Responses of Local Birds to the Offshore Wind Farms PAWP and OWEZ off the Dutch mainland coast

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Summary

All North Sea countries have ambitious plans for offshore wind development. Offshore wind turbines are an alien element at sea, a “landscape” that is normally wide and open. Large, turning turbines might affect the local seabirds, that are dependent on the sea. One of the possible effects of offshore wind farms might be that the seabirds will be displaced from the sites, which would mean habitat destruction or at least habitat degradation for this group (Petersen et al. 2006; Arends et al. 2008). All seabirds, being migratory, are protected under the EU Birds Directive. Yet, there are no studies into the question where wind farms should best be built (with respect to seabirds) or how they should be designed to minimize disturbance.

This report describes the results of four years of T-1 Local Bird surveys around the Dutch offshore wind farms PAWP and OWEZ in comparison to the results of a one-year T-0 study. The two wind farms are situated off the Dutch mainland coast, in close proximity to each other and are owned and managed by two different parties, Eneco and NUON/Shell (now Vattenfall). In a unique process of mutual agreements, commissioning and data sharing between these two parties, a single, large-scale, multi-year line of research has resulted in a joint approach to address the difficult question: how do local seabirds react to offshore wind farms? The long-term cooperation between the two commissioning parties is probably unique in this line of research, where all too often different wind farms are studied by different parties and different methods.

The project has been a learning process for all involved, certainly also for the biologists and analysts carrying out the field word and the reporting. Both the survey design and the statistical analyses techniques were adapted (improved) in the course of the study. The initial study design comprised ten parallel and equidistant transects, encompassing a rather large area around the wind farms. Seabirds were counted from survey ships along these ten lines, during series of repeat surveys. After one year of pre-construction surveys (T-0) and two years of T-1 surveys it was realised that more count data were required from within the wind farms themselves and the survey set-up was adjusted accordingly, introducing new survey lines running through the two wind farms and parallel to the isobaths in the general study area. A first major report was produced after three years of T-1 surveys (Leopold et al. 2011) when the work, required for the first wind farm (OWEZ) was completed. In this report, we used only presence/absence data to look for evidence that birds avoided the wind farms, or were attracted to them. Another year of field data, required for the second wind farm (PAWP) was collected subsequently, using the exact methodology of the previous year. In addition, and the core of this report, we developed and deployed new statistical analysis methods allowing analysis of on-site deviations of seabird densities. To this end, we use Generalized Additive Mixed Models (GAMMs) or Zero-Inflated GAMMs.

This study compares the effects of two wind farms of different design in close proximity of each other. PAWP has a much higher turbine density (4.3 turbines / km^2) than OWEZ (1.3/km^2). This difference in turbine density probably constitutes the main difference in design between PAWP and OWEZ. The turbines deployed in PAWP (n=60) are Vestas V80 - 2 MW, at 59 m above mean sea level (amsl), with a rotor diameter of 80 m. Those in OWEZ (n=36) are Vestas V90 - 3MW turbines at 70 m amsl, with a rotor diameter of 90 m.

However, besides the difference in lay-out, PAWP was built in slightly deeper waters (19-24 m versus 18-20 m) and further offshore (ca 23 km versus ca 15 km) than OWEZ. The latter might seem trivial, but the exact location of the two wind farms turned out the have important consequences on the impact on local seabirds, simply because PAWP is situated just outside the realm of a suit of coastal seabirds, while OWEZ is just touching this zone of coastal avifauna. Birds that keep an offshore wind farm at bay, because their normal habitat does not include that wind farm, will not be disturbed, no matter how sensitive to disturbance they might be. In this particular case, birds that prefer nearshore waters could

not be disturbed by PAWP that is situated too far offshore. Indeed, negative effects on coastal species like divers, grebes, seaduck, and several terns, were only found for OWEZ. PAWP did not impact these coastal birds and is thus ecologically better placed than OWEZ in this respect.

Most gull species often follow fishing vessels to obtain food and by doing so, occur very clumped at sea (i.e. around fishing vessels). Clearly, as fishing is banned from the wind farms, large flocks around fishing vessels occur only outside the wind farms, after their construction. This phenomenon, however, is not turbine-related, but follows from regulations. Gulls were also regularly seen inside either wind farm, often resting on its hardware.

One species, the Great Cormorant, was clearly attracted to the wind farms. These birds now use the sites in rather large numbers, as a basis for at-sea feeding where they can dry their plumage after diving for food, by resting on the turbine-poles and other structures available.

Significant avoidance was found in species occurring over most of the study area and in relatively even numbers over this area: Northern Gannet, Black-legged Kittiwake, Common Guillemot and Razorbill. All showed avoidance with respect to PAWP, but only the Common Guillemot and the Northern Gannet were also found to avoid OWEZ. For all species, avoidance was not 100%, as some individuals were observed with the wind farms. The stronger reaction towards PAWP may be related by the less ‘open’ setup of this wind farm.

We did not find statistically significant effects for Northern Fulmar, although we found some indications that these birds might be avoiding wind farms. Their numbers around both PAWP and OWEZ were probably too low for such effects to be detected, but this might be different in more offshore situations.

The results obtained in this study seem to be robust, in that these were largely in line with the earlier evaluation based only on presence/absence data (Leopold et al. 2011a): attraction in Great Cormorants, avoidance in most other seabirds, while results for most gull species remain ambiguous.

Future wind farms are unlikely to be built in nearshore waters in the Netherlands and therefore, studying effects on coastal seabirds, although apparently vulnerable to disturbance, should receive lower priority in future projects. Species with more offshore distributions will be more at risk. The most important conclusion of this study probably is, that the Common Guillemot would seem to be the most promising seabird for future studies of disturbance by offshore wind farms, considering that this species occurs all over the North Sea, occurs often in substantial numbers that would allow for a useful analysis and show some, but not 100% avoidance of wind farms. These properties make the Common Guillemot a suitable species for comparisons of the effects of different wind farms. In the present, first inter-wind farm comparison, admittedly based on only two wind farms, a lay-out with larger, but more spaced-out turbines, disturbed the birds to a lesser extent than a wind farm with smaller but more densely packed turbines. Bigger is better, it would seem, all other things being equal.

In conclusion, most local seabird species showed significant reactions in terms of avoidance or attraction to PAWP and OWEZ. For a large part, this could probably be attributed to the location of these two wind farms: just far enough offshore to be outside the realm of coastal seabirds. That wind farms are capable of displacing local seabirds was shown for a number of species. None of these, however, were totally absent from the wind farms. Looking at the larger North Sea, the Common Guillemot should probably be selected for comparative future studies that should look into the effects of wind farm lay-out on disturbance.

1. Introduction

The Princes Amalia Wind Farm (in Dutch: Prinses Amaliawindpark, or PAWP) is located in the south-eastern North Sea, off the Dutch mainland coast, approximately 25 km northwest of the port of IJmuiden (Figure 1). The wind farm consists of 60 Vestas V80 - 2 MW turbines on monopoles, and, centrally, a transformer platform. The turbines are at 59 m above mean sea level (amsl), with a rotor diameter of 80 m. Construction of PAWP commenced in October 2006 and the park became fully operational in June 2008.

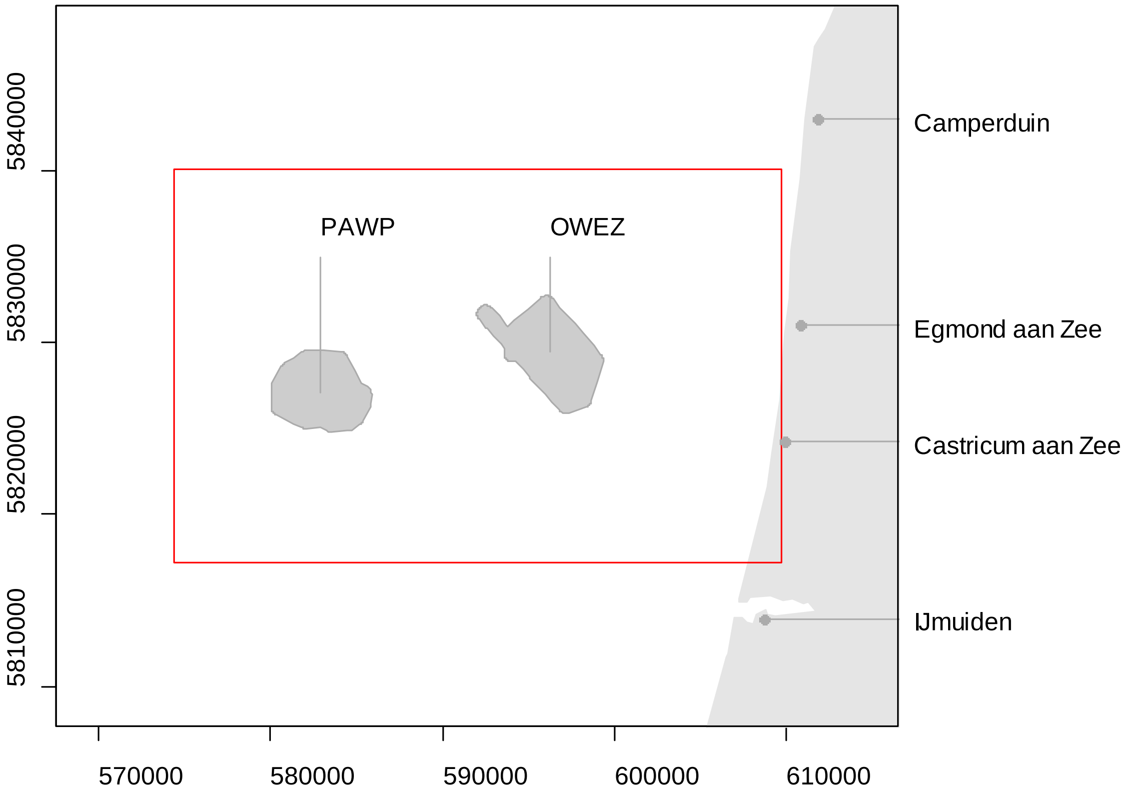

Figure 1. *Overview of the study area (bordered by a red line), with the two wind farms located in the centre and the Dutch mainland with four towns indicated at the right side.*

