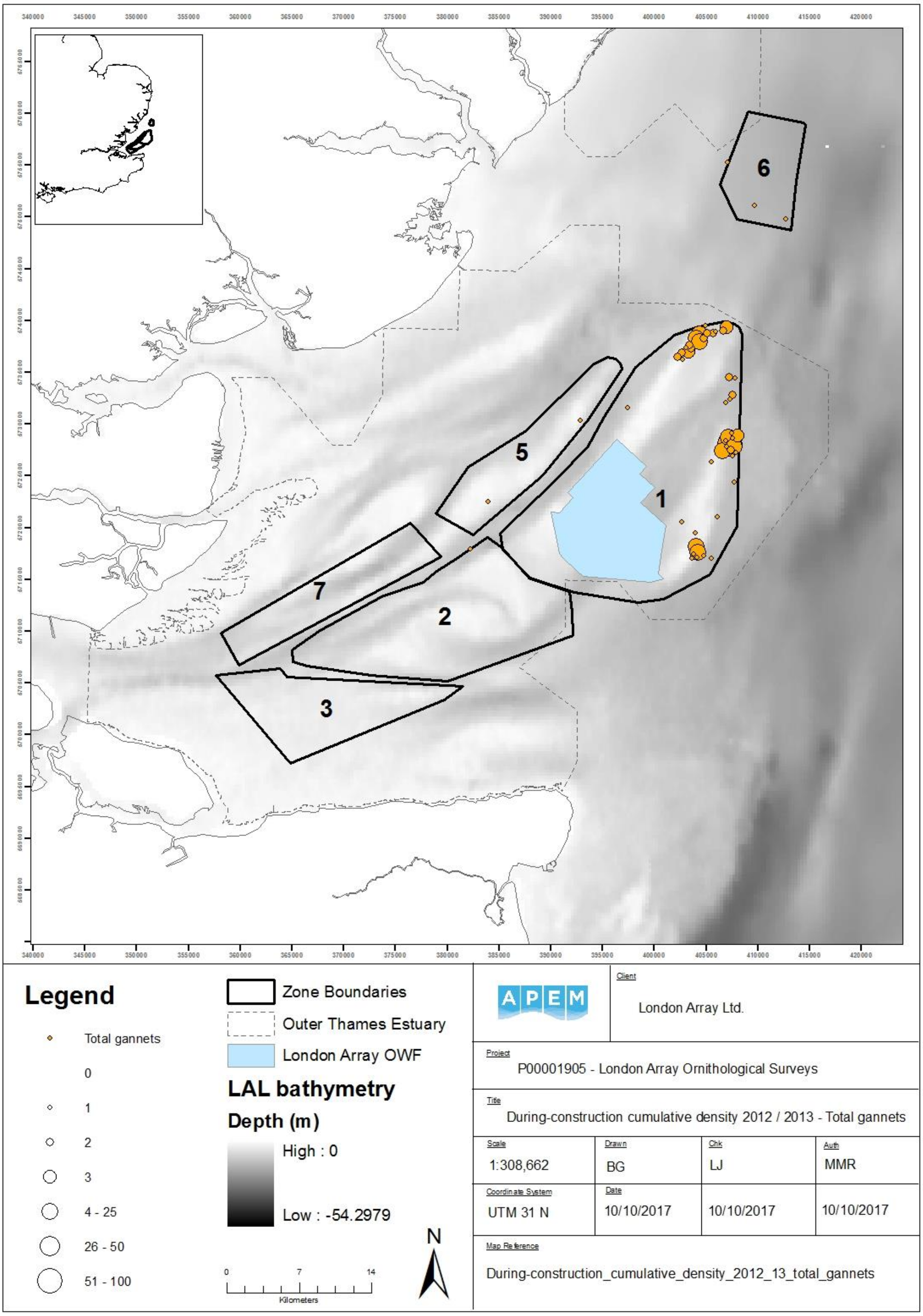
Gannet



2010 / 11 Pre-construction



2011 / 12 Construction



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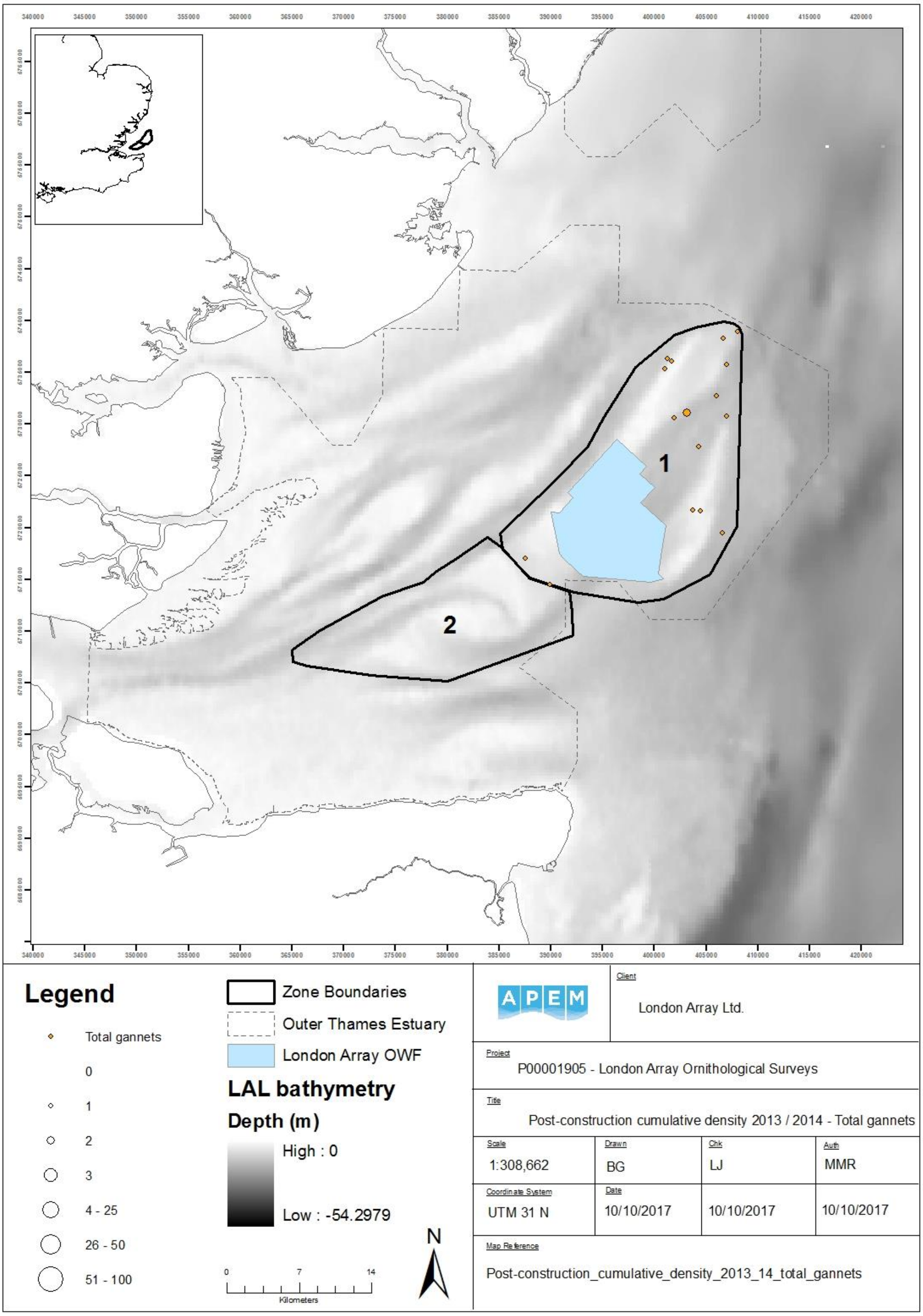
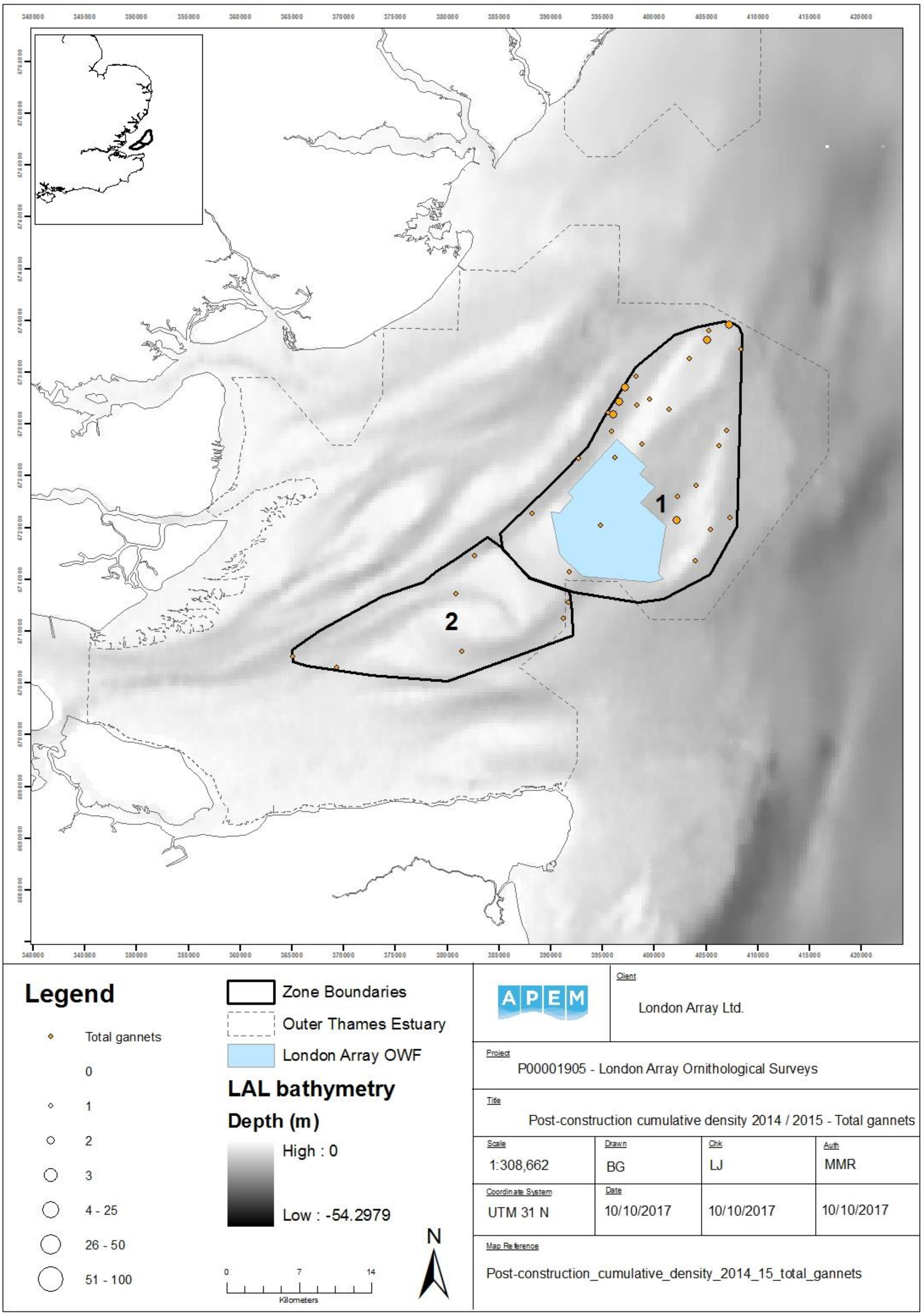
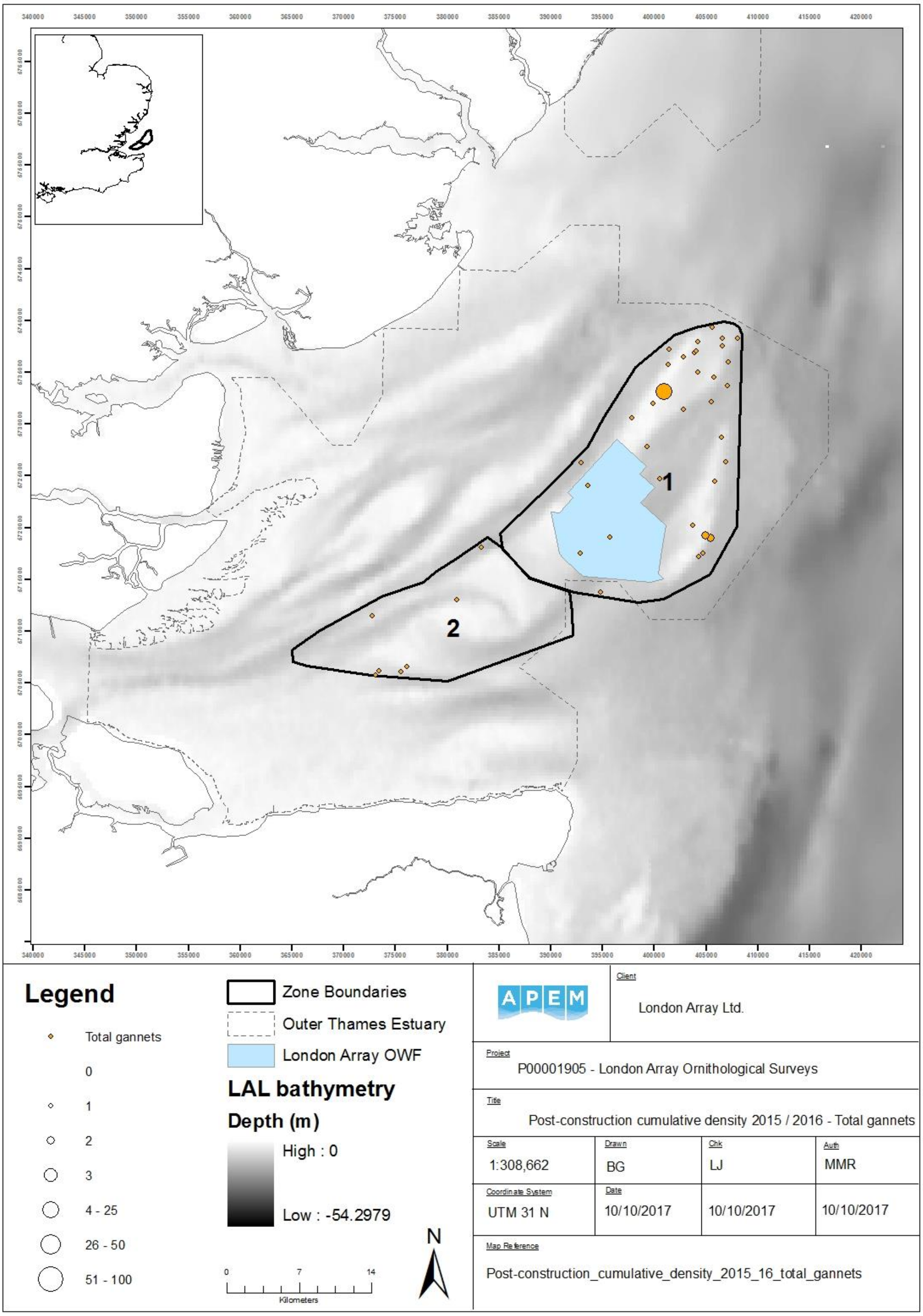
2012 / 13 Construction



2013 / 14 Post-construction



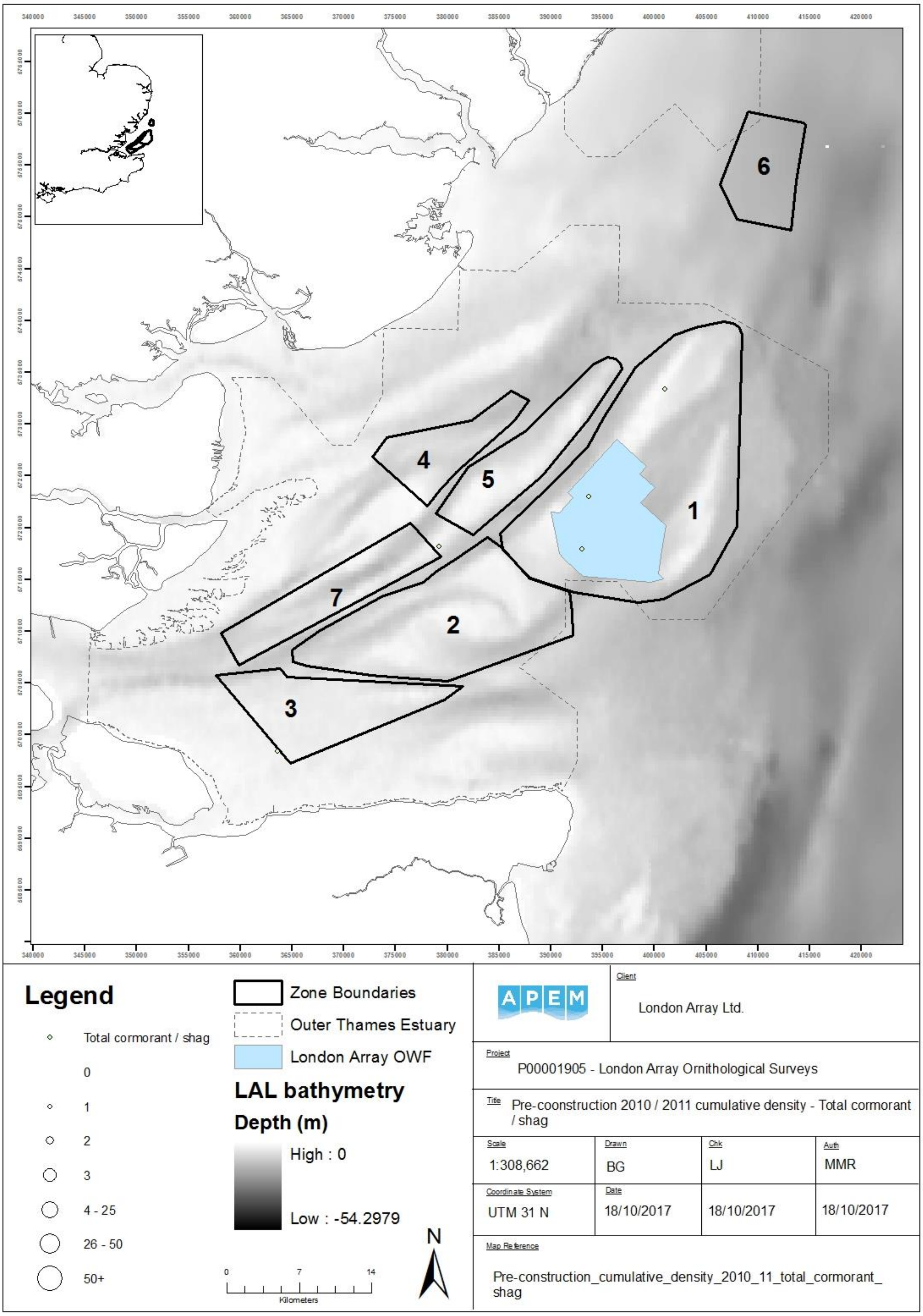
2014 / 15 Post-construction



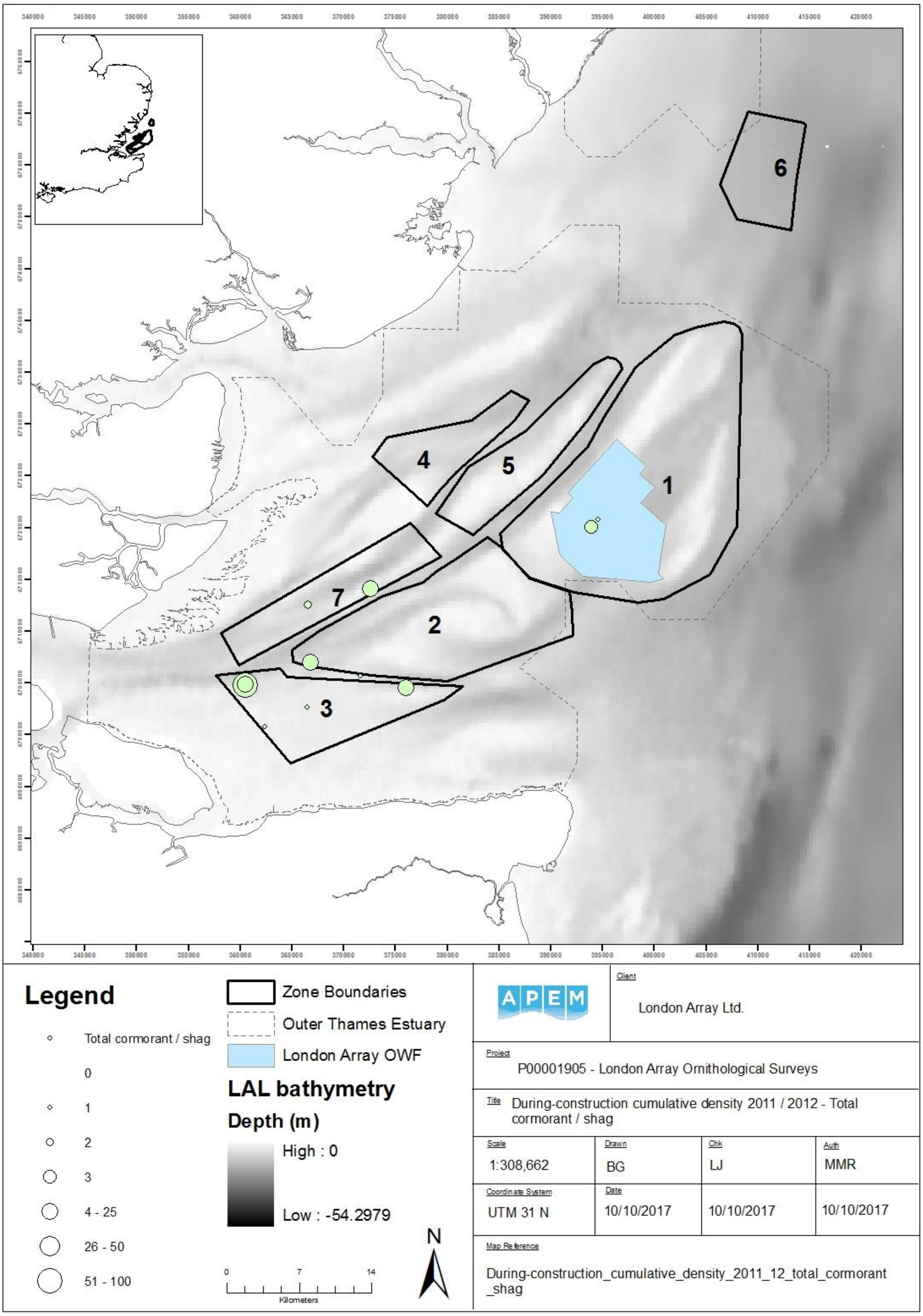
2015 / 16 Post-construction

Figure 4 Cumulative distribution maps for gannets recorded between the years 2010-2016.

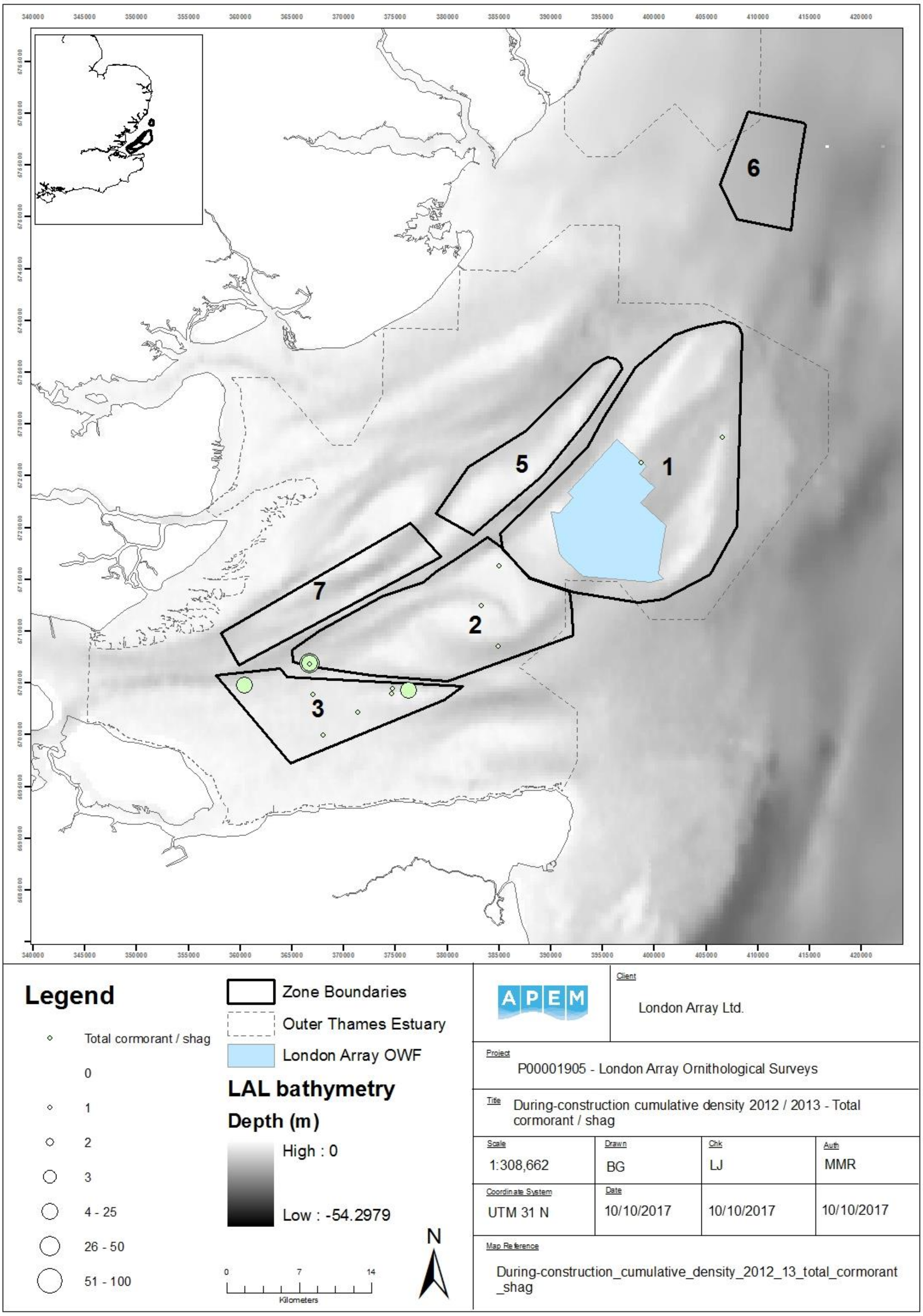
Total cormorant / shag



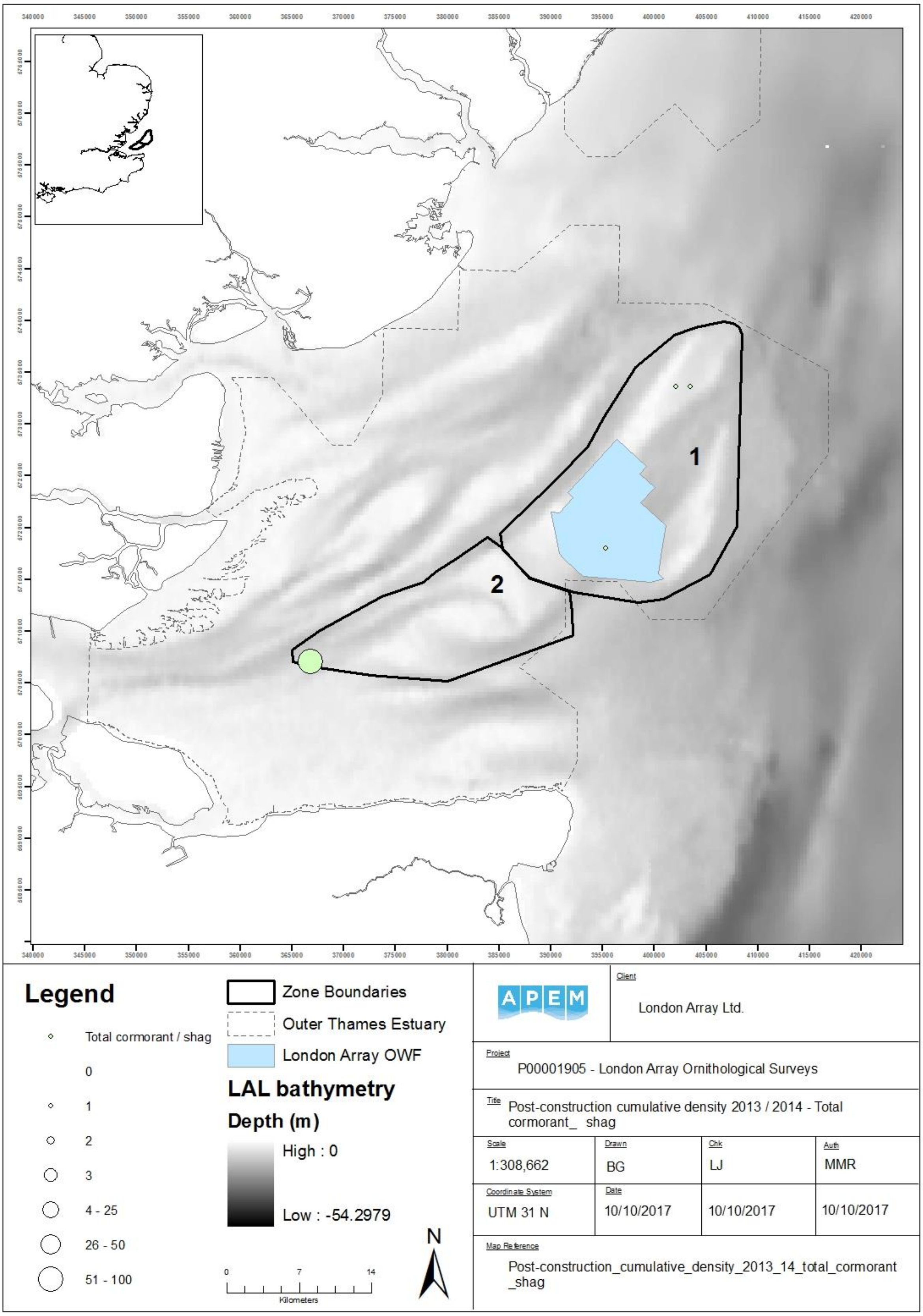
2010 / 11 Pre-construction



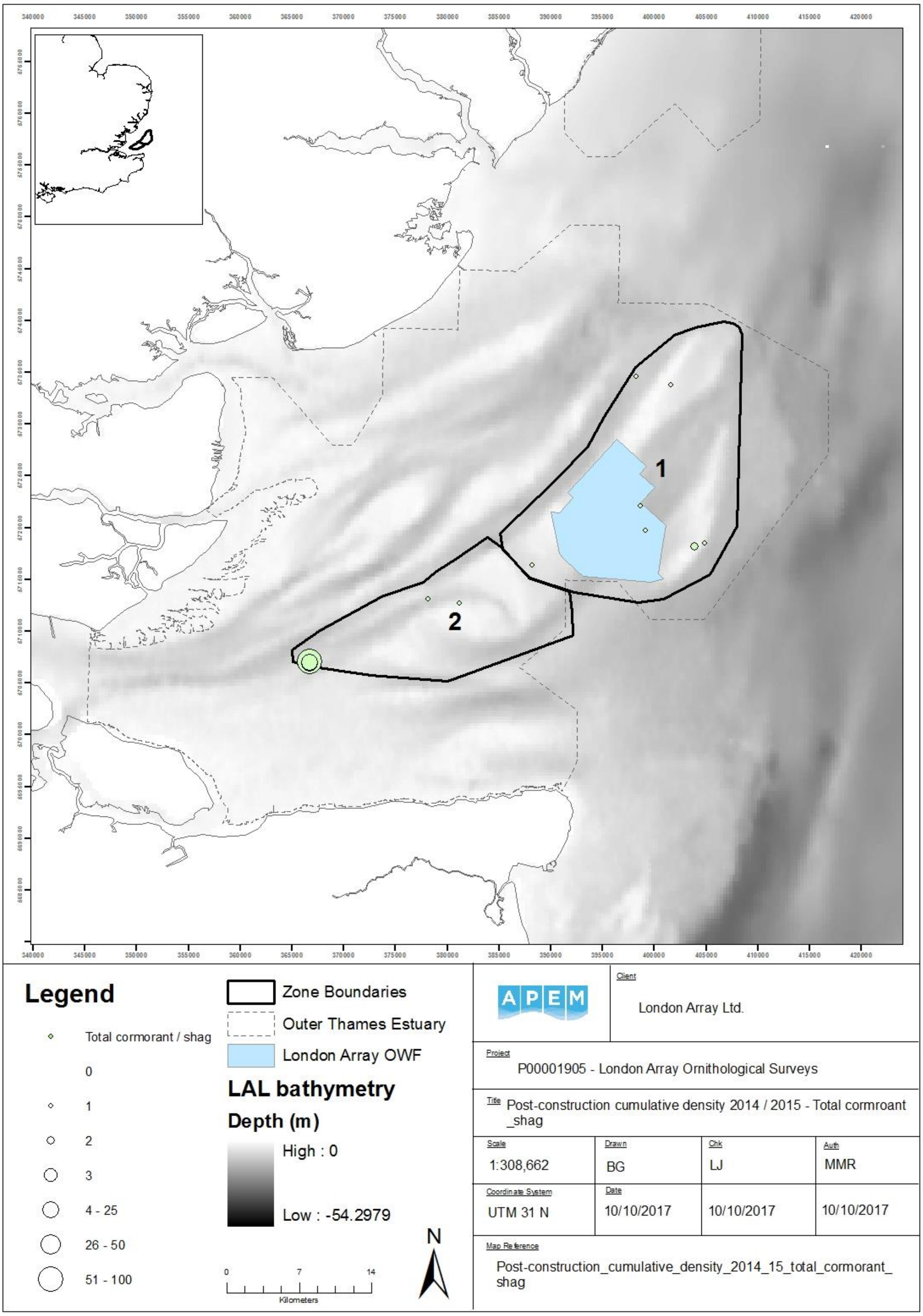
2011 / 12 Construction



2012 / 13 Construction



2013 / 14 Post-construction



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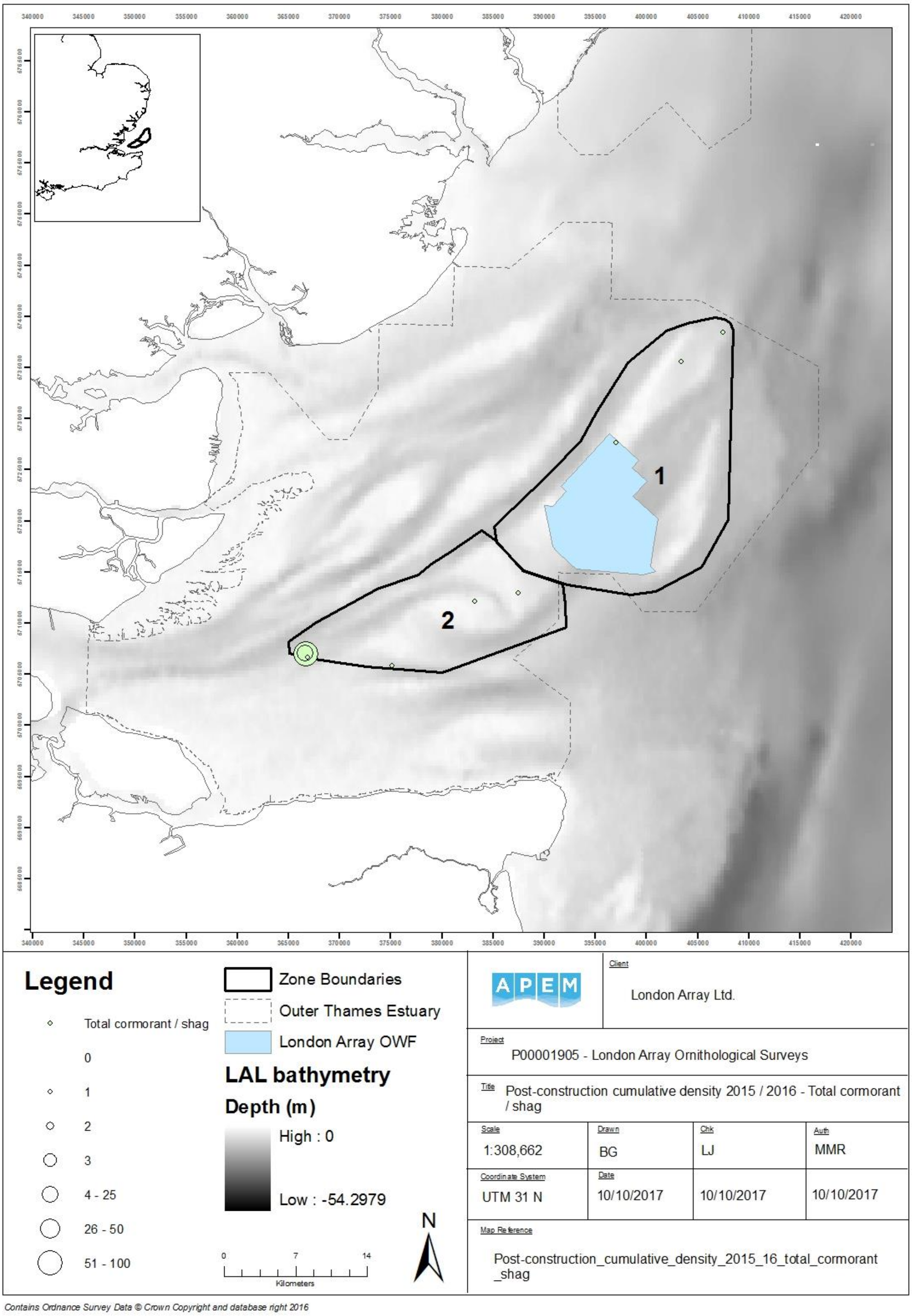
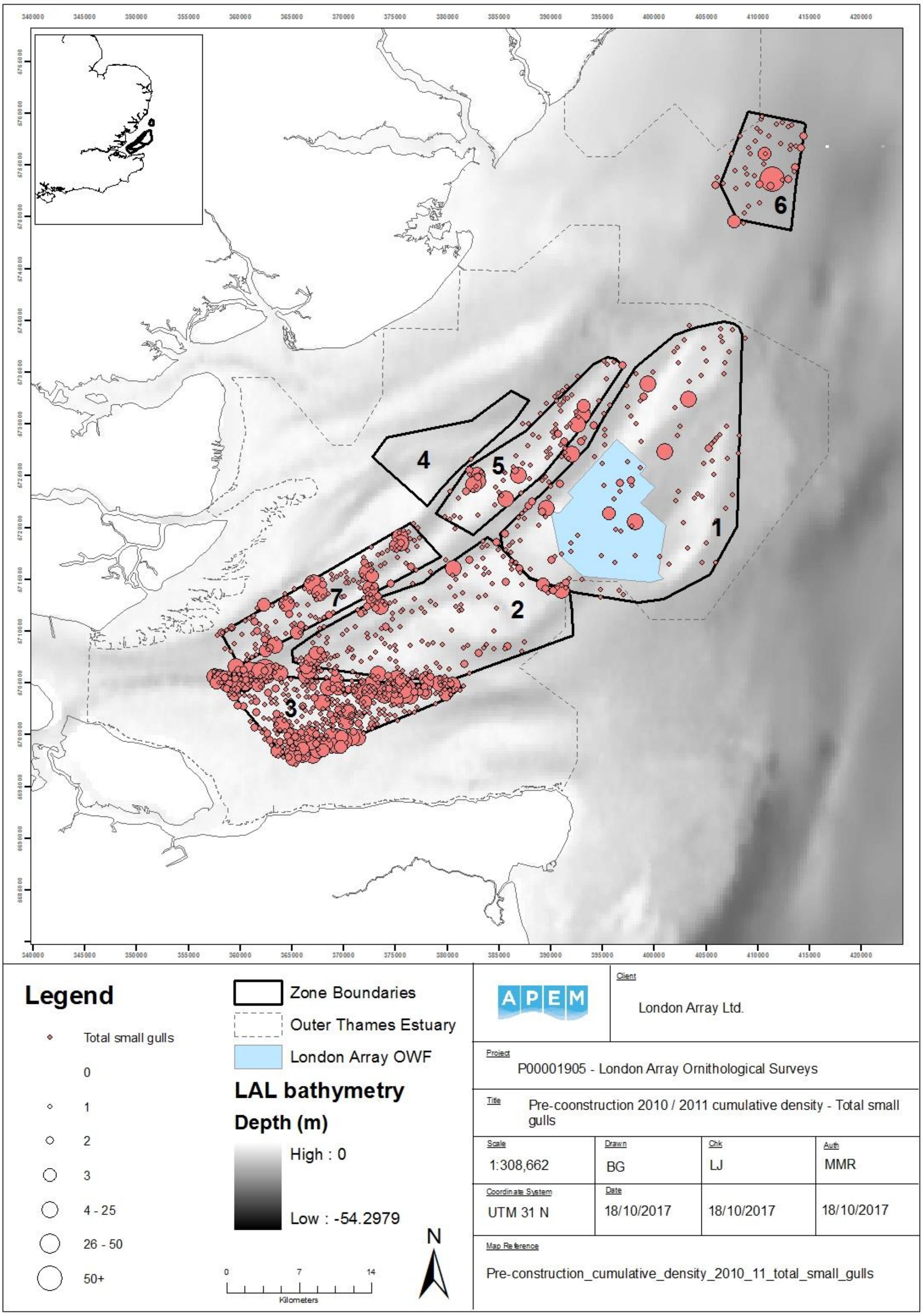
2014 / 15 Post-construction



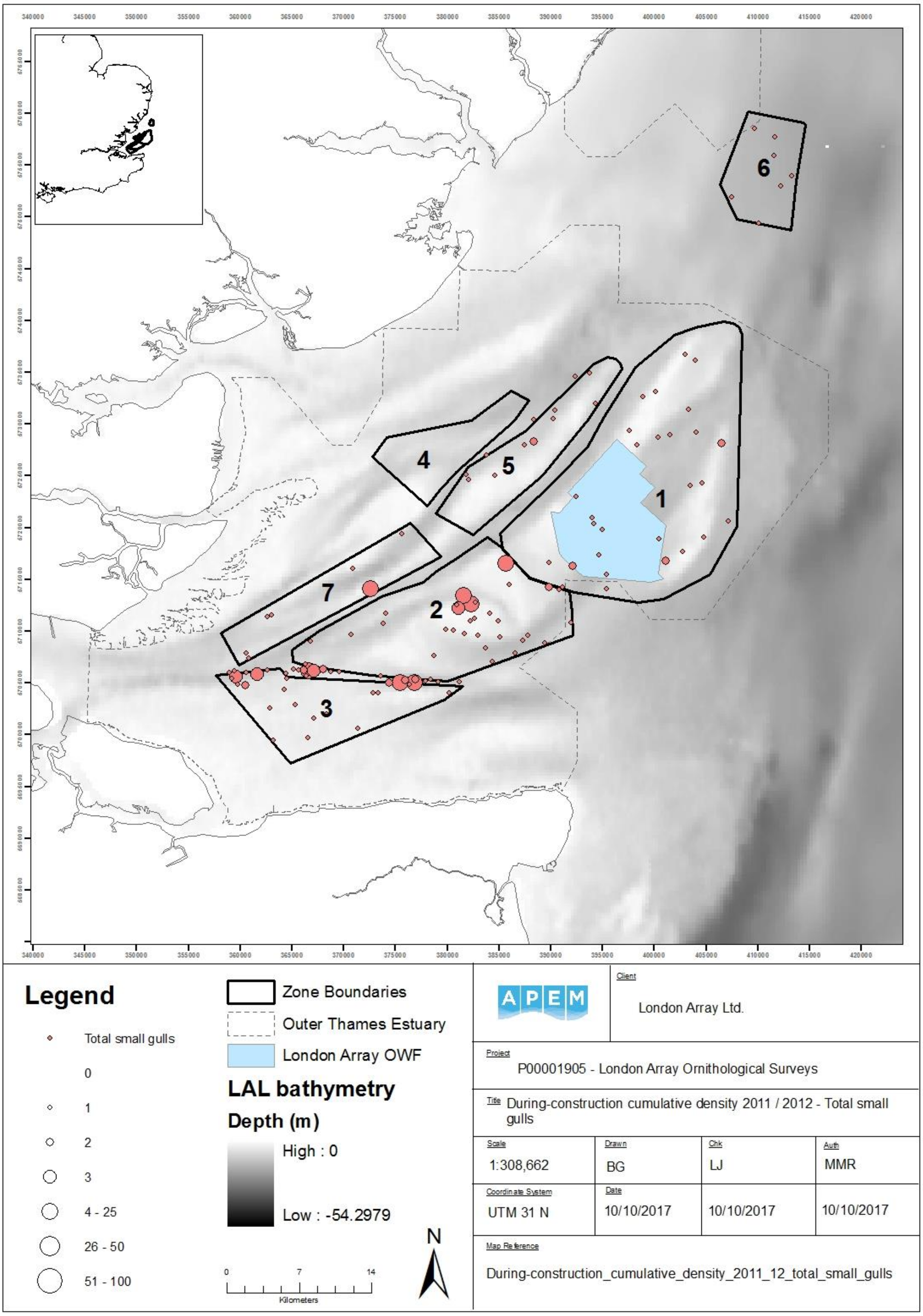
2015 / 16 Post-construction

Figure 5 Cumulative distribution maps for total cormorant / shag recorded between the years 2010-2016.

Total small gulls



2010 / 11 Pre-construction



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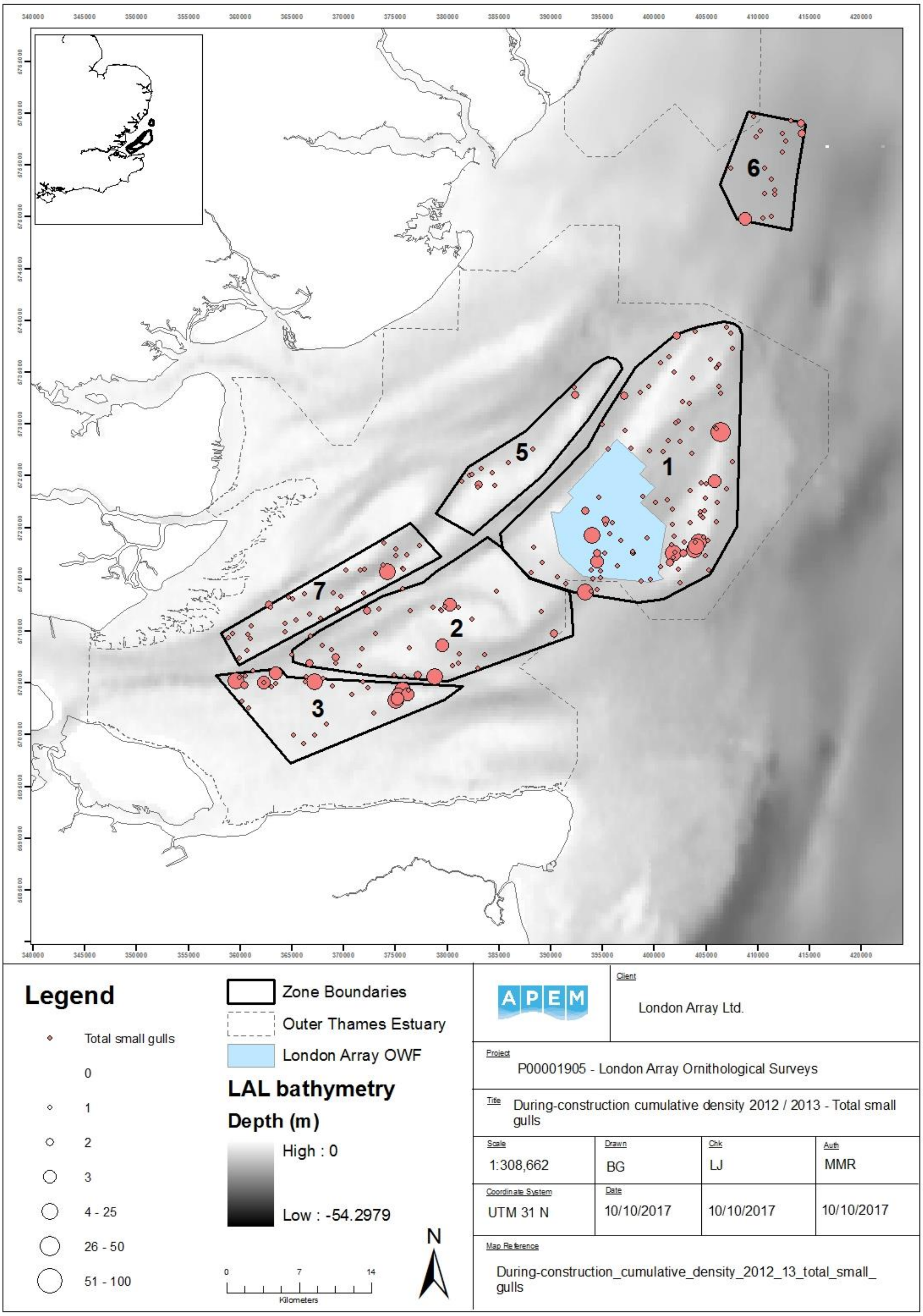
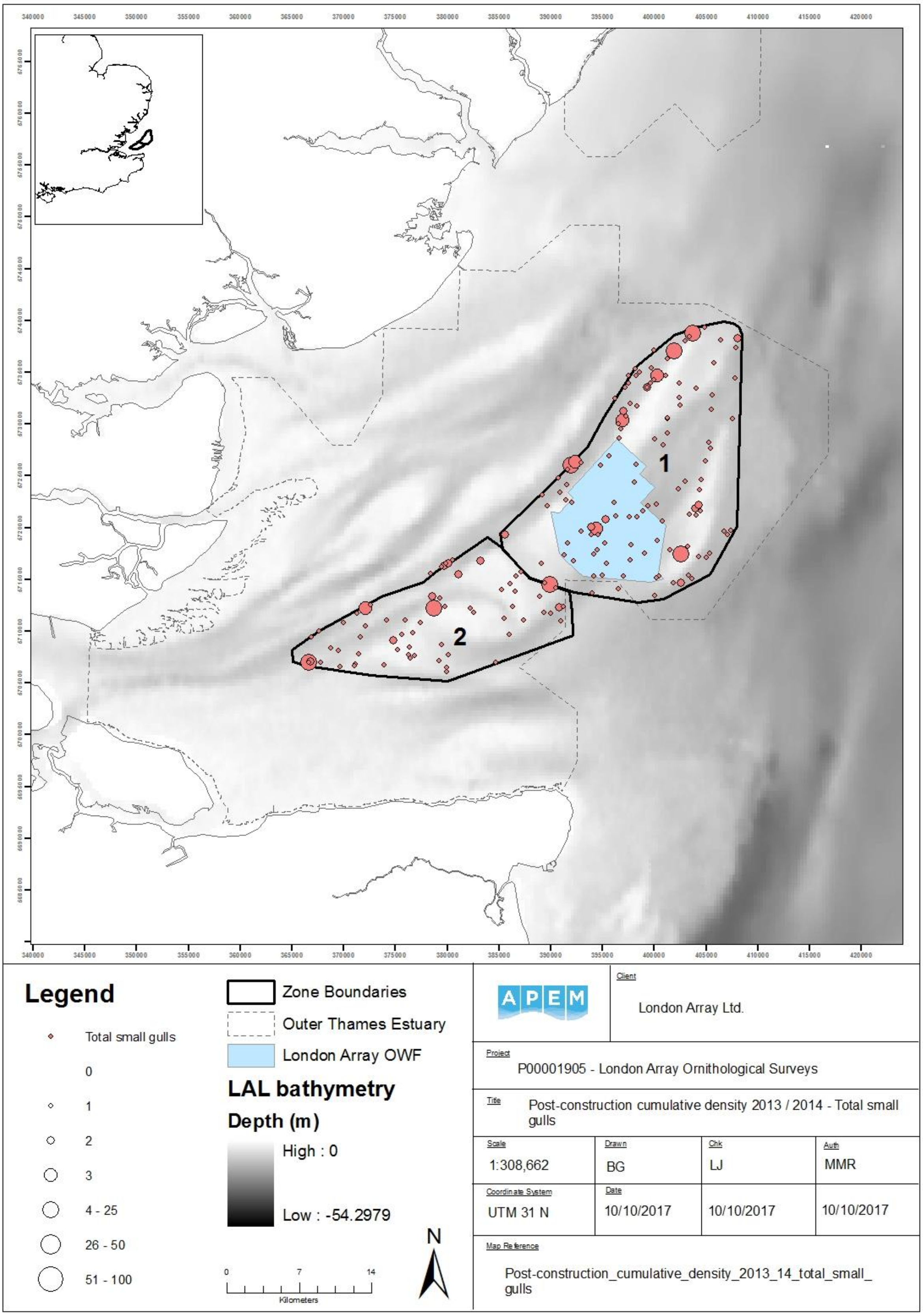
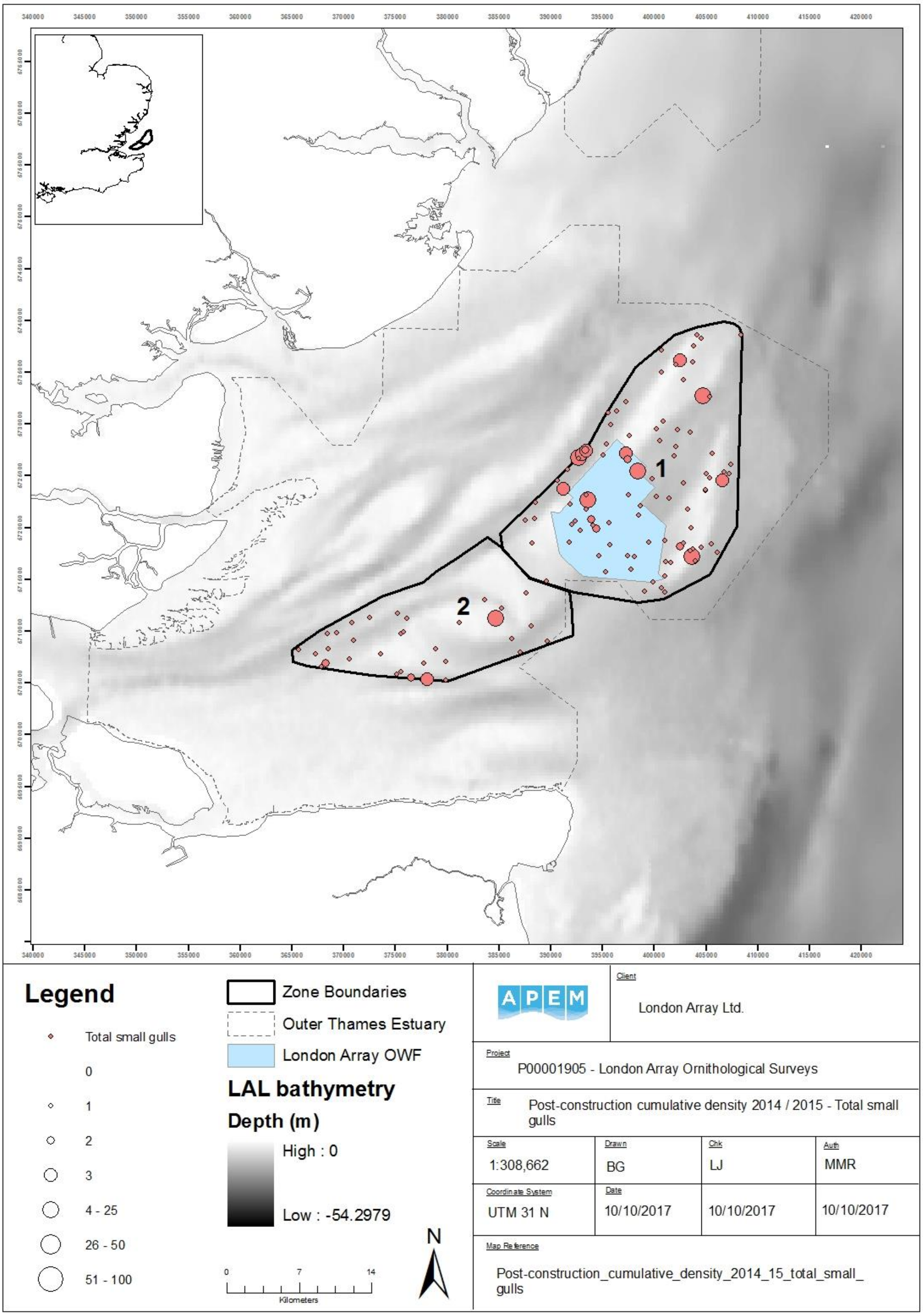
2011 / 12 Construction



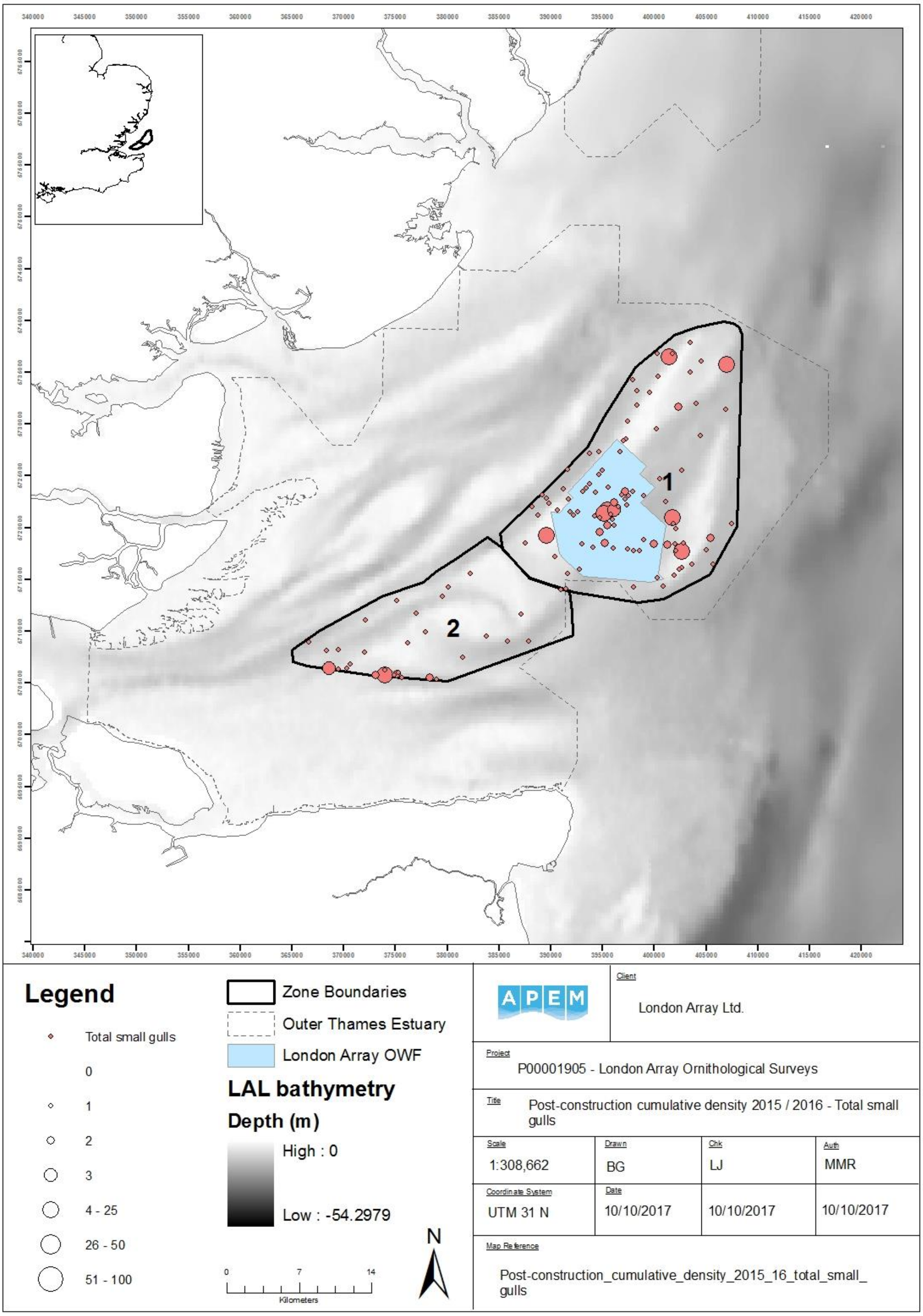
2012 / 13 Construction



2013 / 14 Post-construction



2014 / 15 Post-construction



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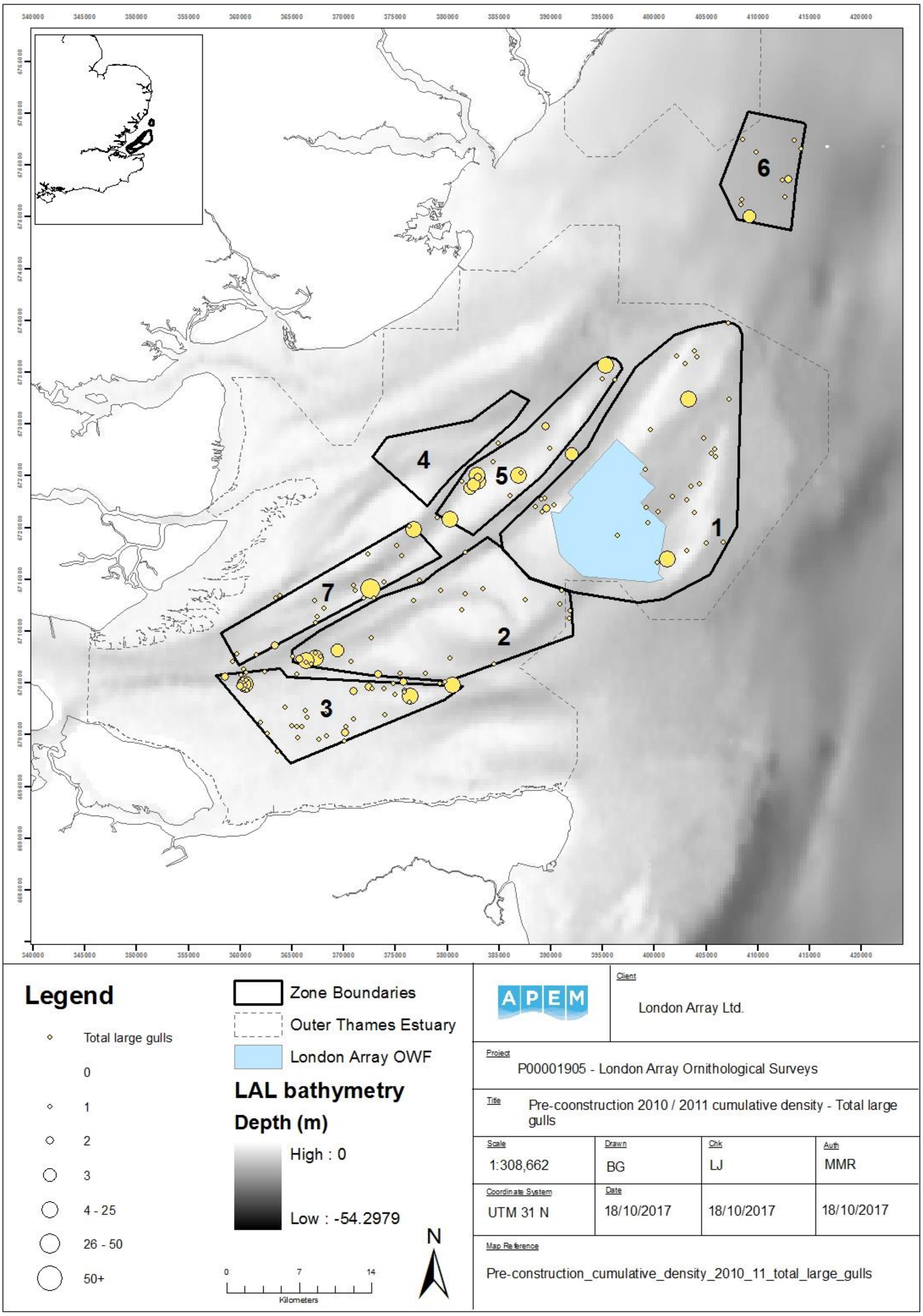
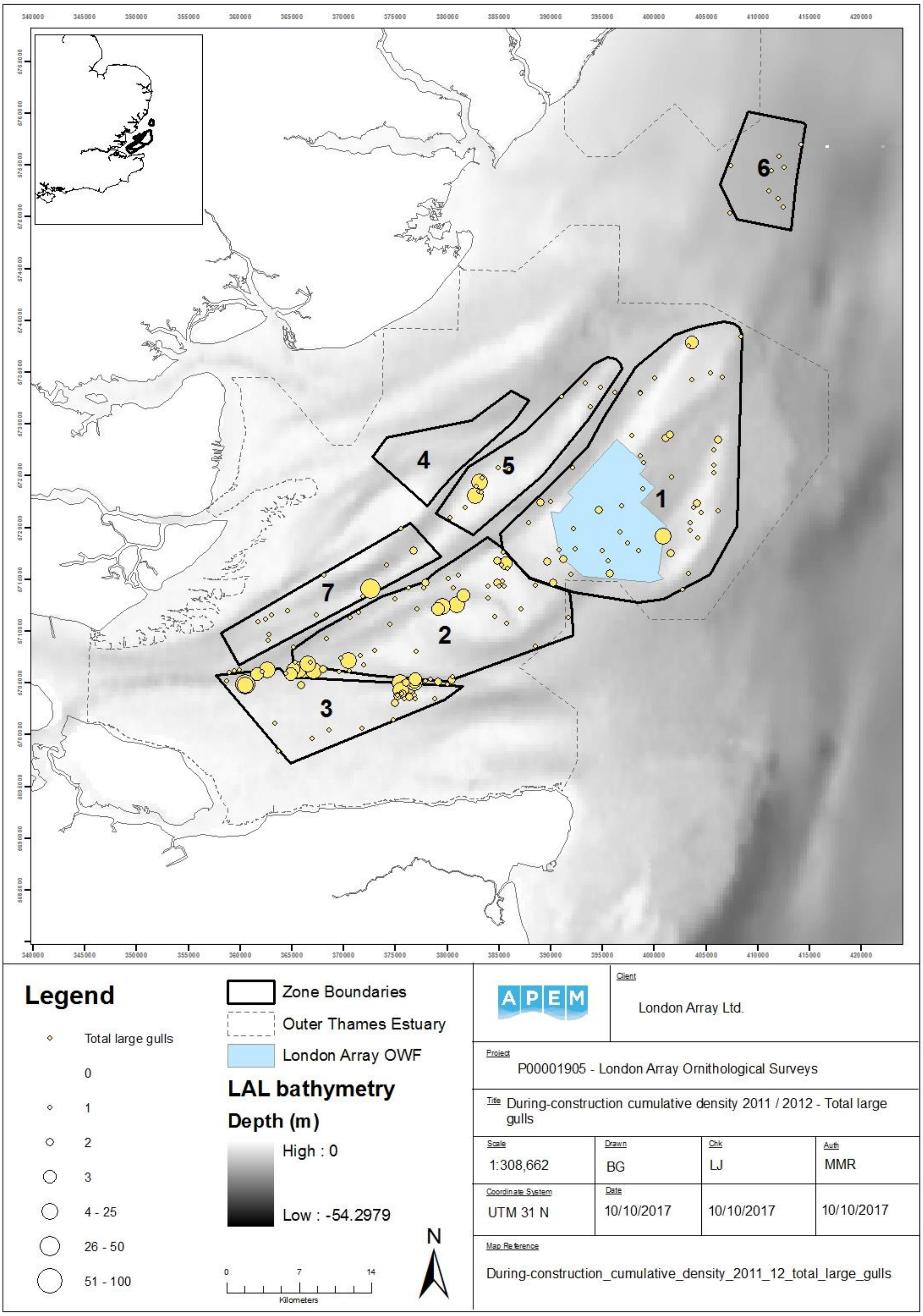
2015 / 16 Post-construction

Figure 6 Cumulative distribution maps for total small gulls recorded between the years 2010-2016.

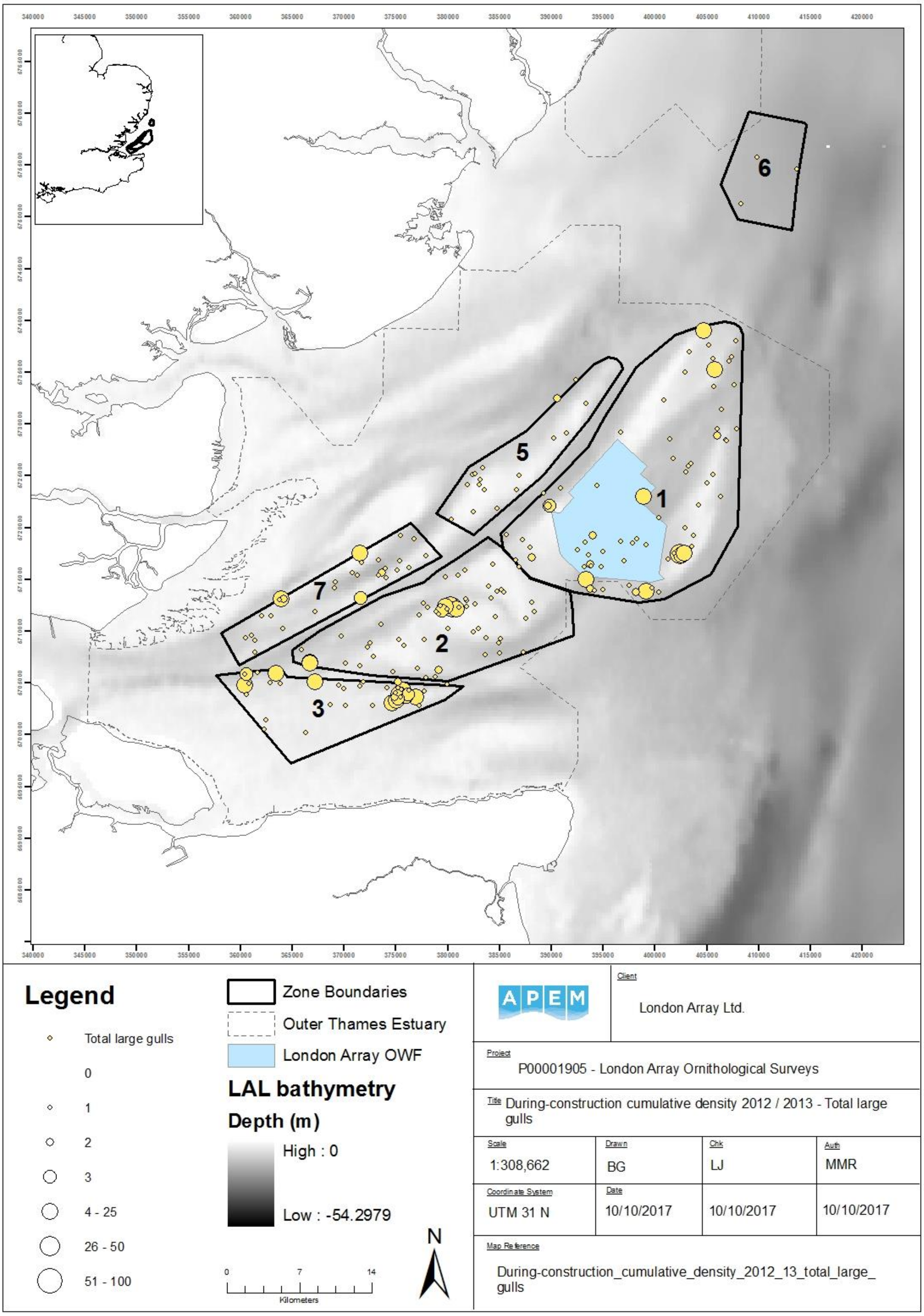
Total large gulls



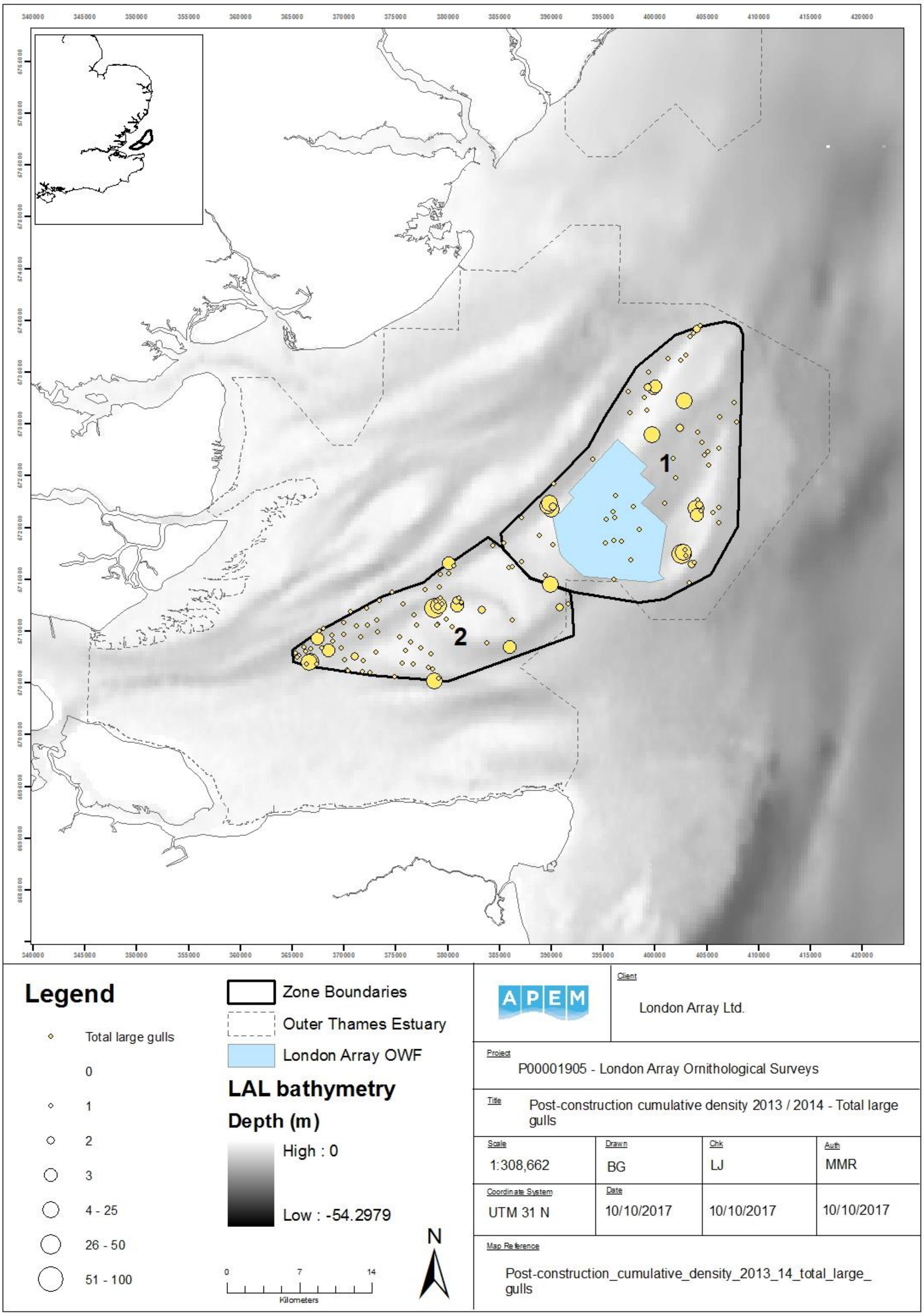
2010 / 11 Pre-construction



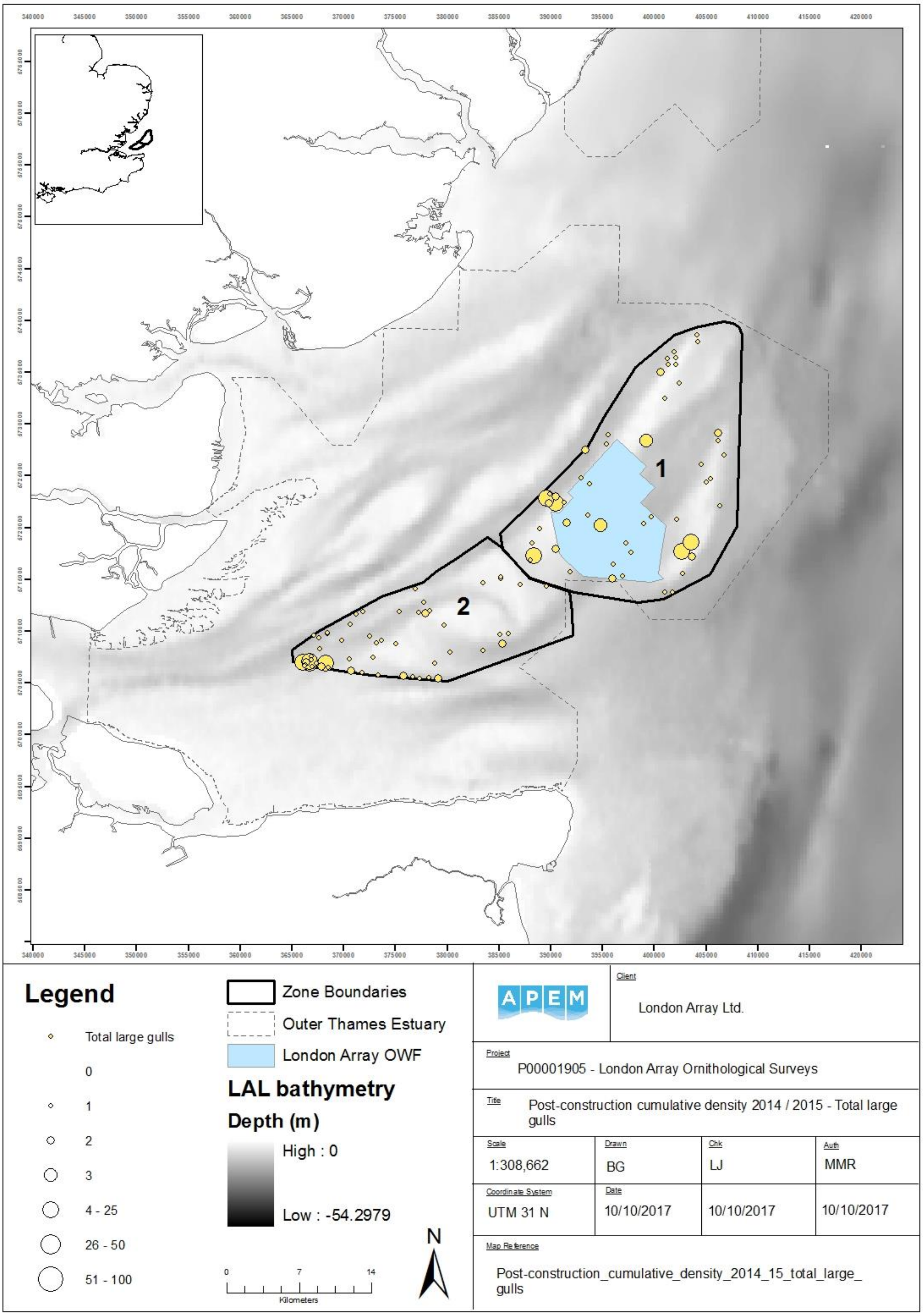
2011 / 12 Construction



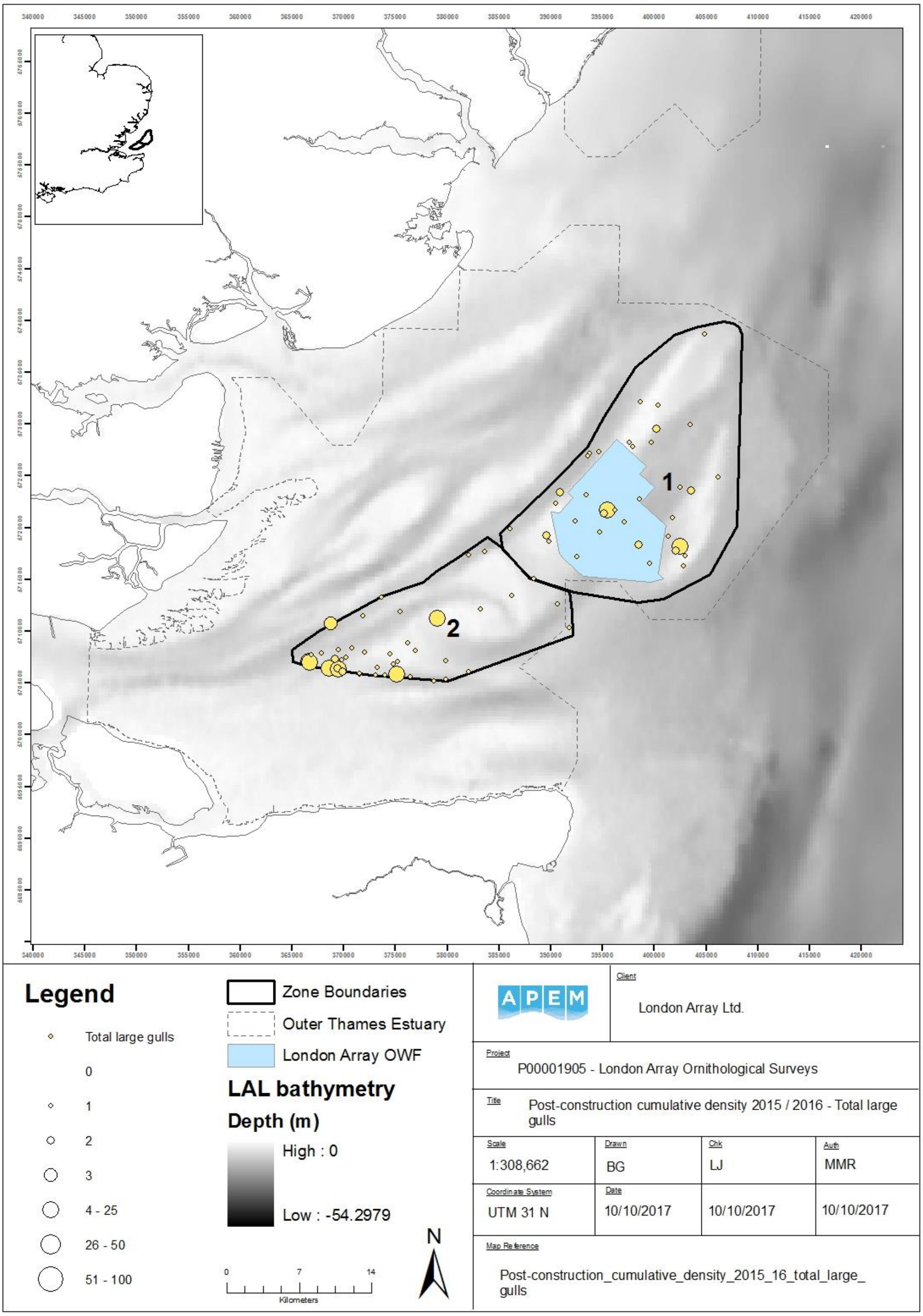
2012 / 13 Construction



2013 / 14 Post-construction



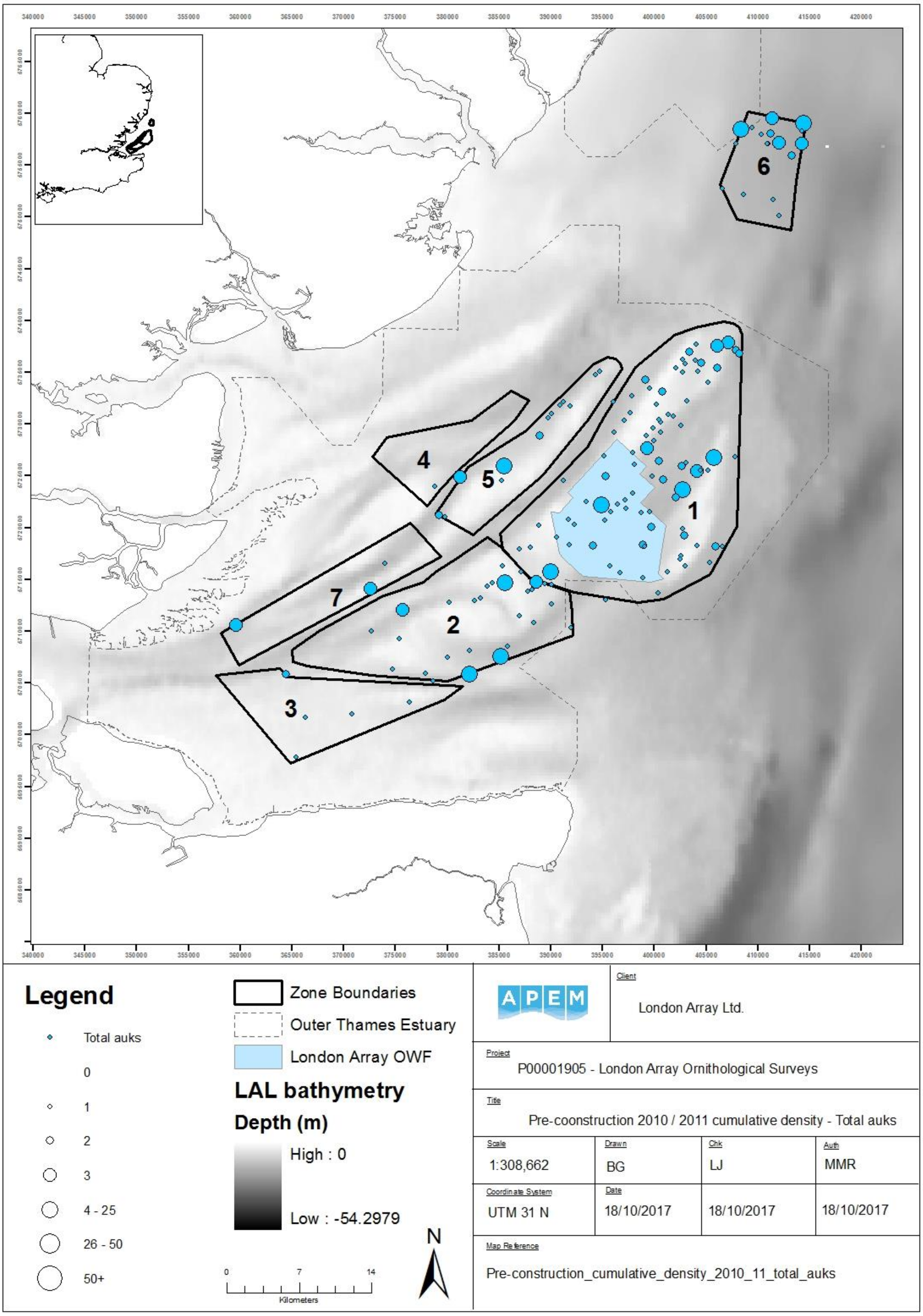
2014 / 15 Post-construction



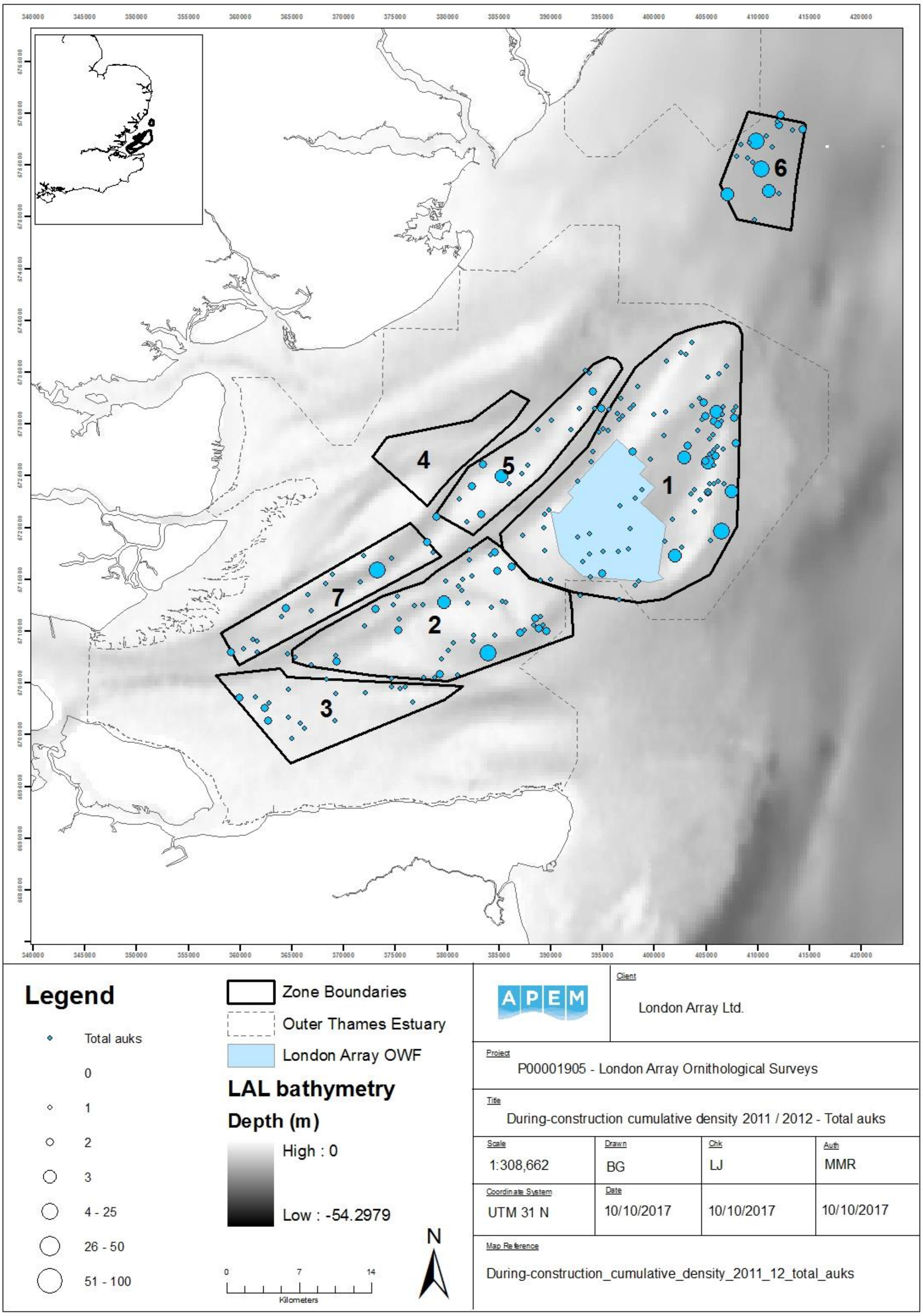
2015 / 16 Post-construction

Figure 7 **Cumulative distribution maps for total large gulls recorded between the years 2010-2016.**

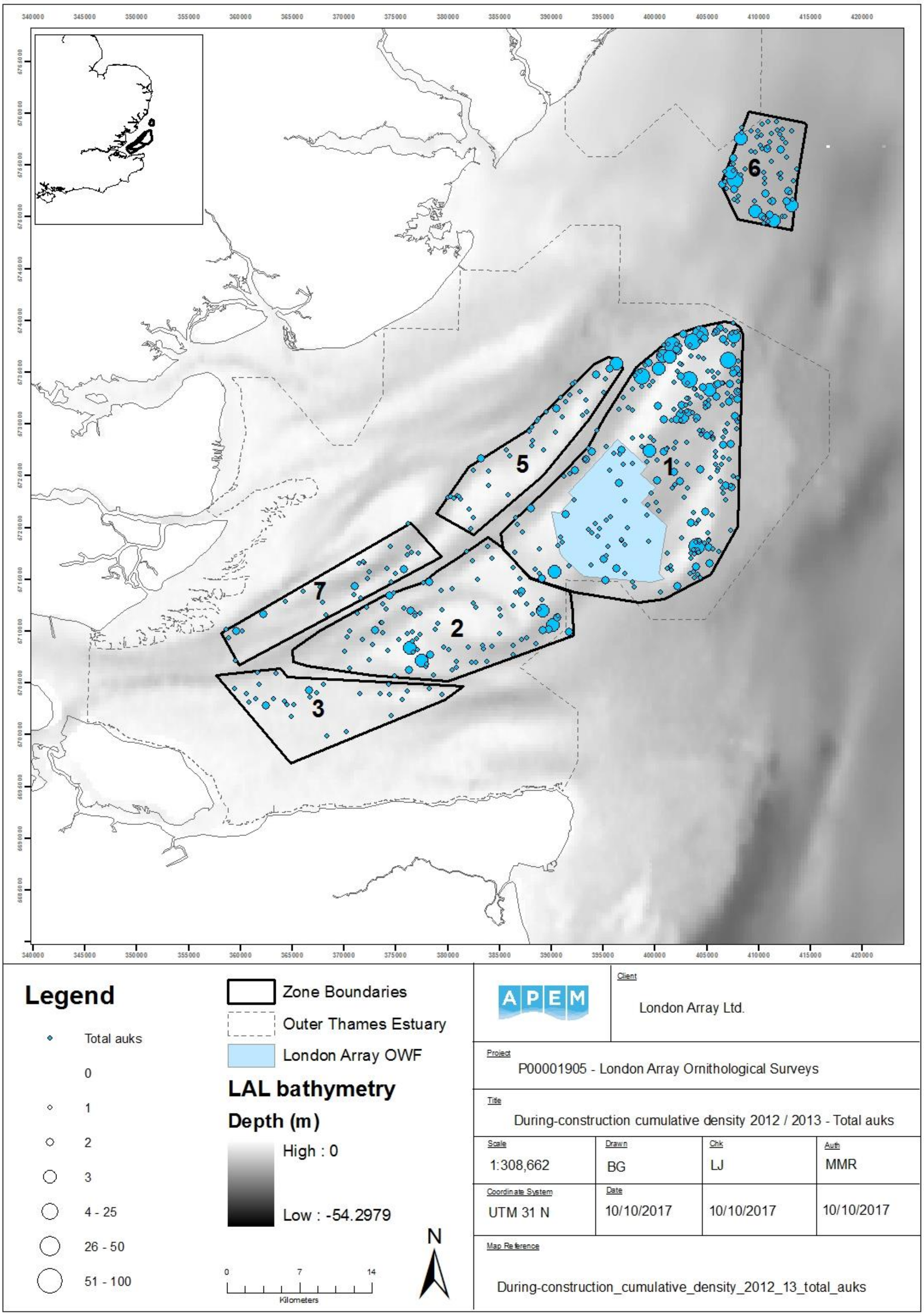
Total auks



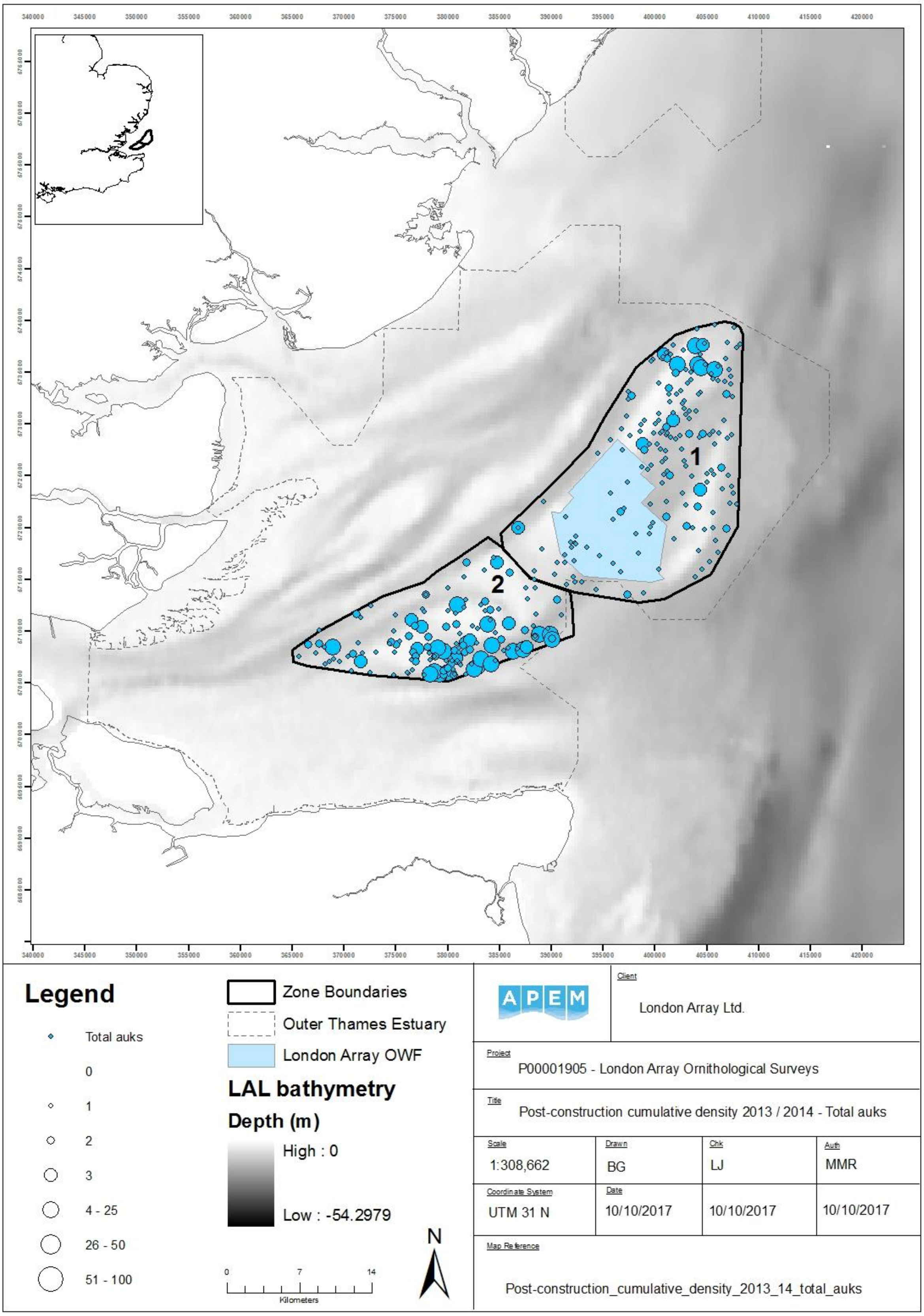
2010 / 11 Pre-construction



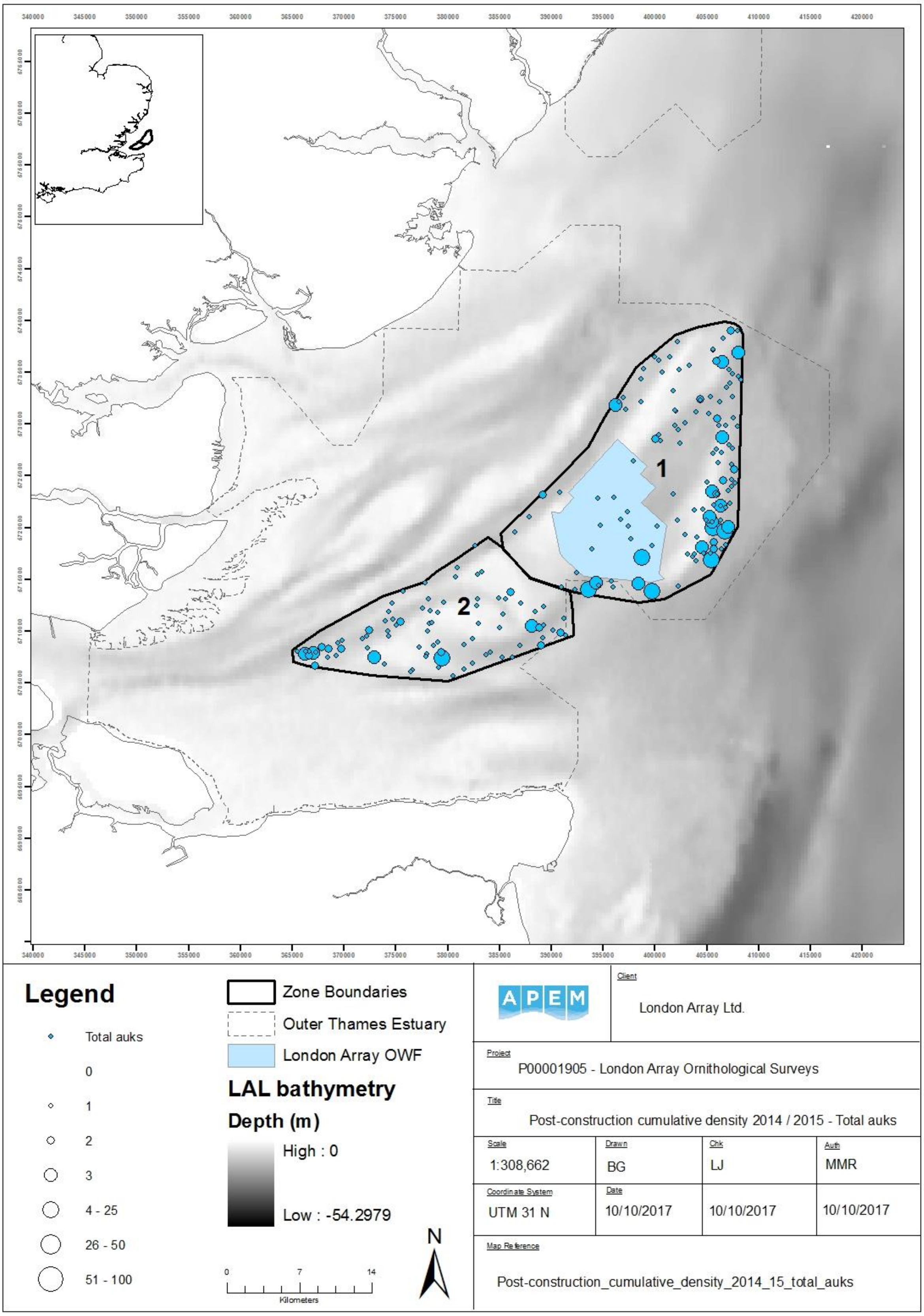
2011 / 12 Construction



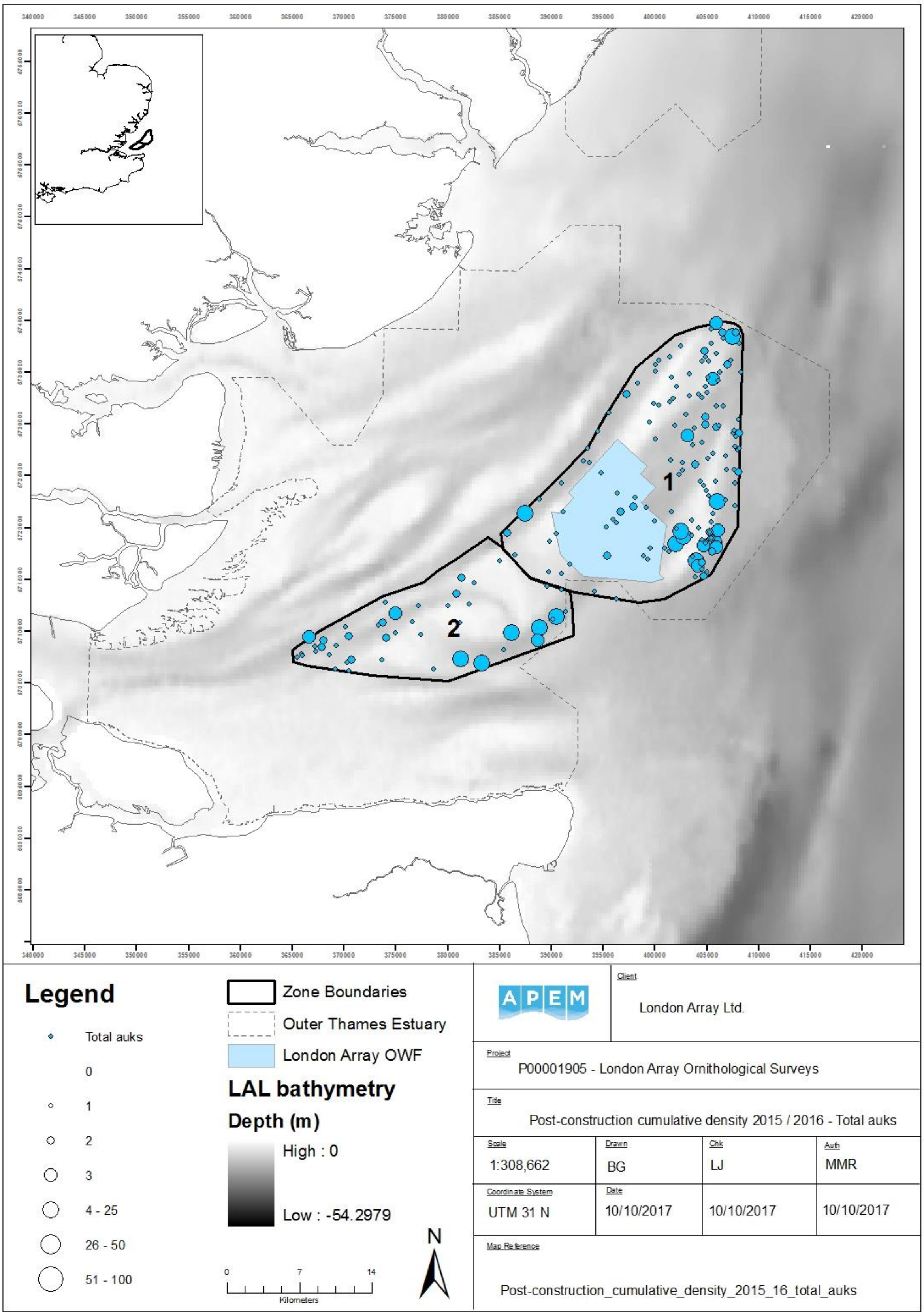
2012 / 13 Construction



2013 / 14 Post-construction



2014 / 15 Post-construction



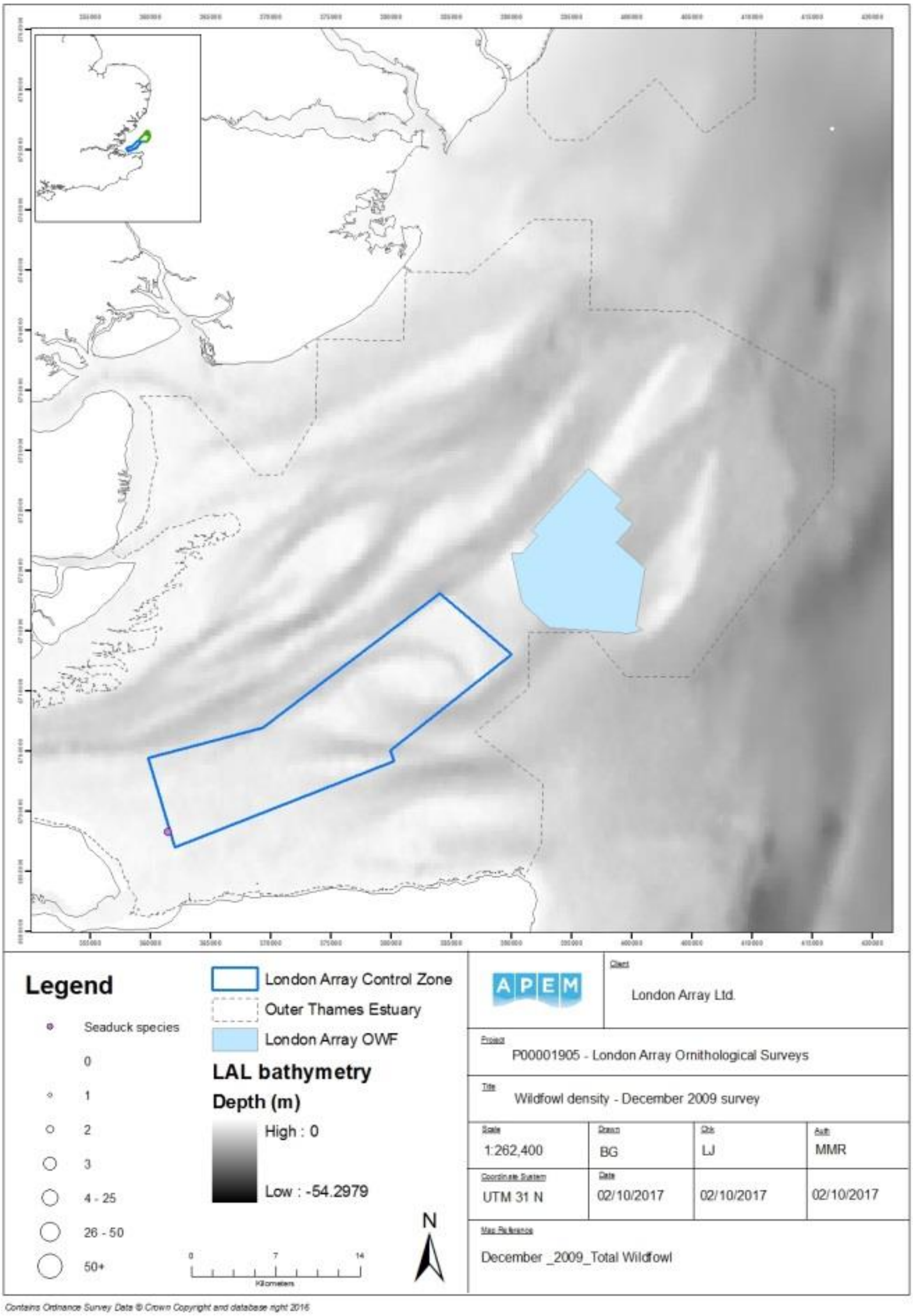
2015 / 16 Post-construction

Figure 8 Cumulative distribution maps for total auks recorded between the years 2010-2016.