PAWP is the second wind farm realised in these parts. Another wind farm, known as "Offshore Wind farm Egmond aan Zee" (OWEZ), with 36 Vestas V90 - 3MW turbines at 70 m amsl, is situated half-way between PAWP and the shore (Figure 1). The two wind farms were built in close succession: pile driving for OWEZ (36 piles, each 45 m long, 4.6 m diameter, and 250 tonnes each) took place from mid-April to late July 2006. The placement of turbines and rotors started during the pile driving phase and lasted until the end of August 2006. OWEZ started producing electricity on 18 September 2006. Pile driving for PAWP followed almost immediately upon the completion of construction work of OWEZ, on 10 October 2006. PAWP construction involved amongst others driving 60 piles, each 54 m long, 4 m across and weighing 320 tonnes into the seabed. The construction phase of PAWP lasted almost a year and a half, but with a relatively slow start including an almost idle period from December 2006 to January 2007. Building intensity picked up afterwards, until the last pole was driven in at 3 April 2007 (Figuur 2).

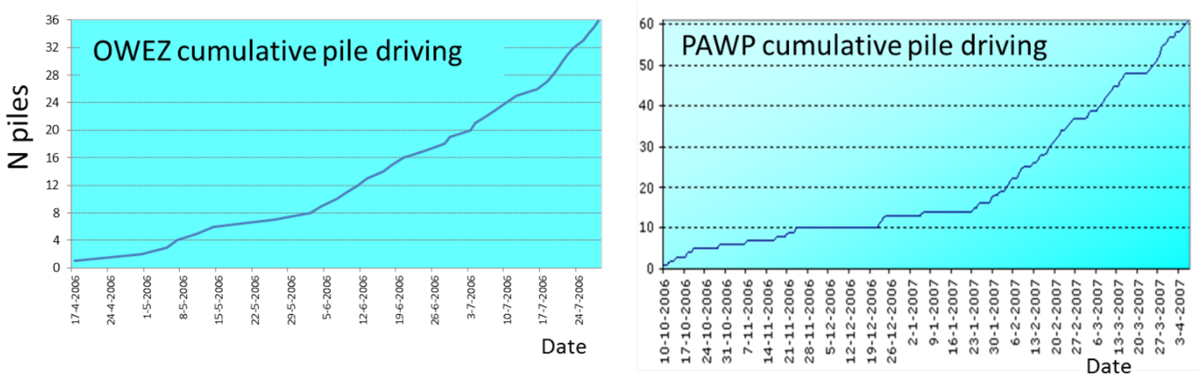

Figure 2. *Progression of construction works in both wind farms, as cumulative numbers of piles driven into the seabed at either site, over time. The gap between the last OWEZ pile and the first PAWP pile was two and a half months.*

Construction work for both parks together thus lasted from April 2006 until June 2008. However, construction work was sometimes interrupted by periods of poor weather and shorter and longer quiet periods happened during the building stages. The construction period is therefore a rather variable time, in terms of activities conducted and noise produced. From the point of view of seabirds, there was a clear pre-construction period (before April 2006), a construction period from April 2006 to June 2008 with variable human activity levels, and a post-construction, or operational phase from July 2008 onward. Note that these distinctions are less clear than it would seem. Prior to the piling of the first turbine poles in OWEZ, offshore (seabed) surveys were conducted from June 2002 and a meteo-mast was built just west of this park, on a single monopole, from September 2002 to January 2003 (Noordzeewind 2008). The main construction phase of PAWP happened post-construction of OWEZ, so during the operational phase of OWEZ major construction works, including extensive pile driving happened nearby, in PAWP. And finally, during the operational phase of both parks, the relative quiet of this period was often interrupted by maintenance work, involving a fleet of both small and large offshore vessels visiting the wind farms for a variety of tasks.

The two wind farms differ in several dimensions, other than the onset of the operational period. PAWP was built in slightly deeper waters (19-24 m versus 18-20 m) and further offshore (ca 23 km *vs* ca 15 km) than OWEZ (Figure 1). PAWP, although equipped with smaller turbines, was built up much more densely than OWEZ (Figure 3). The 60 PAWP turbines were placed within an a surface area of 14 km^2, while the 36 OWEZ turbines operate within 27 km^2 (http://www.prinsesamaliawindpark.eu/nl/index.asp; NoordzeeWind 2008). This makes OWEZ a much more “open” wind farm than PAWP. Distances between turbines are circa 550 m in PAWP, in all directions. OWEZ has a different design, with its turbines placed in four lines some 850 m apart, while inter-turbine densities on each line are similar to those in PAWP (NoordzeeWind 2003). The nominal rotor speed of the two turbine types is similar: 16.7 RPM for PAWP and 16.1 RPM for OWEZ.

Wind farms, both onshore and offshore, might impact local birds *inter alia* by displacing them from the site (Langston & Pullan 2003; Stewart et al. 2004; Drewitt & Langston 2006; Petersen et al. 2006). Displacement leads to habitat loss if birds will no longer enter the wind farm perimeter, or to habitat degradation if they do so only partially, or loose foraging efficiency while inside the wind farm. Whether or not birds are displaced by a wind farm differs, however. Some species are more wary than others and are thus more susceptible to disturbance. However, offshore wind farms are not usually completely avoided by seabirds, not even by species that are considered to be very easily disturbed (see: Garthe & Hüppop 2004; Dierschke & Garthe 2006; Leopold & Dijkman 2010 for assessments of this). In only one study (Petersen et al 2006) were some birds (Red-throated Diver *Gavia stellata* and Common Scoter *Melanitta nigra*) found to completely avoid an operational offshore wind farm. In other studies and/or species, only partial avoidance was found, in Red-throated Diver (Rexstad & Buckland 2012), Common Eider *Somateria mollissima* and Long-tailed Duck (Guillemette et al. 1999; Tulp et al. 1999; Petersen et al. 2006), Common Guillemot *Uria aalge* (Petersen et al. 2006; Leopold et al. 2011a; Vanermen et al. 2012) and European Gannet *Morus bassanus* (Krijgsveld et al. 2011; Vanermen et al. 2012). The amount of disturbance might furthermore depend on background bird densities, weather, or other pressures on the birds involved, or wind farm lay-out (Beale & Monaghan 2004; Petersen et al. 2004; Powlesland 2009; Vanermen et al. 2012). Over time, birds that were initially displaced might learn to adapt to the presence of a wind farm, particularly when food is abundant within wind farm perimeters (Petersen & Fox 2007). Moreover, not all birds will be displaced: some species like gulls and Great Cormorants *Phalacrocorax carbo* seem either indifferent to the presence of a wind farm or are even attracted (Petersen et al. 2006; Leopold et al. 2011a; Vanermen et al. 2012).

Figure 3. *A bird's eye view of OWEZ in the foreground and PAWP in the background. Note difference in turbine density and the meteo mast on the far right of OWEZ. Photo Hans Verdaat, IMARES, 7 July 2010.*

Attraction might be easily recognized, e.g. when seabirds roost on wind farm installations or forage at their base, or in their tidal wakes (Figure 4). Avoidance is less easily observed and demonstrated. To demonstrate avoidance, specific seabird densities in the operational wind farms must be compared to pre-construction densities, to densities at comparable sites outside the wind farm or to predicted densities on-site, with the effect of the wind farm statistically removed. All three options have intrinsic difficulties. Comparisons to pre-construction densities are less meaningful if year to year variation in local seabirds densities are large and if only few pre-construction data can be collected. One year of pre-construction data seems to be the standard in many European studies (with the Danish and Belgium studies at Horns Rev, Nysted and Thorntonbank / Bligh Bank with three years of pre-construction data as the notable exceptions: Petersen et al. 2006; Vanermen et al. 2012). With only one year of pre-construction data and little knowledge of year to year variation, pre-post construction differences in local bird densities are hard to interpret. Likewise, comparing a wind farm site to a "similar" reference area seems tricky. Finding a reference area that is exactly like the wind farm site, but outside its range of influence is difficult enough, and seabirds usually have a patchy occurrence. Patches may overlap (or not) with either the impact site or the reference area and exact locations of patches may differ over time. A simple comparison of two small sites (impact versus reference) is also prone to "data pulling" from patches of birds at the fringes of either area (Rexstad & Buckland 2012). Differences between impact and reference areas may thus be due to the actual impact, or to a patchy distribution of the seabirds concerned. The solution to this problem would seem to study a larger area around and including the wind farm and to predict seabird densities within the wind farm parameter on the basis of a more general distribution pattern, assessed over a larger area.

Figure 4. *Examples of attraction.*

Top: Great Cormorants Phalacrocorax carbo *roosting on a turbine pole, 20 February 2012.*

Left: Adult Herring Gull Larus argentatus *inspecting the base of a turbine pole at low tide in PAWP, 5 June 2012.*

Photos: Hans Verdaat, IMARES.

2. Acknowledgement

The full length of the study on both PAWP and OWEZ had four phases, each with a different commissioner. We could not have conducted this work without the continuing support of all parties involved. The first phase of the study, the so-called T-0 study prior to construction of OWEZ, was Commisioned by the Dutch government, by the Ministry of Transport and Public Work, now the Ministry of Infrastructure and the Environment. The second phase of the project, the T-1 study for OWEZ, was commissioned by Noordzeewind, aided by a subsidy of the Ministry of Economic Affairs under the CO_2 reduction scheme of The Netherlands. By that time, construction for PAWP had started and later on, during the post-construction studies for OWEZ, PAWP became operational. In the third phase of this work, Noordzeewind (for OWEZ) and Prinses Amaliawindpark (for PAWP) joined forces and shared the costs for this study. In the final year of this project, OWEZ had fulfilled its monitoring commitments and Prinses Amaliawindpark was the sole commissioner of the work. In person, we want to thank Mariska Harte (Rijkswaterstaat / Ministry of Transport and Public Works), Henk Kouwenhoven (Noordzeewind / Nuon / OWEZ) and Luuk Folkerts and Jan Dam (Ecofys / PAWP).

At least as important as their financial support was the mutual understanding between OWEZ and PAWP that, no matter which party was financially responsible at a given time, it was of prime importance that the observers conducting the seabird counts should always be given permission to work in both parks. We want to thank Martin Dekker (OWEZ) and Jesse Don and Christien Deen (PAWP/EELSING), Vestas, and BCE vessel control for excellent co-operation.

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3. Materials and Methods

3.1 Survey design

A survey design was chosen, in which a much larger area than the PAWP and OWEZ sites was repeatedly surveyed. The total survey area extended from the shore out to nearly 4°E, covering an area of approximately 725 km2 (ca 22 x 33 km), with PAWP and OWEZ more or less centrally. A third anomaly is present within this area, the anchorage (“A”) for sea-going vessels situated between the port of IJmuiden and PAWP (Figure 5). This site might be seen as a third built-up space within the survey area, as between 10 and 30 massive vessels would be anchored here at any one time during the survey period (***Figure 6***).

At the time of designing the study lay-out, the exact locations of the OWEZ turbines was not yet known and it was uncertain altogether whether PAWP would even be built. Only the two wind farm sites had been designated. For this reason, a study area was chosen that encompassed both presumed future wind farms. From the onset of this study, a survey design was chosen without clear, distinct reference areas, but rather a much larger “background” area surrounding the future wind farms. This was done because sharp gradients in seabird abundance and occurrence were expected (based on earlier survey work in the general area: Camphuysen & Leopold 1994), both from inshore to offshore, and from North to South. Therefore, it was deemed very risky, if not impossible to choose, *a priori*, reference areas that would be fully comparable to the impact sites. We rather opted for an approach in which we would model seabird densities in the wind farm sites, based on measured gradients in these densities over a larger area.

The study area chosen, extended from about 52°30’N (IJmuiden) to about 52°45’N (Hondsbossche Zeewering) and from the shore to circa 18 nm out to sea. The size of the study area was circa 725 km^2 (ca 22 x 33 km), which was some 18 times the surface area of the two future wind farms combined. Ten equidistant (1.33 nautical miles or 2.47 km apart) principal transect lines, running from East to West over the full width of the study area, were sailed during each survey. The orientation of these transects was deliberately chosen to be largely perpendicular to the main physical and ecological parameters, such as distance from the coast, water depth, temperature and salinity and from that, presumed seabird community parameters. This, with the rather even coverage of the study area, should facilitate later spatial modelling of the results. To rule out, as much as possible effects of survey day (within surveys) and time of day, survey lines were sailed in this order: 1-3-5-7-9-10-8-6-4-2 (twice if time permitted). This ensured that the greater survey area was covered several times and that nearshore and offshore parts were not always surveyed at similar times of day.

After two years of (OWEZ) T-1 surveys (named T-1a and T-1b in Leopold et al. 2011a) it became clear that too little time and effort was spent within the wind farms themselves. It was therefore decided to include eight extra lines through the wind farms, after an evaluation of a try-out during the January 2008 survey (Leopold et al. 2009). Because these lines were meant to highlight park effects, their orientation was along presumed seabird density gradients (parallel to the isobaths; Figure 5). These eight extra lines (four for each park) came at a cost, in that during the subsequent T-1 surveys (T-1c and T-1d) no attempt was made to complete the principal survey lines twice, so that each survey could still be completed within one week. The ten principal lines were always covered, however.

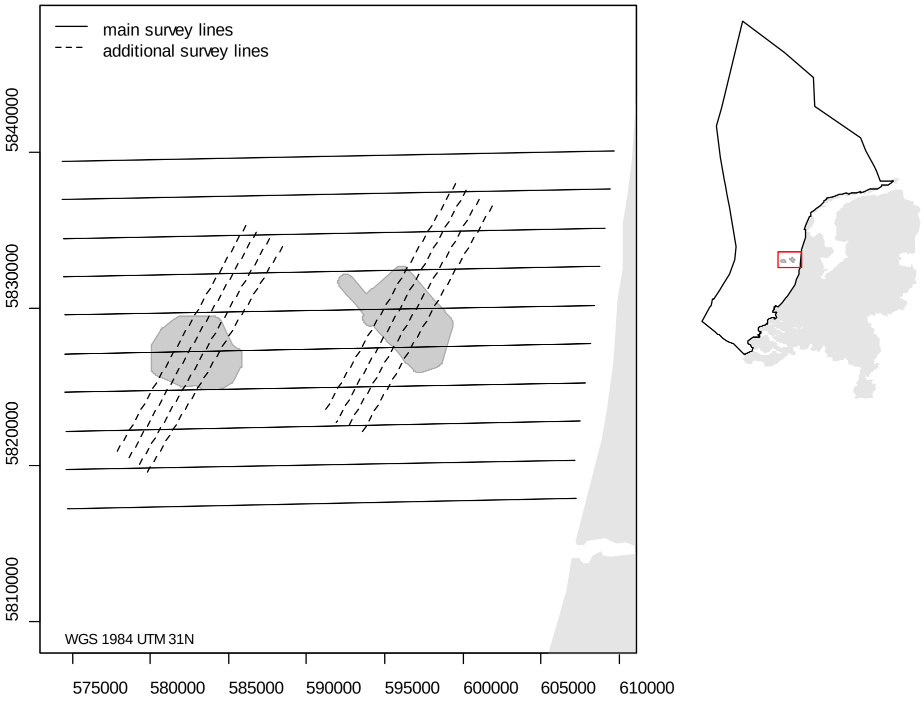

Figure 5. *Study area and survey design, consisting of ten principal (East-West) transects (black lines) and eight diagonal transects (dotted lines). The two wind farms are indicated as two grey polygons. The inset shows the Netherlands (grey), the Dutch Continental Shelf (bordered black) and the study area (bordered red).*

Figure 6. *View of the anchorage area at IJmuiden Approach, January 2010. Photo: Martin Poot, Bureau Waardenburg.*

Densities and species composition of seabirds in a nearshore study area such as covered here, are likely to vary considerably with the distance to the coast (or water depth, or salinity or temperature; these variables are often highly correlated). These physical parameters were studied during the T-0 phase of the project (Leopold et al. 2004). Indeed, distance to shore correlated strongly with water depth, water temperature and salinity, in all seasons. We therefore used distance to shore, or rather Easting as a good proxy, in our subsequent spatial modelling, and excluded the other, correlated factors.

3.2 Seabird counting techniques

On each transect run, counts were done simultaneously in two parallel strips, each 300 m wide, at both sides of the ship (weather permitting). This doubled the effort compared to a single side count, and made that a large relative surface area was studied compared to the total study area (Table 4).

Data on bird presence and bird densities were collected at sea, using ship-based strip-census techniques (Tasker et al. 1984). In summary, birds were counted in one or (mostly) two, 300 m wide strips on either side of the survey vessel, by two separate teams of two observers. Although considerable numbers of seabirds were also seen beyond the 300 m limits, or at closer range but outside the snap-shots used in the strip counts (Tasker et al. 1984), only birds seen ‘in transect’ were used for modelling purposes. These birds were always seen within 300 m perpendicular distance to the ship’s transect line and in the case of flying birds, at the right snapshot moments (see Tasker et al. 1984).