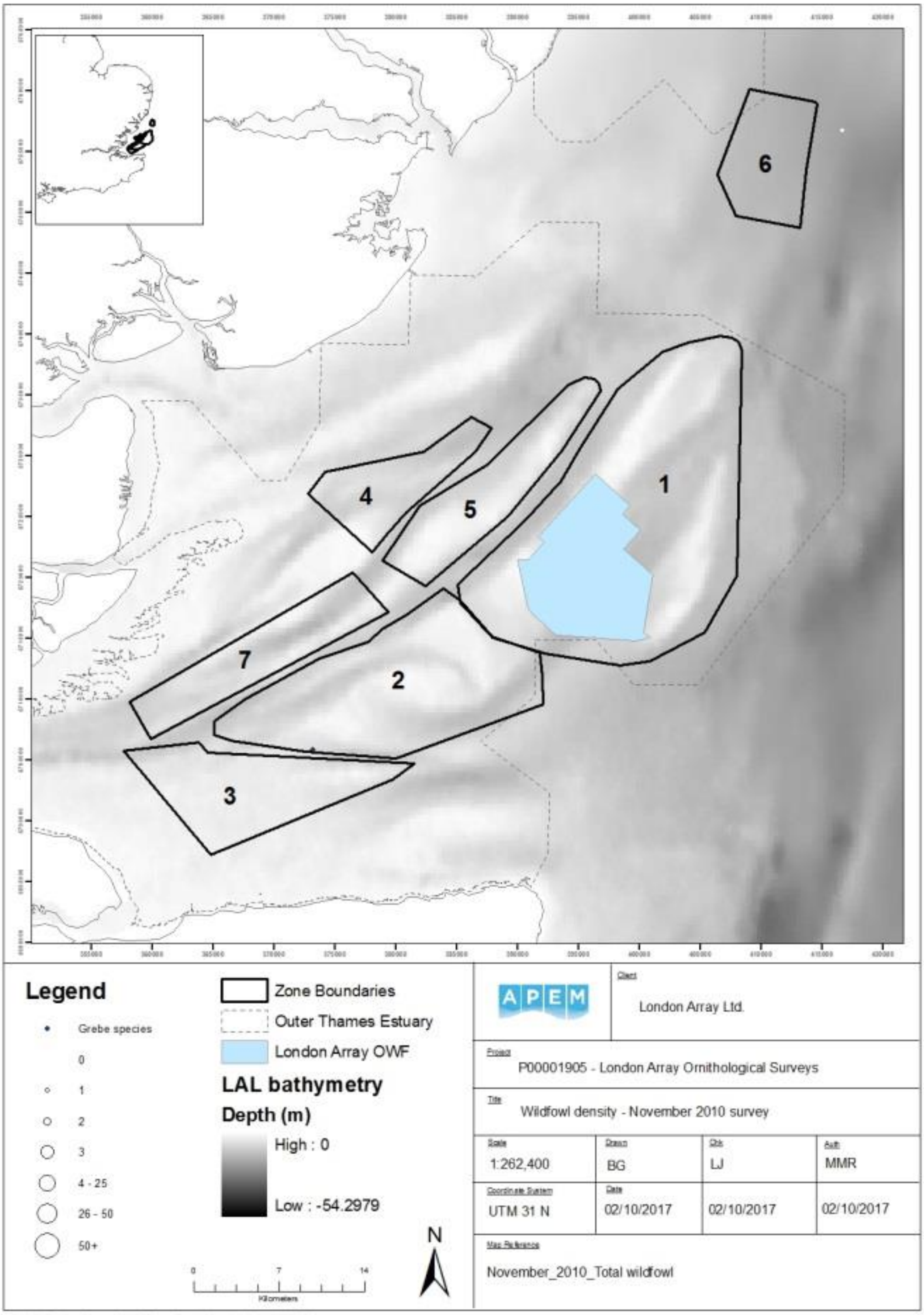
Appendix 4 Key Species Group Monthly Distribution

The following figures present the relative distribution of the key identified species and species groups recorded during the London Array digital aerial surveys conducted between the years 2009 to 2016.

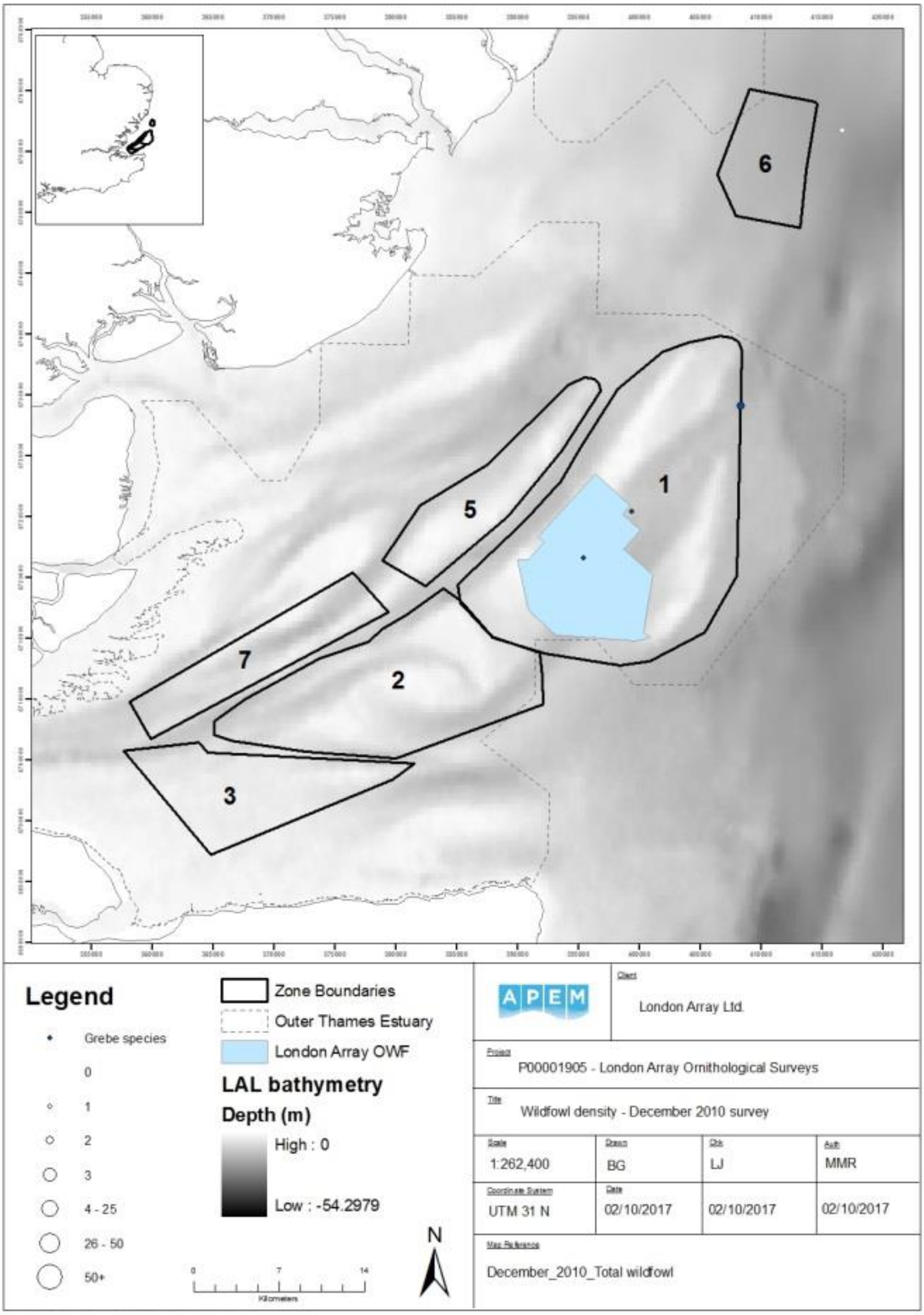
Wildfowl



December 2009



November 2010



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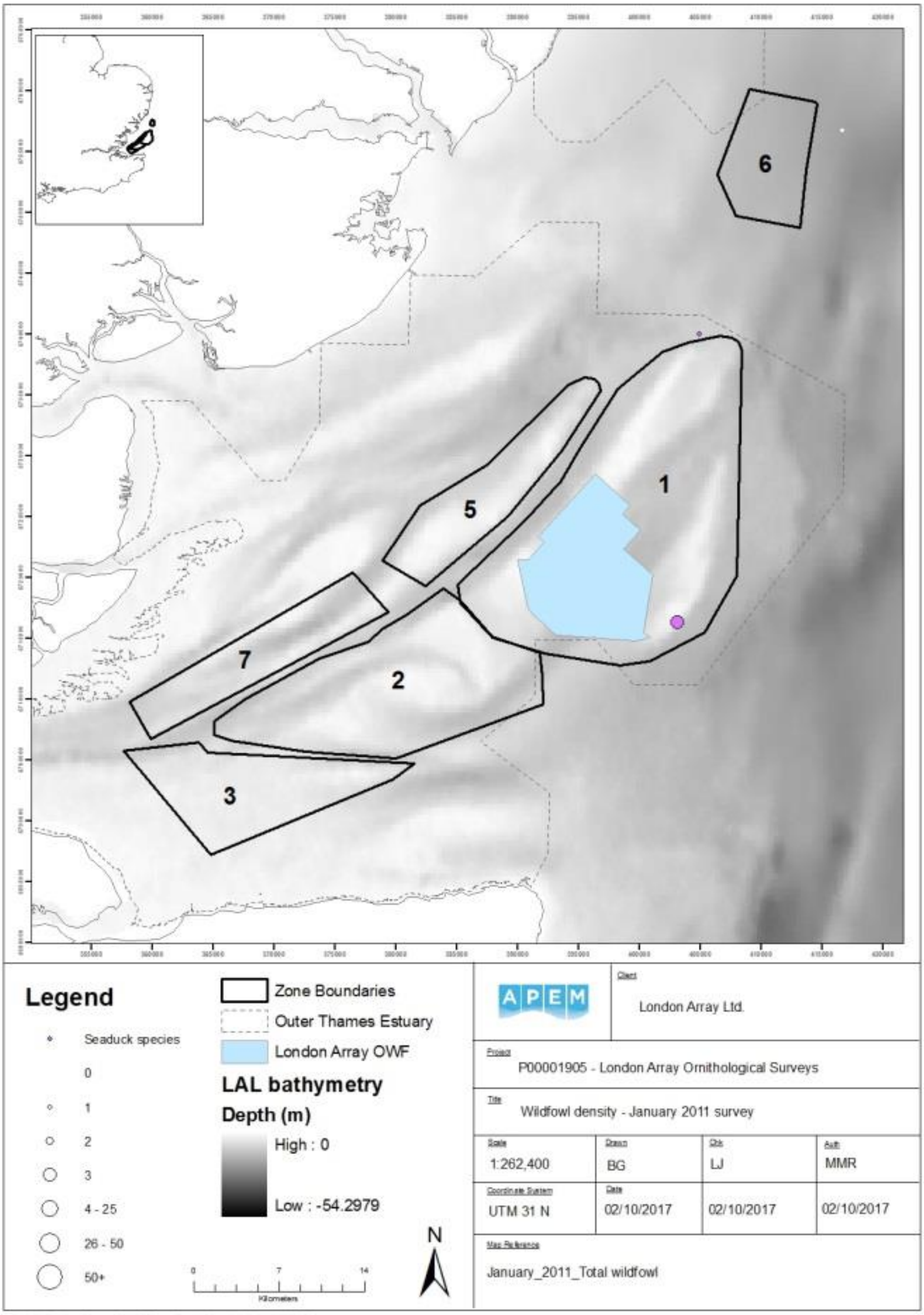
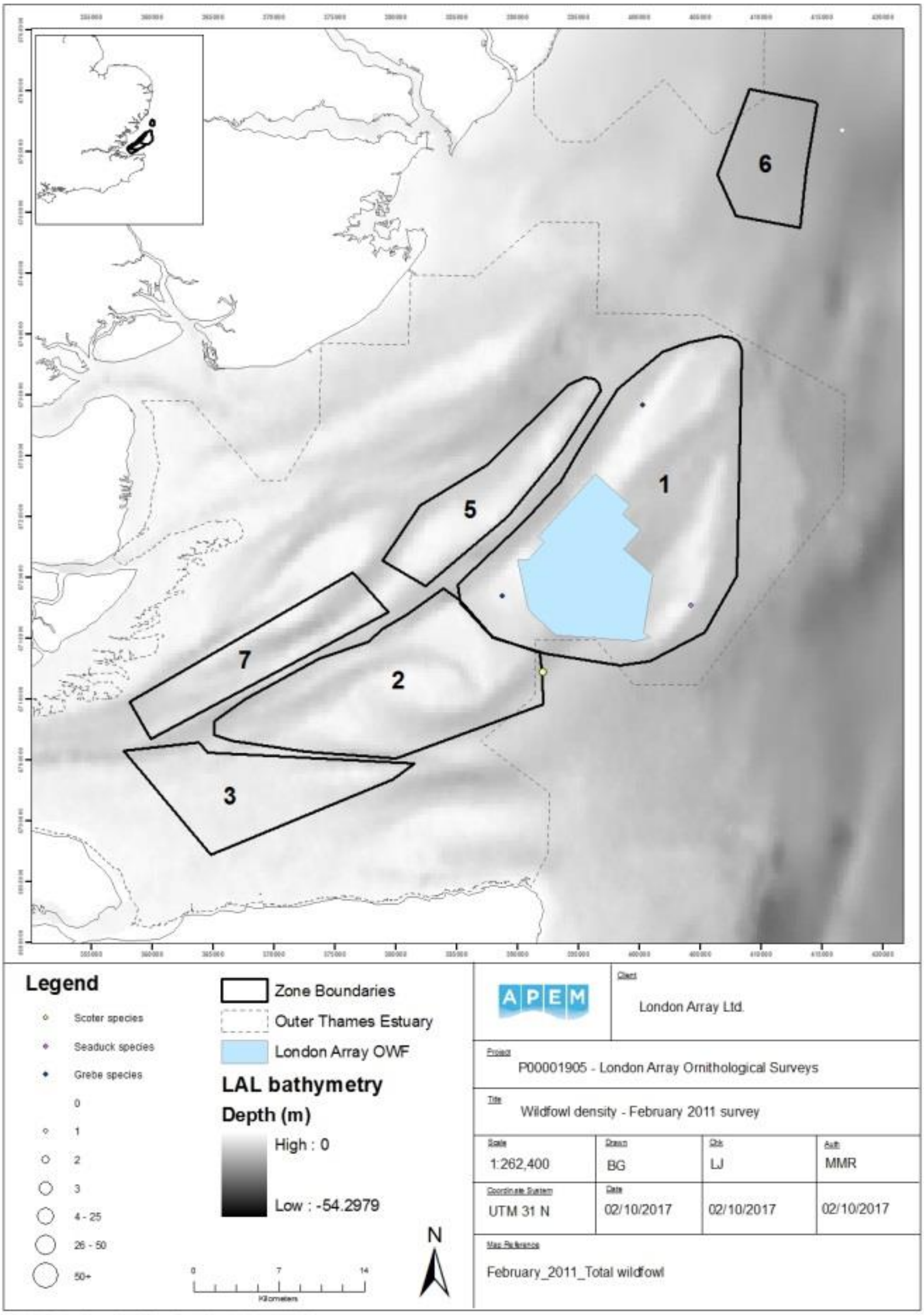
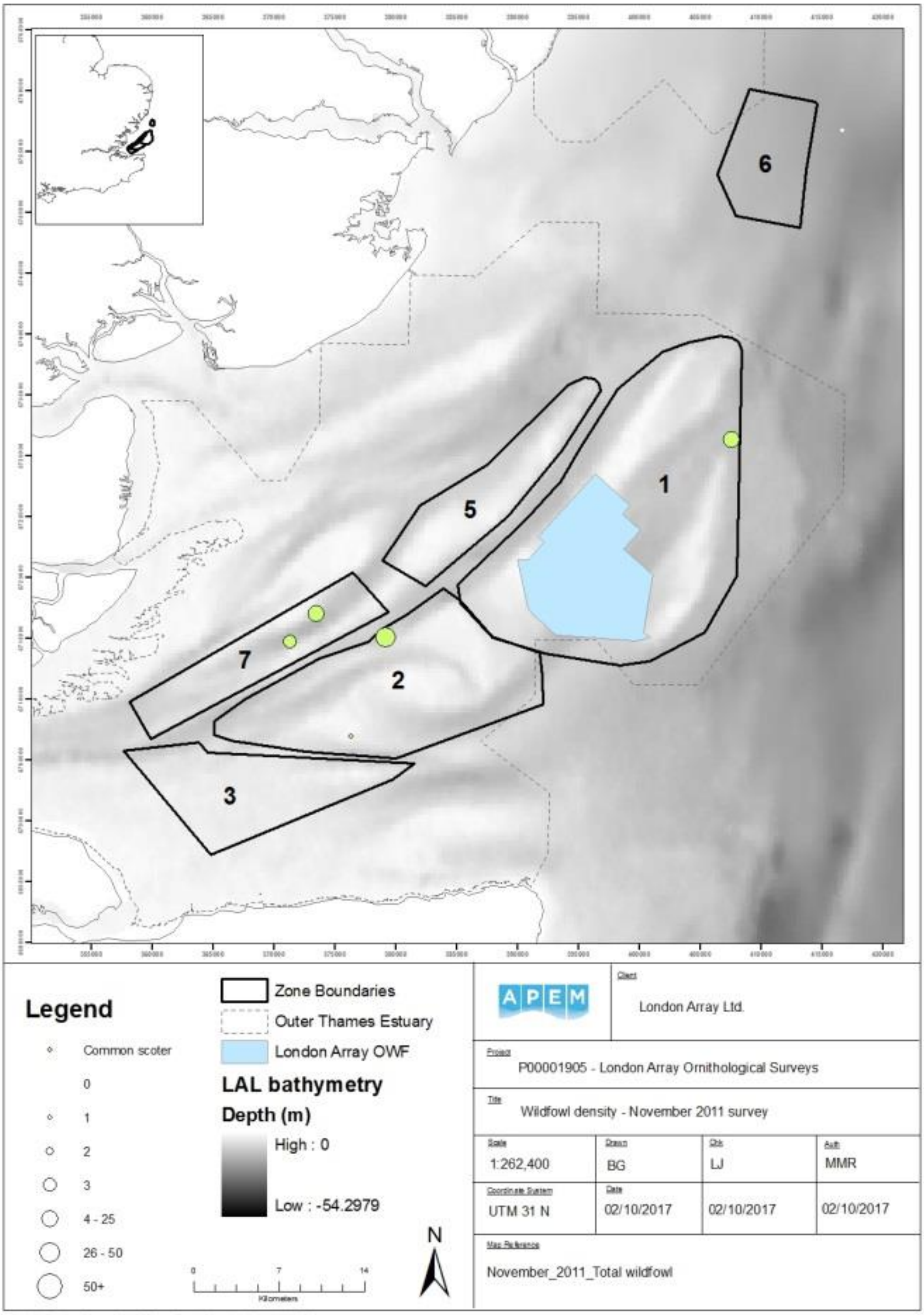


January 2011



February 2011



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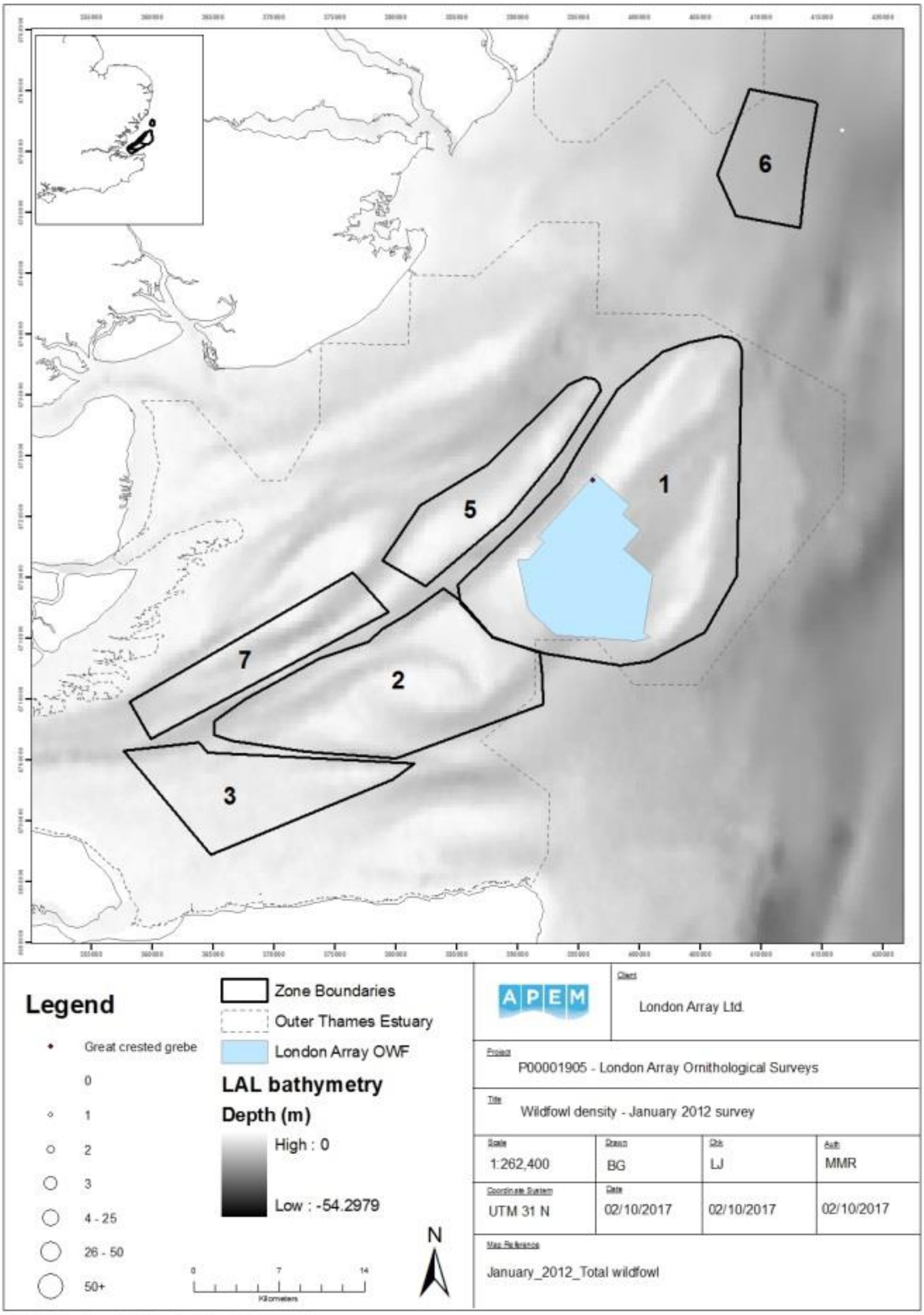

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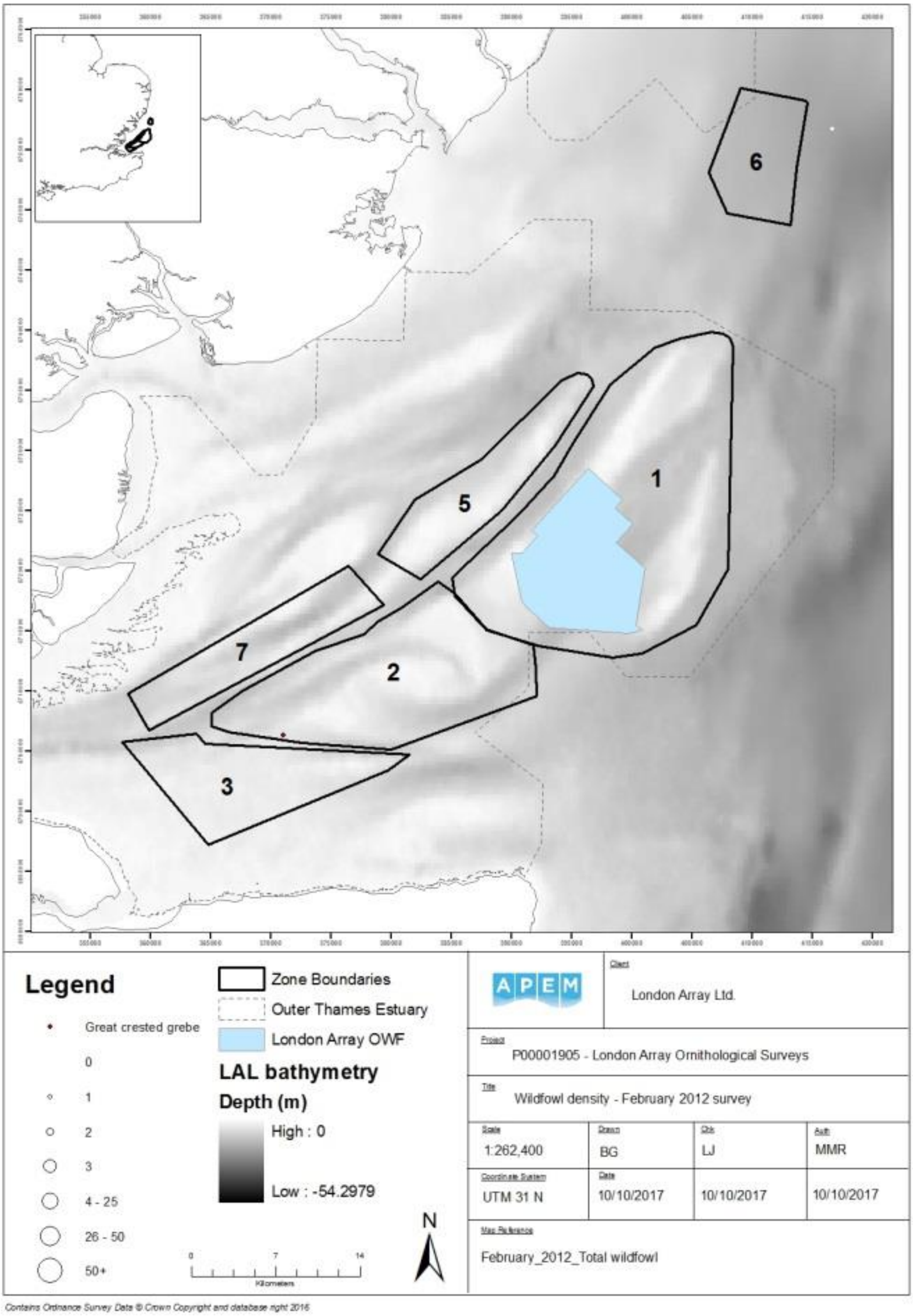

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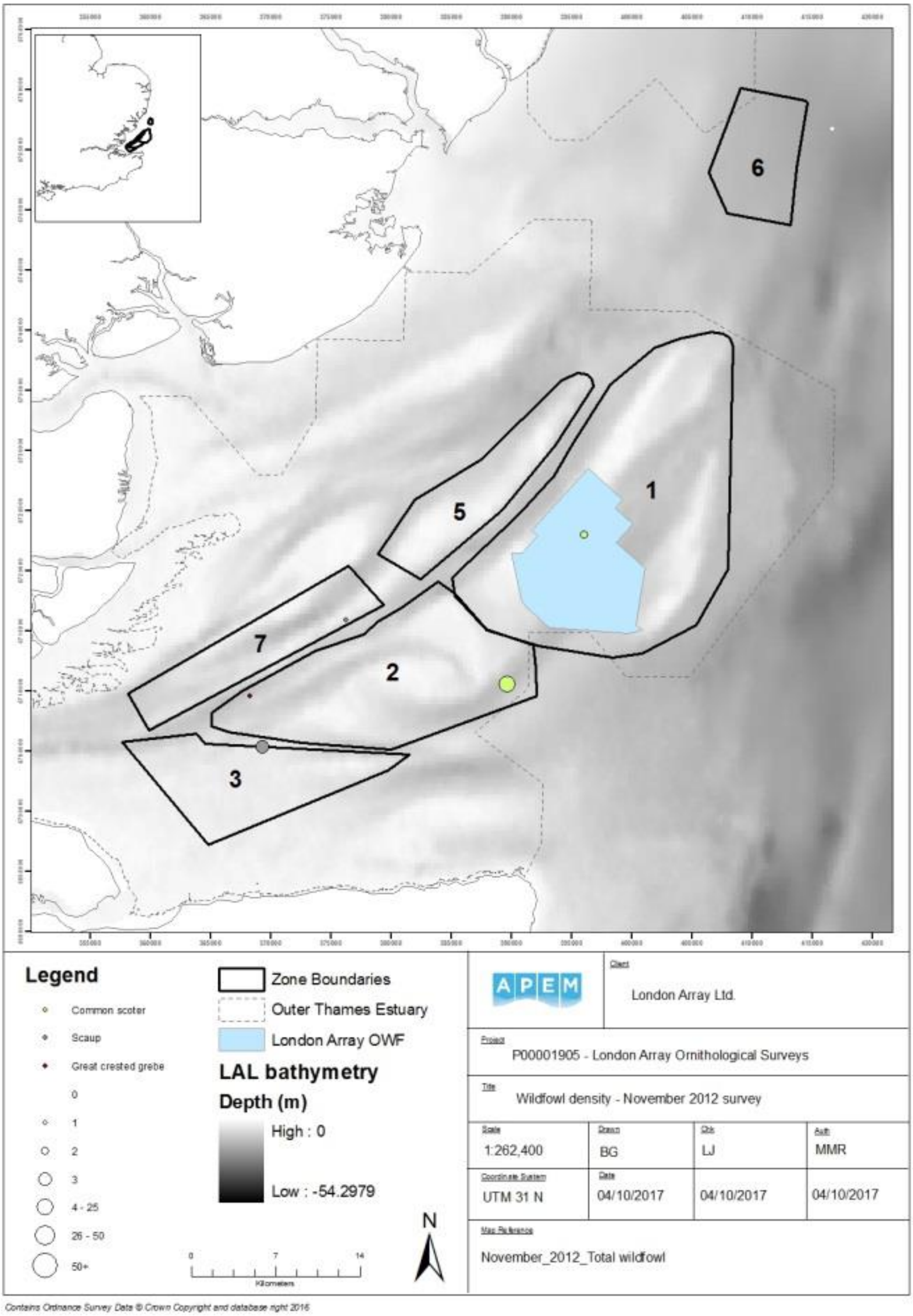

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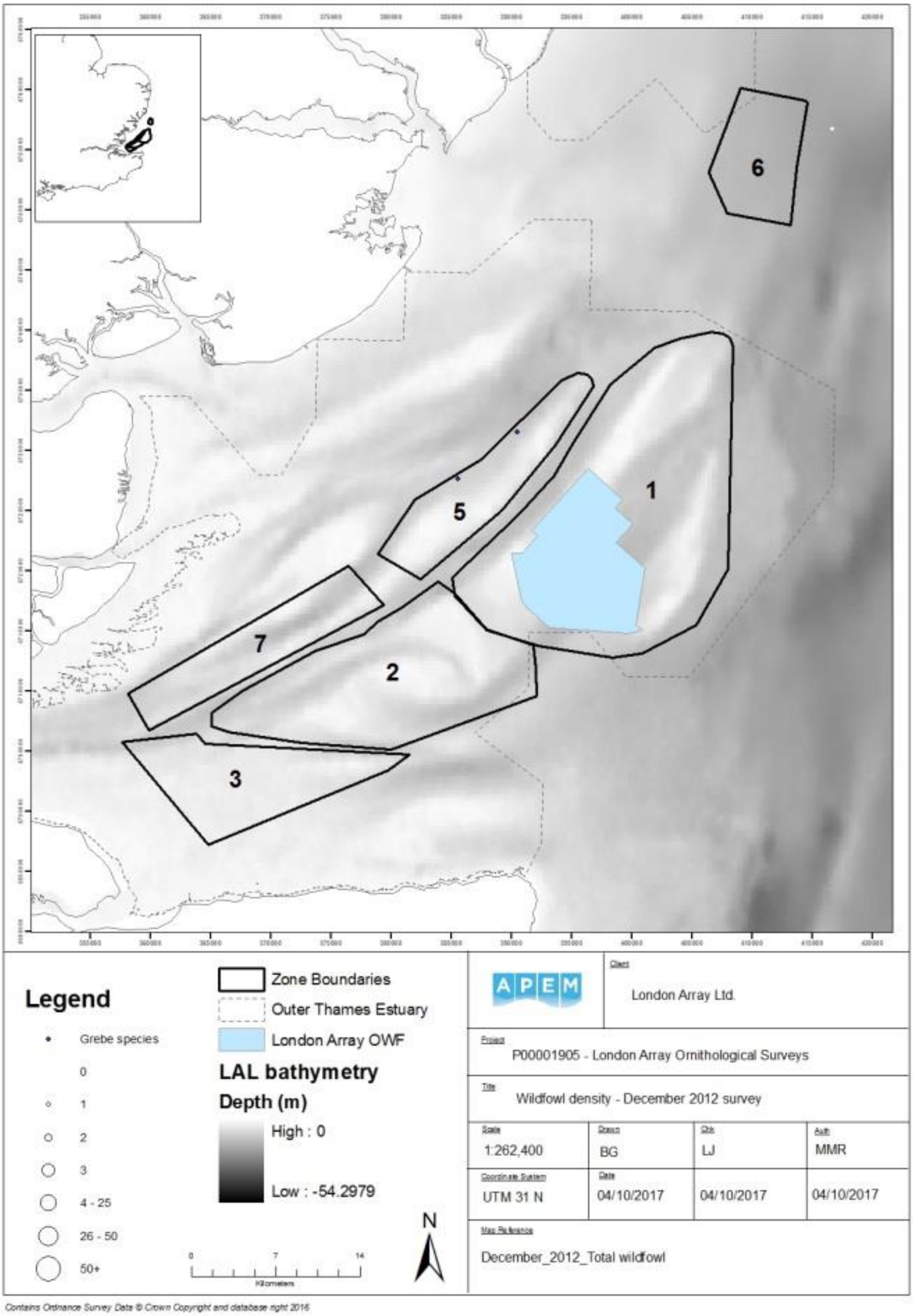

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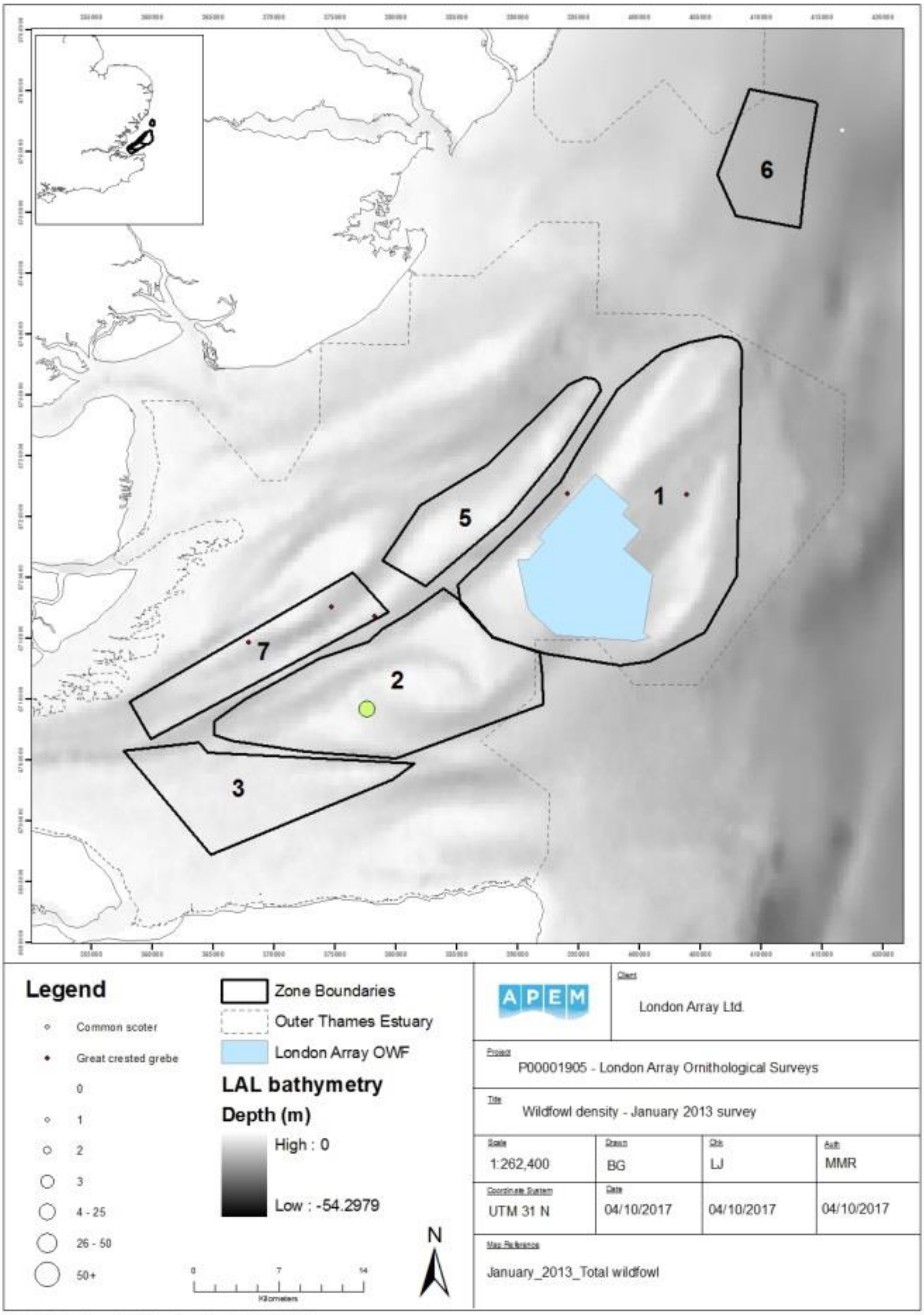

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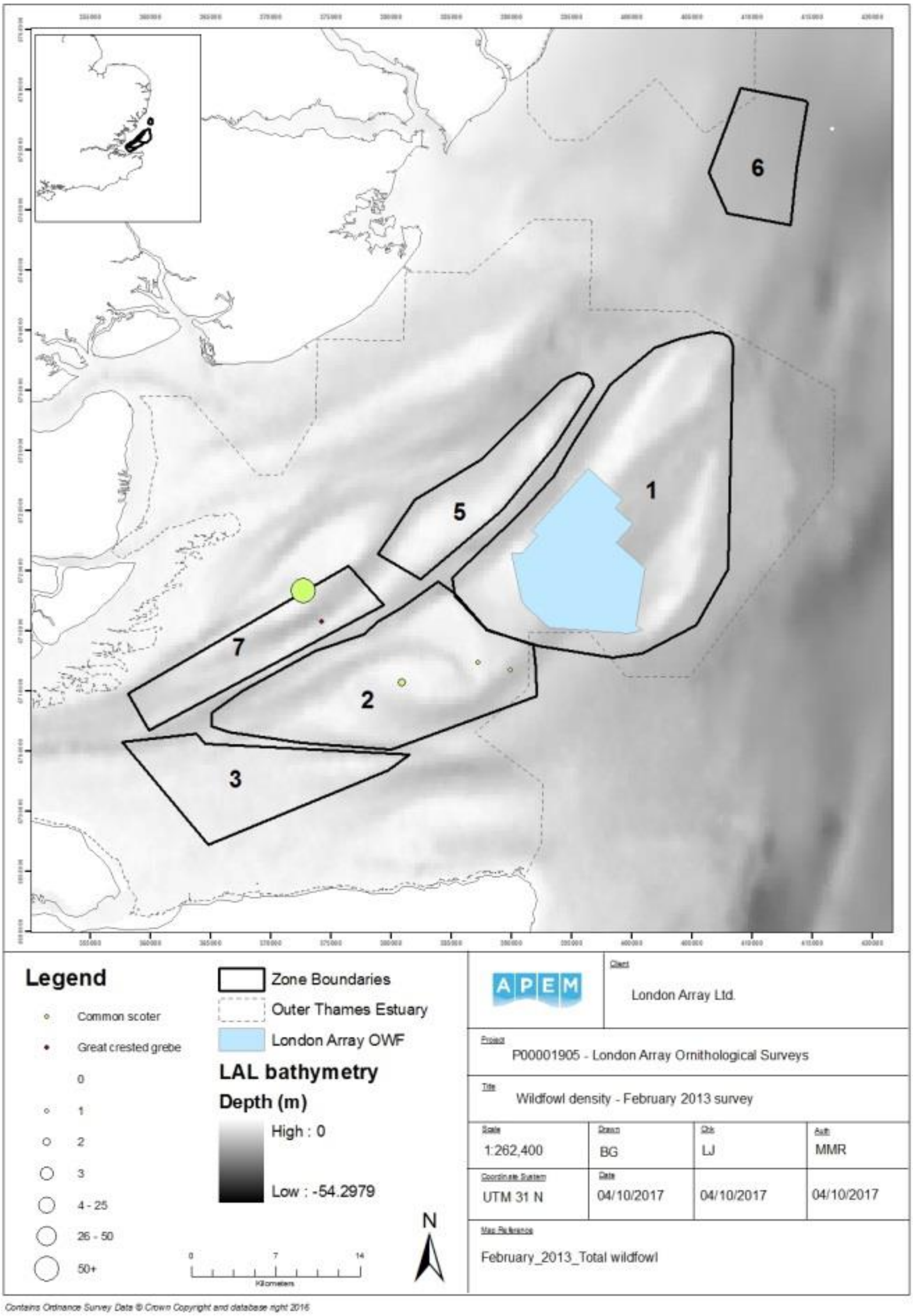

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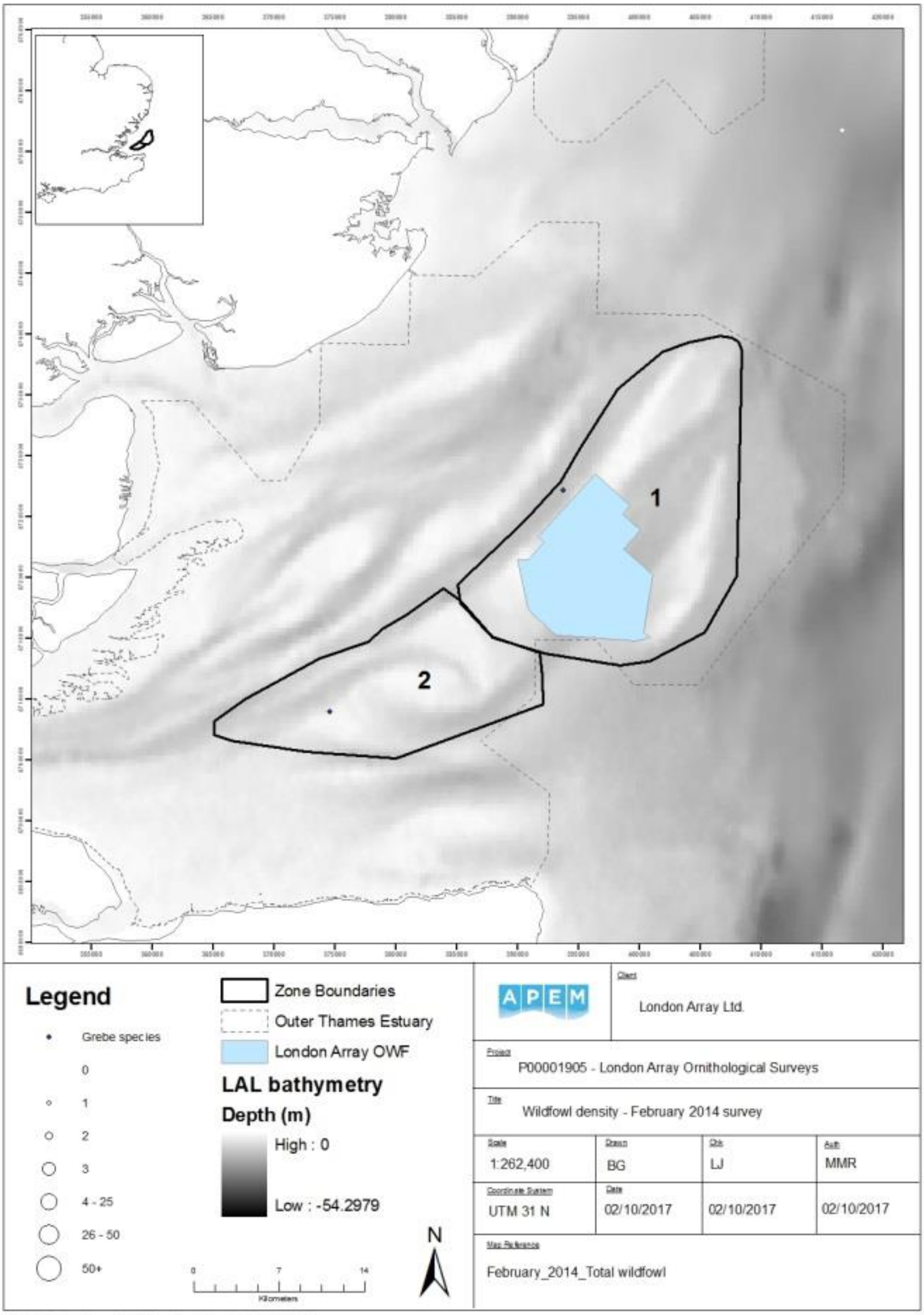

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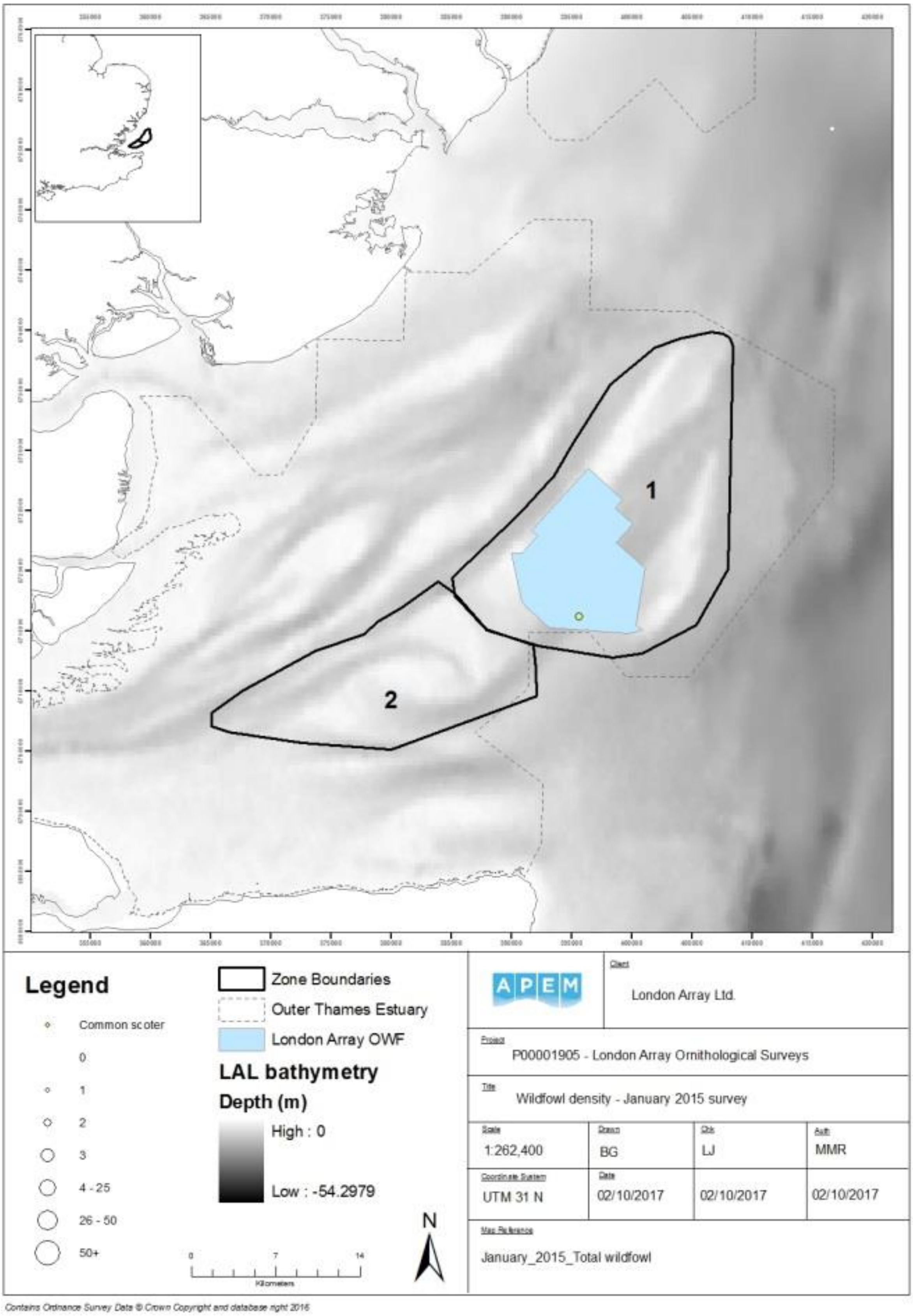
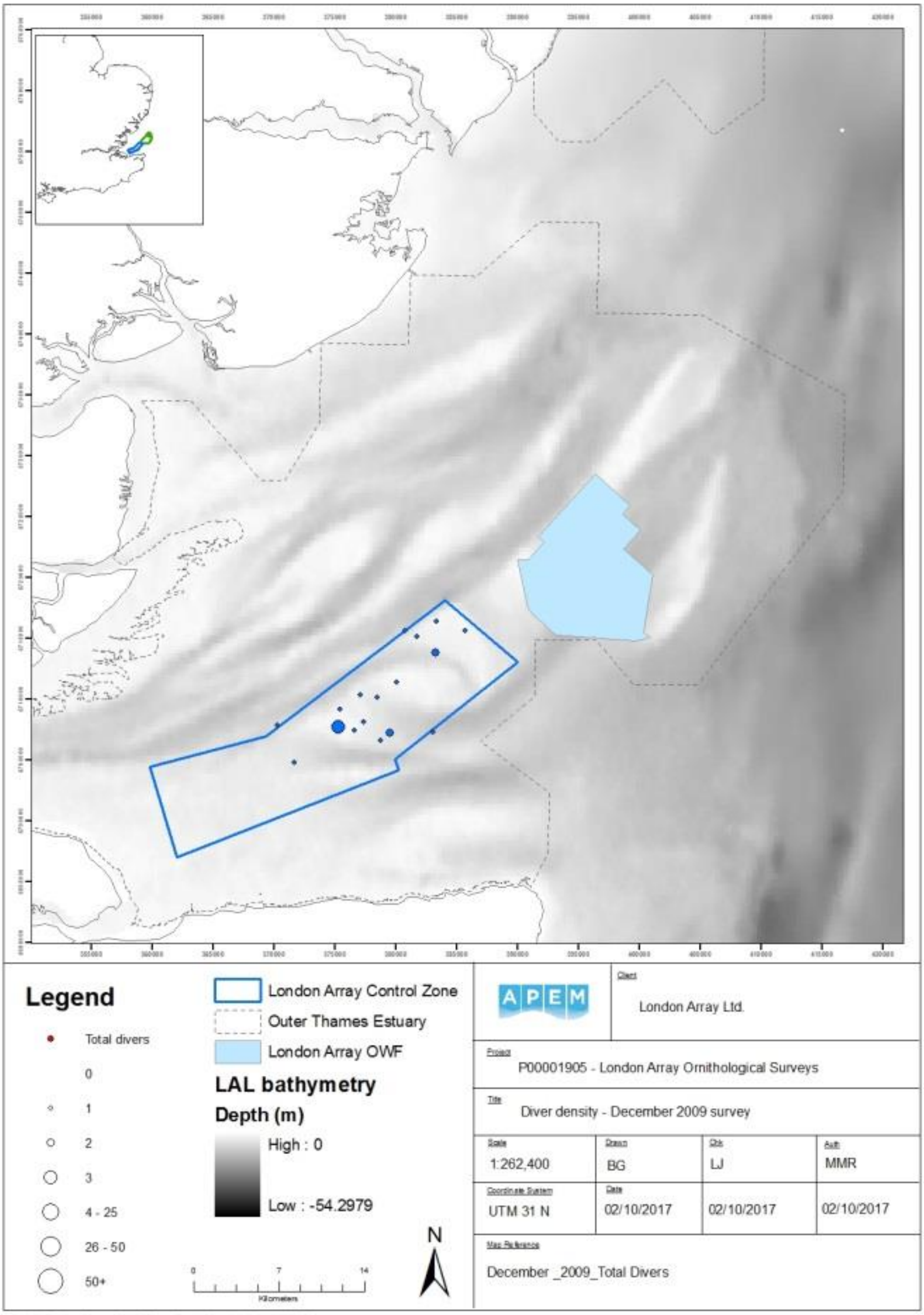


January 2015

Figure 1 Monthly distribution maps for wildfowl recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Divers



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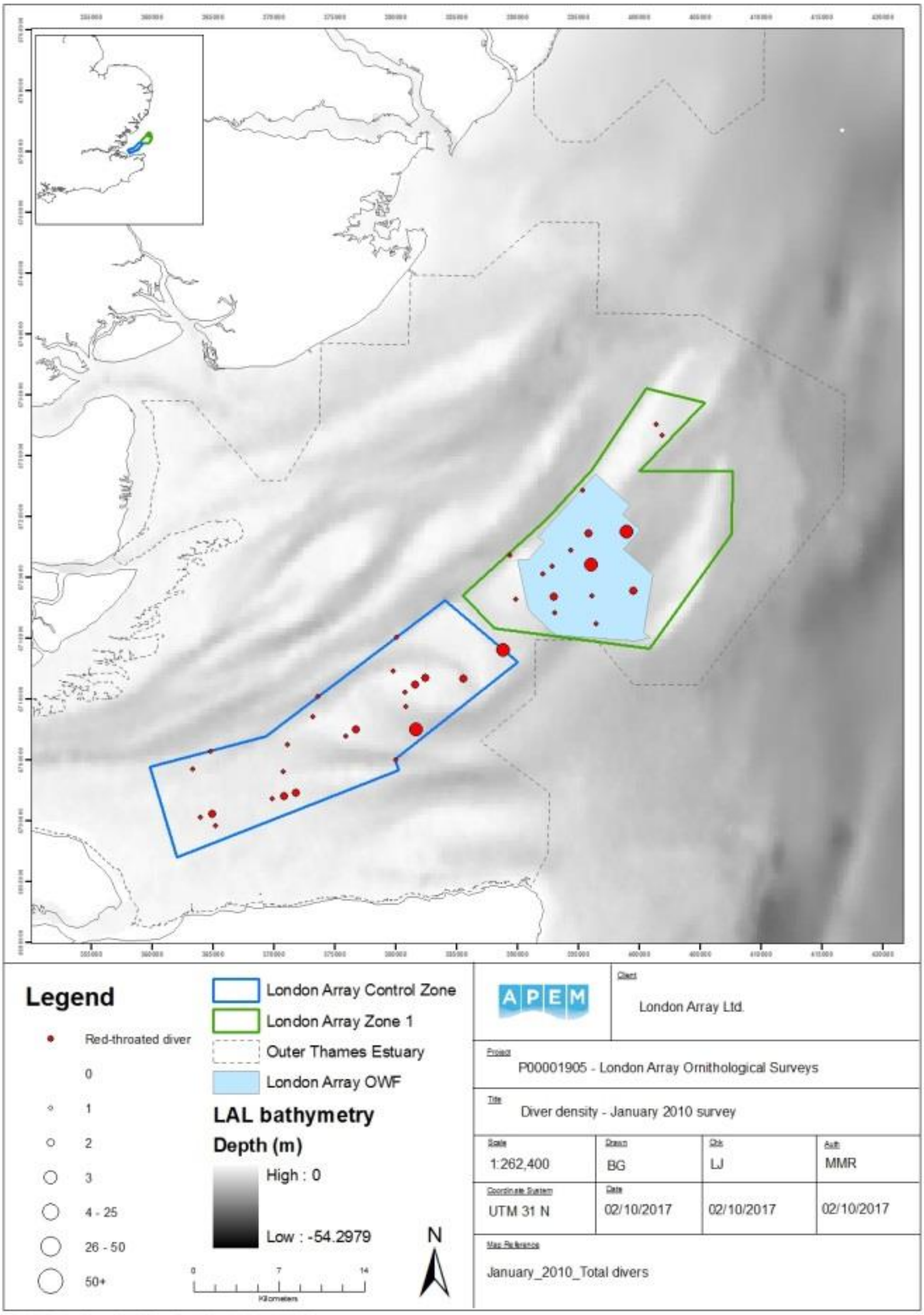
December 2009



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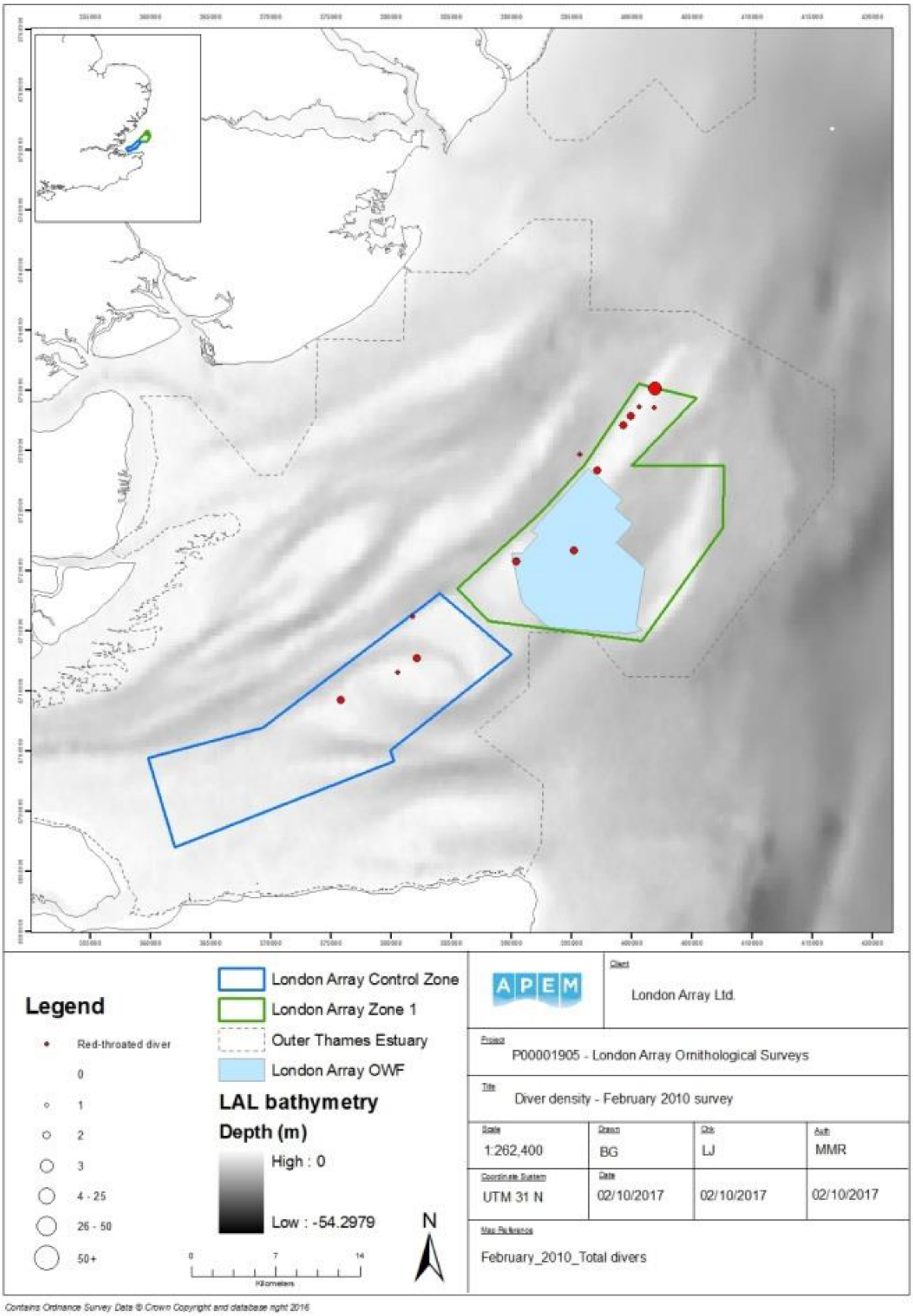

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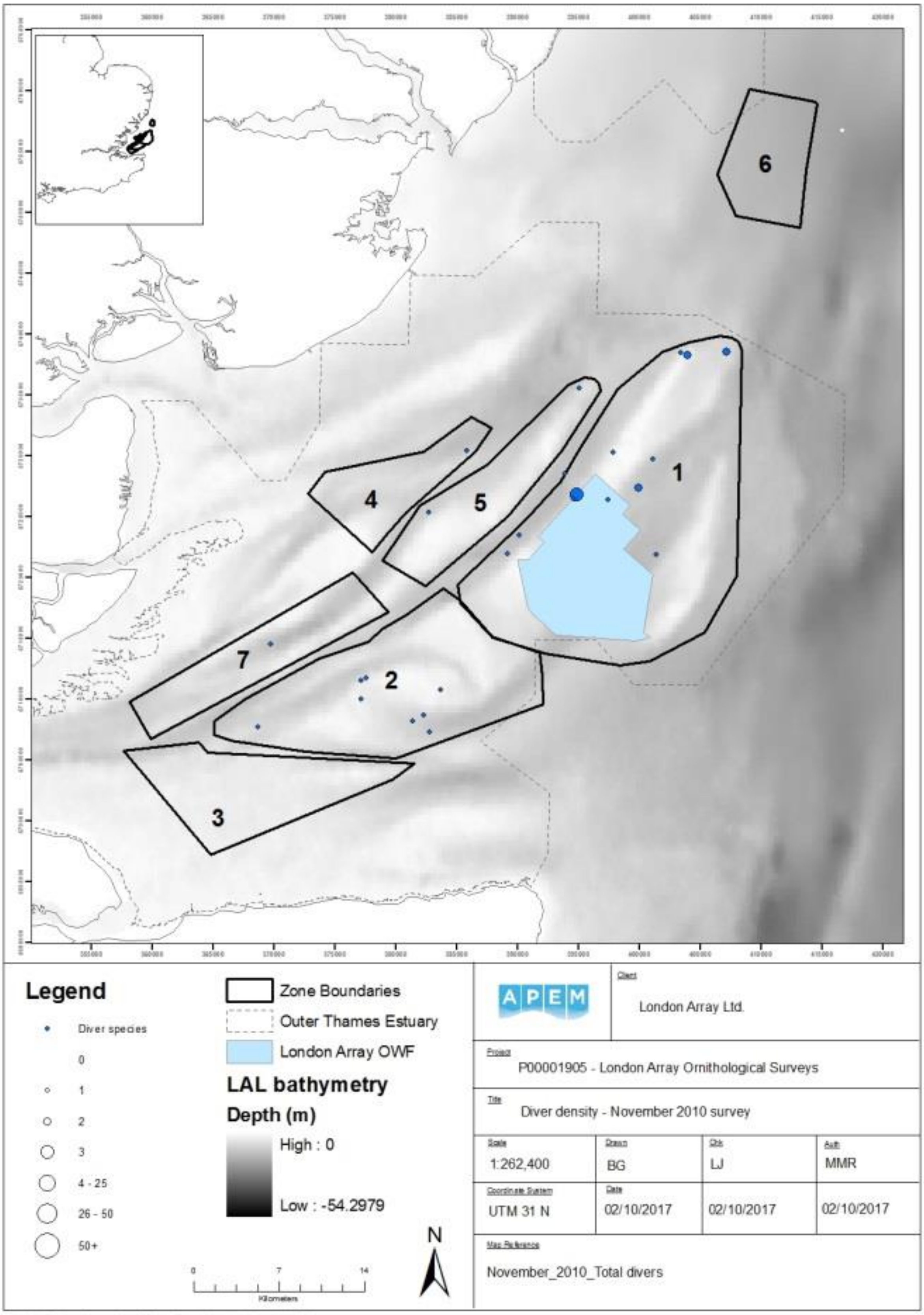

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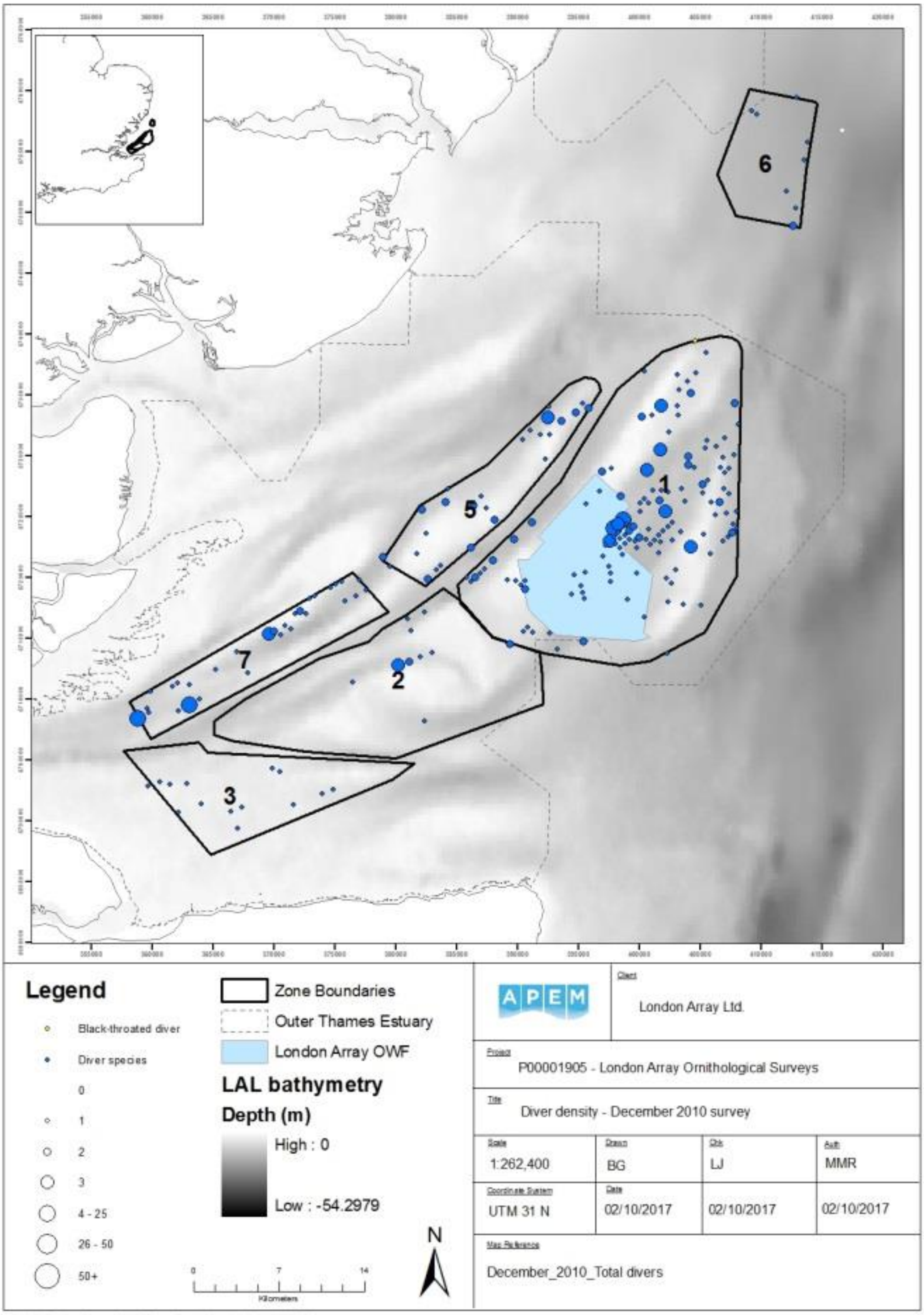

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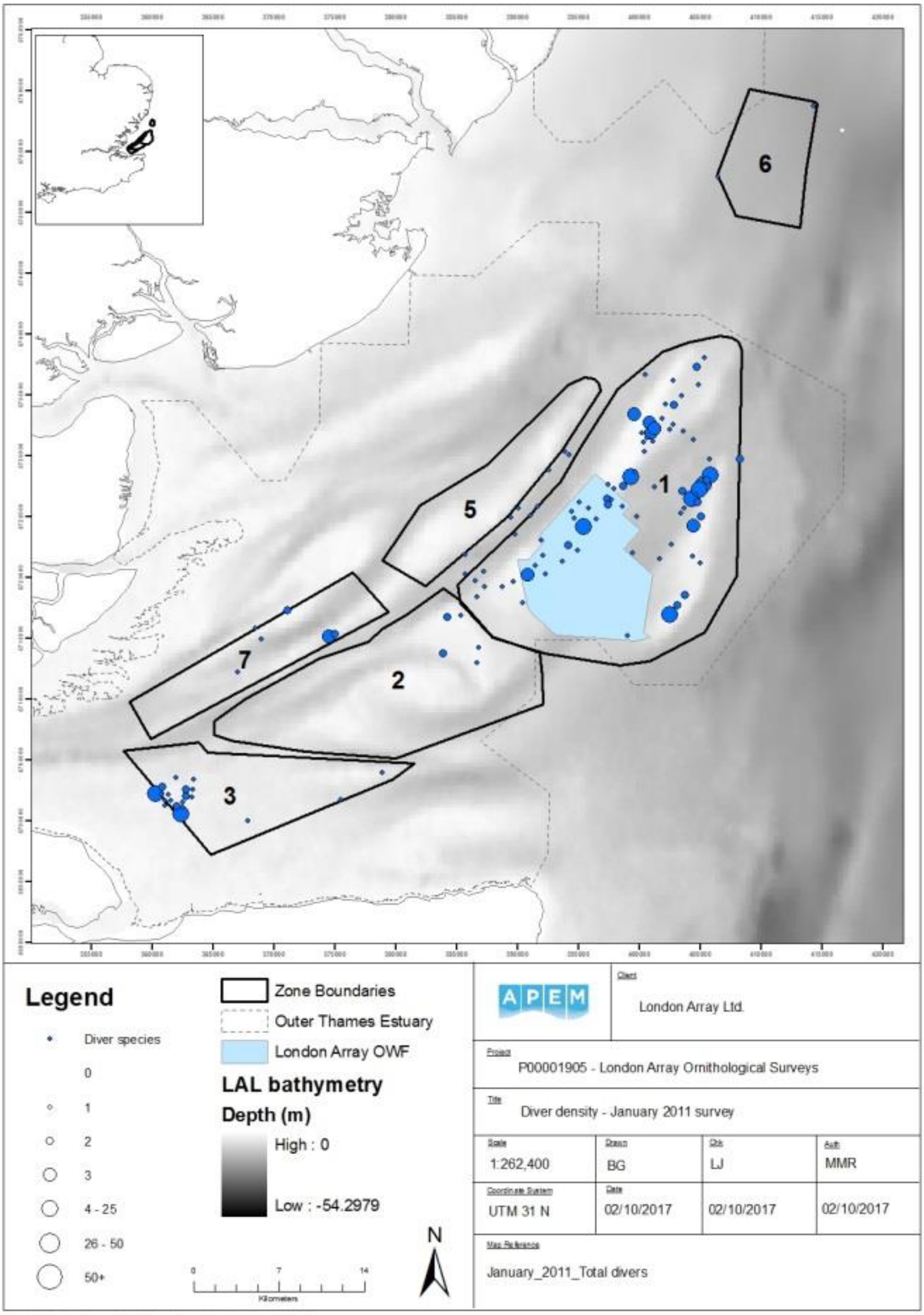

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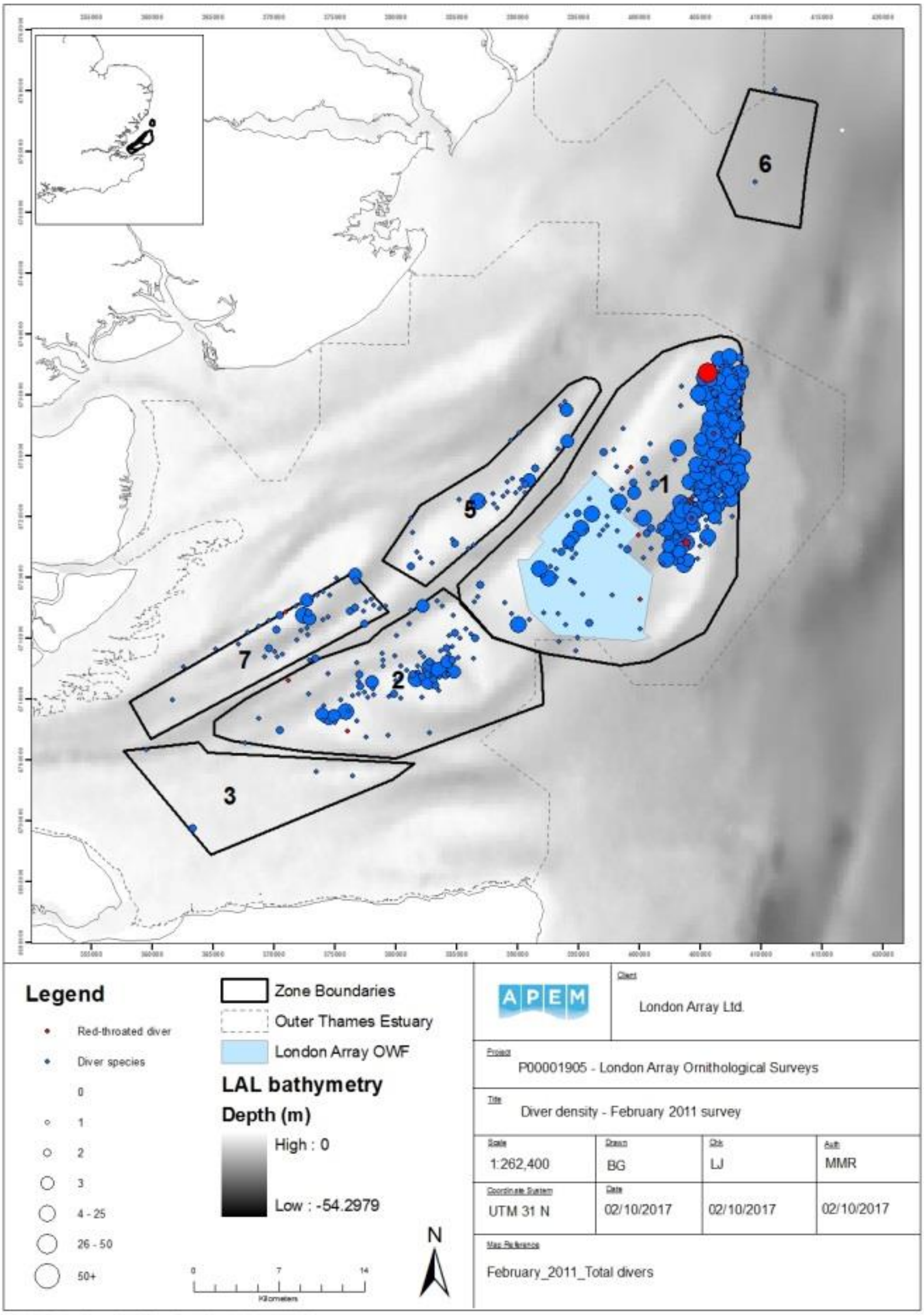

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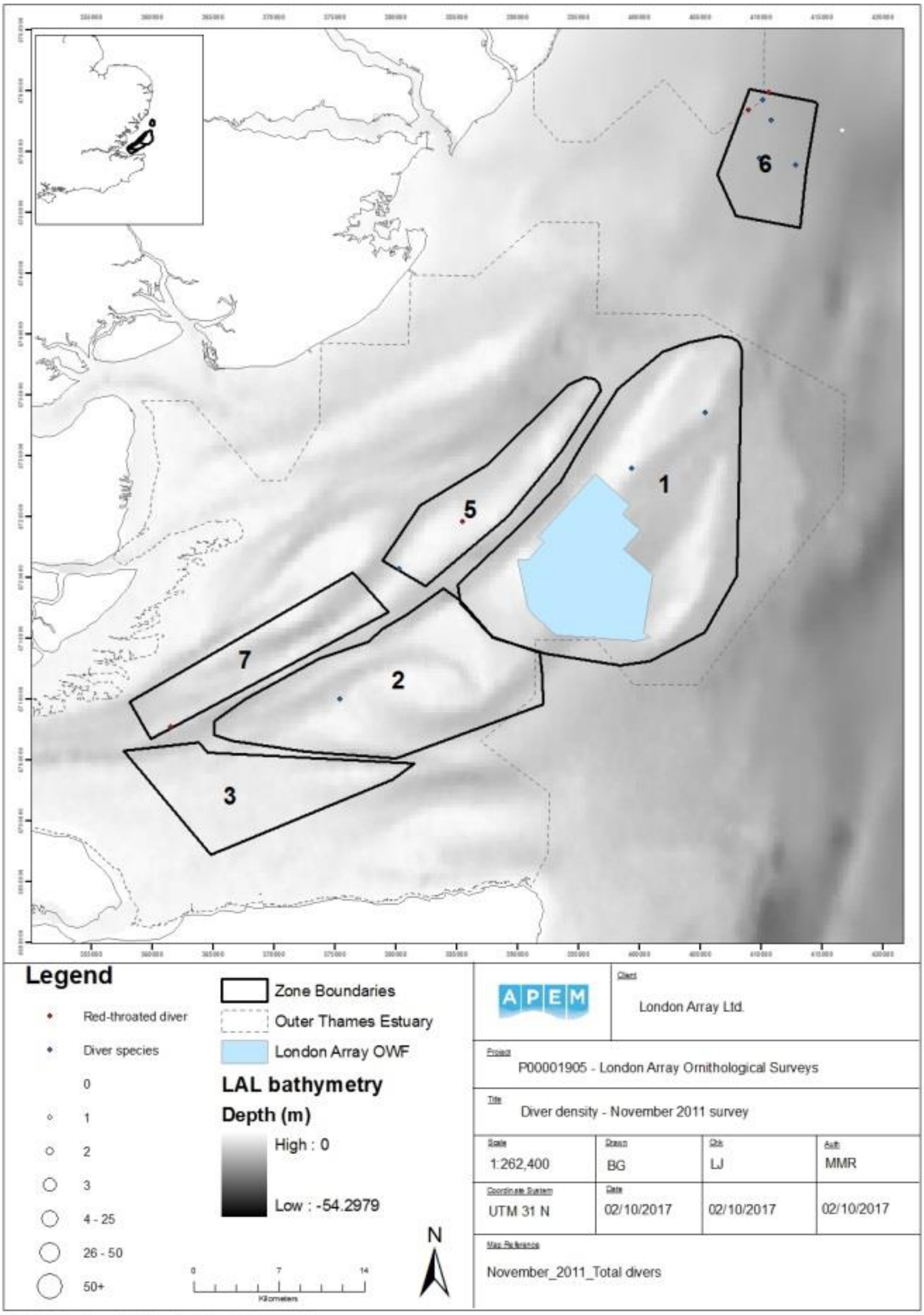

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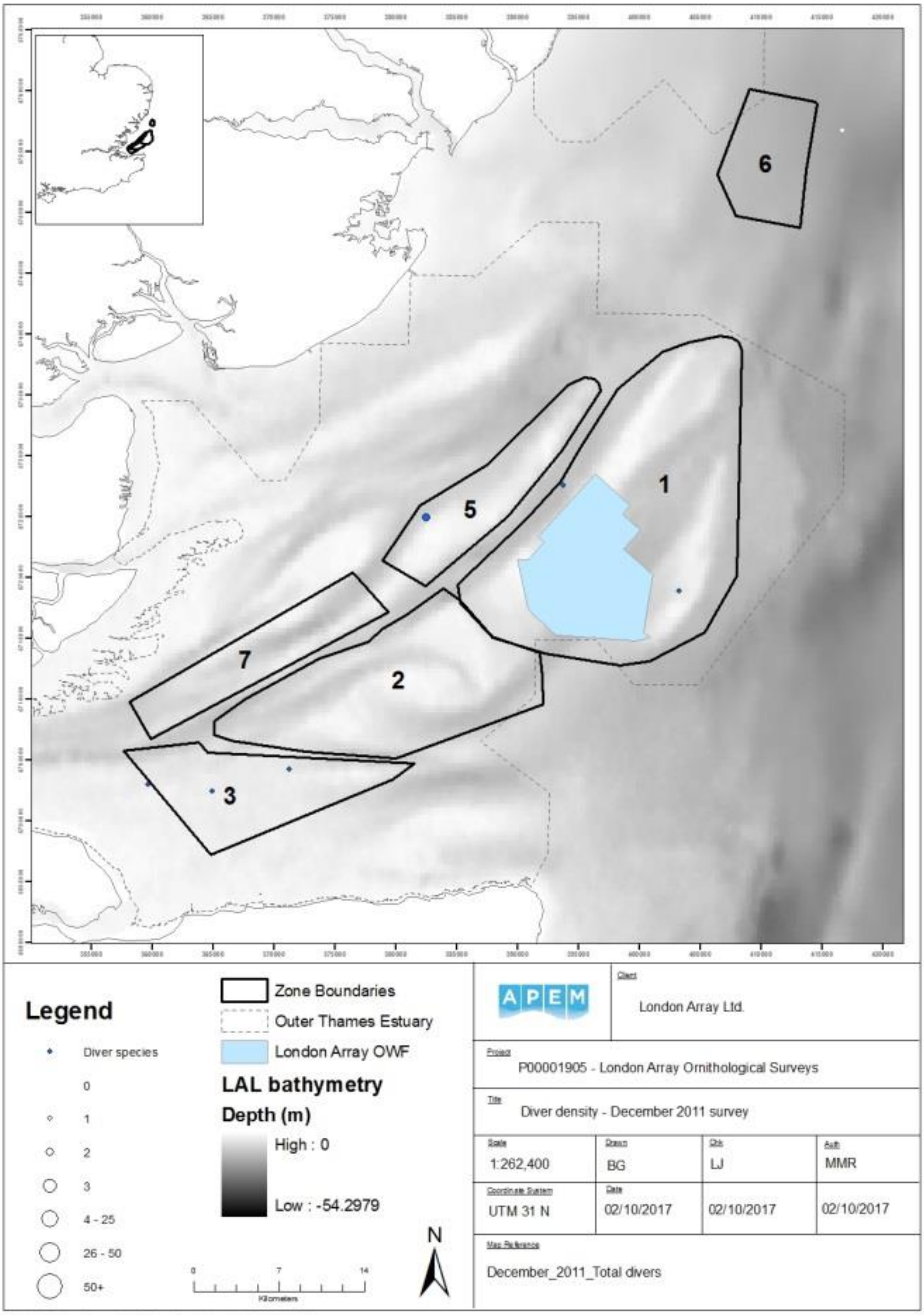

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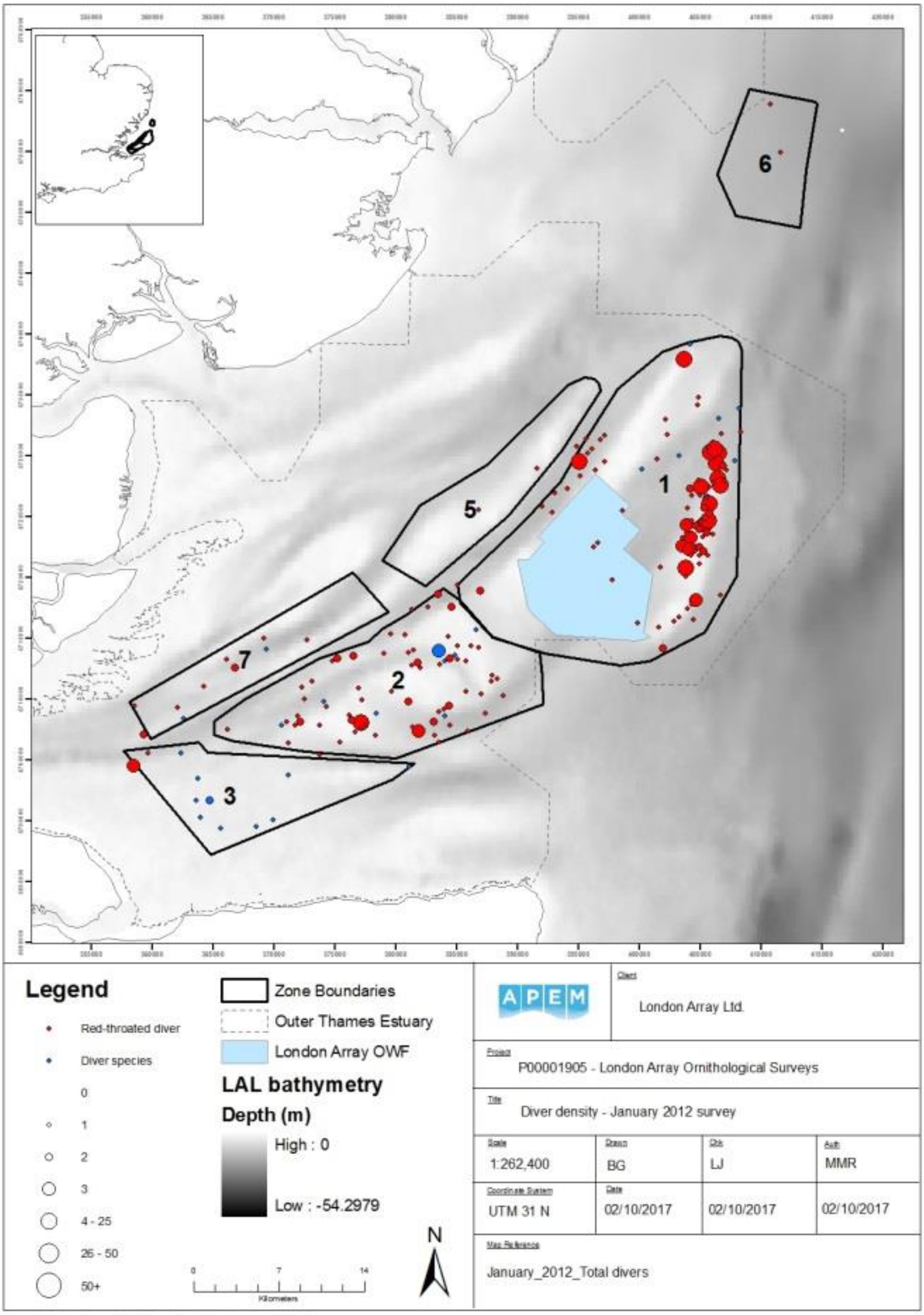

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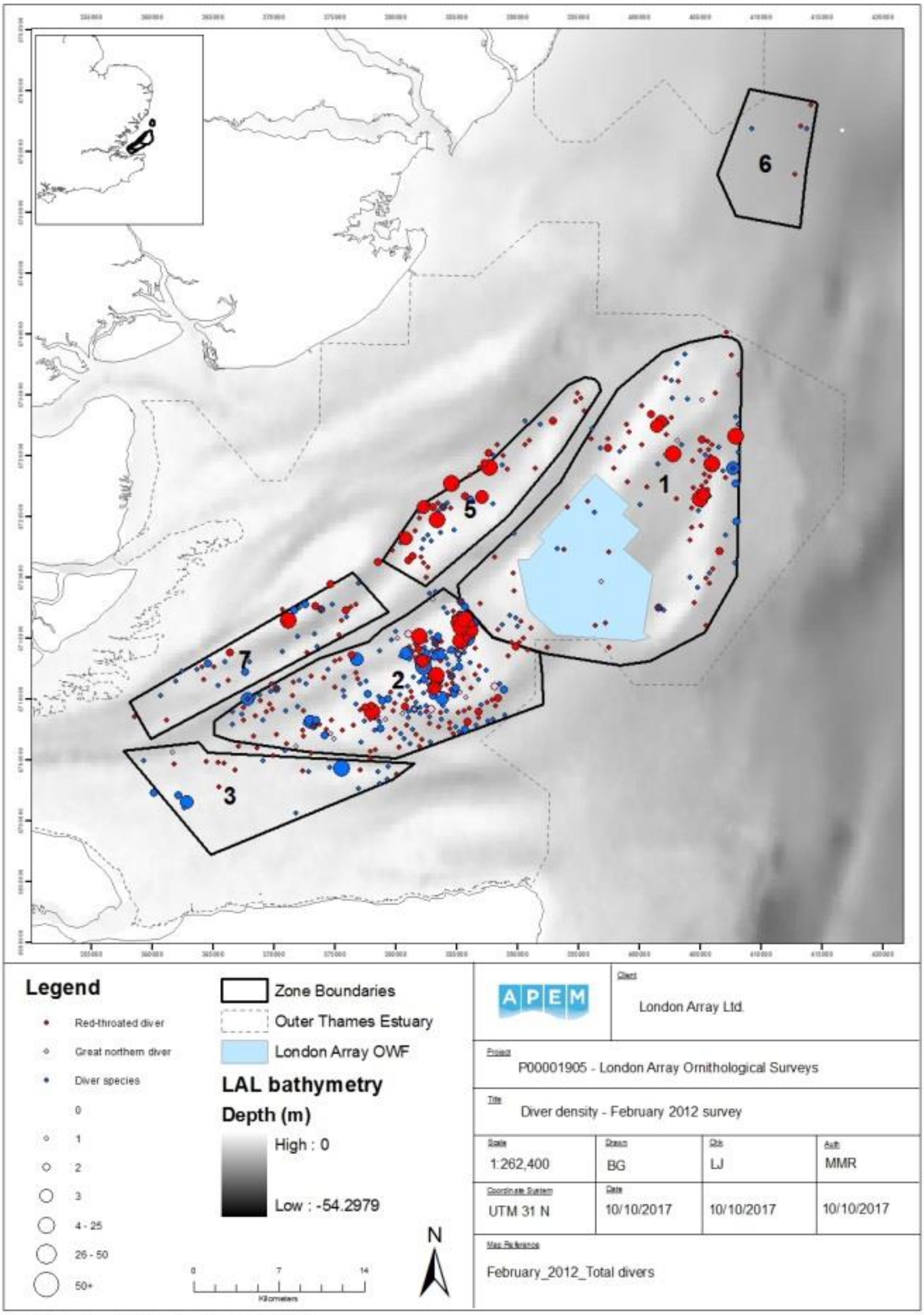