Transect lines were broken up into 5 minute (time) stretches and birds seen “in transect” in each individual 5 minute count were pooled (from t=0 to t=5 mins and for portside and starboard). At t=5 mins, the next count commenced, from t=5 mins to t=10 mins, etc. Densities were calculated as numbers seen in transect, divided by area surveyed. Area surveyed is the way length covered in that particular 5 minute period (depending on sailing speed, which was continuously monitored but kept close to 10 knots or 18.5 km/h) and strip width (300 or 600 m), corrected for the proportion of birds that were missed by the observers (see next section: distance sampling). The location of each count was taken as the mid-position between the positions at t=0 and t=5 mins, for each count, on the ship’s transect line.

3.3 Distance analysis

Birds swimming or floating on the water surface (as opposed to birds in flight) may be hard to detect. Detection probability is determined by several factors, such as colour, shape and behaviour of the bird, but especially the distance from the transect line (i.e. the observer) is a major determinant of detection probability. The technique of distance sampling (Buckland et al. 2001) was used to infer the relationship between detectability and distance.

All (groups of) birds on the water were assigned to a particular distance class, perpendicular to the ship's track line (Table 1, *Figure* ***7***). From the number of individuals counted in bands A-D, a detection function can be estimated. In order to arrive at a density estimate corrected for imperfect detection, detection functions can be used in two ways. First, one can calculate a correction factor for scaling up the number of birds within the counting strip. Second, the width of the counting strip can be downscaled to the so-called effective strip width (ESW), which represents the width within which the expected number of detected objects would be the same as the numbers actually detected within the full width of 300 m (Buckland et al. 2001).

Detection functions were created using the software package Distance (v6.0) (Thomas *et al*. 2010). This software offers several model 'key' functions that are fitted to the counts per distance band. Models can include covariates and 'series adjustment terms' (the latter allow extra flexibility). Within the Multiple Covariates Distance Sampling engine, the available key functions are the half-normal and the hazard-rate functions. Available series adjustment functions are the cosinus, simple polynomial and hermite polynomial functions. As detection probabilities may vary with weather conditions, seastate was included as a covariate in modelling the detection function. First, all combinations of model functions and adjustments were tested with and without seastate as a covariate. Then, the model with the lowest AIC was selected.

Note that it is implicitly assumed that all swimming birds will be detected if they swim on the track line, or in the case of sub-bands within a wider strip, within the first band (A). However, detection probability on the track line (the so-called g(0), Buckland et al. 2001) is unlikely to be perfect, for example due to escape diving by alcids. There is however no correction factor available for an imperfect g(0). Observations using 'double-platforms' (Hammond et al. 2002) are needed to assess the fraction of birds seen on the trackline.

In distance analyses, detection probability of clusters of individuals is modelled. This means that the resulting density represents the density of clusters of individuals. To arrive at a density of individuals, the density of clusters needs to be multiplied by the average group size. However, detection probability may depend on cluster size. To correct for such a bias, we used the expected cluster size on the transect line. This value is obtained from the intercept of a regression line of cluster size against distance from the transect line.

Table 1. *Distance classes for birds seen perpendicular to the ship's track line.*

Distance class	Distance range (m)
A	0-50
B	50-100
C	100-200
D	200-300
E	>300
F	Flying birds*

** Flying birds need to fulfil two criteria to be counted as 'in transect' and thus to enter the seabird density calculations. First, they have to pass by the ship at the side of the transect and within 300 m perpendicular distance. Second, they have to do so at pre-determined snap-shot moments (exactly once every whole minute) and within a distance forward from the observers which is covered by the steaming ship in one minute (circa 300 m at 10 knots). For more details, see Tasker et al. 1984) and the next section of this report.*

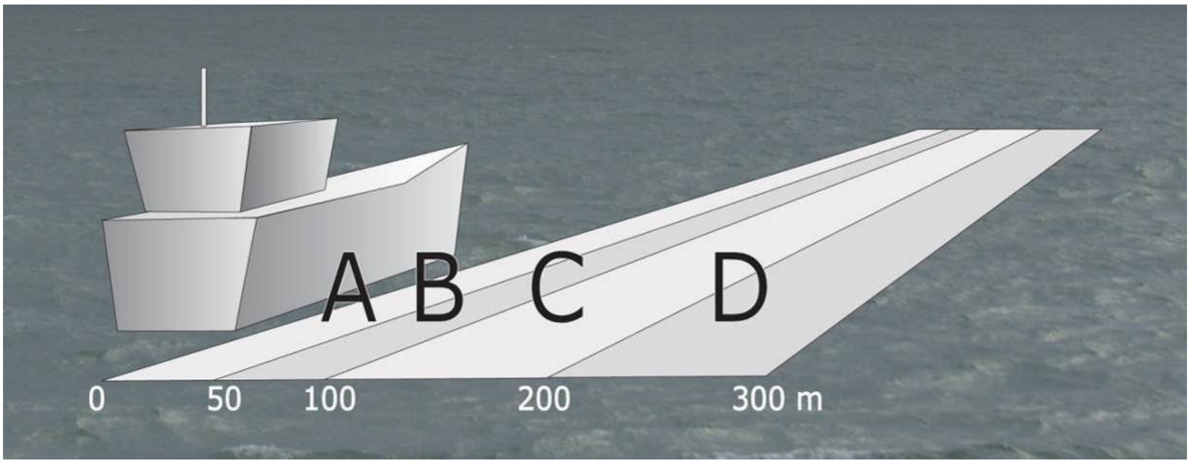

Figure 7. *The counting strip is divided into sub-strips A-D. Numbers (0-300) indicate the width of each sub-strip. Note that for this project, 300 m wide strips were normally counted at both sides of the vessel. Figure prepared by Oscar Bos, IMARES. Idealised picture: strip A actually starts on mid-line of ship.*

Detection of flying and perched birds

All birds in flight were assigned to distance class F. Birds in flight are much more easily detected than swimming birds and are assumed to be always detected within 300 m. This assumption may not be necessarily true, but unlike swimming birds, there is no way yet to correct for missed birds. This is an important issue when it comes to calculating absolute densities, but is of no consequence for relative measures of abundance. In ship-based seabirds surveys in the North Sea it is commonly assumed that all flying birds are detected within 300 m but this assumption was never tested. Barbraud & Thiebot (2009) provided the first data on this issue, during seabirds surveys in the Southern Ocean. They found that medium-sized seabirds (like gulls and Northern Fulmars in the North Sea situation) were detected with a probability of circa 0.8 within 300 m, by a single observer watching from the bridge (indoors). Finally, detection probabilities are influenced by bird behaviour: some birds avoid approaching ships by diving or by flying off (e.g. divers, auks), while others are attracted to ships (e.g. Fulmars, gulls, Gannets). The final detection probability is thus dependent from several factors, some working against each other. We tackled this problem to some extent by always using two observers working as a team (two observers detect more birds than a single observer, see Evans Mack et al. 2002; Hoekman et al. 2011), and by always carrying out observations from the top-deck (outdoors). Given that this *modus operandi* was used, from relatively large ships offering stable and high vantage points, that always well-trained observers were used and that most flying birds in the study area are medium-sized, with light colouration, we feel that detection probability for flying birds within 300 m approached 1.

Moreover, we assume that all birds perched on platforms (such as turbine poles) were detected. Hence, birds perched on platforms within the transect are treated in the same way as flying birds: their density is calculated from the number of individuals seen within the surface of a counting strip with a 300m width. The assumption of perfect detection of perched birds seems safe, considering that such birds are usually entirely exposed on positions high above the water surface, giving ample time to detect these birds, even at great distances (Figure 4).

Due to movement of flying birds and the fact that they usually fly much faster than the sailing speed of the ship, the density of flying birds is easily overestimated. To account for this overestimation, flying birds were counted by the so-called snap-shot method (Tasker *et al.* 1984). This method prescribes that all birds flying above the transect should be recorded as ‘in the transect’ at fixed time intervals and only to a fixed distance ahead. Here, we used a 1-minute interval (note that these sightings are still part of a 5-minute counting bout, see above). The distance travelled within one time interval determines the forward distance that is regarded as ‘in the transect’. For example, at a speed of 12 kt, the distance travelled in one minute is 370 m, and consequently, all birds flying above the 370 x 300 m rectangle at whole minutes are noted as within the transect.

Effective Strip Width, correction for number of flying and perched birds

Incomplete detection can be incorporated in the response variable (the density of individuals) in two ways: either the number of birds is scaled up, or the surveyed area (as a function of the width of the count strip) is scaled down. However, given the fact that numbers of birds need to be modelled as count data (i.e. as having a Poisson or Negative Binomial distribution), we need to select the latter option.