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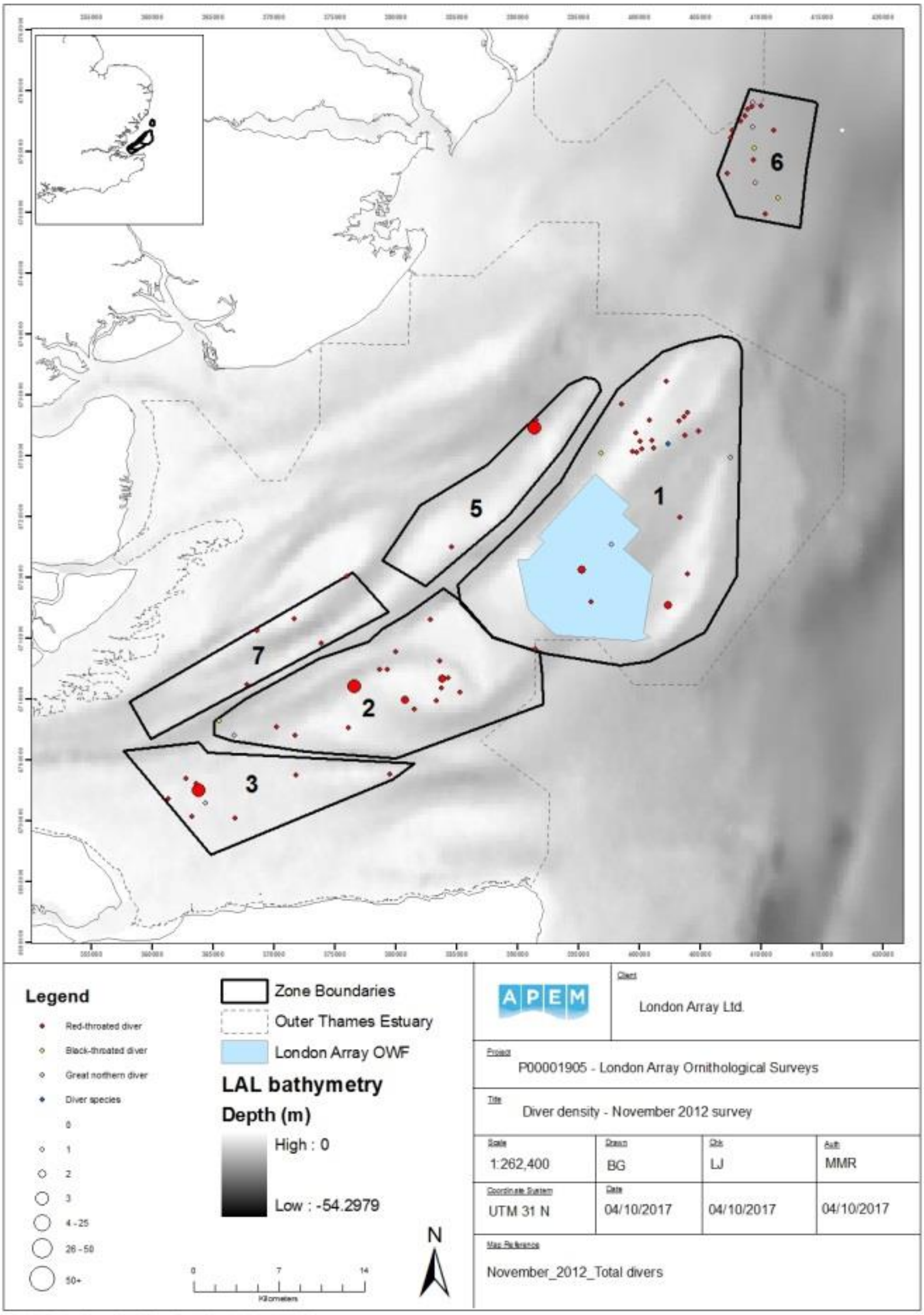

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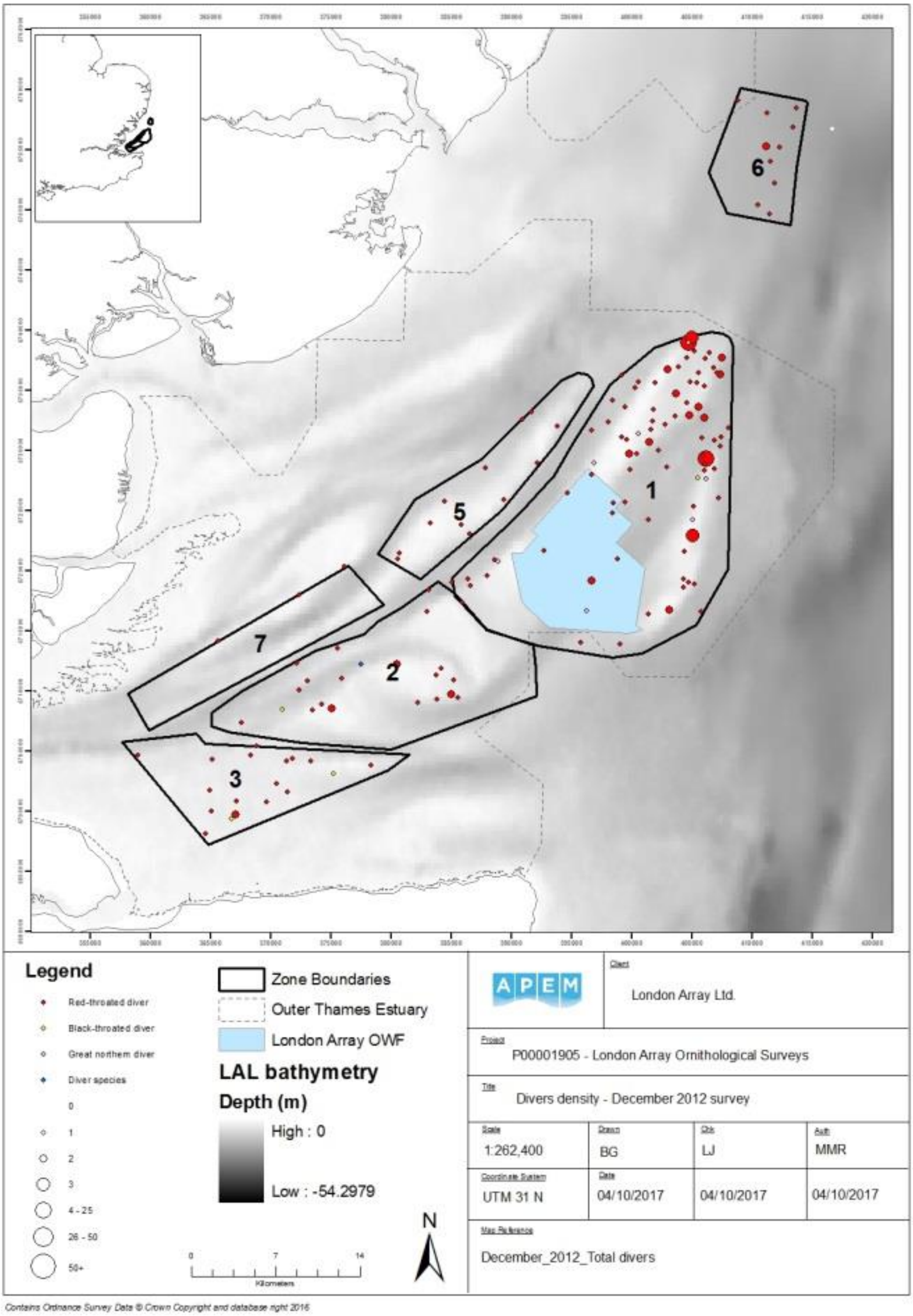

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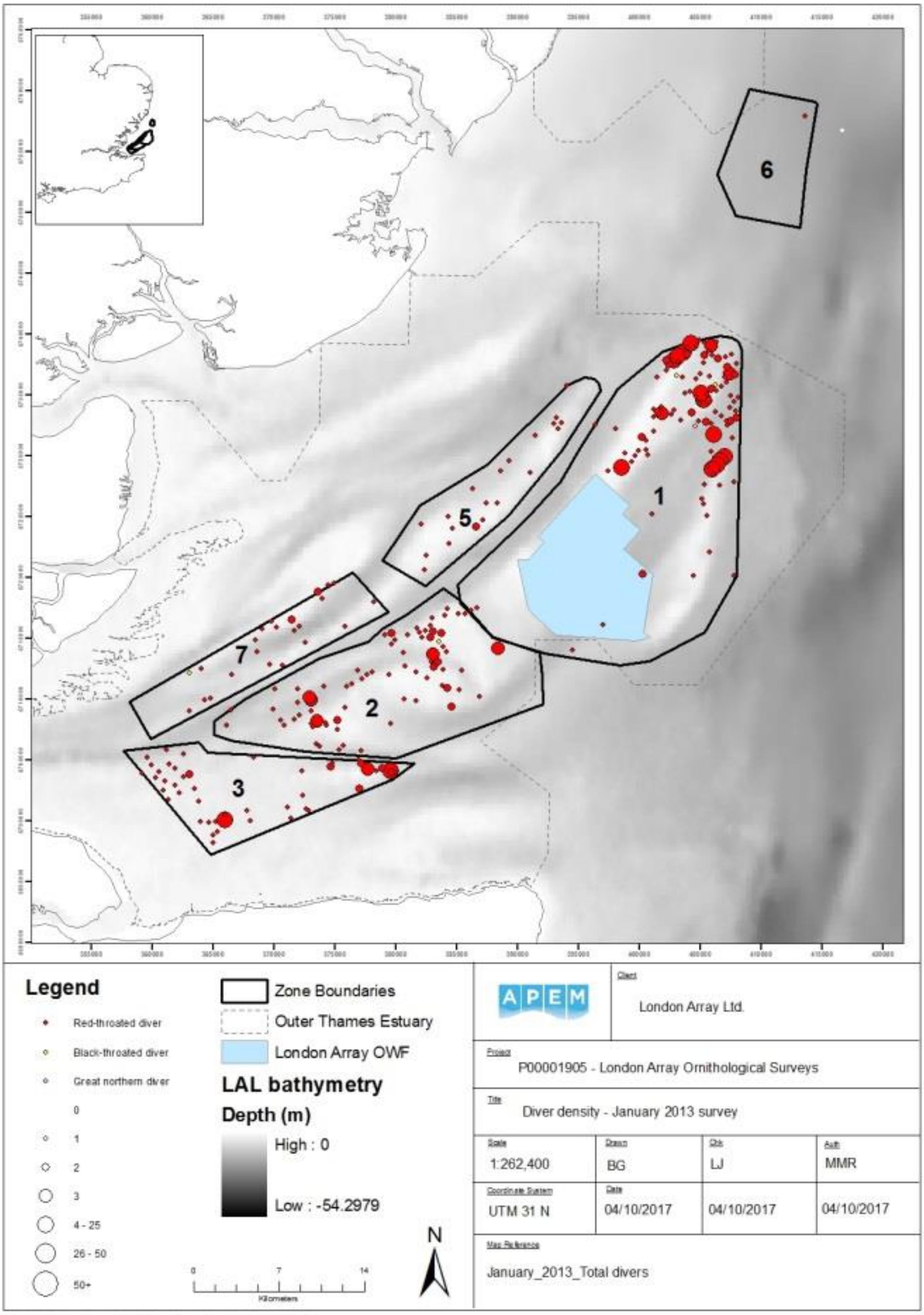

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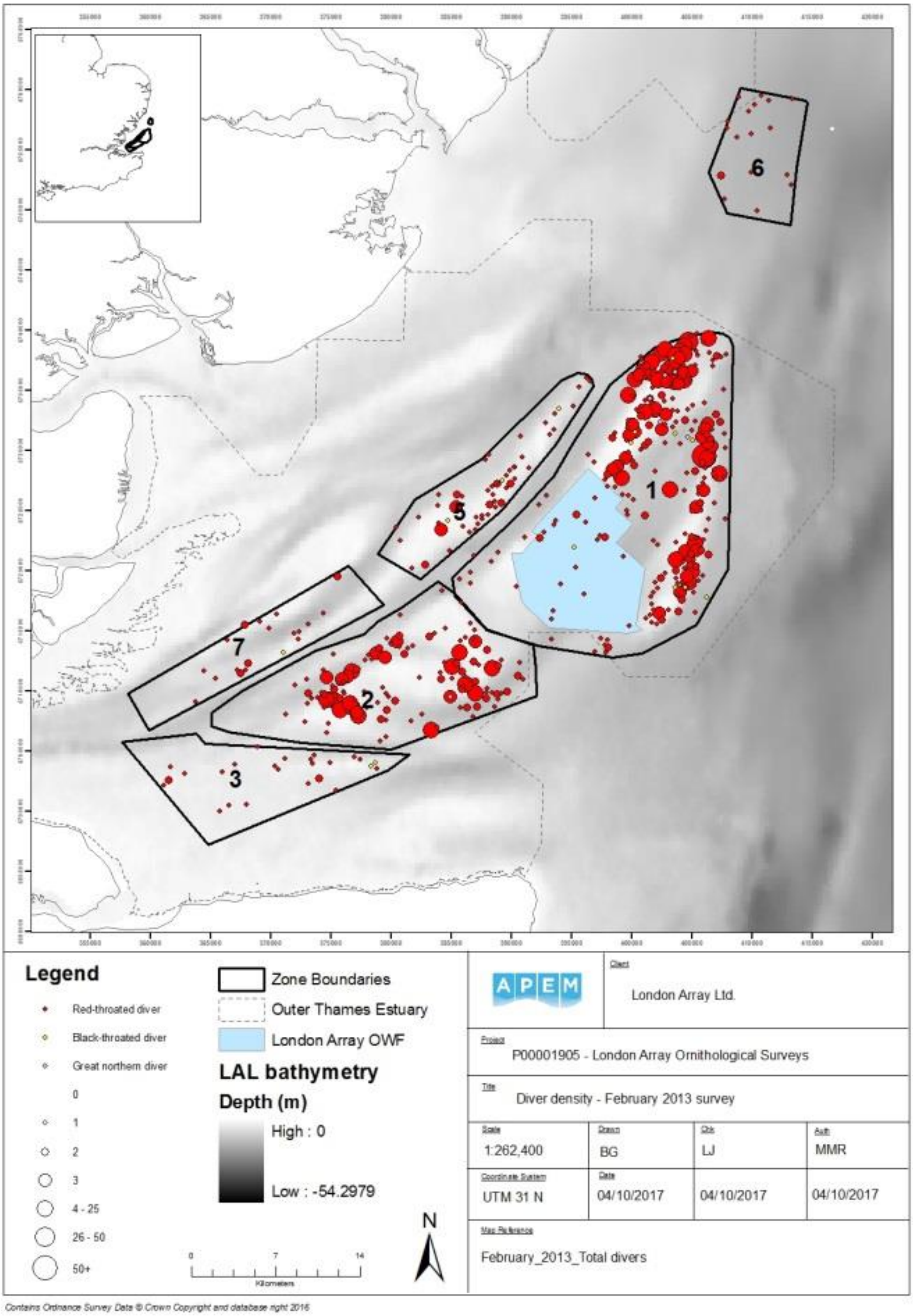

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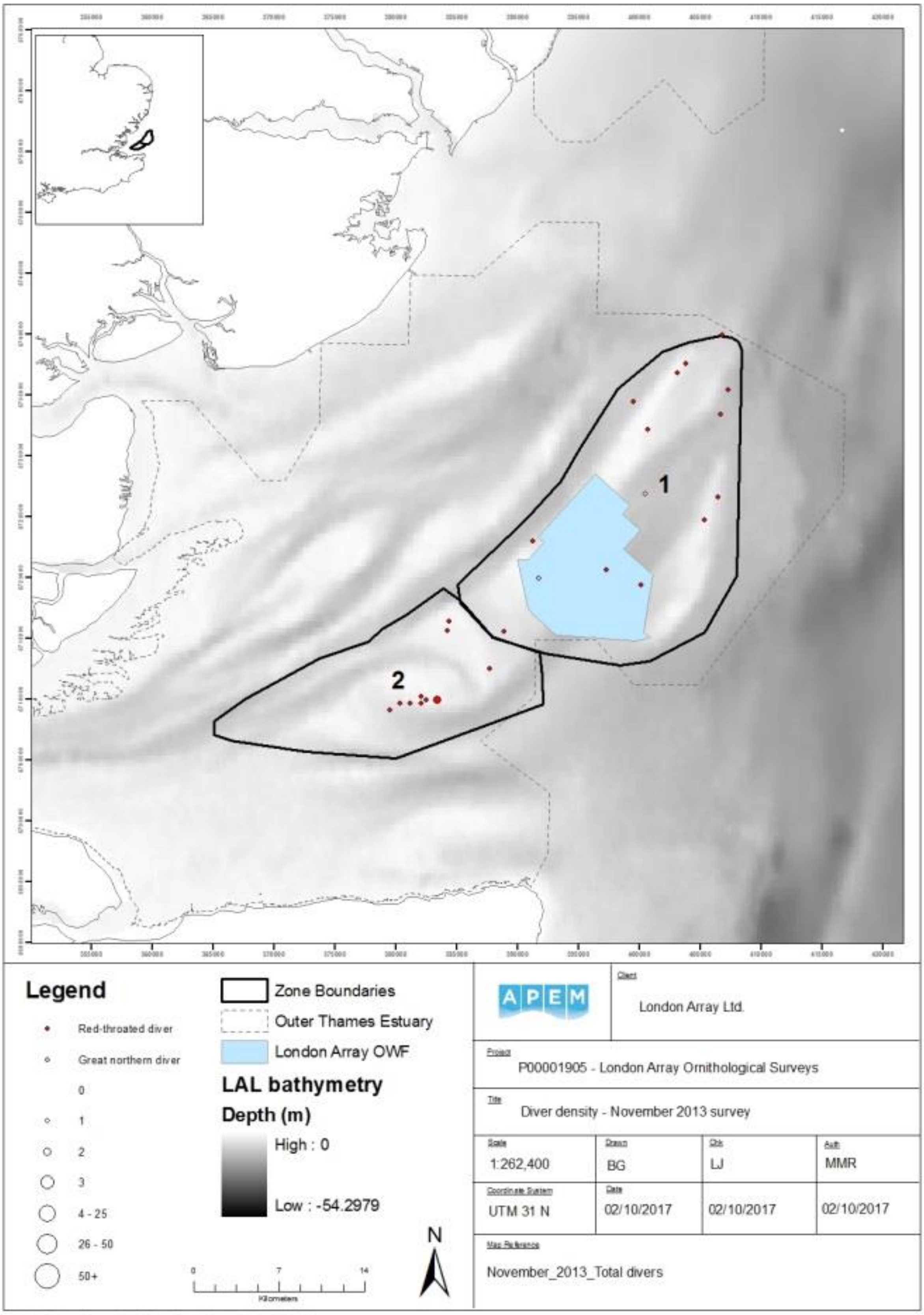

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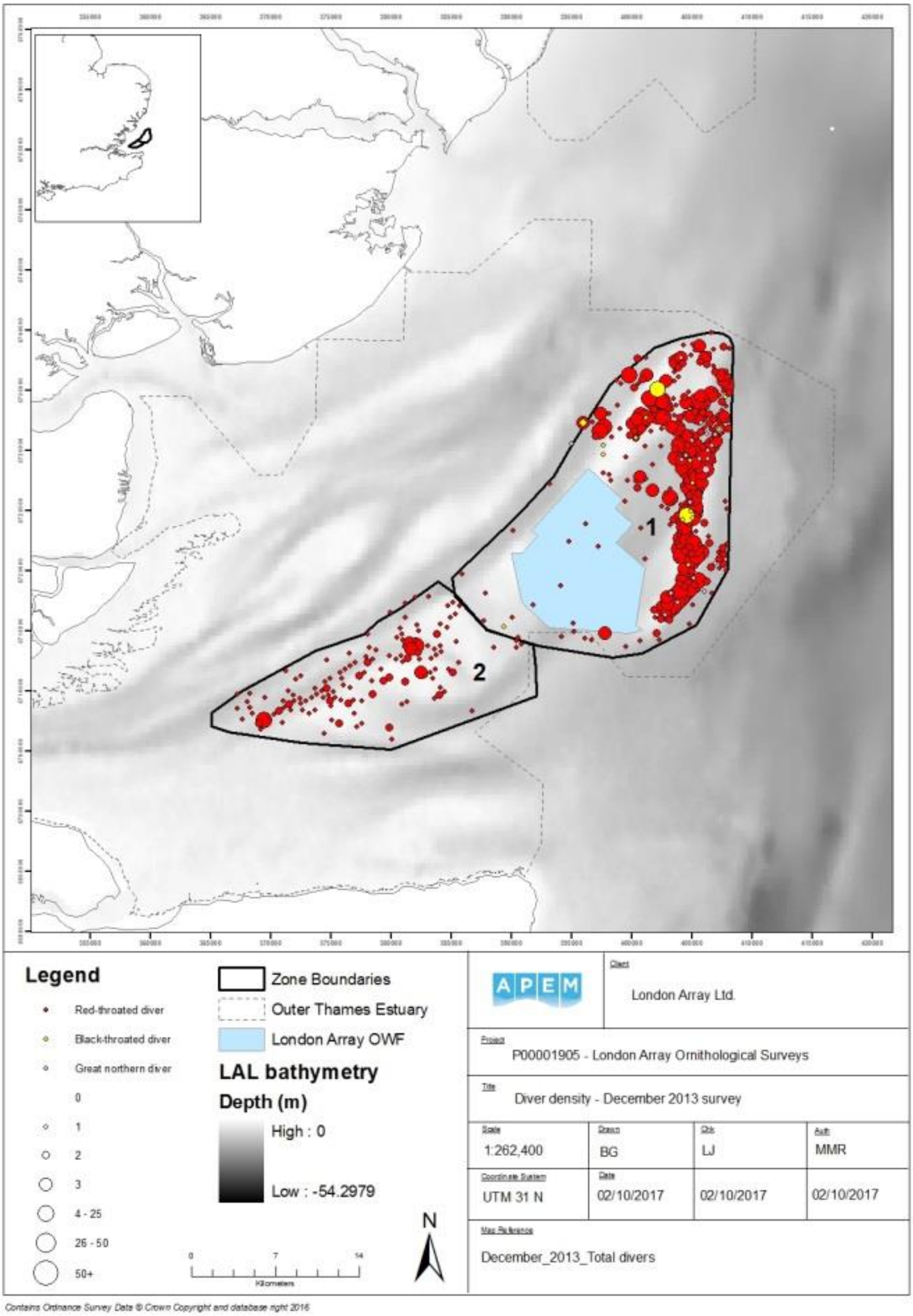

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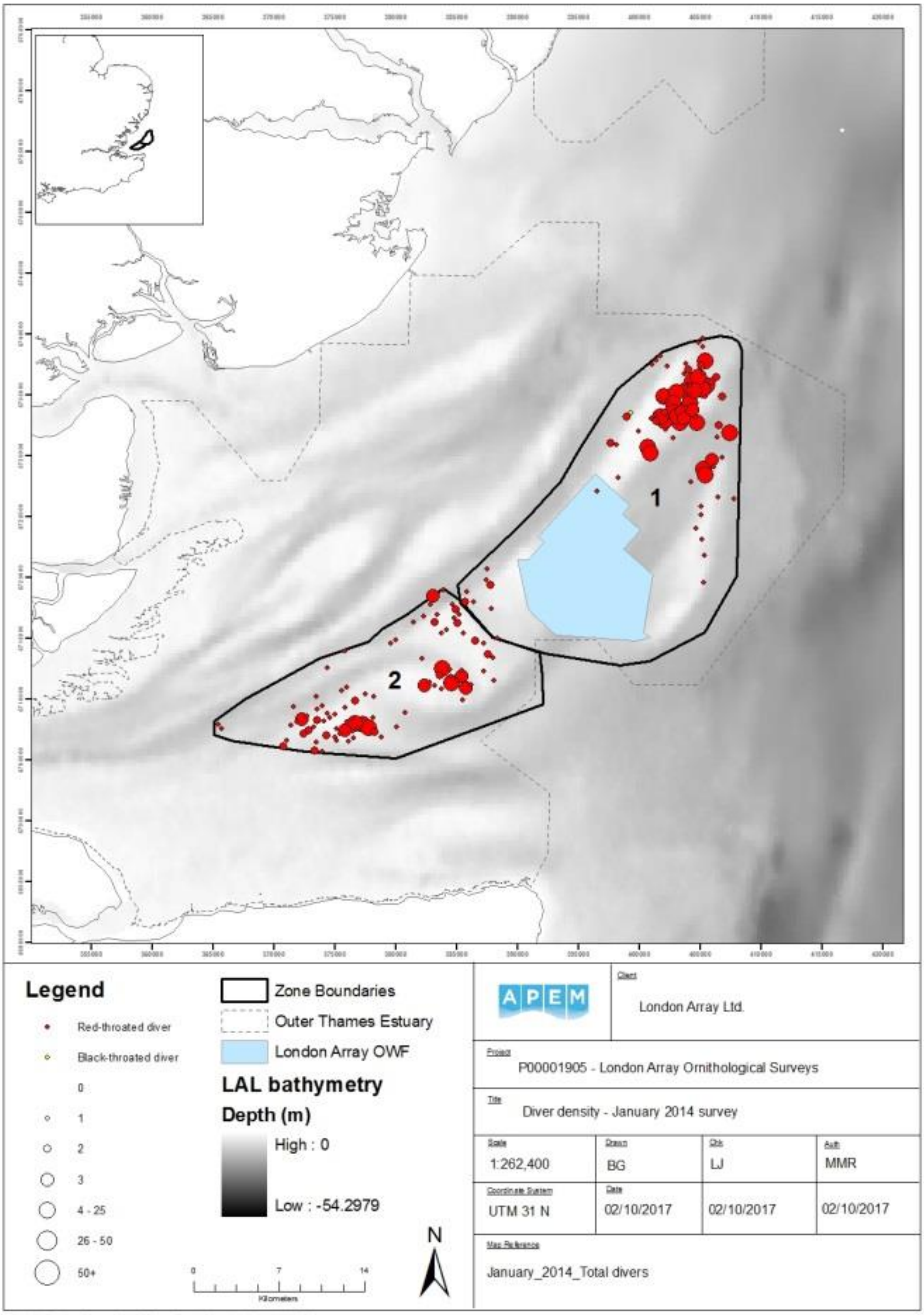

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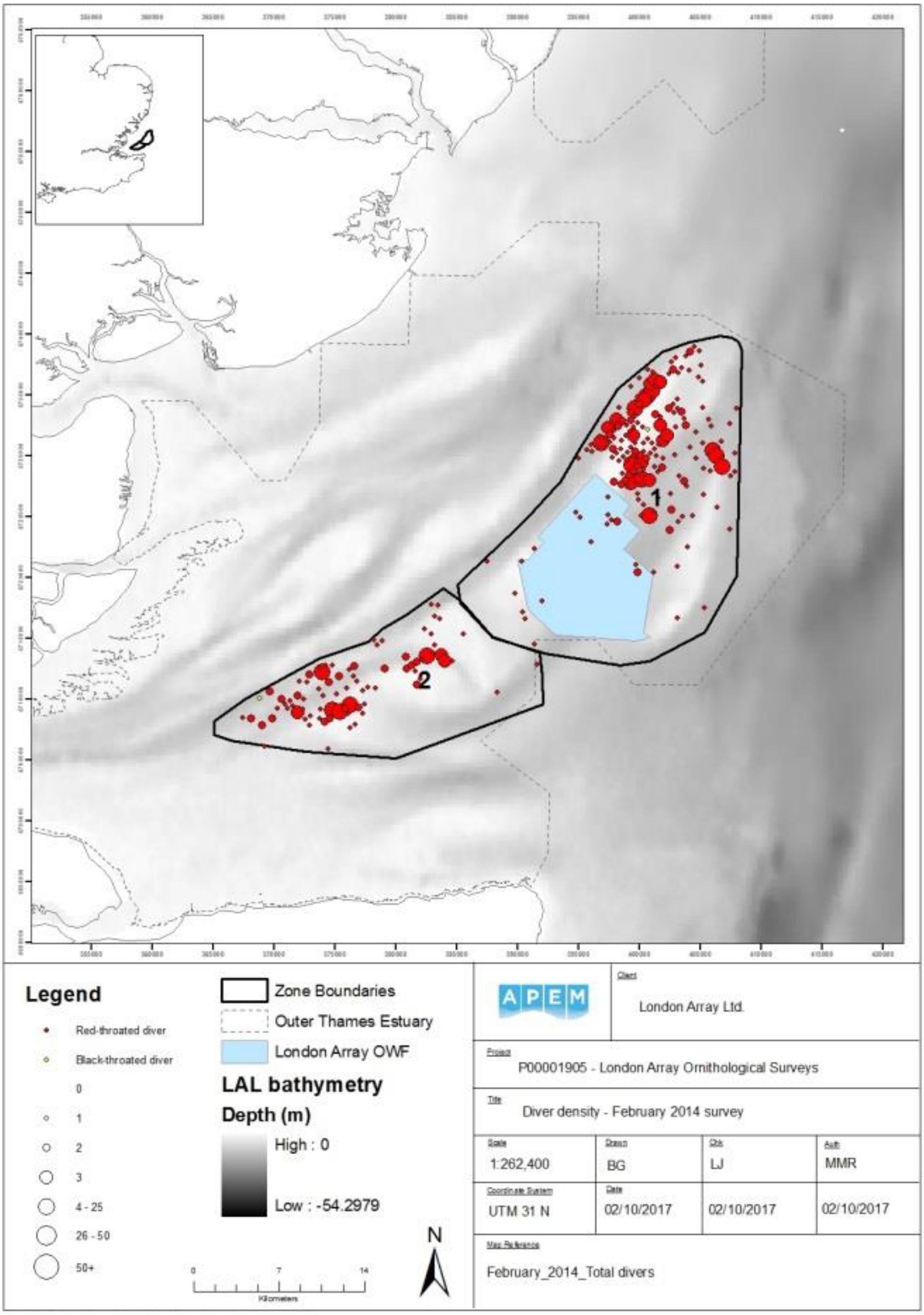

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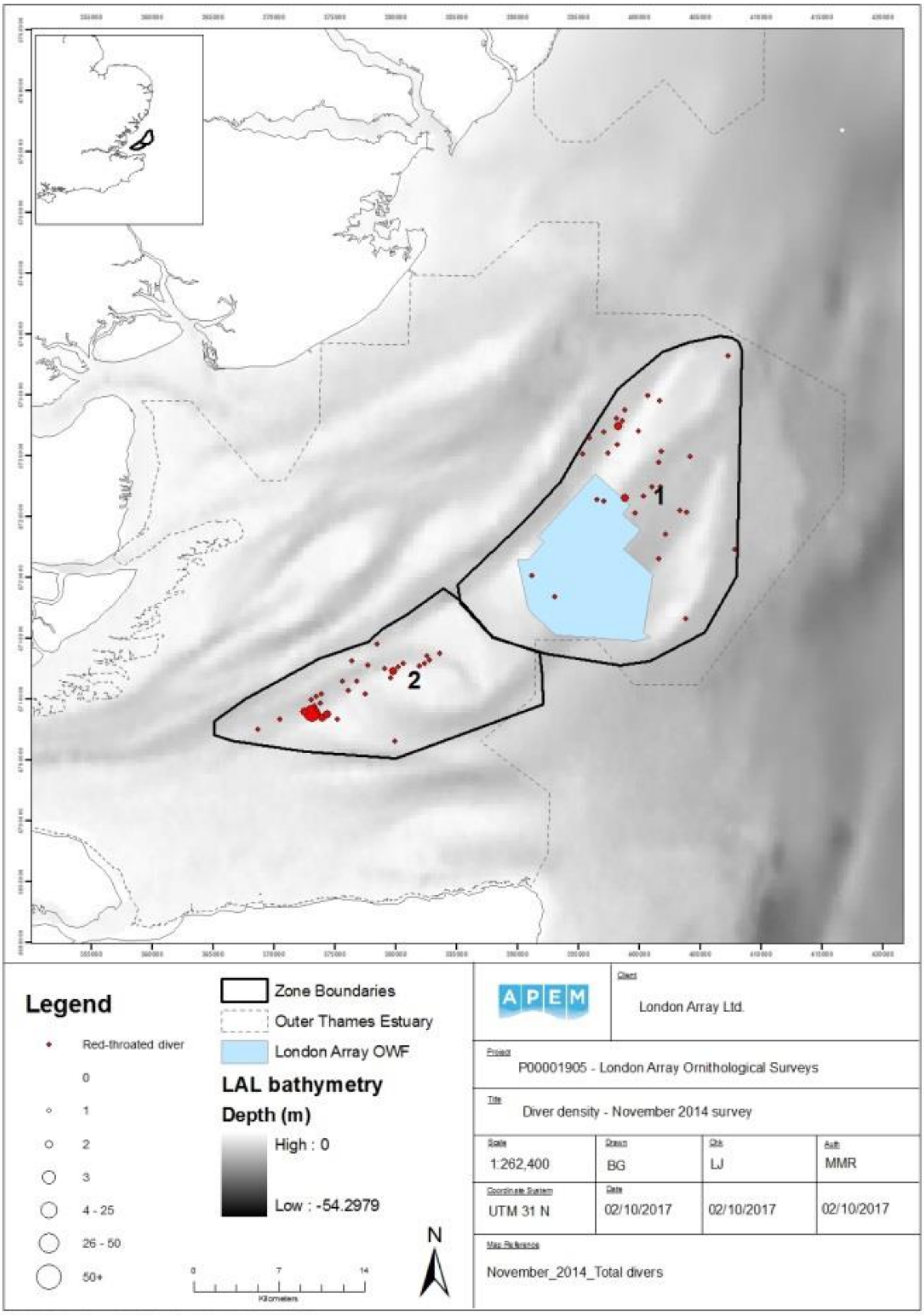

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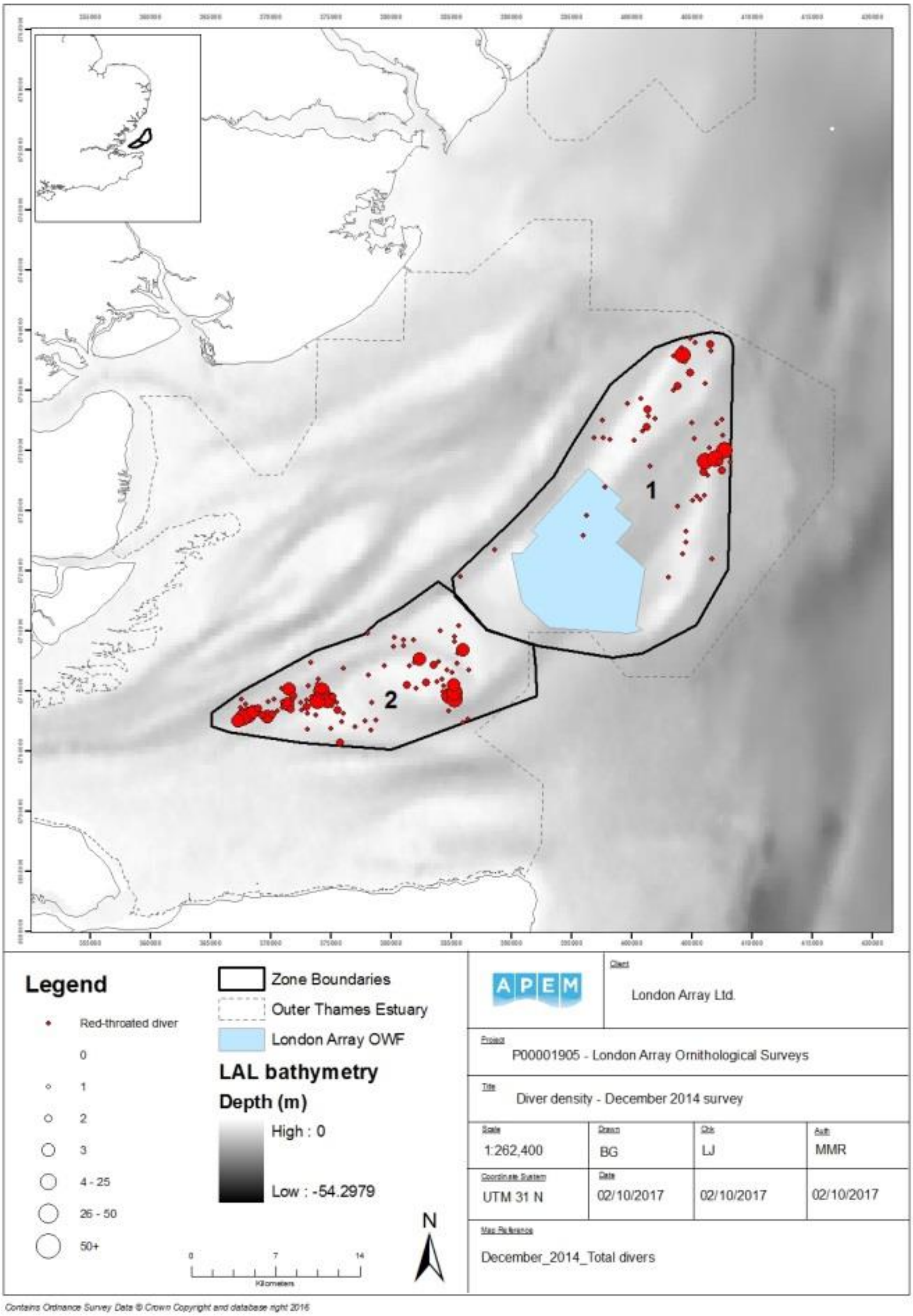

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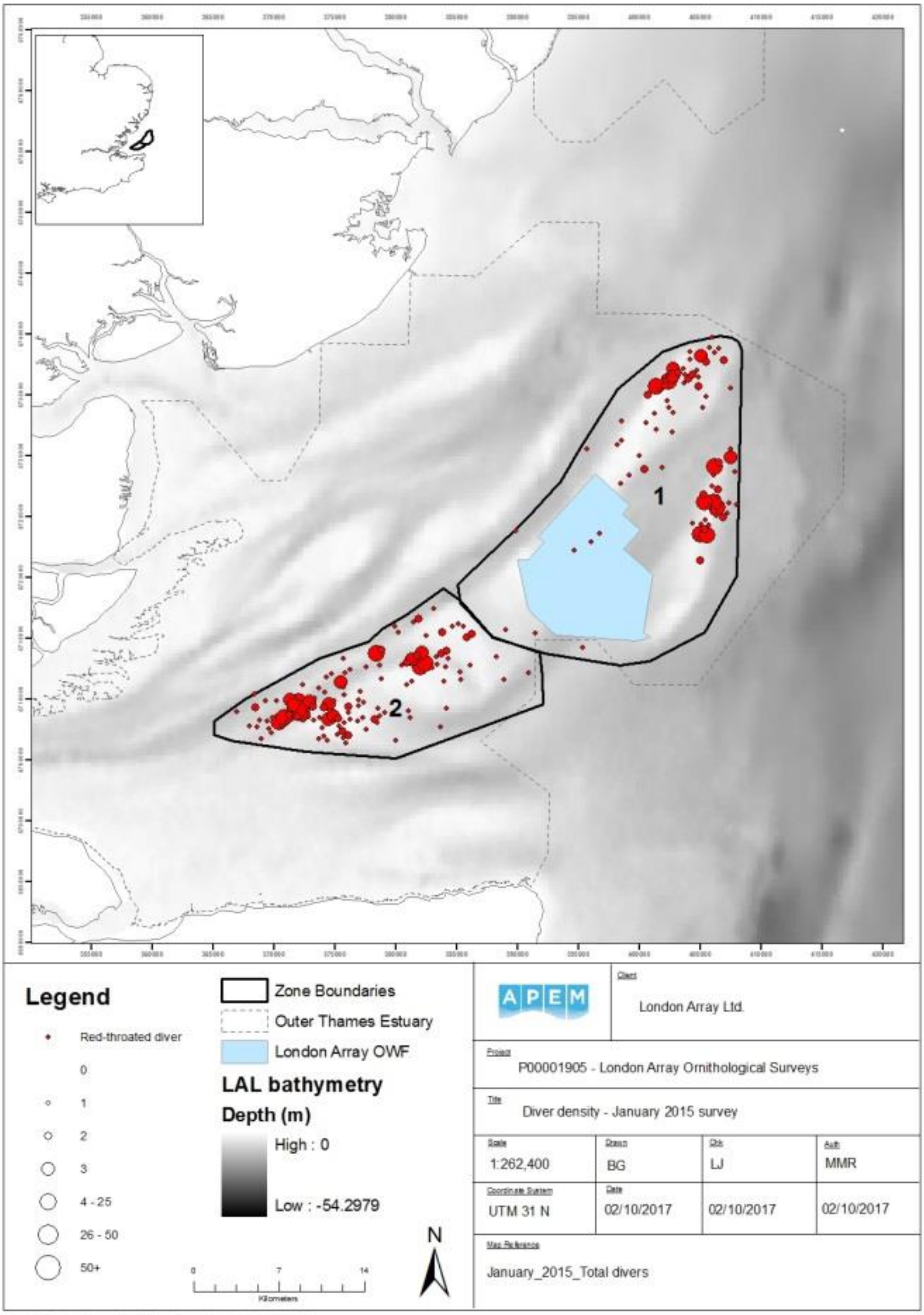

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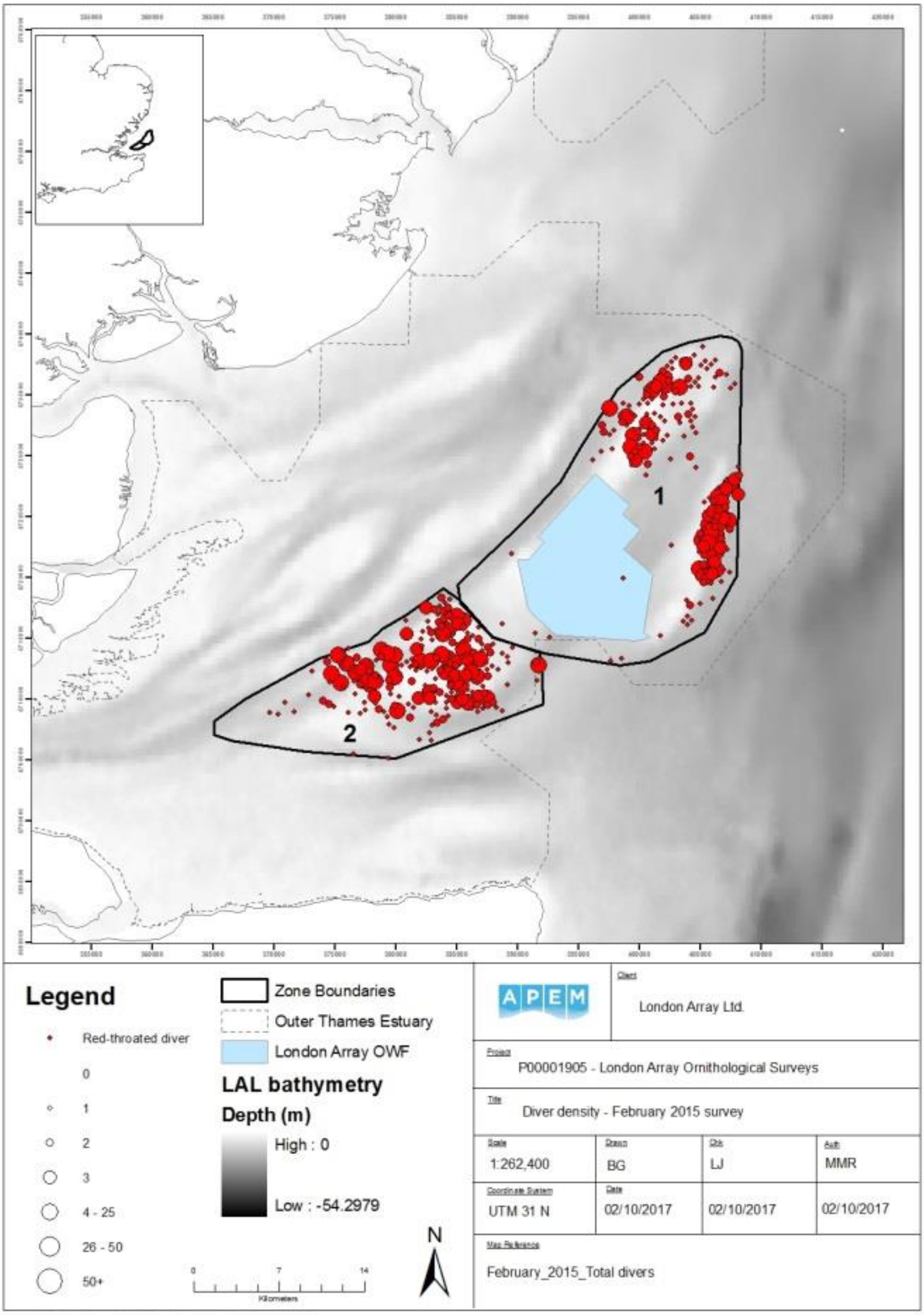

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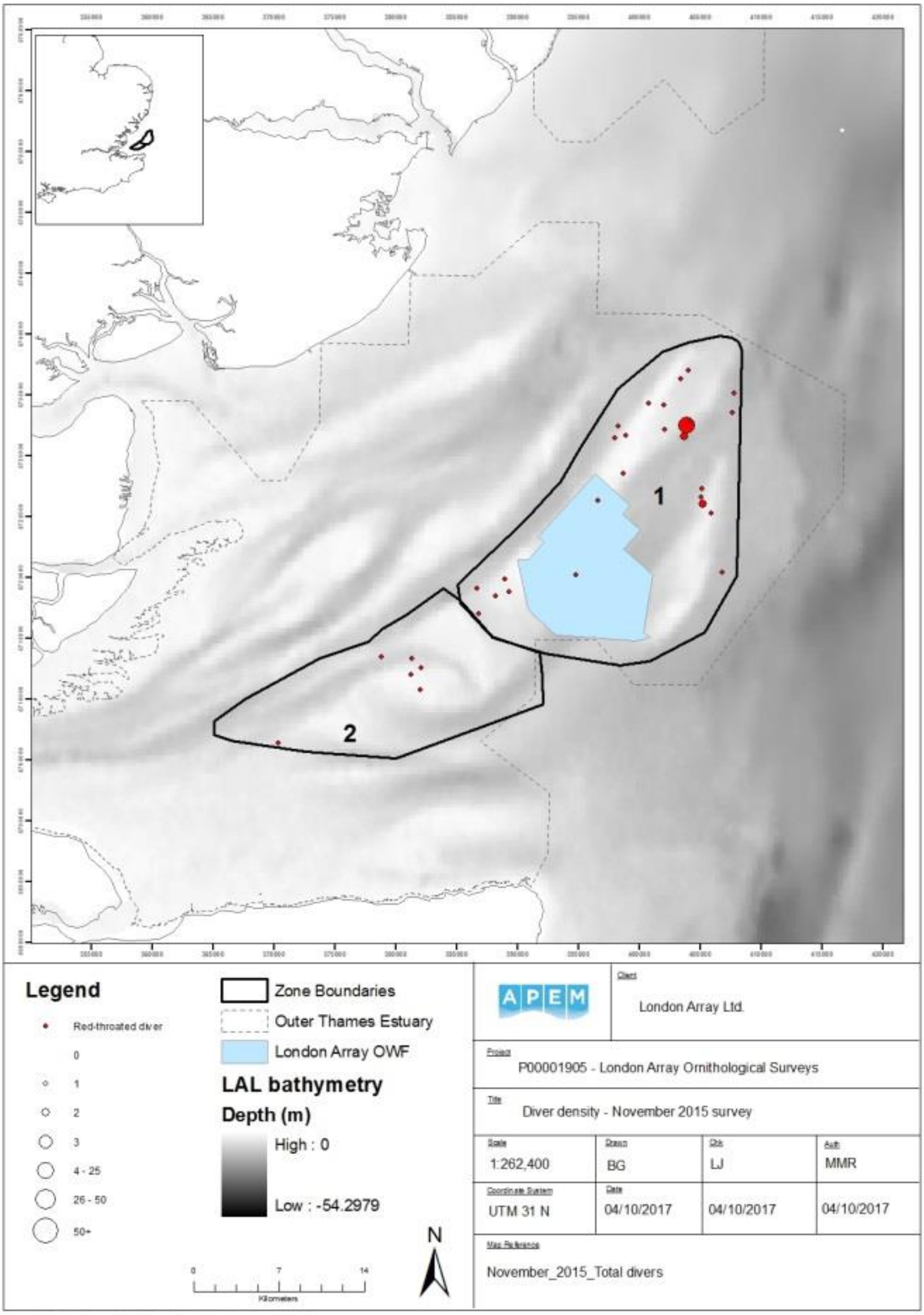

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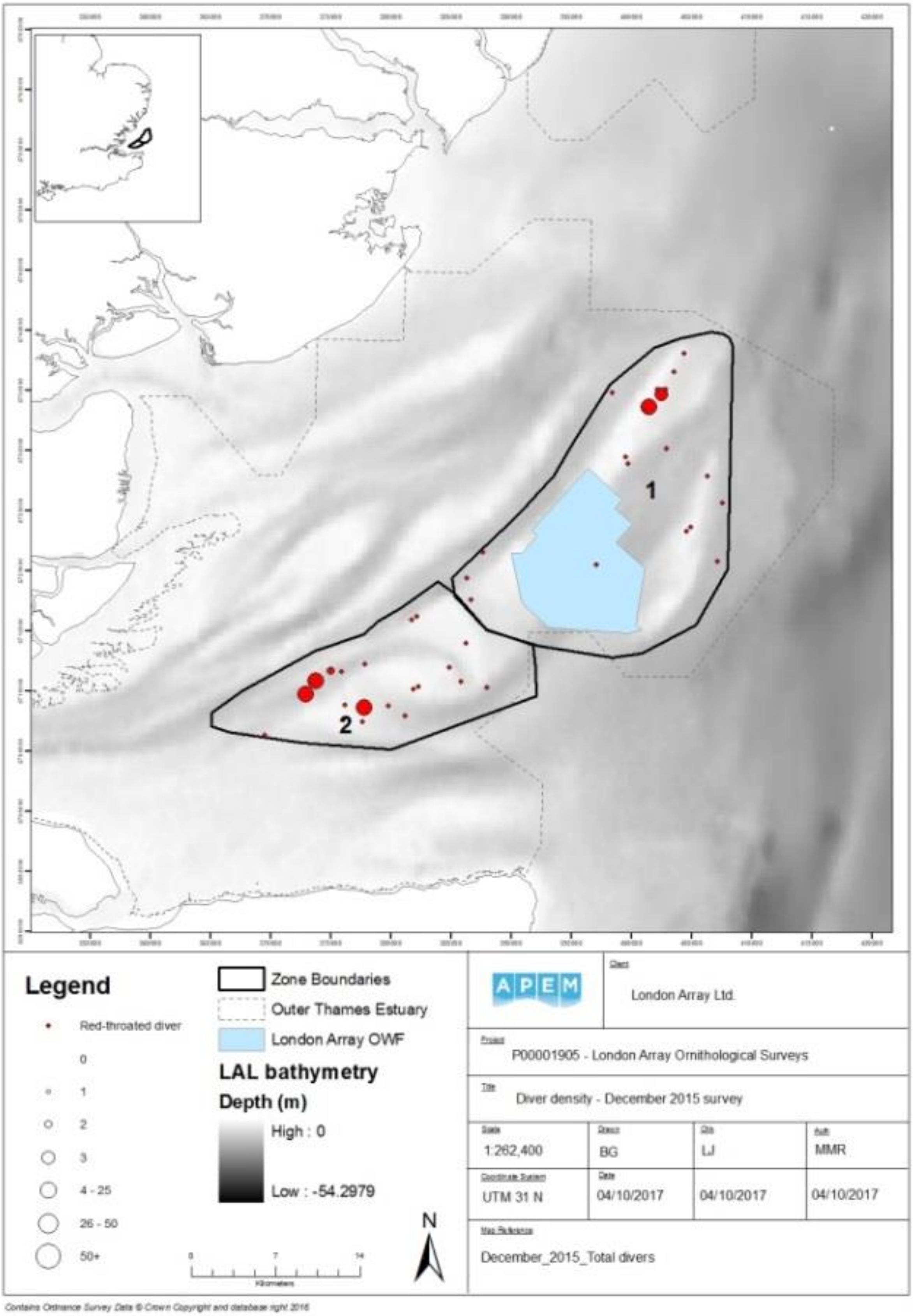

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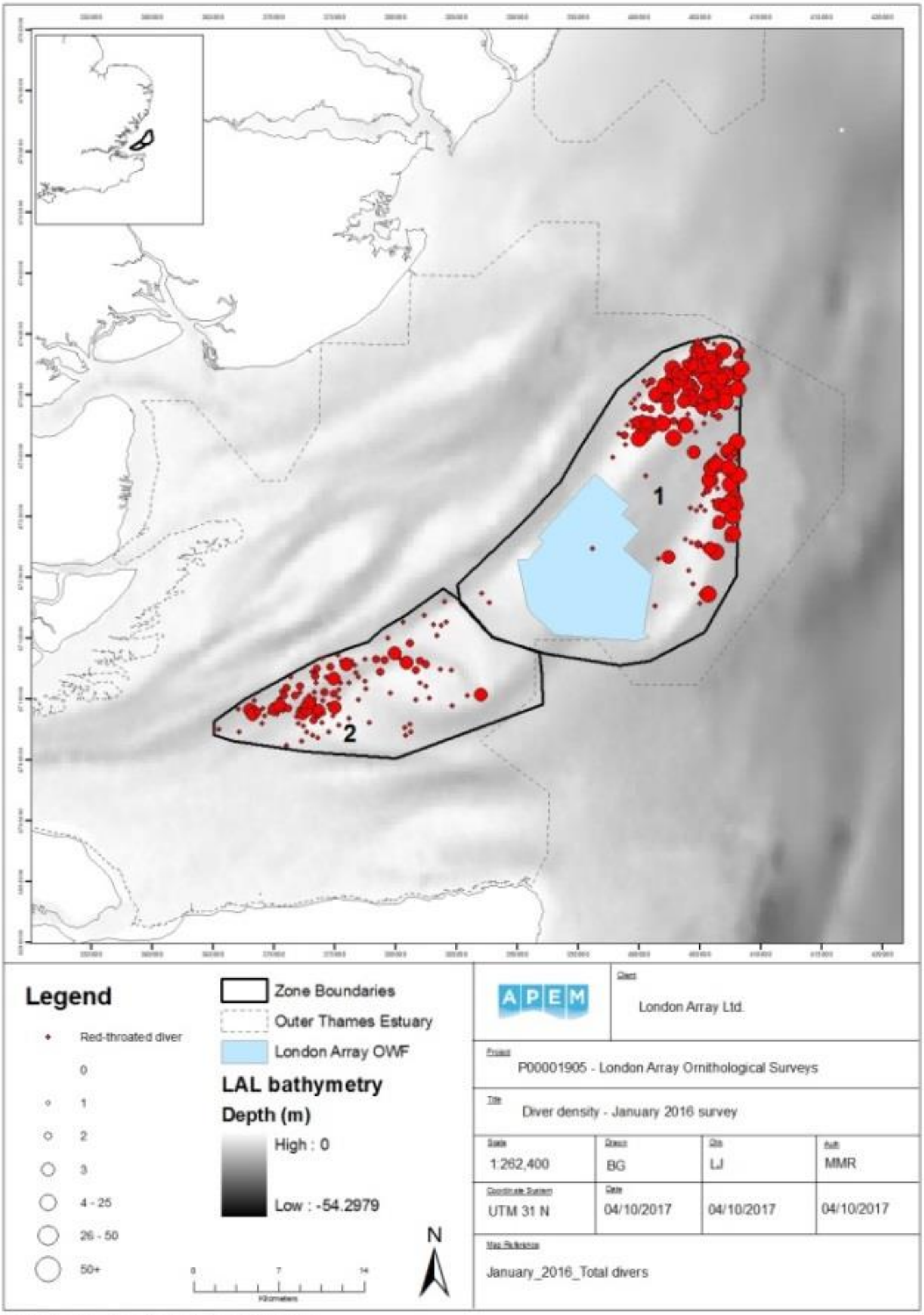

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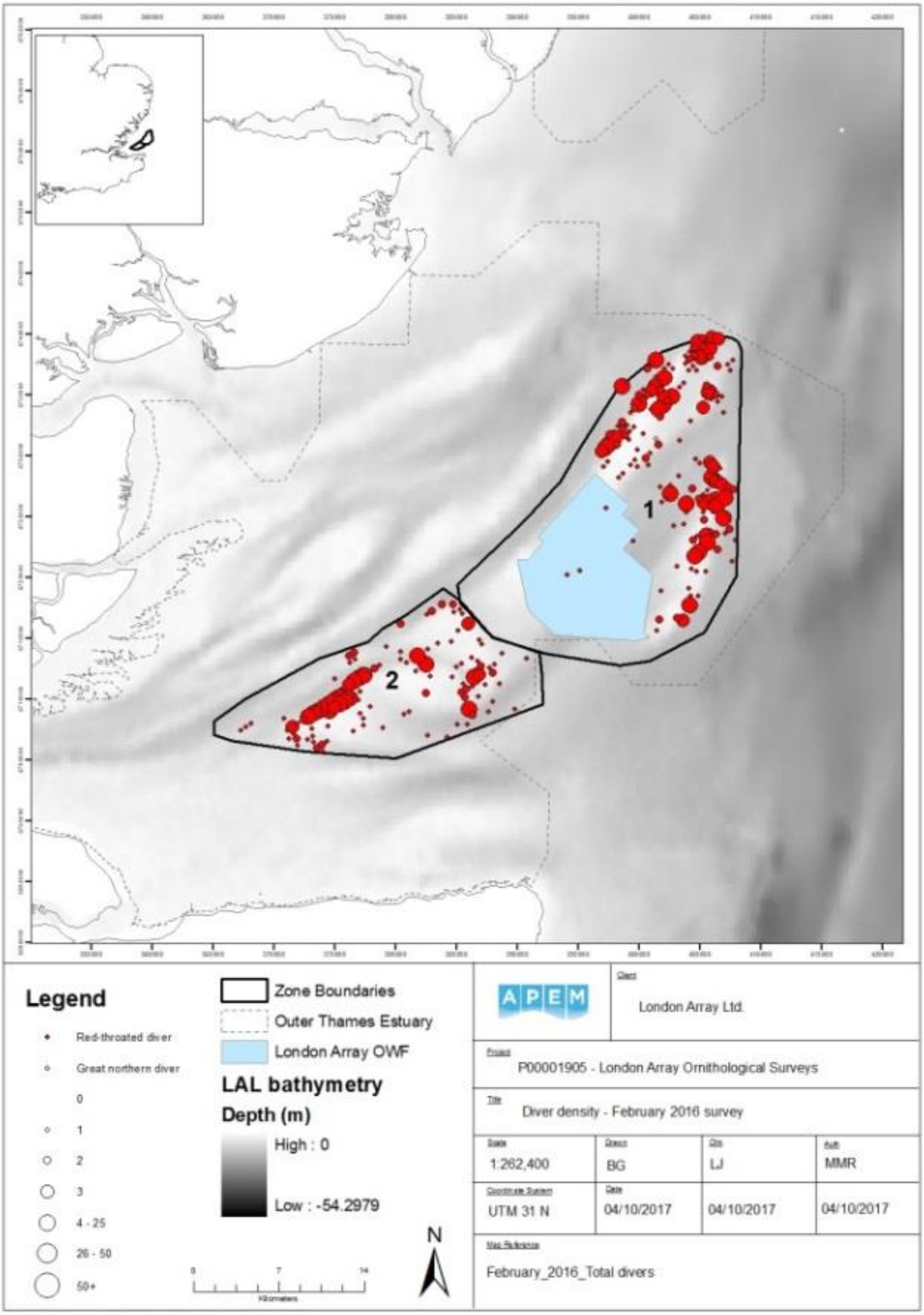
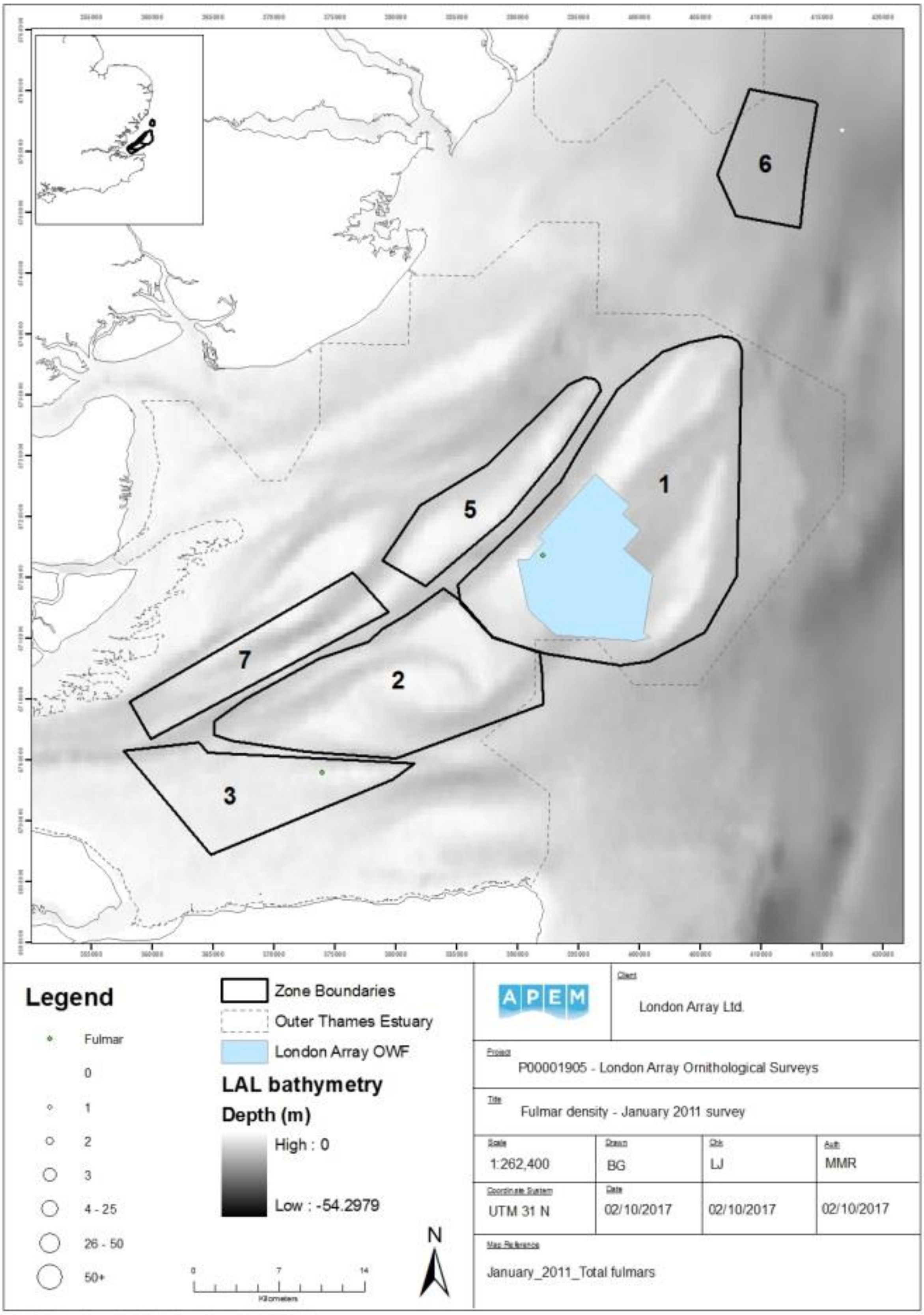


February 2016

Figure 2 Monthly distribution maps for divers recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Fulmar



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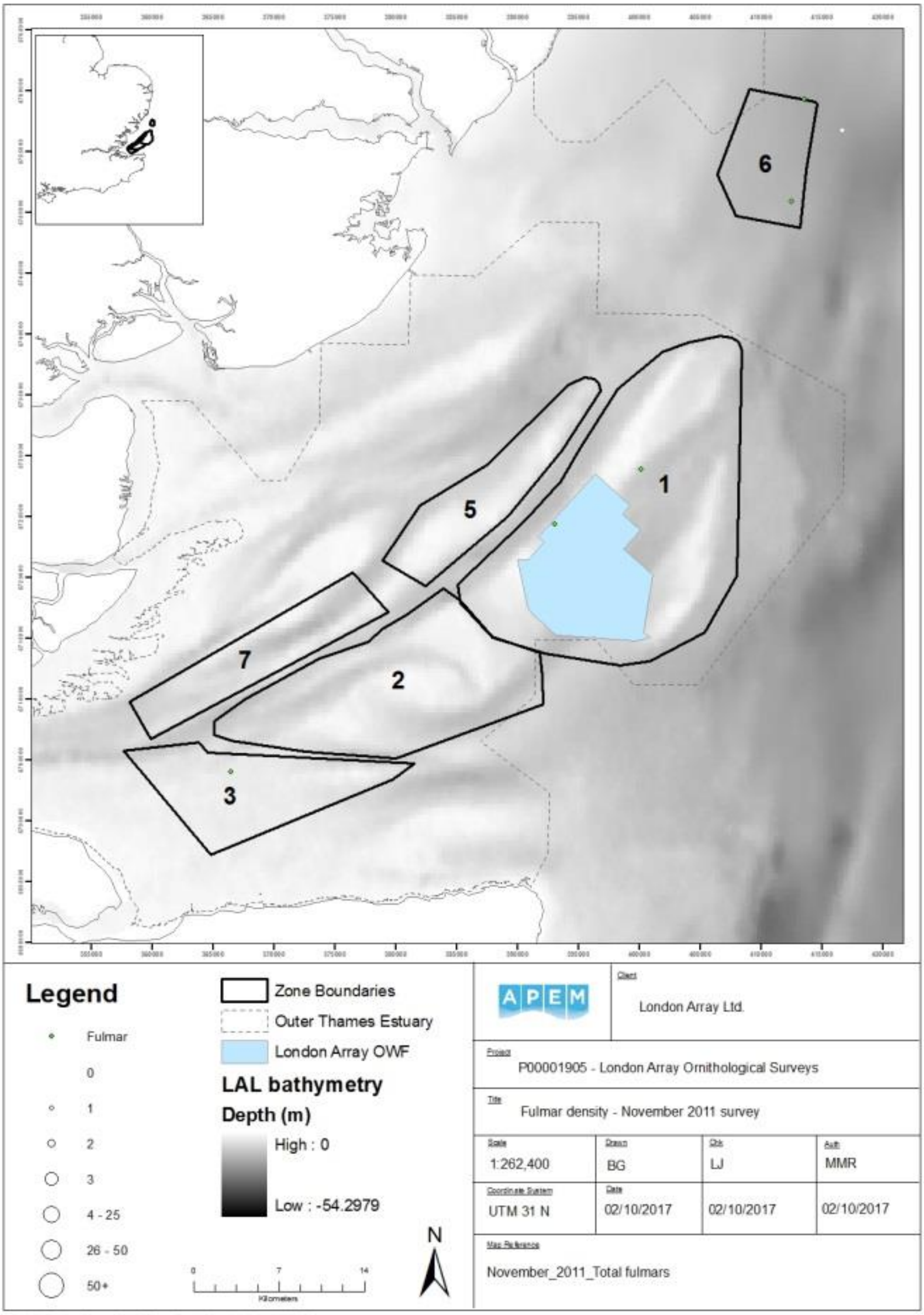

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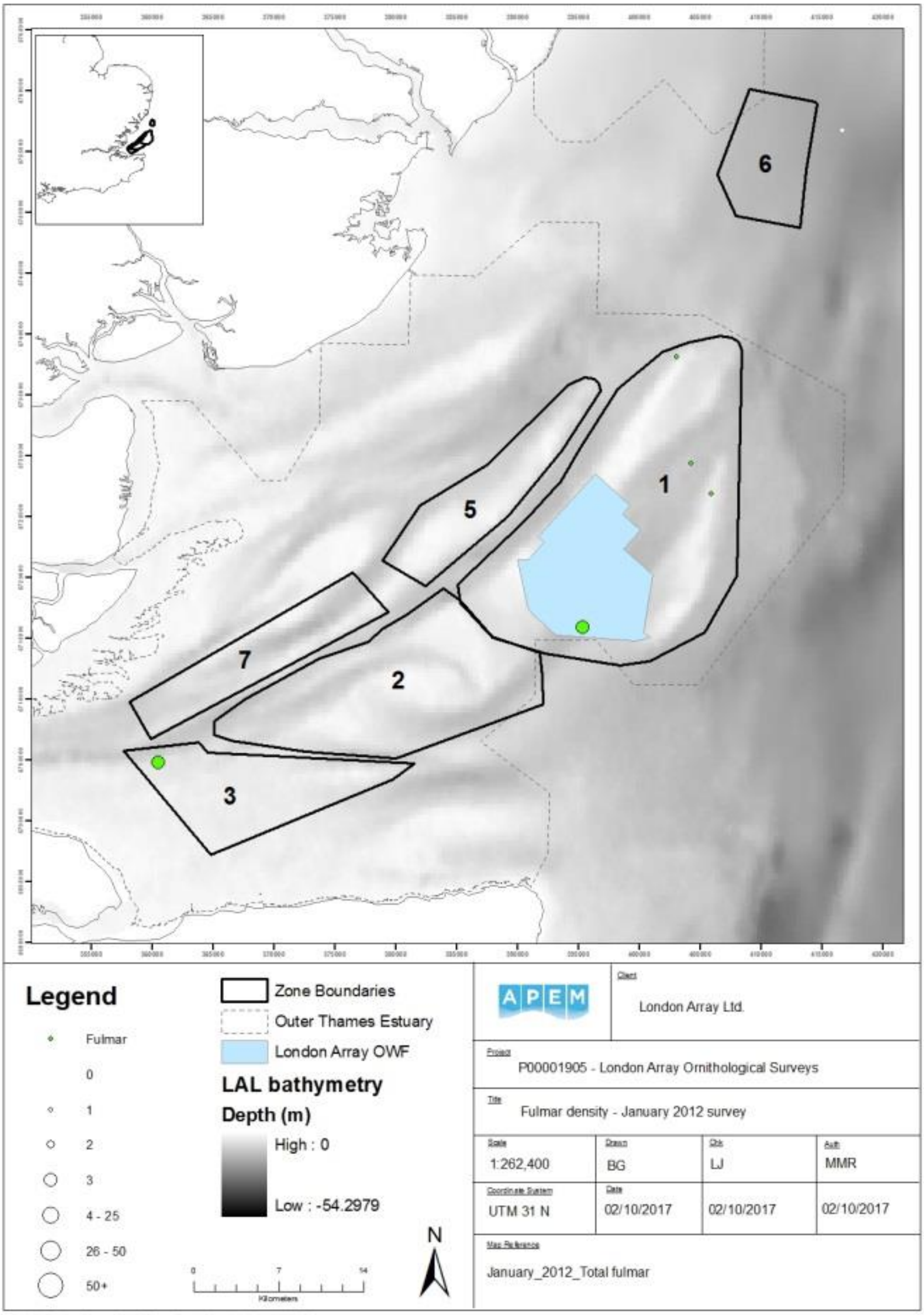

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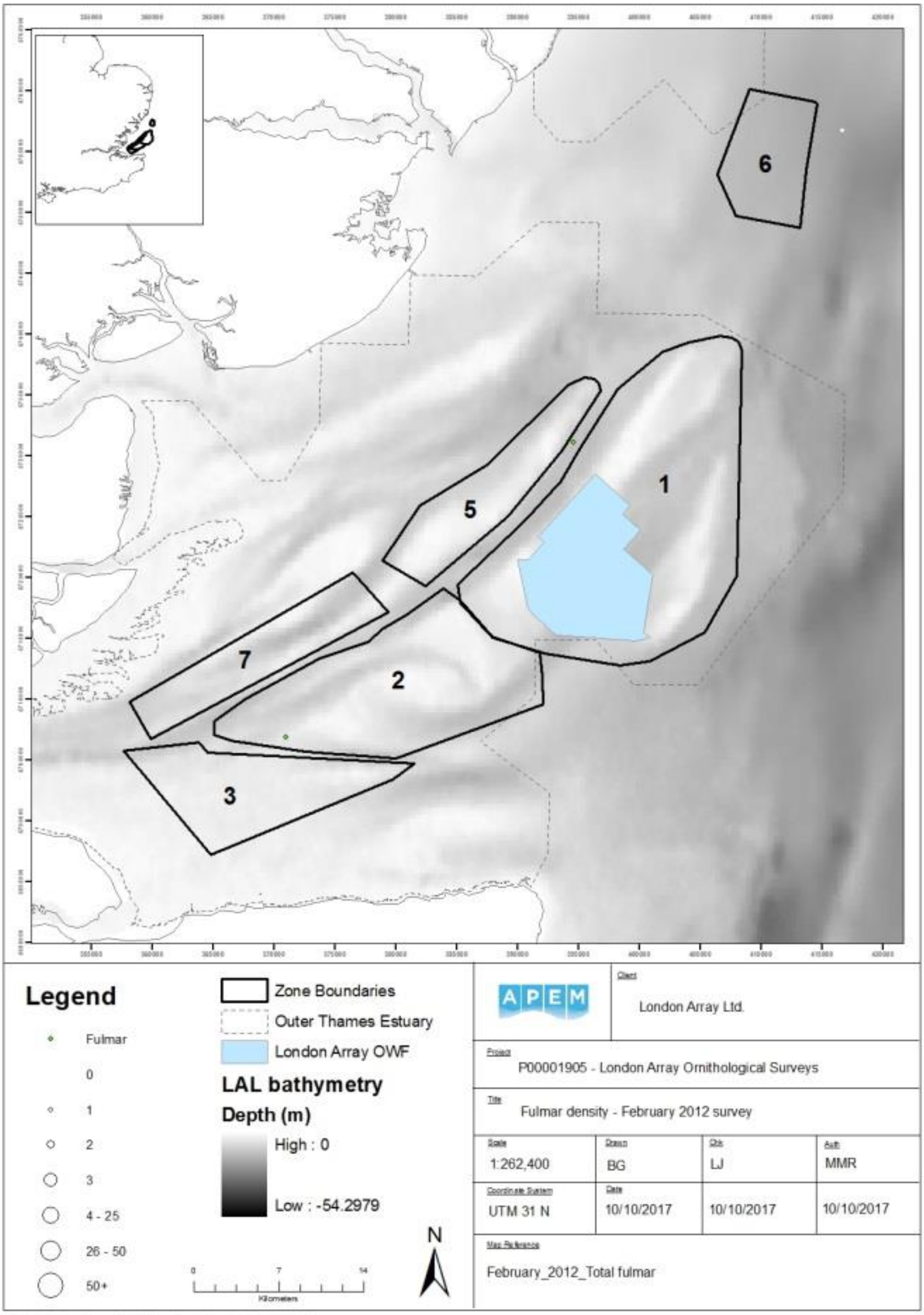

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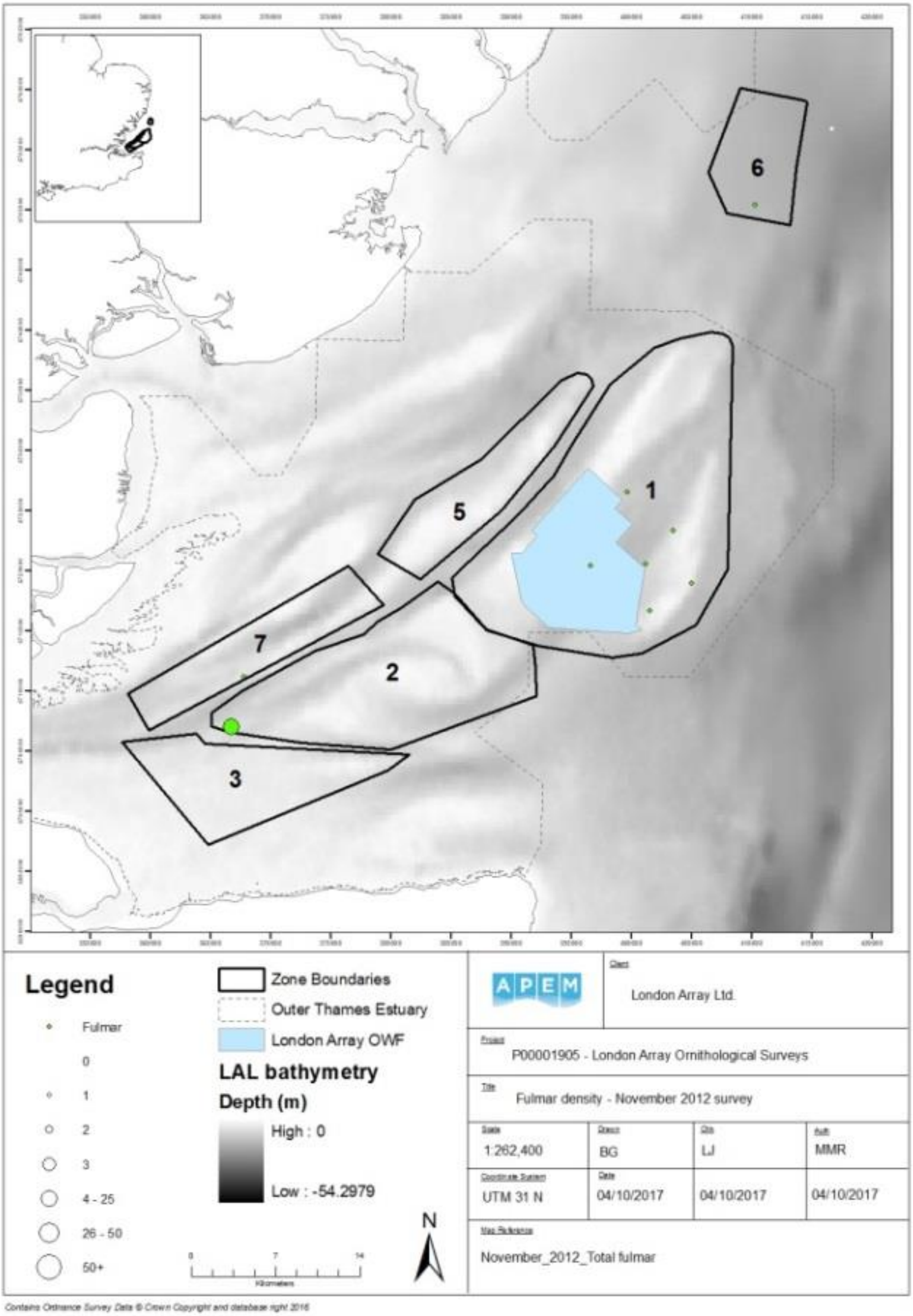

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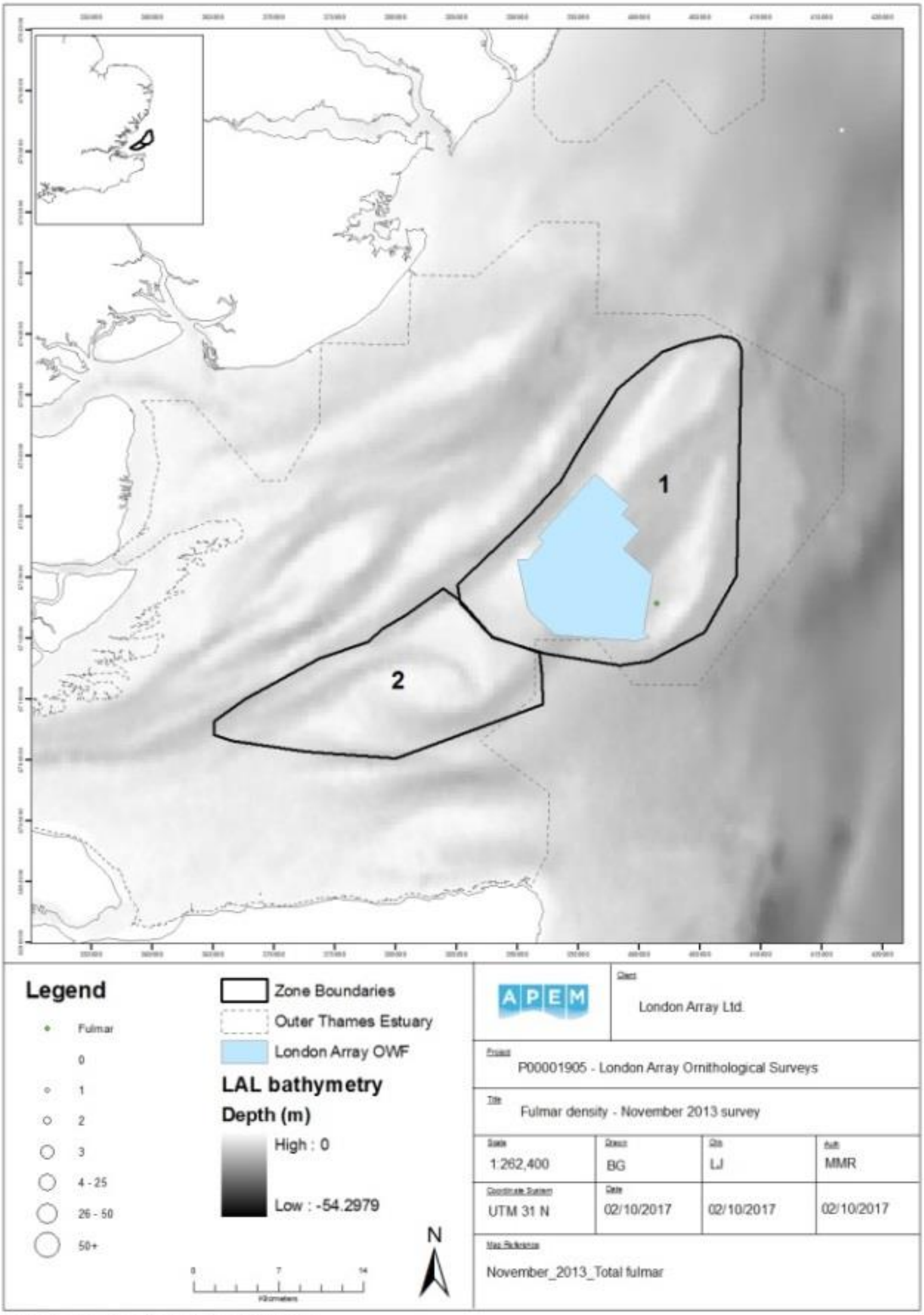

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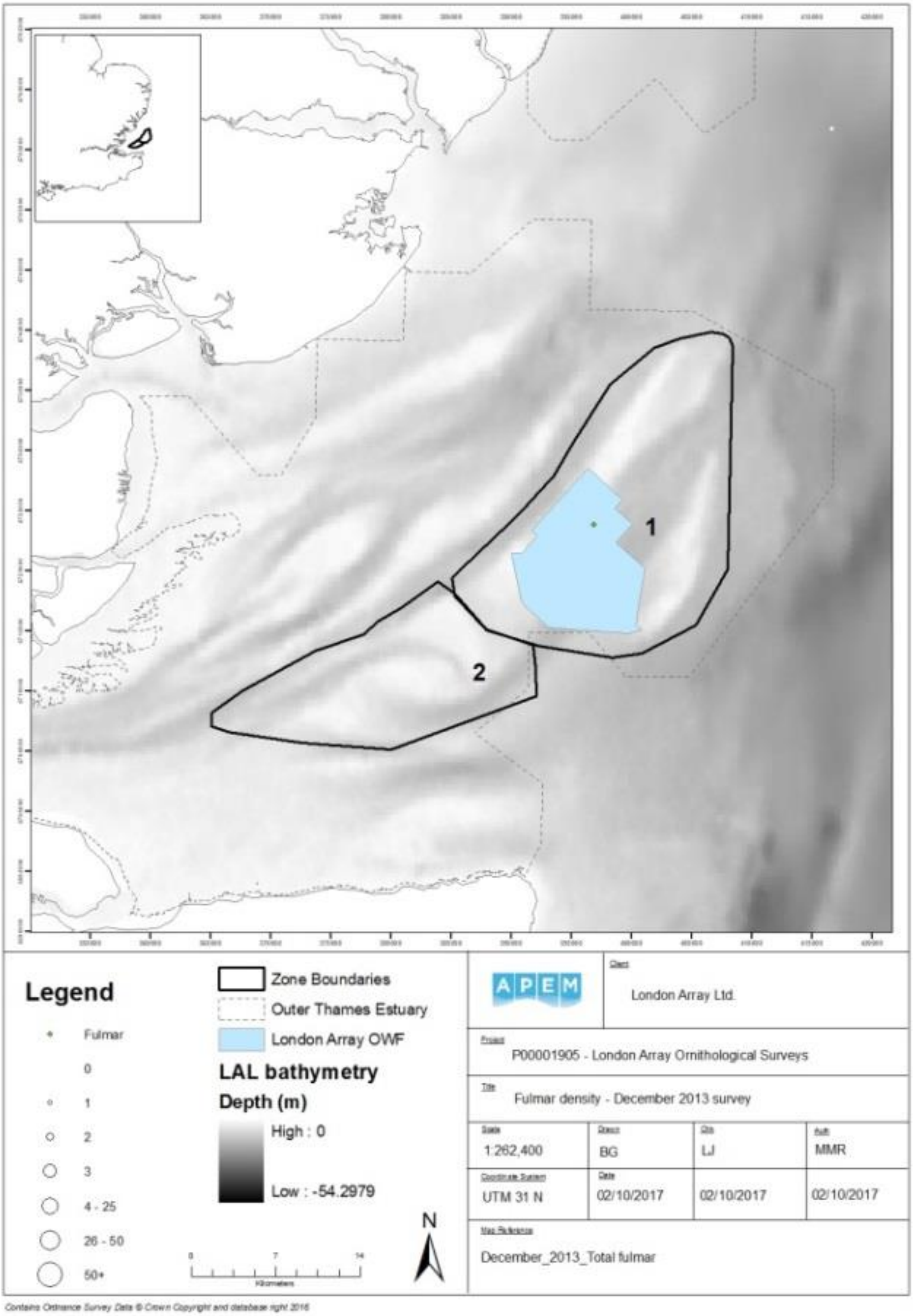

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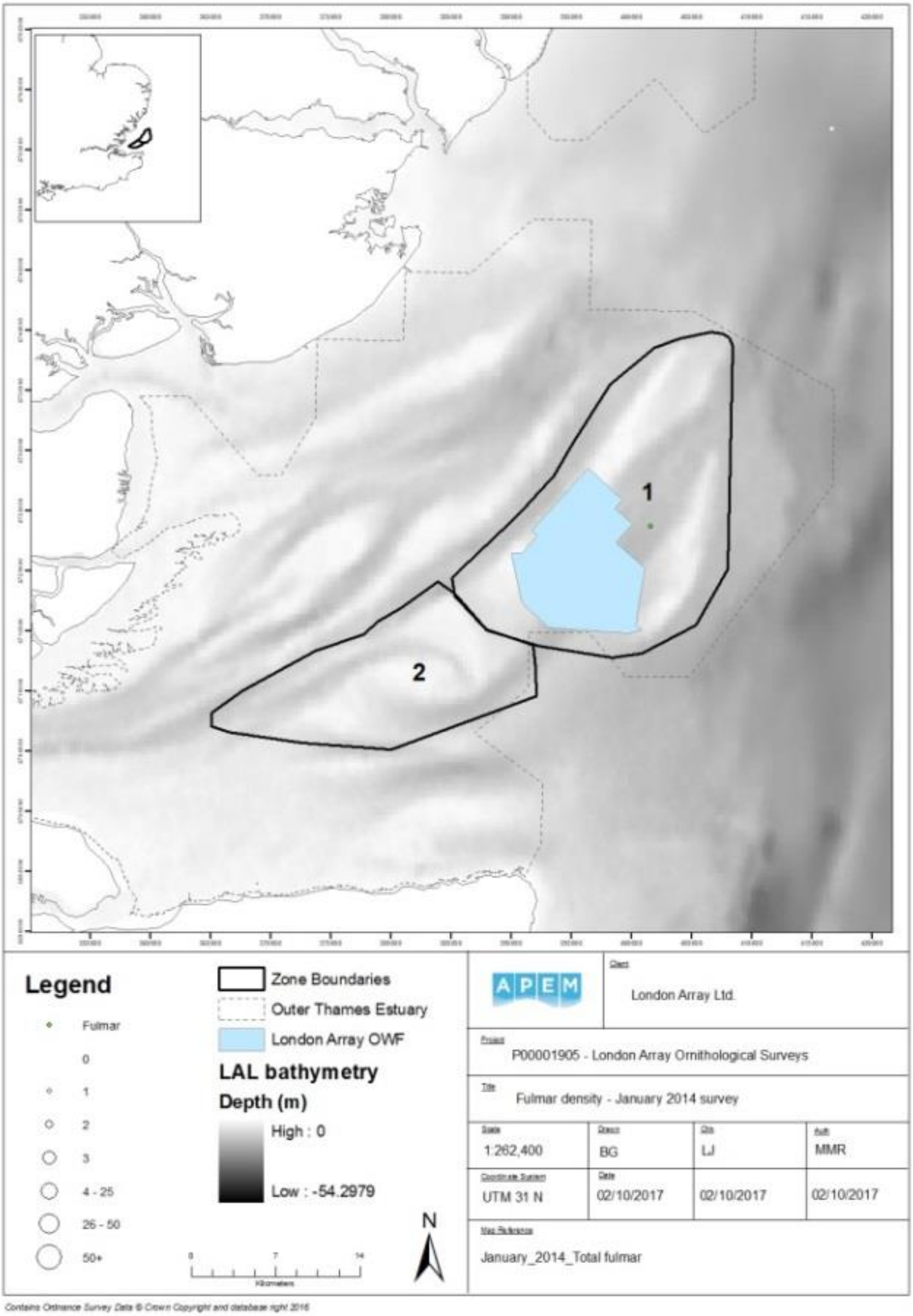
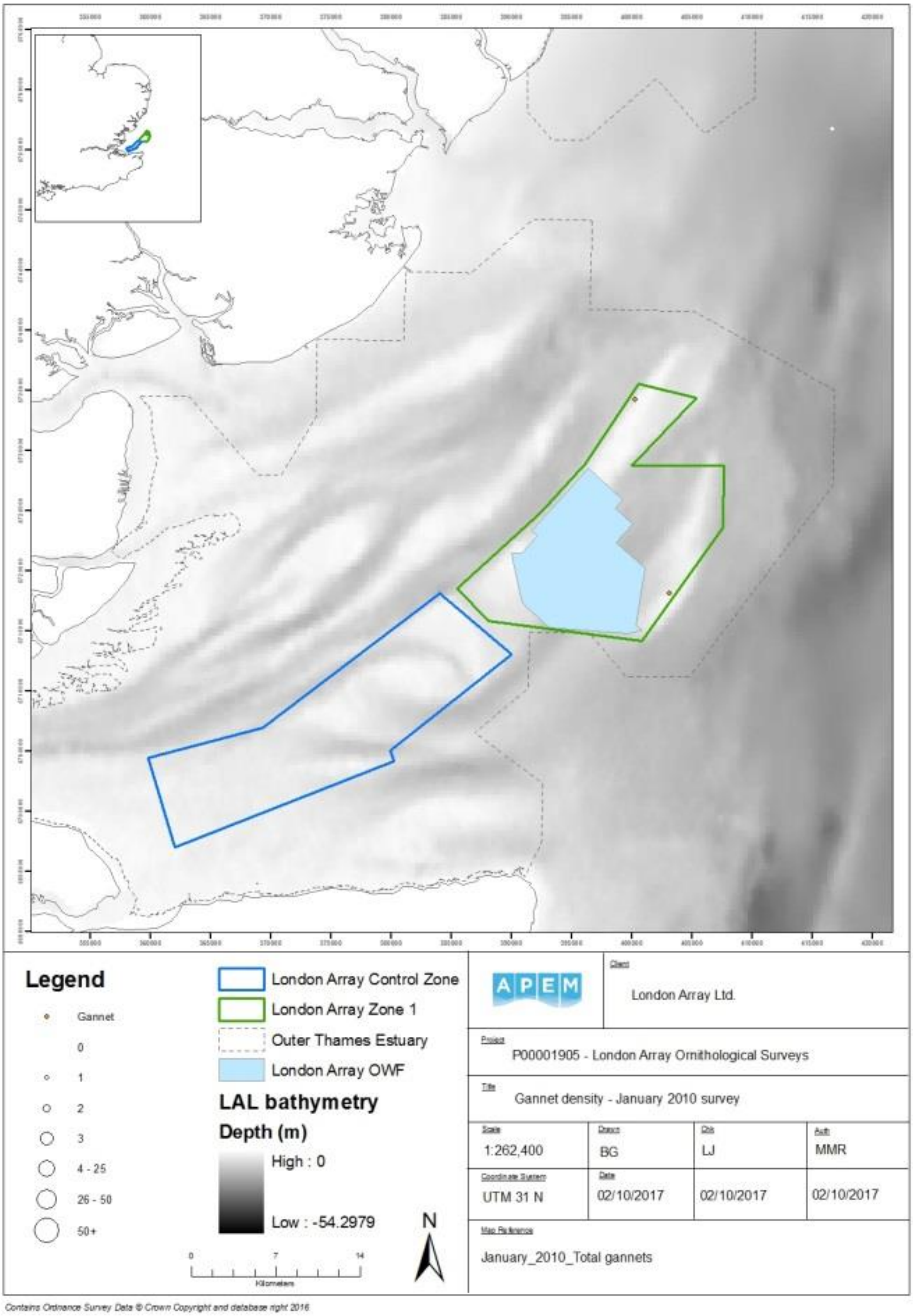


January 2014

Figure 3 Monthly distribution maps for fulmar recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Gannet



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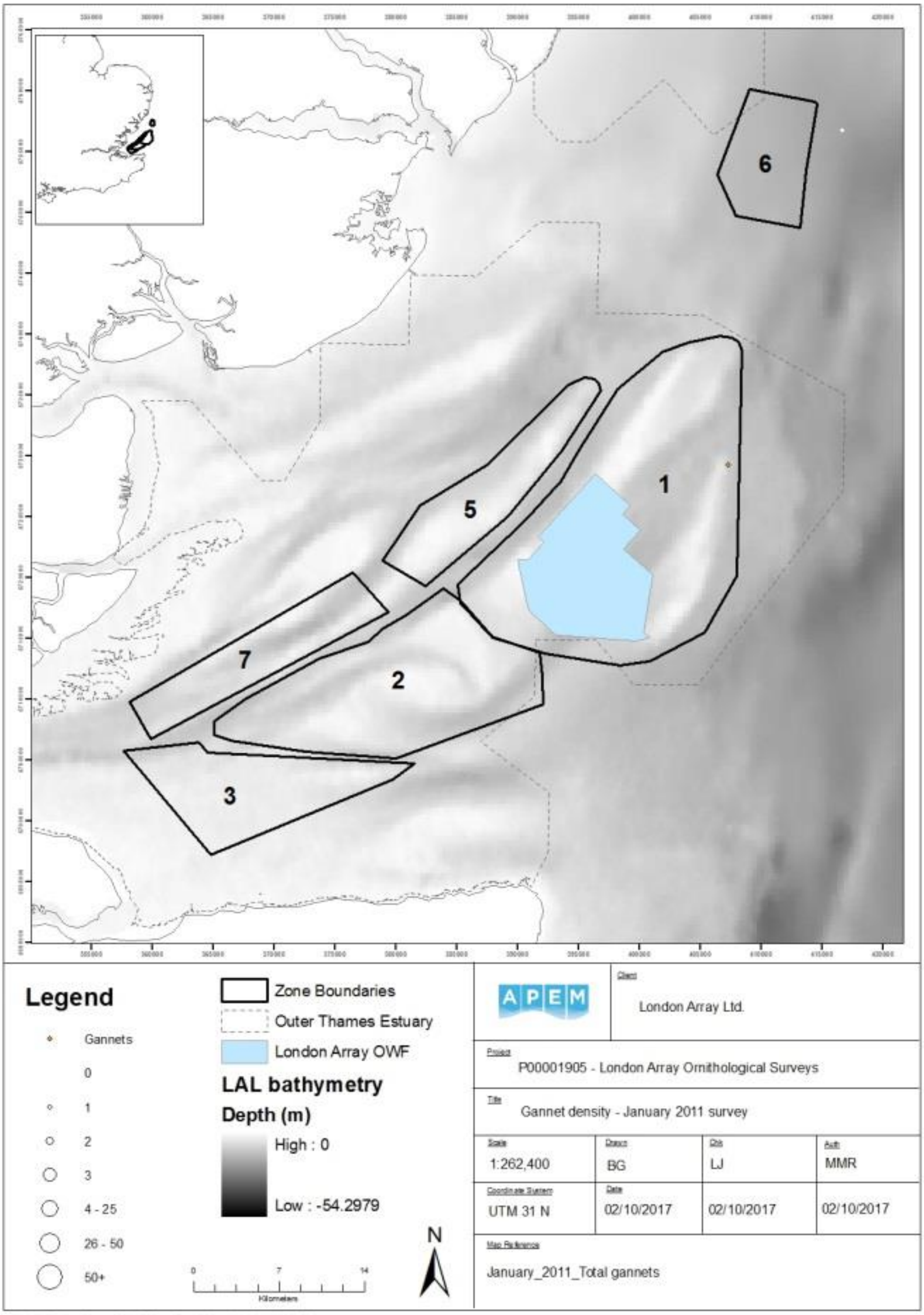

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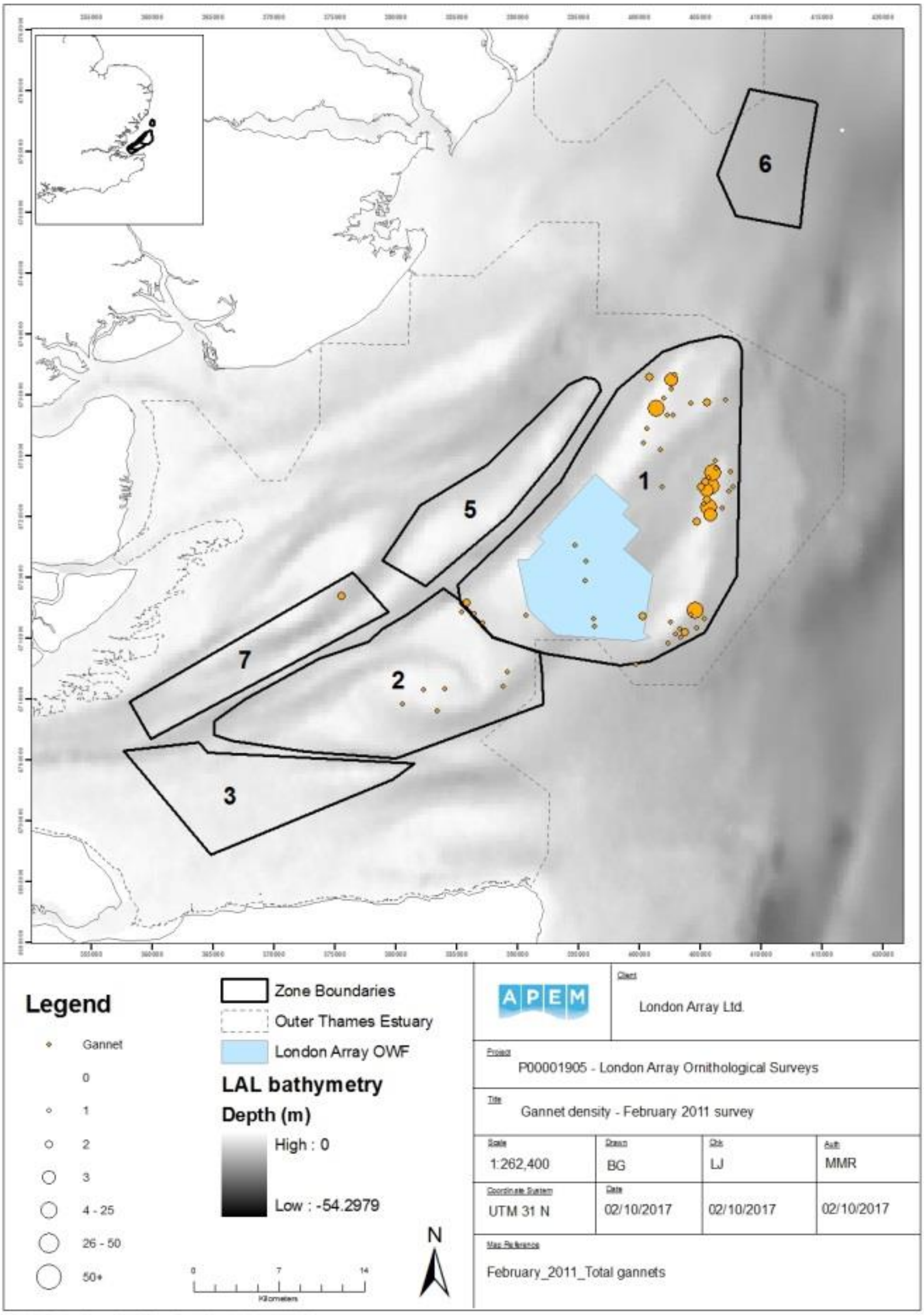