Due to the disparity in assumed detection completeness within the counting strip of 300m of swimming birds on one hand (incomplete), and birds that are flying and perching on offshore platforms (including turbine poles) on the other hand, the eventual ESW must be a compromise between the ESW calculated for swimming birds and 300m. This corrected ESW_{corr} is calculated by formula (1),

$$ESW_{corr} = (N_{fly} + C_{swim} * Cs) / (N_{fly} / SW + (C_{swim} / ESW_{uncorr}) * Cs) \qquad (1)$$

in which N_{fly} represents the number of flying and perched birds, C_{swim} is the number of sightings of swimming birds, Cs is the mean cluster size, N_{swim} the number of (clusters of) swimming birds, D is the covered distance (in km), SW the total strip width (in this case: 300m), ESW_{swim} is the Effective Strip Width for swimming birds. This formula re-calculates the ESW by dividing the density estimate within the 300m wide strip by the number of birds actually detected.

Corrected ESWs were calculated for all species groups (see below). Furthermore, if seastate was found to significantly influence the detection, corrected ESWs were calculated for each seastate, and surveyed areas were adjusted accordingly.

Species groups

Small samples can lead to non-robust estimates of effective strip width – in particular if covariates such as seastate are to be included in the modelling of the detection curve. Therefore, some species of similar size, colouration and behaviour were grouped in order to get robust modelling outcomes. The composition of these groups is presented in Table 2. For the sake of completeness, also species that have not been lumped with other species are shown. Although the sample size is small for some of these species, such as Black Scoter, it is not possible to lump these with other species given their distinctness in colouration, behaviour and size.

Table 2. *Grouping of species for distance analysis. Some individuals were only identified to species group level, but could be used in distance analyses for groups: small divers (G stellata/G arctica), 'commic' terns (S hirundo/S paradisaea) and large auks (U aalga/A torda).*

Group	**Species**
Divers	Red-throated Diver (*Gavia stellata*) Black-throated Diver (*Gavia arctica*)
Grebes	Great Crested Grebe (*Podiceps cristatus*)
Fulmars	Northern Fulmar (*Fulmarus glacialis*)
Gannets	Northern Gannet (*Morus bassanus*)
Cormorants	Great Cormorant (*Phalacrocorax carbo*)
Scoters	Black Scoter (*Melanitta nigra*)
Small gulls	Little Gull (*Hydrocoloeus minutus*) Black-headed Gull (*Chroicocephalus ridibundus*) Common Gull (*Larus canus*) Black-legged Kittiwake (*Rissa tridactyla*)
Large gulls	Herring Gull (*Larus argentatus*) Lesser Black-backed Gull (*Larus fuscus*) Great Black-backed Gull (*Larus marinus*)
Terns	Sandwich Tern (*Sterna sandvicensis*) Common Tern (*Sterna hirundo*) Arctic Tern (*Sterna paradisaea*)
Auks	Common Guillemot (*Uria aalge*) Razorbill (*Alca torda*)

3.4 Statistical analysis

Whether bird densities within PAWP, OWEZ and the anchorage area differed from ‘background densities’ in the surrounding area was tested using statistical models. The likeliness to statistically detect an effect of the ‘disturbance areas’ is a function of the bird density in surrounding waters, the variability and/or uncertainties in these densities and the ‘true’ size of the effect.

Statistical analysis of data from ship-based seabird surveys is often fraught with difficulties. Seabirds often show a patchy distribution and consequently data from ship-based surveys are often characterized by high variance in numbers per counting bout and a high proportion of counts with zero birds. This is problematic, as models are built on assumptions about the distribution of the response variable, but a response variable with lots of zeros and very high variance does not fit distributions such as the Poisson distribution. Moreover, this spatial patchiness can be highly variable over time, resulting in large differences in distributions and densities between and within seasons and years, and therefore between surveys.

In Leopold et al. (2011a) it was decided not to model bird densities, but only presence/absence data. This strategy is often used as it avoids many statistical problems. However, it ultimately does not answer several key questions. In this study, we model bird density by taking the number of counted birds as the response variable and the surveyed area, adjusted for imperfect detection by distance sampling (see previous chapter), as an offset. We modelled the counts (i.e. the densities) of birds per 5-minute counting bout *i* as a function of the following covariates:

- the location, using a two-dimensional, radial smoother, consisting of longitude *X* and latitude *Y*, which is allowed to differ between surveys *k* both in shape and height; and
- a ‘disturbance area effect’, with different levels for PAWP, OWEZ and the anchorage area.

To account for correlation between observations, the following random effects were included:

- each hour of observation *j*, to account for small-scale correlation within transects and
- each survey *k*, to account for differences between surveys,
  in which ‘Hour’ was nested within ‘Survey’.

Given this set of covariates and random effects, we started for each species, with two Poisson Generalized Additive Mixed Models (GAMM), one with one general smoother for all surveys (equation 2), and one with a smoother for each survey (equation 3), in which Y_{ijk} is observation *i* in hour *j* in survey *k*.

$$\begin{aligned} &Y_{ijk} \sim Poisson(\mu_{ijk}) \\ &\log(\mu_{ijk}) = \beta_1 \times I_{OWEZ} + \beta_2 \times I_{PAWP} + \beta_3 \times I_{IJmuiden} + f(x_{ijk}, z_{ijk}) + s_k + a_{jk} \end{aligned} \qquad (2)$$

$$\begin{aligned} &Y_{ijk} \sim Poisson(\mu_{ijk}) \\ &\log(\mu_{ijk}) = \beta_1 \times I_{OWEZ} + \beta_2 \times I_{PAWP} + \beta_3 \times I_{IJmuiden} + f_k(x_{ijk}, z_{ijk}) + a_{jk} \end{aligned} \qquad (3)$$

The random effect s_k imposes a correlation on all observations within one survey; a_{jk} imposes a correlation on all observations made within the same hour and captures small-scale temporal and spatial correlation.

These analyses were performed using the package ‘gamm4’ (Wood 2012b), which is based on ‘mgcv’ (Wood 2012a) and lme4 (Bates & Maechler 2012) in R (R Development Core Team 2011).

Often, such models were overdispersed. This means that the variance in the empirical data is larger than expected from the model. A dispersion parameter is estimated by dividing the sum of the squared model residuals by the residual degrees of freedom. If this parameter exceeds 1.5, models are generally regarded overdispersed.

Overdispersion can result from, for example, missing covariates, a large proportion of zeros in the response variable and/or large variance in the response variable. In case of seabird survey data, the latter two are often the case. Zero-Inflated Poisson GAMM (ZIP GAMM) can be used to account for a large proportion of zeros in the response variable, by splitting the model in two parts: a binary part modelling the occurrence of zeros and a ‘count’ (Poisson) part for modelling the positive values. As there is no software package in which such a model is readily implemented, we had to program it.

The full ZIP GAMM model can be written as:

$$\begin{aligned}
&Y_{ijk} \sim ZIP(\mu_{ijk}, \pi_{ijk})\\
&\text{logit}(\pi_{ijk}) = \gamma_k\\
&\log(\mu_{ijk}) = \beta_1 \times I_{OWEZ} + \beta_2 \times I_{PAWP} + \beta_3 \times I_{IJmuiden} + f_k(x_{ijk}, z_{ijk}) + a_{jk}\\
\\
&I_{OWEZ} = \begin{cases} 1 & \text{if observation } ijk \text{ is made in OWEZ} \\ 0 & \text{else} \end{cases}\\
&I_{PAWP} = \begin{cases} 1 & \text{if observation } ijk \text{ is made in PAWP} \\ 0 & \text{else} \end{cases}\\
&I_{IJmuiden} = \begin{cases} 1 & \text{if observation } ijk \text{ is made in IJmuiden} \\ 0 & \text{else} \end{cases}\\
&a_{jk} \sim N(0, \sigma^2_{Hour})
\end{aligned} \tag{4}$$

In equation (4), Y_{ijk} is observation *i* in hour *j* in survey *k*. The random effect a_{jk} imposes a correlation on all observations made within the same hour and captures small-scale temporal and spatial correlation.

If the ZIP GAMM still showed overdispersion, we assumed a Negative Binomial distribution of the response variable instead of a Poisson distribution. We first fitted a Negative Binomial GAMM (NB GAMM), using formulae (3), but using (5):

$$G_{ijk} \sim NB(\mu_{ijk}, k) \tag{5}$$

If the resulting model still showed overdispersion or bad mixing of the chains, we adjusted the ZIP GAMM formulae (4) to get a Zero-Inflated a Negative Binomial GAMM (ZINB GAMM) by assuming (6):

$$G_{ijk} \sim ZINB(\mu_{ijk}, \pi_{ijk}, k) \tag{6}$$

The 2-D smoothers f_k are modelled using a radial basis spline (Ngo & Wand 2004). Each 2-D smoother contains an intercept allowing for different mean values per survey. Markov Chain Monte Carlo (MCMC) was used to estimate the posterior distribution of the parameters. Calculations were carried out in JAGS

(Plummer 2003) using the R package R2jags (Su & Yajima 2012) in R (R Development Core Team 2011). A burn-in of 100,000 iterations was used and 100,000 iterations were carried out using a thinning rate of 100, with 3 chains, resulting in 3000 iterations for each posterior distribution. Mixing of the chains for the regression parameters β_1 to β_3, and for the parameters $a\beta_1$ to $a\beta_{13}$ (survey intercepts in the binary part of the model) was good. Diffuse priors were used for all parameters.