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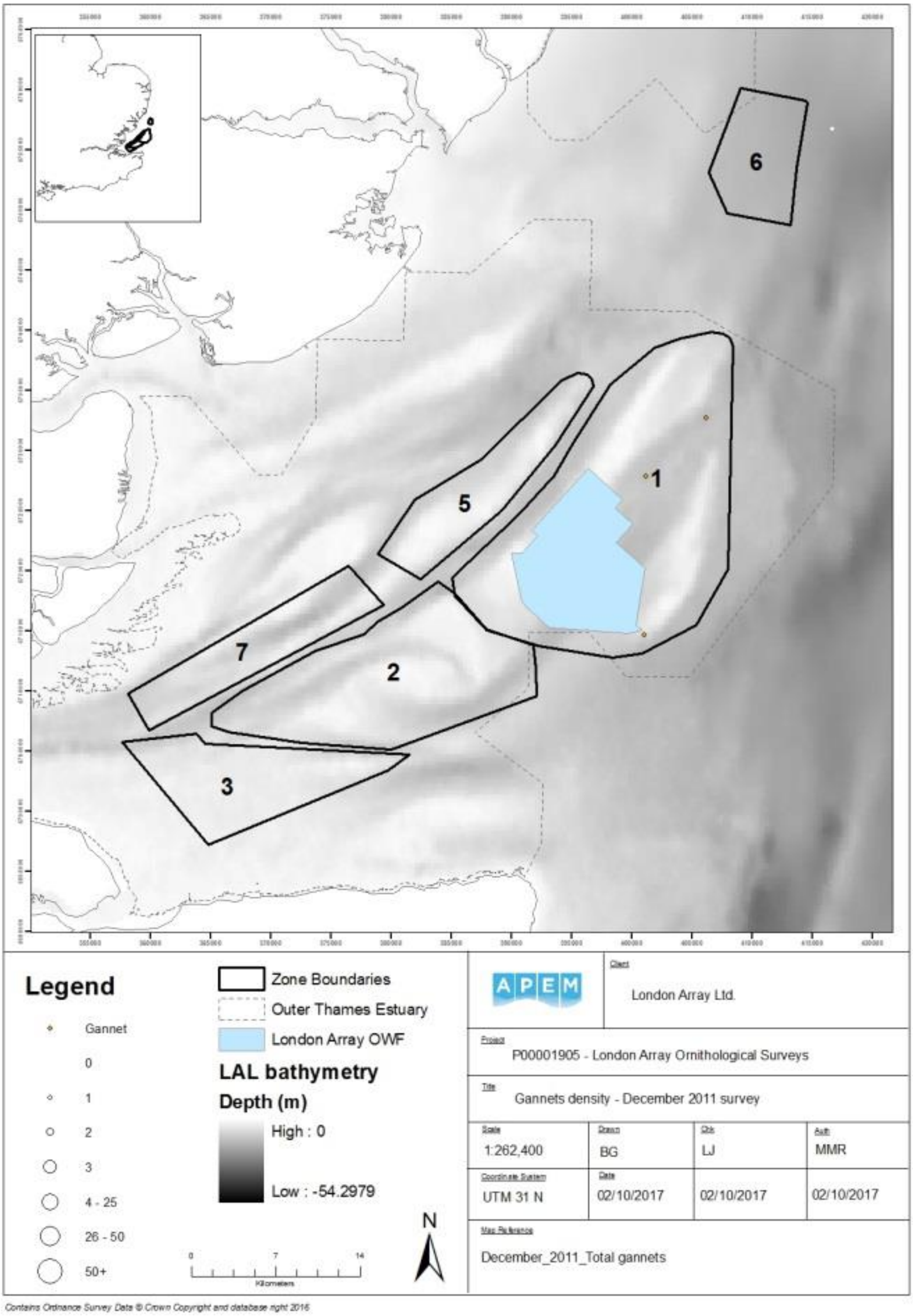

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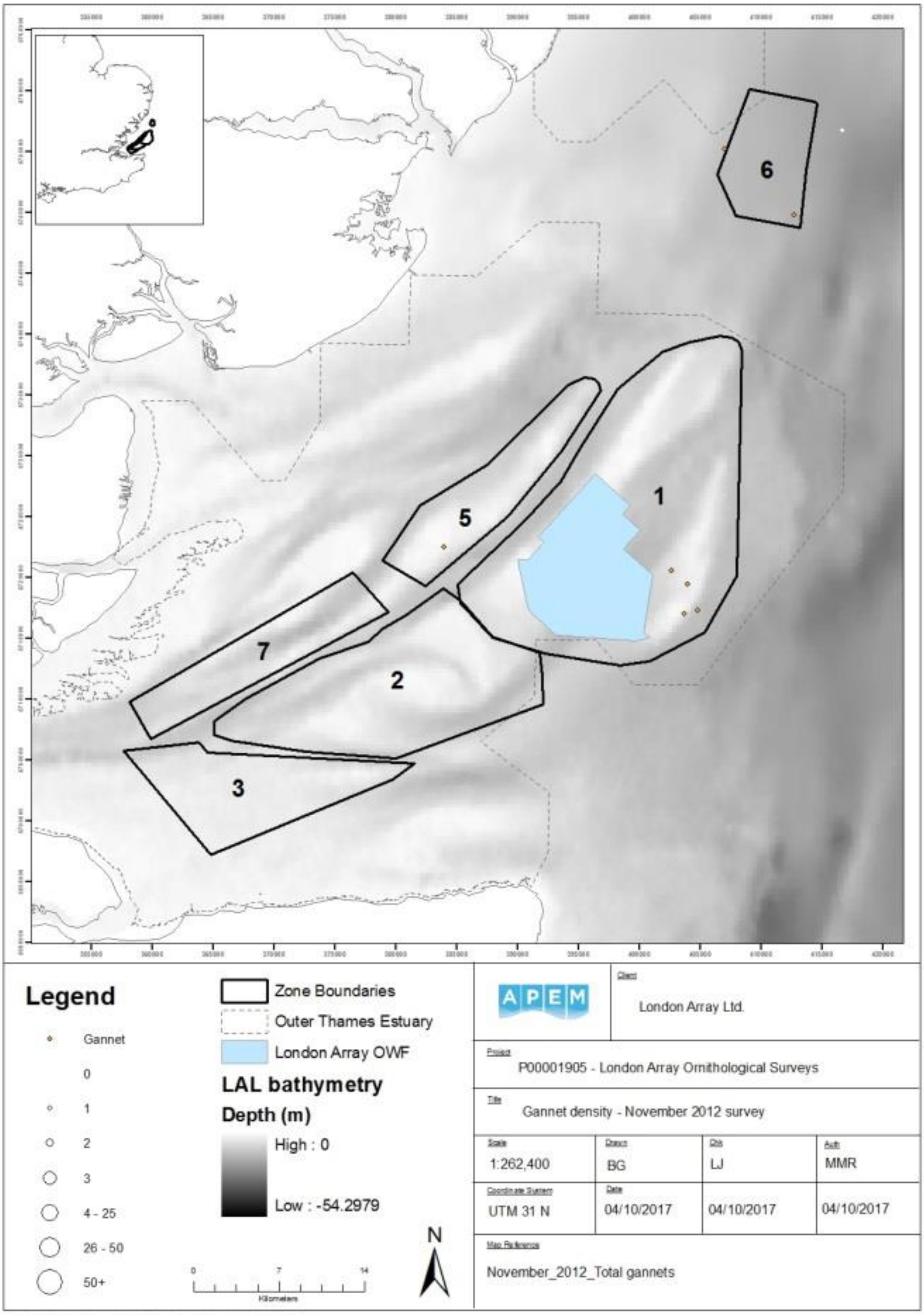

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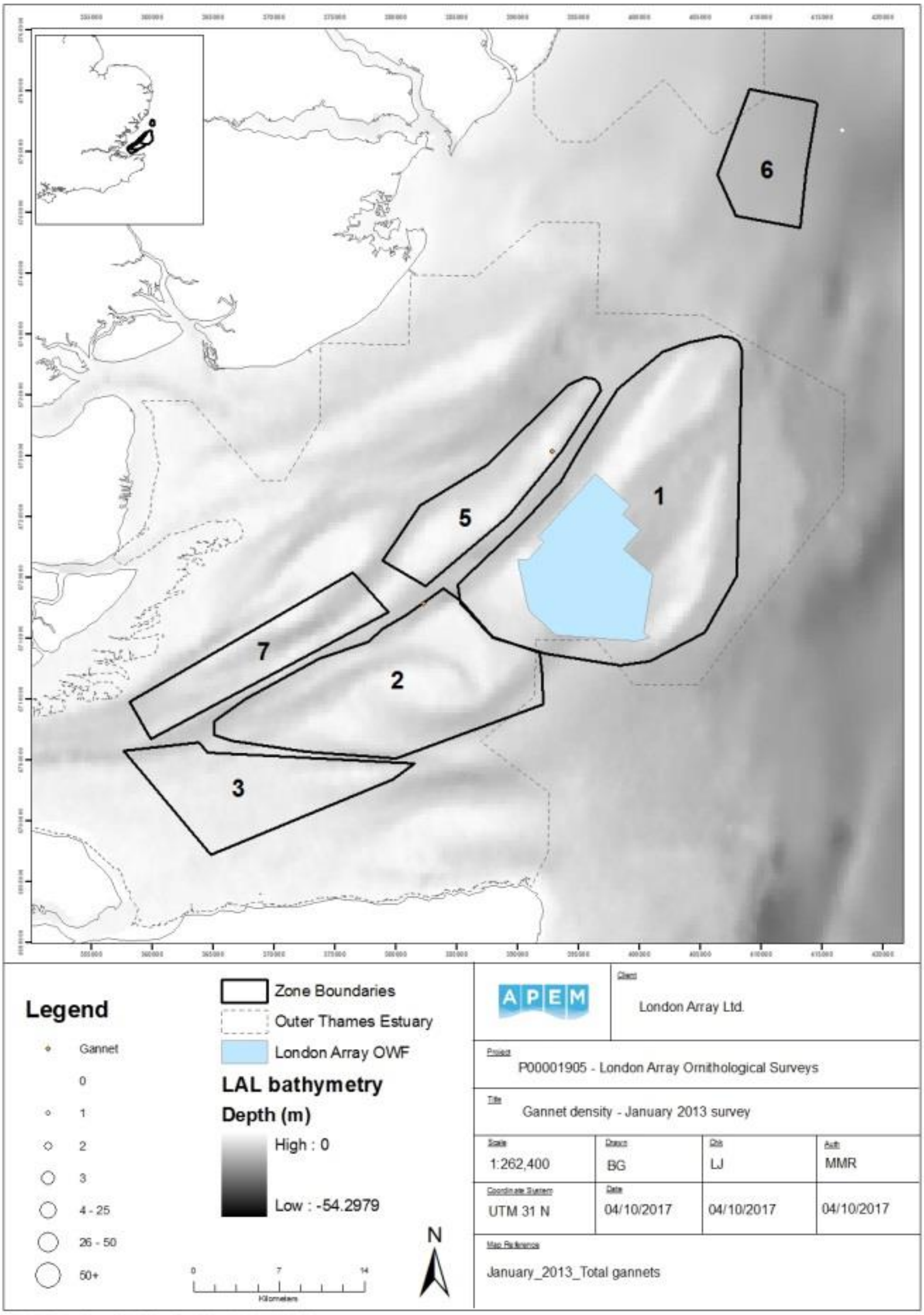

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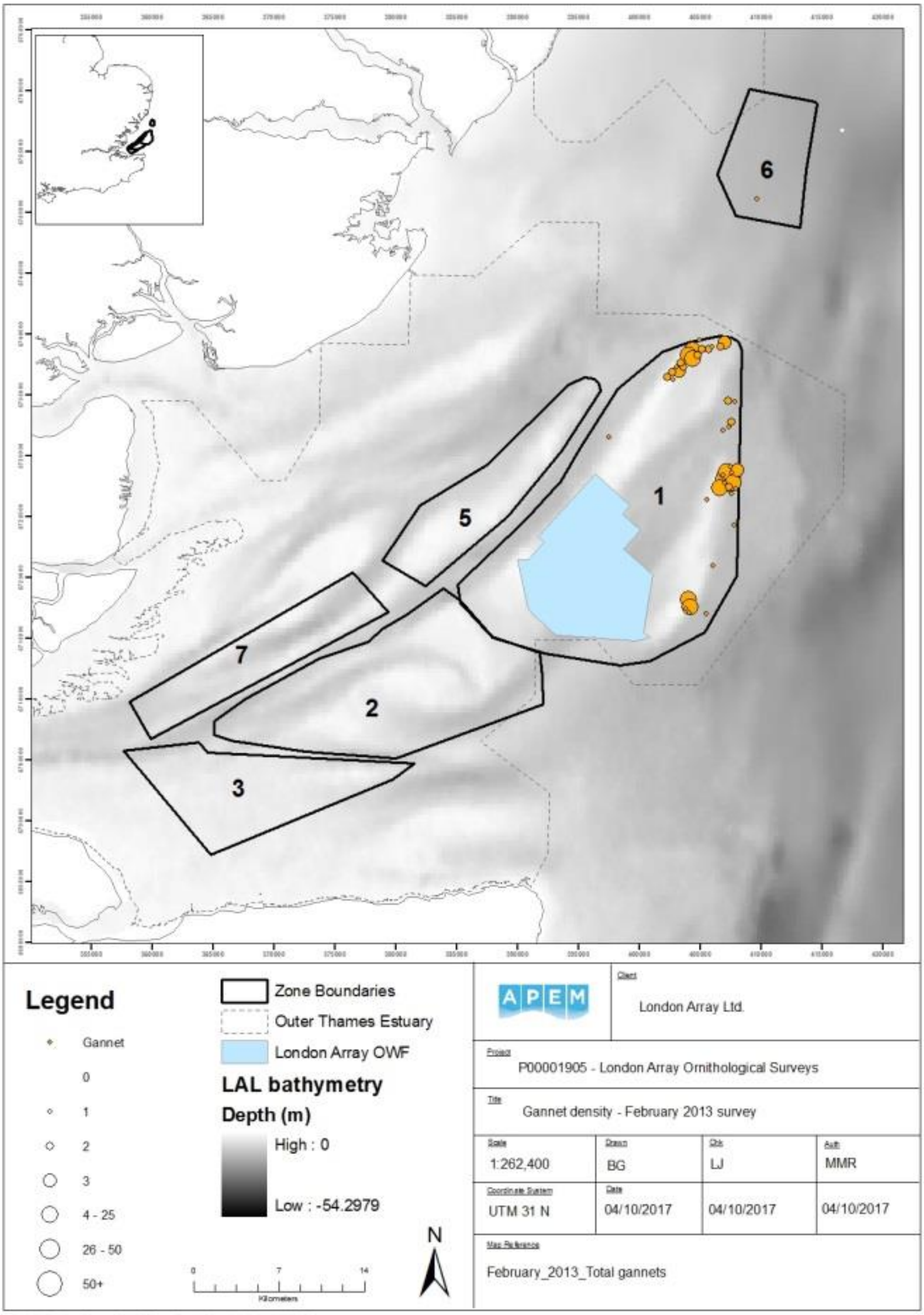

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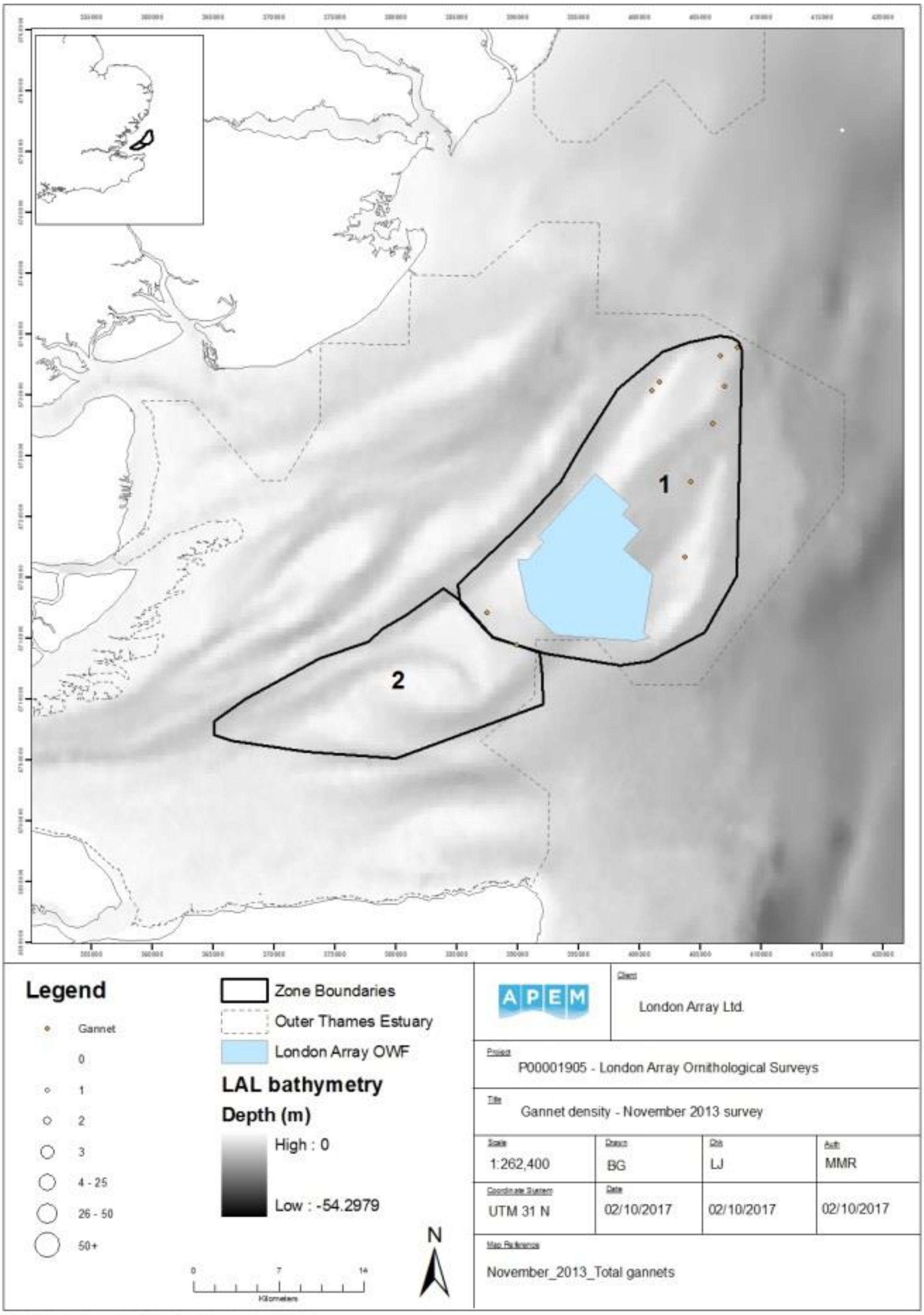

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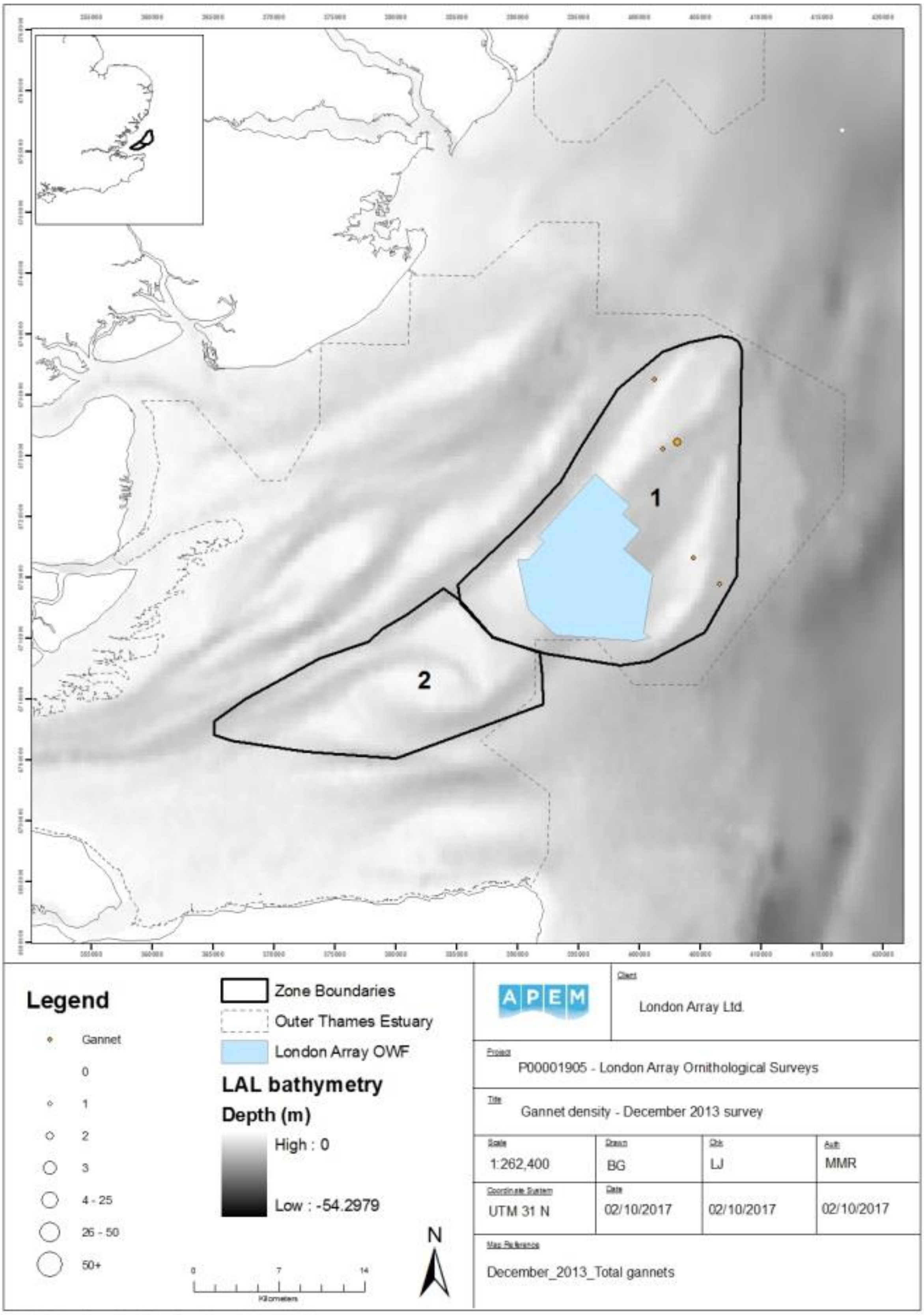

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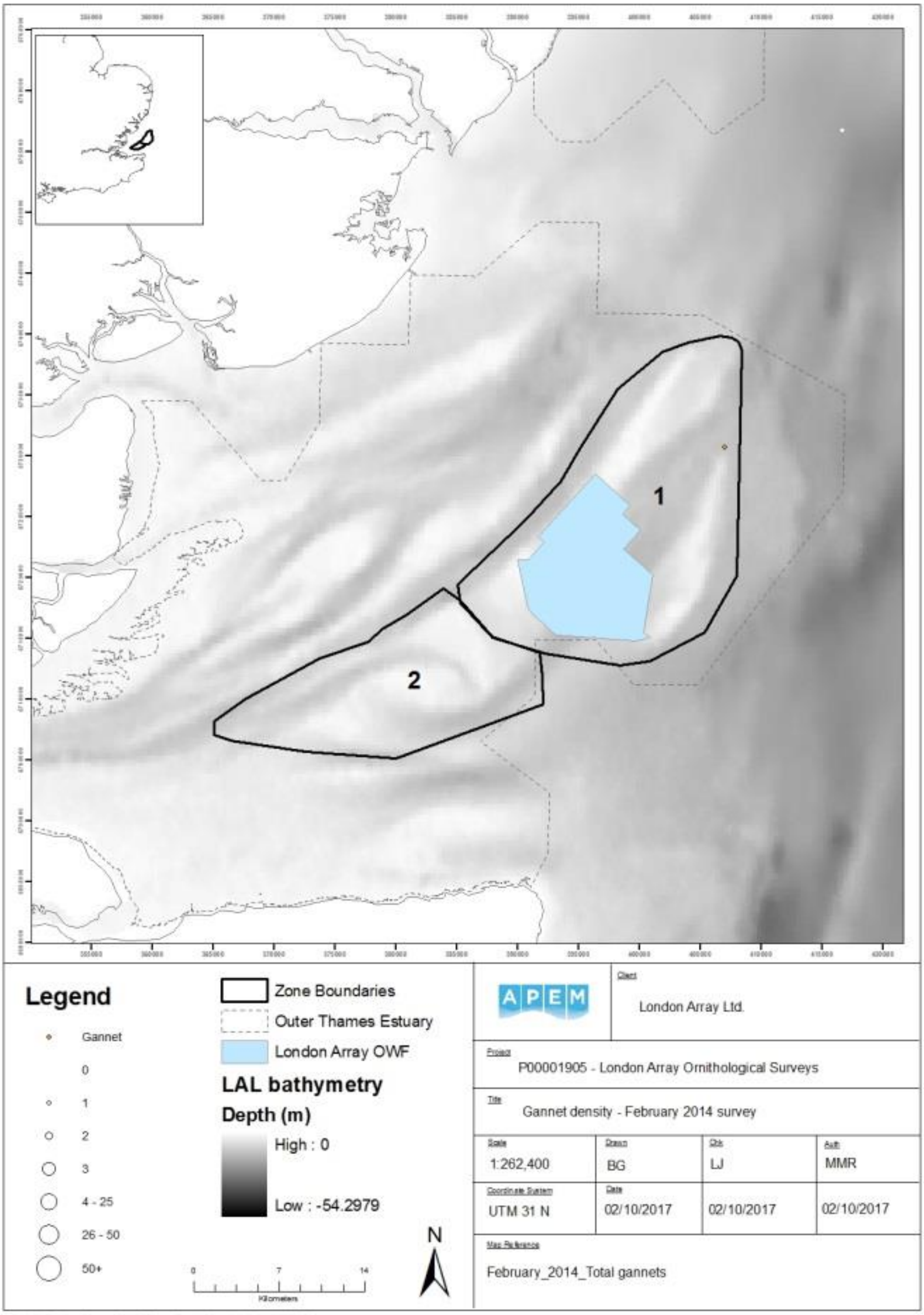

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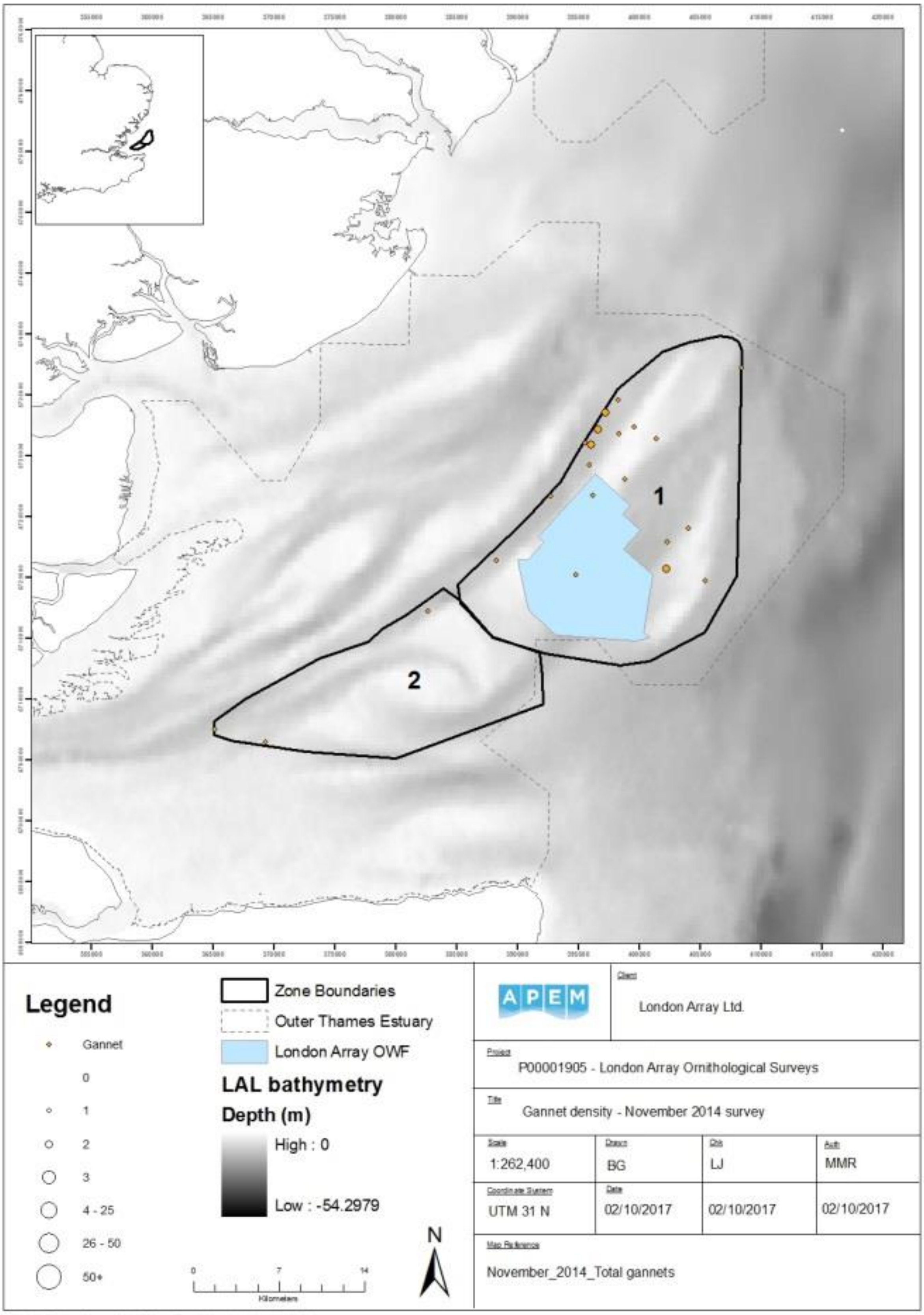

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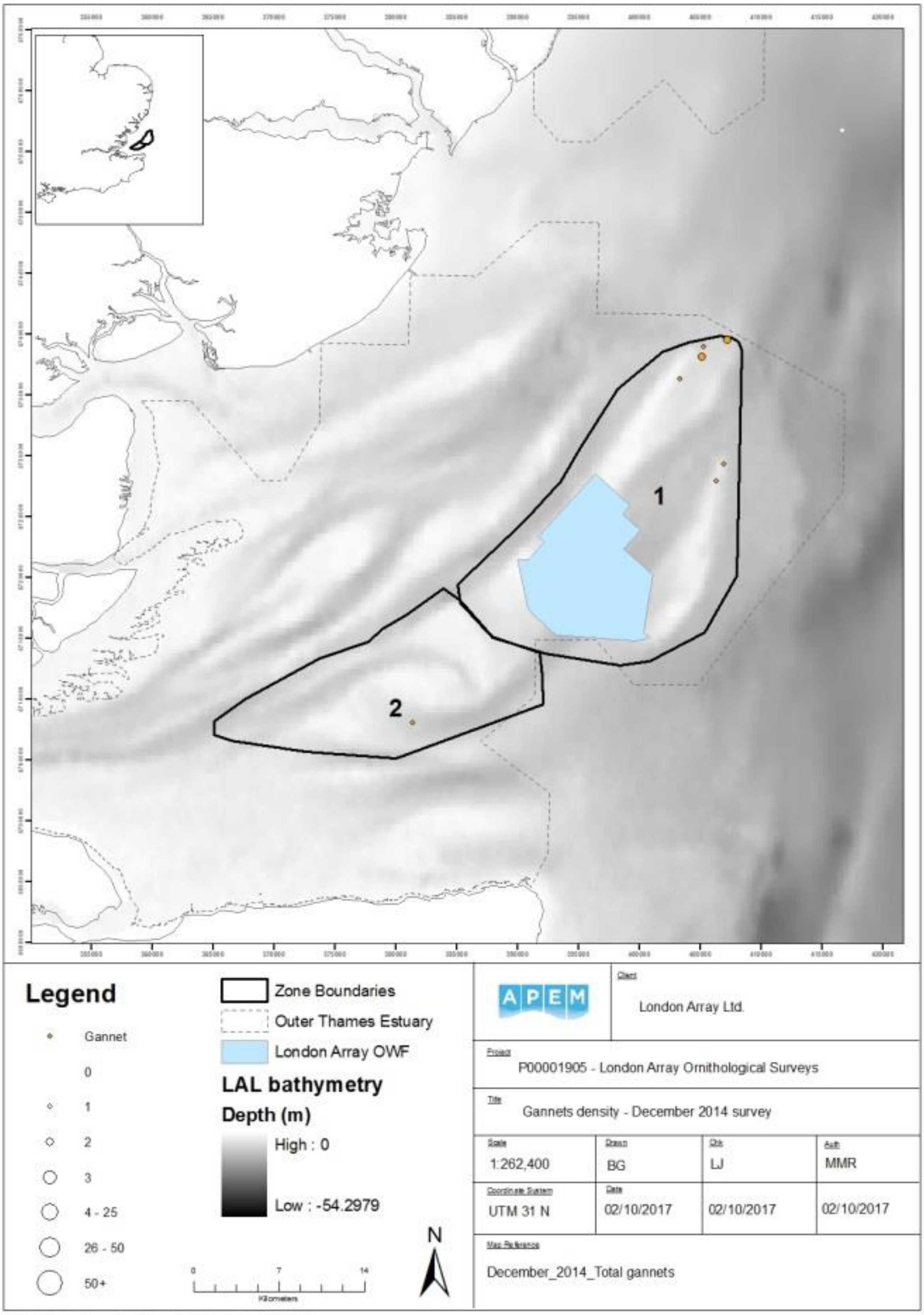

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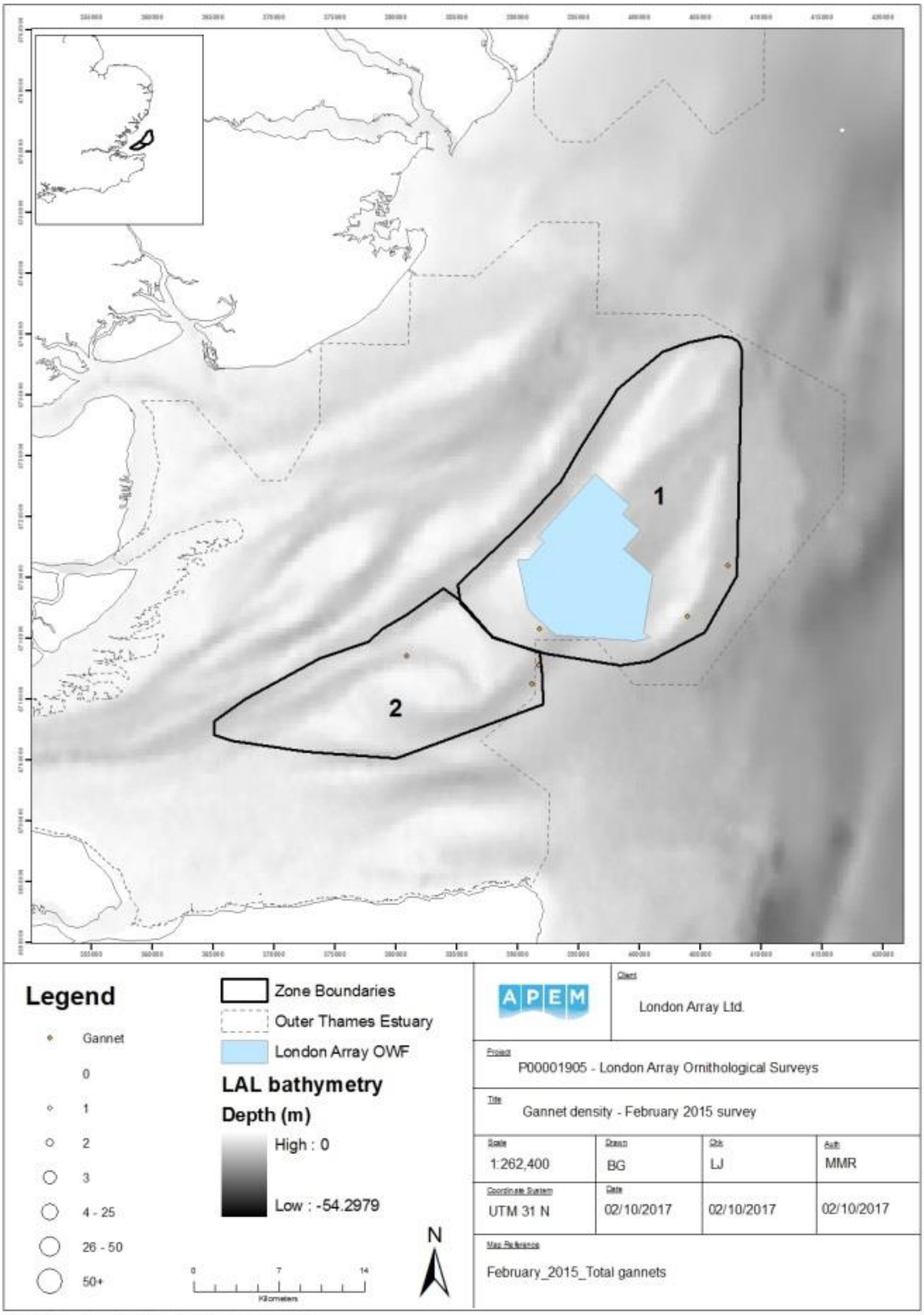

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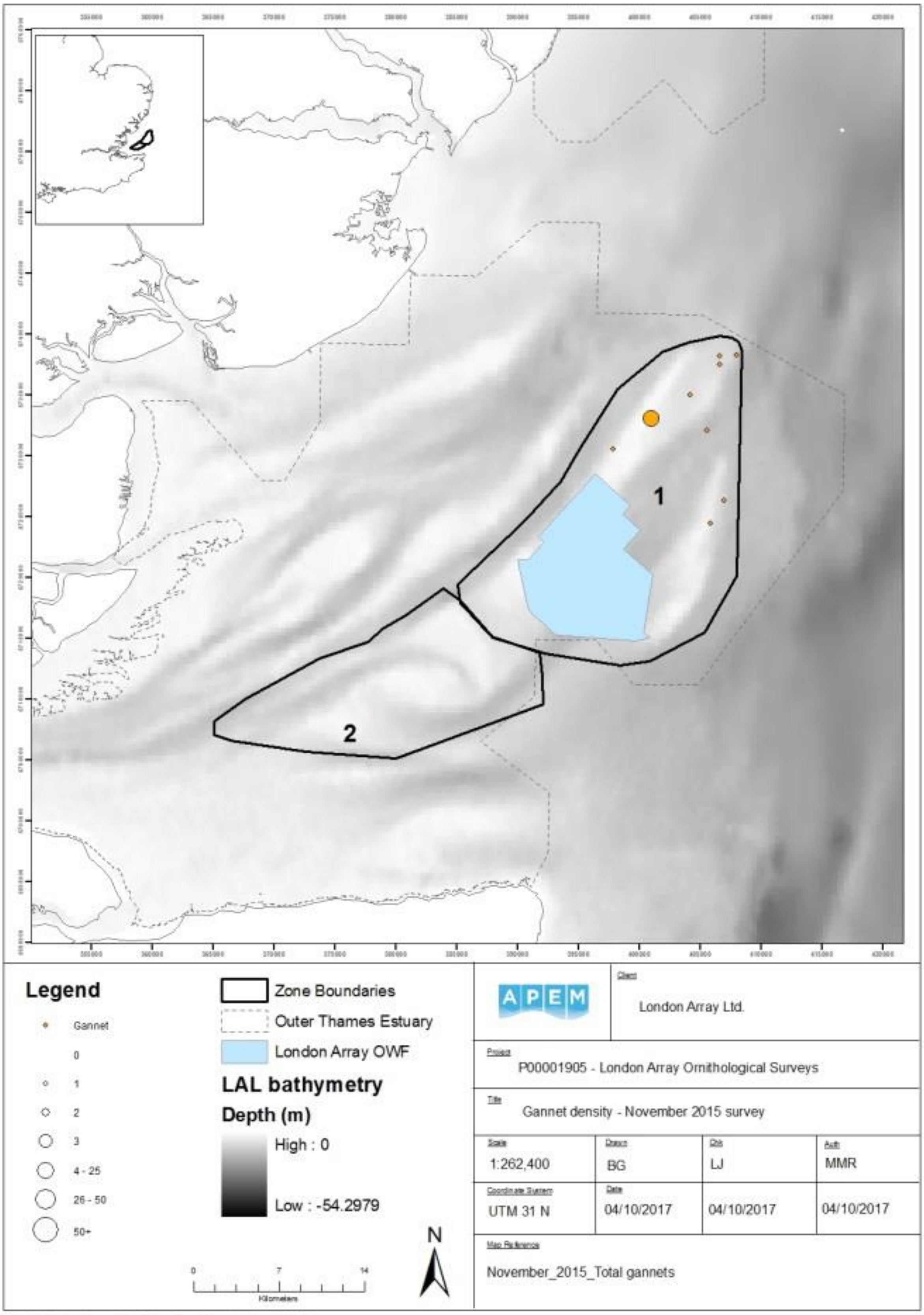

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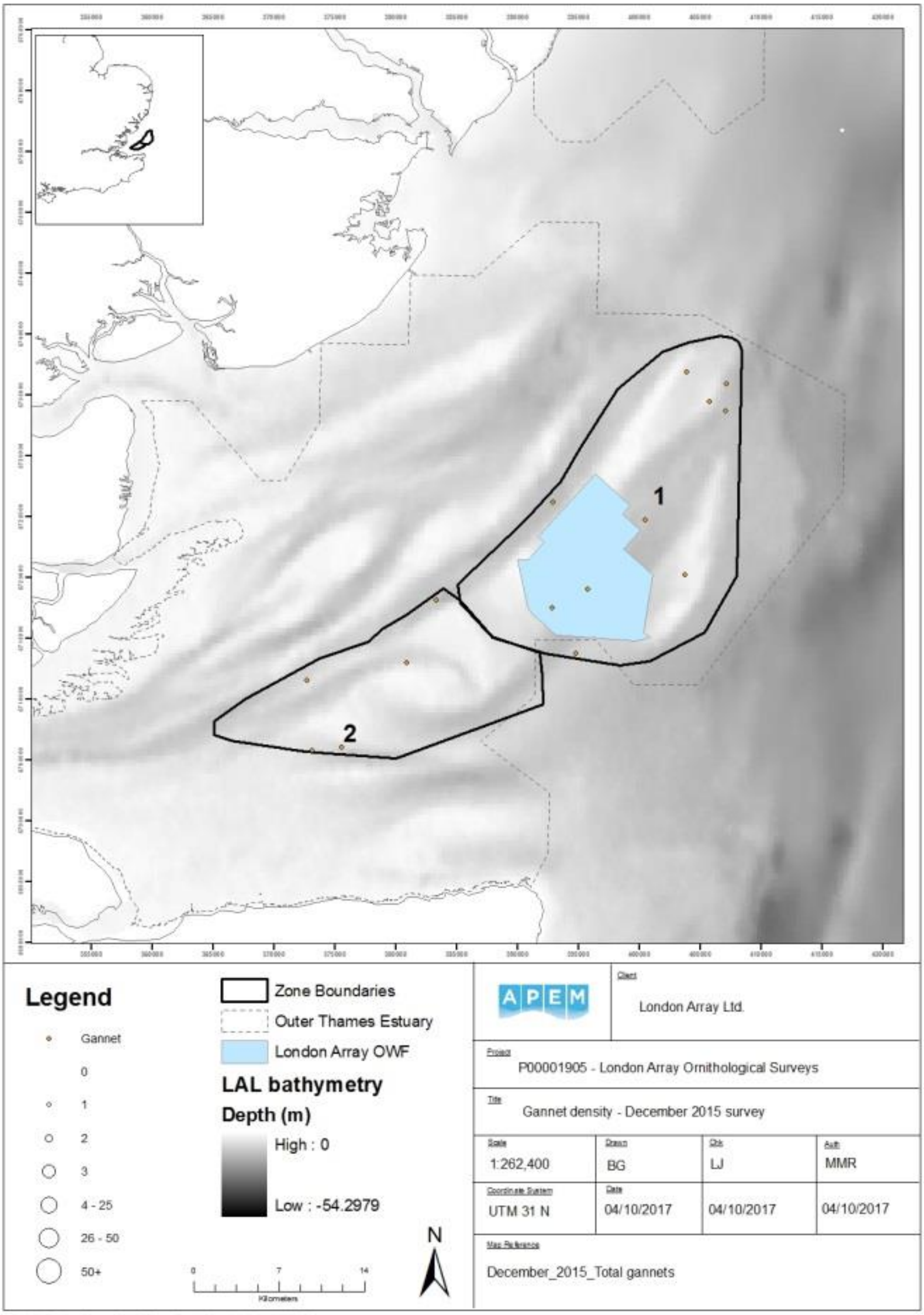

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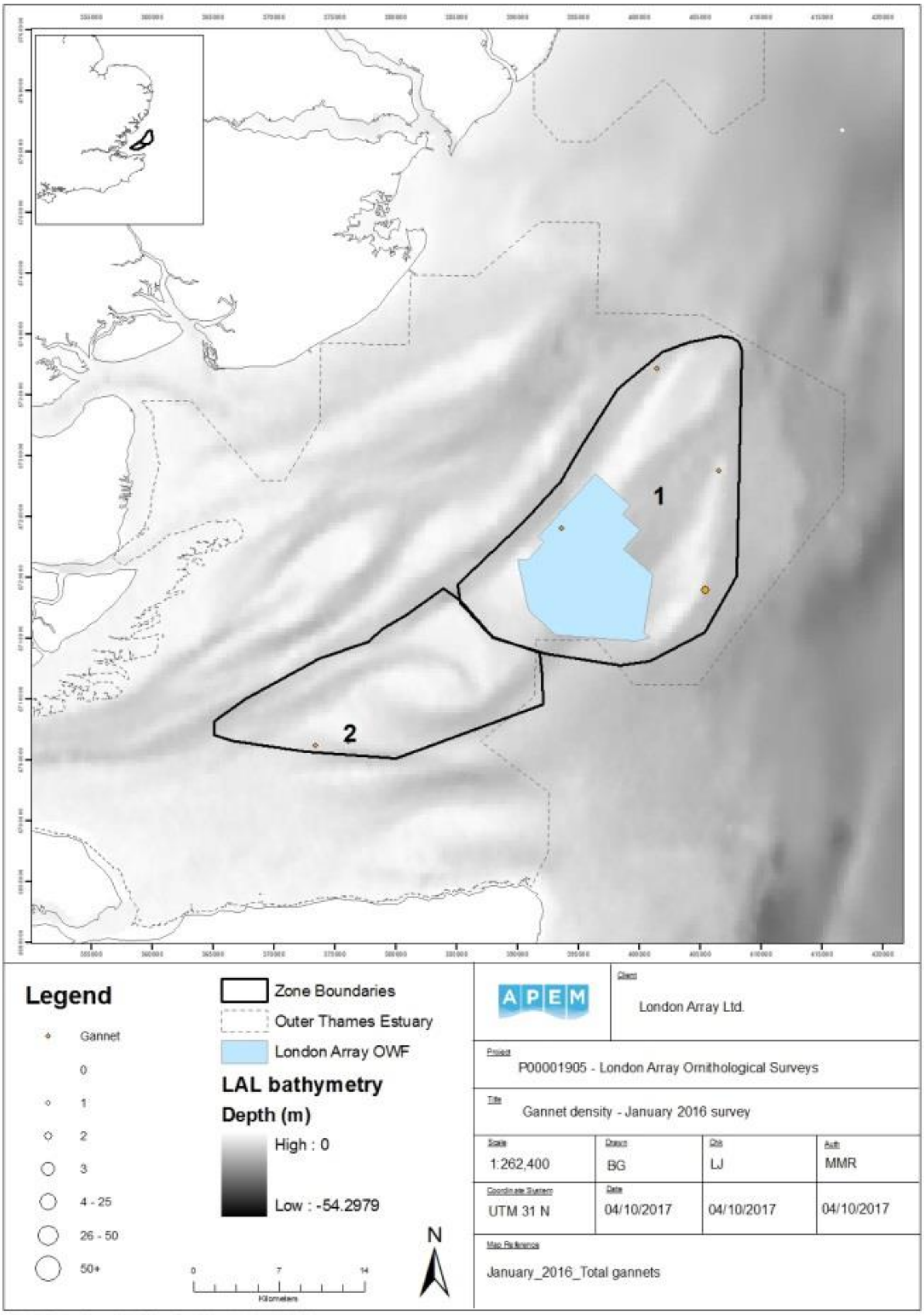

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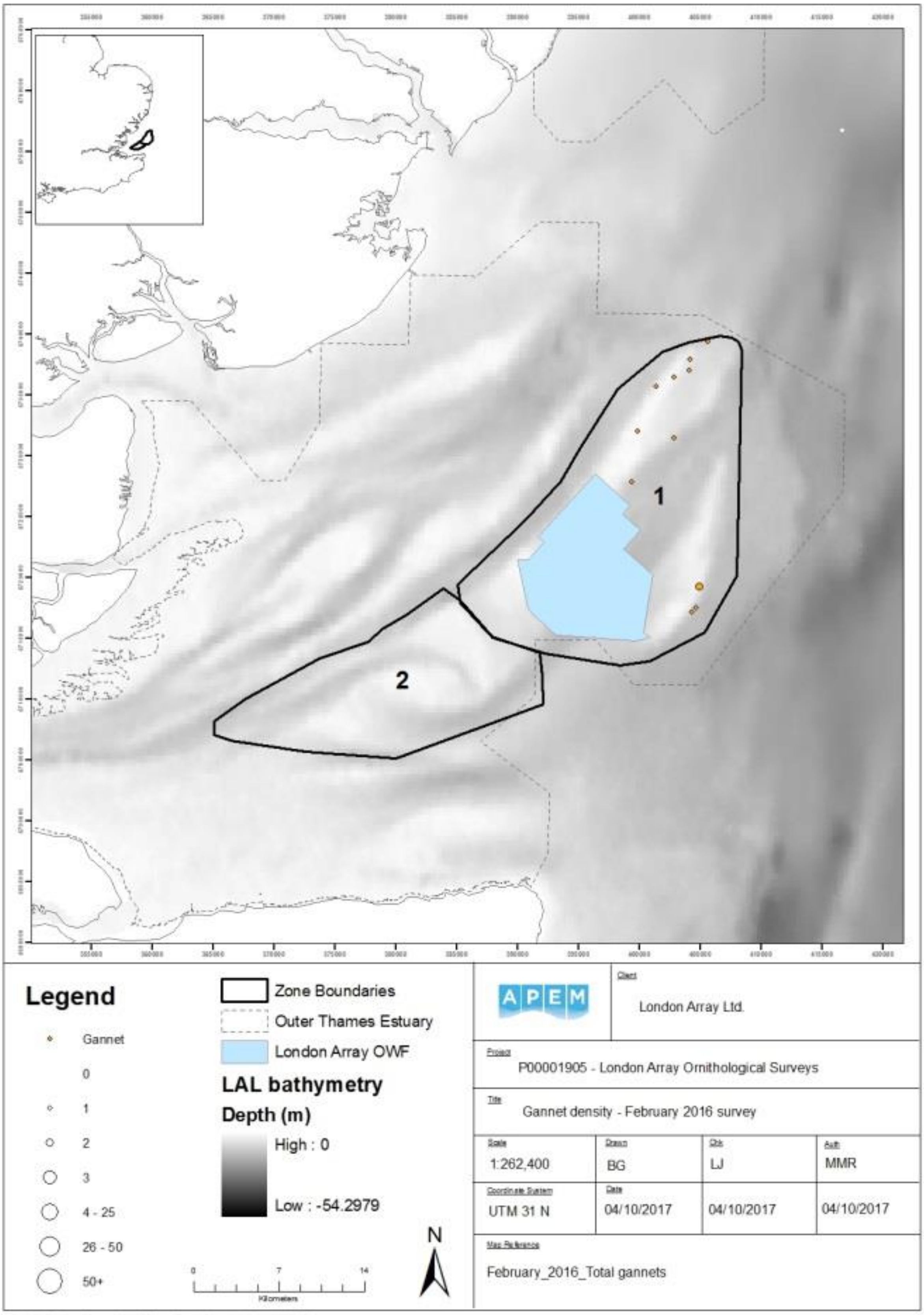
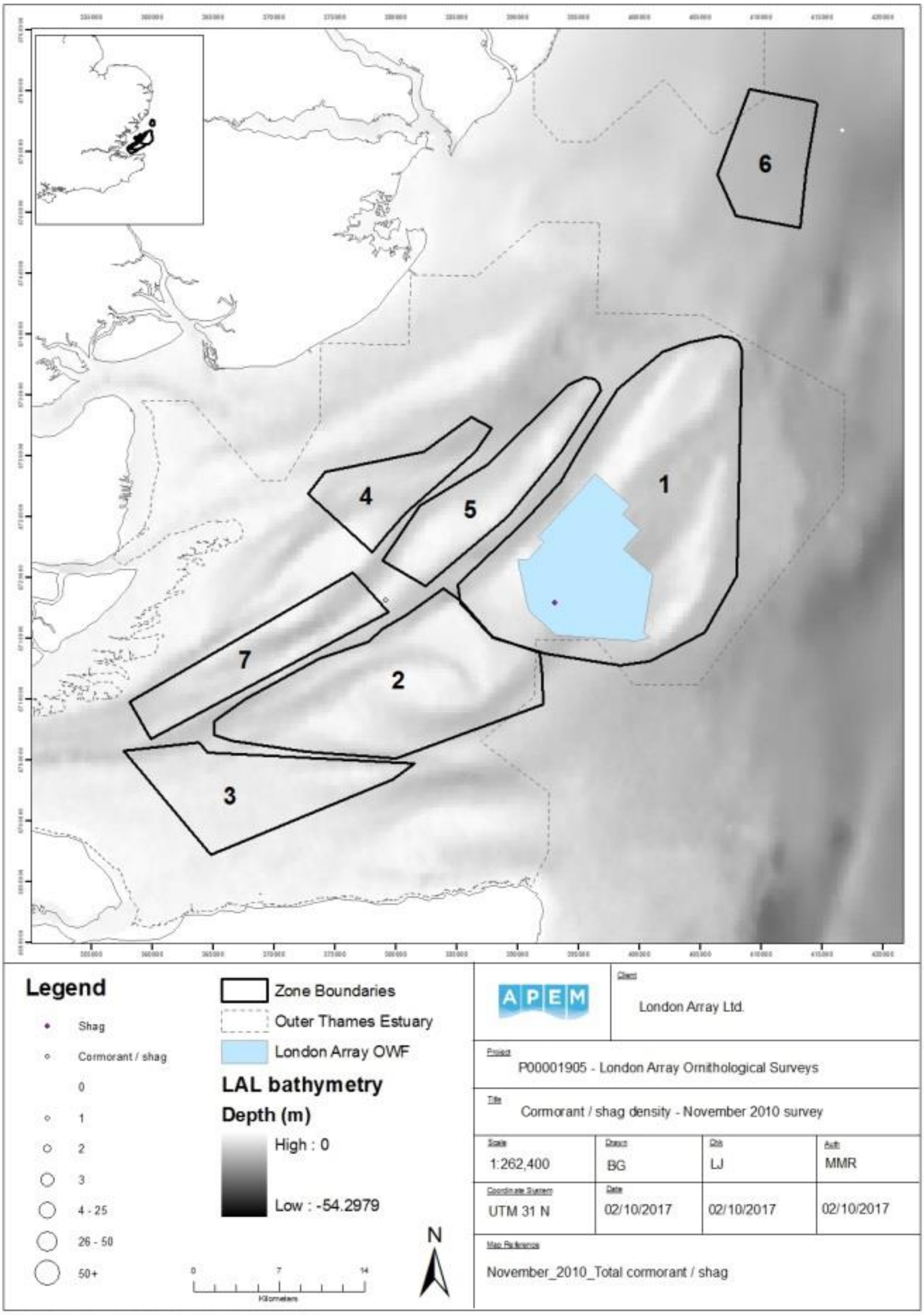


February 2016

Figure 4 **Monthly distribution maps for gannets recorded in the pre-, during- and post-construction aerial surveys of the LAW.**

Cormorant / Shag



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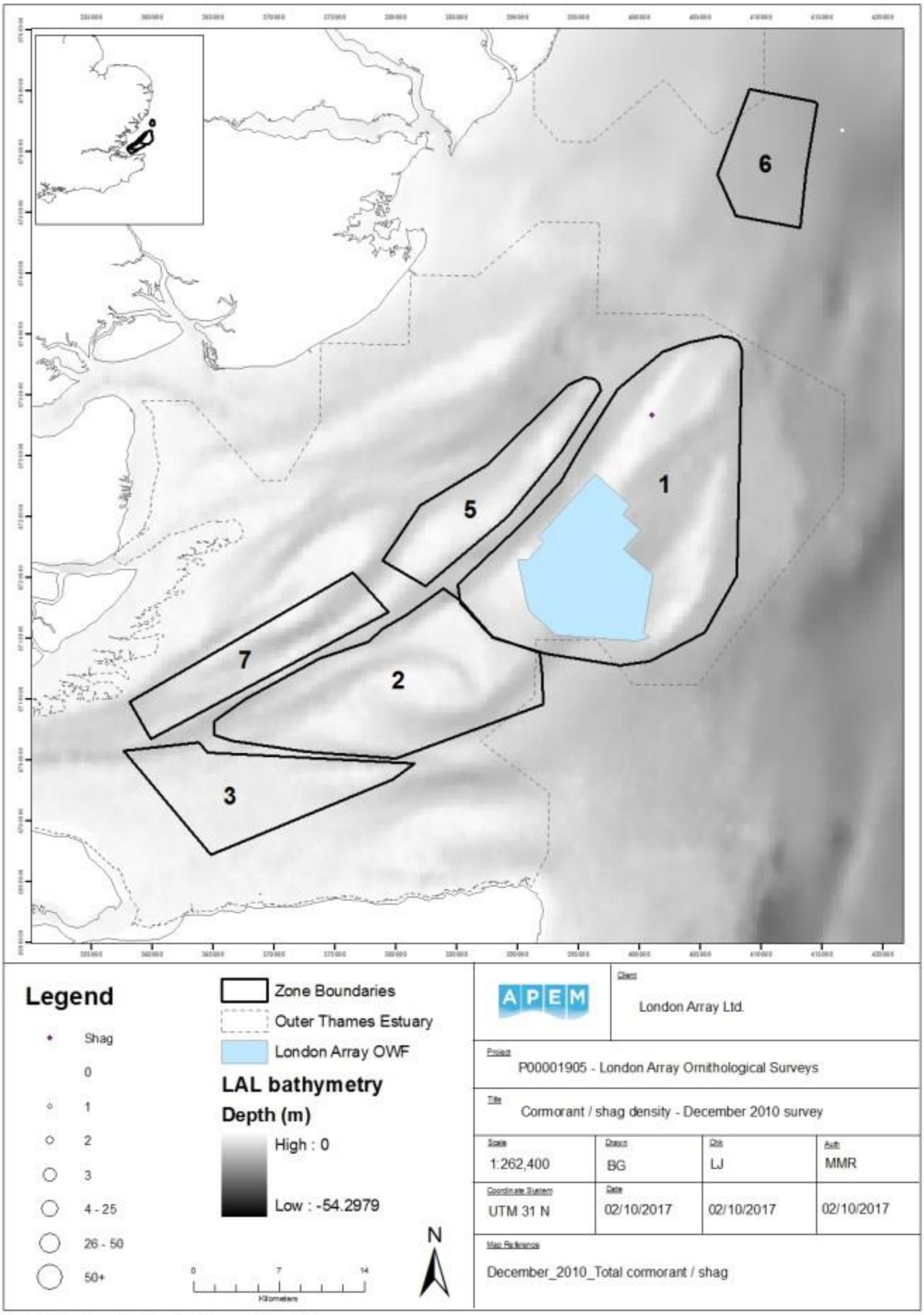

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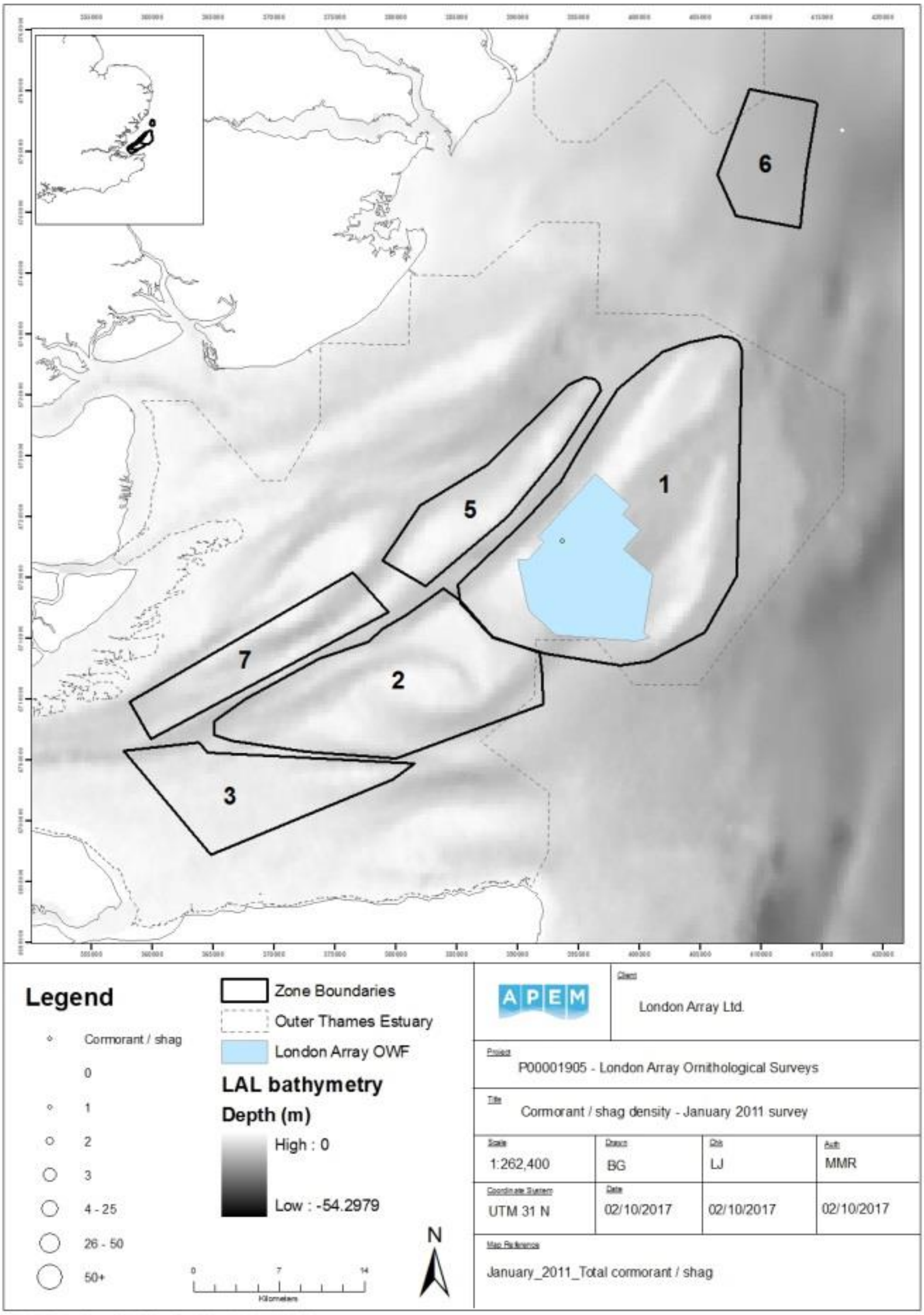

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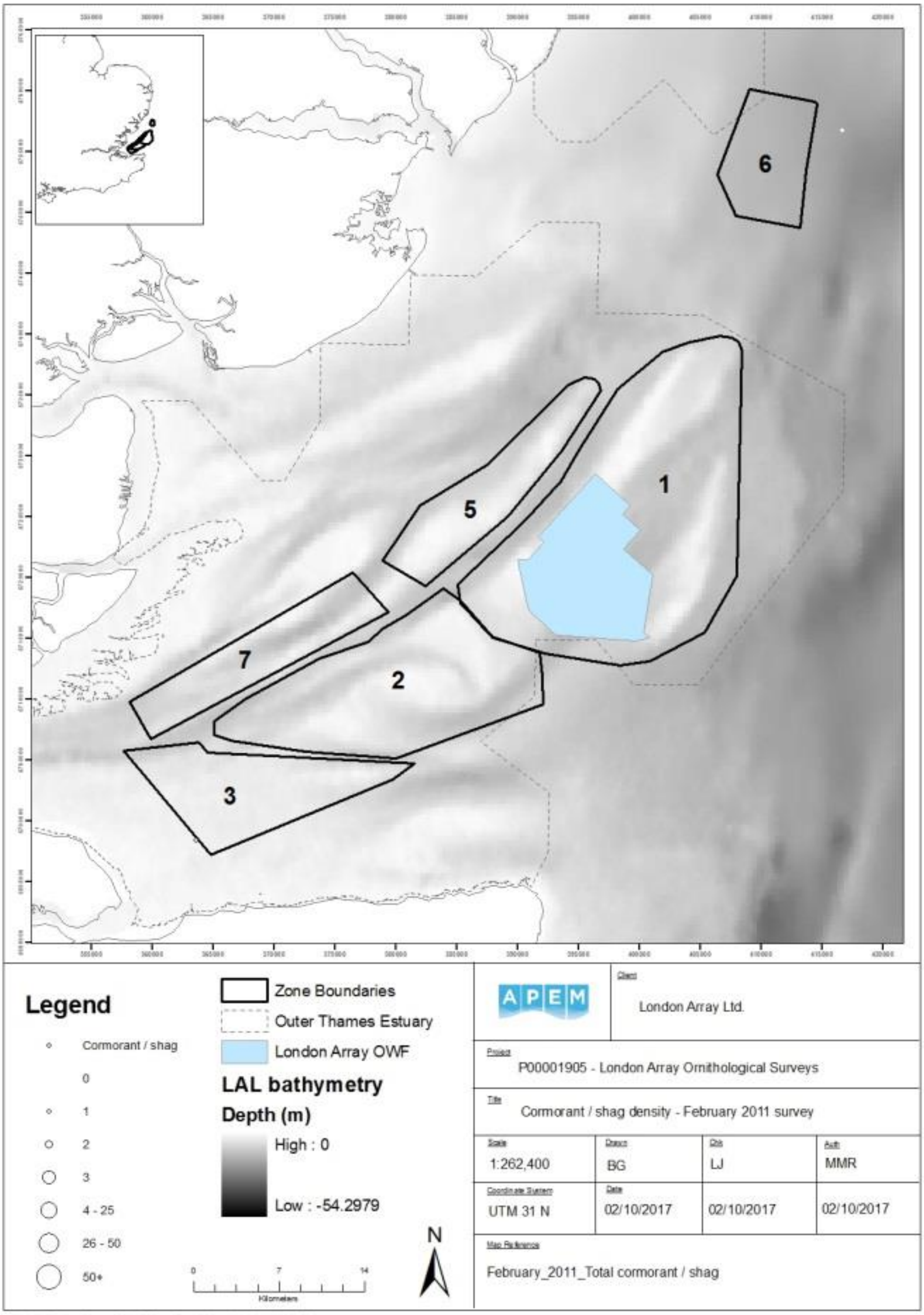

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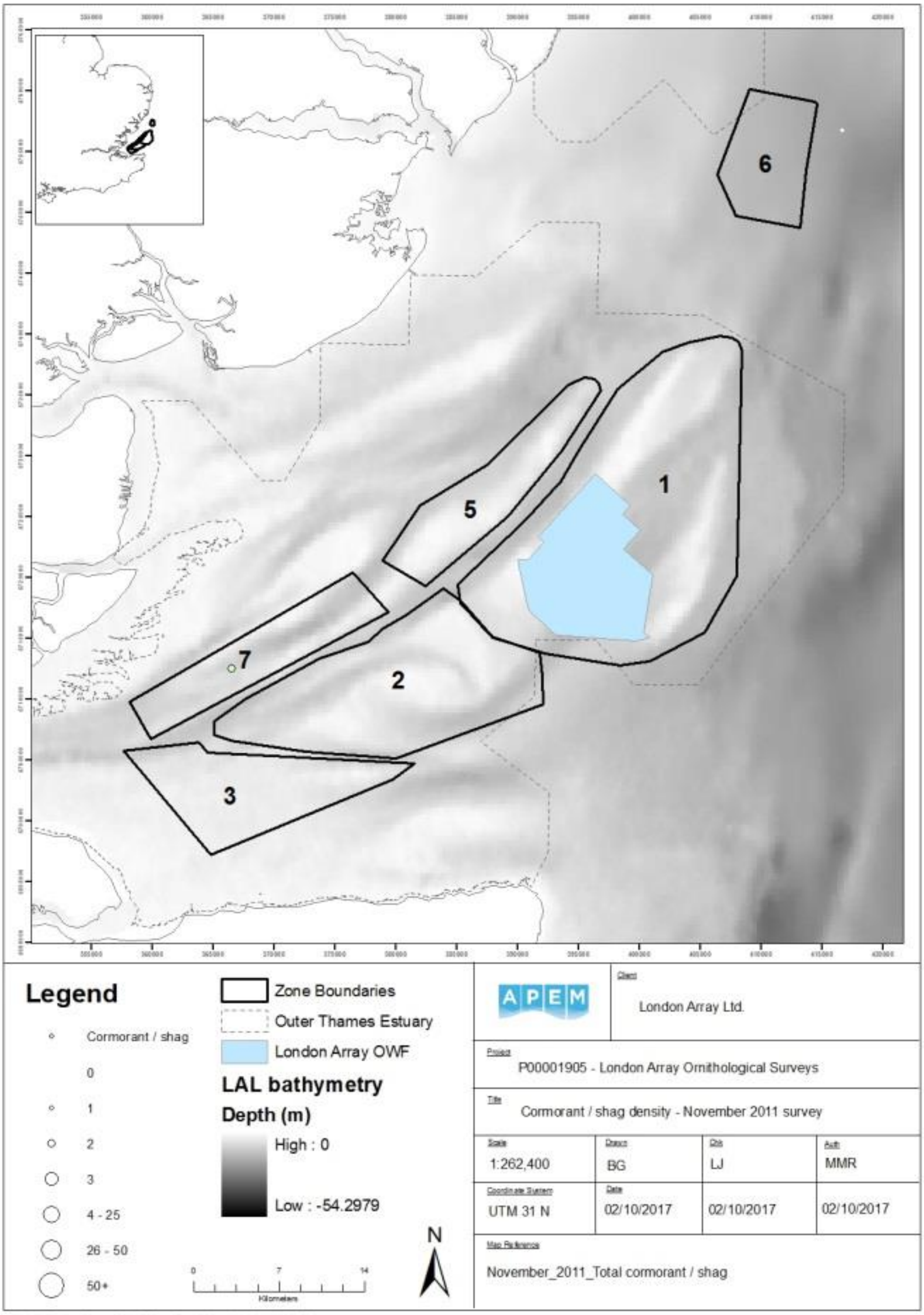

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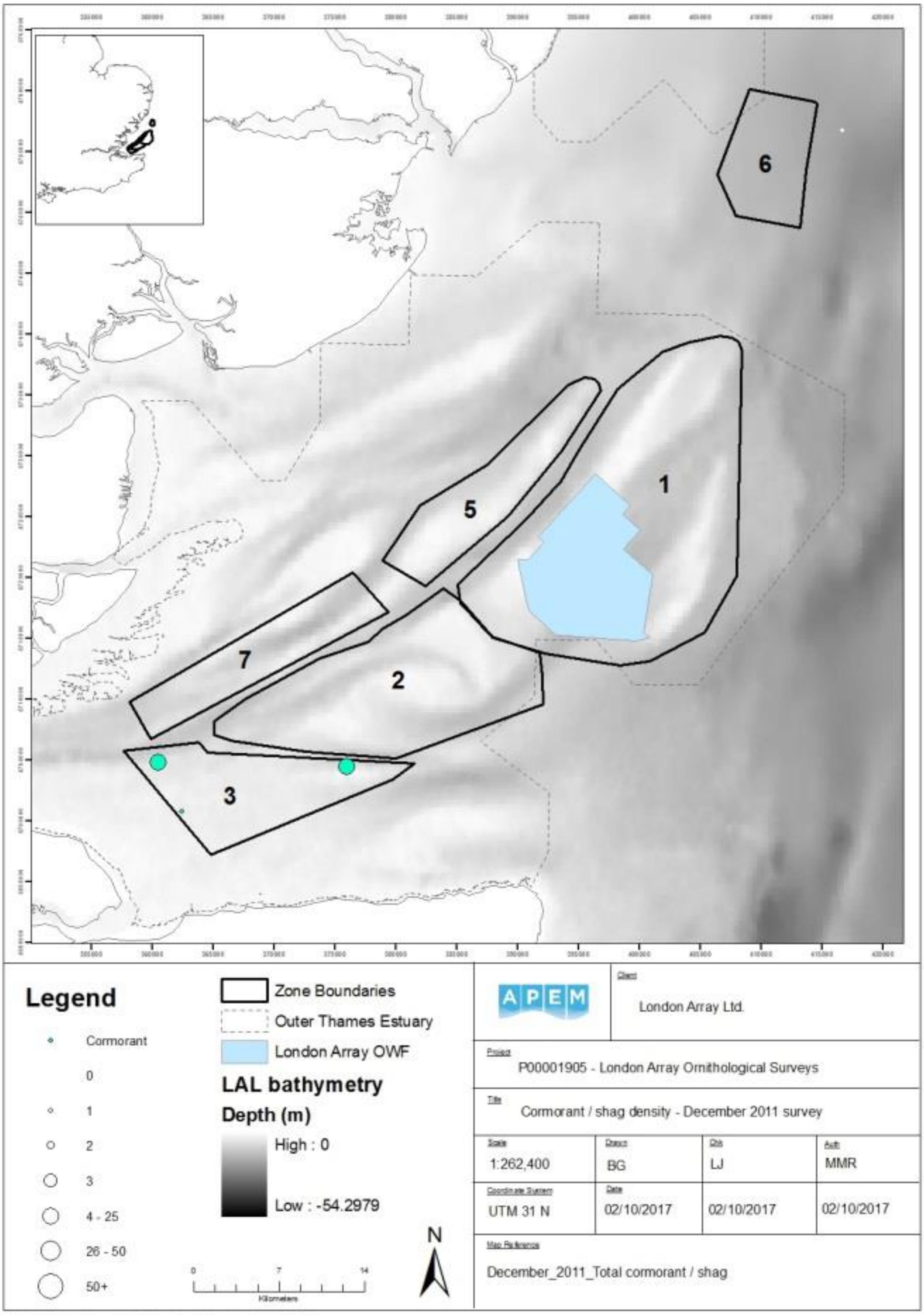

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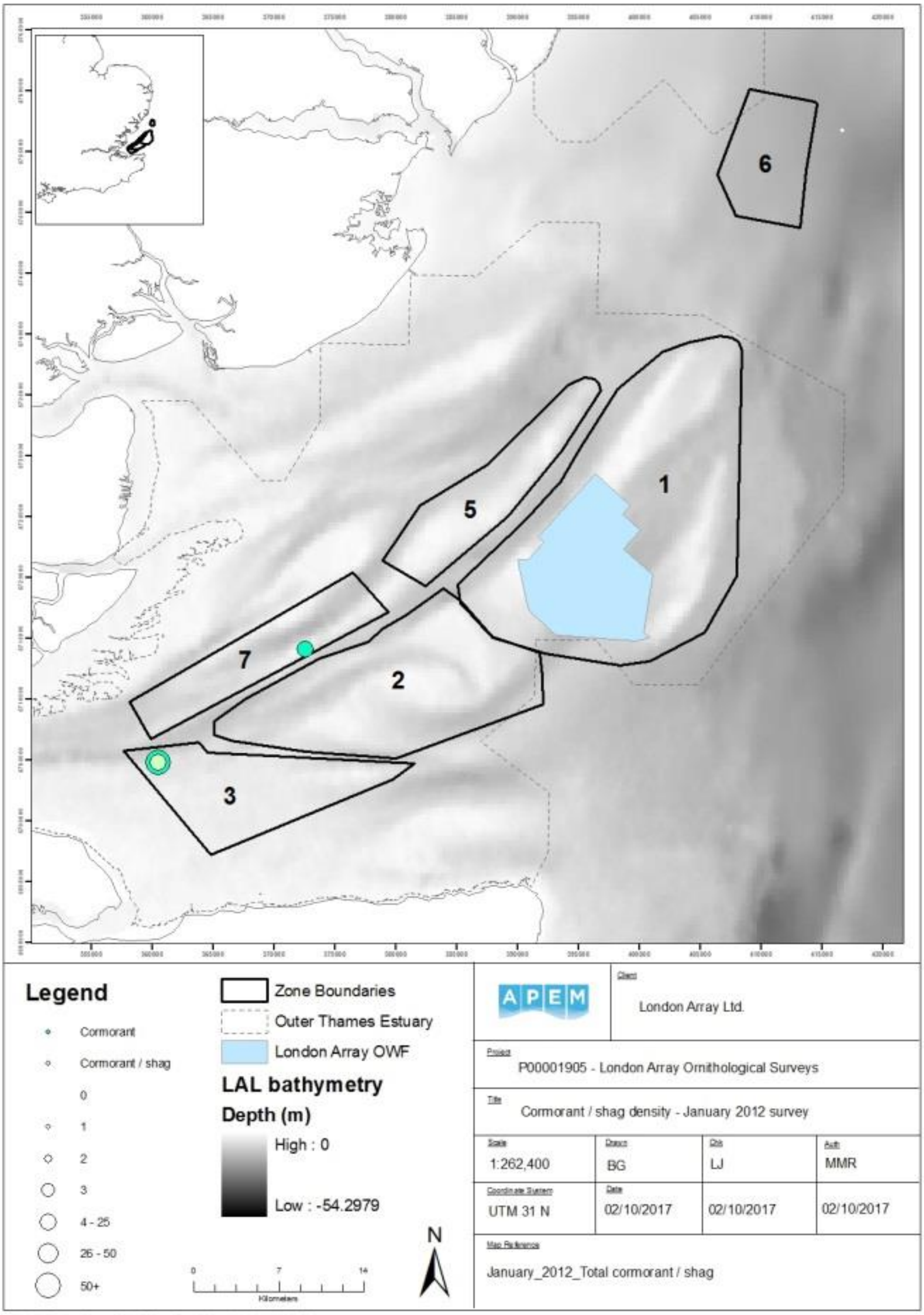

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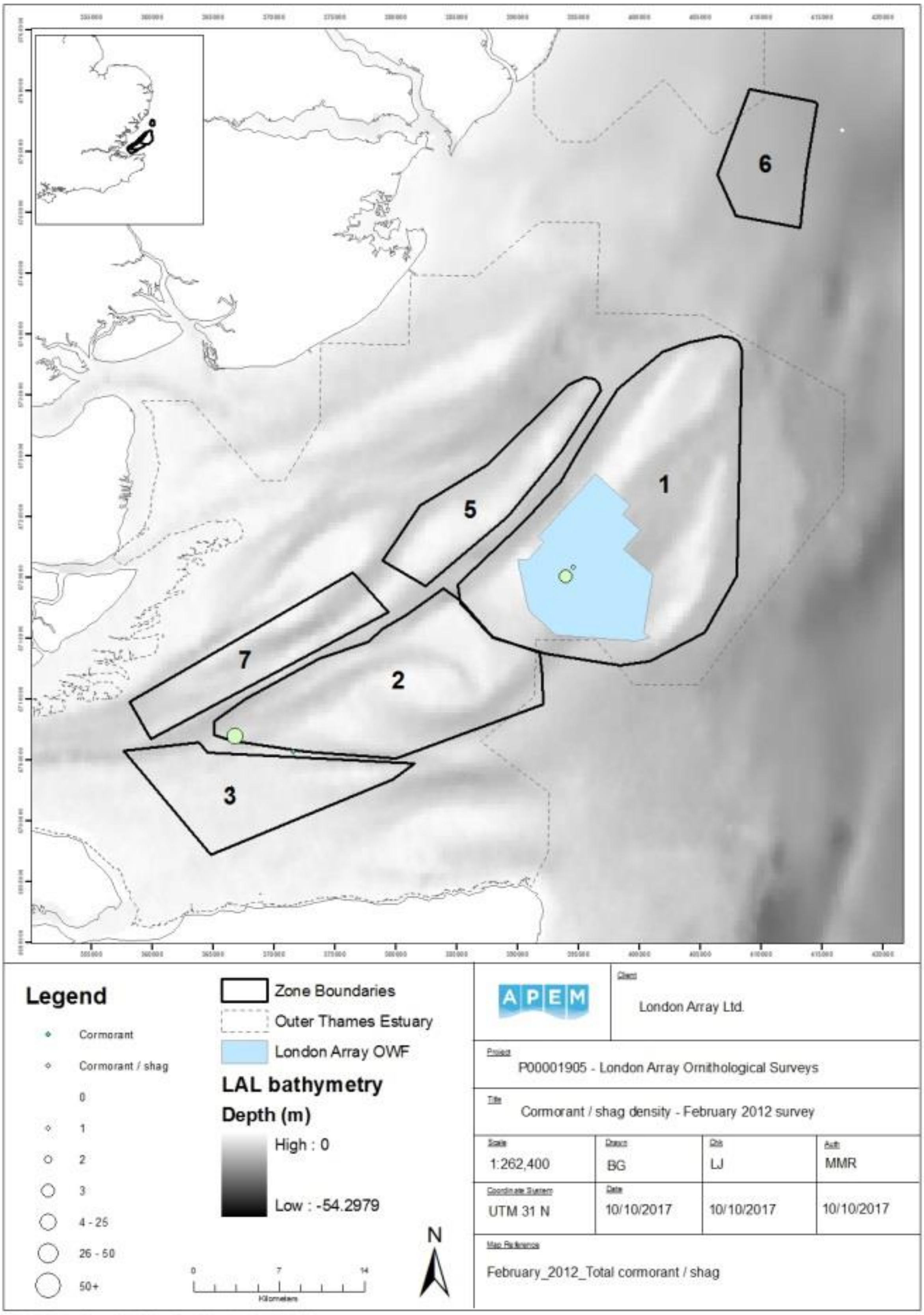

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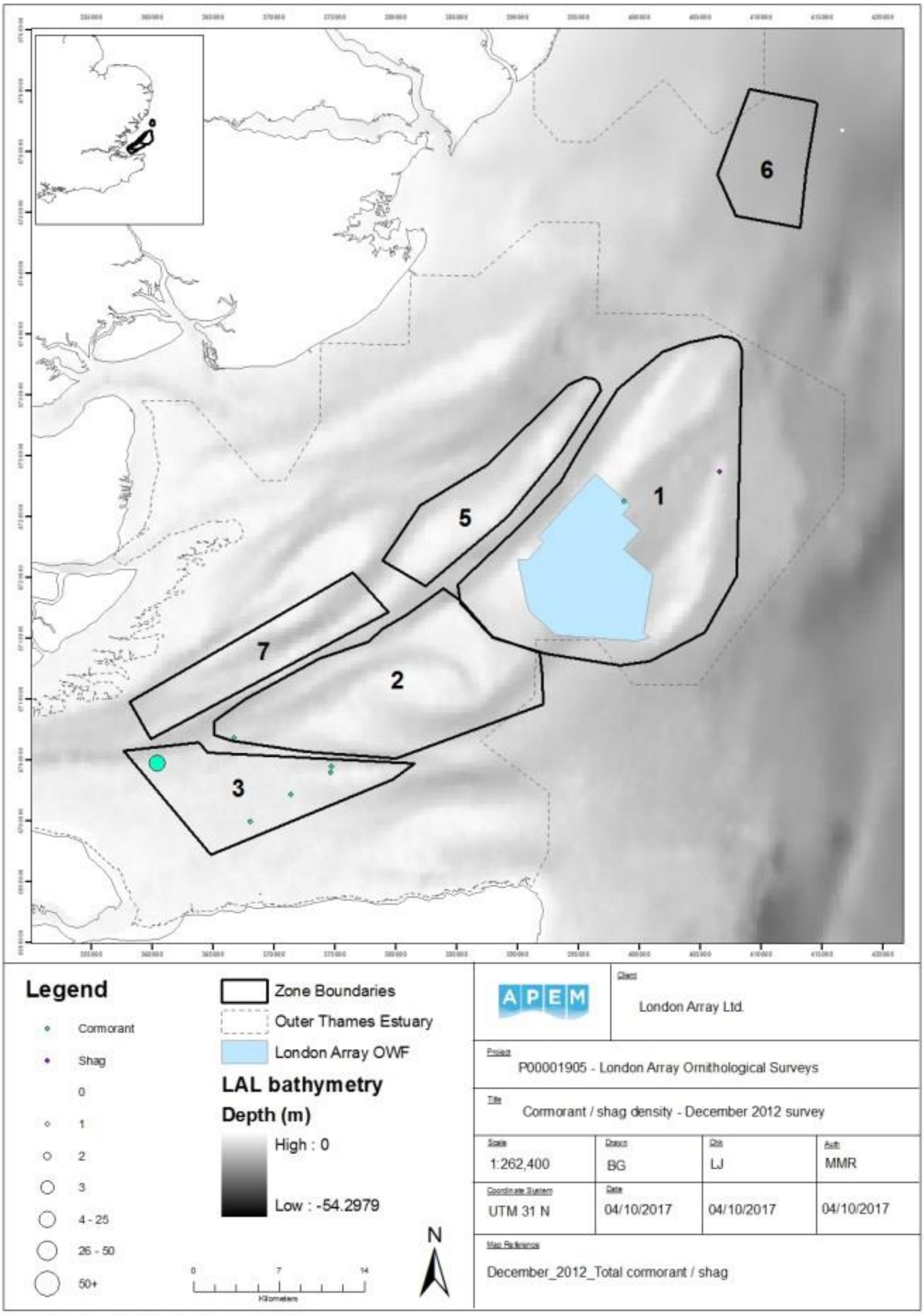

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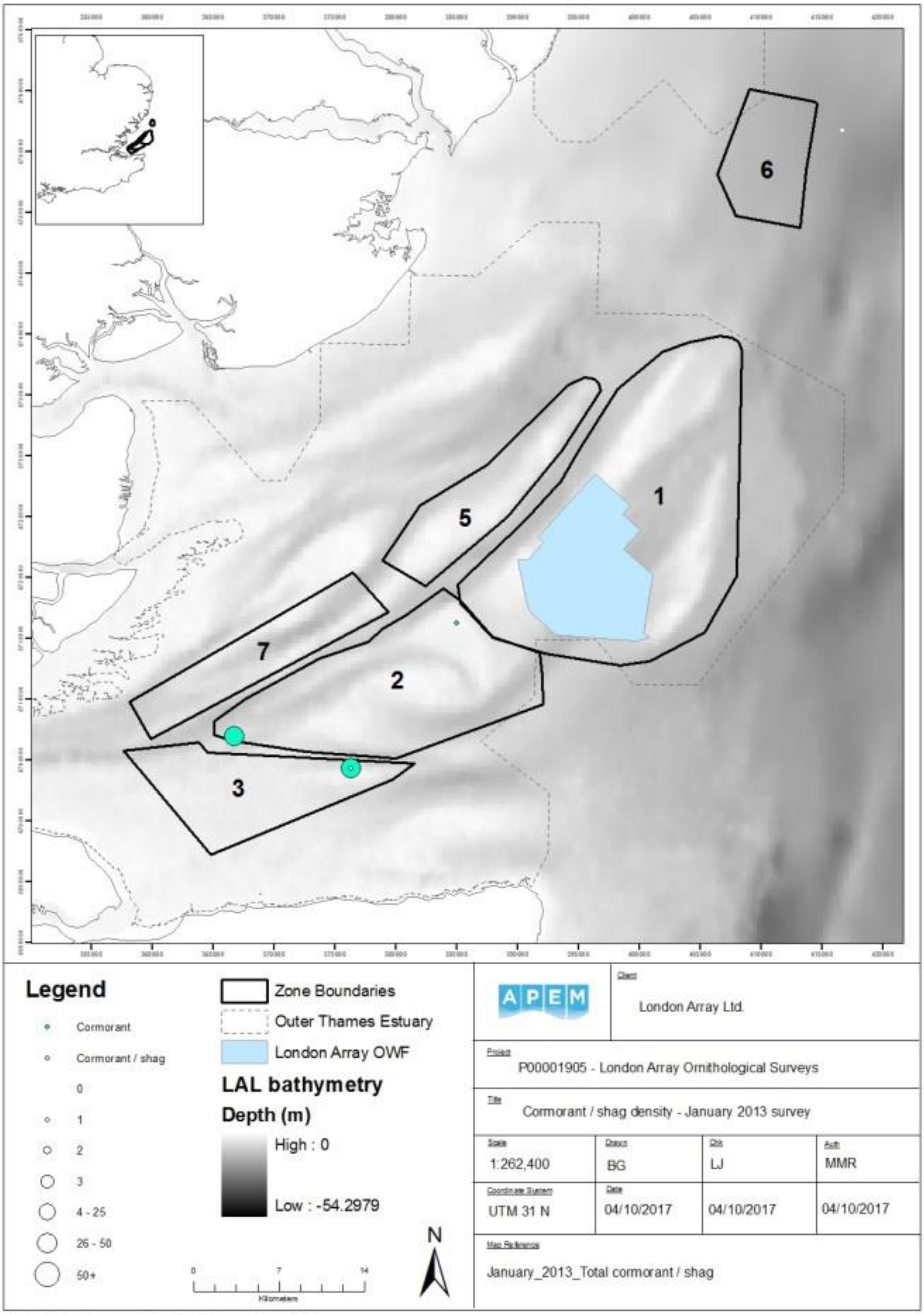

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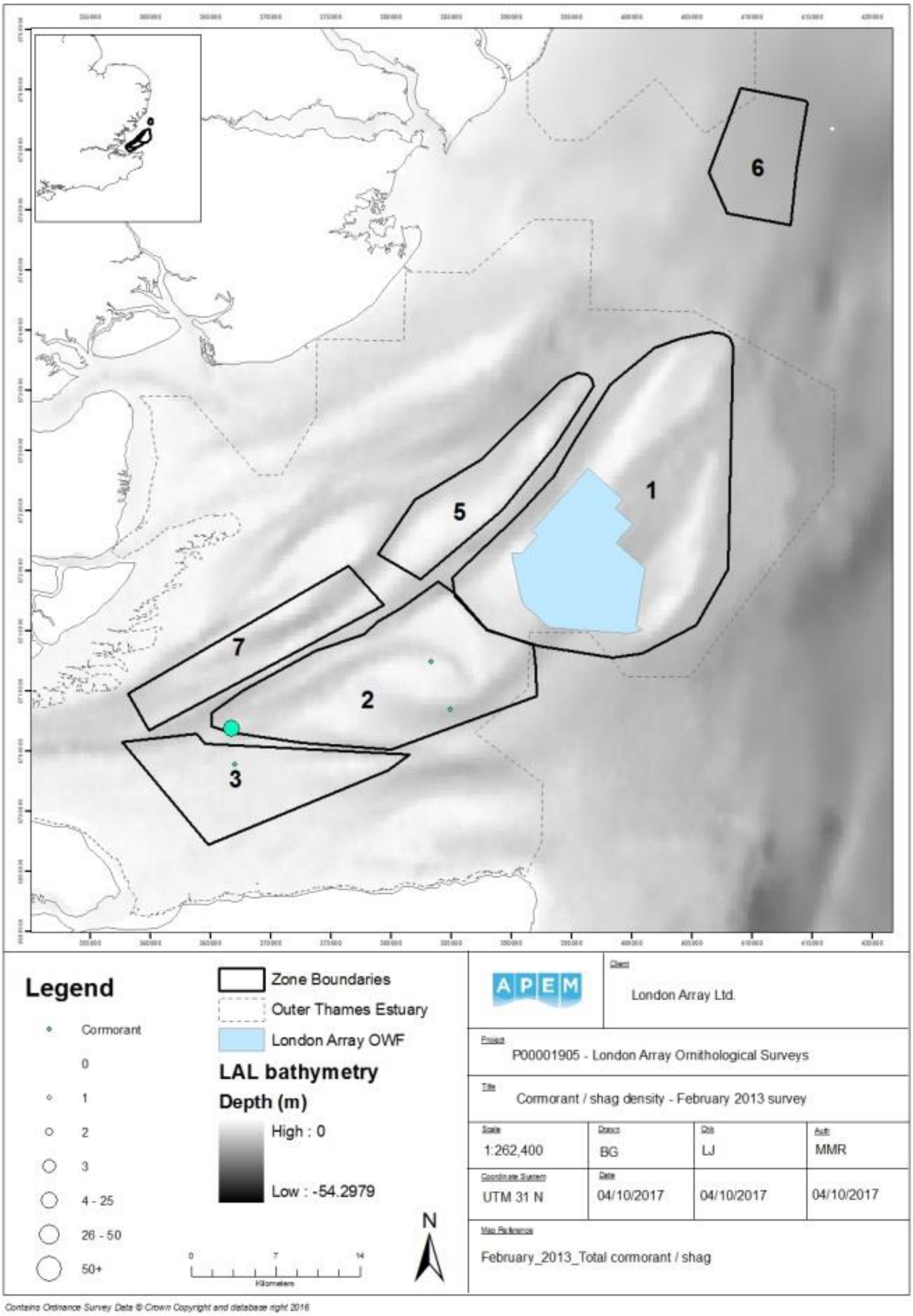

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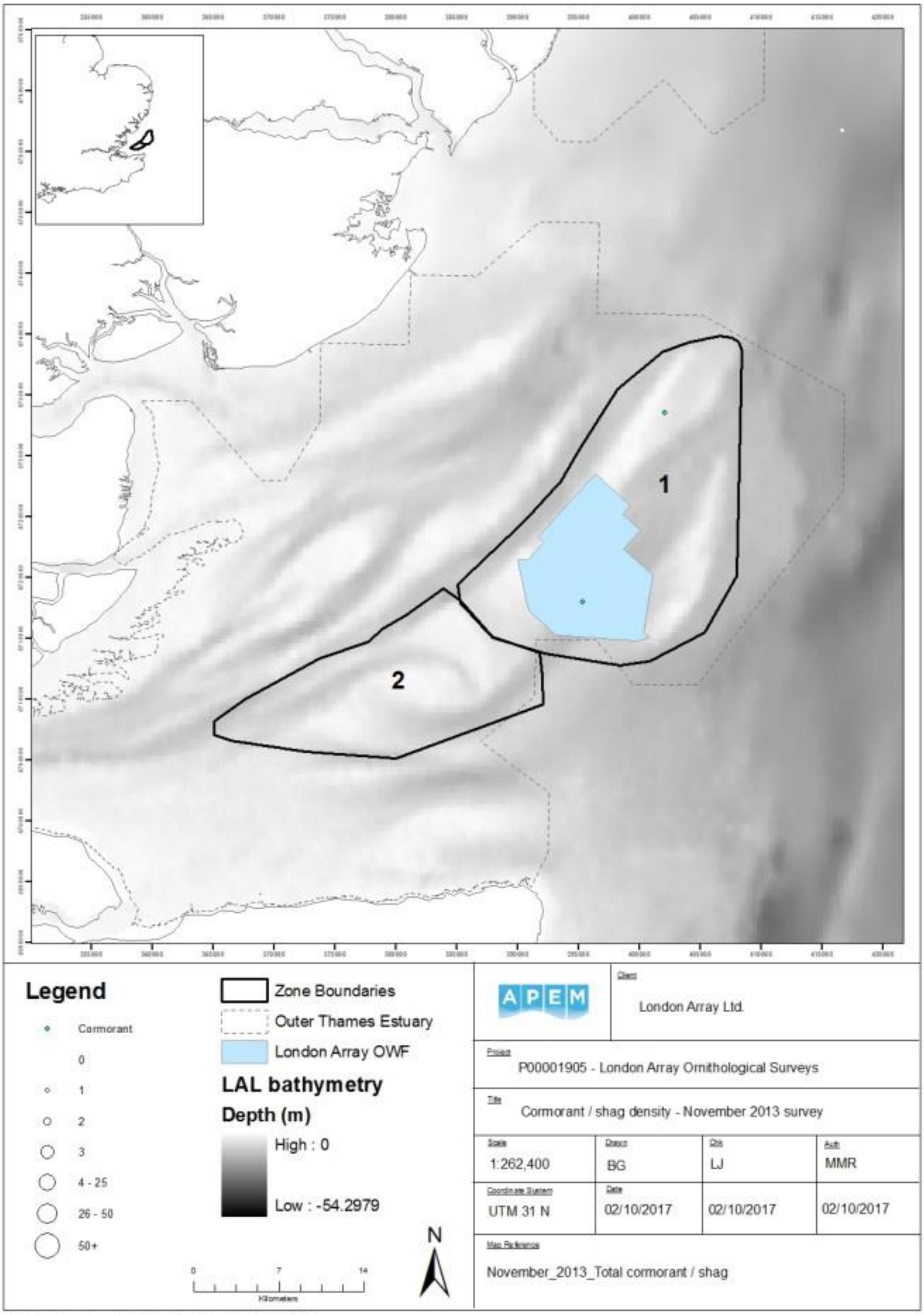

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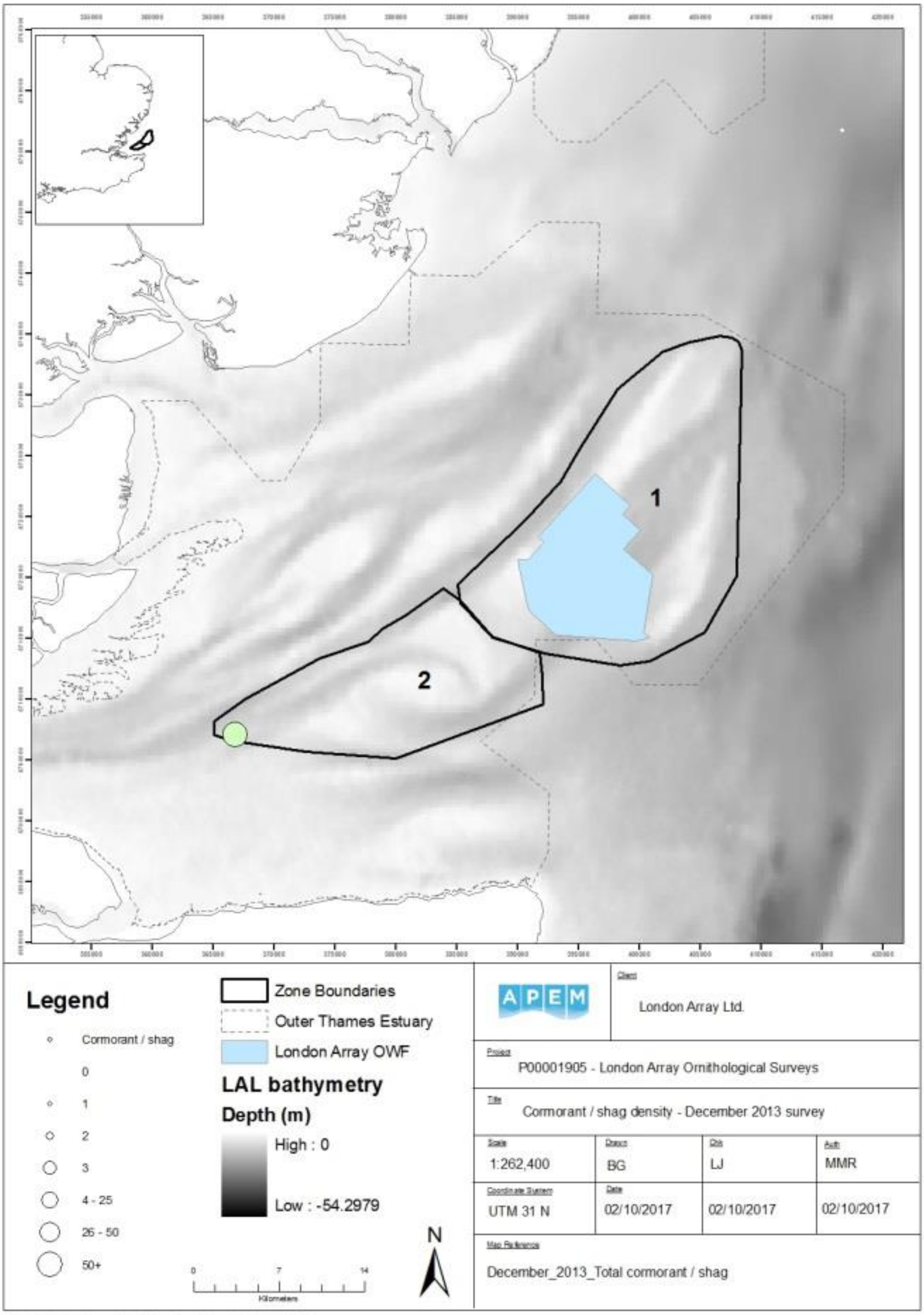

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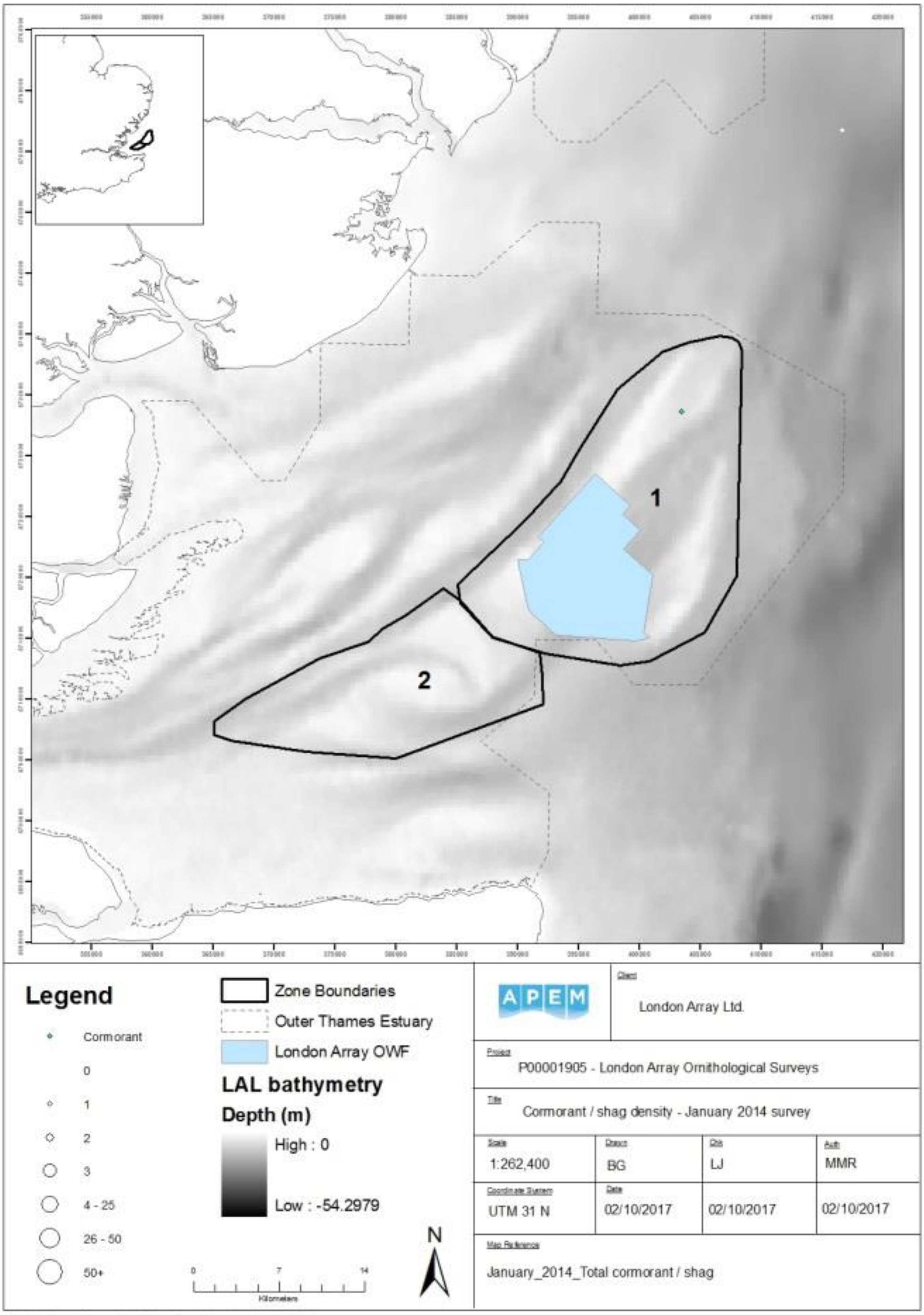

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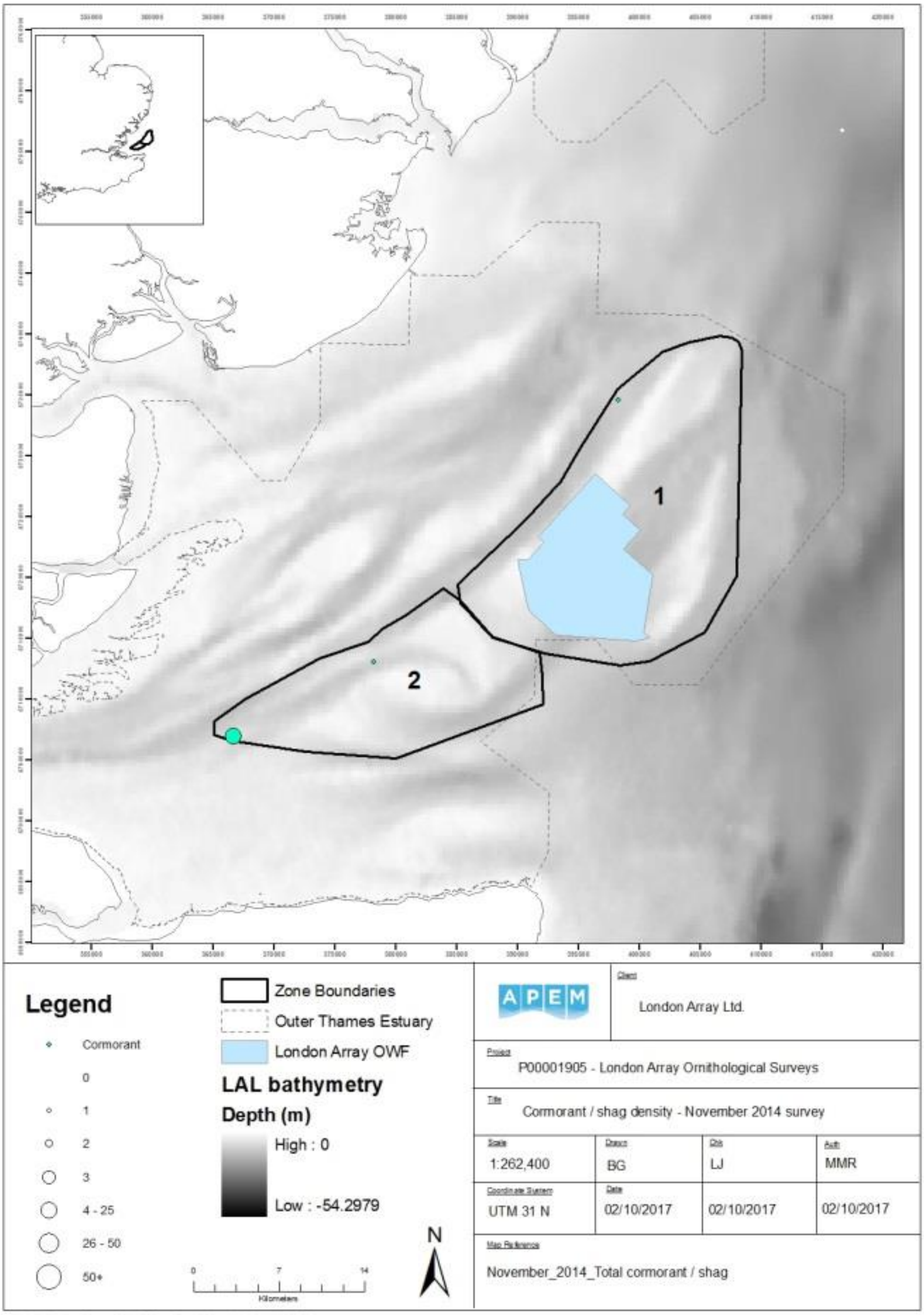

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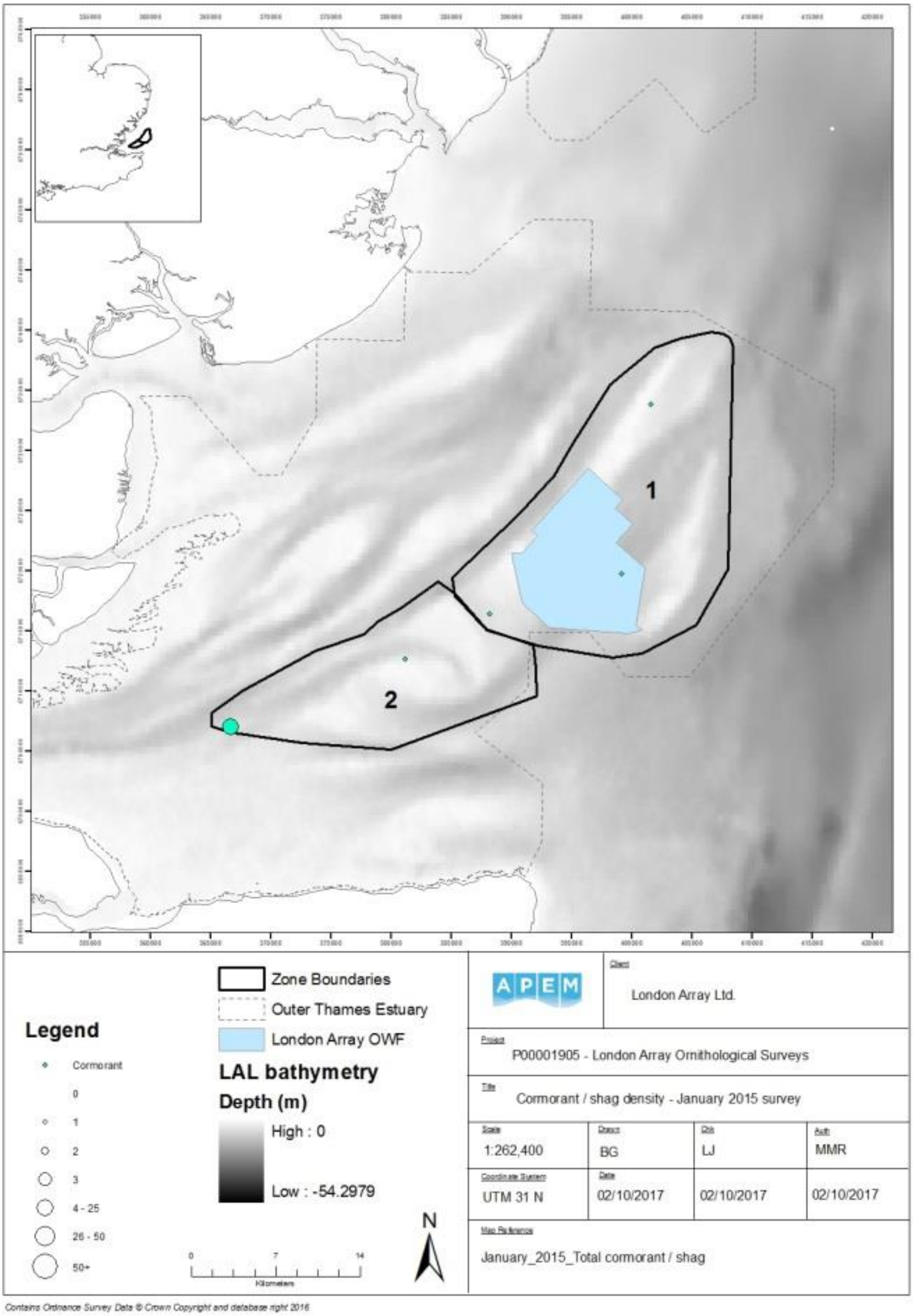

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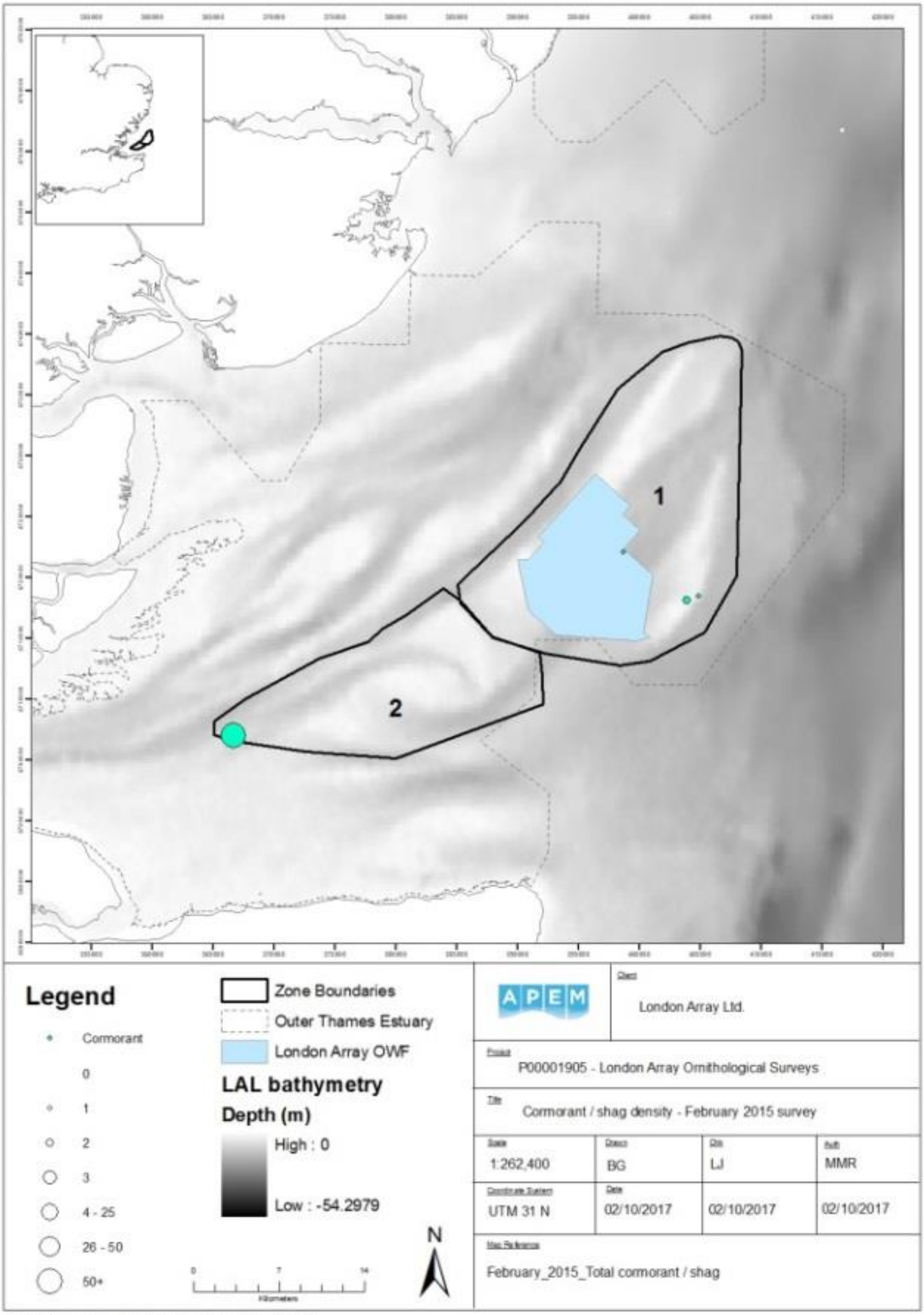

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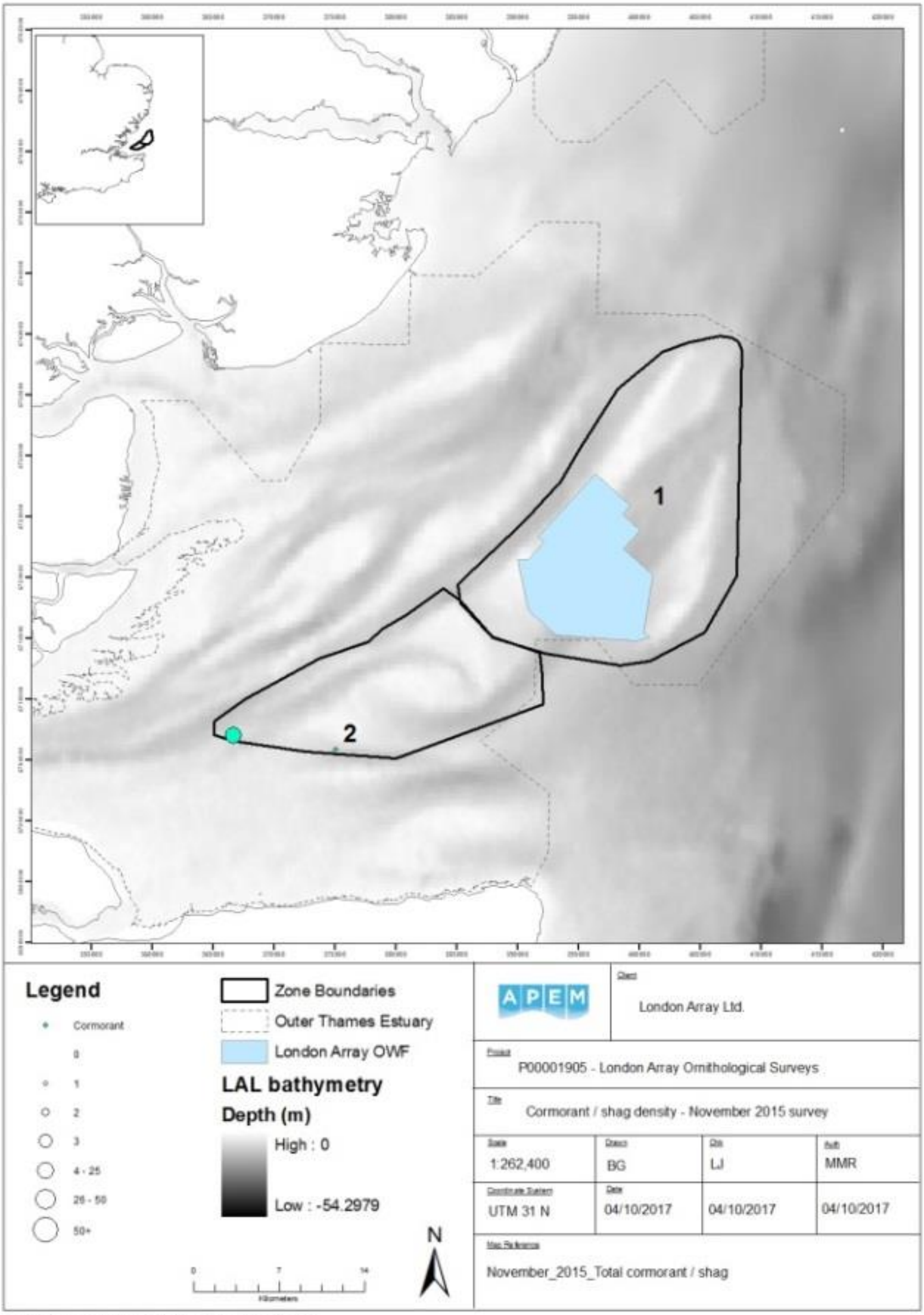

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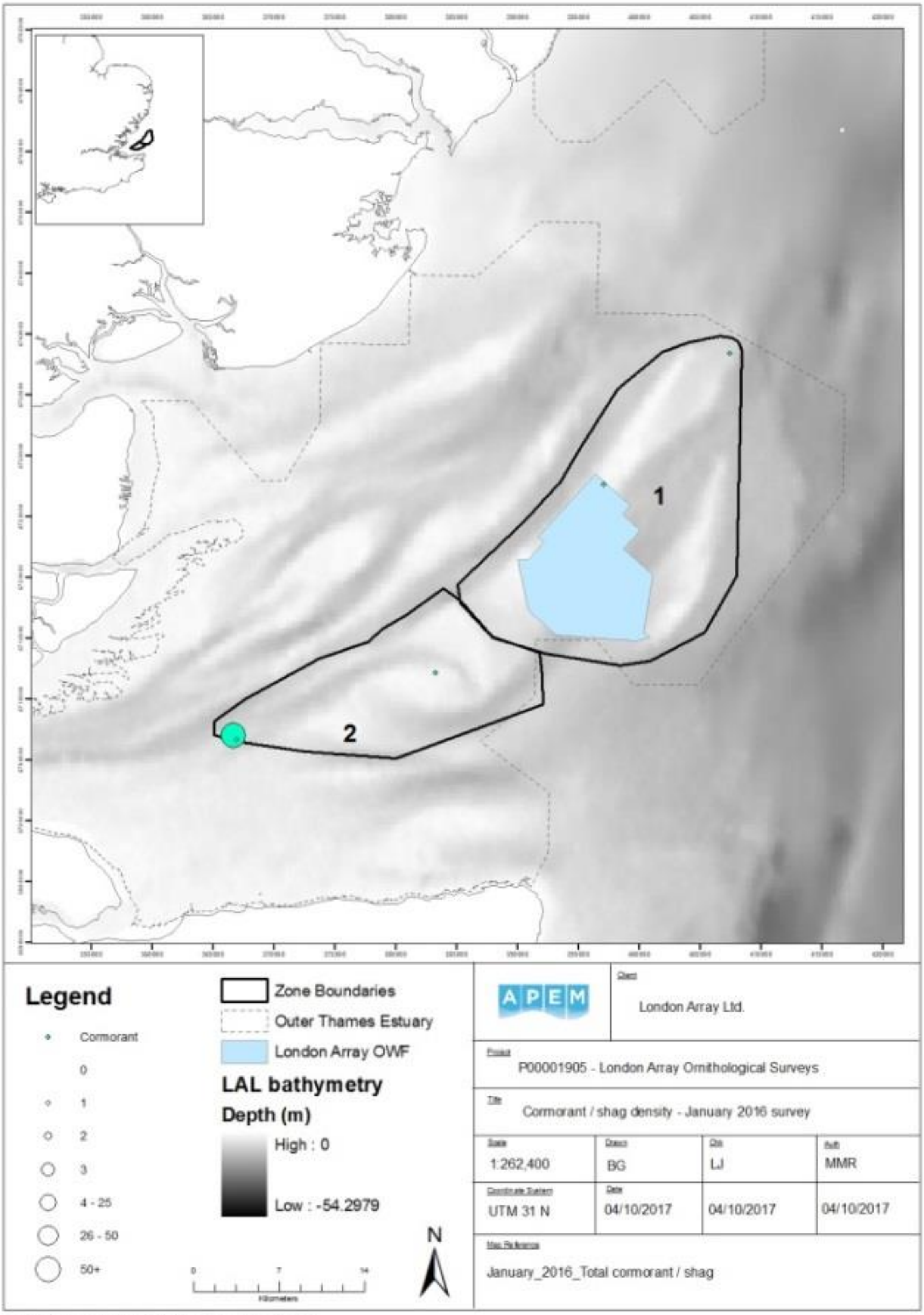

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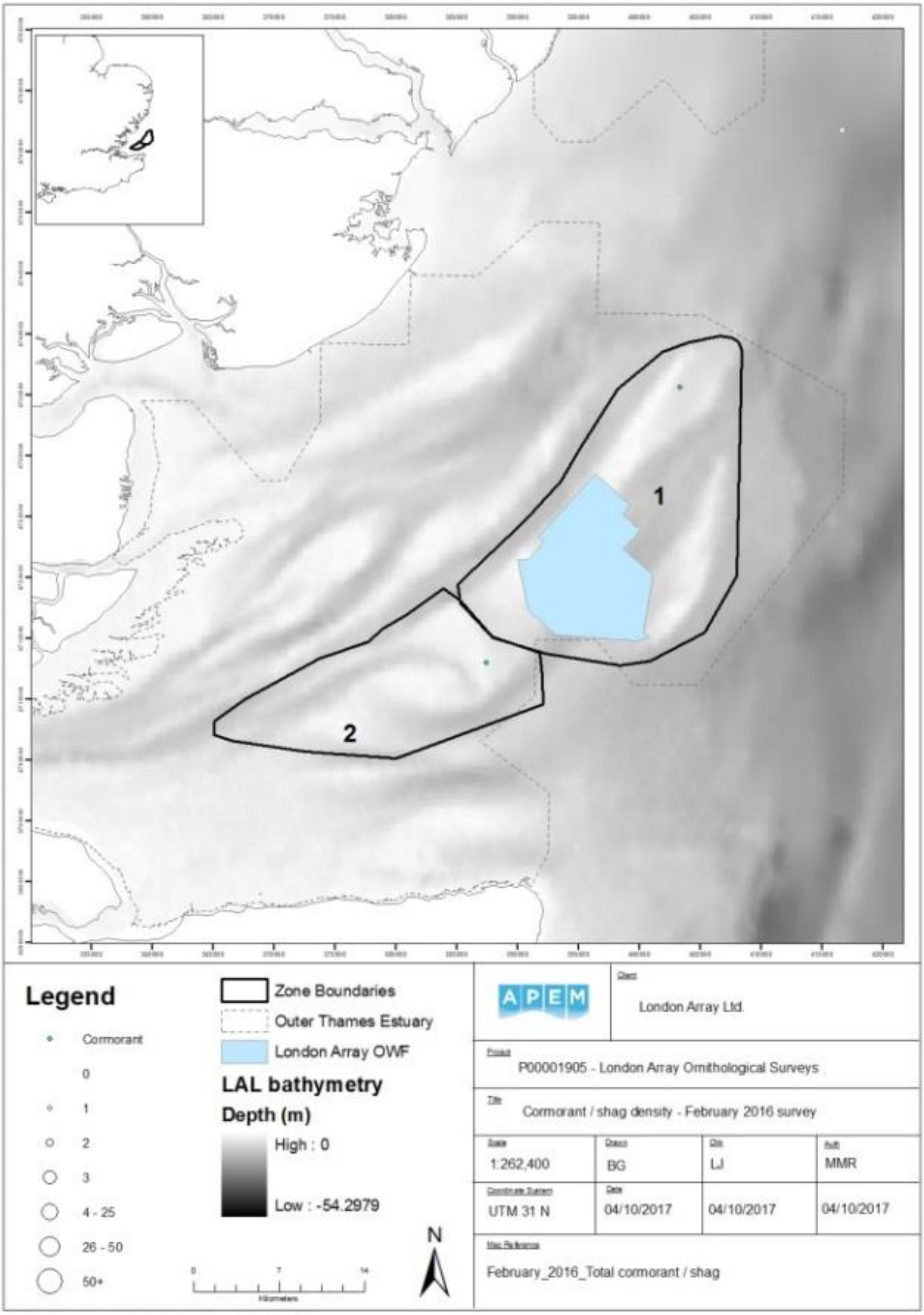
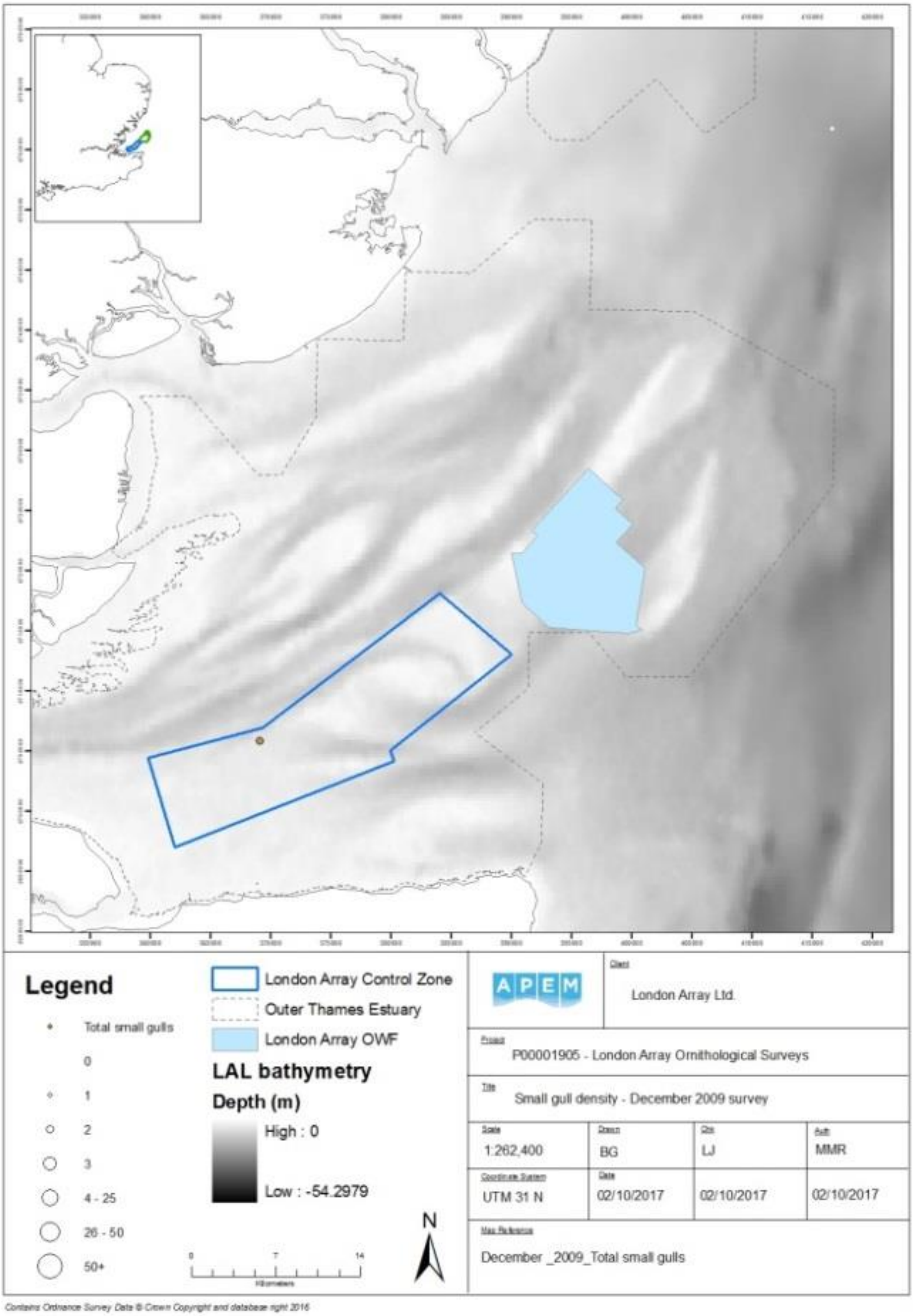


February 2016

Figure 5 **Monthly distribution maps for cormorant/shags recorded in the pre-, during- and post-construction aerial surveys of the LAW.**

Small Gulls



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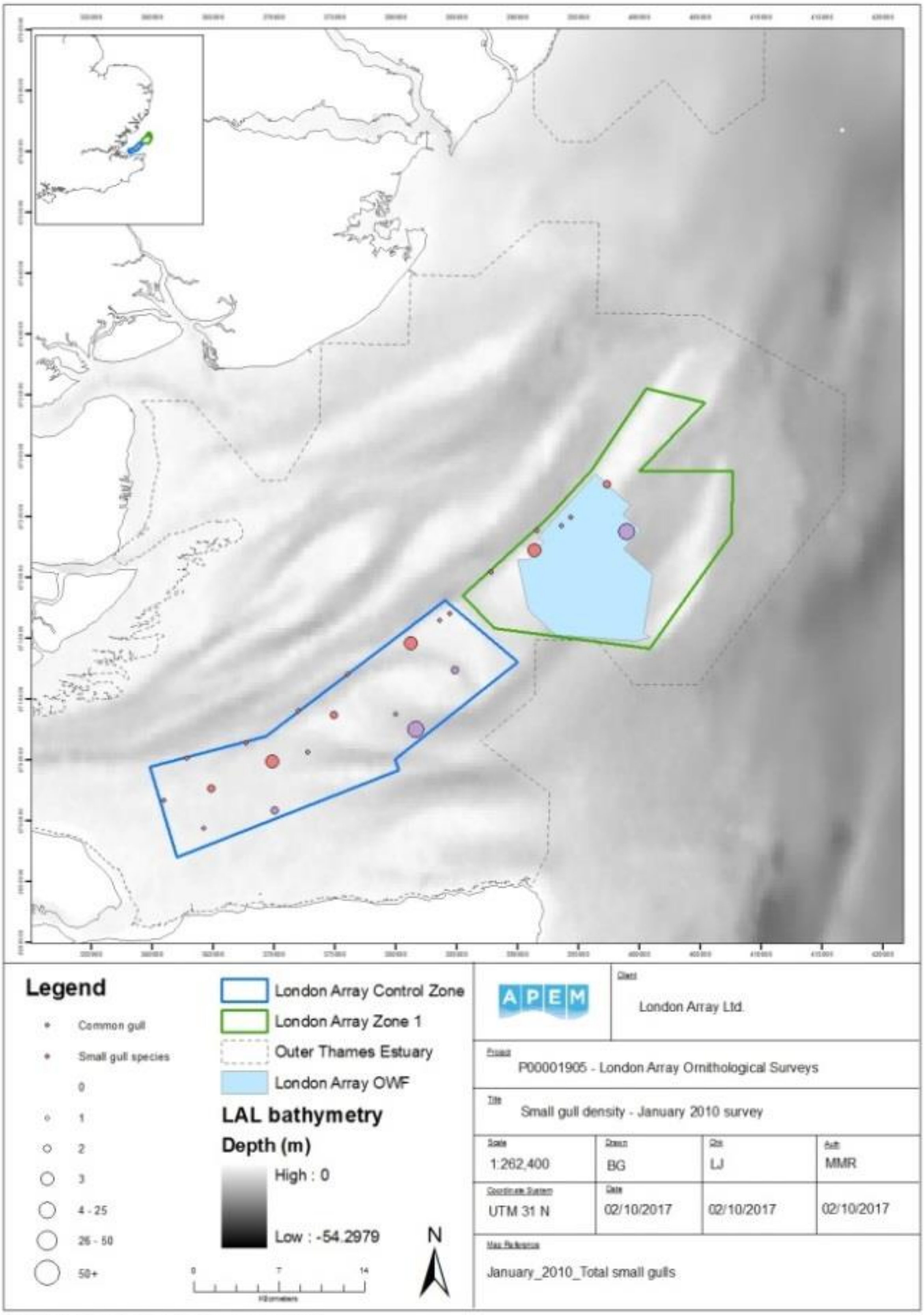

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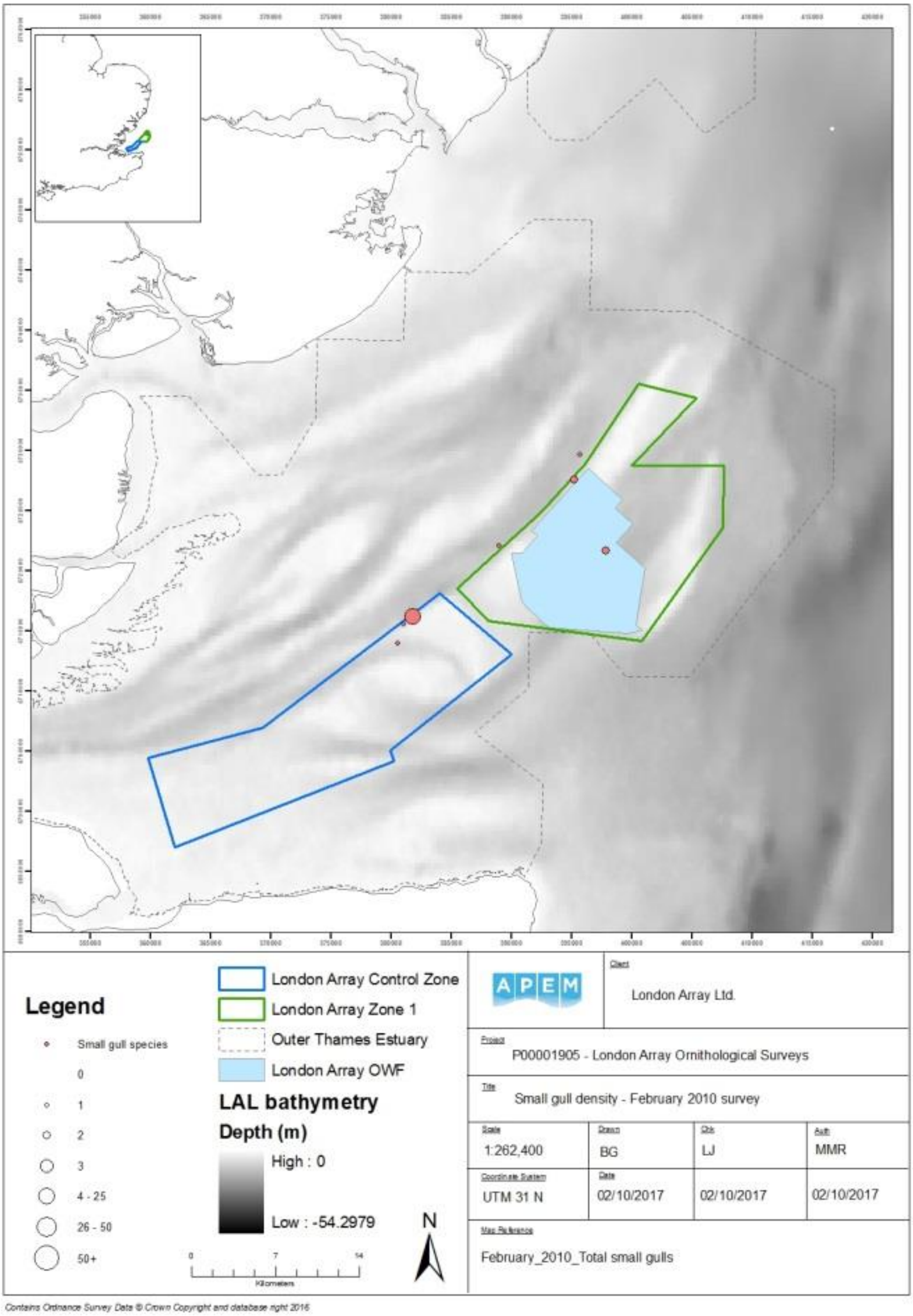

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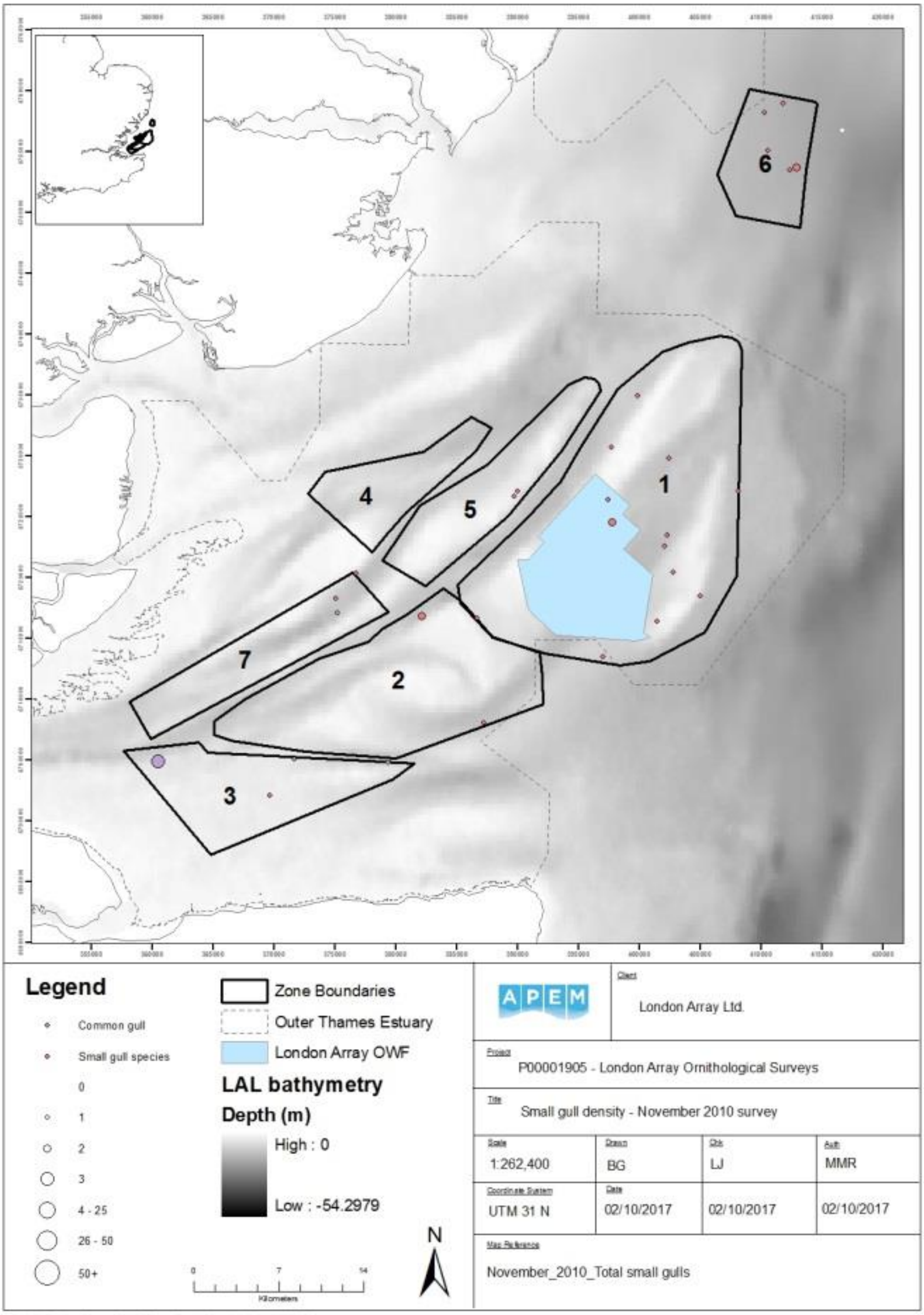

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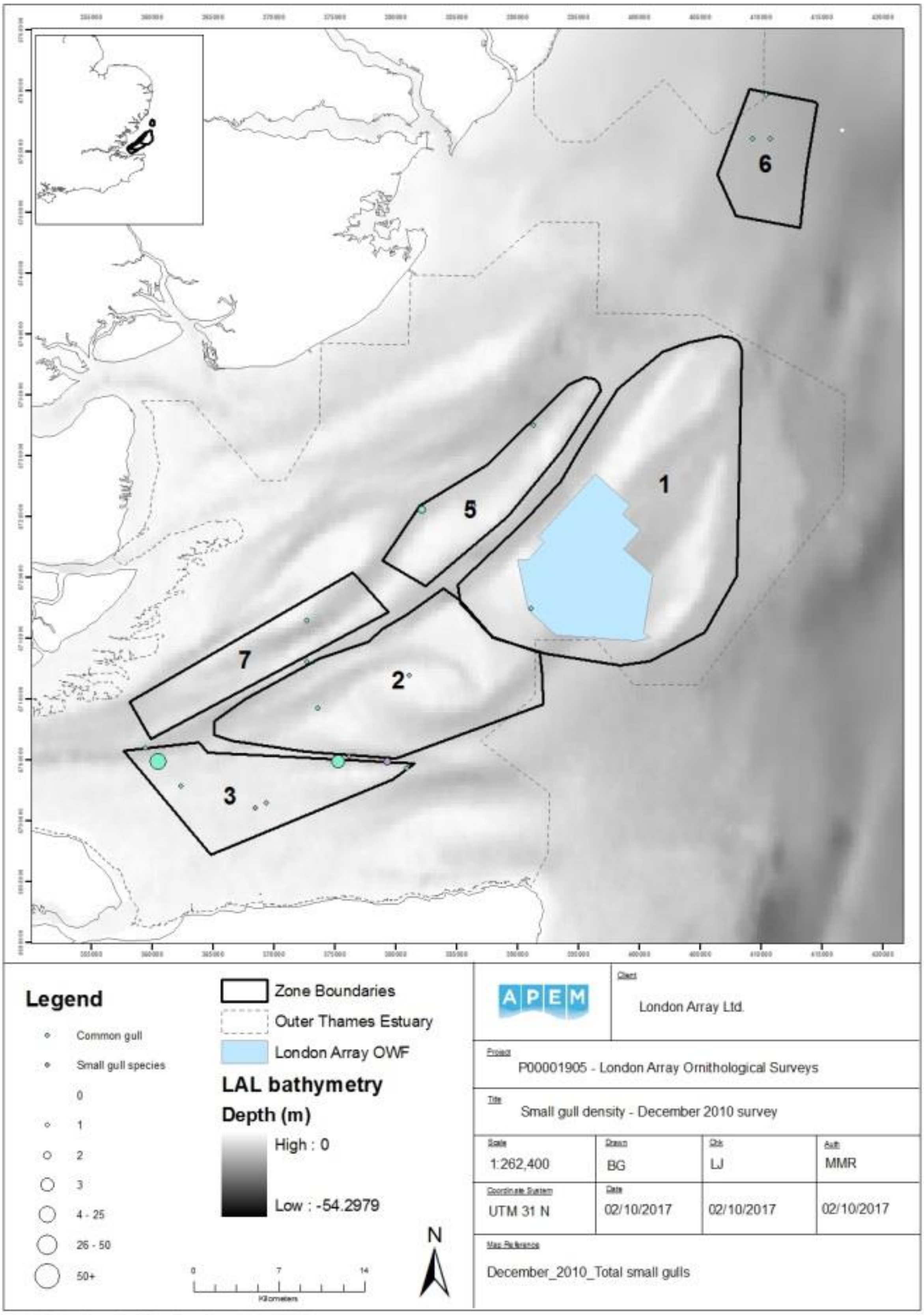

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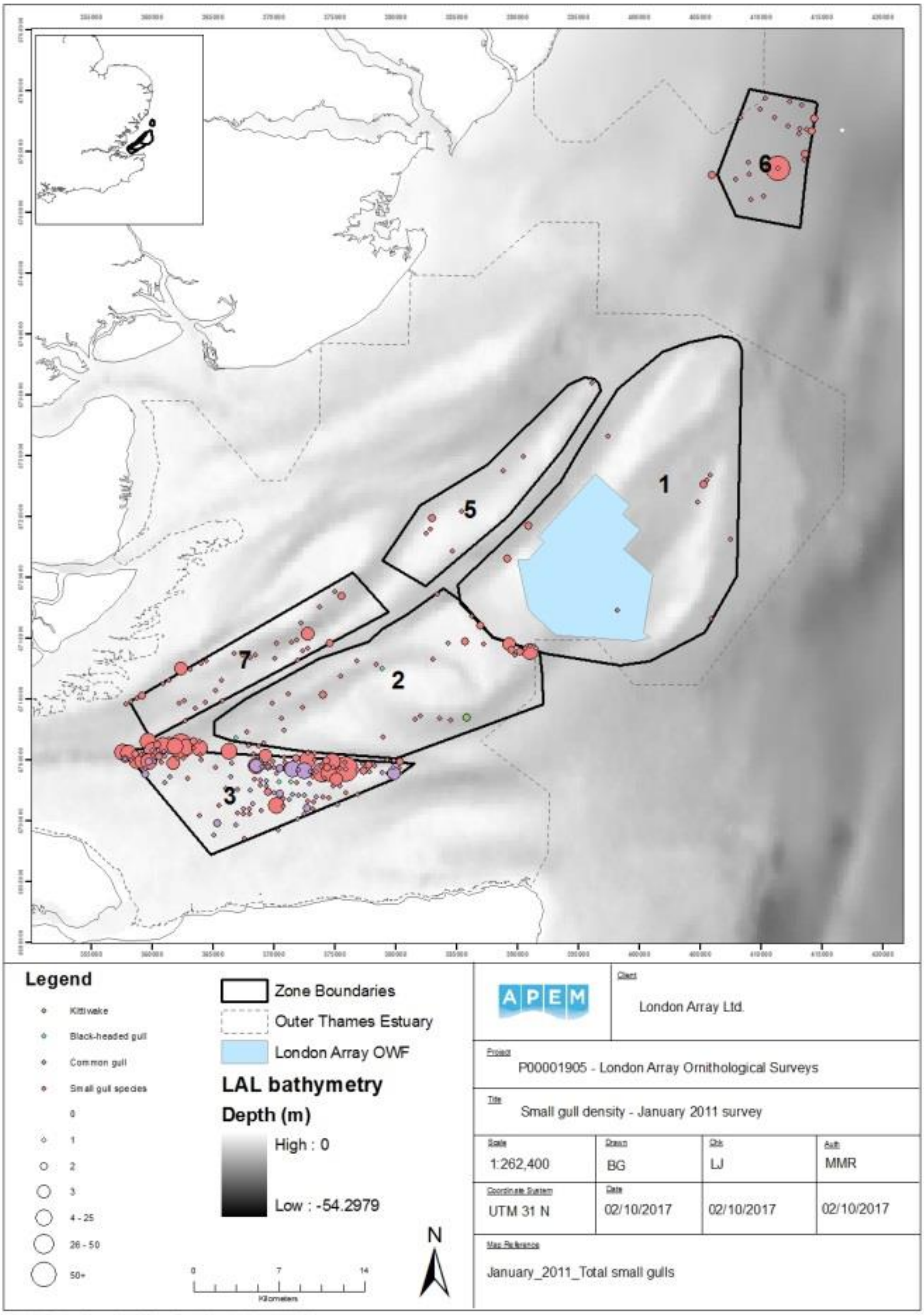

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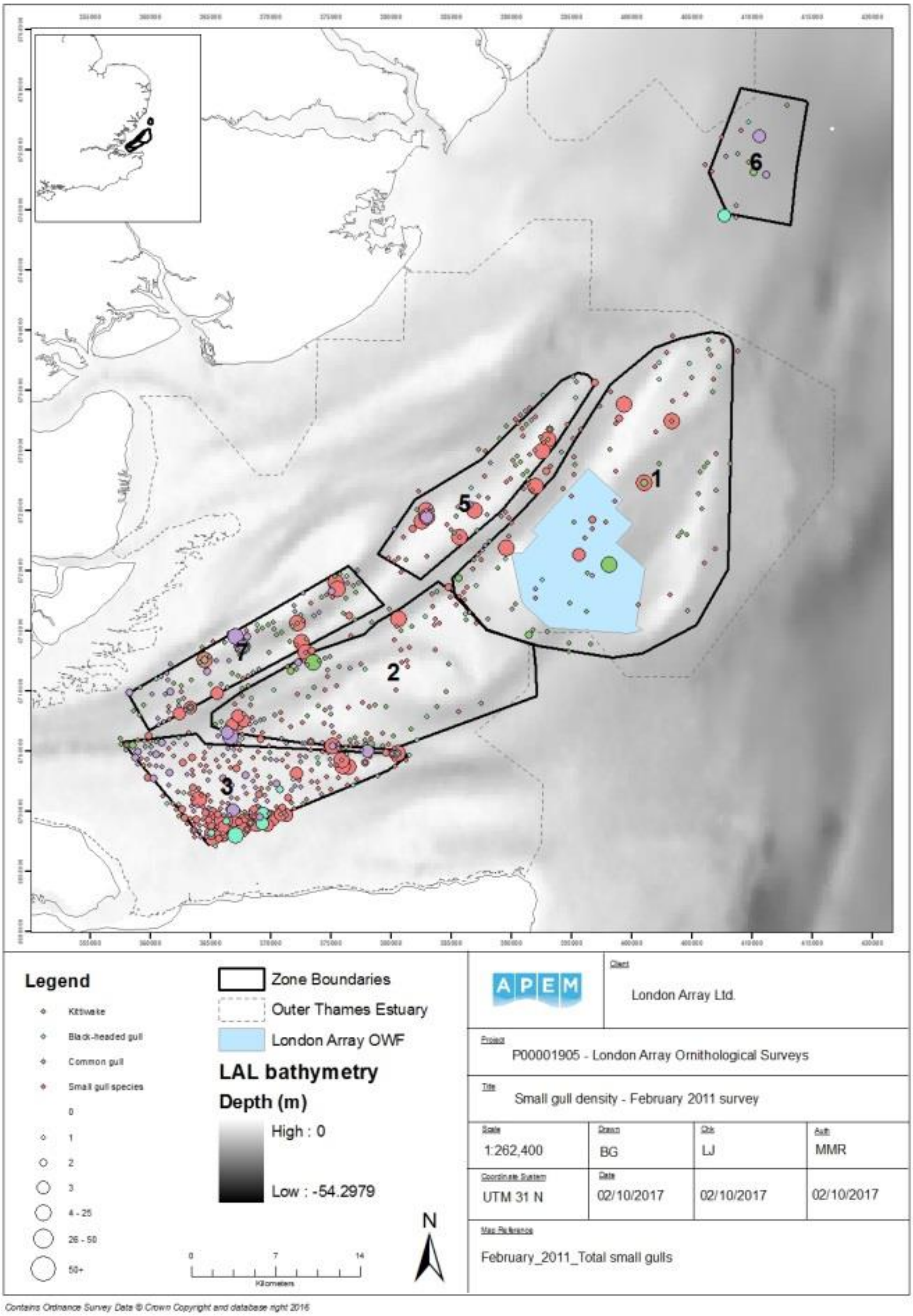

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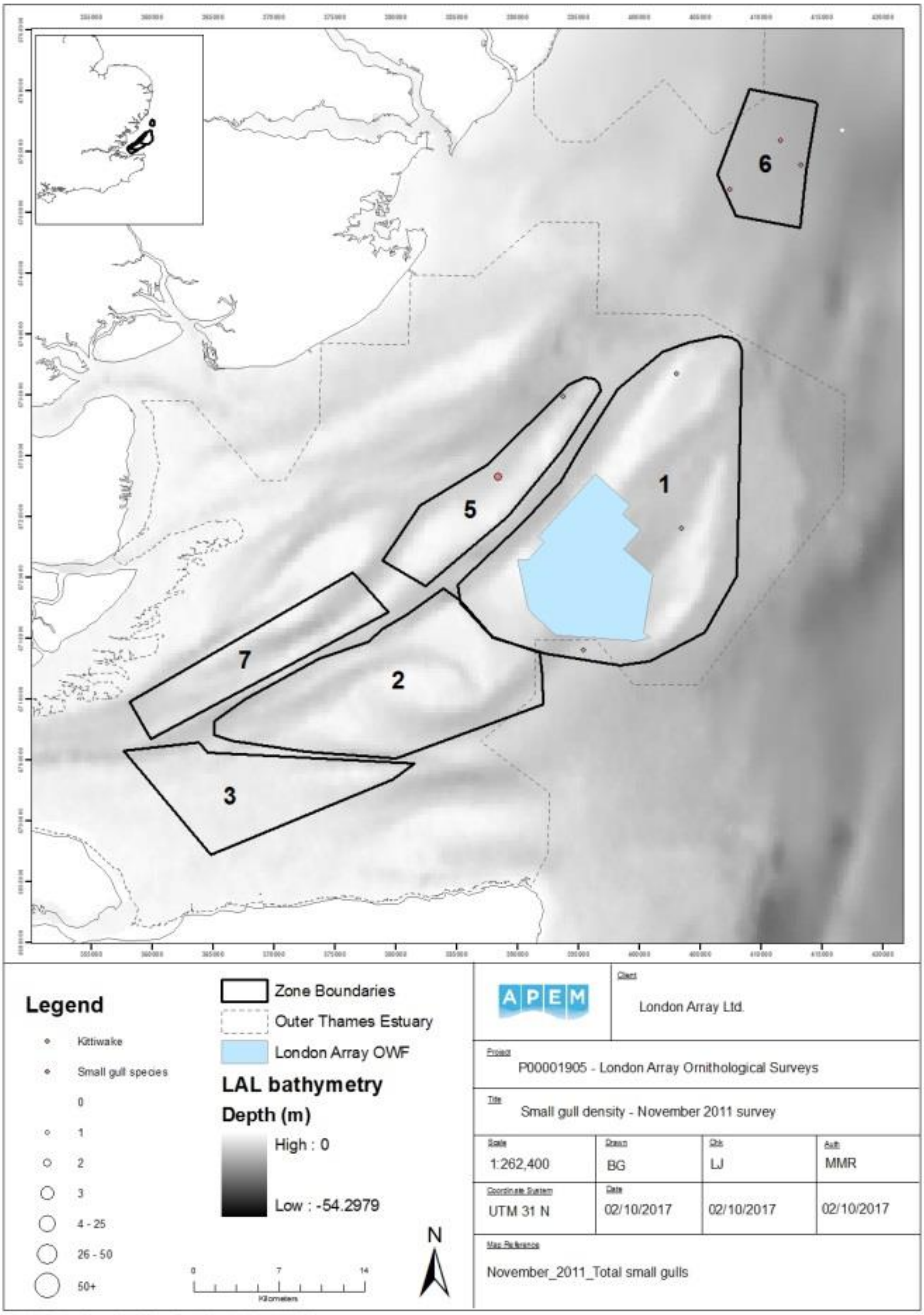

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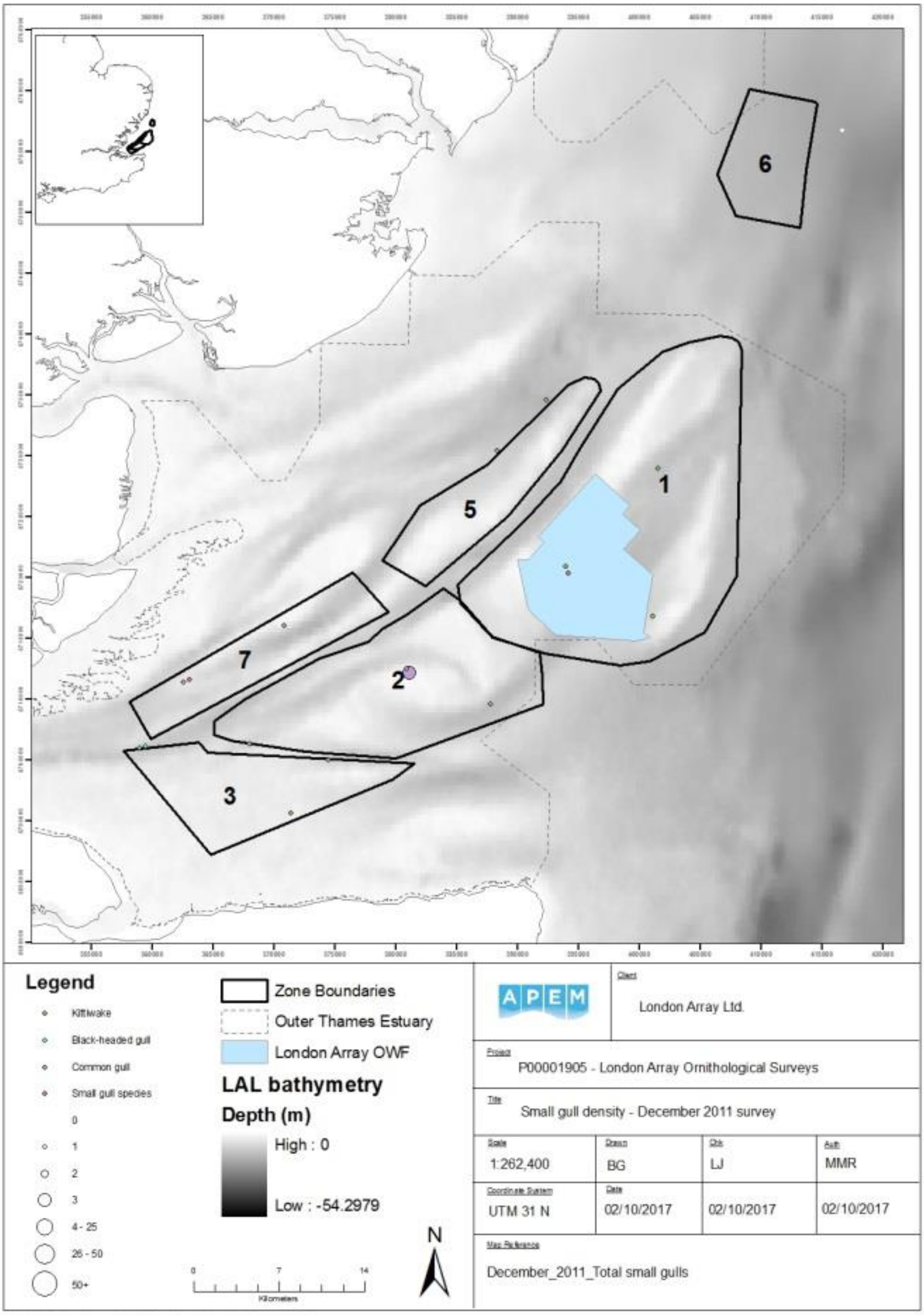

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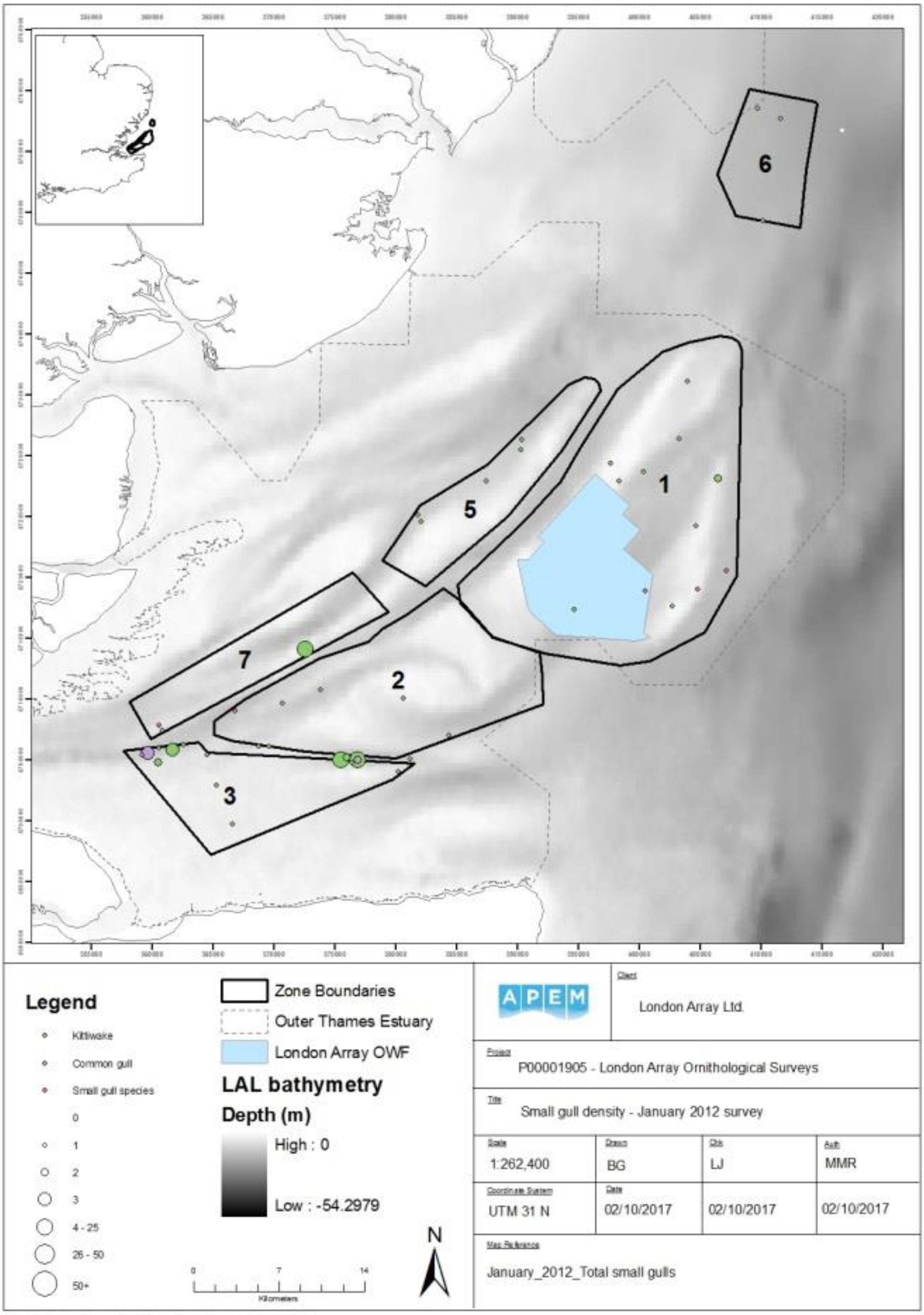

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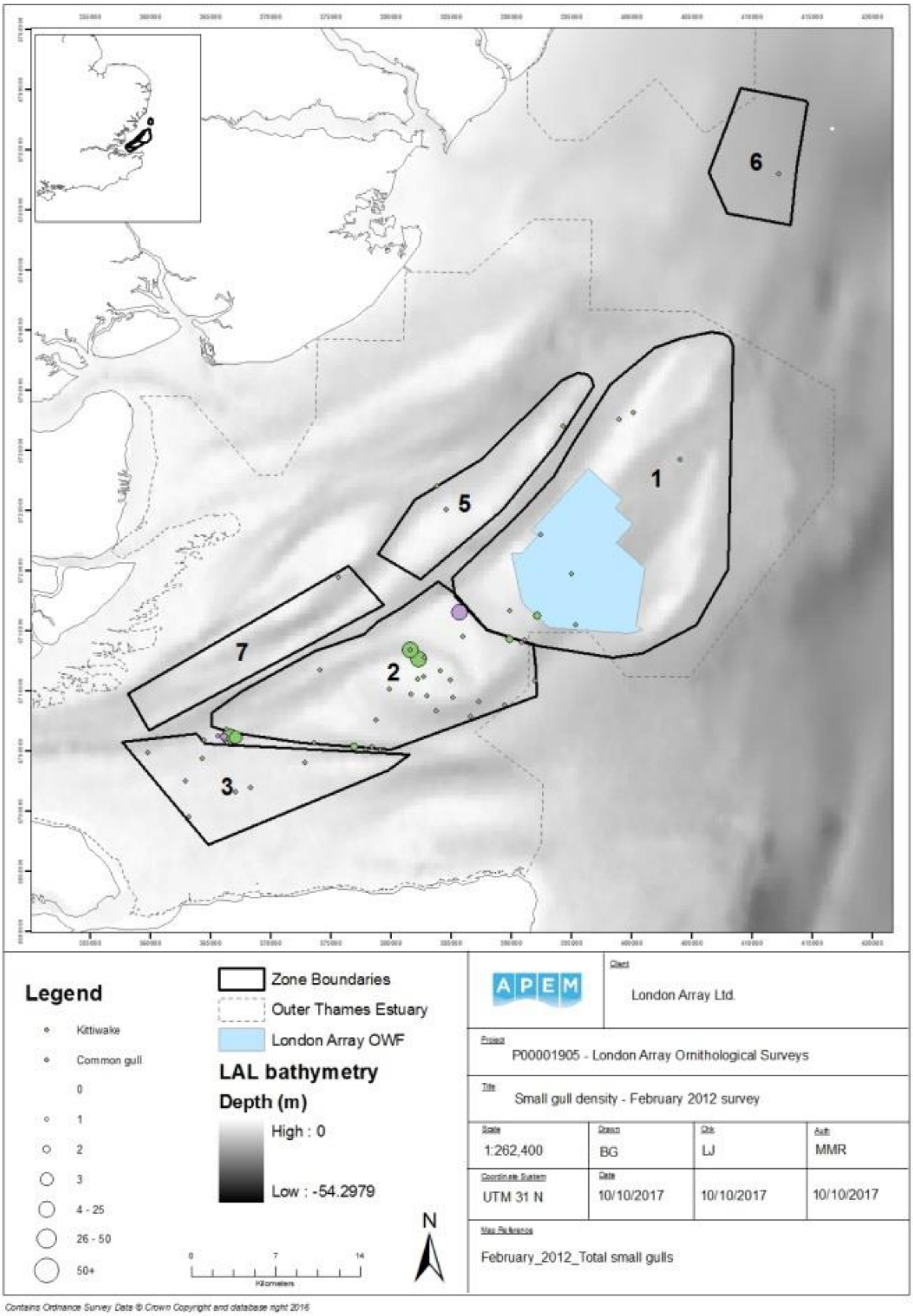

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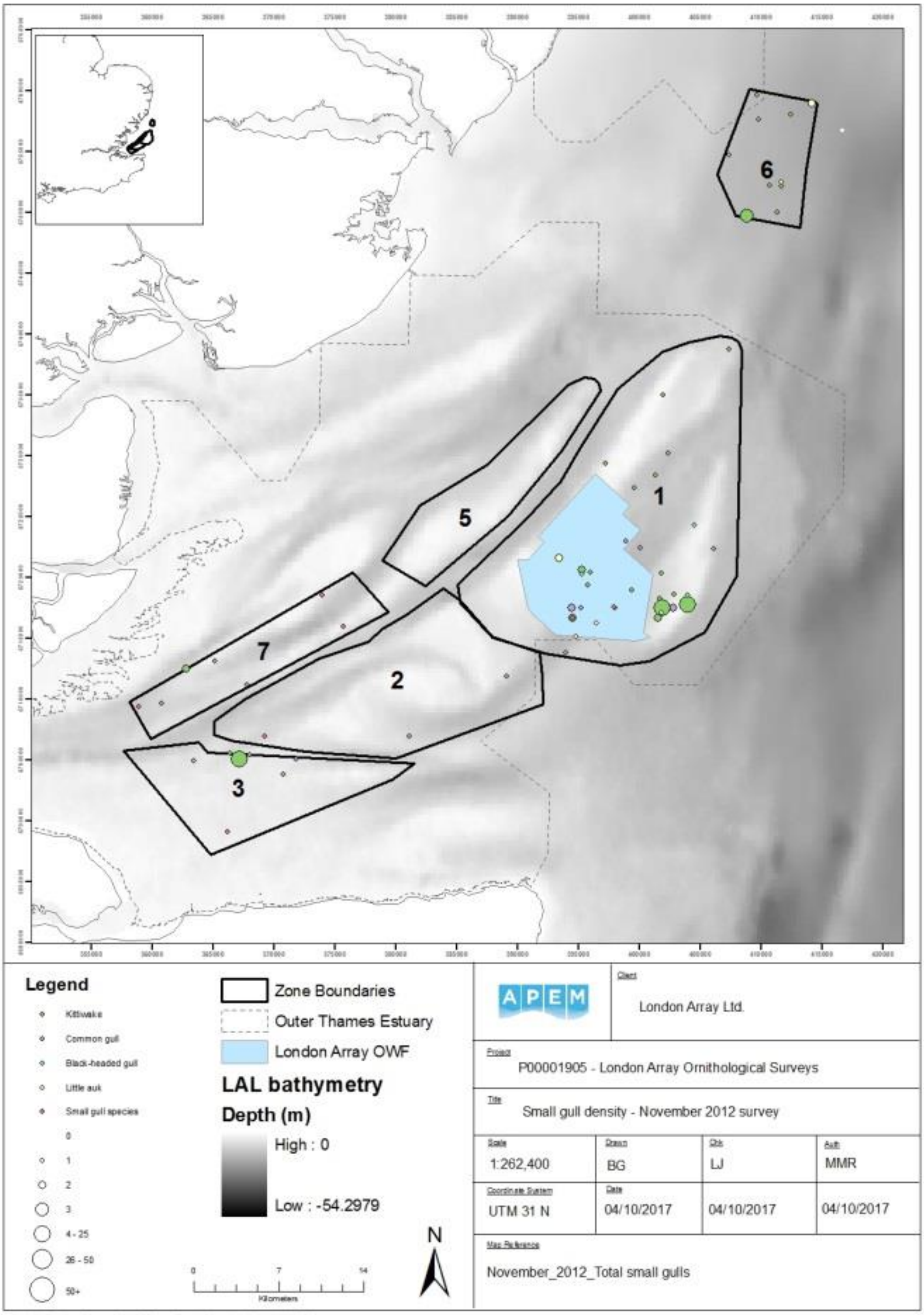

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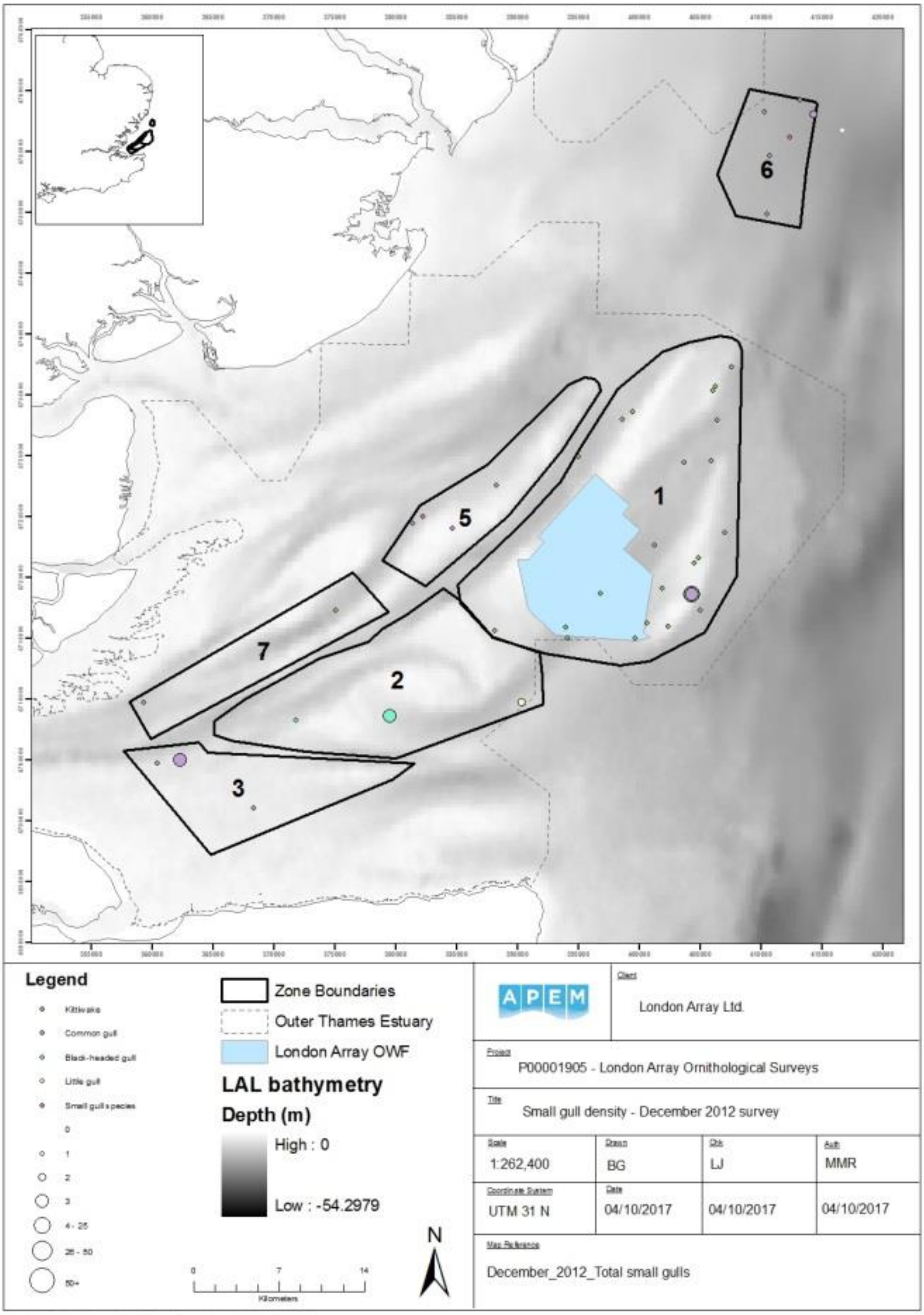

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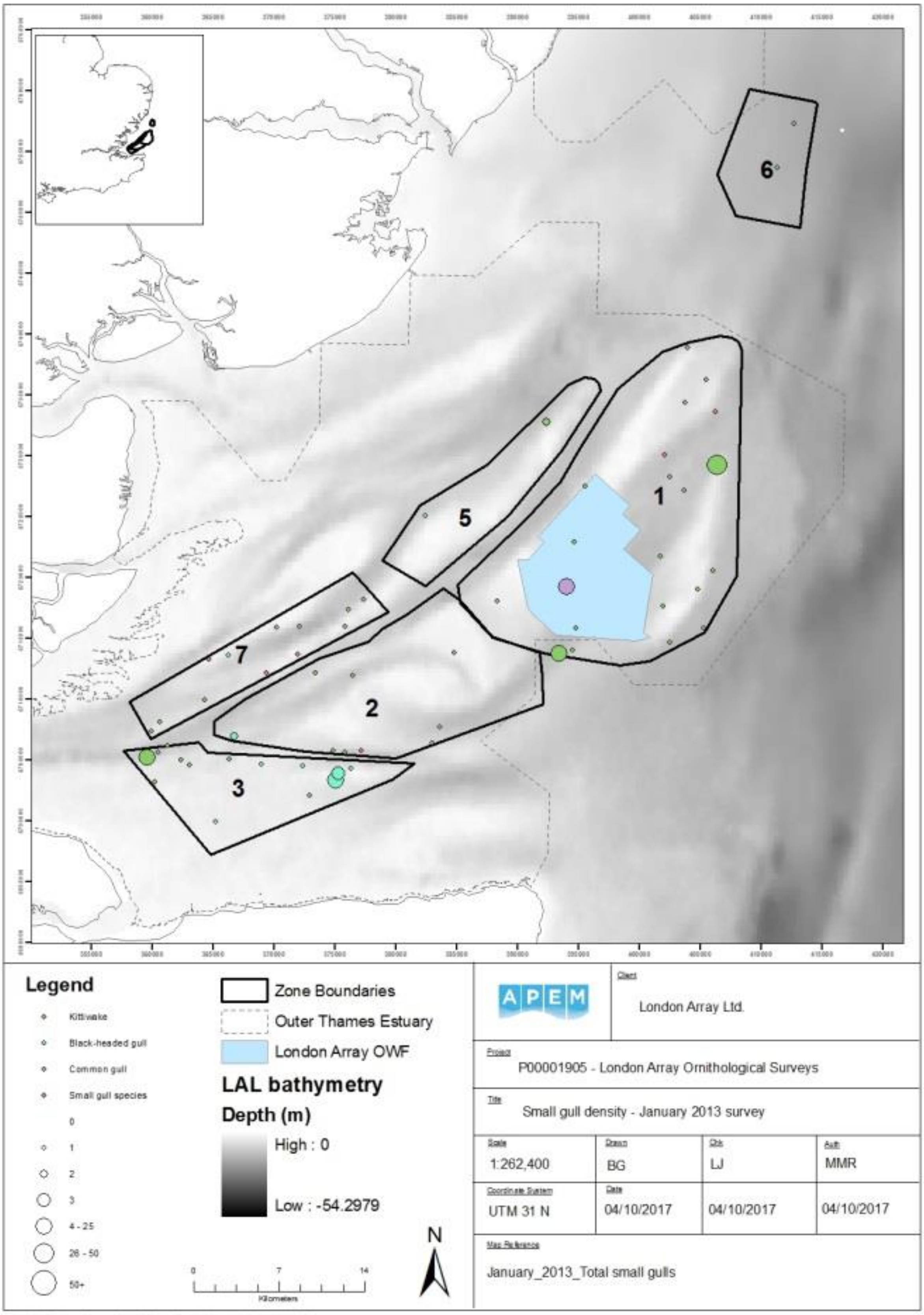

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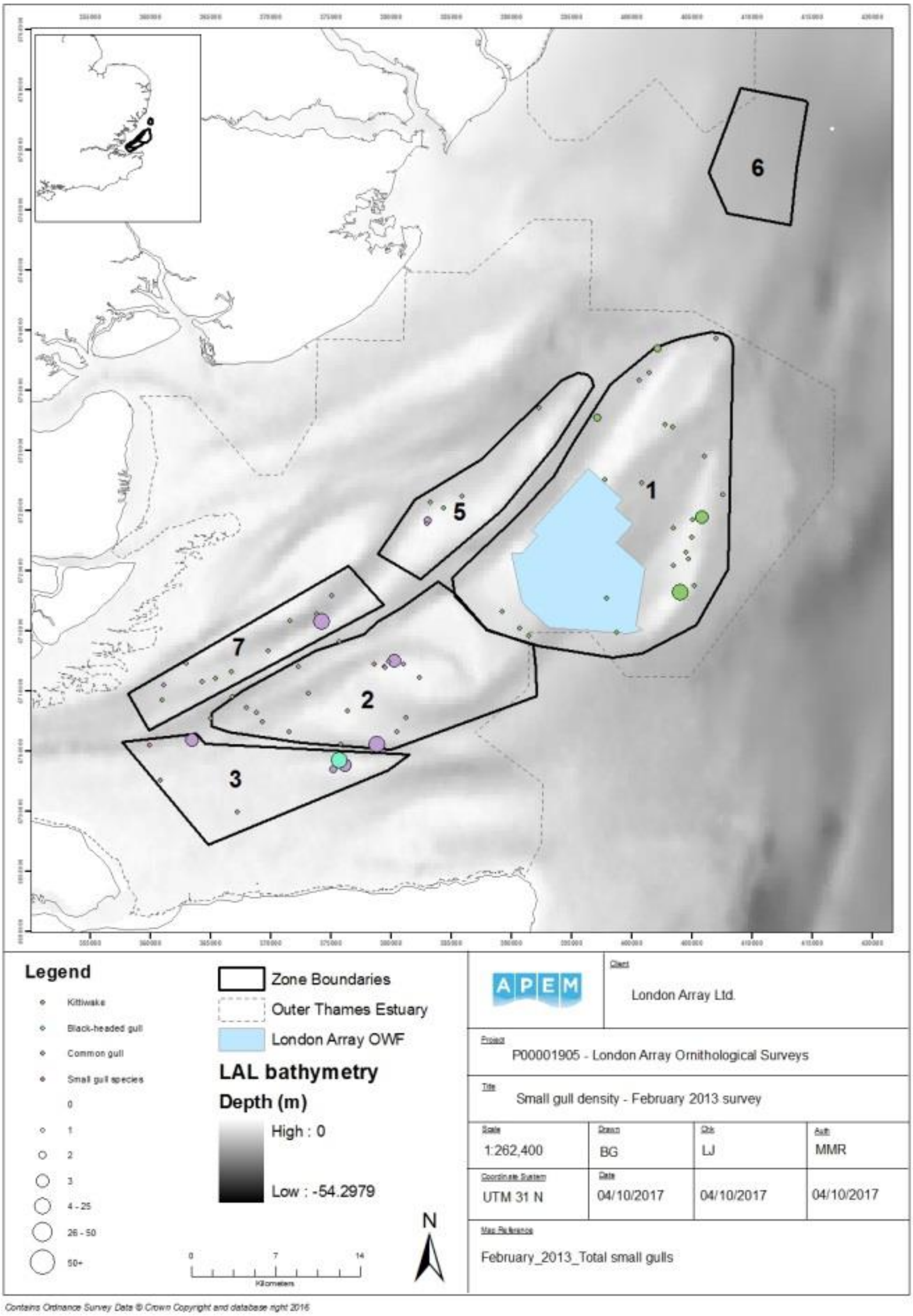

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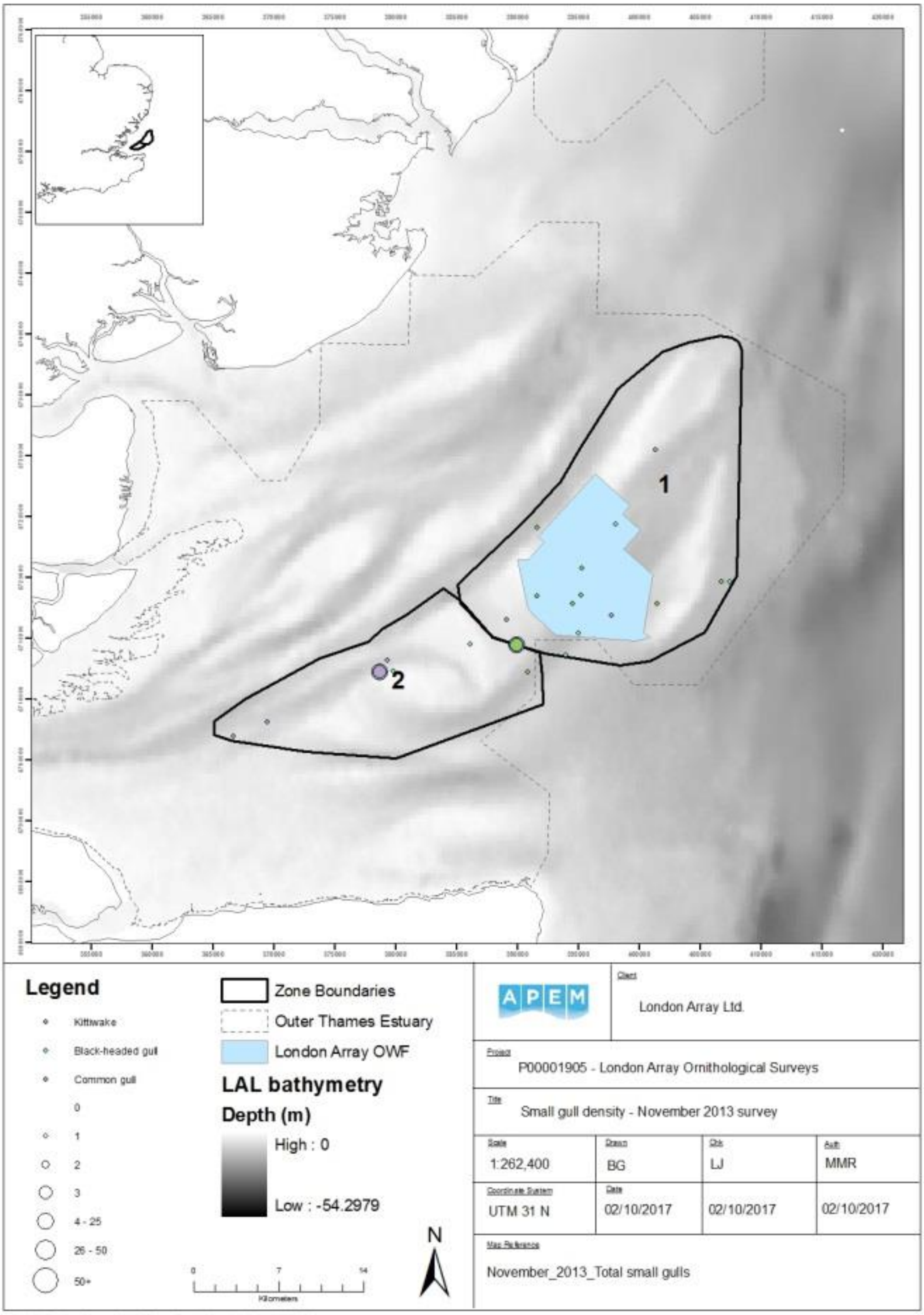

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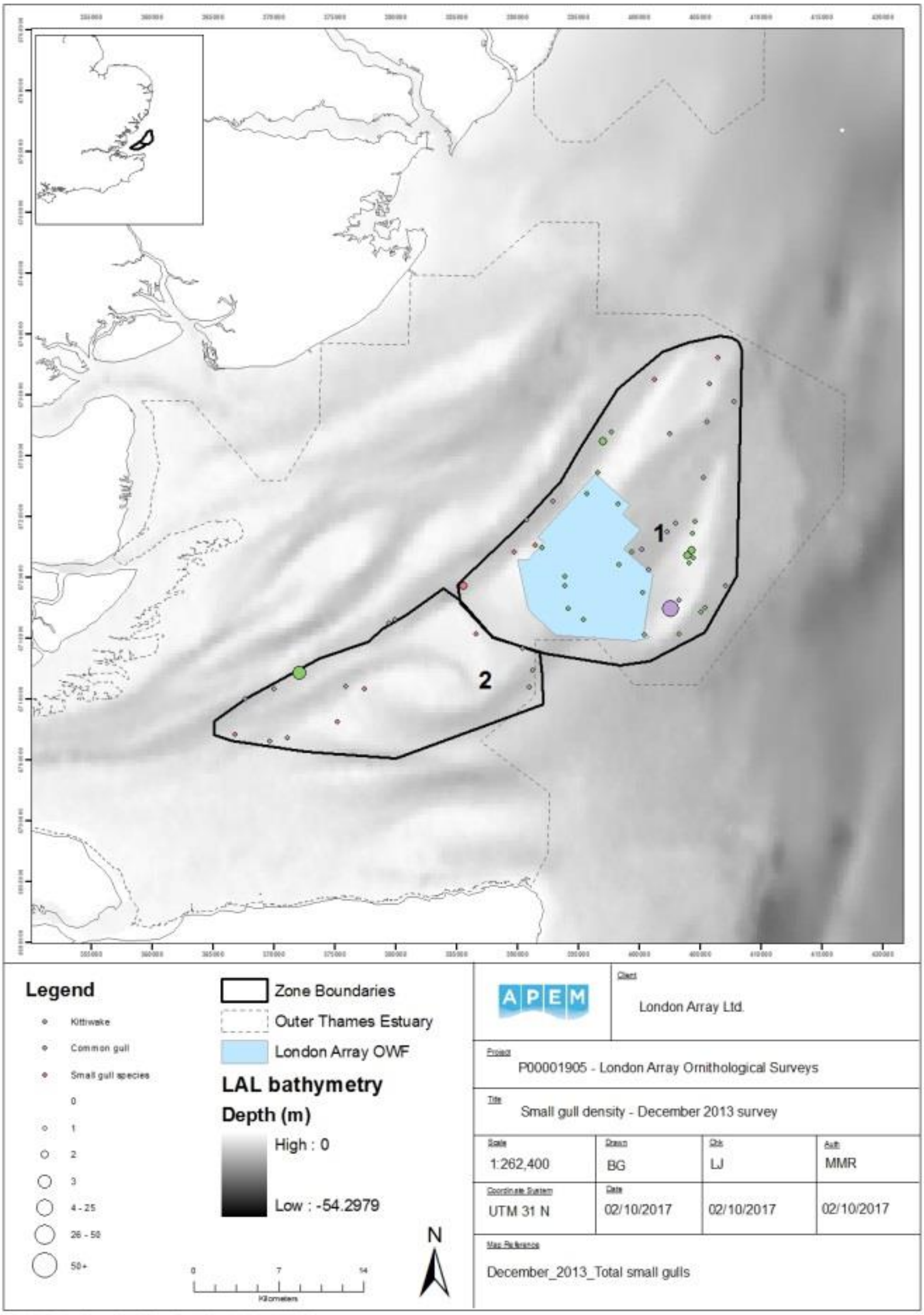

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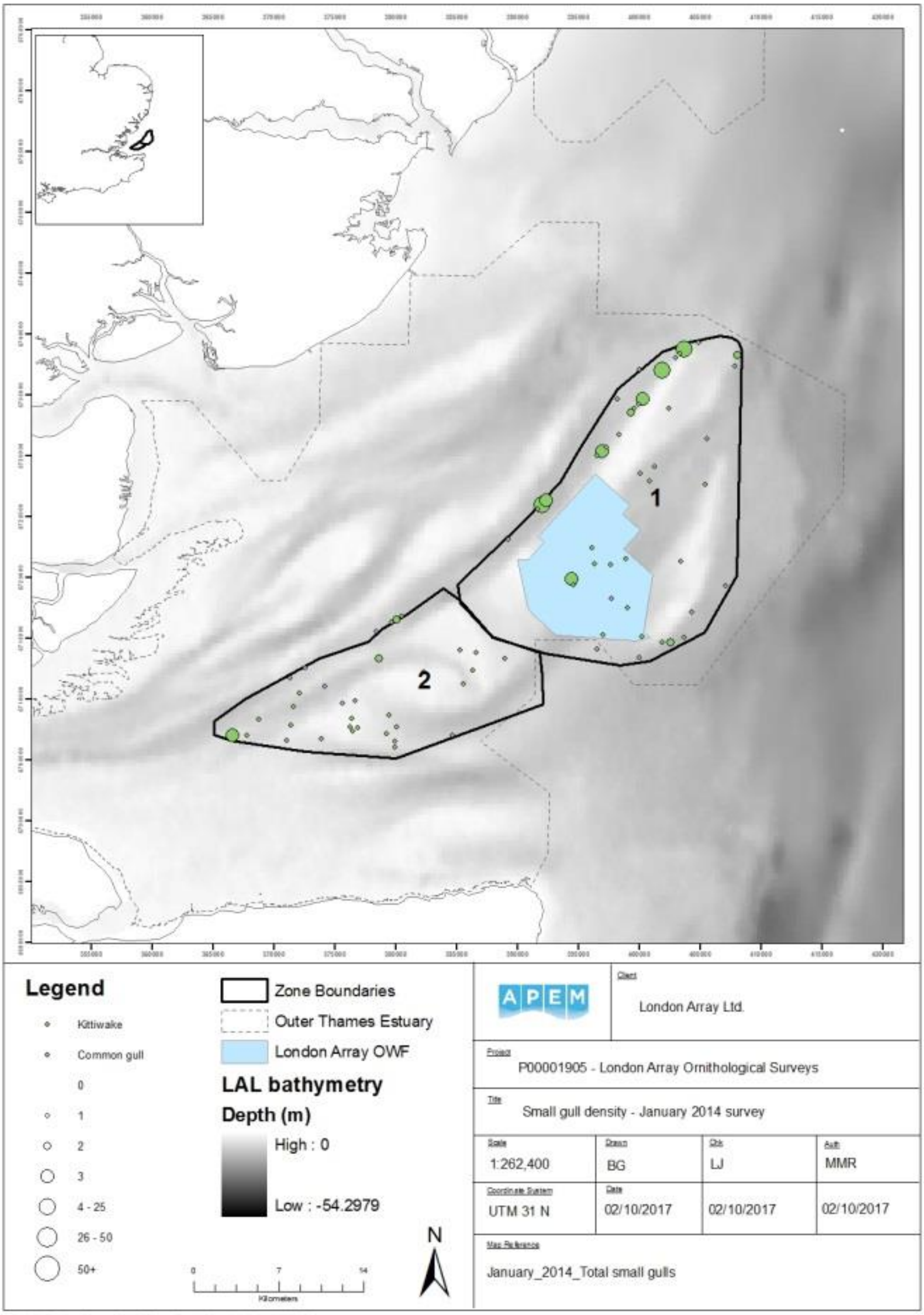

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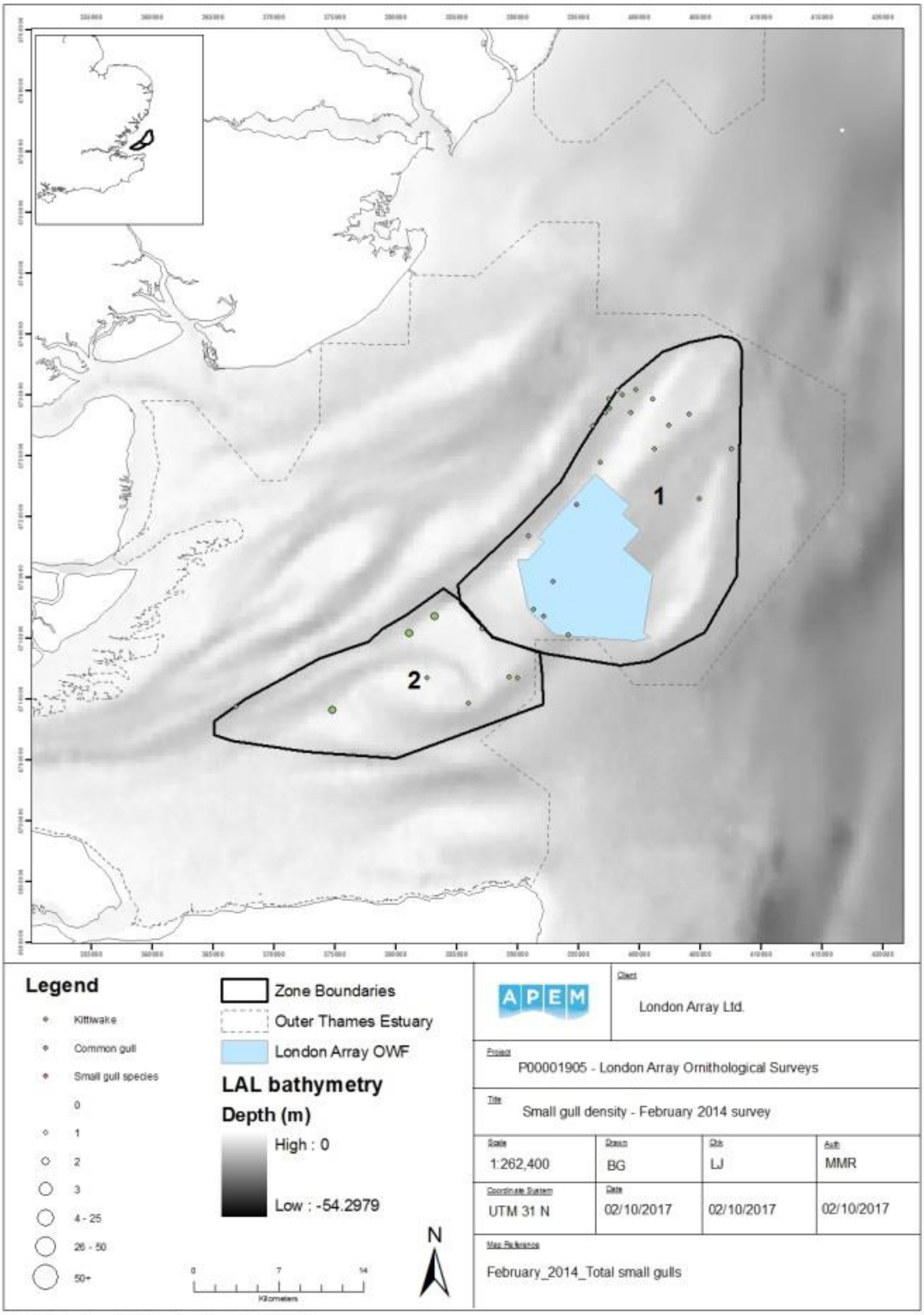

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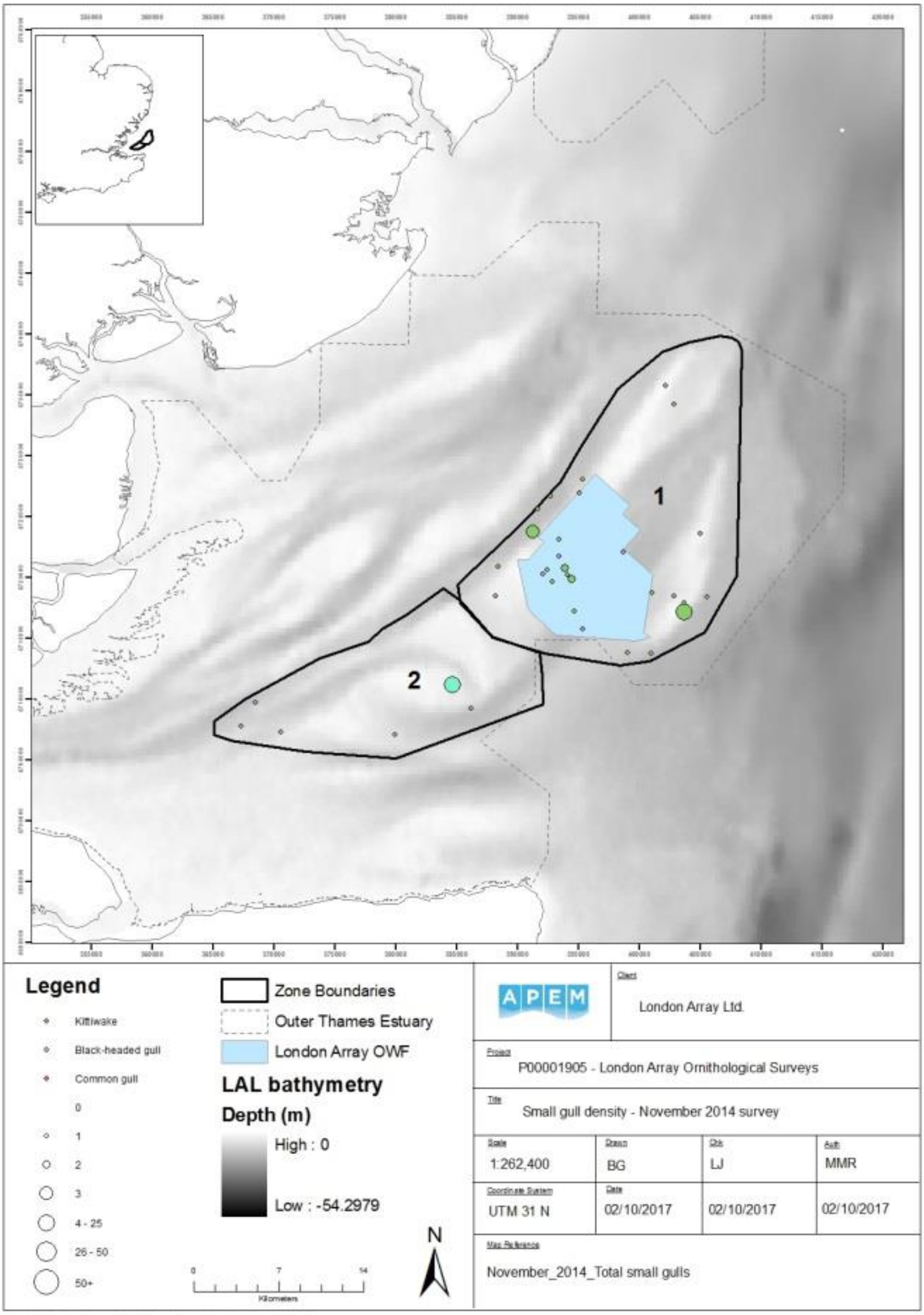