The model results for the effects of the ‘disturbance’ areas (β_1, β_2 and β_3, or the on-site deviations from background densities at respectively OWEZ, PAWP and the anchorage area) are presented for each species(group) separately.

3.5 Data selection

The abundance of most bird species show high seasonal variation within Dutch waters in general and within the study area in particular. Considering that the likelihood of finding a significant effect of the wind farm(s) very likely declines with lower bird densities, we excluded months during which the species is known to be virtually absent from Dutch waters, based mainly on land-based counts (Camphuysen & van Dijk 1983, Platteeuw et al. 1994), but also on at-sea surveys (Camphuysen & Leopold 1994). We checked this against the mean densities found in the study area (*Figure 8*). The list of excluded months is presented in (Table 3).

***Table 3**. Excluded months per species.*

Nr	species	n records	n months	Excluded months
1	Black-headed Gull	9237	8	none
2	Black-legged Kittiwake	9237	8	none
3	‘commic’ terns	5504	5	Jan, Feb, Nov
4	Common Guillemot	4785	5	Apr, Jun, Aug
5	Common Gull	6083	5	Jun, Aug, Sep
6	Common Scoter	9237	8	None
7	divers	6083	5	Jun, Aug, Sep
8	Great Black-backed Gull	9237	8	none
9	Great Cormorant	9237	8	none
10	Great Crested Grebe	9237	2	Apr, Jun, Aug, Sep, Oct, Nov
11	Herring Gull	5504	8	none
12	Lesser Black-backed Gull	4785	5	Jan, Feb, Nov
13	Little Gull	6083	3	Jan, Feb, Jun, Aug, Oct
14	Northern Fulmar	9237	8	None
15	Northern Gannet	6083	8	None
16	Razorbill	9237	5	Apr, Jun, Aug
17	Sandwich Tern	9237	5	Jan, Feb, Nov

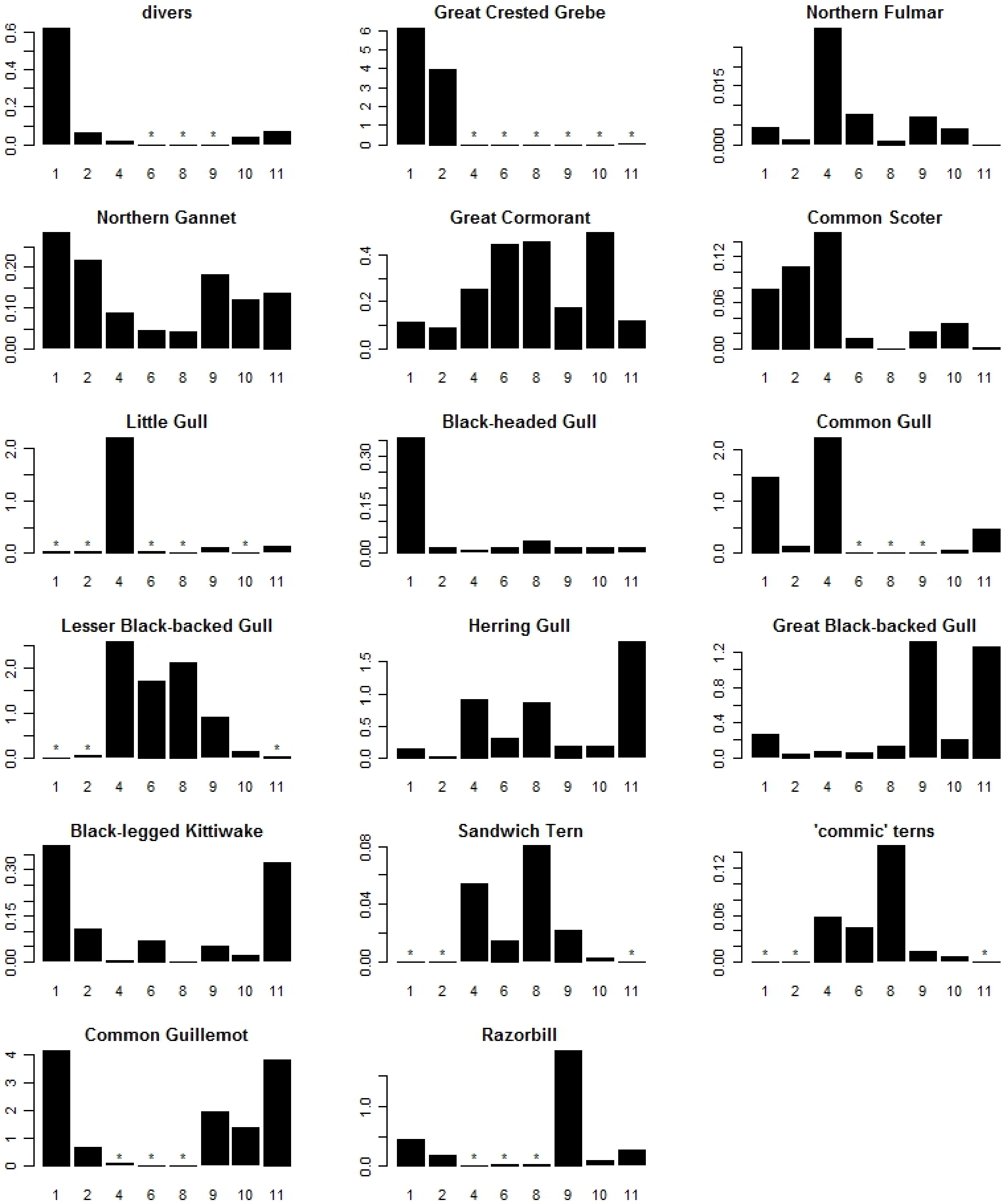

Figure 8. *The mean abundance per species per month, over all t1 surveys. Months marked with an asterisk are excluded from the analysis to avoid wasting computational time.*

3.6 Data presentation

Two figures showing distribution patterns are presented for each species; the first comprising two maps of the study area comparing all T-0 surveys versus all T-1 surveys, and the second comprising five maps comparing all T-0 surveys and the four T-1 survey phases. In all cases, the data has been aggregated to 1 km^2 blocks, and shows the mean density of birds across surveys, calculated as the number of observed birds within the transect, divided by the effectively surveyed area. The red dots represent this density and are scaled to the highest density found within one 1 km^2 block. All blocks that have been covered (so contain effort) are shown as grey-bordered squares. Sightings with effort but in which no sightings were recorded, are thus shown as empty squares. The three disturbance areas (PAWP, OWEZ and the anchorage area) are delimited by blue lines.

The outcome of the statistical analysis are shown for each species in a table, with an estimated effect size for each wind farm. Which model was selected is presented in the table heading. This has consequences for which information is shown as an indication of the statistical significance of the found mean effect. For Poisson GAMMs, this is shown as a p-value. If below 0.05, this is taken as significant. The ZIP GAMMs are based on Bayesian statistics, which means that we provide the 95% credible intervals of the parameters. If zero is within 95% of the generated values, or in other words, within the 95% credible intervals, the effect is statistically not significant.

4. Results

4.1 Effort

Prior to the construction of OWEZ, eight T-0 surveys were conducted, from September 2002 to February 2004, using only the principal E-W transects (Figure 5). Note, however, that while the two wind farms only existed on the drawing table at this stage, the anchorage area was already in use.

From April 2009, a total of 23 post-construction, T-1 surveys were completed. These cluster into four series, T-1a to T-1d. The T-1a series (April 2007 to January 2008) took place post-construction of OWEZ, and post-pile driving for PAWP. Construction work was still going on in PAWP in this phase, but all poles had been placed and so had some of the turbines and rotors. From the point of view of local seabirds, and hence also for analysis, this phase might be seen as a T-1 phase for both wind farms. Only the standard E-W transects were used in this phase.

The T-1b series was conducted from April 2008 to January 2009. Both parks were now fully operational, with the exception of PAWP during the first survey in this series (April 2008). However, also during this April survey, PAWP was near-complete and almost totally functional (most turbines turned on). Only the standard E-W transects were used in this phase.

Two further years of study, T-1c and T-1d had a different study design, with additional survey lines through both PAWP and OWEZ, at the expense of double coverage of the standard E-W transects, which were now only covered once. Another difference with the T-a and T-1b series was, that in T-1c and T-1d the August survey was replaced by a February survey. This had two advantage: a better matching with the T-0 situation and more winter coverage rather than summer coverage. In winter, densities of auks are high and auks were now considered the best indicators of possible effects.