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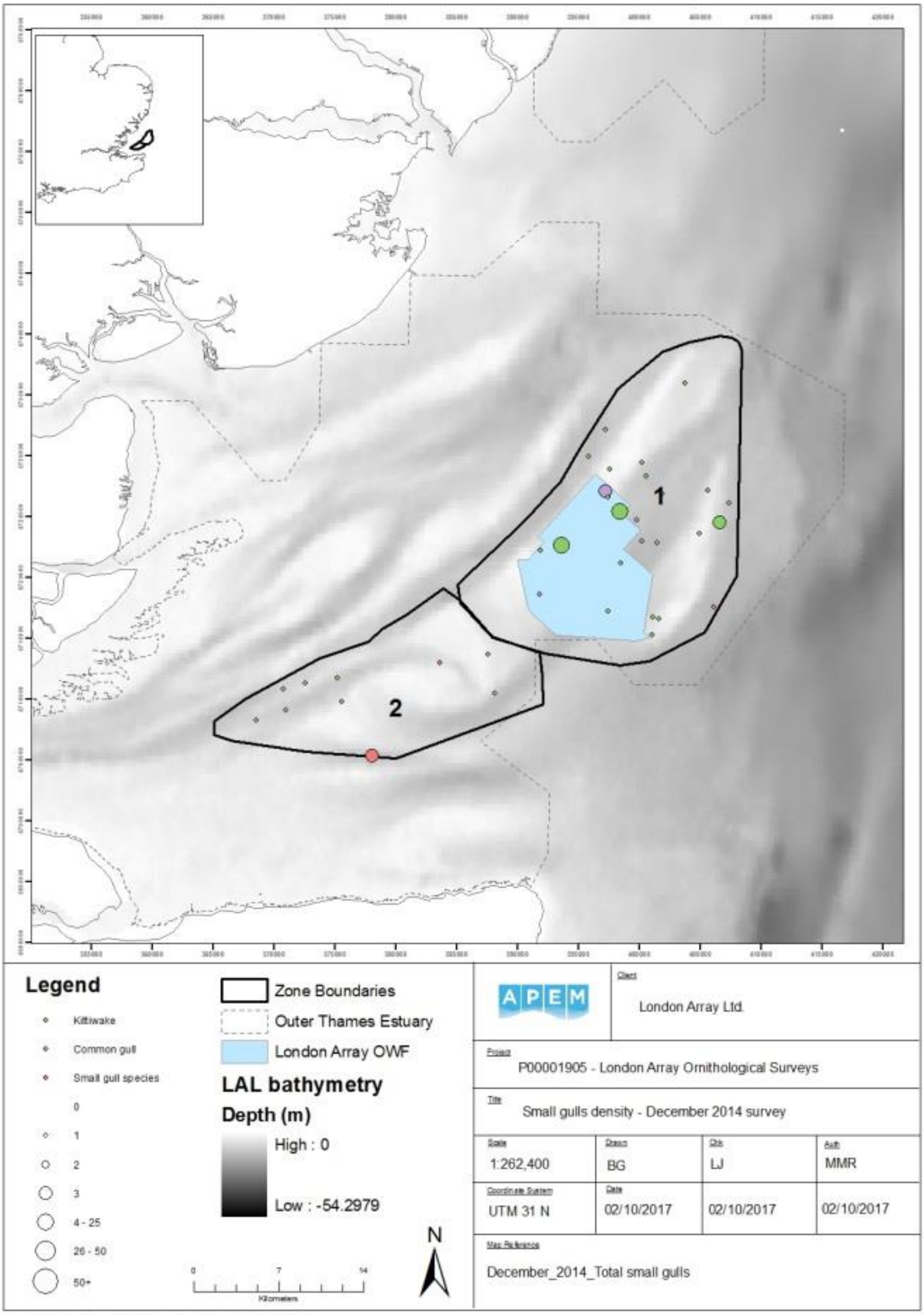

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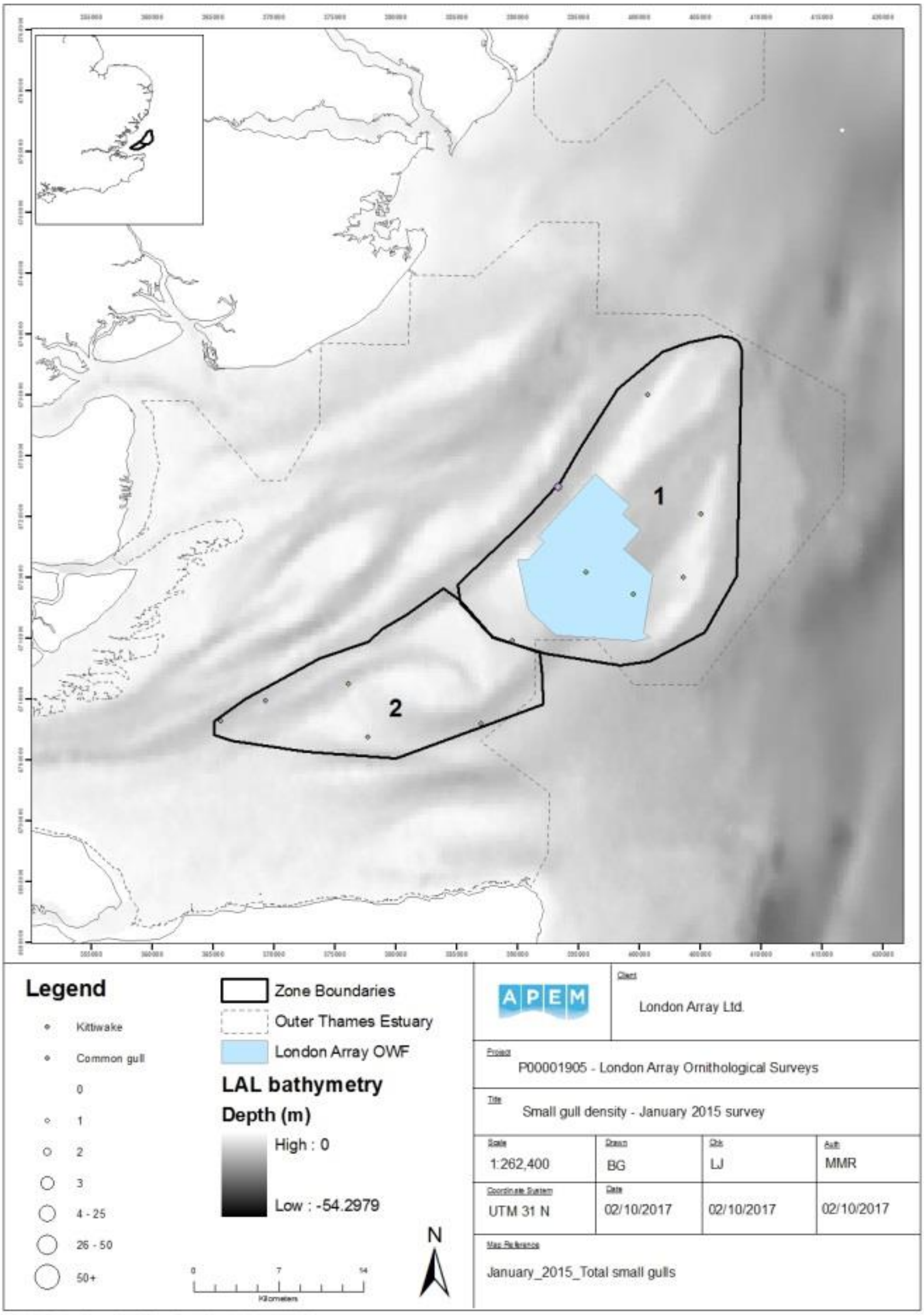

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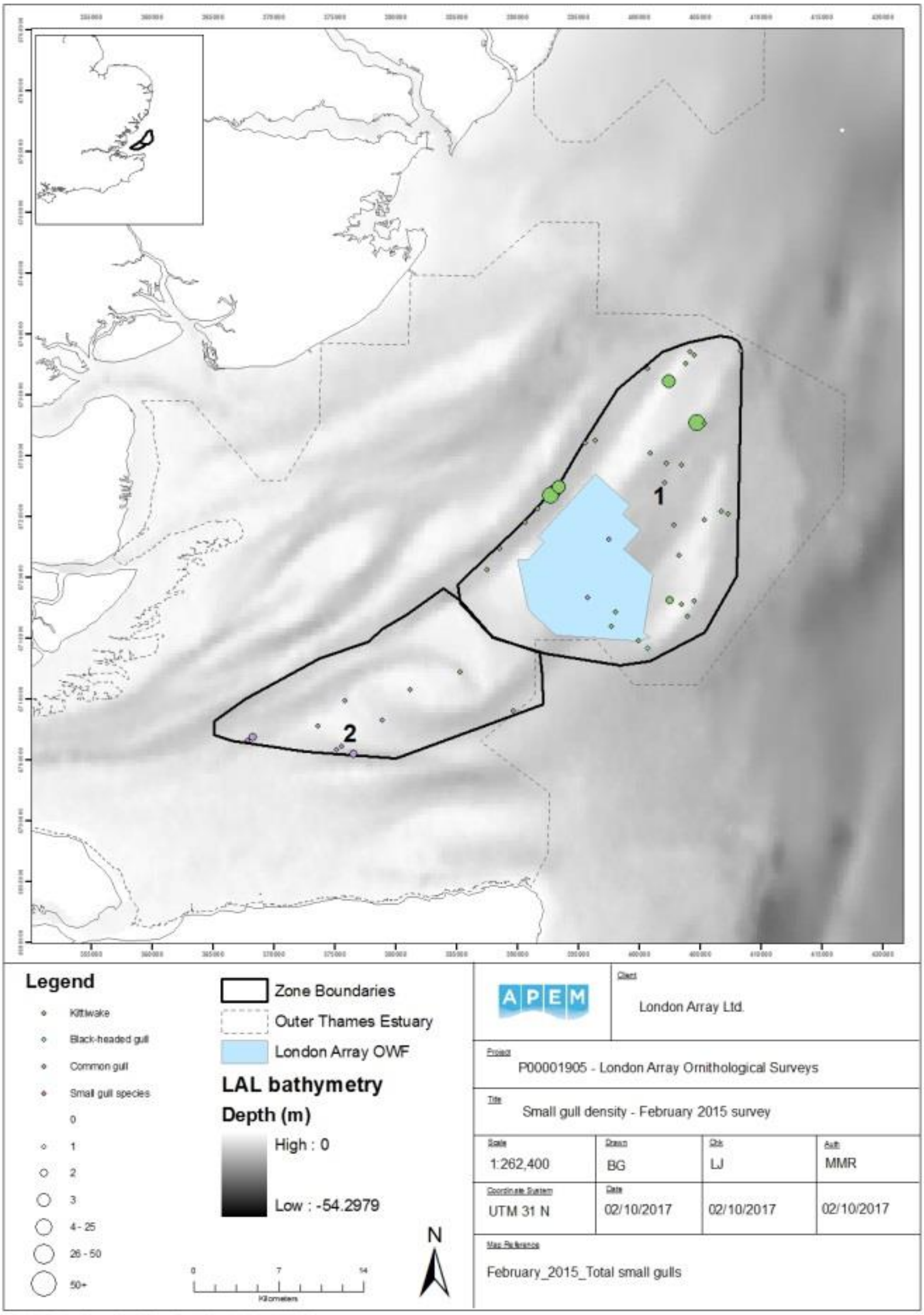

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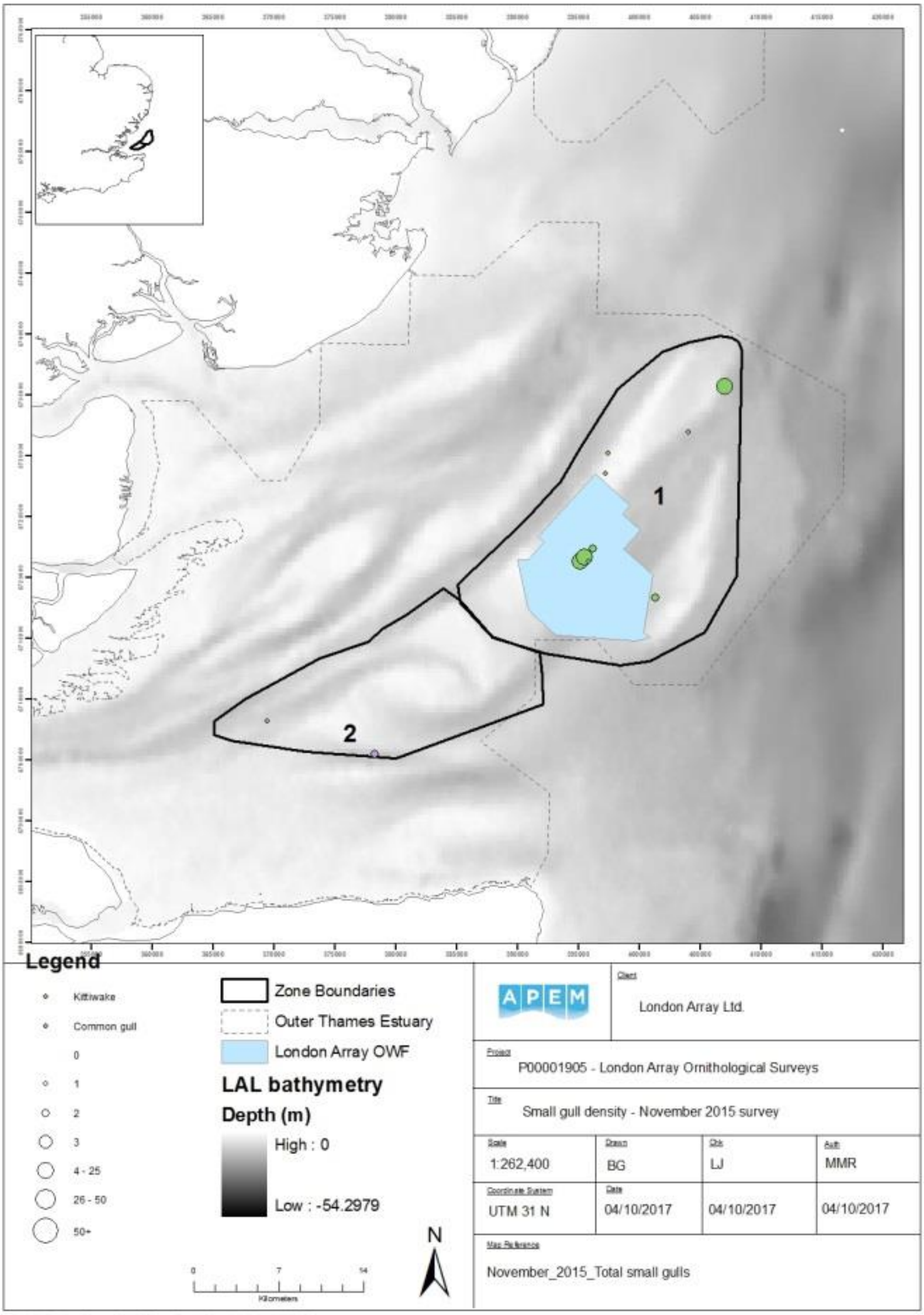

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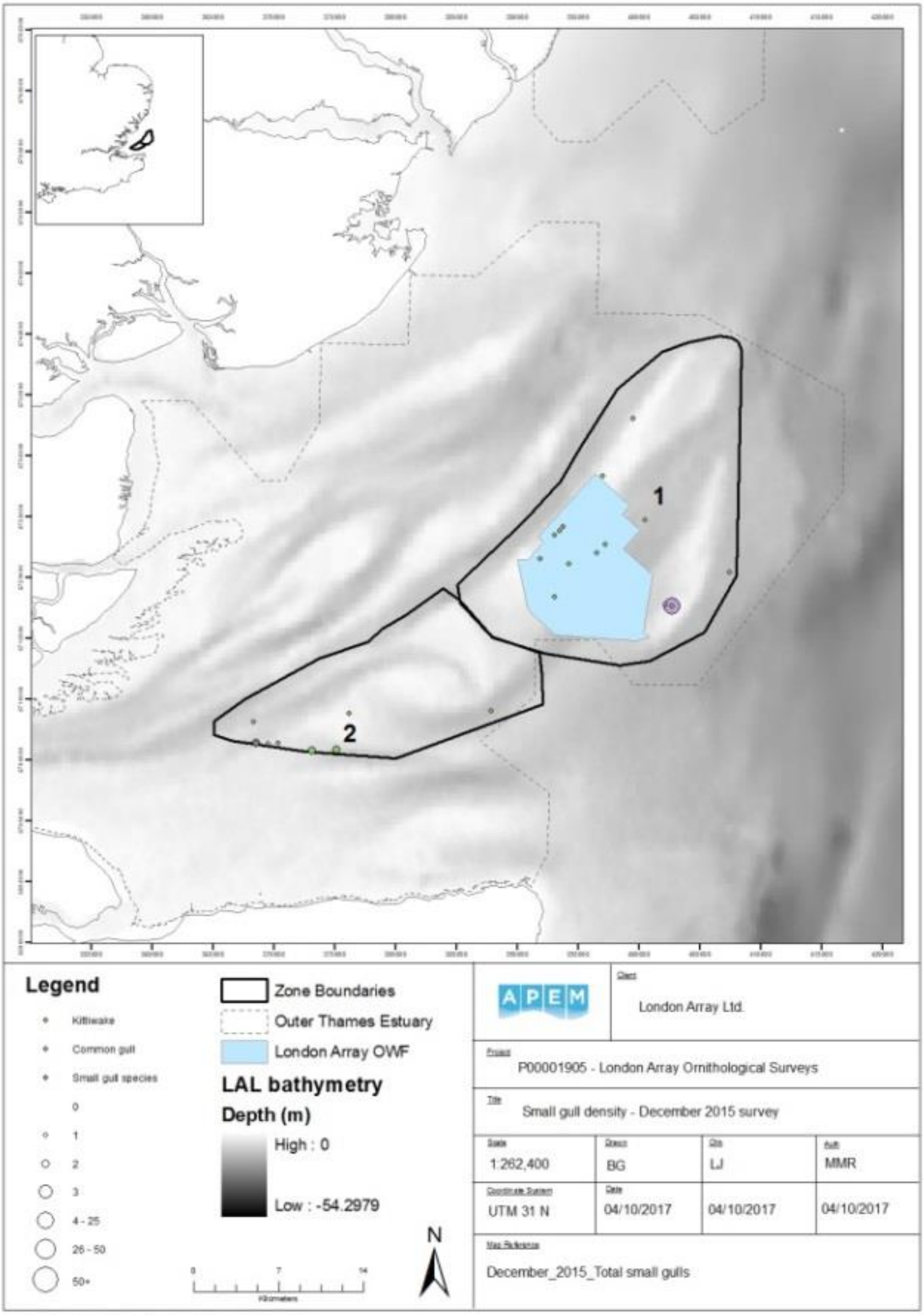

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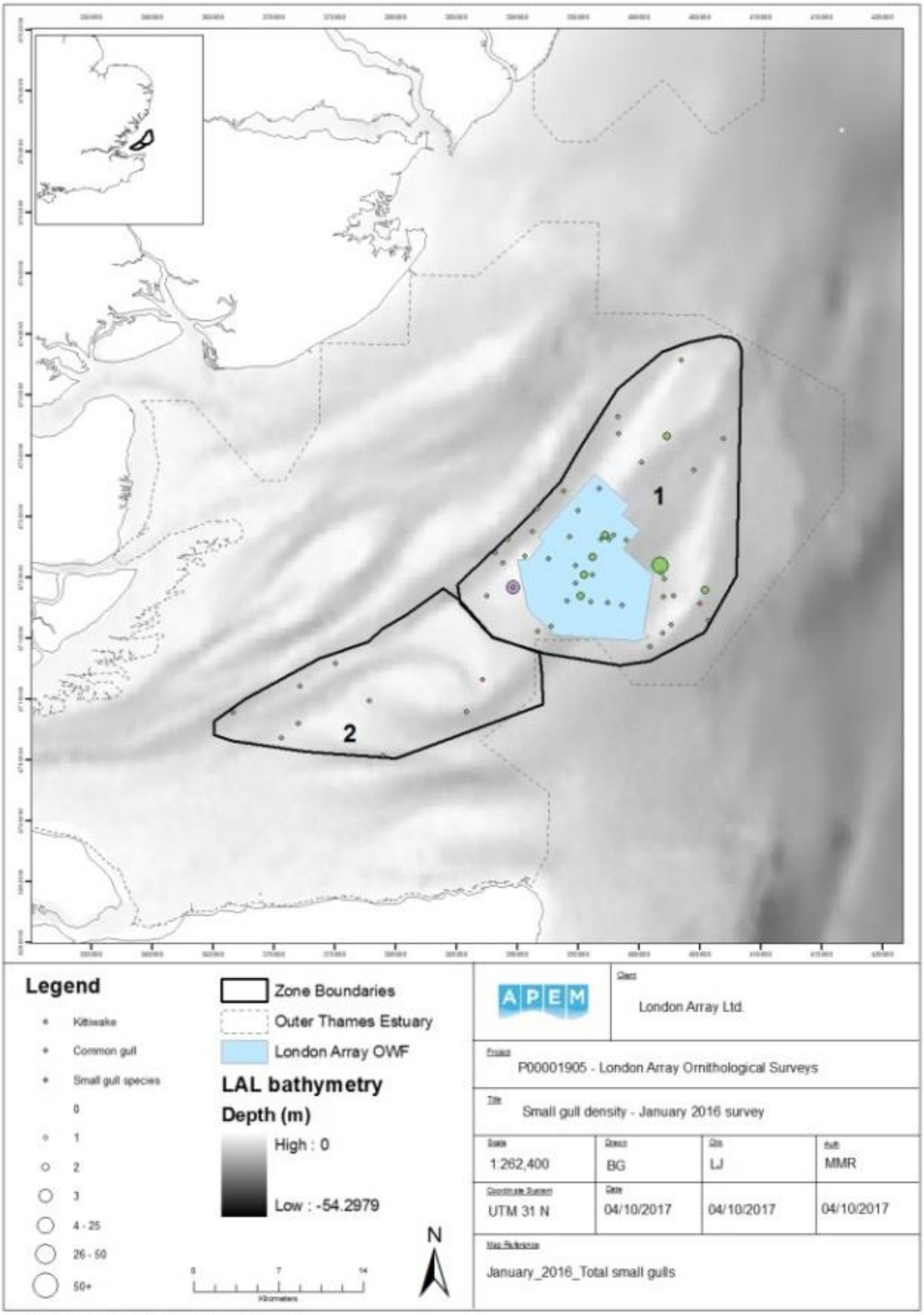

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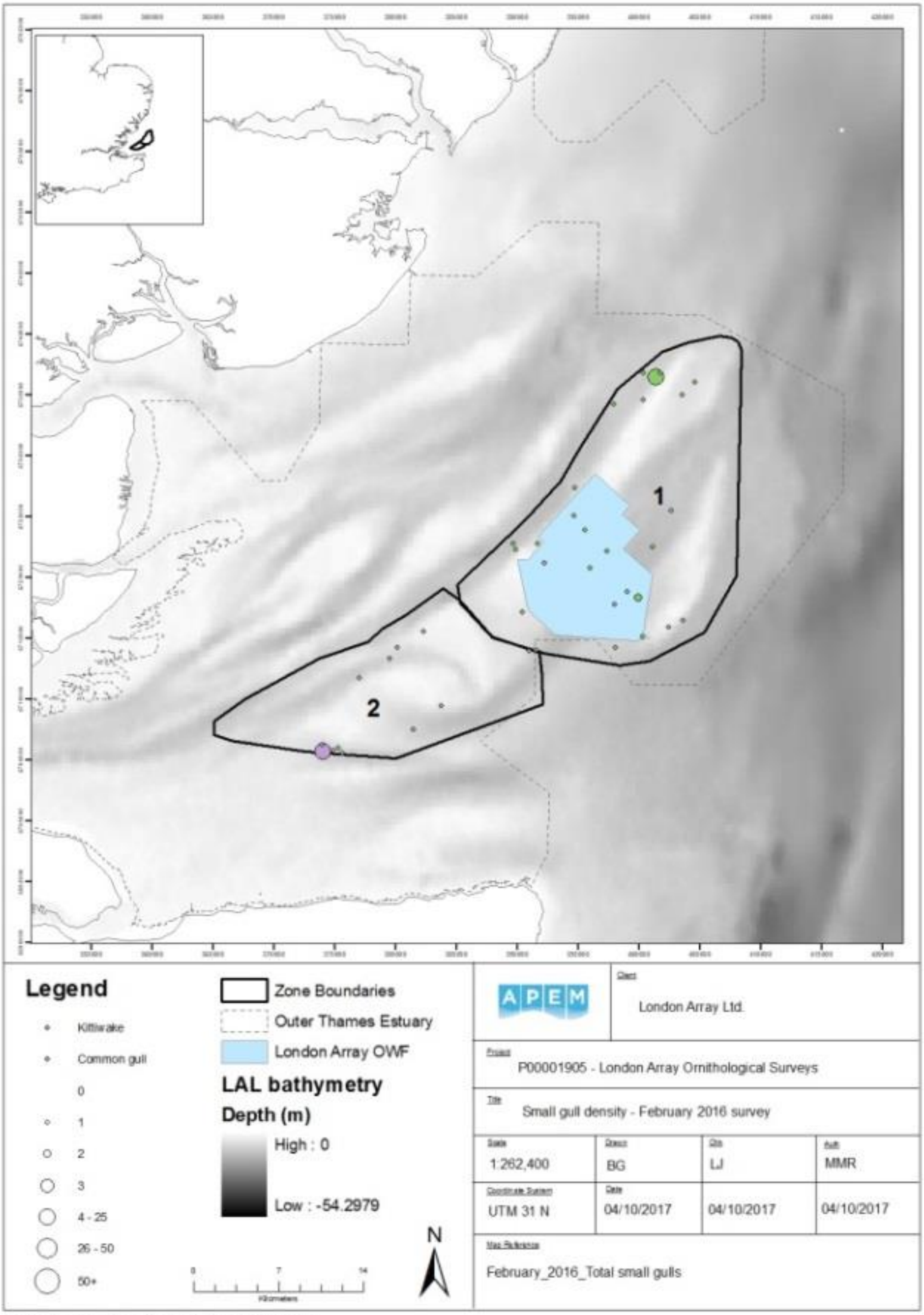

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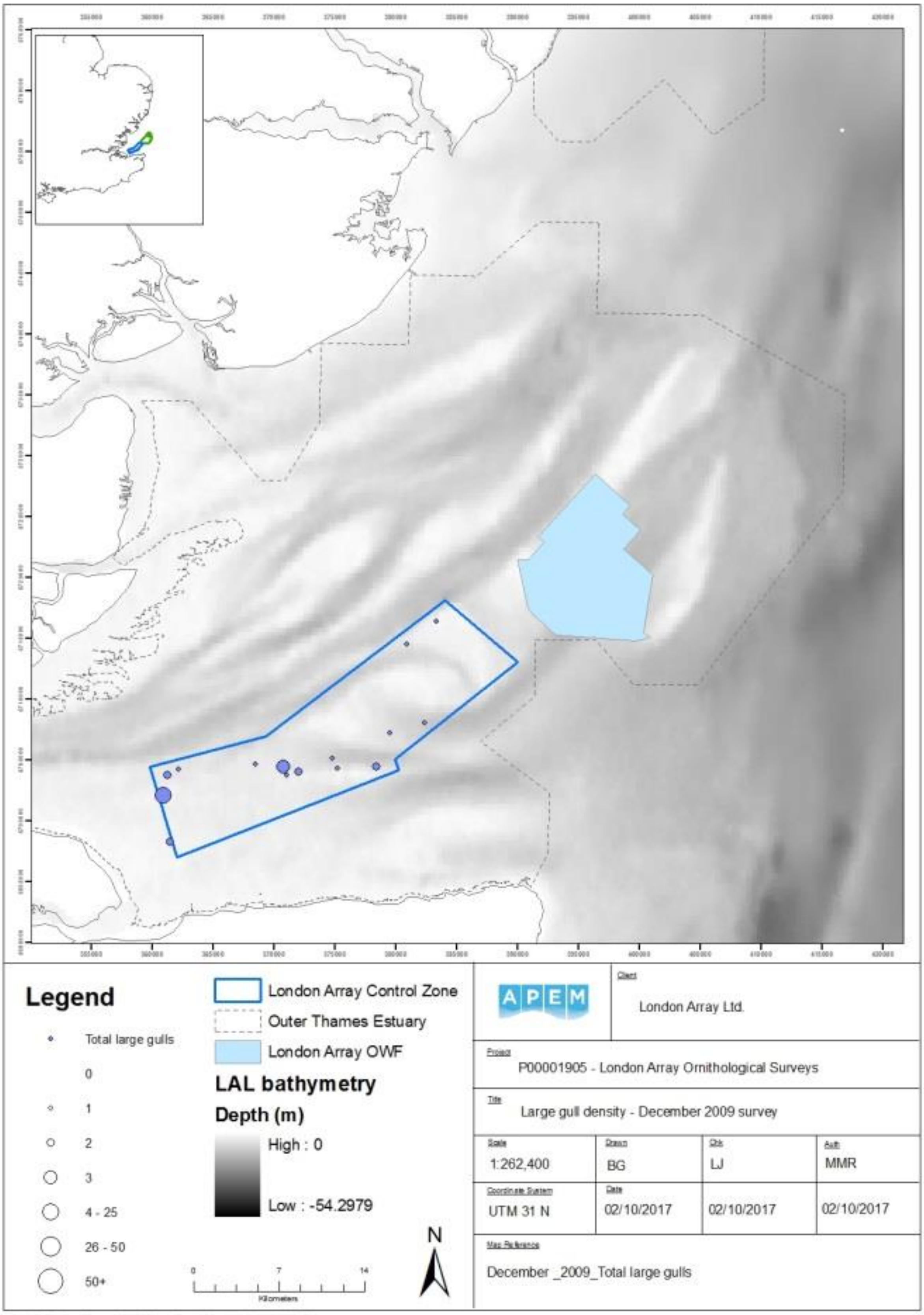
Figure 6 Monthly distribution maps for small gulls recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Large Gulls



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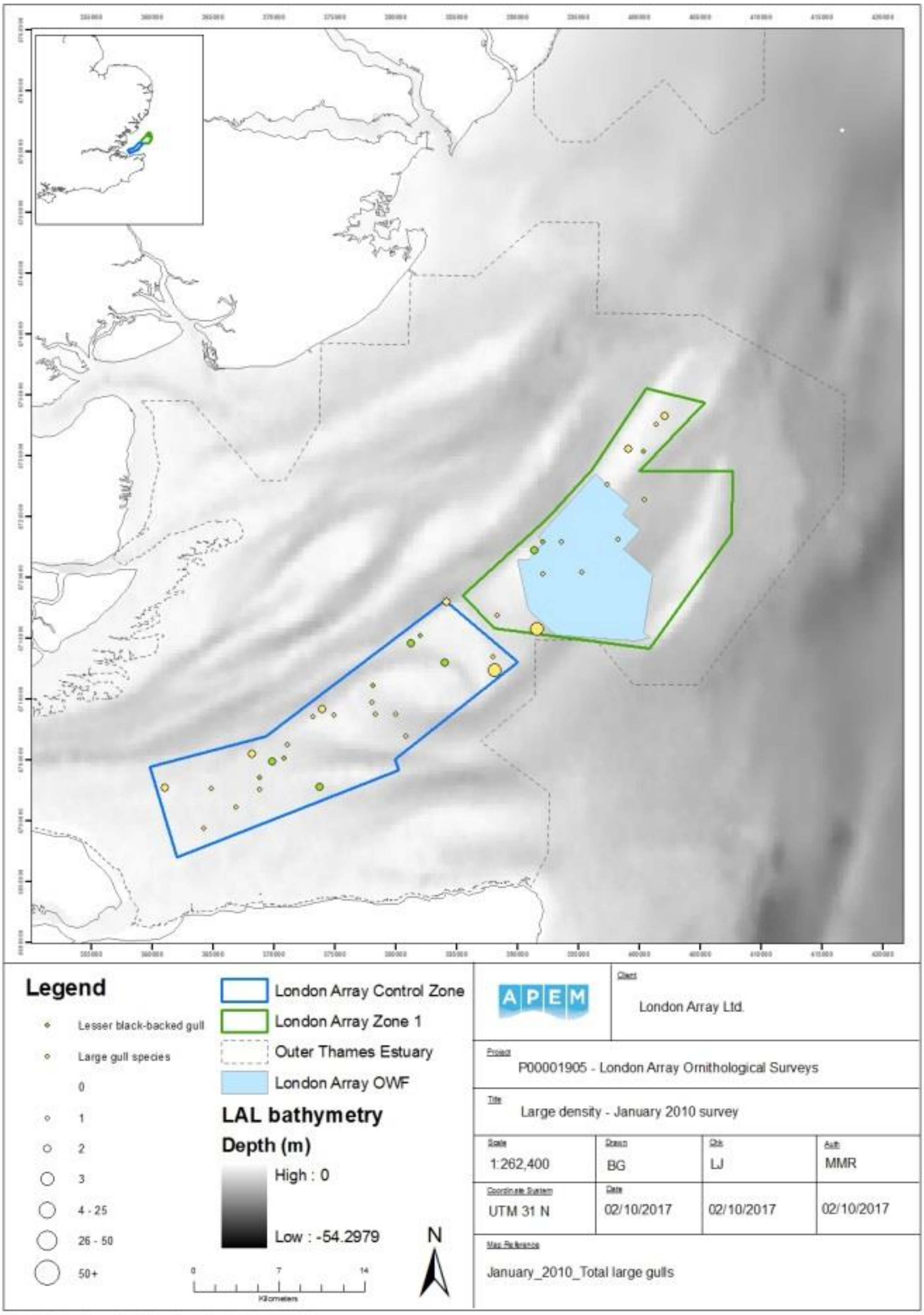

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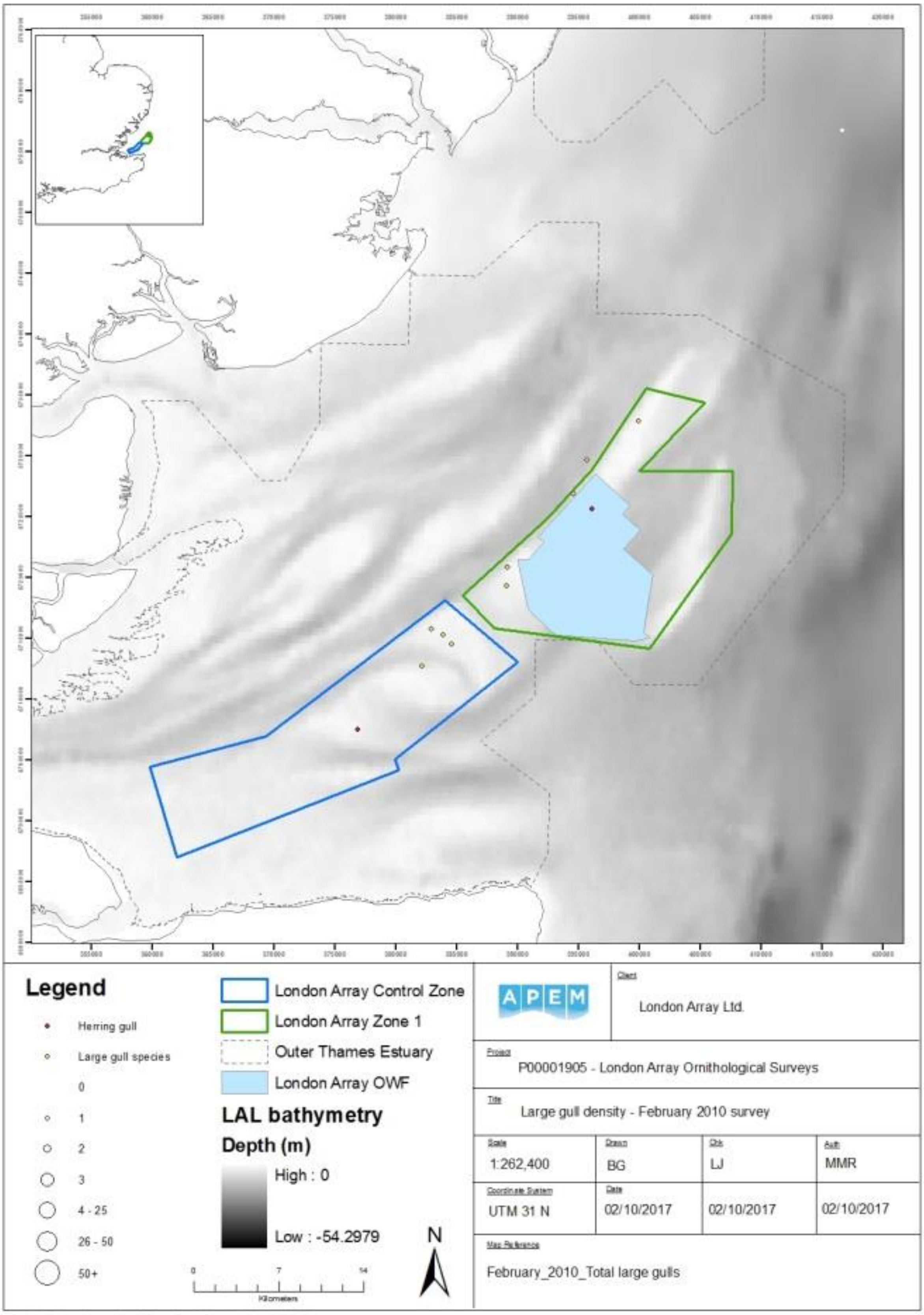

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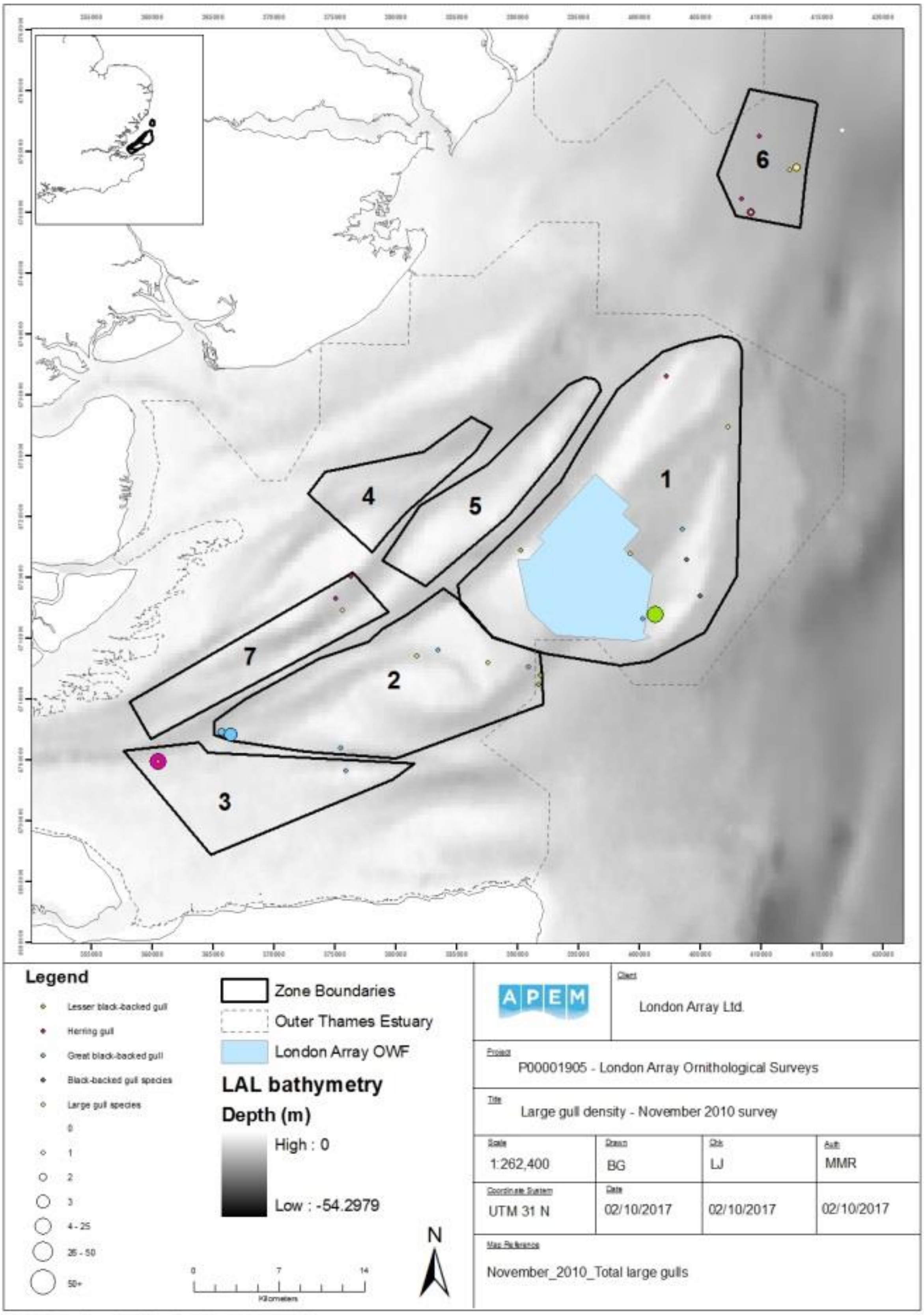

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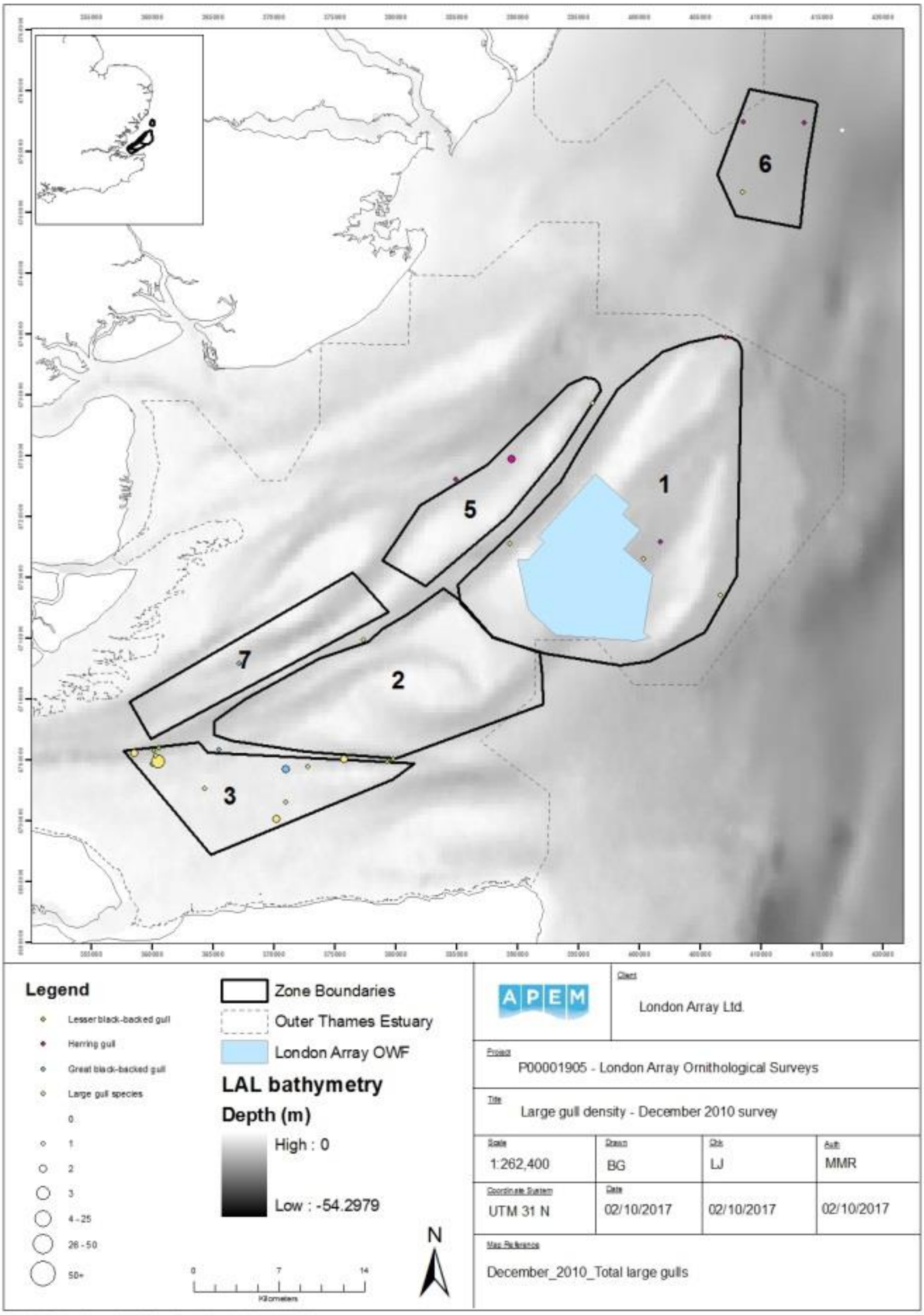

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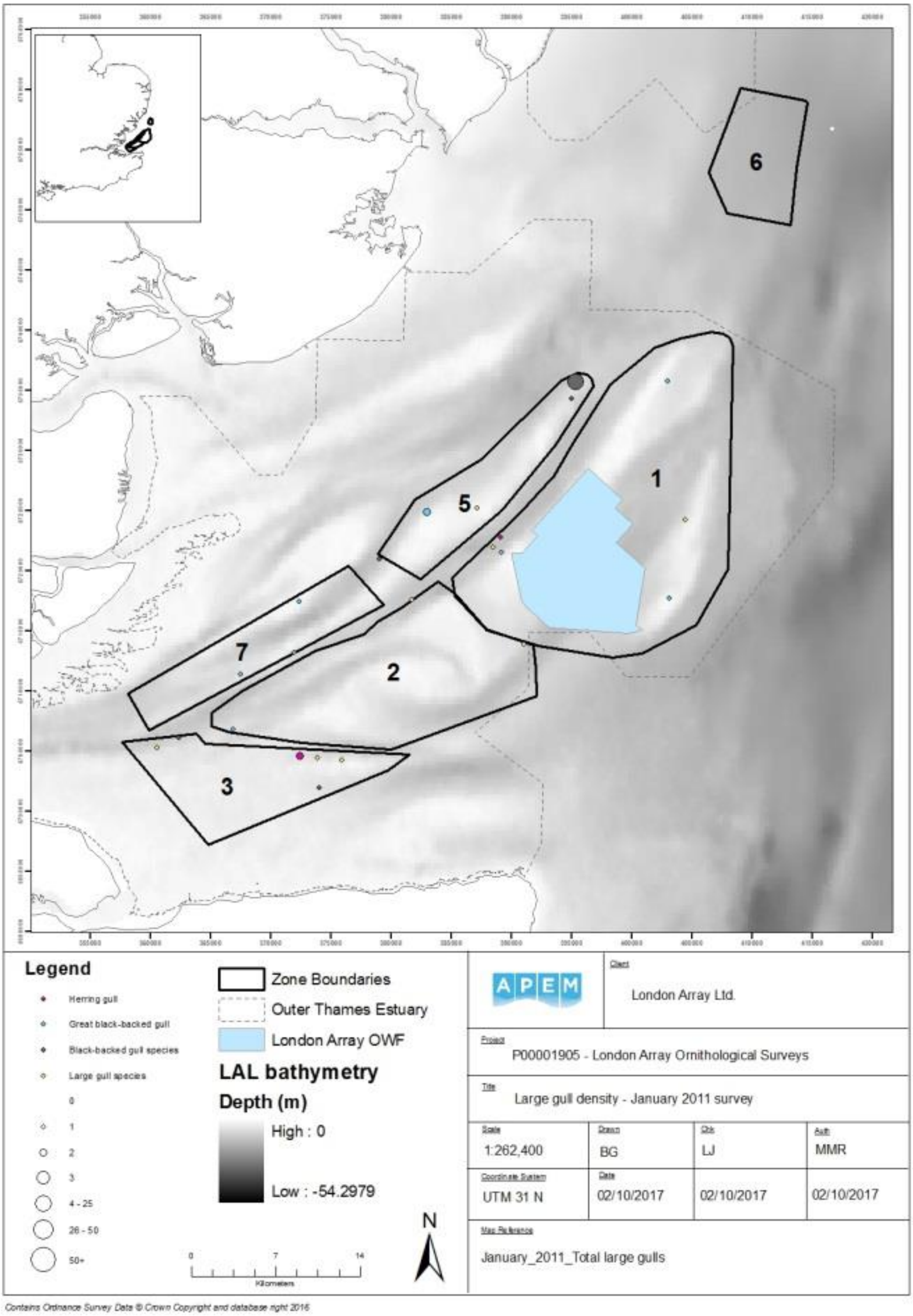

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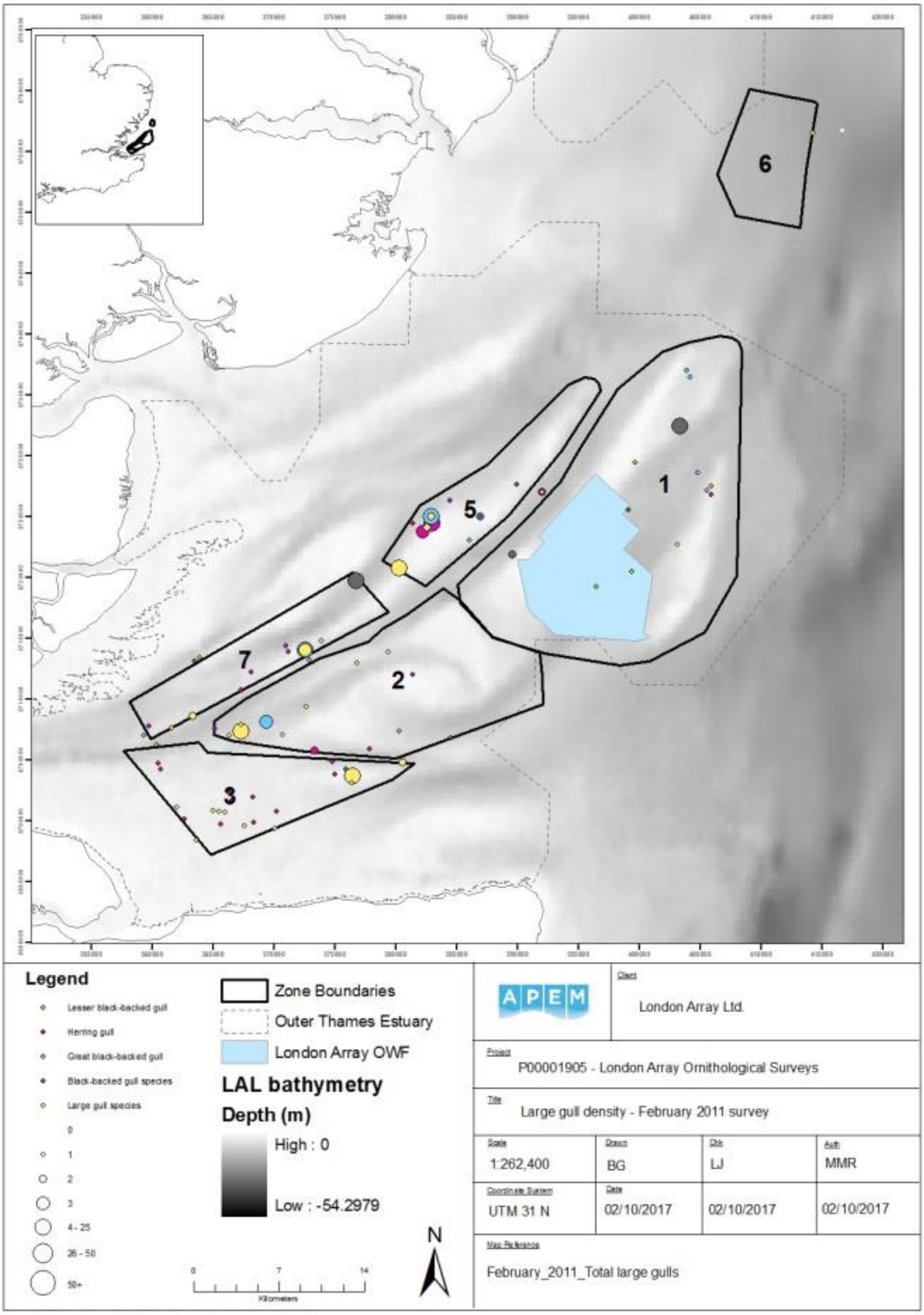

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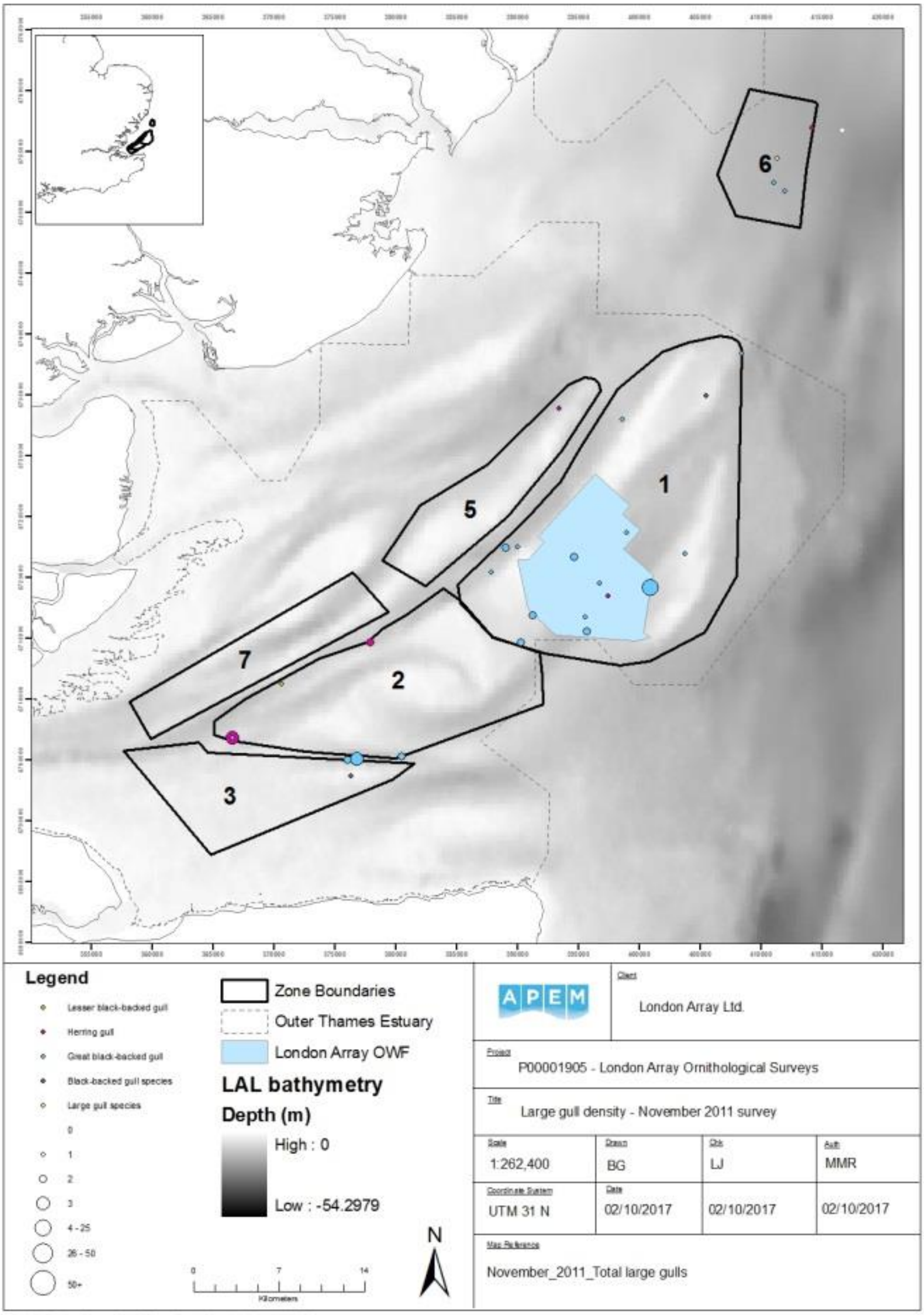

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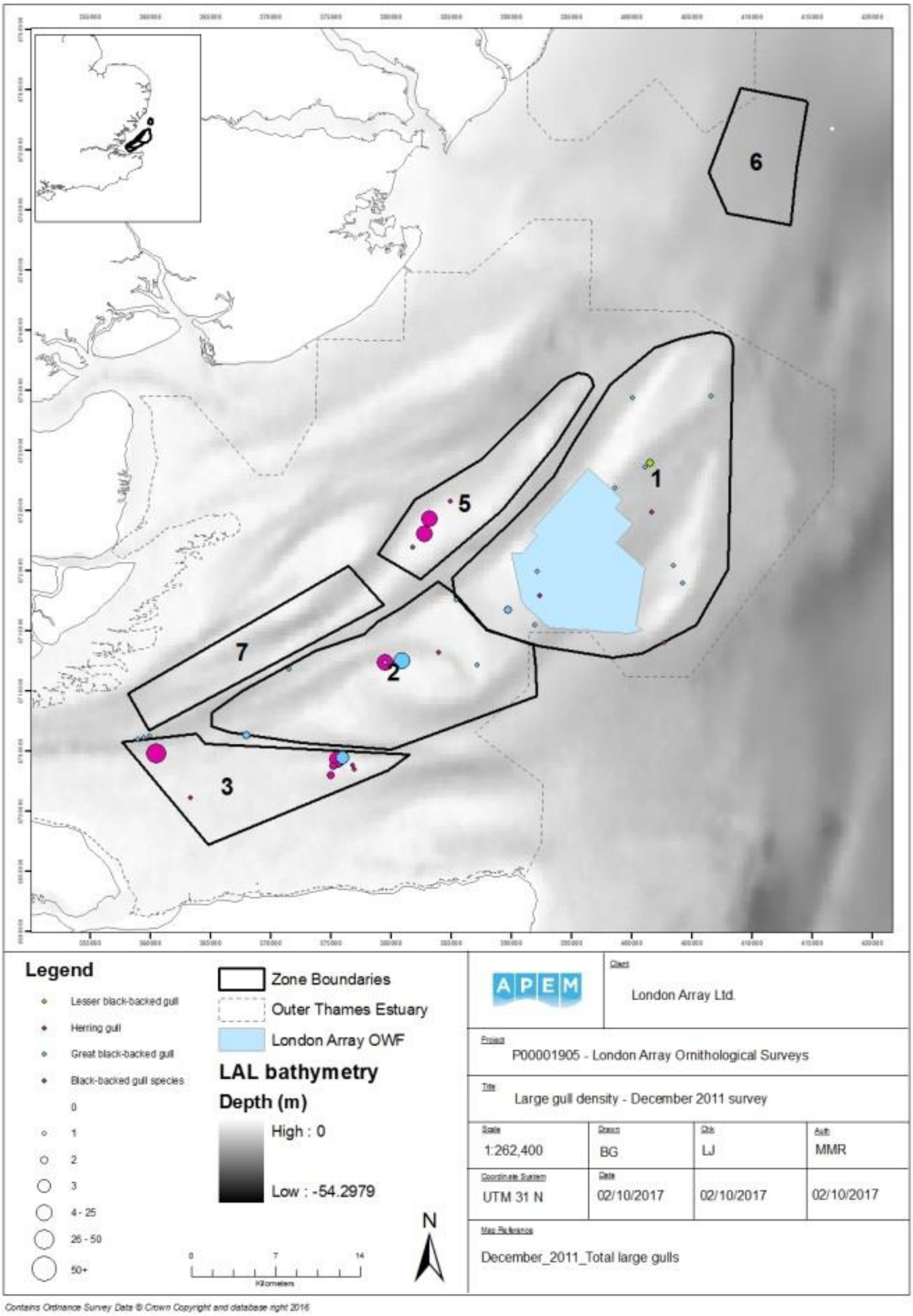

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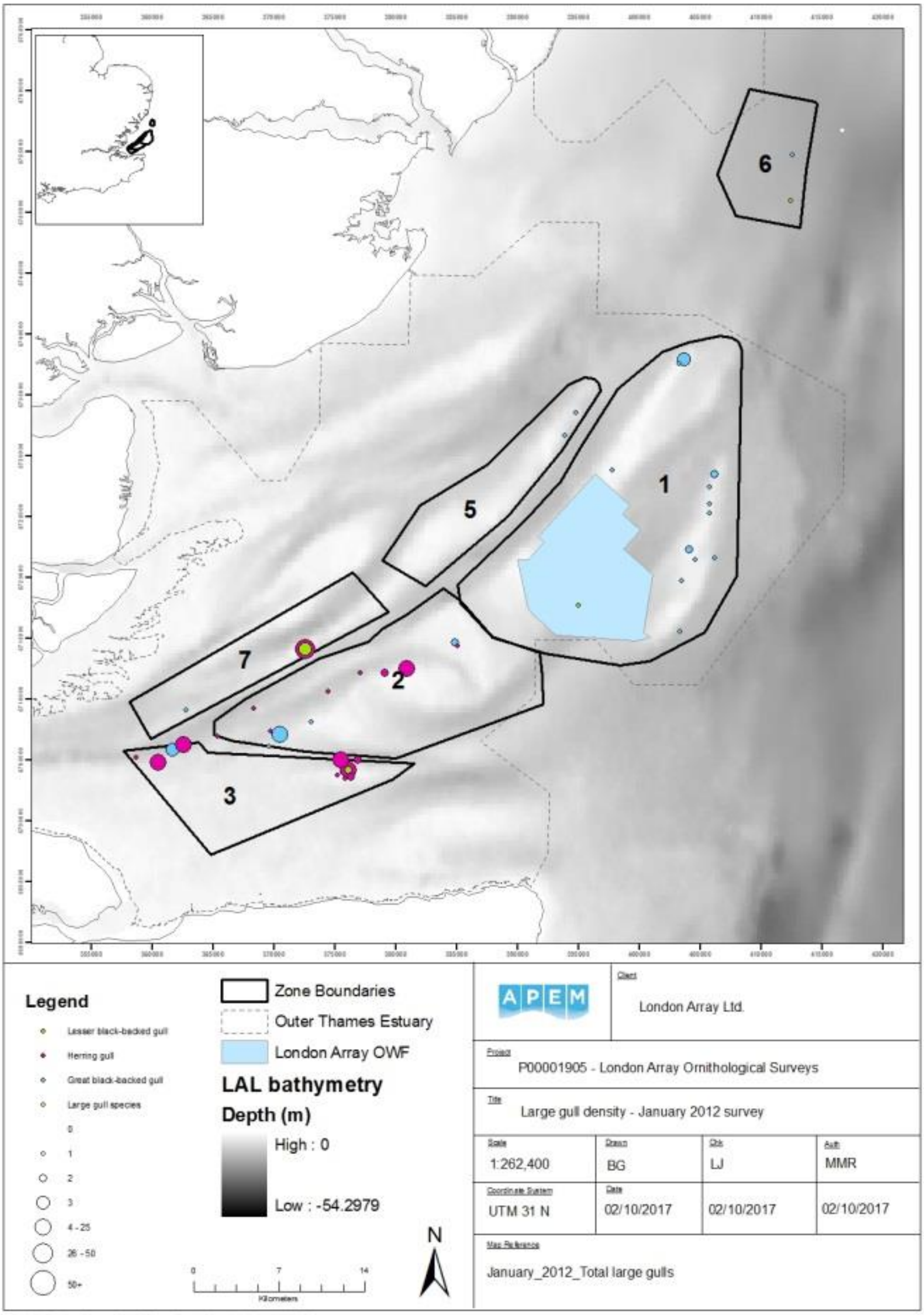

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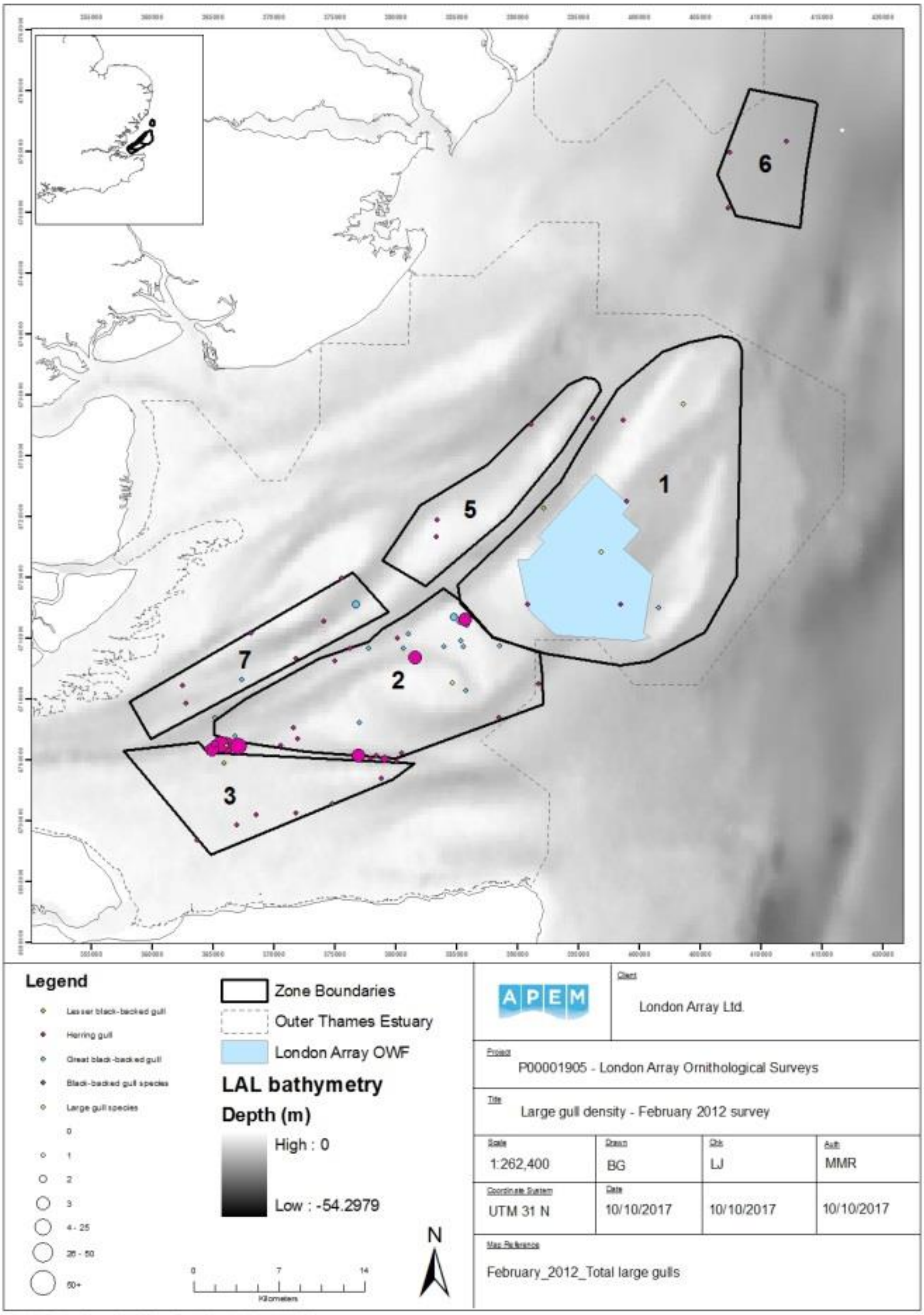

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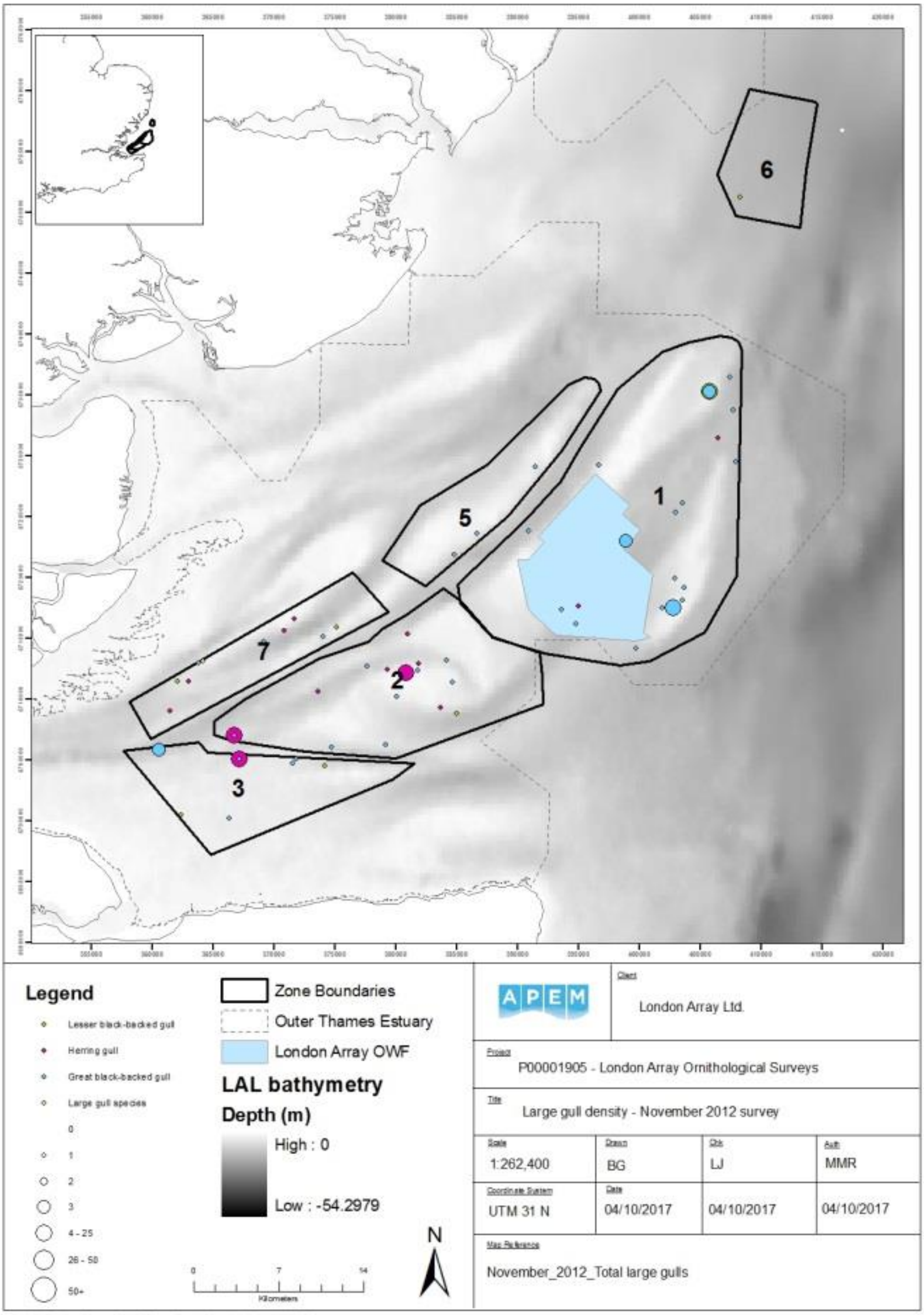

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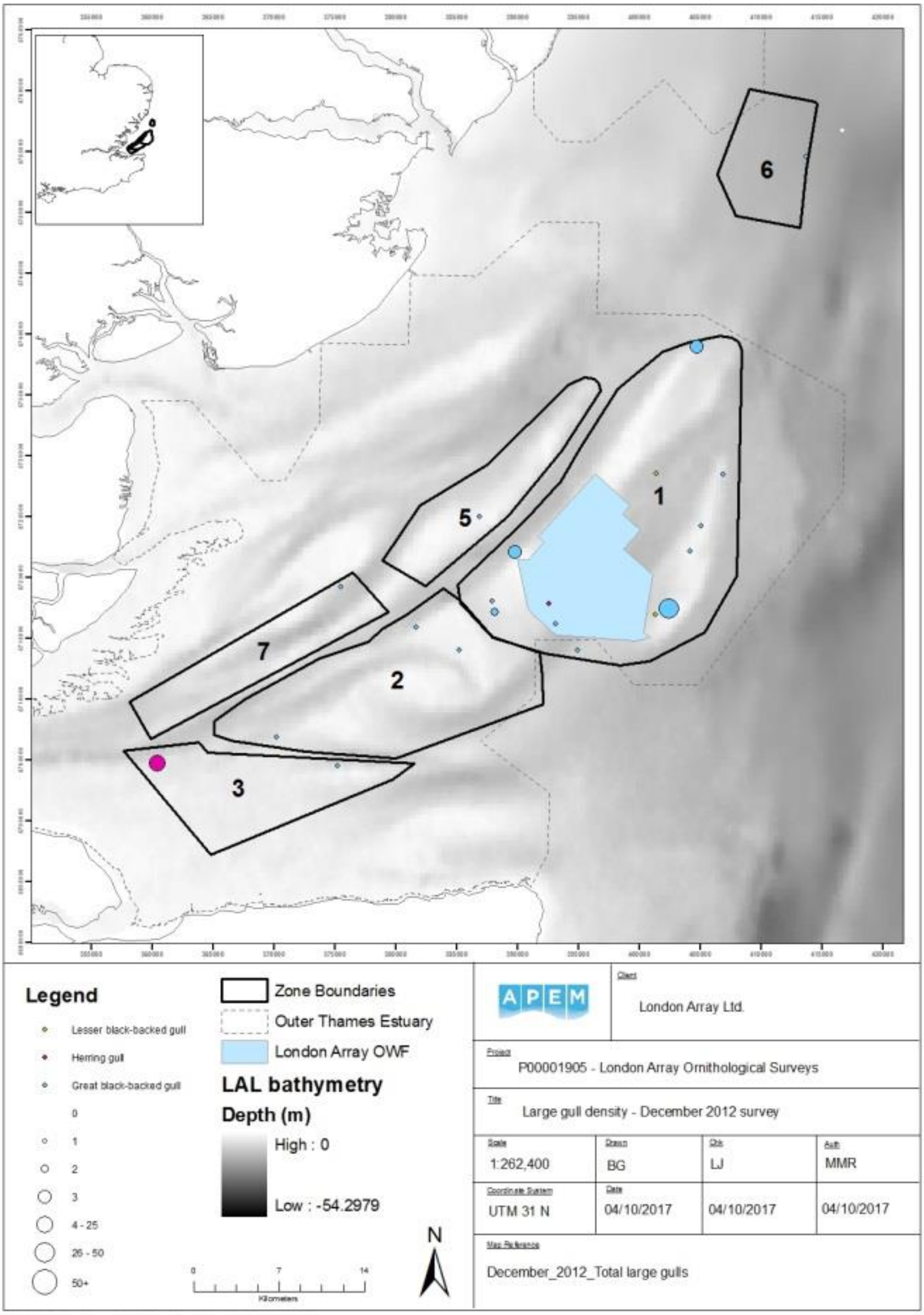

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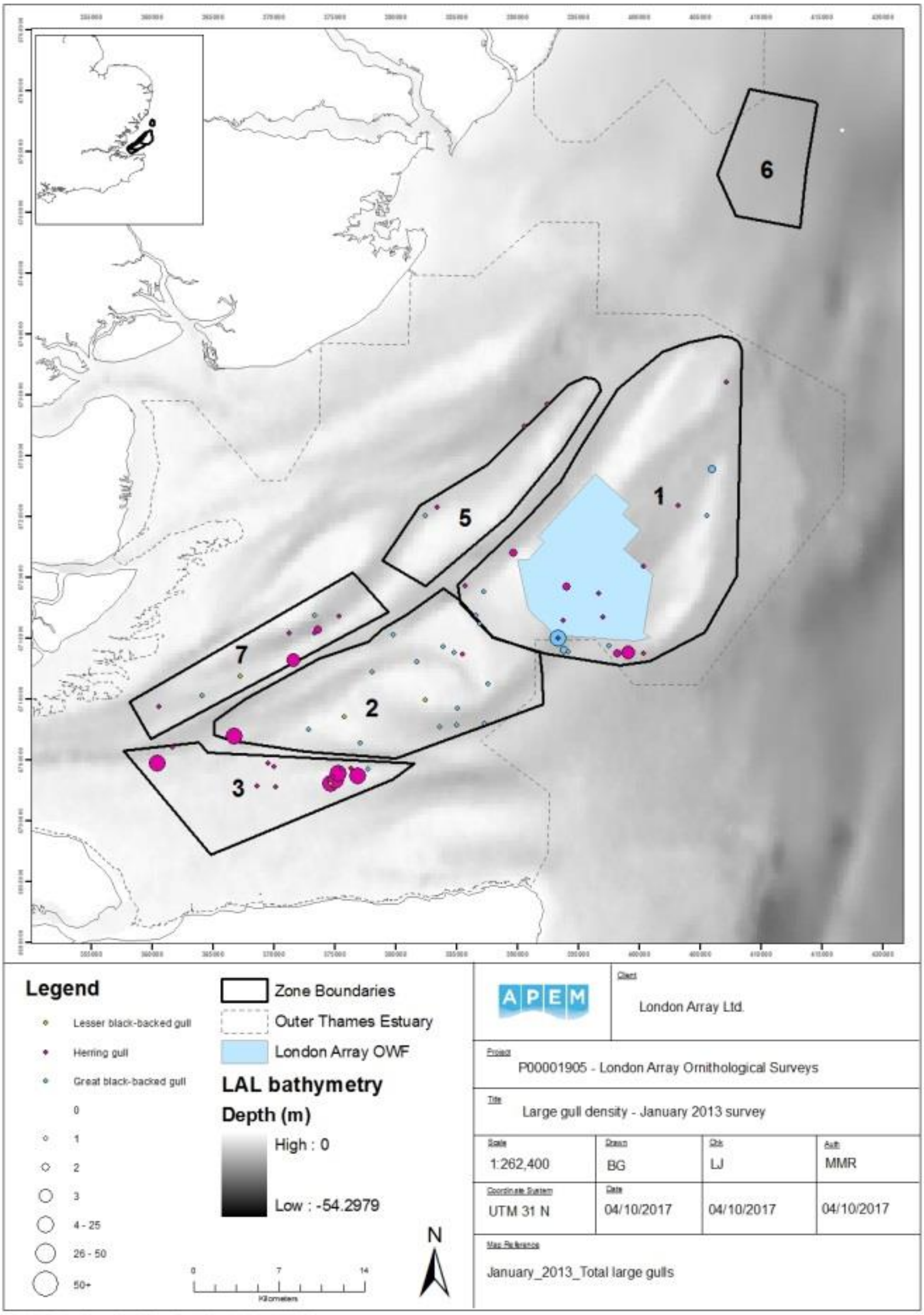

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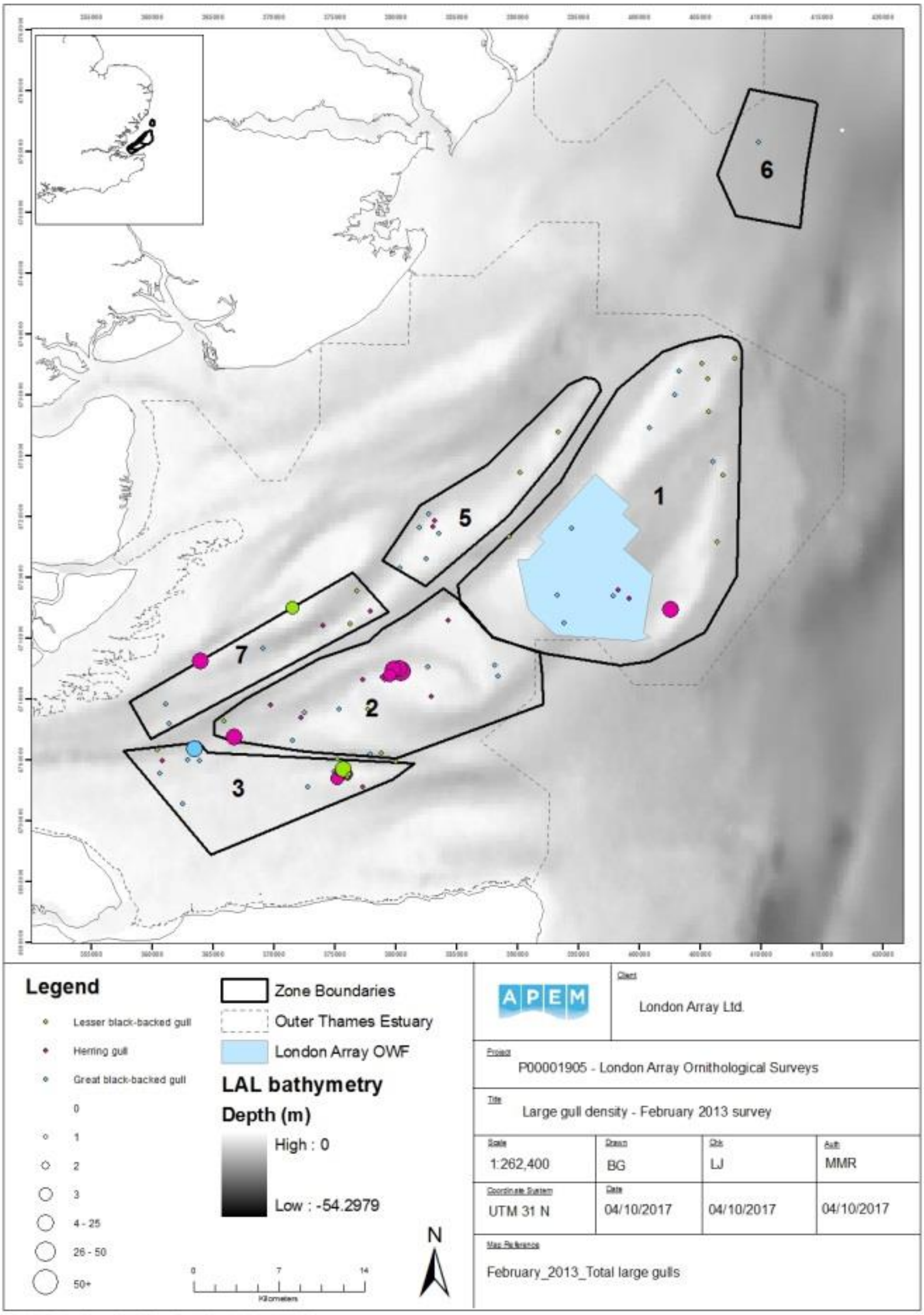

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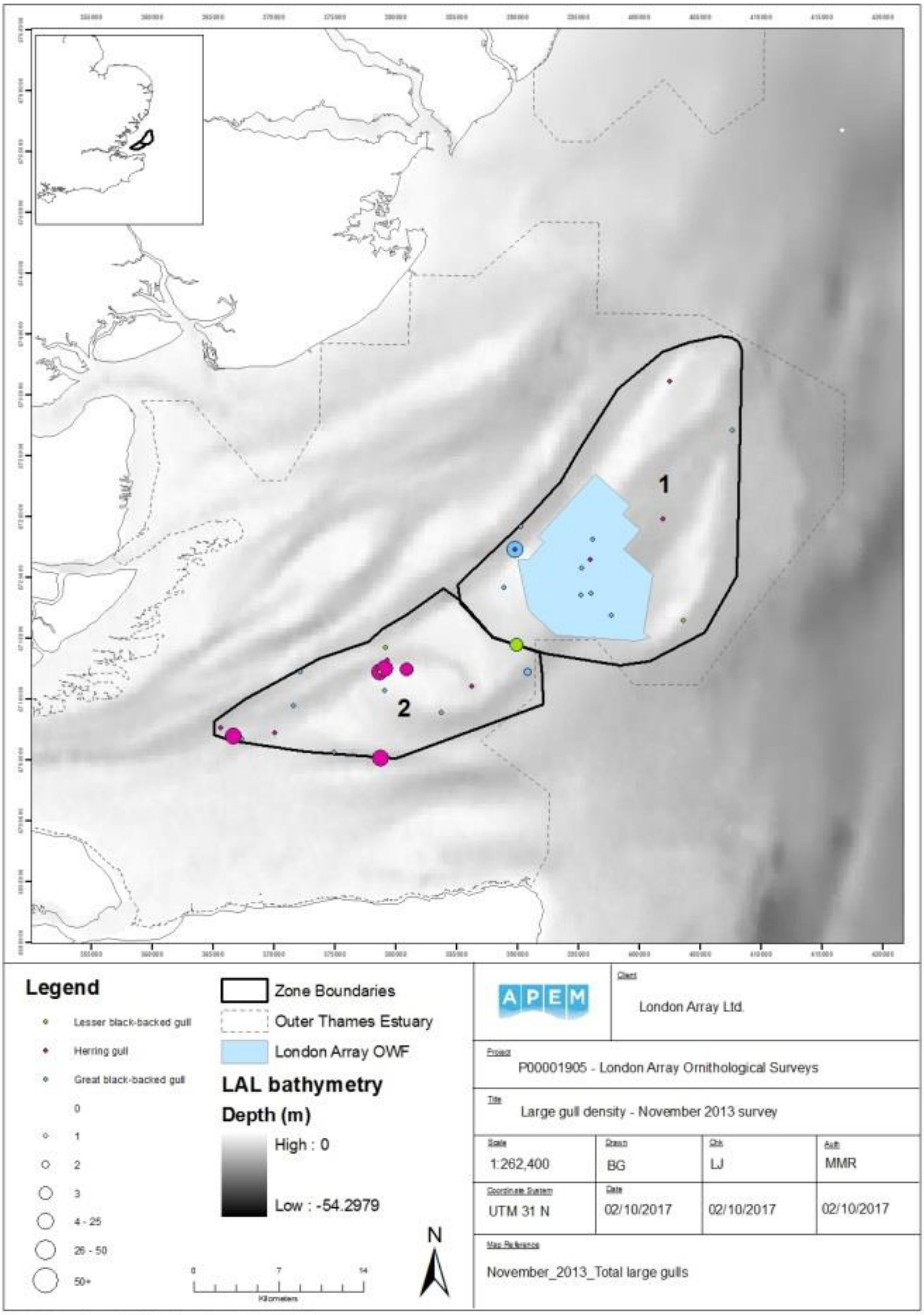

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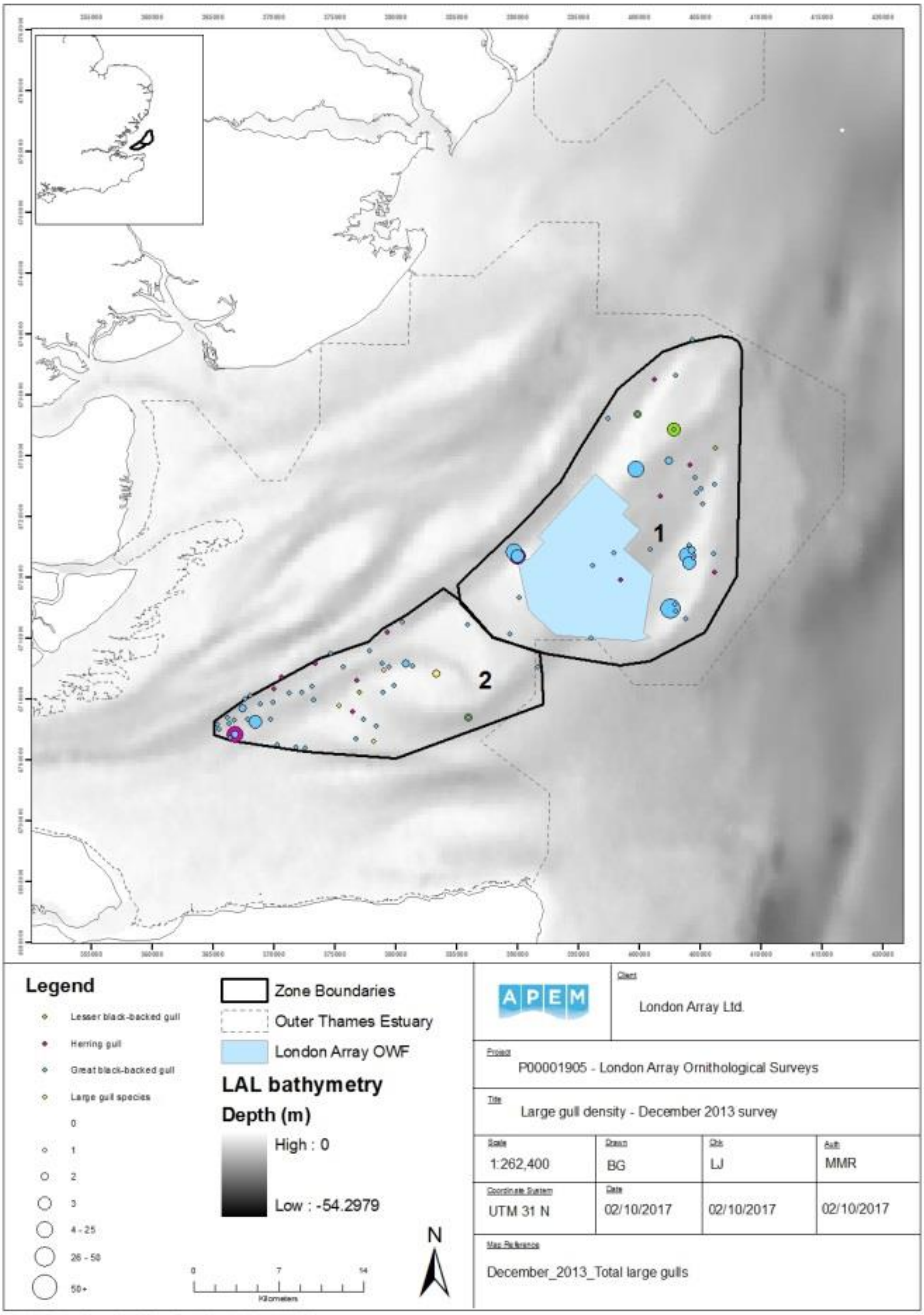

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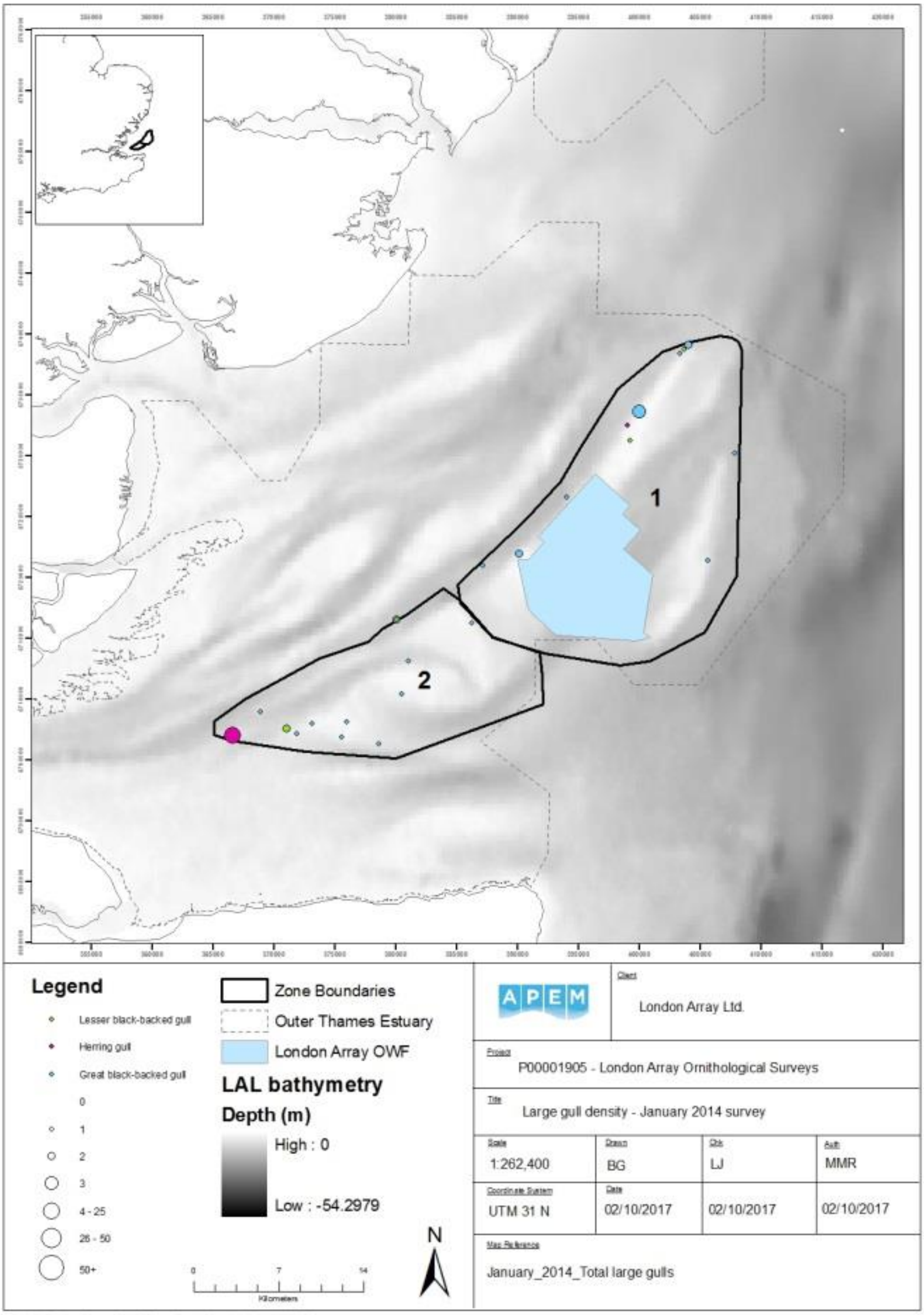

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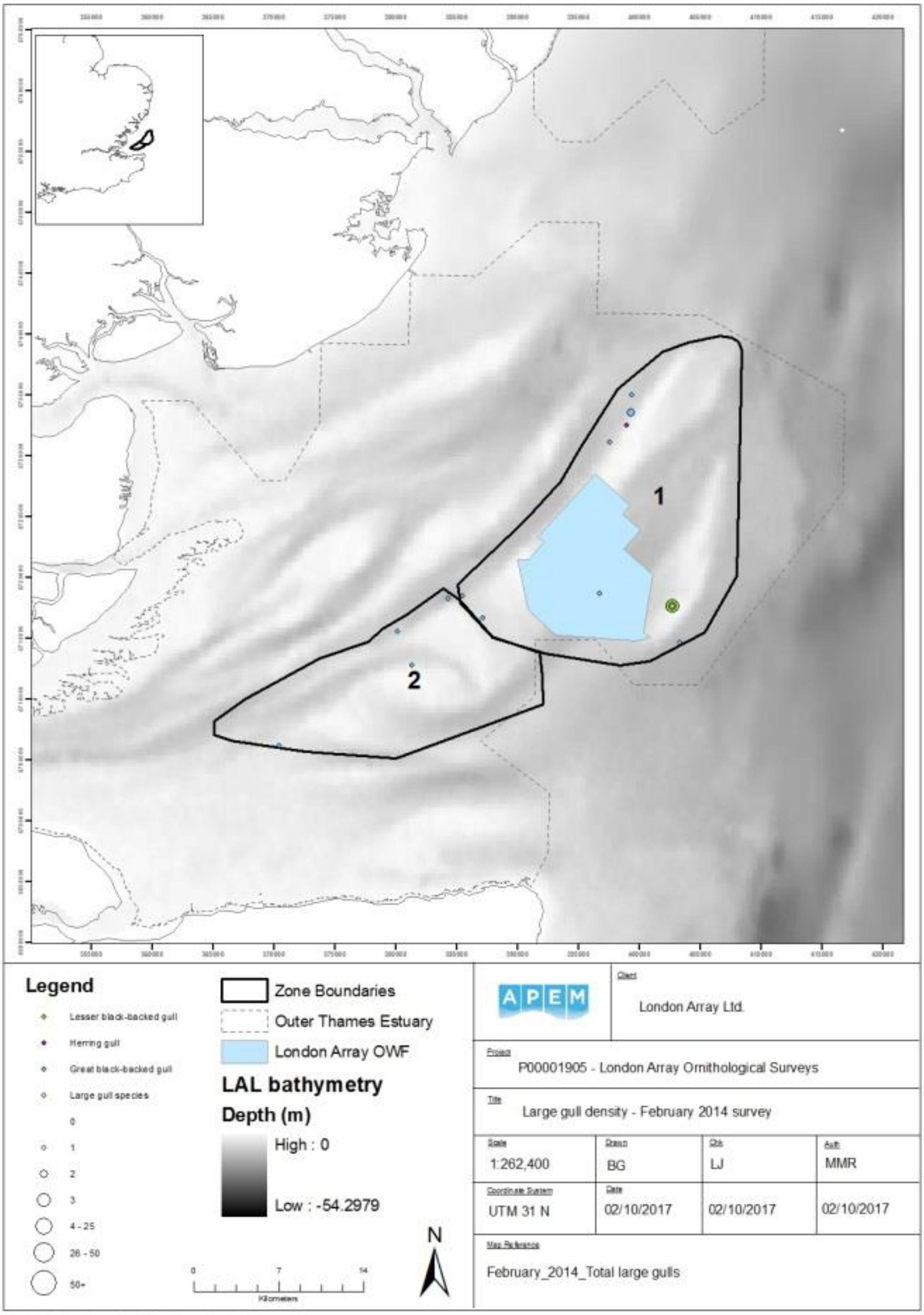

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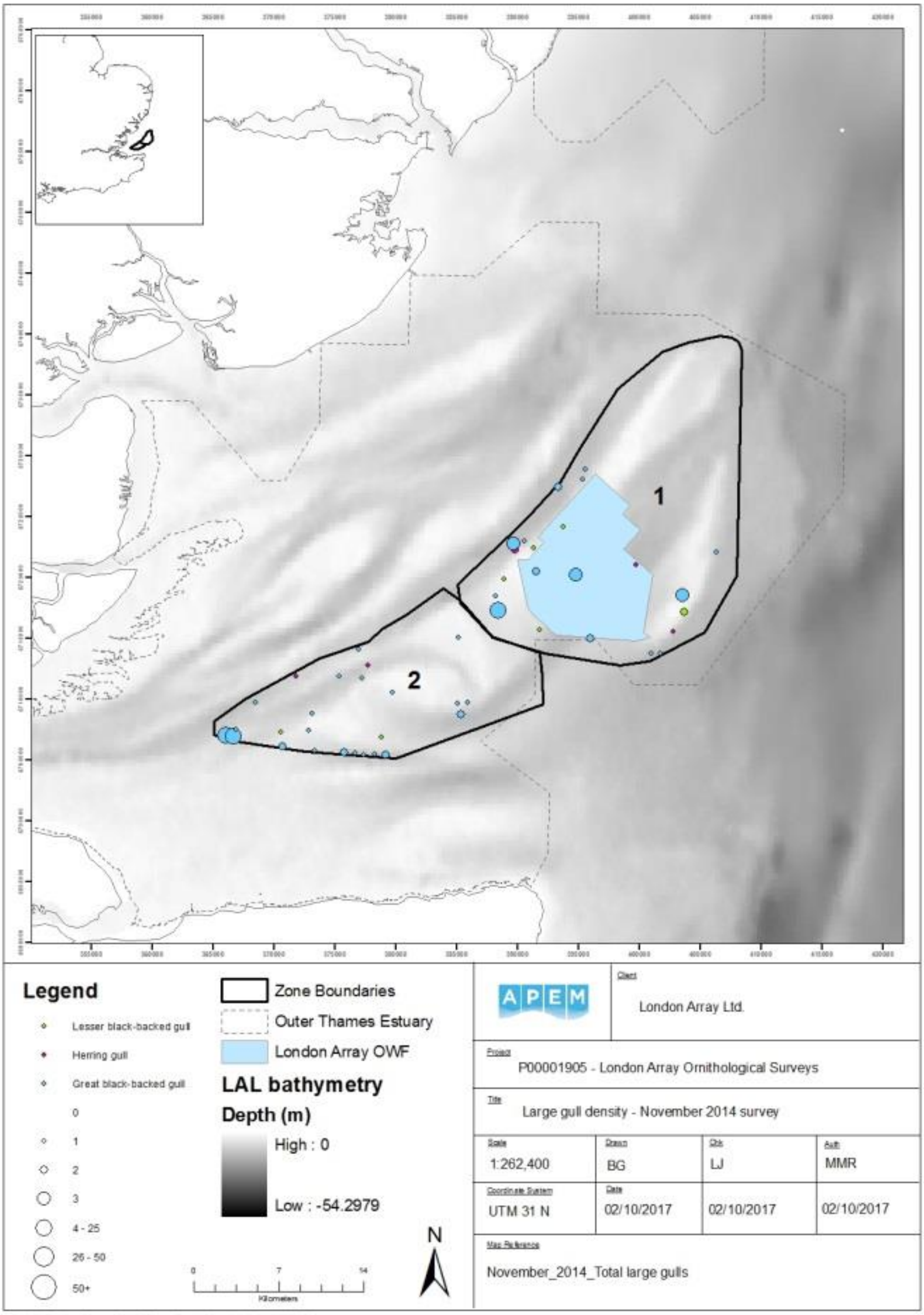

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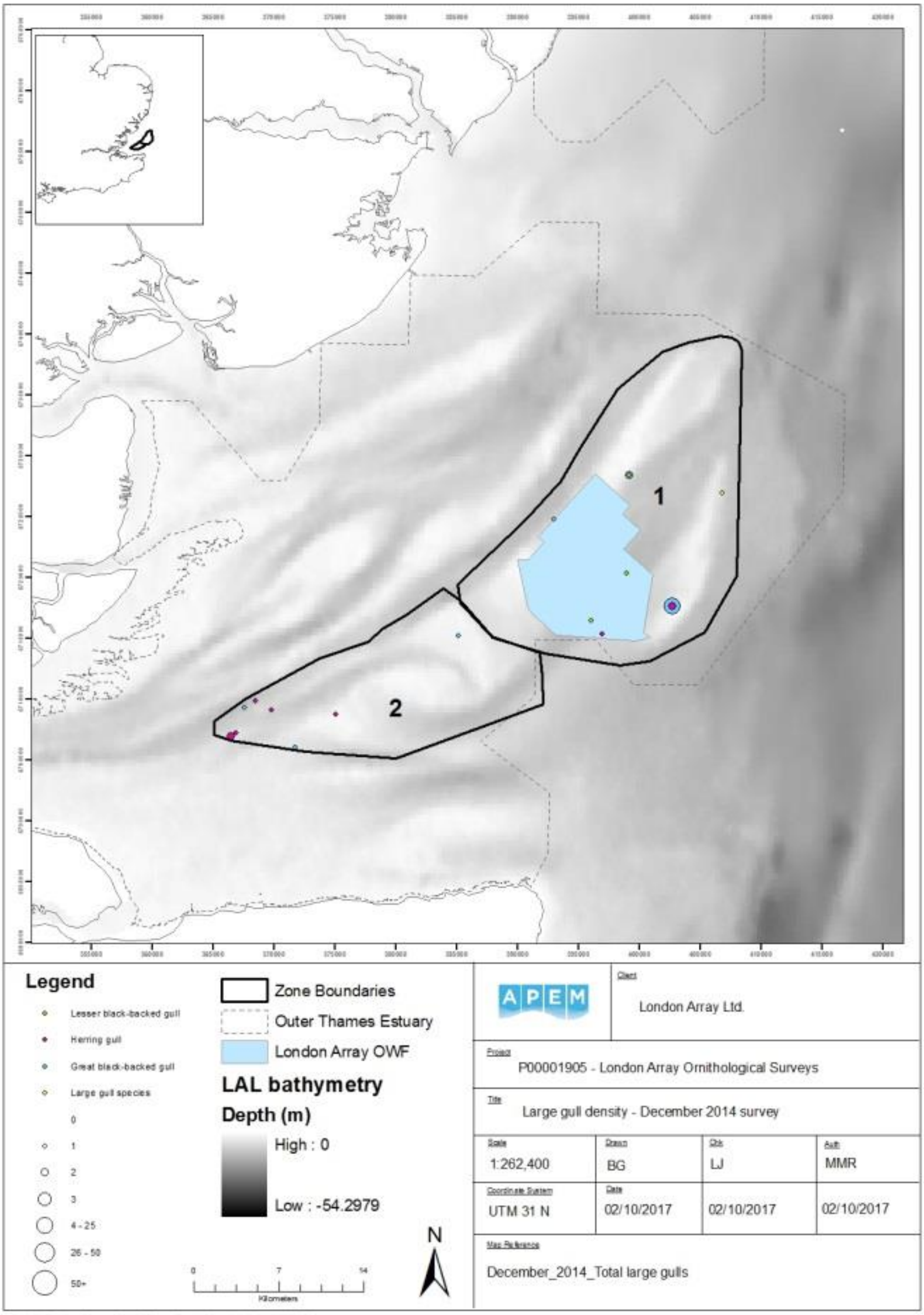

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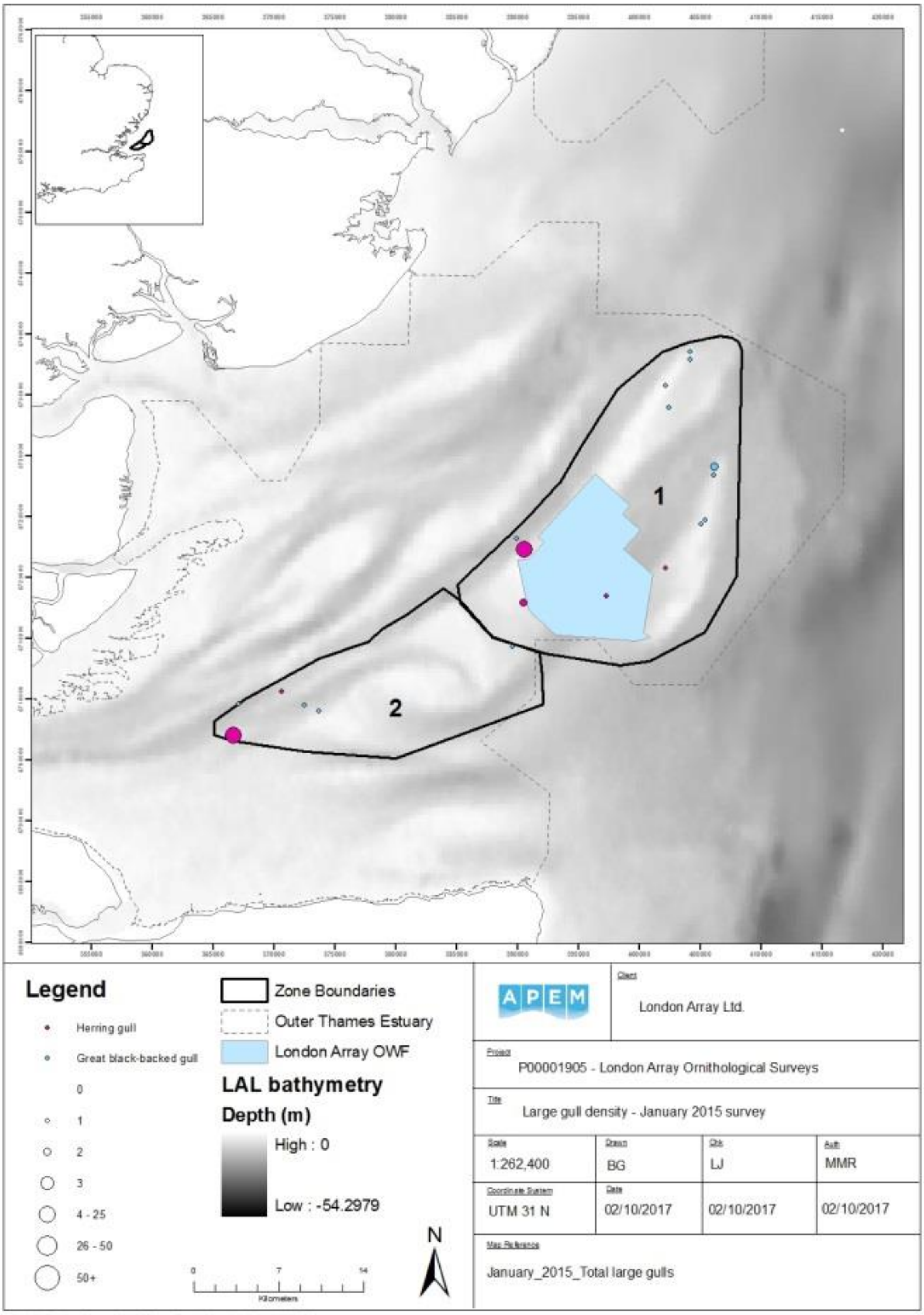

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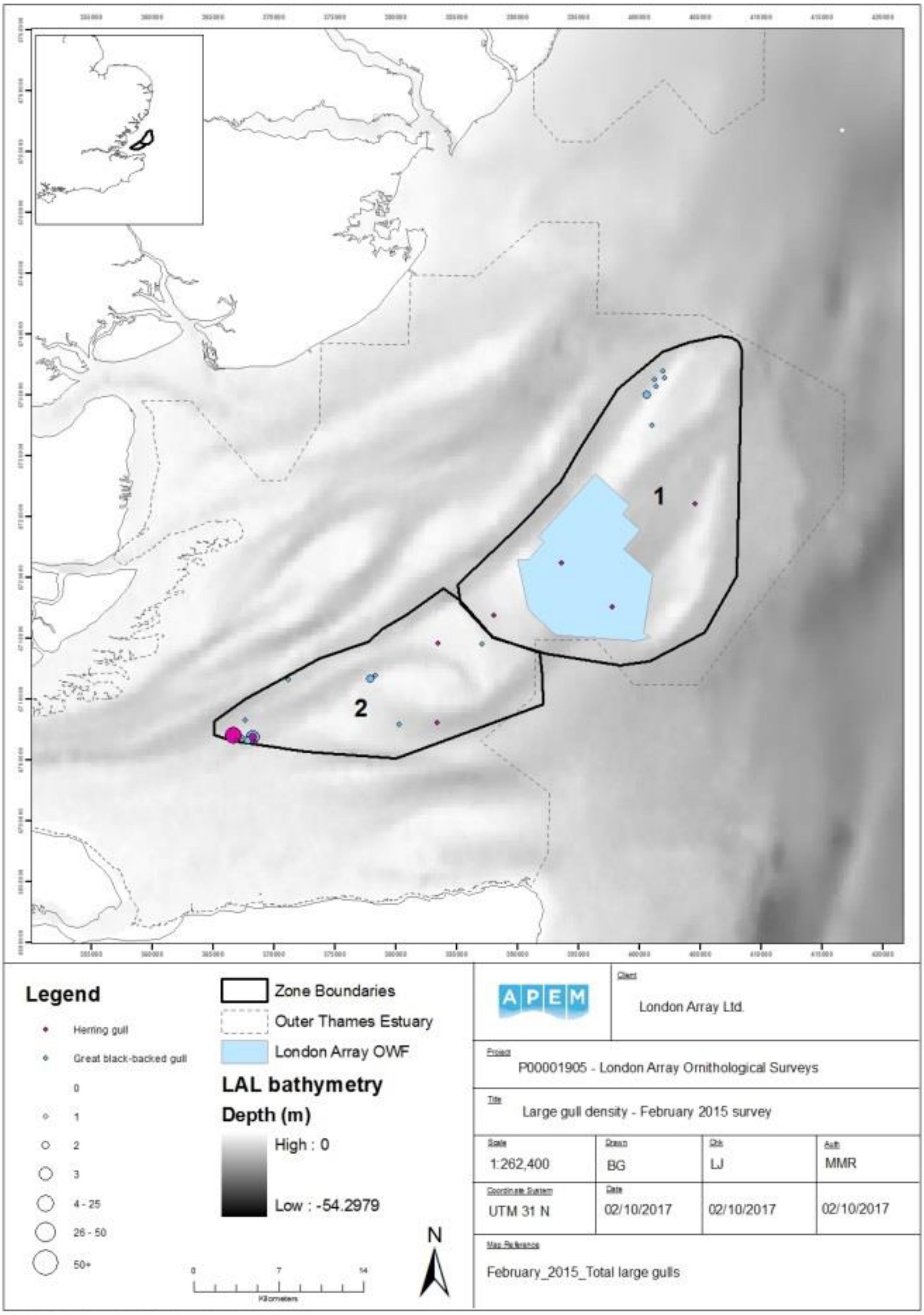

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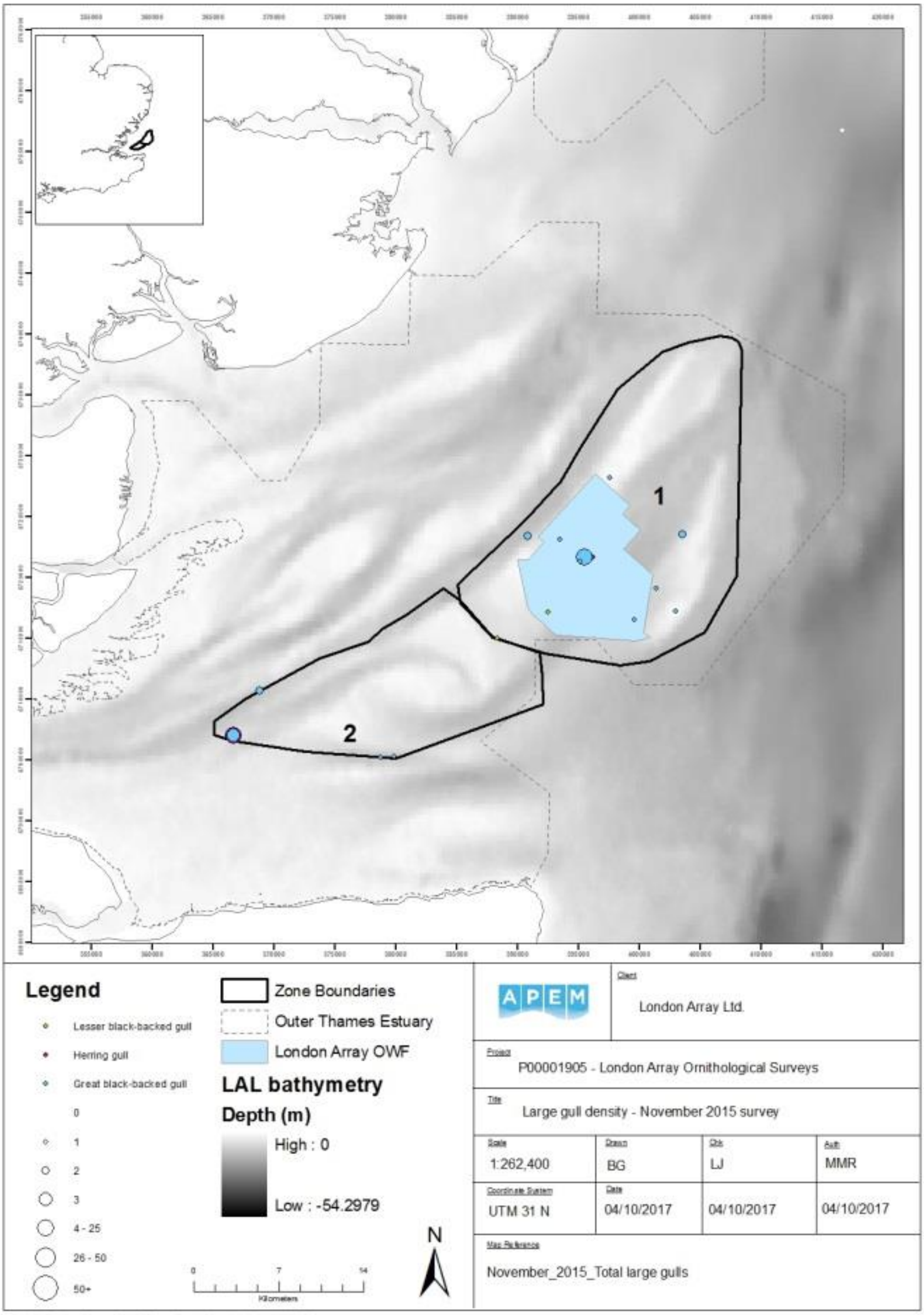

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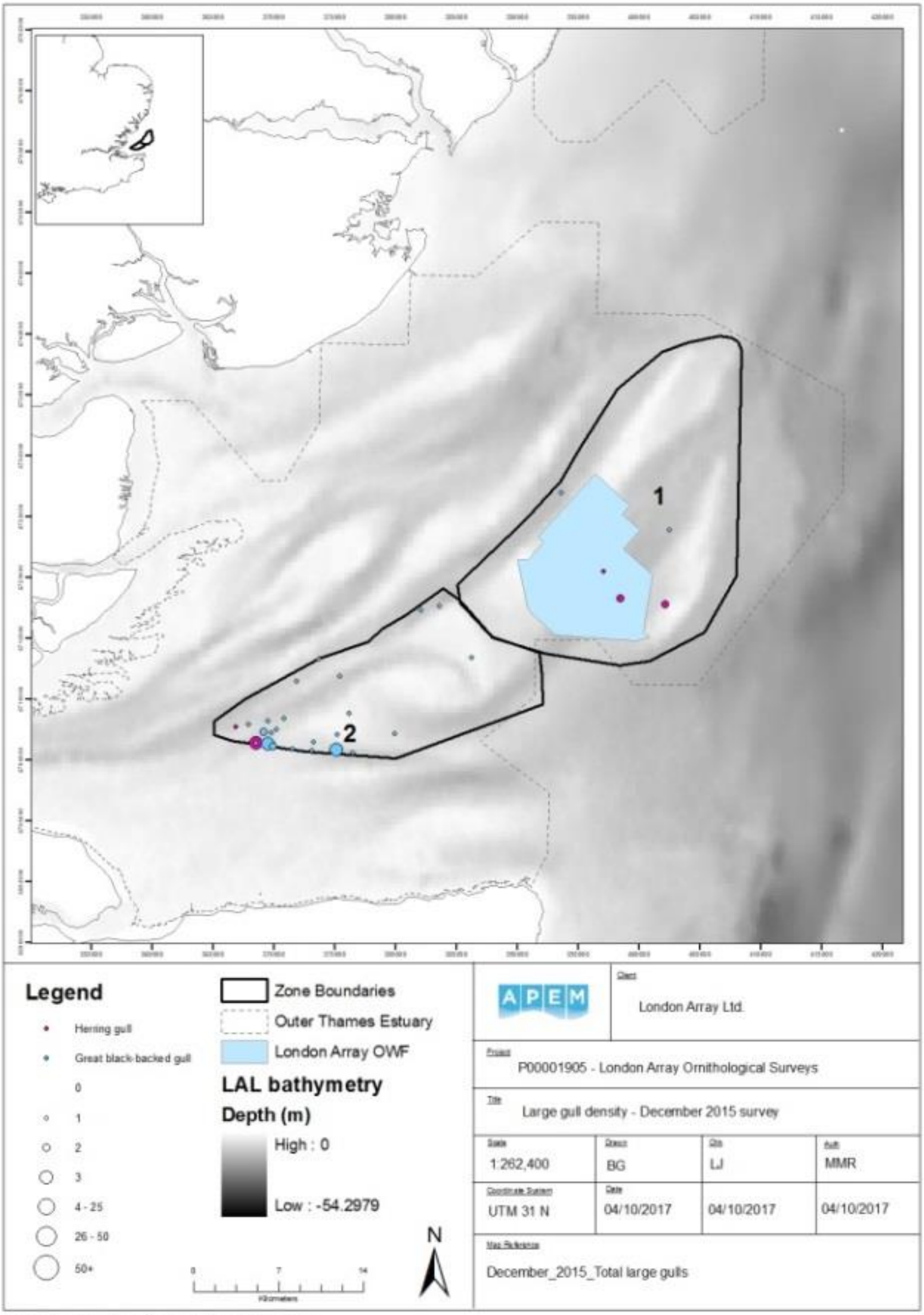

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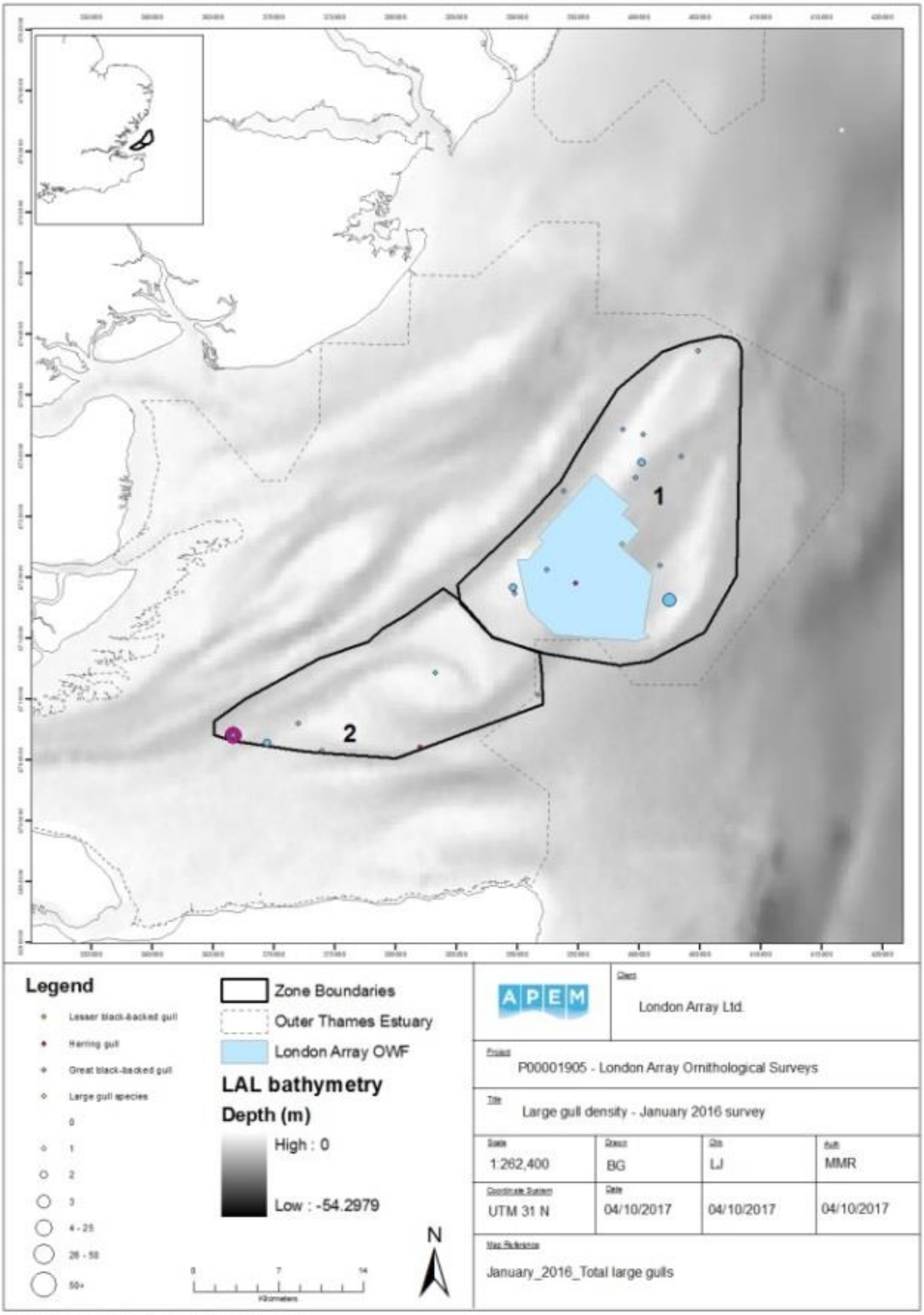

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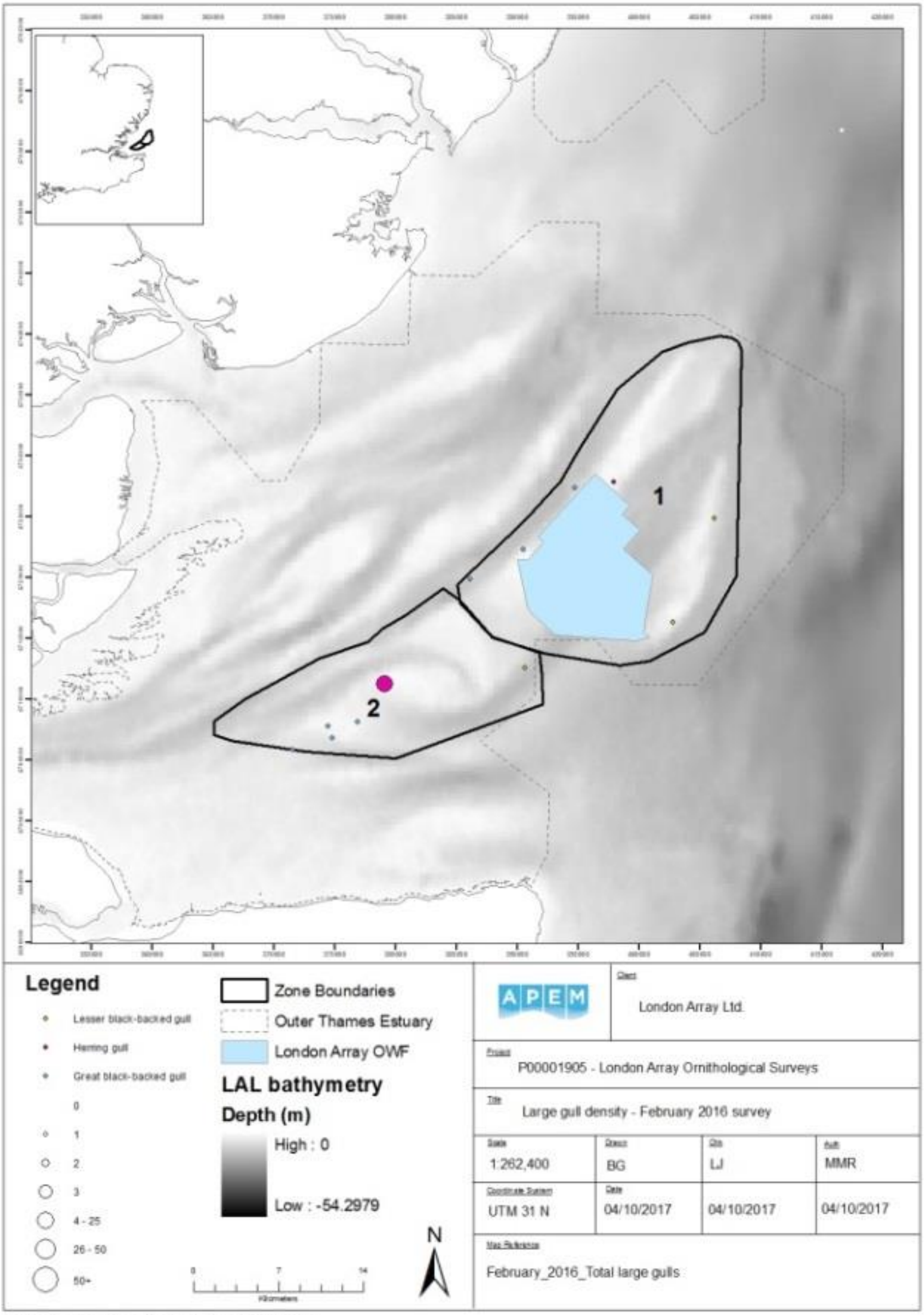
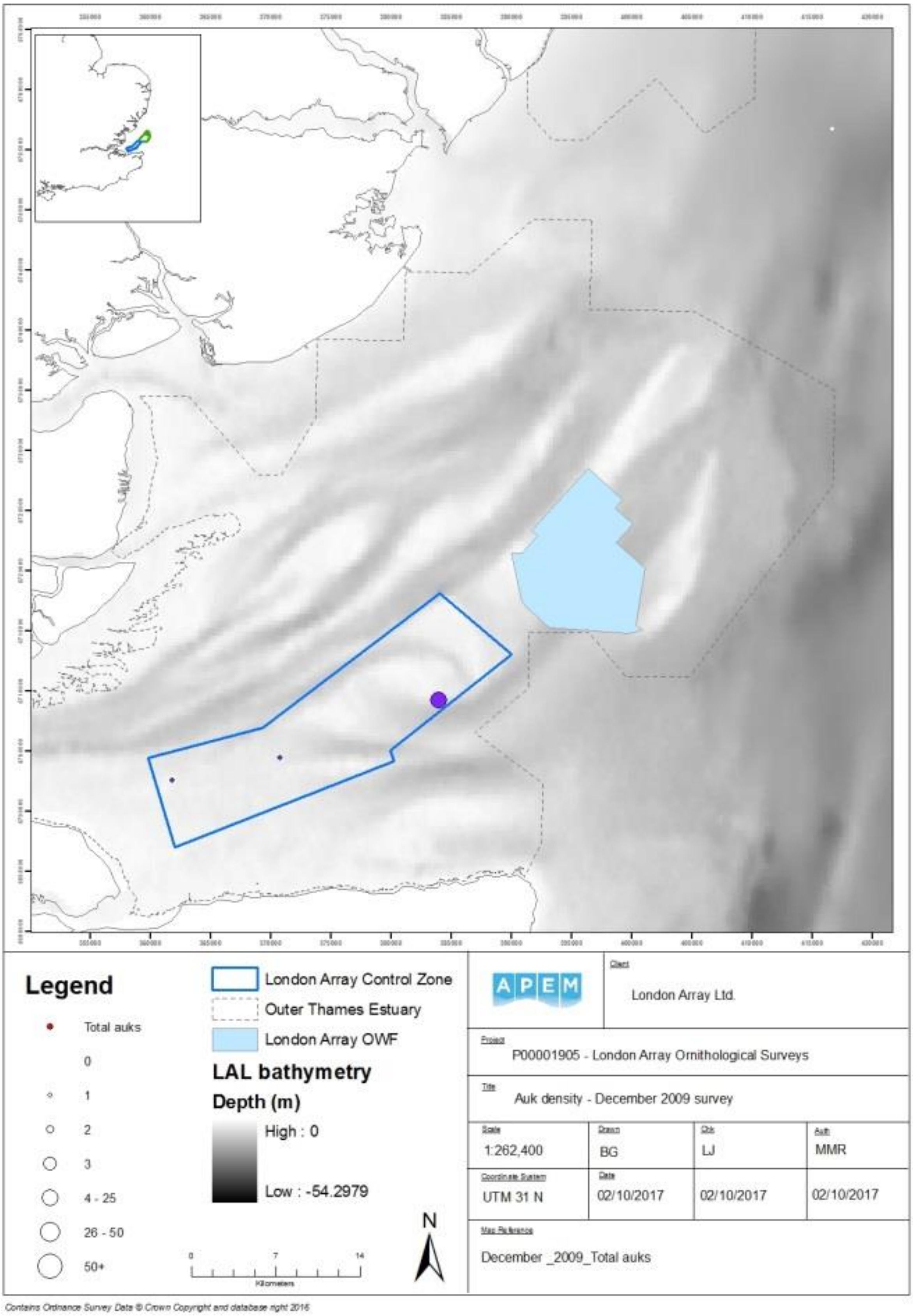


February 2016

Figure 7 Monthly distribution maps for large gulls recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Auks



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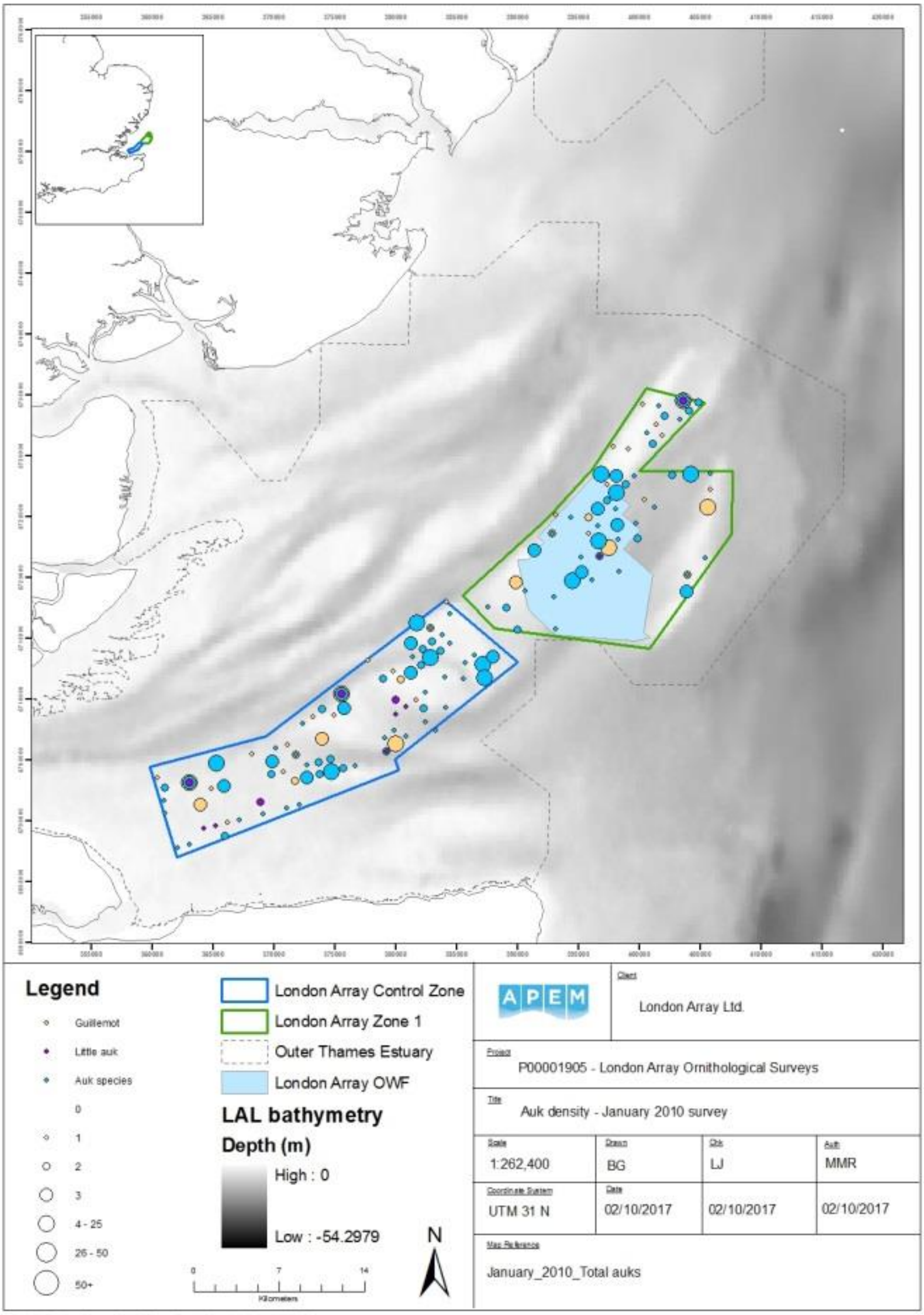

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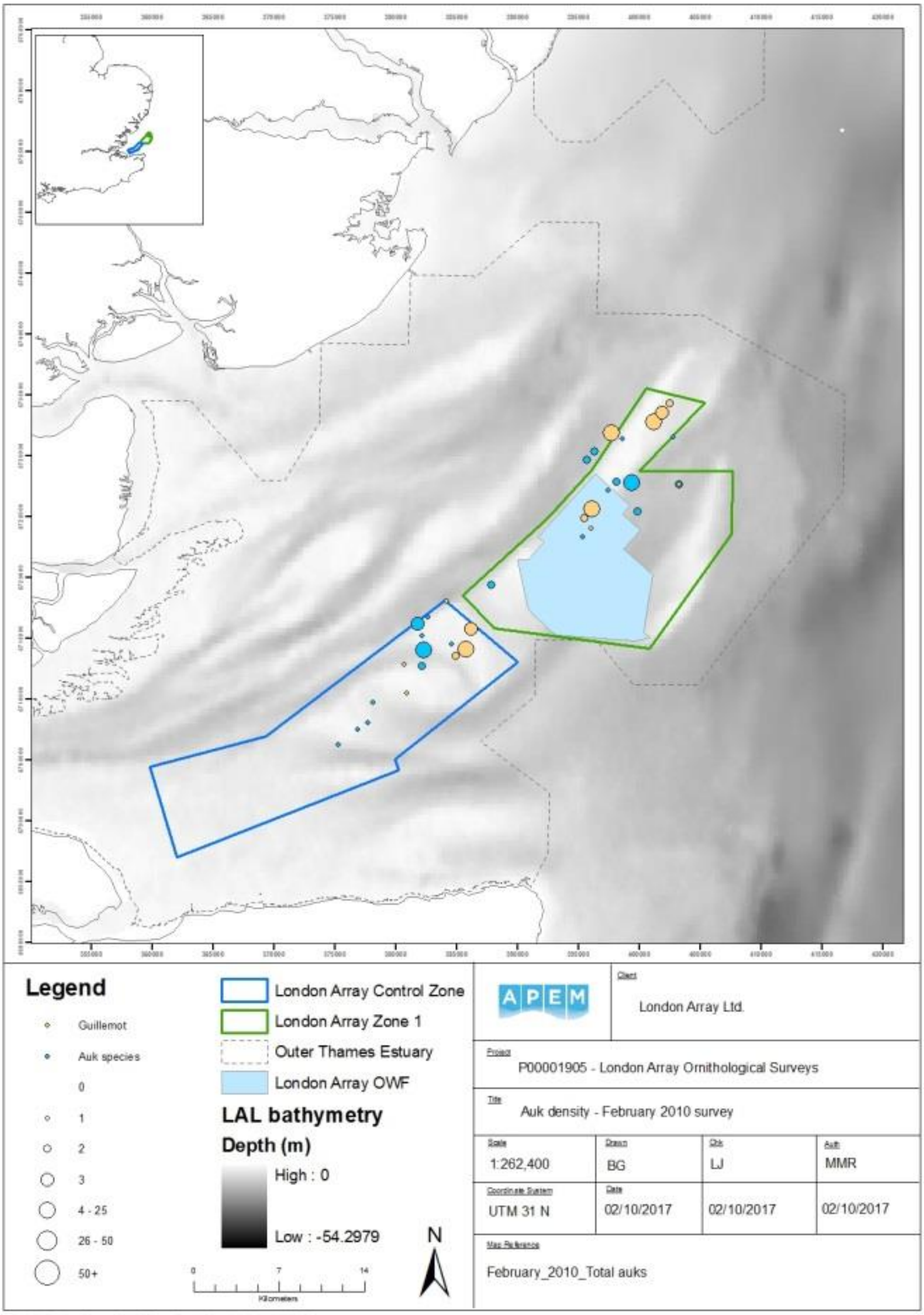

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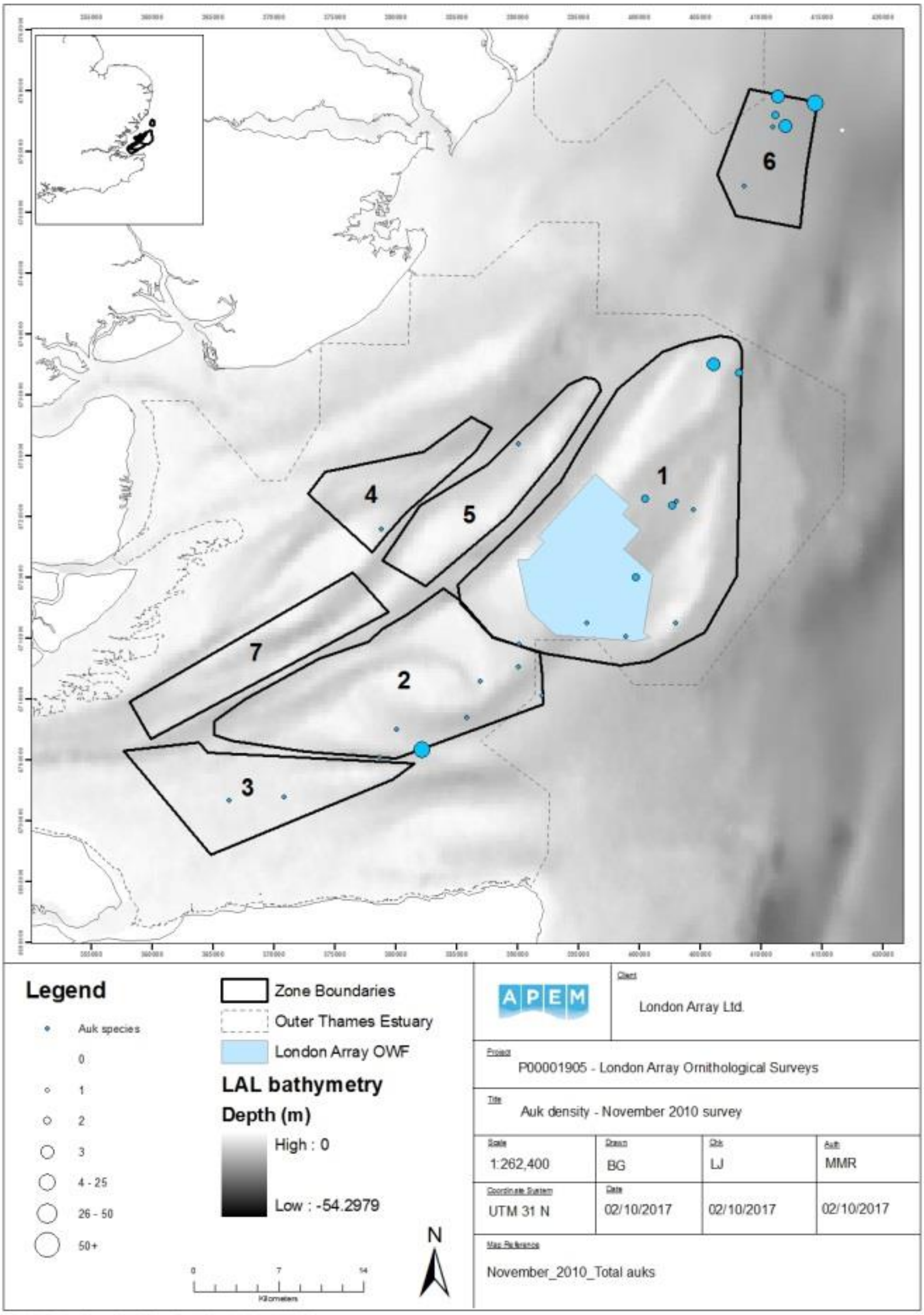

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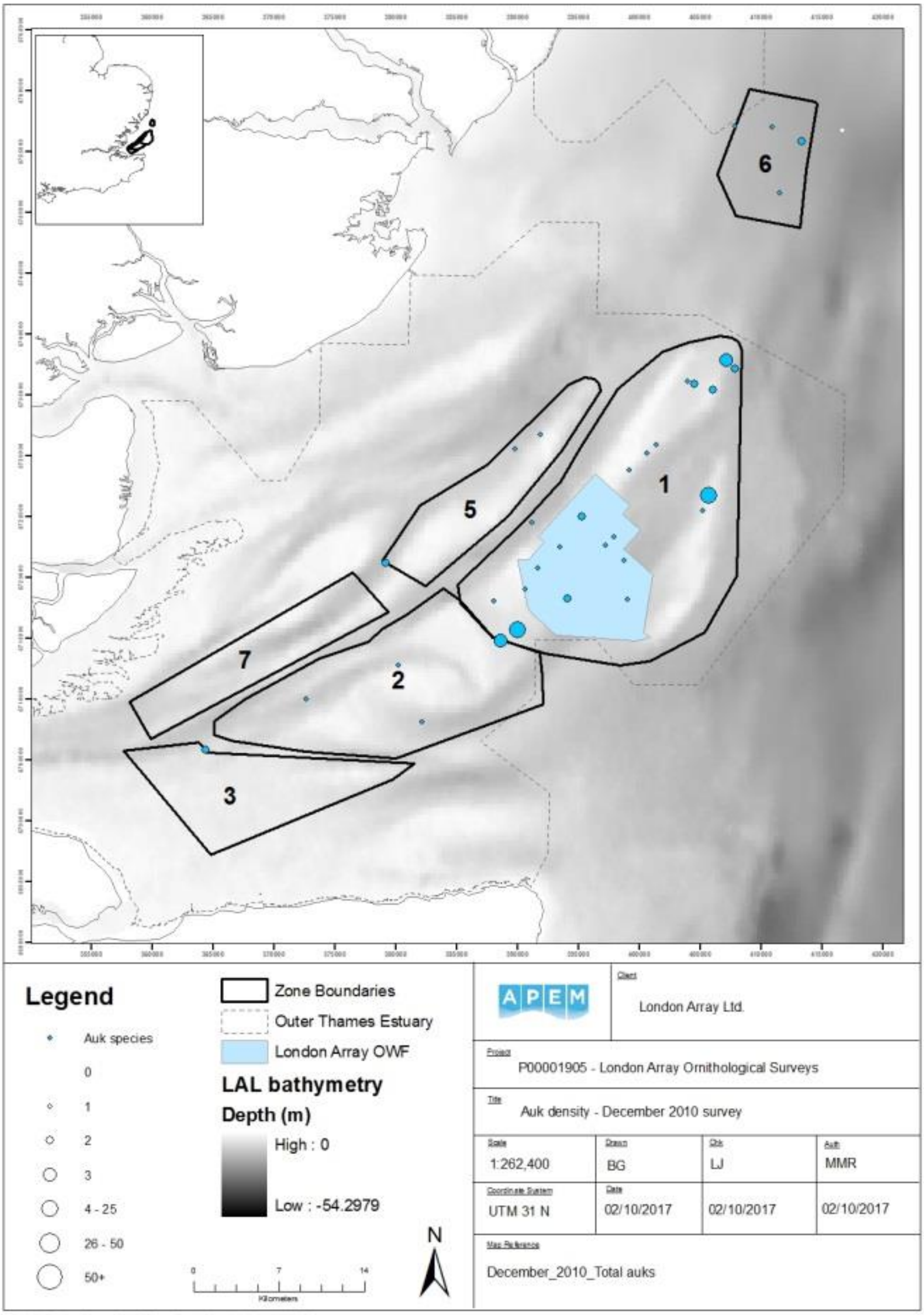

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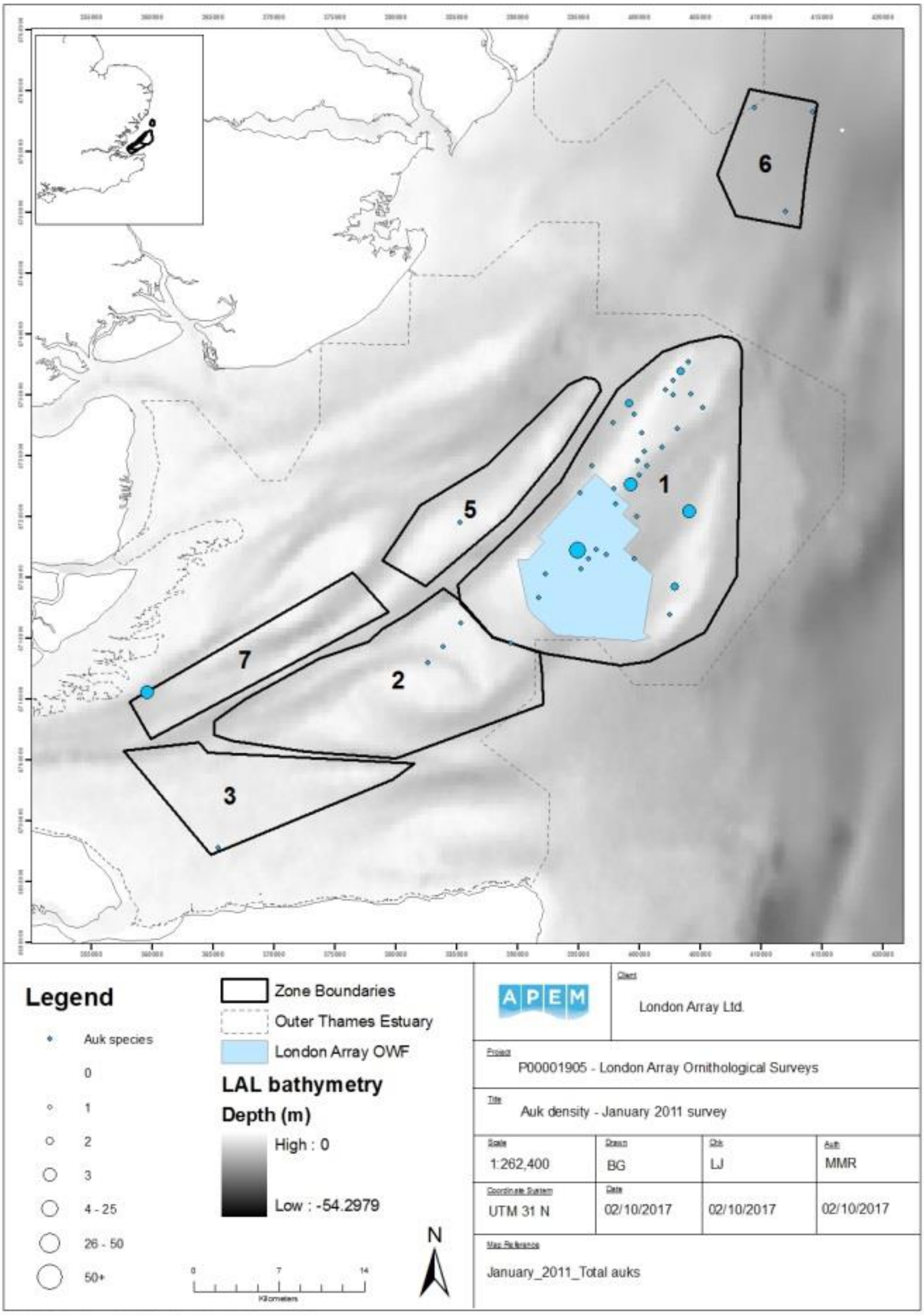

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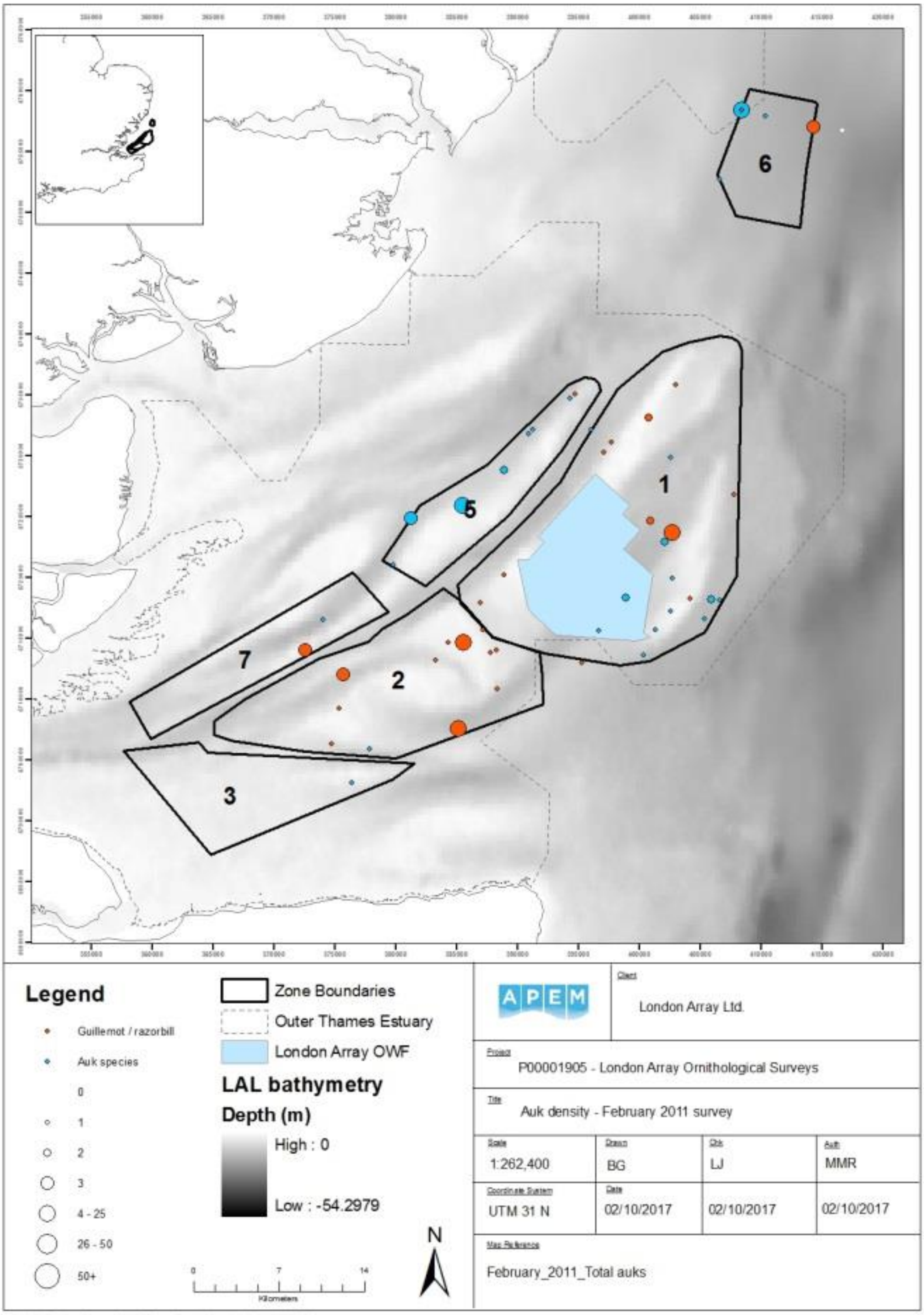

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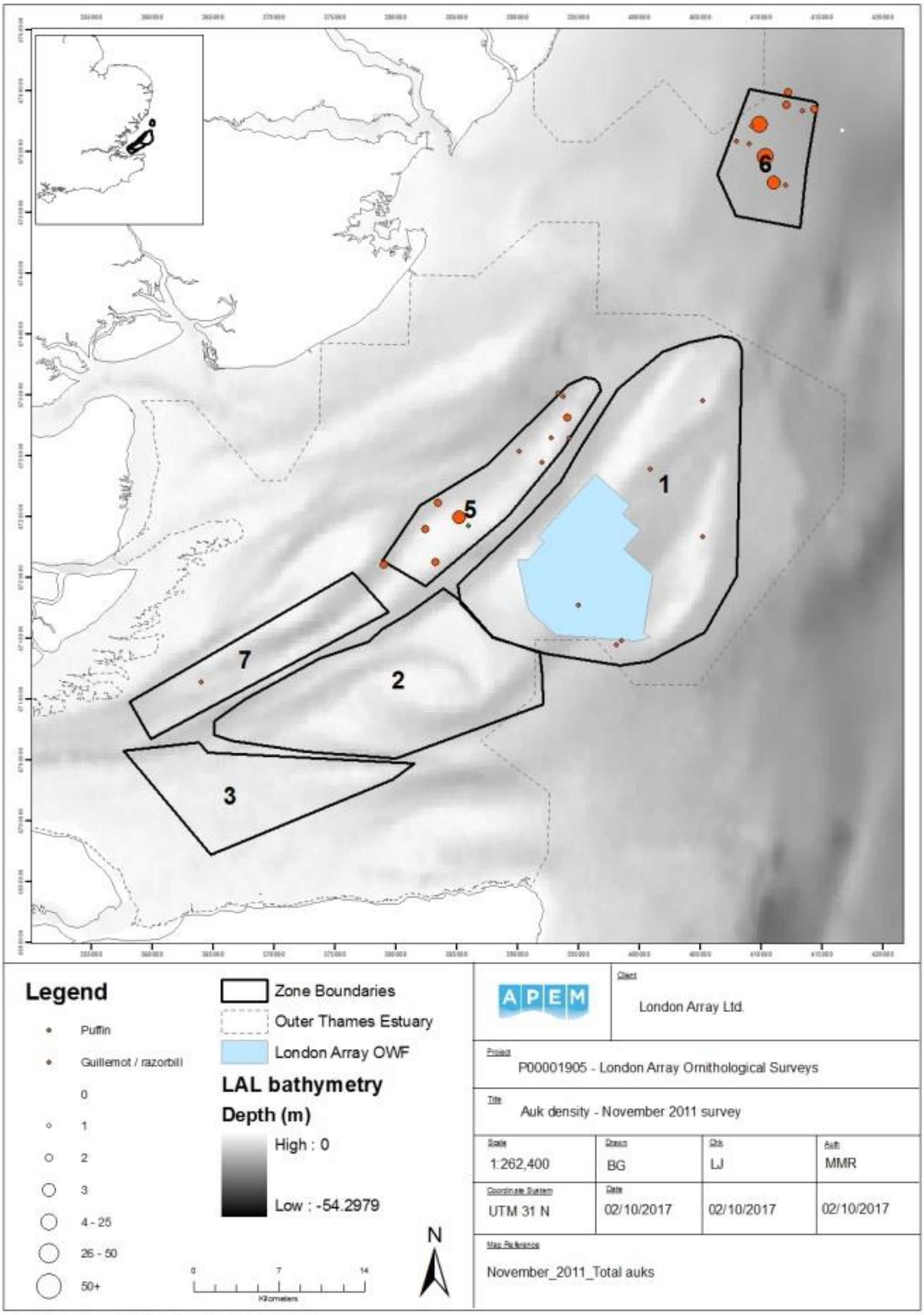

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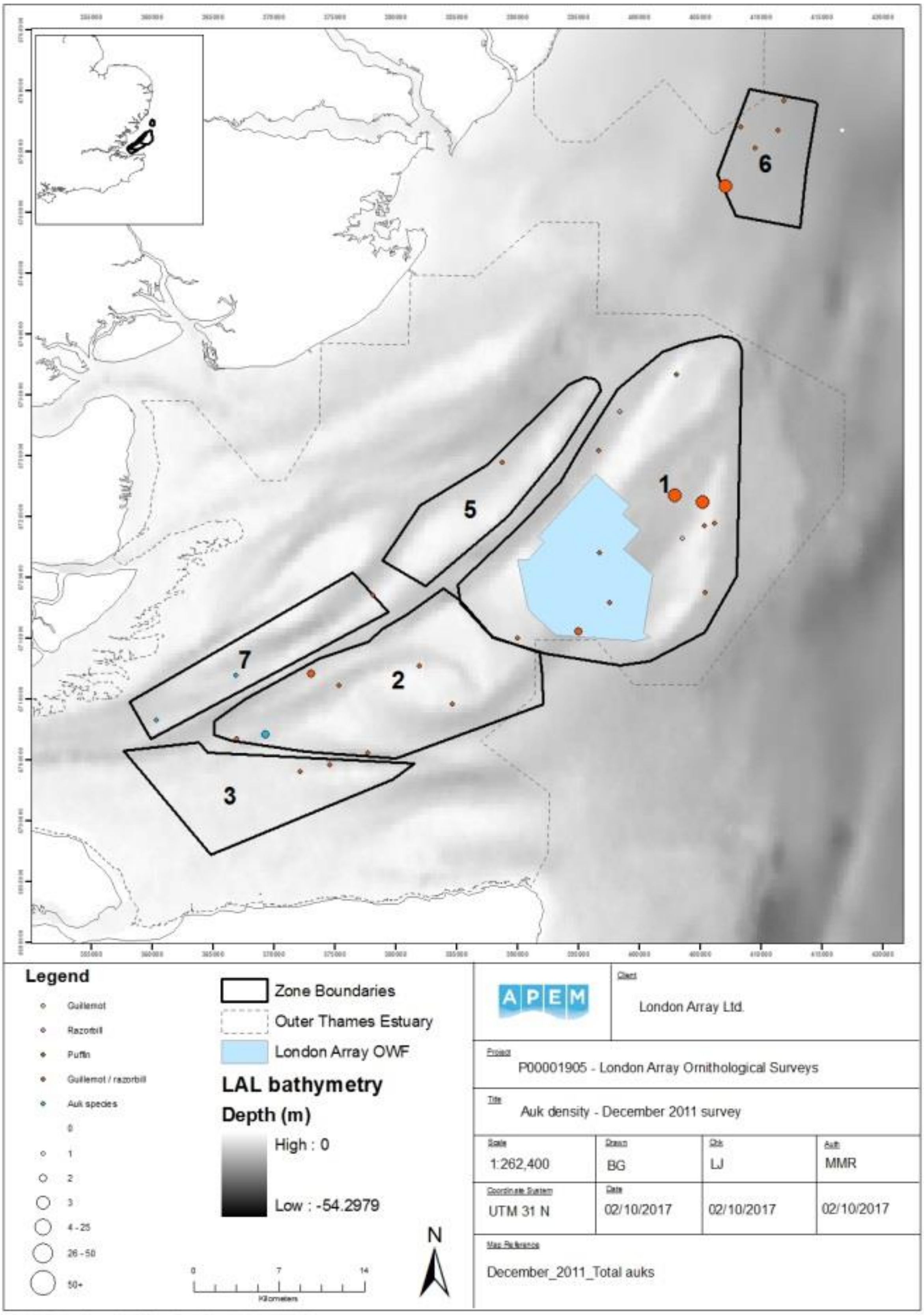

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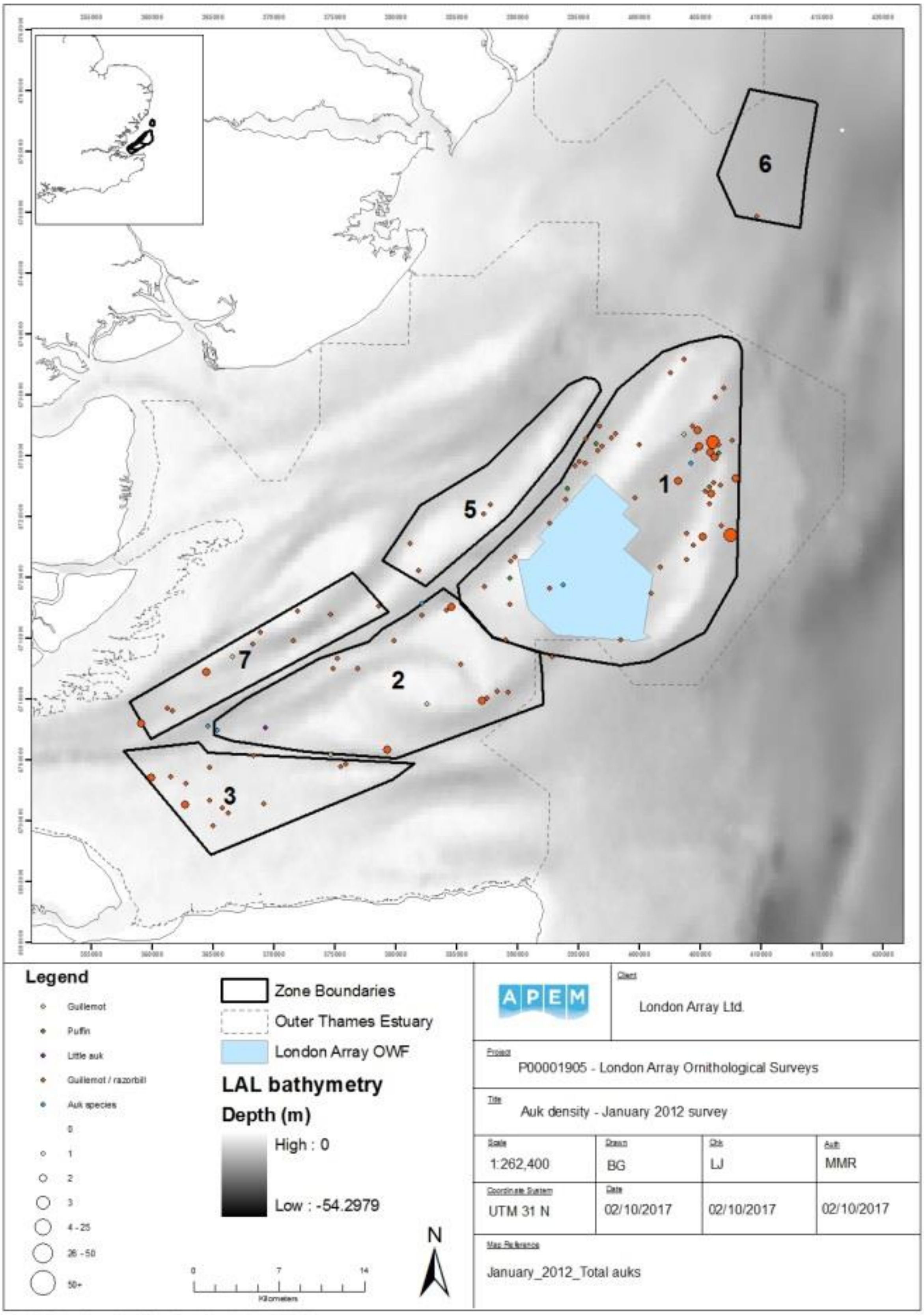

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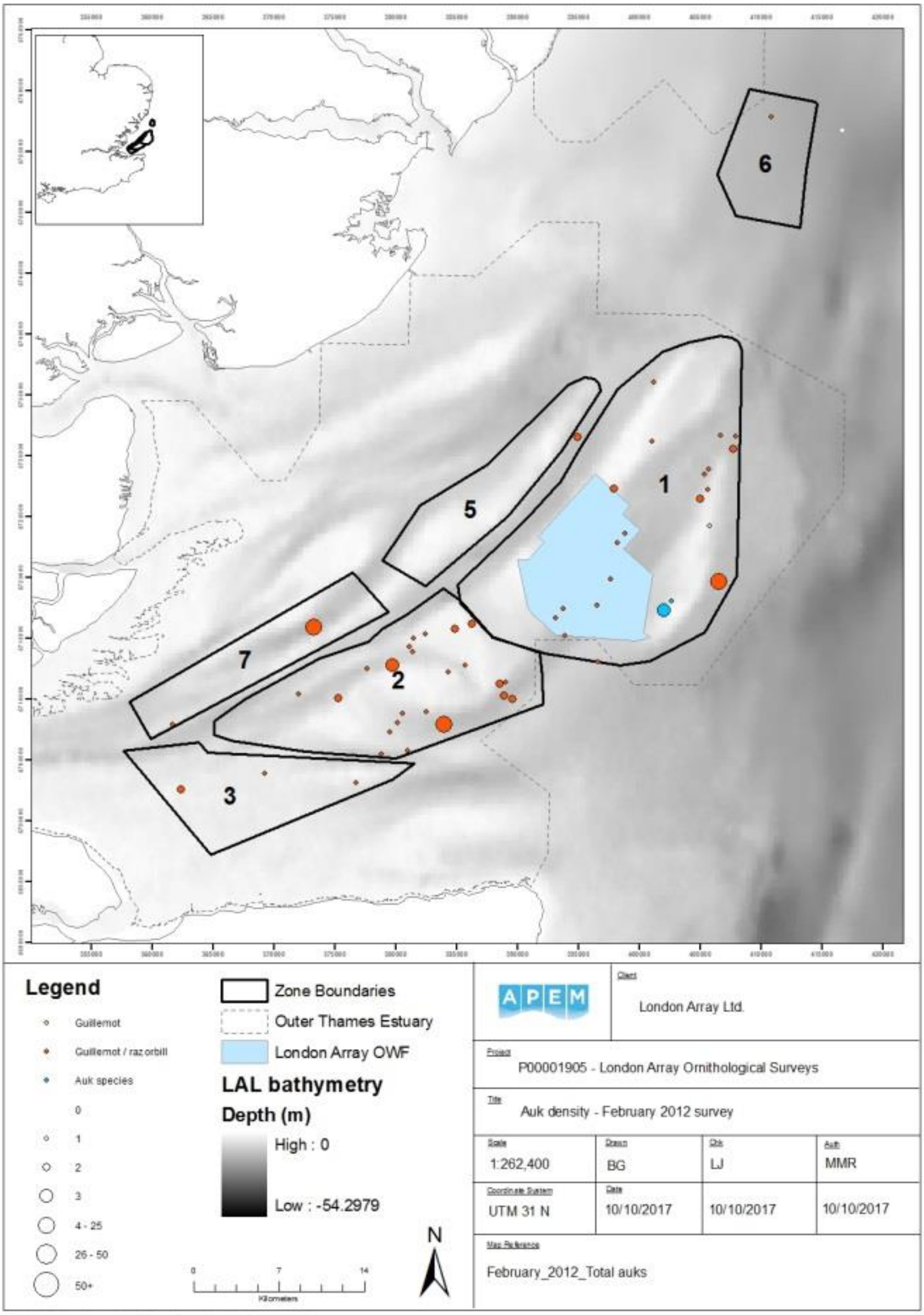

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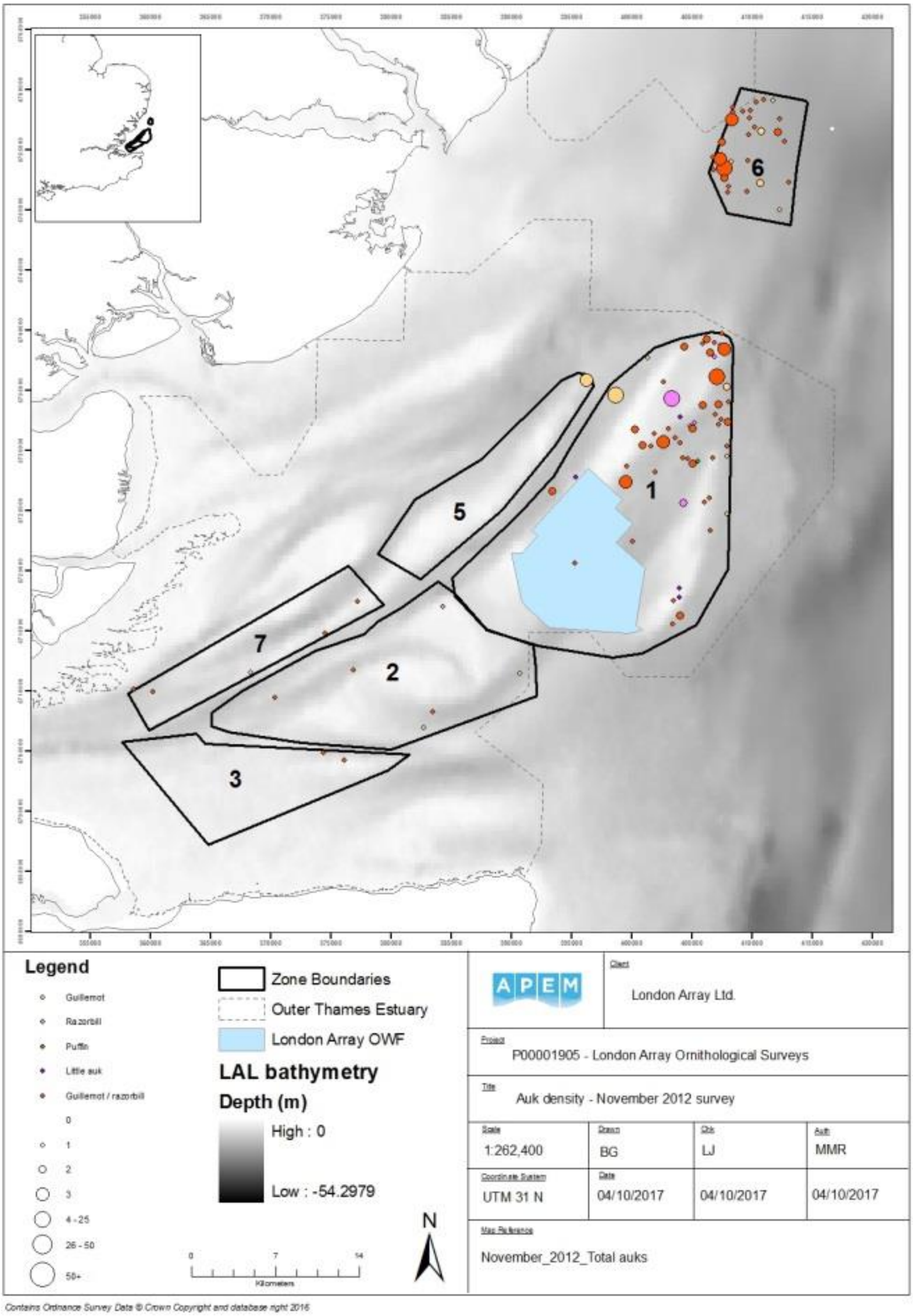

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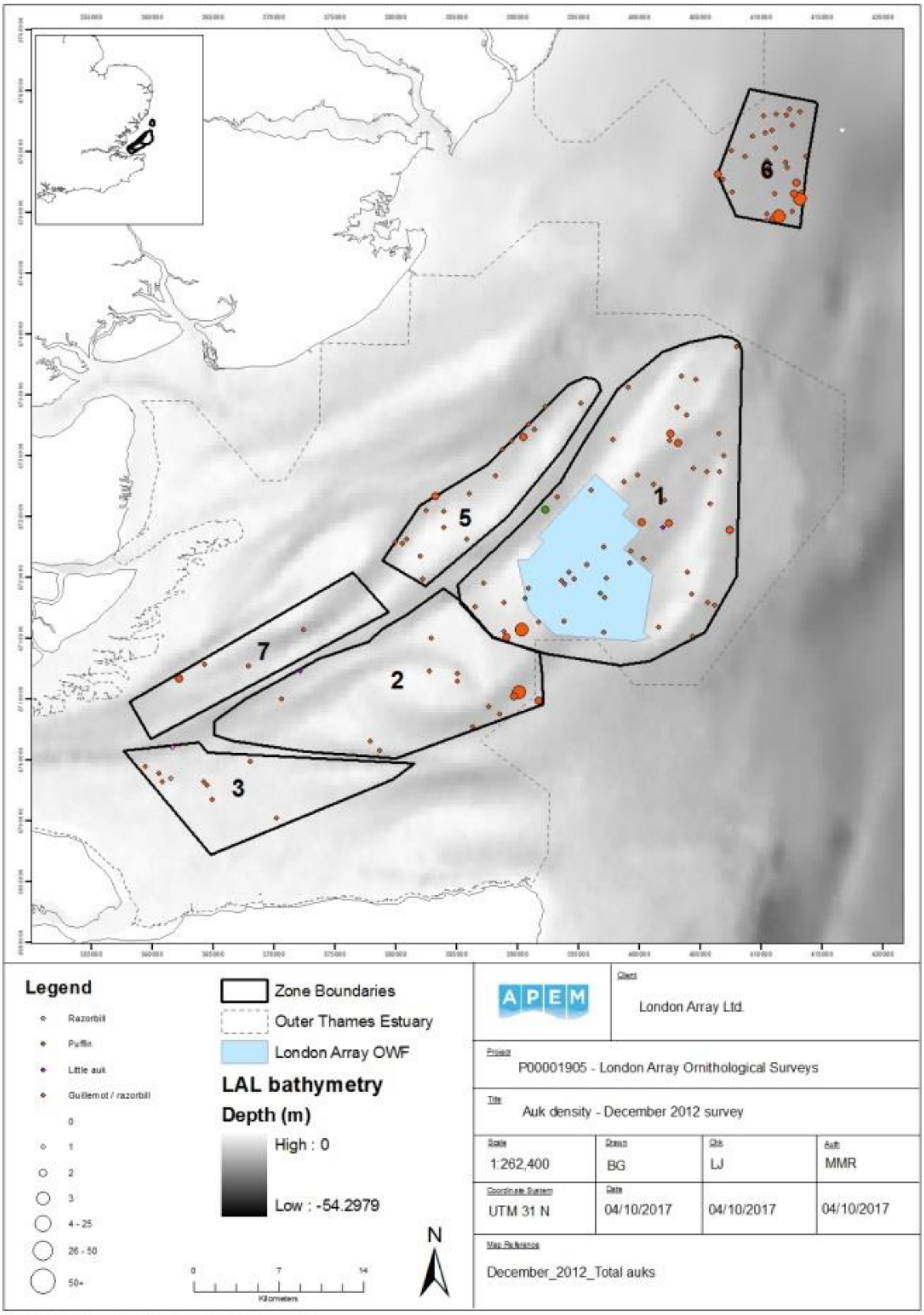

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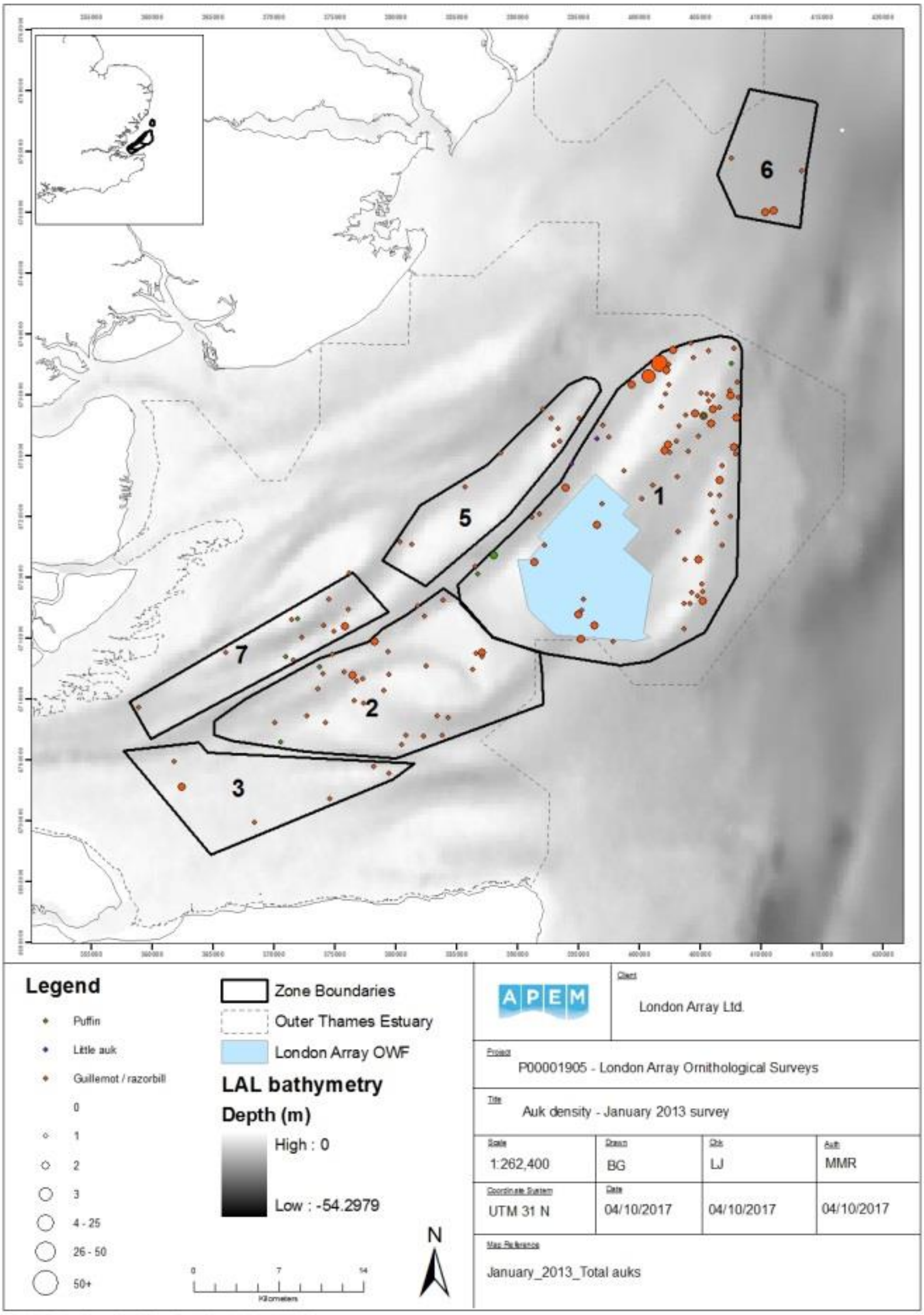

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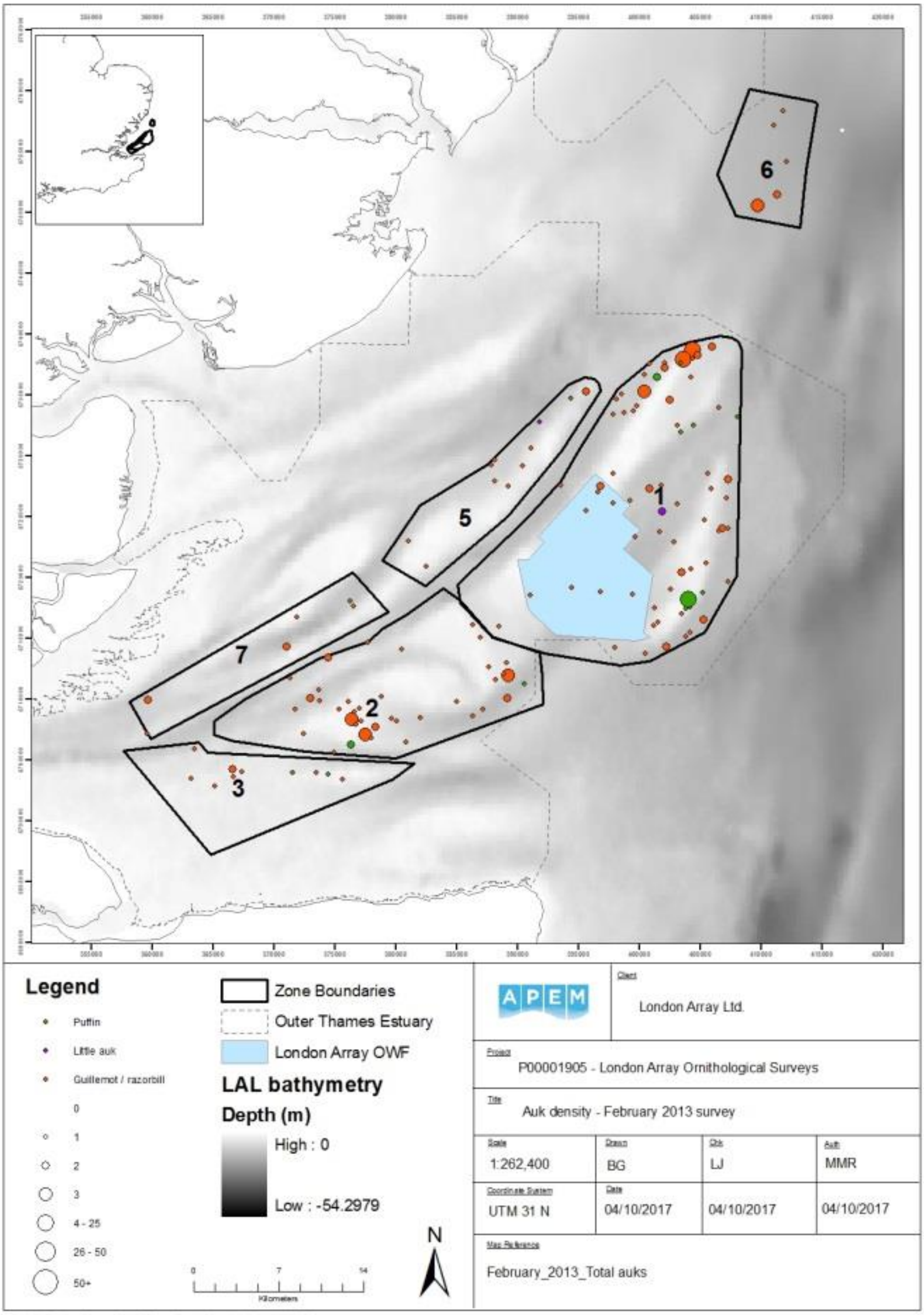

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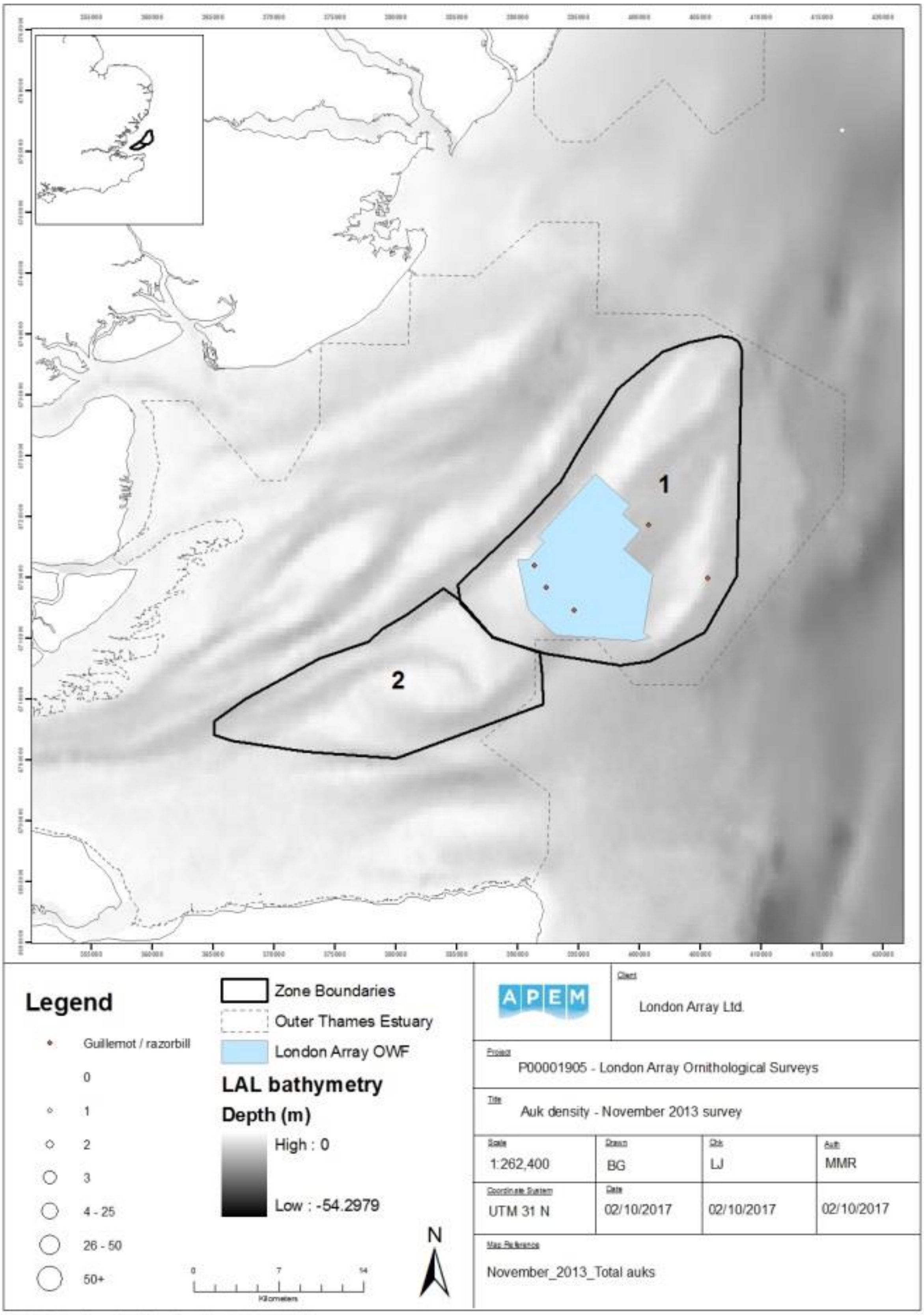

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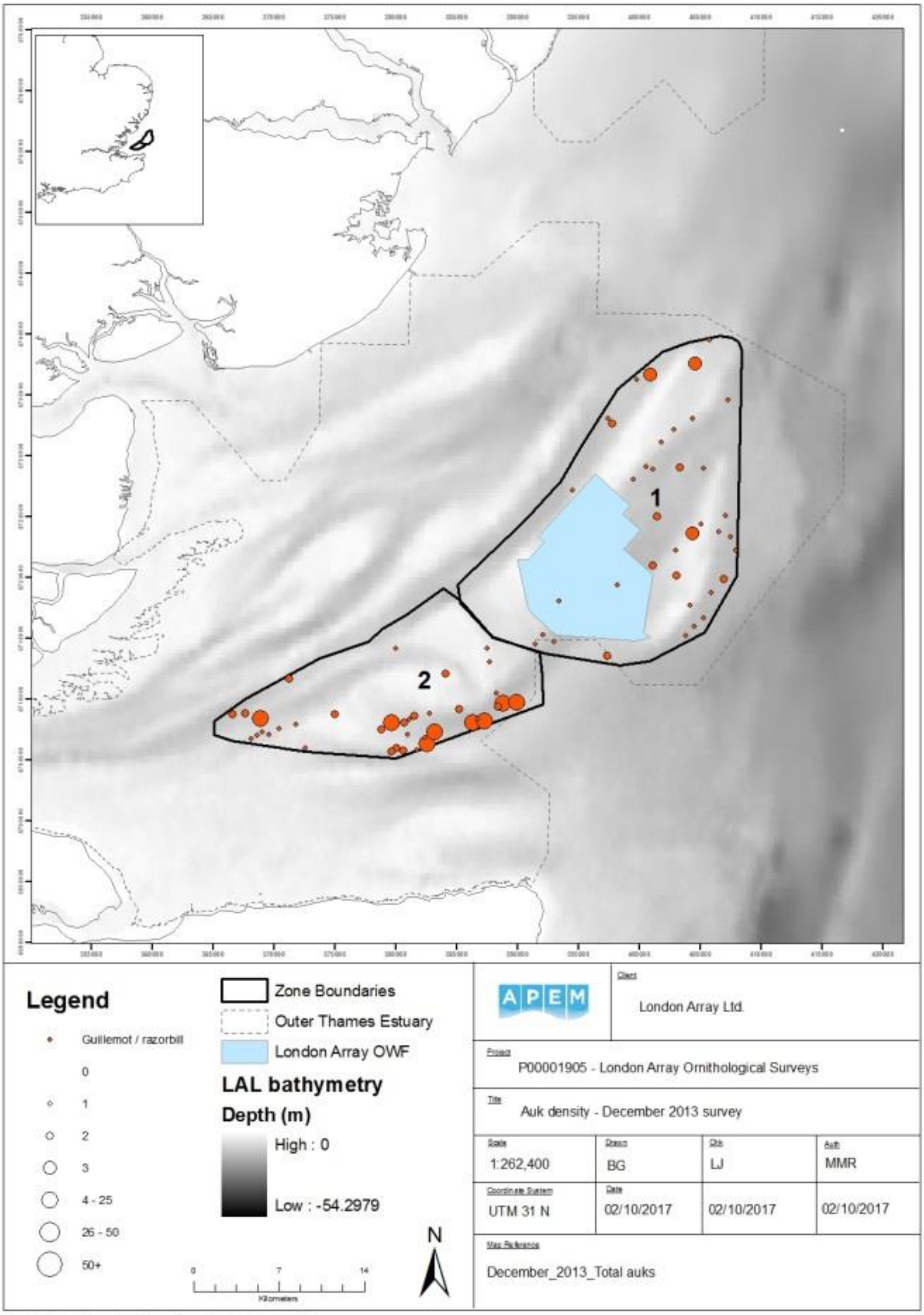

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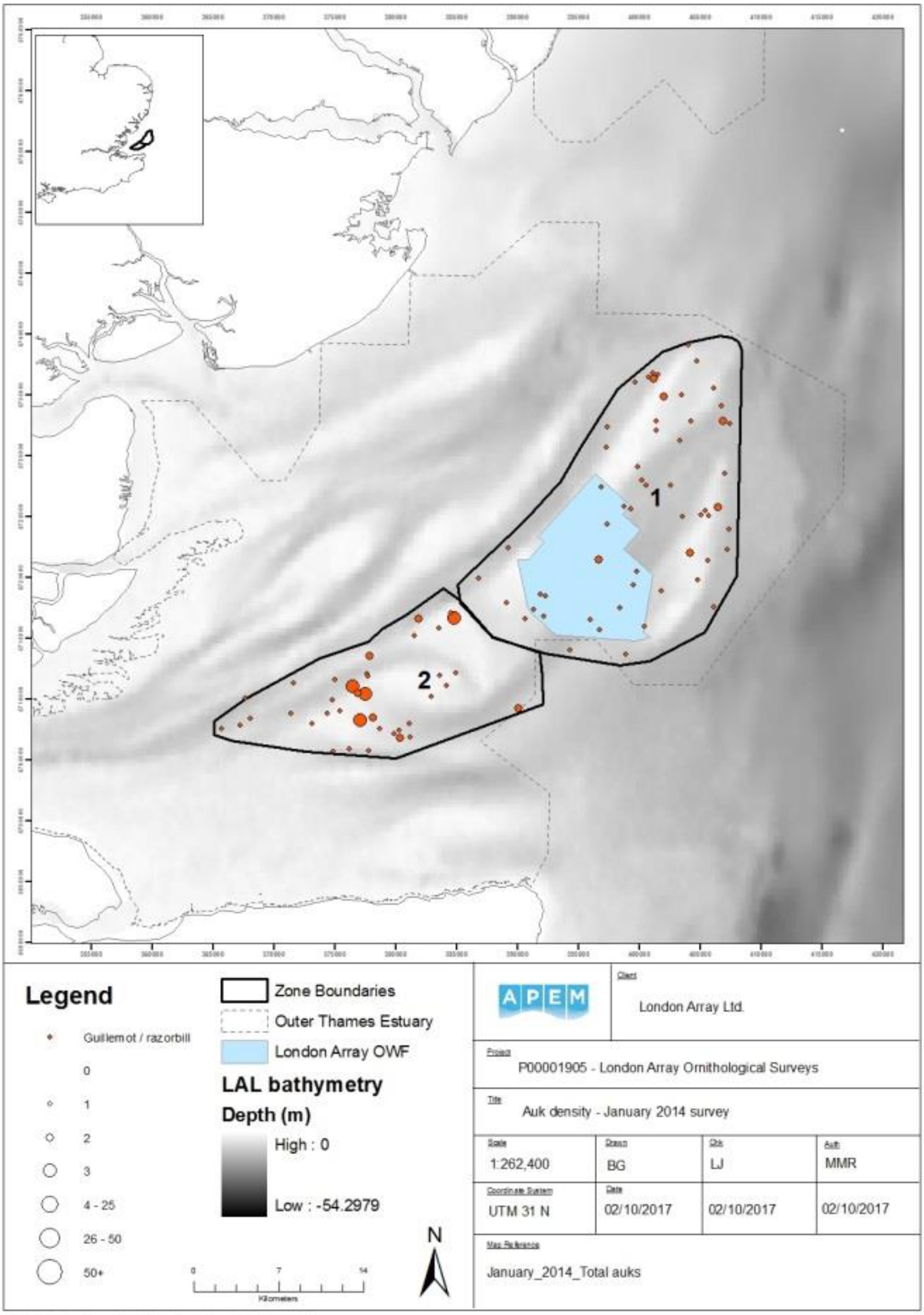

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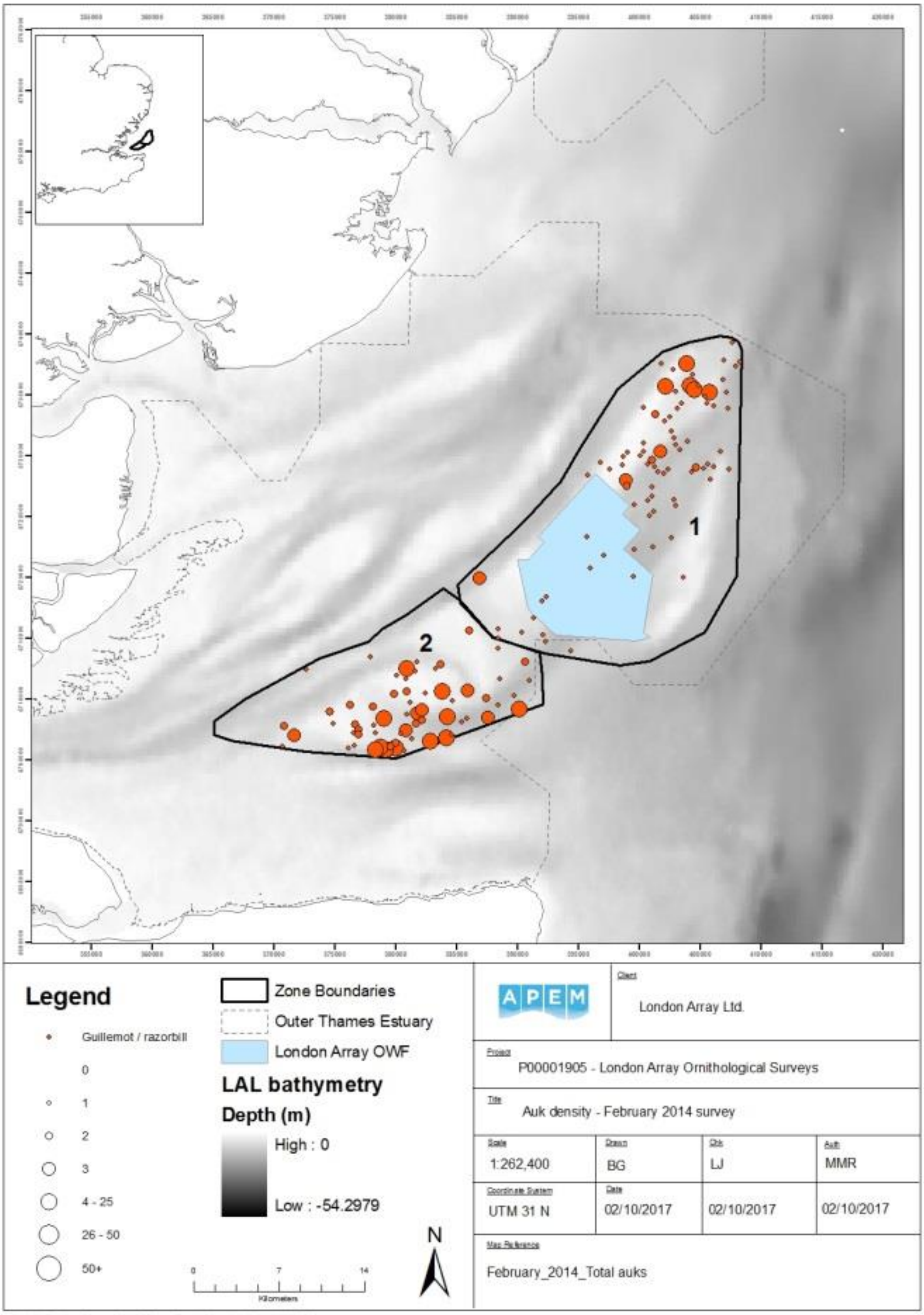

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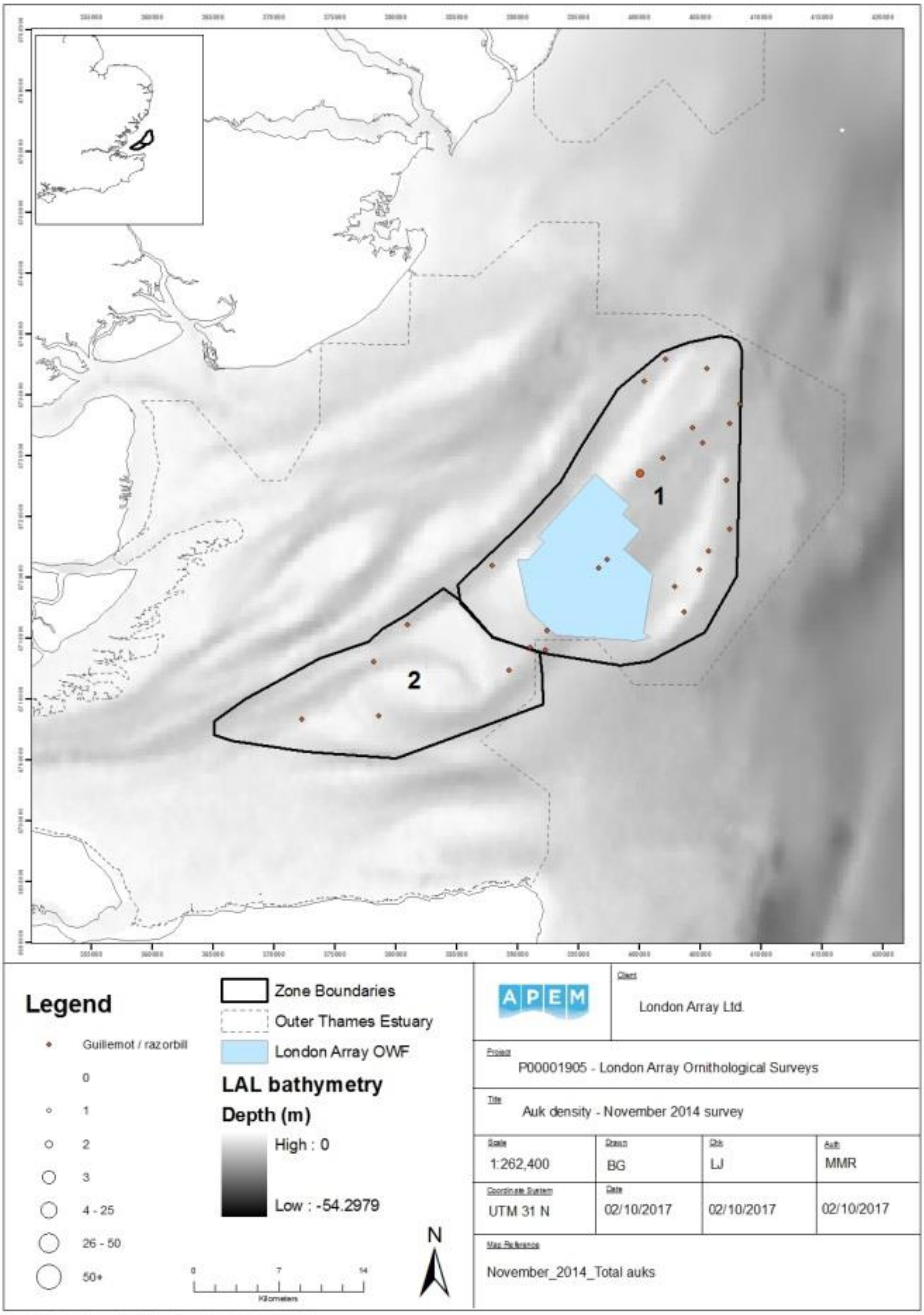