At the onset of the project, it had been decided to cover the whole year, rather than to focus on particular seasons. Clearly, seabird presence would vary substantially between seasons and at the start of the project it was not yet known which species-season combinations would be most suitable to study wind farm effects on local seabirds. Eight T-0 surveys were budgeted, that covered the yearly seabirds' calendar. T-0 surveys were conducted in February (mid-winter), April (spring migration), May (early breeding), June (chick-phase; parent breeders fetching food at sea), August (dispersal of juveniles), September, October, and November (autumn migration, onset of winter). During the T-1 phase, only six surveys per year were budgeted and these were to be timed to match the T-0 surveys. It was decided not to repeat the May survey, as bird densities were very low in that month and surveys were conducted one month earlier (April) and later (June). Likewise, it was decided to skip surveying in October, but bad weather in two T-1 surveys frustrated work in later September T-1 surveys. By combining September and October surveys, still a time series of autumn T-0 through T-1 surveys is kept. Finally, during the last two series of T-1 surveys, it was decided to put more effort in the winter period when more birds that might be susceptible to disturbance (divers, auks) were present. The T-1a&b August surveys were therefore replaced by February surveys, which also better matched the T-0 situation (Table 1).

The area surveyed (=km travelled times strip width, times the number of strips) differed between surveys, mainly in response to the amount of daylight available and wind conditions (Table 1), and rain and mist. Relatively little effort could be realized in some autumn and winter surveys, when short days and poor weather conditions sometimes prevented counting on both sides of the survey vessel, or completing all E-W survey lines twice. These E-W survey lines were covered at least once, in each survey, however.

Table 4. *Total area (km^2) and km travelled in the study area, per survey. The summed km travelled has been split up in km travelled per Beaufort seastate (Columns 0 to ≥6). The column AVG(Bft) gives unweighted average seastates. These figures are not exact measures for average windspeed, as the Beaufort scale is logarithmic; but provide an impression of conditions during various surveys. The T-0 May 2003 survey and two broken off T-1 surveys (all marked grey) are not further used. Two surveys (marked grey) had to be broken off due to very bad weather. These results have been omitted from further analyses.*

					Effort per seastate (Bft), as percentage of covered distance							**AVG**
Survey	**Year**	**Month**	**km^2**	**km**	**0**	**1**	**2**	**3**	**4**	**5**	**≥ 6**	**(Bft)**
T-0	2002	9	418	1392	0	0	5.2	21.4	52	21.4	0	3.9
T-0	2003	4	487	1625	0.4	9.8	42.9	31.7	12.9	2.5	0	2.54
T-0	2003	5	404	1351	0	0	0	4.1	47.7	26.4	21.8	4.66
T-0	2003	6	462	1539	0	0	10.2	46.5	40	3.3	0	3.36
T-0	2003	8	457	1523	4.5	9.1	19.4	27.7	29.3	10	0	2.98
T-0	2003	11	321	1069	3.2	3.3	20	29.4	41.3	2.8	0	3.11
T-0	2004	2	368	1227	5	15.6	17.5	14.6	21.7	21.7	4	3.14
T-0	2002	10	237	791	0	0	3.7	7.6	32.7	36.8	19.2	4.6
T-1a	2008	1	286	952	0	0	0	1.5	10.4	62.8	25.3	5.12
T-1a	2007	4	445	1483	15.2	3	19	49.5	13.4	0	0	2.43
T-1a	2007	6	376	1252	0	0	0	0	0	77.8	22.2	5.22
T-1a	2007	8	400	1334	4	11.2	17.7	26.4	16.9	6.3	17.5	3.3
T-1a	2007	11	27	89	0	0	0	0	43.8	20.2	36	4.92
T-1a	2007	9	115	383	0	0	0	3.9	6	29.6	60.5	5.46
T-1a	2007	11	360	1202	0	0	6.9	16.6	30.2	24.8	21.5	4.38
T-1b	2009	1	222	739	0	0	0	5.1	44.9	34.3	15.7	4.61
T-1b	2008	4	448	1492	3.6	6.3	31.5	41	17.3	0.3	0	2.63
T-1b	2008	6	437	1457	0	6.6	23.1	28.1	36.9	5.4	0	3.11
T-1b	2008	8	429	1481	0	0	0	2.5	33.6	46.7	17.2	4.79
T-1b	2008	9	84	280	0	0	0	0	0	45.9	54.1	5.54
T-1b	2008	11	376	1254	0.6	16.3	19.7	23.1	37.1	3.3	0	2.9
T-1c	2010	1	378	1261	5.9	5.9	11.7	31.9	37.4	7.2	0	3.11
T-1c	2010	2	376	1314	0	1.8	19.4	13.8	24.9	19.5	20.6	4.03
T-1c	2009	4	294	979	6	14.7	45.7	20.4	3.8	9.1	0.3	2.3
T-1c	2009	6	382	1273	0	0	8.7	40.8	42.1	8.4	0	3.5
T-1c	2009	10	376	1255	0	0	2.5	36.8	40	18.5	2.3	3.81
T-1c	2009	11	371	1235	0	0	13.2	25.1	54.1	7.6	0	3.56
T-1d	2012	1	301	1002	0	0	2.4	21.6	22	32.6	21.3	4.48
T-1d	2012	2	310	1034	0	0	1.2	18.1	31.4	38.9	10.4	4.42
T-1d	2012	4	304	1012	0	0	0	4.3	53.4	38.6	3.7	4.42
T-1d	2012	6	309	1030	4.6	23.5	8.3	38.3	25.4	0	0	2.59
T-1d	2011	10	271	903	0	0	1.1	26.5	4.1	21.2	47.2	4.93
T-1d	2011	11	371	1237	0	0.5	3.2	18.5	54.7	17.3	5.7	4.01

4.2 Distance analysis

Estimated Effective Strip Widths

The number of adjustment terms was limited to a maximum of two, considering that a larger number would give unrealistic flexibility given the small amount of distance bands. Table 5 gives an overview of the selected models per species group. Seastate was only maintained in the final model in gulls and alcids; see Figure 9 for a visualisation of the effect of seastate on the ESW. The fact that seastate was not maintained in the model for the remaining species groups may have been due to relatively small sample sizes.

***Table 5**. Per taxon, the sample size used for distance analyses, and the properties of the final model: key function, adjustment term, number of parameters, and whether seastate was included. In addition, the cluster size expected at the transect line.*

Species/ Group	Sample size	Key function*	Adjustment term	Number of parameters	Seastate in model	Expected cluster size
Divers	512	HN	cosinus	2	n	1.1810
Grebes	1356	HN	cosinus	2	n	4.4056
Fulmar	81	HN	cosinus	2	n	1.1566
Gannets	485	HN	cosinus	2	n	1.3436
Cormorants	1176	HN	cosinus	2	n	1.2190
Scoters	41	HN	cosinus	2	n	16.2680
Small gulls	1610	HN	cosinus	3	y	2.9388
Large gulls	4654	HR	cosinus	4	y	1.6432
Terns	35	HN		1	n	2.2436
Alcids	9443	HN	cosinus	3	y	1.3557

* *HN = Half-normal; HZ = Hazard-rate.*

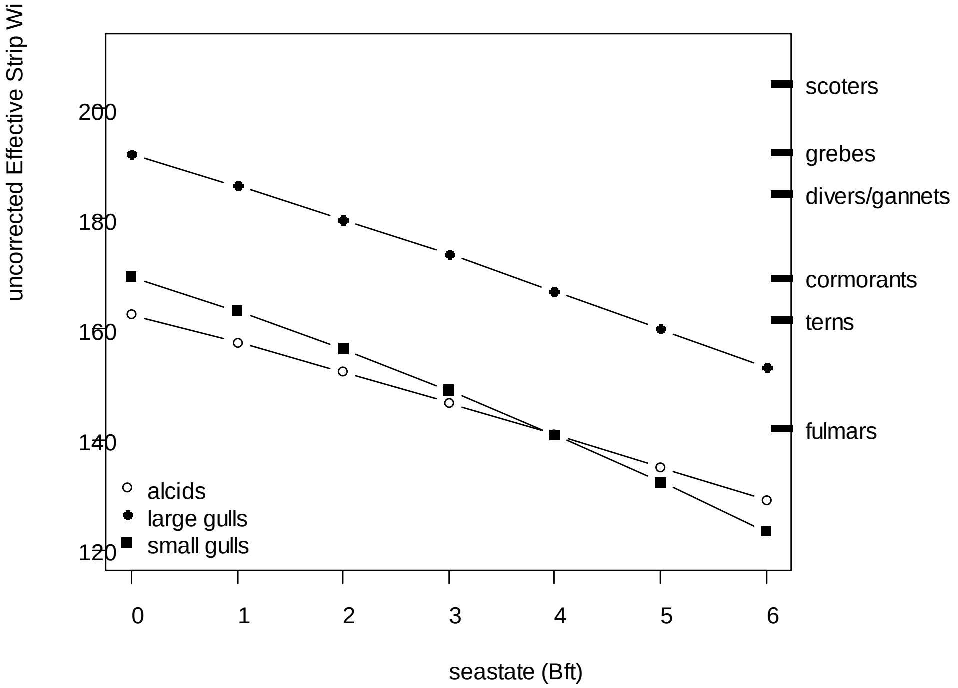

***Figure 9**. Estimated Effective Strip Width (m) for alcids, small and large gulls per seastate. For comparison, the remaining species (groups) are presented on the right side. These ESW values are only for swimming birds – they are not corrected for the presence of flying birds.*

Percentage of flying birds and corrected effective strip widths

The relative percentages of individuals noted as flying, sitting, or swimming differed markedly between species groups (Figure 10). Whereas grebes, auks, divers and cormorants were mostly noted swimming, terns were almost exclusively seen flying. A large proportion of species showed intermediate values. For species groups mostly seen swimming, the ESW corrected for the proportion of swimming individuals is almost identical to the uncorrected ESW, but for species seen almost exclusively flying, the corrected ESW is close to the total strip width: 300m (Table 6). Subsequently, the corrected ESW values were used to calculate the effectively surveyed area per 5-minute count. This was included as an offset in the modelling.