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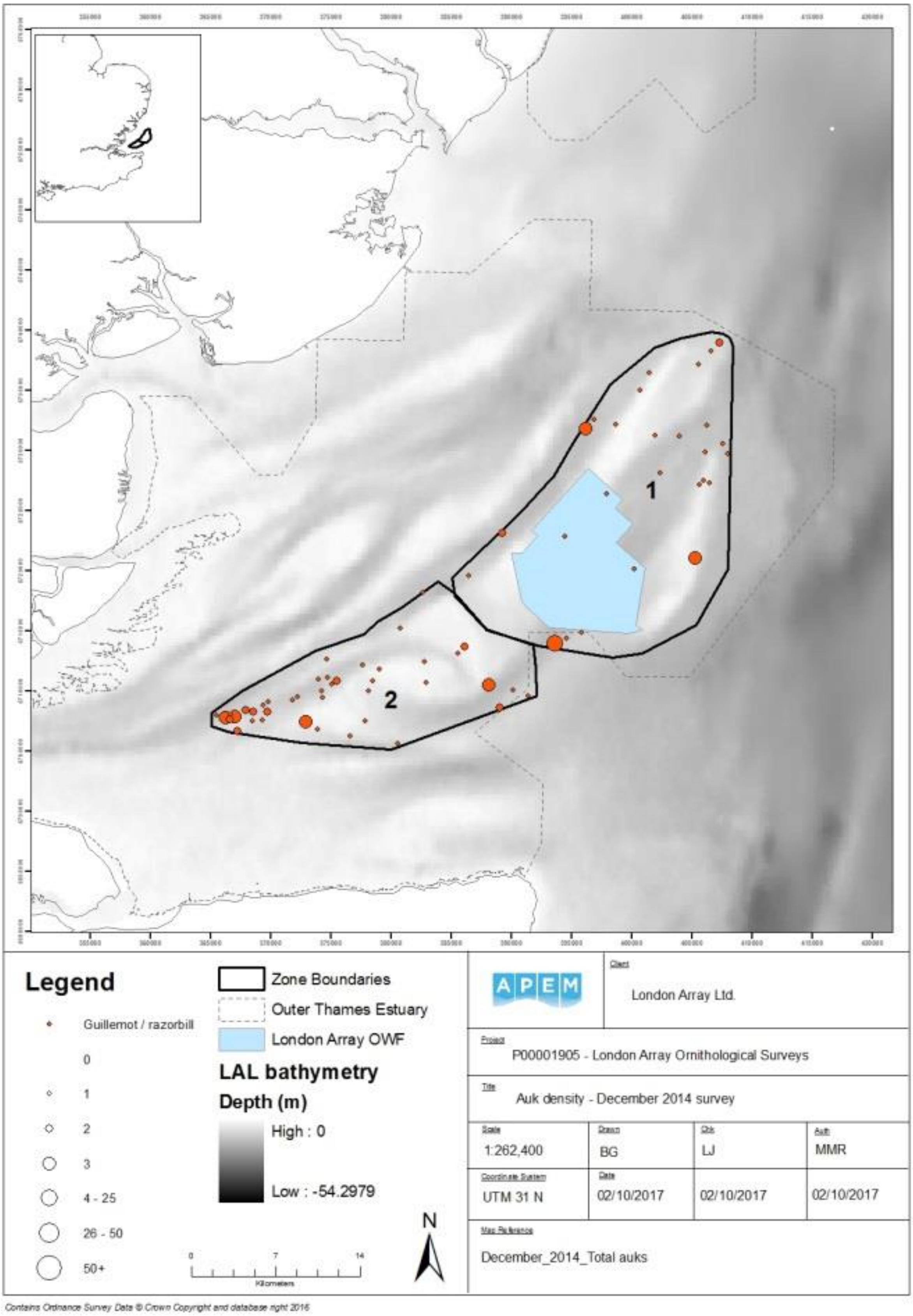

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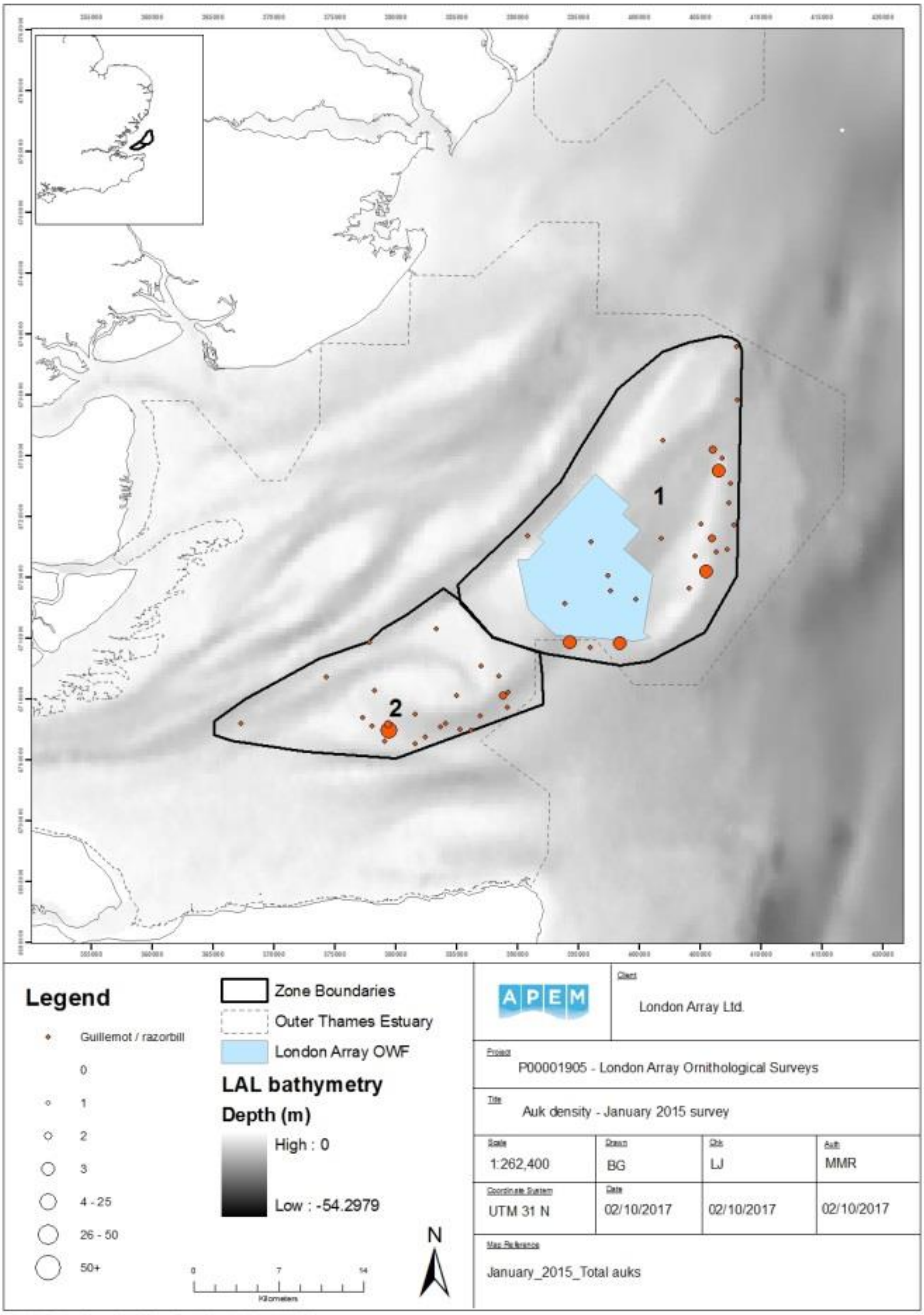

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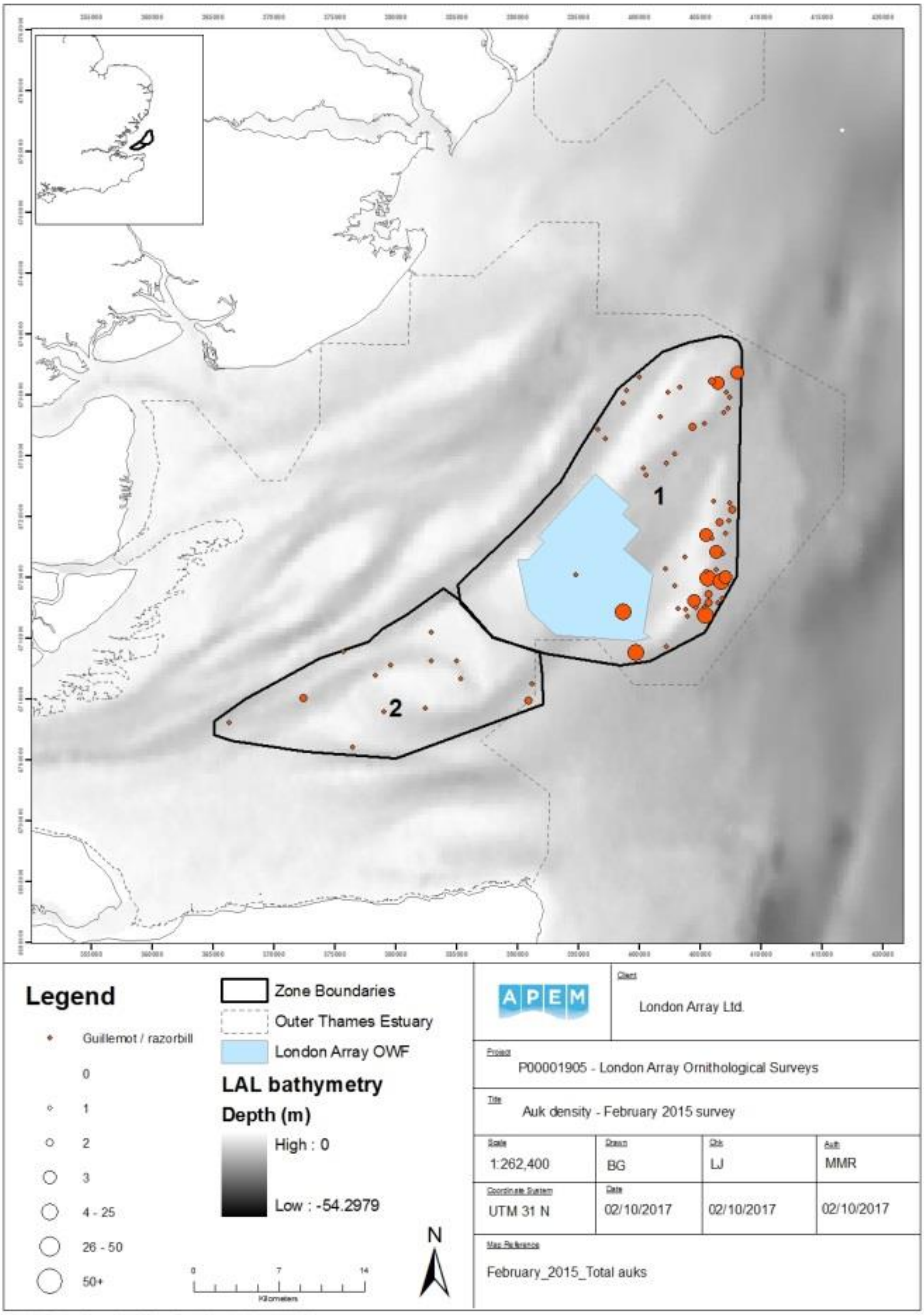

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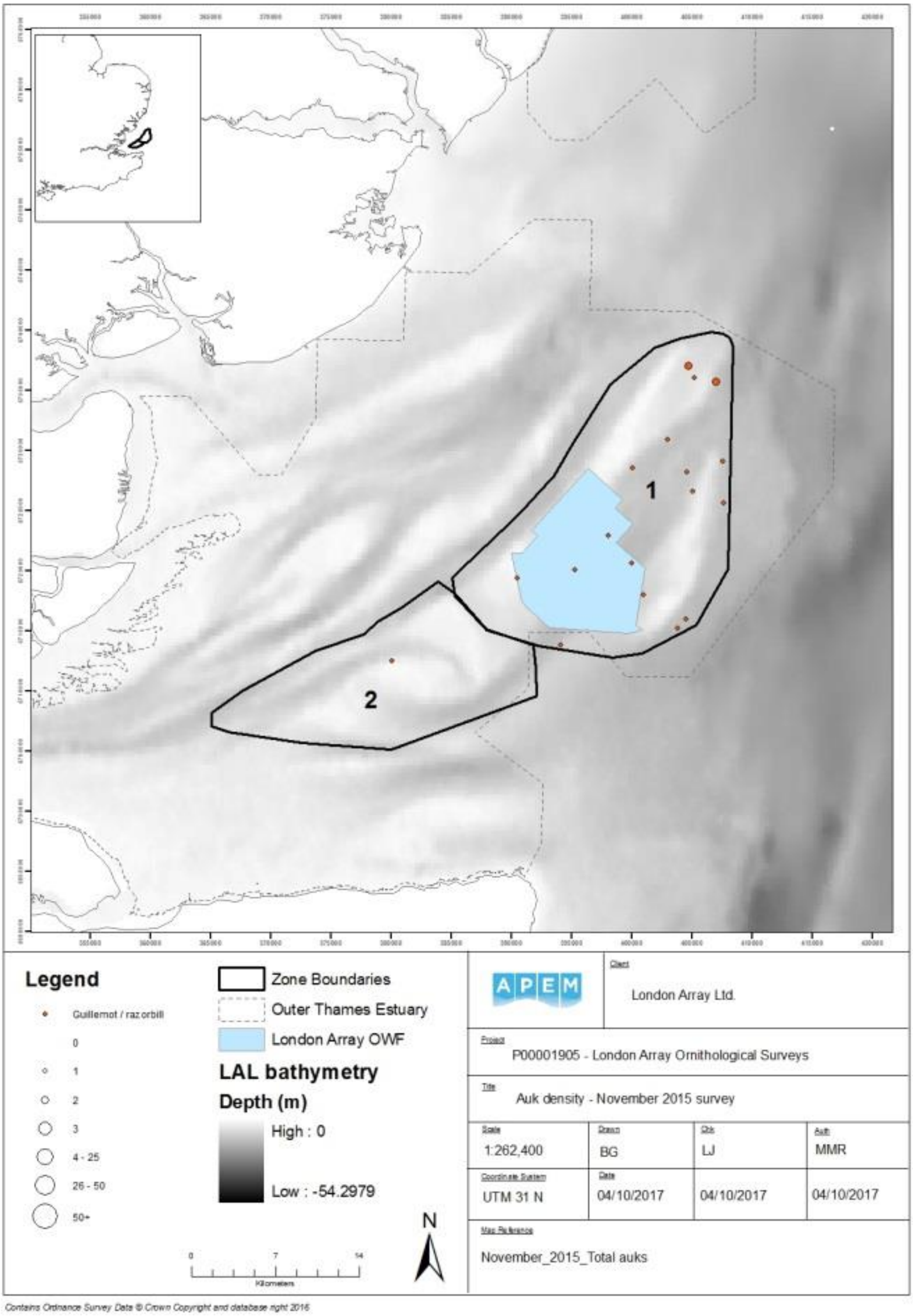

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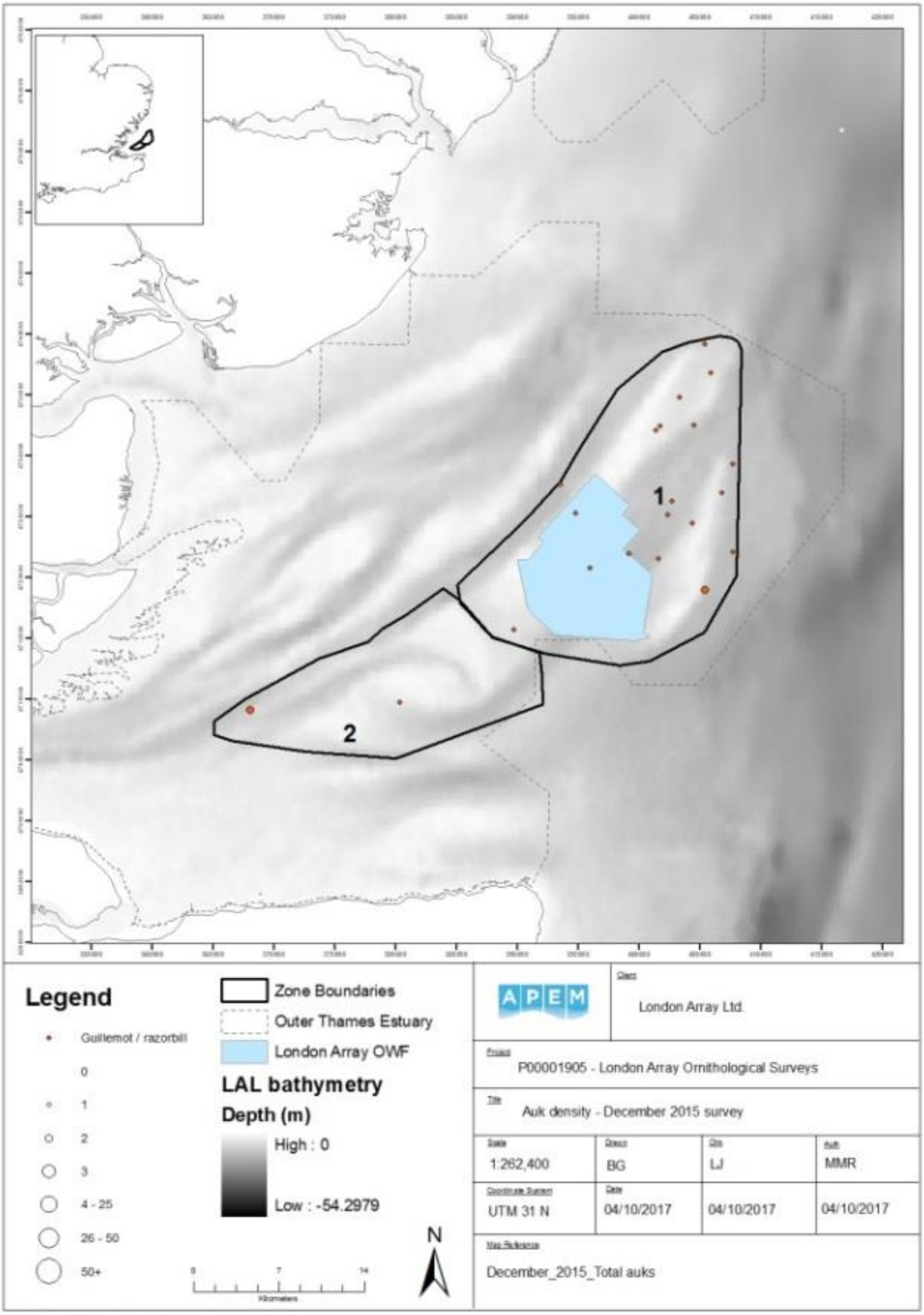

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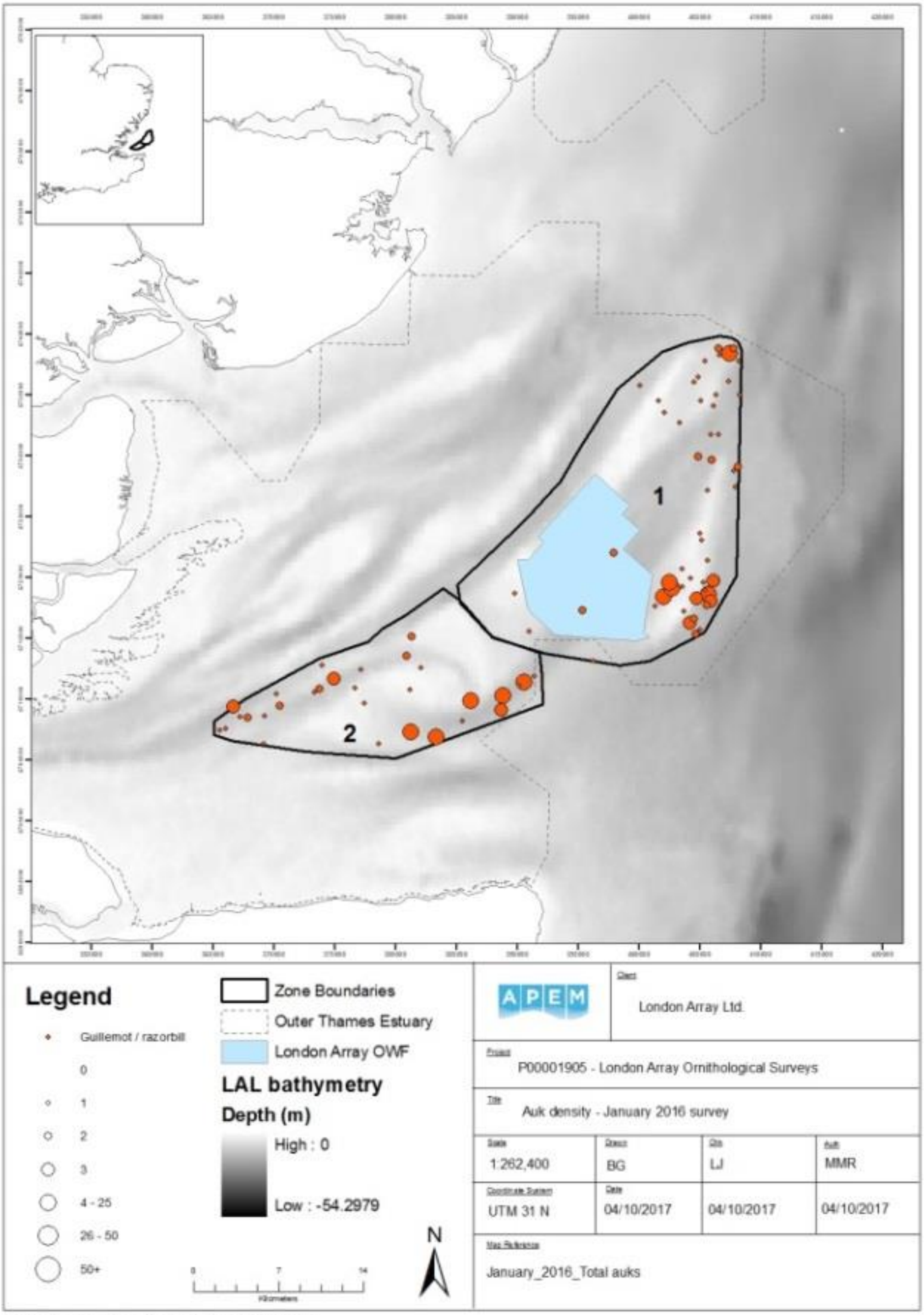

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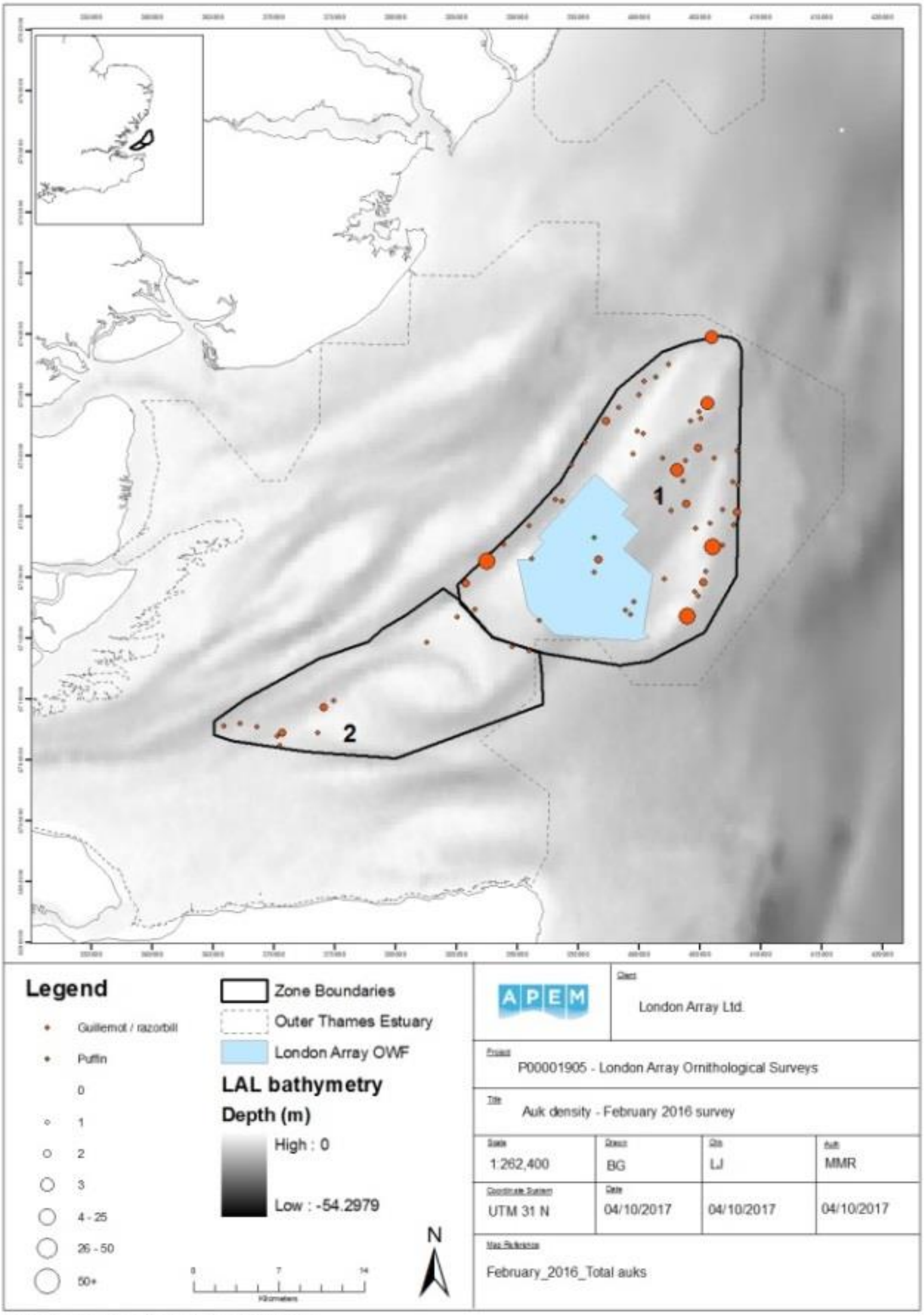


February 2016

Figure 8 Monthly distribution maps for auks recorded in the pre-, during- and post-construction aerial surveys of the LAW.

Appendix 5 Yearly Peak Densities (2009-2016)

Tables 1 to 7 present the peak density of species collated from pre-, during and post-construction digital aerial surveys between 2009 and 2016 in Zones 1 to 7. All the species recorded during the surveys are presented in the tables to aid comparability between each Zone.

Table 1 Peak density for all birds recorded in Zone 1

Species / Species Group	2009-2010*	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Scaup	-	-	-	-	-	-	-
Common scoter	-	-	0.23	0.04	-	0.03	-
Seaduck species	-	0.05	-	-	-	-	-
Red-throated diver	5.41	0.93	3.29	7.82	11.38	6.65	8.90
Black-throated diver	-	-	-	0.11	0.29	-	-
Great northern diver	-	-	0.05	0.06	0.27	-	0.02
Diver species	-	19.25	0.63	0.02	-	-	-
Fulmar	-	0.02	0.12	0.12	0.02	-	-
Shearwater species	-	0.28	-	-	-	-	-
Gannet	-	1.49	0.06	1.90	0.18	0.39	0.24
Cormorant	-	-	-	0.05	0.04	0.07	0.03
Shag	-	0.02	-	0.05	-	-	-
Cormorant / shag	-	0.02	0.05	-	-	-	-
Great crested grebe	-	-	0.02	0.03	-	-	-
Grebe species	-	0.08	-	-	0.02	-	-
Oystercatcher	-	-	-	-	-	-	-
Pomarine skua	-	-	-	0.02	0.02	-	-
Great skua	-	-	0.02	-	-	0.02	-
Kittiwake	-	0.70	0.19	0.95	1.39	0.71	0.96
Black-headed gull	-	0.12	-	0.06	0.09	0.02	-
Common gull	-	0.08	0.02	0.18	0.13	0.13	0.20
Little gull	-	-	-	0.10	-	-	-
Small gull species	-	1.56	0.06	0.04	0.07	0.02	0.02
Lesser black-backed gull	-	0.14	0.04	0.20	0.22	0.12	0.08
Herring gull	-	0.04	0.06	0.27	0.26	0.15	0.08
Great black-backed gull	-	0.07	0.45	0.56	0.91	0.44	0.27
Black-backed gull species	-	0.13	0.02	-	-	-	-
Large gull species	-	0.06	0.04	-	0.02	0.02	0.02
Guillemot	-	-	0.02	0.20	-	-	-
Razorbill	-	-	0.02	0.22	-	-	-
Guillemot / razorbill	-	0.33	1.24	1.54	2.07	1.51	1.76
Puffin	-	-	0.10	0.16	-	-	0.03
Little auk	-	-	-	0.08	-	-	-
Auk species	-	0.80	0.05	-	-	-	-

*Table note: In this winter of the 'pilot survey' species-specific population estimates were created only for red-throated diver. The survey areas, design, and coverage in this pilot year differed to subsequent years.

Table 2 Peak density for all birds recorded in Zone 2

Species / Species Group	2009-2010*	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Scaup	-	-	-	-	-	-	-
Common scoter	-	-	1.20	0.55	-	-	-
Seaduck species	-	-	-	-	-	-	-
Red-throated diver	2.16	0.06	3.92	5.47	5.08	15.86	8.14
Black-throated diver	-	-	-	0.04	0.04	-	-
Great northern diver	-	-	0.64	0.02	-	-	-
Diver species	-	4.16	5.62	0.04	-	-	-
Fulmar	-	-	0.02	0.13	-	-	-
Shearwater species	-	-	-	-	-	-	-
Gannet	-	0.21	-	0.04	-	0.10	0.16
Cormorant	-	-	-	1.56	-	2.88	2.60
Shag	-	-	-	-	-	-	-
Cormorant / shag	-	-	0.50	-	2.17	-	-
Great crested grebe	-	-	0.02	0.02	-	-	-
Grebe species	-	0.04	-	-	0.04	-	-
Oystercatcher	-	-	-	-	-	-	-
Pomarine skua	-	-	-	-	-	-	-
Great skua	-	-	-	0.02	-	0.03	0.03
Kittiwake	-	1.22	1.19	0.27	1.18	0.16	0.29
Black-headed gull	-	0.25	-	0.15	0.25	0.16	-
Common gull	-	0.51	0.20	0.41	0.25	0.35	0.22
Little gull	-	-	-	0.08	-	-	-
Small gull species	-	2.34	0.04	0.04	0.09	0.13	0.03
Lesser black-backed gull	-	0.07	0.04	0.08	0.11	0.13	0.06
Herring gull	-	0.15	0.94	1.71	1.51	0.64	0.22
Great black-backed gull	-	0.29	0.39	0.51	1.69	1.19	0.93
Black-backed gull species	-	-	-	-	-	-	-
Large gull species	-	0.37	0.02	-	0.11	-	-
Guillemot	-	-	0.04	0.04	-	-	-
Razorbill	-	-	-	0.02	-	-	-
Guillemot / razorbill	-	0.21	0.90	1.29	5.58	1.82	2.16
Puffin	-	-	-	0.08	-	-	-
Little auk	-	-	0.04	0.04	-	-	-
Auk species	-	0.46	0.08	-	-	-	-

*Table note: In this winter of the ‘pilot survey’ species-specific population estimates were created only for red-throated diver. The survey areas, design, and coverage in this pilot year differed to subsequent years.

Table 3 Peak density for all birds recorded in Zone 3

Species / Species Group	2010-2011	2011-2012	2012-2013
Scaup	-	-	0.13
Common scoter	-	-	-
Seaduck species	-	-	-
Red-throated diver	-	4.29	2.75
Black-throated diver	-	-	0.15
Great northern diver	-	0.05	0.05
Diver species	1.37	1.00	-
Fulmar	0.06	0.23	-
Shearwater species	-	-	-
Gannet	-	-	-
Cormorant	-	4.45	0.70
Shag	-	-	-
Cormorant / shag	-	0.39	0.05
Great crested grebe	-	-	-
Grebe species	-	-	-
Oystercatcher	-	-	0.05
Pomarine skua	-	-	-
Great skua	-	-	-
Kittiwake	0.93	1.27	0.60
Black-headed gull	0.87	-	0.48
Common gull	3.87	0.39	0.82
Little gull	-	-	-
Small gull species	22.80	0.05	0.15
Lesser black-backed gull	0.14	0.16	0.60
Herring gull	1.21	3.73	1.31
Great black-backed gull	0.22	0.71	0.75
Black-backed gull species	0.11	0.07	-
Large gull species	0.79	0.07	-
Guillemot	-	-	-
Razorbill	-	-	0.08
Guillemot / razorbill	-	1.11	0.67
Puffin	-	-	0.15
Little auk	-	-	-
Auk species	0.14	-	-

Table 4 Peak density for all birds recorded in Zone 4

Species / Species Group	2010-2011
Scaup	-
Common scoter	-
Seaduck species	-
Red-throated Diver	-
Black-throated diver	-
Great northern diver	-
Diver species	0.11
Fulmar	-
Shearwater species	-
Gannet	-
Cormorant	-
Shag	-
Cormorant / shag	-
Great crested grebe	-
Grebe species	-
Oystercatcher	-
Pomarine skua	-
Great skua	-
Kittiwake	-
Black-headed gull	-
Common gull	-
Little gull	-
Small gull species	-
Lesser black-backed gull	-
Herring gull	-
Great black-backed gull	-
Black-backed gull species	-
Large gull species	-
Guillemot	-
Razorbill	-
Guillemot / razorbill	-
Puffin	-
Little auk	-
Auk species	0.11

Table 5 Peak density for all birds recorded in Zone 5

Species / Species Group	2010-2011	2011-2012	2012-2013
Scaup	-	-	-
Common scoter	-	-	-
Seaduck species	-	-	-
Red-throated diver	-	2.93	3.10
Black-throated diver	-	-	0.16
Great northern diver	-	-	-
Diver species	3.33	1.49	-
Fulmar	-	-	-
Shearwater species	-	-	-
Gannet	-	-	0.09
Cormorant	-	-	-
Shag	-	-	-
Cormorant / shag	-	-	-
Great crested grebe	-	-	-
Grebe species	-	-	0.10
Oystercatcher	-	-	-
Pomarine skua	-	-	-
Great skua	-	-	-
Kittiwake	0.94	0.46	0.20
Black-headed gull	0.14	-	0.09
Common gull	0.99	-	0.16
Little gull	-	-	-
Small gull species	6.40	0.10	0.06
Lesser black-backed gull	-	-	-
Herring gull	0.99	1.13	0.27
Great black-backed gull	0.53	0.47	0.26
Black-backed gull species	0.42	0.09	-
Large gull species	0.94	-	-
Guillemot	-	-	0.16
Razorbill	-	-	-
Guillemot / razorbill	0.07	0.80	1.10
Puffin	-	0.06	0.06
Little auk	-	-	0.06
Auk species	0.73	-	-

Table 6 Peak density for all birds recorded in Zone 6

Species / Species Group	2010-2011	2011-2012	2012-2013
Scaup	-	-	-
Common scoter	-	-	-
Seaduck species	-	-	-
Red-throated diver	-	0.25	1.23
Black-throated diver	-	-	0.13
Great northern diver	-	-	0.21
Diver species	0.67	0.27	-
Fulmar	-	0.13	0.07
Shearwater species	-	-	-
Gannet	-	-	0.13
Cormorant	-	-	-
Shag	-	-	-
Cormorant / shag	-	-	-
Great crested grebe	-	-	-
Grebe species	-	-	-
Oystercatcher	-	-	-
Pomarine skua	-	-	-
Great skua	-	-	-
Kittiwake	0.45	0.25	0.70
Black-headed gull	0.09	-	-
Common gull	0.63	-	0.21
Little gull	-	-	0.21
Small gull species	12.43	-	0.07
Lesser black-backed gull	0.12	0.12	0.07
Herring gull	0.45	0.13	-
Great black-backed gull	-	0.13	0.07
Black-backed gull species	-	-	-
Large gull species	0.45	0.07	-
Guillemot	-	-	0.49
Razorbill	-	-	-
Guillemot / razorbill	0.09	1.75	2.57
Puffin	-	-	-
Little auk	-	-	-
Auk species	1.59	-	-

Table 7 Peak density for all birds recorded in Zone 7

Species / Species Group	2010-2011	2011-2012	2012-2013
Scaup	-	-	0.06
Common scoter	-	2.14	-
Seaduck species	-	-	-
Red-throated diver	0.07	1.39	2.28
Black-throated diver	-	-	0.09
Great northern diver	-	-	-
Diver species	3.75	1.92	-
Fulmar	-	-	0.06
Shearwater species	-	-	-
Gannet	0.14	-	-
Cormorant	-	1.07	-
Shag	-	-	-
Cormorant / shag	-	0.21	-
Great crested grebe	-	-	0.28
Grebe species	-	-	-
Oystercatcher	-	-	-
Pomarine skua	-	-	-
Great skua	-	-	-
Kittiwake	2.90	2.46	0.76
Black-headed gull	0.35	-	0.09
Common gull	4.03	0.21	0.65
Little gull	-	-	-
Small gull species	5.72	0.11	0.28
Lesser black-backed gull	0.92	0.32	0.27
Herring gull	1.34	2.99	0.86
Great black-backed gull	0.92	0.32	0.19
Black-backed gull species	0.35	-	-
Large gull species	0.35	-	0.06
Guillemot	-	0.11	0.06
Razorbill	-	-	-
Guillemot / razorbill	0.21	1.07	1.23
Puffin	-	-	0.19
Little auk	-	-	-
Auk species	0.21	0.32	-

Appendix 6 Technical Information for Barrier Effect Analysis

The null hypothesis that the proportion of divers flying towards the nearest turbine was the same between different regions was tested using two approaches. If the statistical testing provided a less than 5% probability ($P \leq 0.05$) then the null hypothesis is rejected, which would suggest that divers do not fly in all directions randomly but trend towards a specific direction in relation to the nearest turbine between the regions being tested.

Even though flying divers were recorded in all of the high resolution digital aerial LAW surveys, relatively few individuals were recorded in flight. A small sample size makes data analysis more difficult as most statistical tests need to meet certain data assumptions. Thus, two tests were applied to the data, the latter making no assumptions of the data.

First, a non-parametric chi-squared (χ^2) test was carried out. This test is applied to sets of categorical data to evaluate how likely it is that any observed difference between the sets arise by chance. It is suitable for unpaired data such as these data relating to flying divers. The χ^2 test tests a null hypothesis that the frequency distribution of events observed in a sample is consistent with a particular theoretical distribution. The events considered must be mutually exclusive and have a total probability 1. Using a χ^2 test with a small sample runs the risk of having a type two error, where the null hypothesis is false, but it is not rejected. In this case this would be that the test fails to detect that divers are not as likely to fly in all trajectories, and thus it would fail to detect that there could be evidence of a barrier effect.

The χ^2 test was used to assess whether the proportion of divers flying towards the nearest turbine was different between those recorded in the LAW to 4 km and those recorded in the greater than 4 km region in Zone 1. The null hypothesis was that the proportion of divers was the same between these two regions.

Second, to allow for the sample size being small, thus leading to increased chances of type two errors, a randomisation test based on resampling with replacement (i.e. bootstrapping) was developed that made no assumptions of the distribution of the data. Randomisation tests are based on the collected data and compare a computed statistic with the value of that statistic for other arrangements of the data. The probability value can simply be the proportion of the arrangements leading to a value of the statistic as large as or larger than the value obtained from the actual data.

For each of three buffer regions: the LAW up to 2 km, 2 to 4 km, and greater than 4 km in Zone 1, 999 bootstrapped samples of flight directions was created by randomly sampling with replacement from the observed flight directions for the relevant buffer region. To avoid data inflation, for a buffer region, each of the 999 bootstrapped samples comprised the number of flight directions recorded in the buffer. Thus, for a buffer in which 20 flying birds were recorded, 999 bootstrapped samples were created each comprising of 20 flight directions randomly sampled with replacement. Bootstrapping allows some bird directions to be selected more than once in a sample and others not to be sampled at all to fully represent the variability in the dataset. Then, for each buffer region the number of the 999 bootstraps that held less than 25% of the diver directions towards the LAW was calculated. To reject the null hypothesis ($P \leq 5\%$) that the divers are equally likely to fly towards the wind farm as parallel or away from it we would need 5% or less of the bootstraps to hold less than 25% of divers flying towards the wind farm.

Figure 1 shows the count of flying divers recorded at each time and date in Zone 1. The figure shows that the information was gathered over a wide range of dates and times of day from which it can be inferred that the information was collected over a wide range of tidal states. Flying divers were recorded between approximately 10 am and 3 pm on nine dates across the three post-construction years. More than one bird was recorded at one time and date if multiple birds were captured in the same image. The maximum number of flying divers captured in an image was six however the majority were captured as individuals.

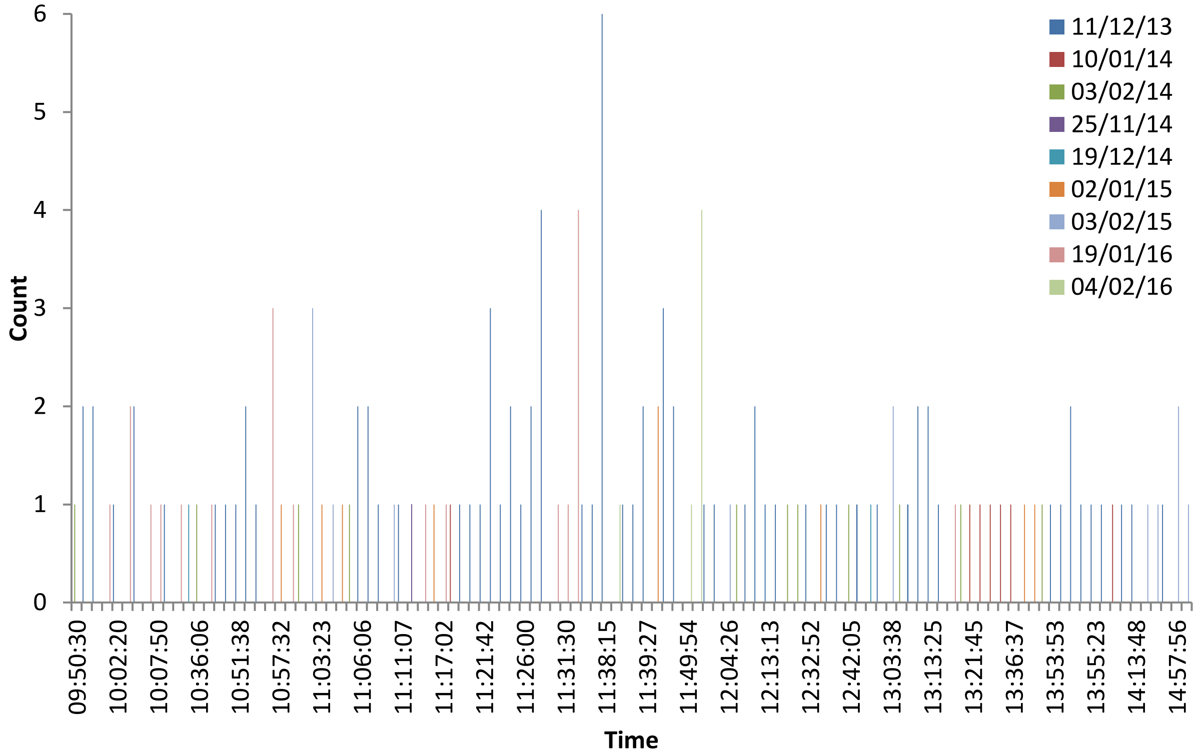


Figure 1 **Time and date of flying divers recorded in Zone 1**

Appendix 7 Technical Information for Displacement Analysis

The information presented in this Appendix pre-supposes knowledge of spatial modelling and smoothing methods.

The MRSea package was used to analyse the distribution and abundance of divers and auks for assessing the effects of displacement. MRSea applies an over-dispersed-Poisson (log link function) ‘Complex Region Spatial Smoother’ with a ‘Spatially Adaptive Local Smoothing Algorithm’ (CReSS-SALSA) based Generalised Additive Model (GAM) framework with robust standard errors to allow for residual correlation.

To compute the robust standard errors a panel structure was identified using an autocorrelation function (ACF) plot and defined as 877 panels of size 100. The ACF plots and relevant descriptions are provided below. To allow for varying survey effort, an offset term was included such that the response was modelled as counts per unit area. All model selection was undertaken using 10-fold Cross-Validation making sure that the panel structure was maintained when defining training and validation sets. There was an analysis issue with data point 55004 (FID=55003). This was most likely owing to a specific combination of covariates, which made the data point highly influential in the variance estimation of the models. For example, the estimated dispersion parameter was approximately 15,000 with the data point included and reduced to approximately 100 when excluded.

All analyses were carried out in R (R Core Team, 2014).

The steps used to fit the models are described below.

1. Prior to modelling, all covariates, the relevant environmental variables, were assessed for co-linearity (significantly linearly correlated) using Variance Inflation Factors (VIFs), a measure of multicollinearity in a set of variables, and pairwise plots (see Figure 1). Pairwise plots demonstrate graphically the relationship between all environmental variables to aid visual representation of any co-linearity. Wave base, tidal base, and distance to coast were correlated with the x-coordinate (VIFs>5), and given the inclusion of the x-coordinate in the spatial smooth, these were removed from the covariate choices. Mean survey shipping and mean pre-survey shipping were highly correlated. A simple model was fitted with and without each one and a 10-fold Cross-Validation method was used to choose the better model. This resulted in the removal of mean survey shipping from the covariate choices.
2. Based on the covariates remaining, models with each of the development phases and each covariate separately were fitted using the MRSea R package to determine inclusion of covariates in the full model. For divers, this reduced the covariate set to bathymetry, mean chlorophyll-*a*, mean sea surface temperature and average frequent thermal front probability (Displacement: Table 24 and Figures 2 to 9). For Auks, this reduced the covariate set to bathymetry, mean chlorophyll-*a*, mean sea surface temperature, average frequent thermal front probability, slope and tidal force (Displacement: Table 25 and Figures 10 to 15).
3. Along with each construction phase, the selected covariates were modelled together and allowed to be either removed, linear (one degree of freedom) or smooth (degree 2 B-spline with 3-5 degrees of freedom). Model selection (knot number and location and covariate inclusion) using 10-fold Cross-Validation was undertaken using SALSA (implemented in the MRSea package).

4. A two-dimensional spatial CReSS smooth of the x and y coordinates was added to the model resulting from (3) and an interaction term included between this smooth and each construction phase. The spatial smooth was allowed between 1 and 50 degrees of freedom, with an initial start of 5. Choice was made using SALSA2D and 10-fold Cross-Validation.
5. Finally, a backwards selection procedure was applied, using 10-fold Cross-Validation, to check for any covariates no longer adding to the model since the inclusion of the spatial interaction term.

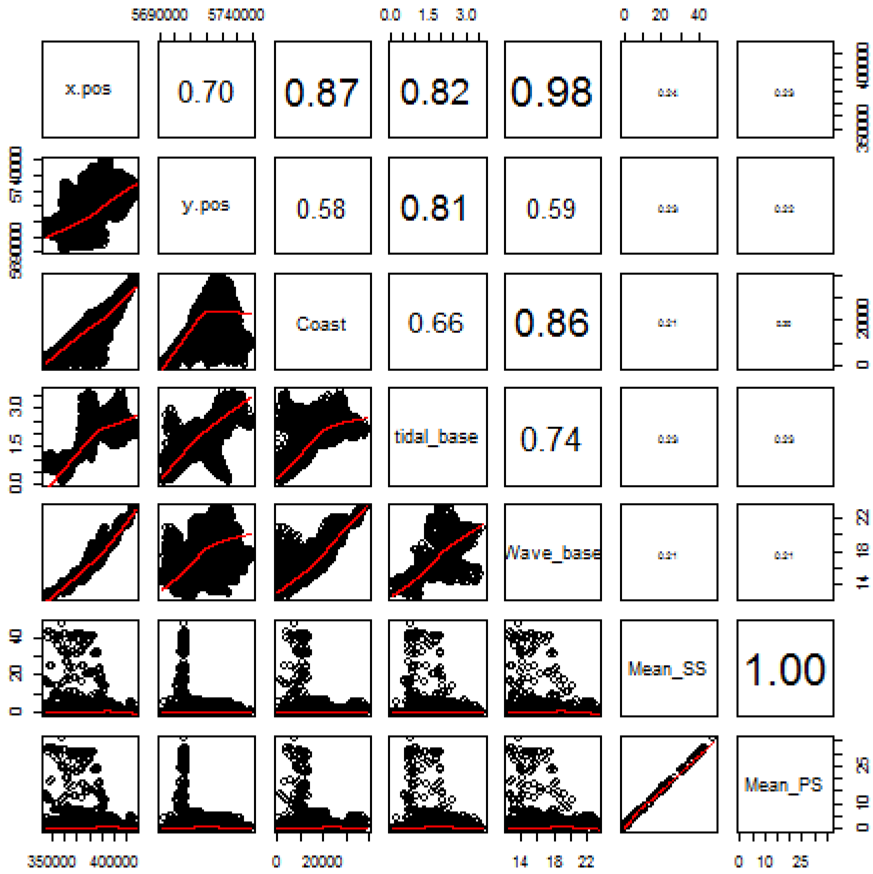


Figure 1 Environmental covariate co-linear pairs plot. The name of each variable is given diagonally through the centre. The probability of the correlation between each pairwise comparison is provided in numbers (with variable size indicating greatest correlations) on the northern half of the square. The bottom half of the square provides the data points with a best fit line in red.

Diver modelling outputs

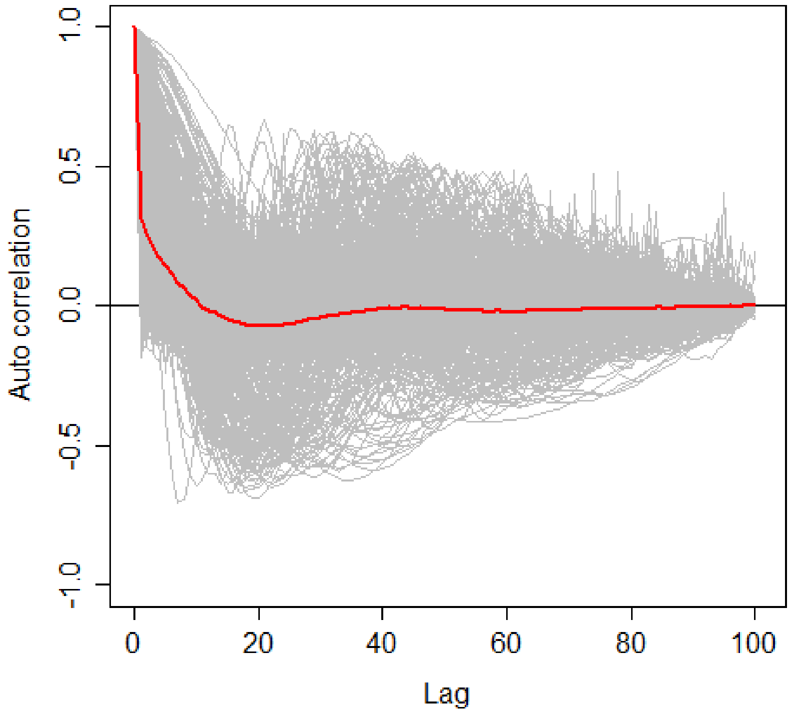


Figure 2 Diver model autocorrelation function (ACF) plot: grey lines indicate model residuals and red line indicates average autocorrelation. The autocorrelation between counts ceases when the red line stabilises at zero.

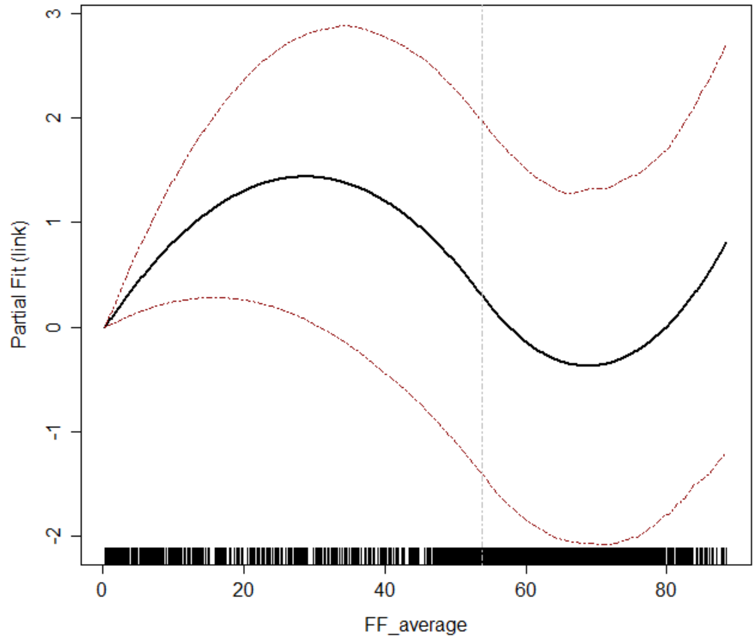


Figure 3 **Fitted link (log) average frequent thermal front probability (FF) relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.**

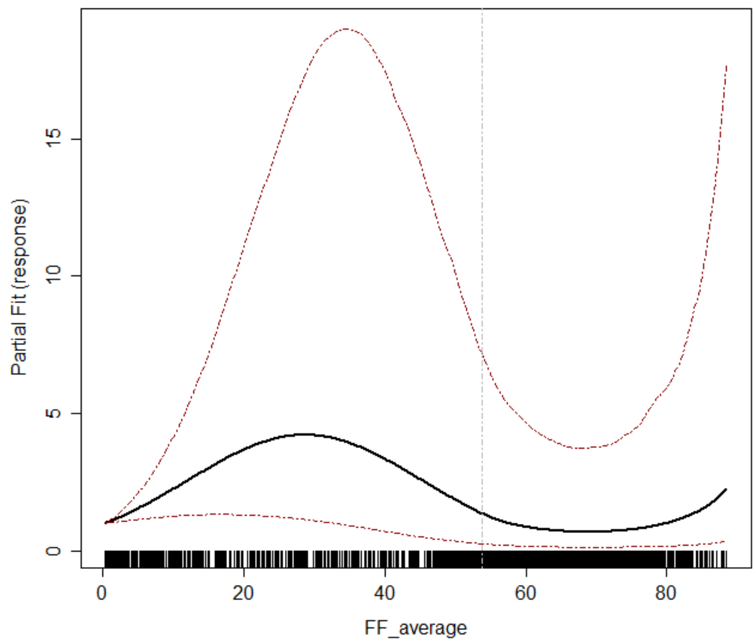


Figure 4 **Fitted average frequent thermal front (FF) probability relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.**

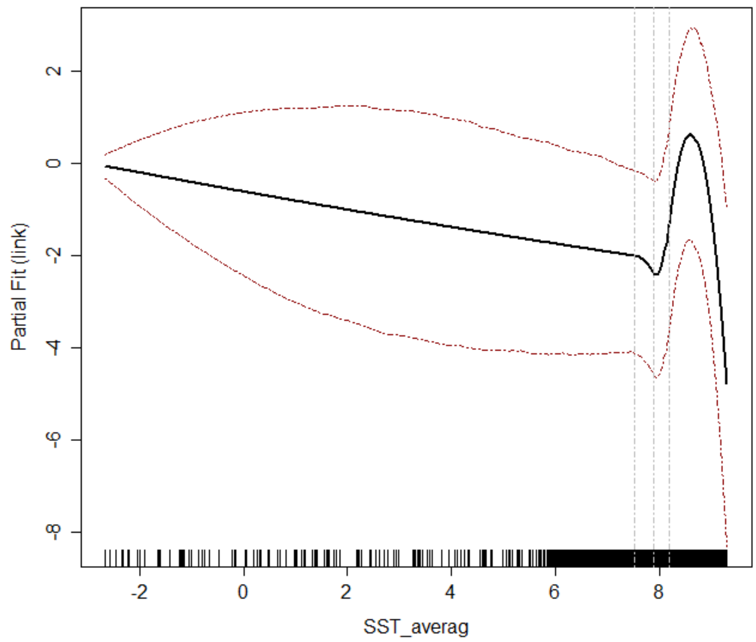


Figure 5 Fitted link (log) average SST relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.

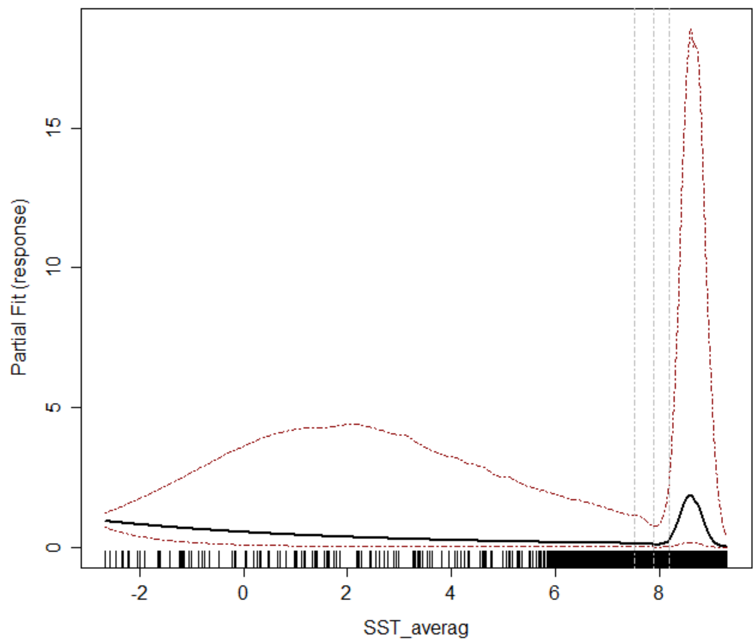


Figure 6 Fitted average sea surface temperature (SST) relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.

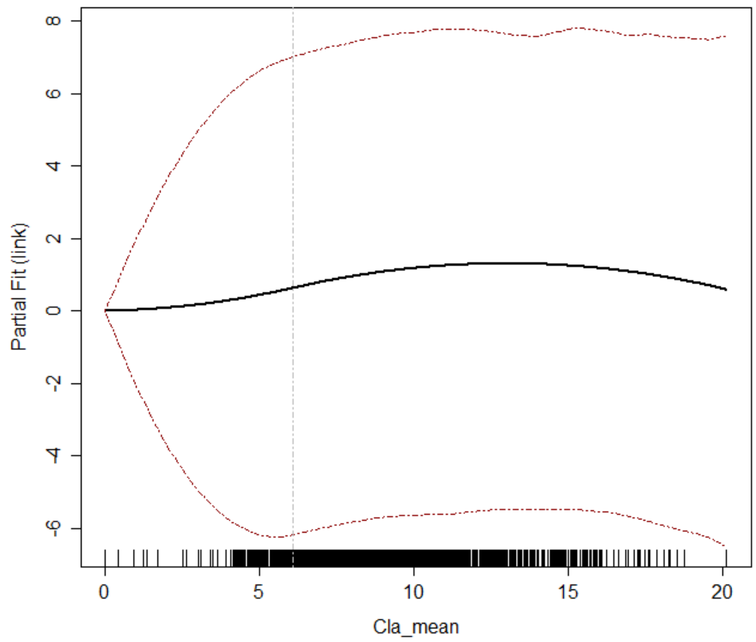


Figure 7 **Fitted log-link average chlorophyll-*a* relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.**

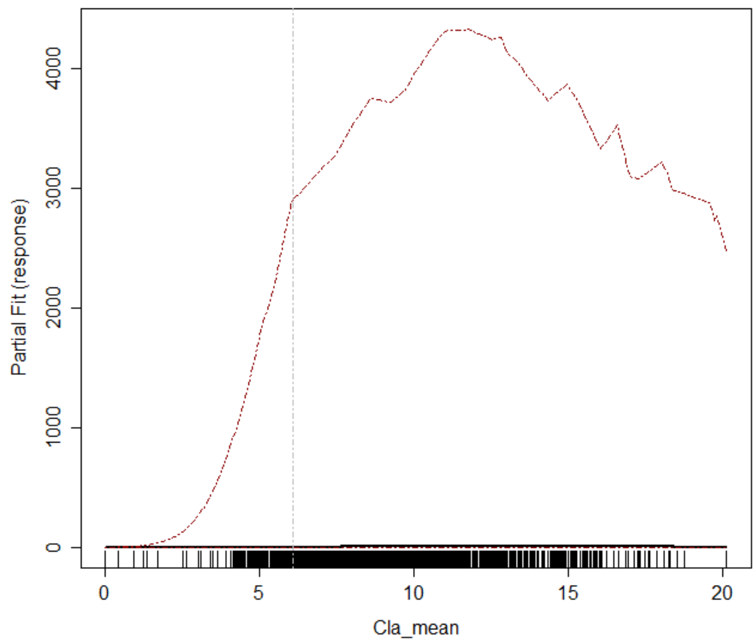


Figure 8 **Fitted average chlorophyll-*a* (Cla) relationship with GEE-based 95% confidence intervals for divers. The vertical lines along the x-axis show the data points of the environmental variable.**

a)

b)

c)

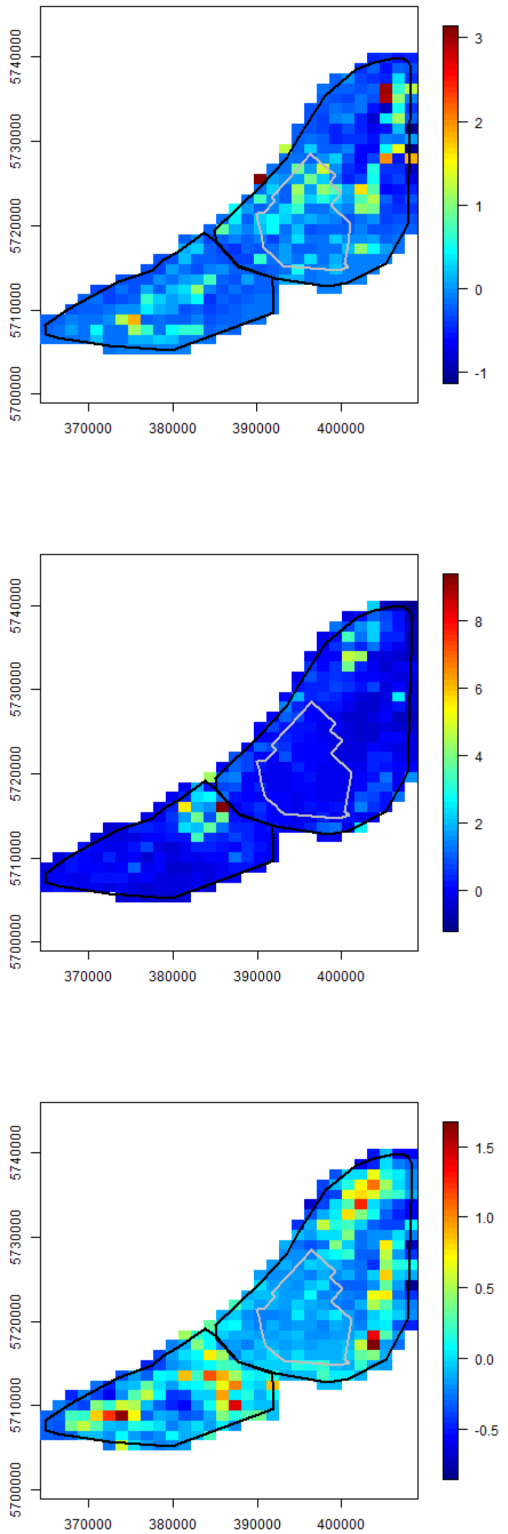


Figure 9 Raw residuals a) pre-construction, b) during construction and c) post-construction. These residuals are fitted values – observed values (mean birds per sq km) for the diver model.

Auk modelling outputs

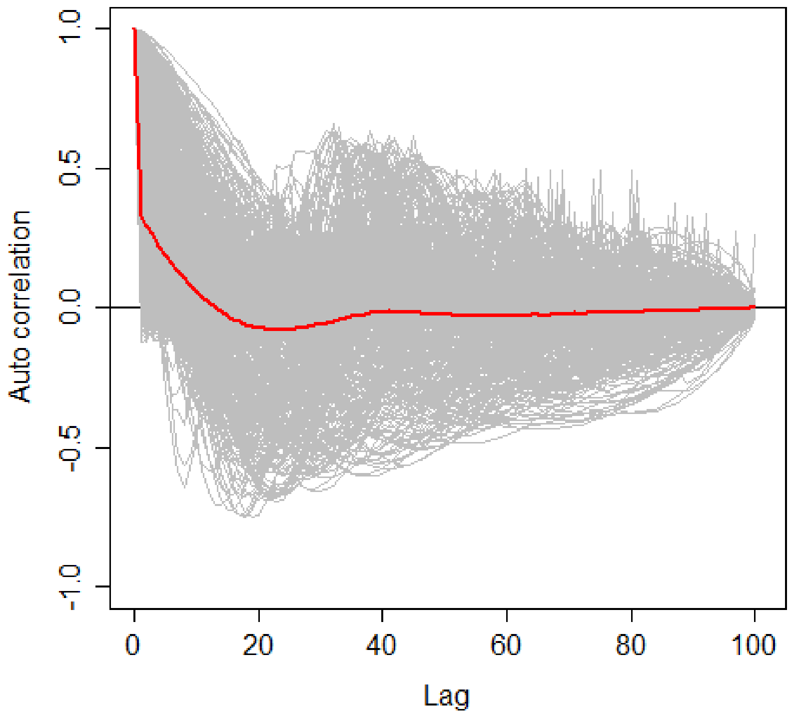


Figure 10 Auk model autocorrelation function (ACF) plot: grey lines indicate model residuals and red line indicates average autocorrelation. The auto-correlation between counts ceases when the red line stabilises at zero.

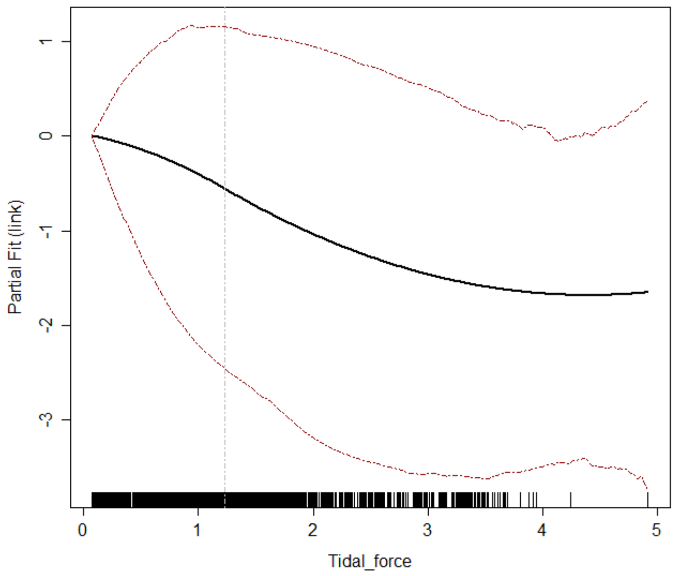


Figure 11 Fitted log-link average tidal force relationship with GEE-based 95% confidence intervals for auks. The vertical lines along the x-axis show the data points of the environmental variable.

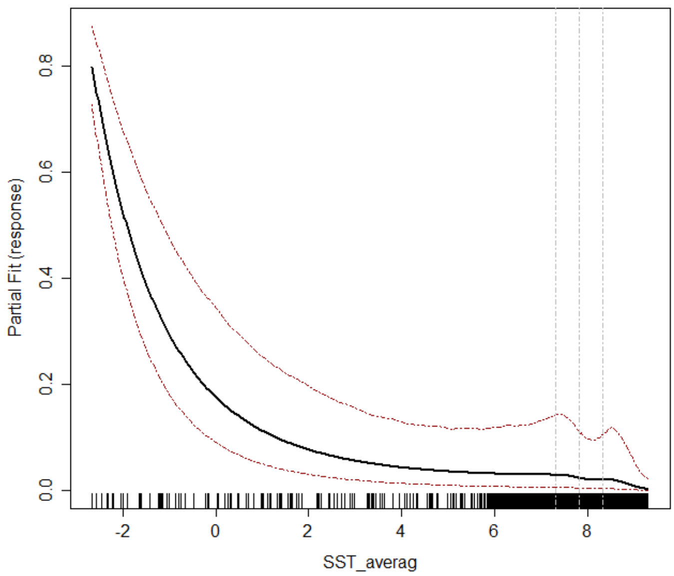


Figure 12 Fitted average frequent tidal force probability relationship with GEE-based 95% confidence intervals for auks. The vertical lines along the x-axis show the data points of the environmental variable.

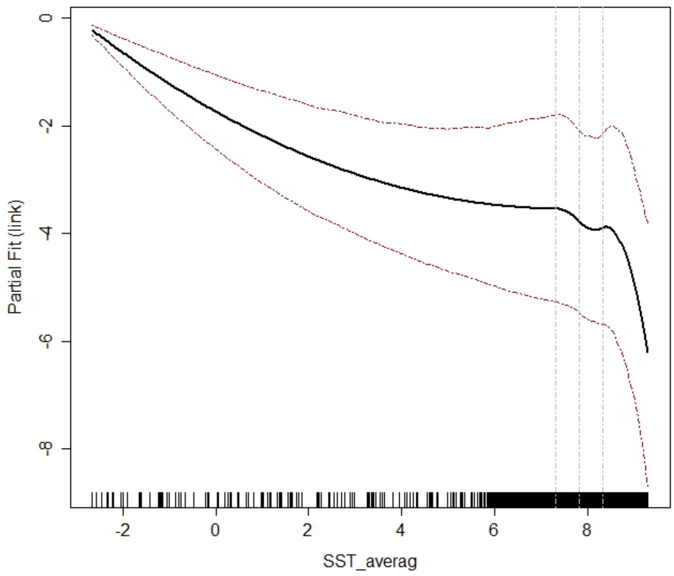


Figure 13 Fitted log-link average SST relationship with GEE-based 95% confidence intervals for auks. The vertical lines along the x-axis show the data points of the environmental variable.

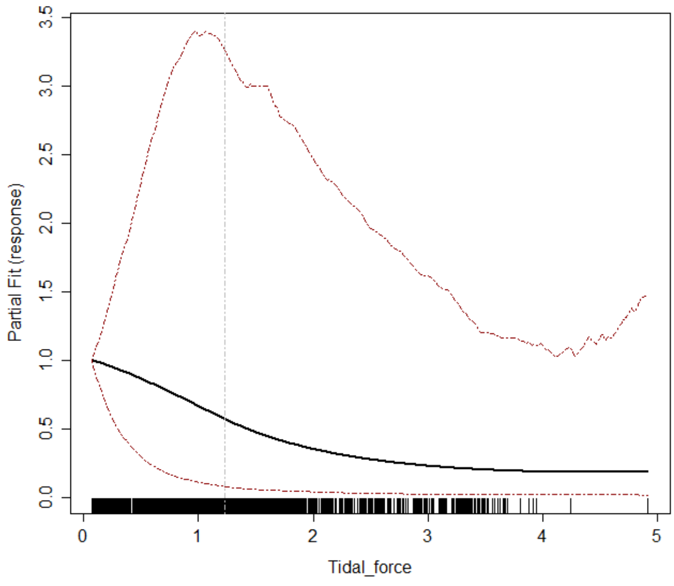
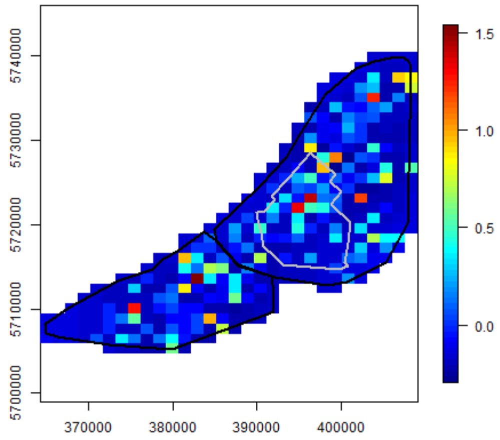
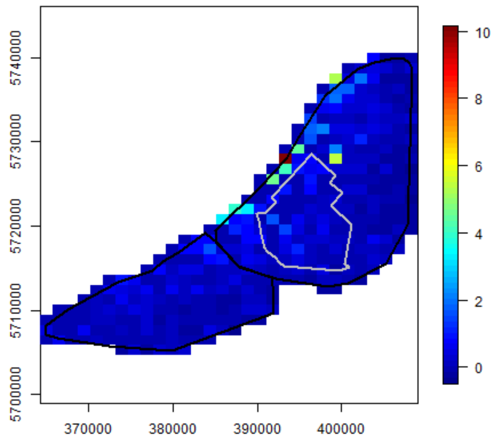


Figure 14 Fitted average sea surface temperature (SST) relationship with GEE-based 95% confidence intervals for auks. The vertical lines along the x-axis show the data points of the environmental variable.

a)



b)



c)

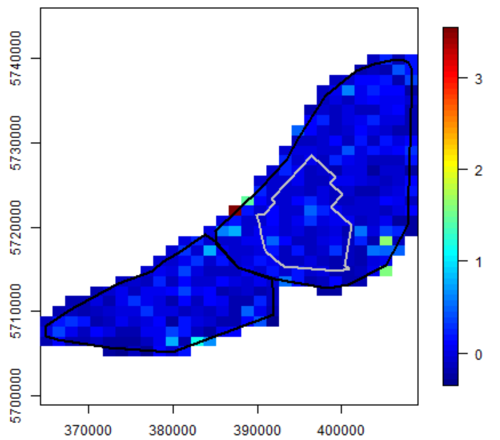


Figure 15 Raw residuals a) pre-construction, b) during construction and c) post-construction. These residuals are fitted values – observed values (mean birds per sq km) for the auk model.

Appendix 8 Supplementary Information – Displacement

Modelled abundance estimates for divers per construction phase of the LAW are presented in Table 1. The percentage decrease in the number of modelled divers within the LAW pre-construction versus during construction was estimated to be 78% (a reduction of 160; Table 1), and pre-construction versus post-construction was estimated to be 55% (a reduction of 112; Table 1). Modelled population estimates have been rounded to whole numbers. It is important to note that these are not absolute diver numbers as availability bias has not been accounted for because the grouping is made up of different species. More importantly no correction factors exist for any diver species.

Table 1 Modelled abundance estimates for divers for the London Array Offshore Windfarm (LAW) and each 0.5 km per construction phase of the development.

Buffer Region	Modelled population estimate of divers			Difference Pre vs During	Difference Pre vs Post
	Pre-construction	During Construction	Post-construction		
LAW	204	44	92	160	112
0.5 km	48	14	25	34	23
1.0 km	55	17	30	38	25
1.5 km	59	19	35	40	24
2.0 km	61	21	37	40	24
2.5 km	67	25	40	43	27
3.0 km	78	30	46	48	32
3.5 km	84	32	51	52	33
4.0 km	90	34	57	55	32
4.5 km	105	39	71	66	35
5.0 km	125	46	86	80	39
5.5 km	134	48	90	86	44
6.0 km	151	54	98	97	53
6.5 km	158	54	101	104	57
7.0 km	153	51	99	102	54
7.5 km	168	55	101	113	67
8.0 km	177	58	104	119	73
8.5 km	175	59	97	116	79
9.0 km	173	62	95	110	78
9.5 km	157	63	88	94	70
10.0 km	137	62	83	75	54
10.5 km	123	62	80	61	42
11.0 km	101	61	77	40	24
11.5 km	81	58	71	23	10
12.0 km	72	67	77	5	-5
12.5 km	66	69	79	-3	-13
13.0 km	58	74	77	-16	-19
13.5 km	51	78	75	-27	-24
14.0 km	39	68	57	-29	-18

Buffer Region	Modelled population estimate of divers			Difference Pre vs During	Difference Pre vs Post
	Pre-construction	During Construction	Post-construction		
14.5 km	34	73	53	-39	-20
15.0 km	25	64	44	-39	-19

Information to supplement Figure 30 is provided in Table 2.

Table 2 Density of divers (birds km^{-2}) recorded in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Density of divers (birds km^{-2})		
	Pre-construction	During Construction	Post-construction
LAW	2.03	0.44	0.92
0.5 km	2.15	0.62	1.12
1.0 km	2.36	0.73	1.30
1.5 km	2.39	0.77	1.41
2.0 km	2.75	0.95	1.68
2.5 km	4.21	1.54	2.51
3.0 km	4.93	1.88	2.90
3.5 km	5.24	1.98	3.17
4.0 km	5.49	2.09	3.51
4.5 km	6.36	2.38	4.26
5.0 km	7.48	2.73	5.12
5.5 km	8.13	2.93	5.45
6.0 km	9.20	3.28	5.98
6.5 km	9.70	3.34	6.20
7.0 km	9.64	3.20	6.21
7.5 km	11.33	3.72	6.79
8.0 km	12.45	4.09	7.31
8.5 km	13.19	4.46	7.27
9.0 km	13.85	5.01	7.60
9.5 km	13.26	5.34	7.40
10.0 km	12.22	5.55	7.38
10.5 km	11.47	5.81	7.52
11.0 km	9.80	5.91	7.46
11.5 km	8.24	5.87	7.20
12.0 km	7.64	7.08	8.19
12.5 km	7.35	7.71	8.82
13.0 km	6.82	8.70	9.10
13.5 km	6.34	9.76	9.38
14.0 km	5.19	9.01	7.58
14.5 km	4.71	10.21	7.49
15.0 km	3.73	9.59	6.62

Information to supplement Figure 31 is provided in Table 3.

Table 3 Proportion of divers estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Proportion of divers		
	Pre-construction	During Construction	Post-construction
LAW	0.0089	0.0032	0.0053
0.5 km	0.0094	0.0045	0.0064
1.0 km	0.0103	0.0053	0.0074
1.5 km	0.0104	0.0056	0.0081
2.0 km	0.0120	0.0069	0.0096
2.5 km	0.0183	0.0113	0.0143
3.0 km	0.0215	0.0137	0.0166
3.5 km	0.0228	0.0145	0.0181
4.0 km	0.0239	0.0153	0.0201
4.5 km	0.0277	0.0174	0.0244
5.0 km	0.0326	0.0200	0.0293
5.5 km	0.0354	0.0214	0.0312
6.0 km	0.0401	0.0240	0.0342
6.5 km	0.0423	0.0245	0.0354
7.0 km	0.0420	0.0234	0.0355
7.5 km	0.0493	0.0272	0.0388
8.0 km	0.0542	0.0300	0.0418
8.5 km	0.0574	0.0327	0.0416
9.0 km	0.0603	0.0367	0.0435
9.5 km	0.0578	0.0391	0.0423
10.0 km	0.0532	0.0406	0.0422
10.5 km	0.0499	0.0425	0.0430
11.0 km	0.0427	0.0432	0.0427
11.5 km	0.0359	0.0429	0.0412
12.0 km	0.0333	0.0518	0.0468
12.5 km	0.0320	0.0564	0.0505
13.0 km	0.0297	0.0636	0.0520
13.5 km	0.0276	0.0714	0.0536
14.0 km	0.0226	0.0659	0.0434
14.5 km	0.0205	0.0747	0.0428
15.0 km	0.0163	0.0701	0.0379

Information to supplement Figure 32 is provided in Table 4.

Table 4 Change (%) in proportion of divers estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Change (%) in proportion of divers between construction phases		
	Pre-construction vs During construction	During construction vs Post-construction	Pre-construction vs Post-construction
LAW	-63.87	64.18	-40.68
0.5 km	-51.40	40.70	-31.62
1.0 km	-48.10	39.13	-27.79
1.5 km	-45.80	42.88	-22.56
2.0 km	-42.23	38.61	-19.92
2.5 km	-38.43	27.01	-21.80
3.0 km	-36.05	20.65	-22.84
3.5 km	-36.43	25.17	-20.43
4.0 km	-35.87	30.97	-16.00
4.5 km	-37.15	40.07	-11.96
5.0 km	-38.64	46.69	-9.99
5.5 km	-39.42	45.33	-11.96
6.0 km	-40.12	42.40	-14.73
6.5 km	-42.09	44.86	-16.11
7.0 km	-44.22	51.70	-15.37
7.5 km	-44.91	42.89	-21.28
8.0 km	-44.74	39.67	-22.82
8.5 km	-43.14	27.28	-27.62
9.0 km	-39.21	18.61	-27.90
9.5 km	-32.31	8.25	-26.73
10.0 km	-23.71	4.05	-20.62
10.5 km	-14.84	1.08	-13.92
11.0 km	1.31	-1.27	0.02
11.5 km	19.64	-4.08	14.76
12.0 km	55.75	-9.60	40.80
12.5 km	76.09	-10.50	57.60
13.0 km	114.34	-18.22	75.29
13.5 km	158.92	-24.92	94.39
14.0 km	191.96	-34.20	92.11
14.5 km	263.80	-42.64	108.68
15.0 km	331.44	-46.02	132.91

Table 5 Change (%) in proportion of divers estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Change (%) in proportion of divers between construction phases		
	Pre-construction vs During construction	During construction vs Post-construction	Pre-construction vs Post-construction
LAW	-78.33	+52.17	-54.68
0.5 km	-71.16	+44.64	-47.91
1.0 km	-69.07	+43.85	-44.92
1.5 km	-67.78	+45.39	-41.00
2.0 km	-65.45	+43.45	-38.91
2.5 km	-63.42	+38.65	-40.38
3.0 km	-61.87	+35.17	-41.18
3.5 km	-62.21	+37.54	-39.50
4.0 km	-61.93	+40.46	-36.07
4.5 km	-62.58	+44.13	-33.02
5.0 km	-63.50	+46.68	-31.55
5.5 km	-63.96	+46.24	-32.96
6.0 km	-64.35	+45.15	-35.00
6.5 km	-65.57	+46.13	-36.08
7.0 km	-66.80	+48.47	-35.58
7.5 km	-67.17	+45.21	-40.07
8.0 km	-67.15	+44.05	-41.29
8.5 km	-66.19	+38.65	-44.88
9.0 km	-63.83	+34.08	-45.13
9.5 km	-59.73	+27.84	-44.19
10.0 km	-54.58	+24.80	-39.61
10.5 km	-49.35	+22.74	-34.44
11.0 km	-39.69	+20.78	-23.88
11.5 km	-28.76	+18.47	-12.62
12.0 km	-7.33	+13.55	+7.20
12.5 km	+4.90	+12.59	+20.00
13.0 km	+27.57	+4.40	+33.43
13.5 km	+53.94	-4.05	+47.95
14.0 km	+73.60	-18.87	+46.05
14.5 km	+116.77	-36.32	+59.02
15.0 km	+157.10	-44.86	+77.48

Modelled population estimates for auks per construction phase of the LAW are presented in Table 6. The percentage decrease in the number of modelled auks within the LAW pre-construction versus during construction was estimated to be 87% (a reduction of 140; Table 6), and pre construction versus post construction was estimated to be 68% (a reduction of 110; Table 6). Modelled population estimates have been rounded to whole numbers. It is important to note that these are not absolute auk numbers as availability bias has not been accounted for because the grouping is made up of different species.

Table 6 Modelled abundance estimates for auks for the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Modelled population estimate of auks			Difference Pre vs During	Difference Pre vs Post
	Pre-construction	During Construction	Post-construction		
LAW	161	22	52	140	110
0.5 km	98	22	44	75	54
1.0 km	94	22	43	72	51
1.5 km	104	29	54	75	50
2.0 km	90	27	49	62	41
2.5 km	82	27	46	55	36
3.0 km	72	26	41	46	31
3.5 km	77	35	49	43	28
4.0 km	75	38	51	36	23
4.5 km	80	48	58	32	21
5.0 km	75	56	63	20	12
5.5 km	81	72	72	9	9
6.0 km	68	61	61	7	7
6.5 km	77	81	71	-4	6
7.0 km	68	64	60	4	8
7.5 km	71	77	63	-6	8
8.0 km	60	56	51	3	9
8.5 km	59	64	52	-4	8
9.0 km	52	46	45	6	7
9.5 km	54	59	48	-5	6
10.0 km	49	46	45	3	4
10.5 km	50	56	47	-6	3
11.0 km	46	44	43	1	3
11.5 km	42	44	41	-1	1
12.0 km	41	42	41	-1	0
12.5 km	39	38	39	1	-1
13.0 km	39	42	41	-4	-2
13.5 km	36	37	38	-1	-3
14.0 km	33	34	36	-1	-3
14.5 km	31	31	36	0	-5
15.0 km	28	23	32	5	-3

Information to supplement **Error! Reference source not found.**Figure 41 is provided in Table 7.

Table 7 Density of auks (birds km^{-2}) recorded in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Region	Density of auks (birds km^{-2})		
	Pre-construction	During Construction	Post-construction
LAW	1.61	0.21	0.52
0.5 km	4.41	1.01	1.99
1.0 km	4.03	0.93	1.85
1.5 km	4.23	1.17	2.18
2.0 km	4.06	1.24	2.22
2.5 km	5.11	1.66	2.85
3.0 km	4.56	1.64	2.60
3.5 km	4.82	2.15	3.07
4.0 km	4.57	2.34	3.15
4.5 km	4.81	2.87	3.53
5.0 km	4.49	3.32	3.77
5.5 km	4.90	4.33	4.38
6.0 km	4.14	3.70	3.73
6.5 km	4.73	4.96	4.39
7.0 km	4.27	4.00	3.77
7.5 km	4.80	5.17	4.26
8.0 km	4.21	3.98	3.61
8.5 km	4.45	4.79	3.89
9.0 km	4.19	3.68	3.62
9.5 km	4.54	4.99	4.06
10.0 km	4.39	4.10	4.00
10.5 km	4.66	5.26	4.43
11.0 km	4.44	4.30	4.19
11.5 km	4.29	4.41	4.18
12.0 km	4.36	4.42	4.35
12.5 km	4.31	4.20	4.38
13.0 km	4.55	5.00	4.79
13.5 km	4.47	4.58	4.80
14.0 km	4.42	4.55	4.78
14.5 km	4.31	4.37	4.98
15.0 km	4.22	3.42	4.69

Information to supplement Figure 42 is provided in Table 8.

Table 8 Proportion of auks estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Proportion of auks		
	Pre-construction	During Construction	Post-construction
LAW	0.0119	0.0020	0.0046
0.5 km	0.0326	0.0094	0.0177
1.0 km	0.0298	0.0087	0.0164
1.5 km	0.0312	0.0110	0.0193
2.0 km	0.0300	0.0116	0.0196
2.5 km	0.0378	0.0156	0.0252
3.0 km	0.0337	0.0154	0.0230
3.5 km	0.0356	0.0202	0.0272
4.0 km	0.0338	0.0219	0.0278
4.5 km	0.0355	0.0269	0.0312
5.0 km	0.0332	0.0311	0.0334
5.5 km	0.0362	0.0406	0.0388
6.0 km	0.0306	0.0346	0.0330
6.5 km	0.0350	0.0465	0.0388
7.0 km	0.0315	0.0375	0.0333
7.5 km	0.0354	0.0484	0.0377
8.0 km	0.0311	0.0372	0.0319
8.5 km	0.0329	0.0449	0.0344
9.0 km	0.0310	0.0344	0.0320
9.5 km	0.0335	0.0467	0.0360
10.0 km	0.0324	0.0384	0.0354
10.5 km	0.0344	0.0492	0.0392
11.0 km	0.0328	0.0403	0.0370
11.5 km	0.0317	0.0413	0.0370
12.0 km	0.0322	0.0414	0.0385
12.5 km	0.0319	0.0394	0.0387
13.0 km	0.0336	0.0469	0.0424
13.5 km	0.0330	0.0429	0.0425
14.0 km	0.0327	0.0426	0.0423
14.5 km	0.0318	0.0409	0.0441
15.0 km	0.0312	0.0320	0.0415

Information to supplement Figure 43 is provided in Table 9.

Table 9 Change (%) in proportion of auks estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Change (%) in proportion of auks between construction phases		
	Pre-construction vs During construction	During construction vs Post-construction	Pre-construction vs Post-construction
LAW	-83.11	127.90	-61.50
0.5 km	-71.07	87.23	-45.84
1.0 km	-70.70	87.64	-45.02
1.5 km	-64.83	76.10	-38.07
2.0 km	-61.27	68.90	-34.58
2.5 km	-58.73	61.61	-33.30
3.0 km	-54.33	49.40	-31.77
3.5 km	-43.37	34.57	-23.79
4.0 km	-35.09	26.97	-17.58
4.5 km	-24.20	16.02	-12.06
5.0 km	-6.43	7.36	0.46
5.5 km	12.14	-4.48	7.12
6.0 km	13.29	-4.58	8.10
6.5 km	33.01	-16.49	11.08
7.0 km	18.91	-11.06	5.76
7.5 km	36.61	-22.08	6.45
8.0 km	19.73	-14.25	2.67
8.5 km	36.41	-23.33	4.58
9.0 km	11.13	-7.04	3.30
9.5 km	39.28	-22.96	7.30
10.0 km	18.31	-7.69	9.22
10.5 km	42.99	-20.41	13.80
11.0 km	22.96	-8.11	12.99
11.5 km	30.41	-10.54	16.67
12.0 km	28.76	-7.10	19.62
12.5 km	23.58	-1.65	21.54
13.0 km	39.36	-9.49	26.13
13.5 km	29.83	-0.89	28.68
14.0 km	30.38	-0.66	29.52
14.5 km	28.63	7.69	38.52
15.0 km	2.65	29.64	33.07

Table 10 Change (%) in proportion of auks estimated in the London Array Offshore Windfarm (LAW) and each 0.5 km buffer per construction phase of the development.

Buffer Region	Change (%) in proportion of auks between construction phases		
	Pre-construction vs During construction	During construction vs Post-construction	Pre-construction vs Post-construction
LAW	-86.96	+59.62	-67.70
0.5 km	-77.10	+49.25	-54.88
1.0 km	-76.92	+49.73	-54.09
1.5 km	-72.34	+46.33	-48.46
2.0 km	-69.46	+44.14	-45.32
2.5 km	-67.51	+41.75	-44.23
3.0 km	-64.04	+36.92	-42.98
3.5 km	-55.39	+29.97	-36.31
4.0 km	-48.80	+25.71	-31.07
4.5 km	-40.33	+18.70	-26.61
5.0 km	-26.06	+11.94	-16.04
5.5 km	-11.63	+1.14	-10.61
6.0 km	-10.63	+0.80	-9.90
6.5 km	+4.86	-12.98	-7.19
7.0 km	-6.32	-6.10	-11.71
7.5 km	+7.71	-21.36	-11.25
8.0 km	-5.46	-10.25	-14.25
8.5 km	+7.64	-23.14	-12.58
9.0 km	-12.17	-1.66	-13.60
9.5 km	+9.91	-22.91	-10.57
10.0 km	-6.61	-2.50	-8.88
10.5 km	+12.88	-18.74	-4.94
11.0 km	-3.15	-2.63	-5.63
11.5 km	+2.80	-5.50	-2.56
12.0 km	+1.38	-1.61	-0.23
12.5 km	-2.55	+4.11	+1.62
13.0 km	+9.89	-4.38	+5.27
13.5 km	+2.46	+4.58	+7.38
14.0 km	+2.94	+4.81	+8.14
14.5 km	+1.39	+12.25	+15.55
15.0 km	-18.96	+27.08	+11.14

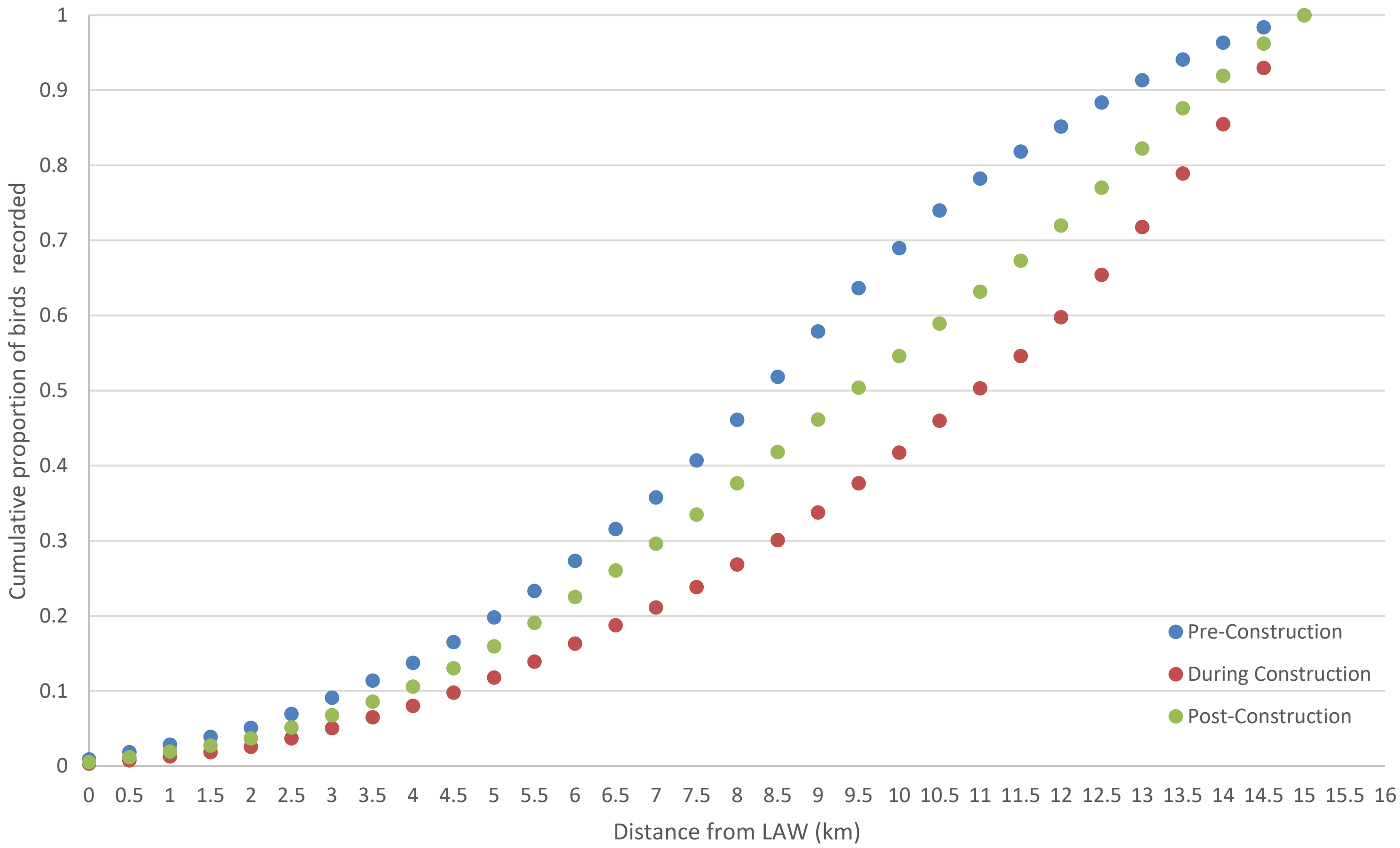


Figure 1 **Cumulative proportion plot of divers (birds km^{-2}) recorded across surveyed area by distance to the London Array Offshore Windfarm in 0.5 km bands up to 15 km for each phase of the development (pre construction, during construction, and post construction).**

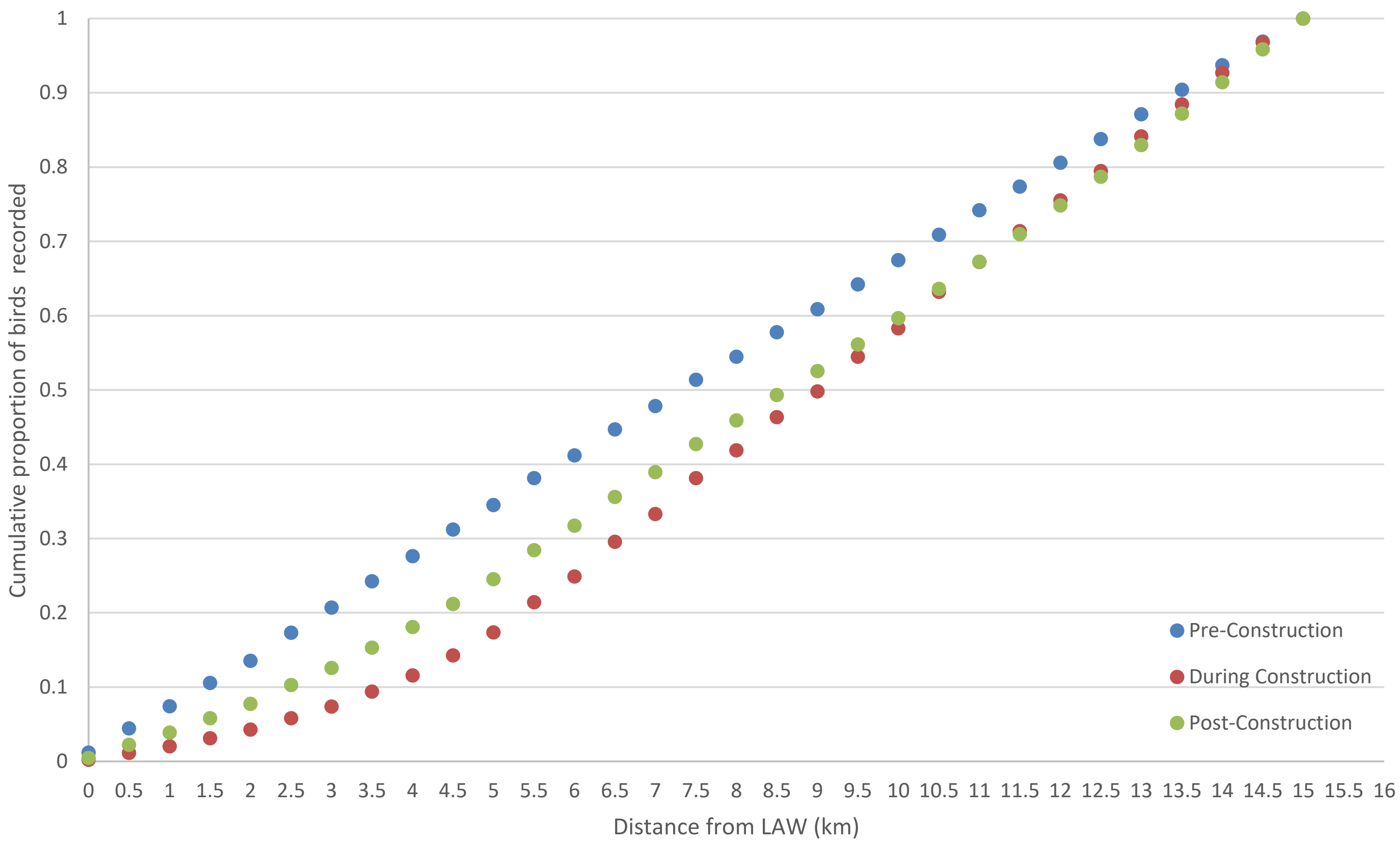


Figure 2 **Cumulative proportion plot of auks (birds km^{-2}) recorded across surveyed area by distance to the London Array Offshore Windfarm in 0.5 km bands up to 15 km for each phase of the development (pre construction, during construction, and post construction).**