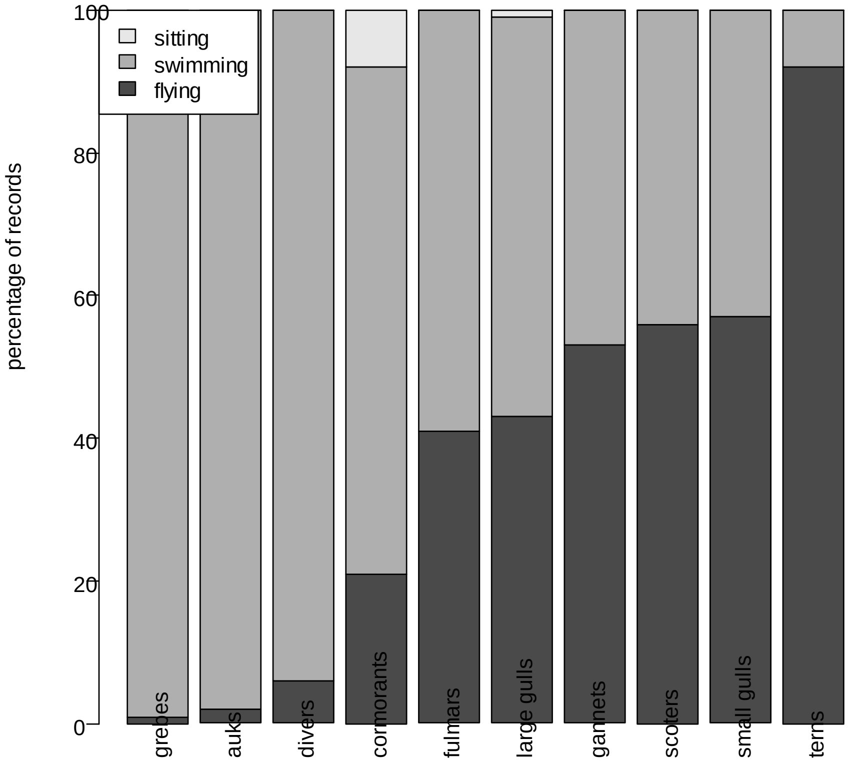

***Figure 10**. Percentage of flying individuals for each species group, ordered for increasing percentage of flying individuals.*

***Table 6**. Estimated Effective Strip Widths for each species group. If seastate is a significant covariate, ESW values for each seastate are presented. Per species group, upper rows show ESW values for only swimming birds, whereas lower rows show ESW values corrected for flying or perching birds.*

Species group	**corr**	**Effective Strip Width (m) per seastate (Bft)**						
		0	**1**	**2**	**3**	**4**	**5**	**6**
Divers	uncorr	185						
	corr	190						
Grebes	uncorr	192						
	corr	193						
Fulmar	uncorr	142						
	corr	183						
Gannets	uncorr	185						
	corr	245						
Cormorants	uncorr	169						
	corr	212						
Scoters	uncorr	205						
	corr	230						
Small gulls	uncorr	169	163	156	149	141	132	123
	corr	232	228	223	217	210	203	195
Large gulls	uncorr	192	186	180	174	167	160	153
	corr	255	251	248	244	240	235	230
Terns	uncorr	162						
	corr	286						
Alcids	uncorr	163	158	152	147	141	135	129
	corr	164	159	154	148	142	136	130

4.3 Species Accounts

A list of all observed bird species with the total number of individuals can be found in Appendix A. A subset of species has been analysed, and presented below.

Divers: Red-throated *Gavia stellata* and Black-throated Divers *G arctica*

Red-throated Diver in winter plumage. Photo: Steve Geelhoed, IMARES.

Divers do not breed in the Netherlands but winter by the tens of thousands in nearshore waters along both sides of the North Sea, including Dutch coastal waters (Skov et al. 1995). The vast majority of divers wintering in Dutch waters are Red-throated Divers *Gavia stellata*, but there is a migration peak in Spring of Black-throated Divers *G. arctica* moving through the area, best known from seawatching data (Camphuysen & van Dijk 1983; Platteeuw et al. 1994; www.trektellen.nl). Divers were absent in summer and generally most numerous during the mid-winter surveys.

Diver distribution patterns, from autumn through winter were mostly rather coastal, with the two wind farms situated at the offshore fringe of the area occupied by these birds. The pattern during the T-0 spring (April) survey was markedly different, when relatively large numbers were seen throughout the study area, but particularly far offshore. Numbers seen offshore were much lower in subsequent (T-1) spring surveys, including all April surveys, indicating much year to year variation. With only high numbers offshore during one T-0 (Spring) survey, it is difficult to show clear effects of PAWP, based on a before-after comparison. PAWP was largely outside the range of the divers, during all T-1 surveys. Given the generally low diver densities at the longitudes of PAWP, it is not surprising that very few birds were actually seen within this wind farm during any of the T-1 surveys (Figure 11). By coincidence (presumably), divers tended to occur mostly around, rather than inside both PAWP and OWEZ during T-0. The general distribution pattern for all T-1 surveys (averaged) does not indicate a clear avoidance of OWEZ, but does indicate a clear avoidance of offshore waters, including PAWP and the anchorage area (Figure 11). Most cases of birds seen within the parameter of OWEZ stem from the first year of post-construction surveys (T-1a; Figure 12). During T-1c and T-1d, after the addition of extra SW-NE transects through both wind farms, loose concentrations of sightings were picked up just NE of OWEZ. Apart from a single T-1c sighting inside OWEZ, divers at large appeared to stay outside this wind farm during the last two years of monitoring, while some birds were seen in close proximity, at all sides around this wind farm.

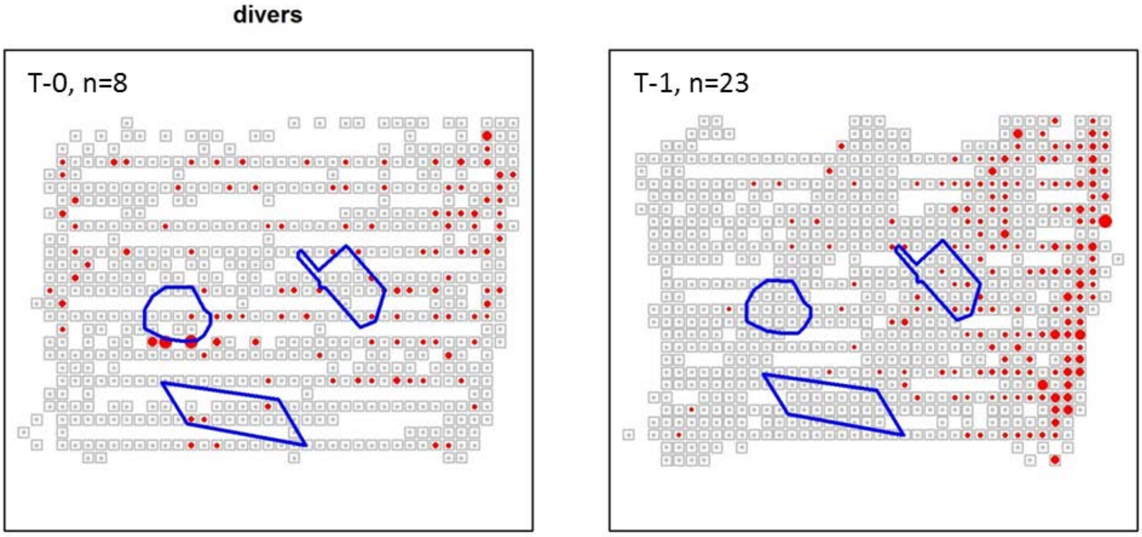

***Figure 11**. Average distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

For modelling purposes, both diver species were summed. Because of (near) absence during summer (Figure 8), results from the months June, August and September were excluded from analysis.

The model results (*Table 7*) indicate a significant negative effect of OWEZ, but no significant negative effects for PAWP and the anchorage area. This pattern is likely to be attributable to the mainly inshore distribution of divers, making it hard to detect any effects of PAWP and the anchorage area.

Table 7. Model results of a Poisson GAMM with a smoother for each survey. This model showed no overdispersion (0.95).

Term	**Coefficient**	**p-value**
PAWP	-3.447	0.720
OWEZ	-1.104	**0.007**
Anchorage	-26.413	1.000

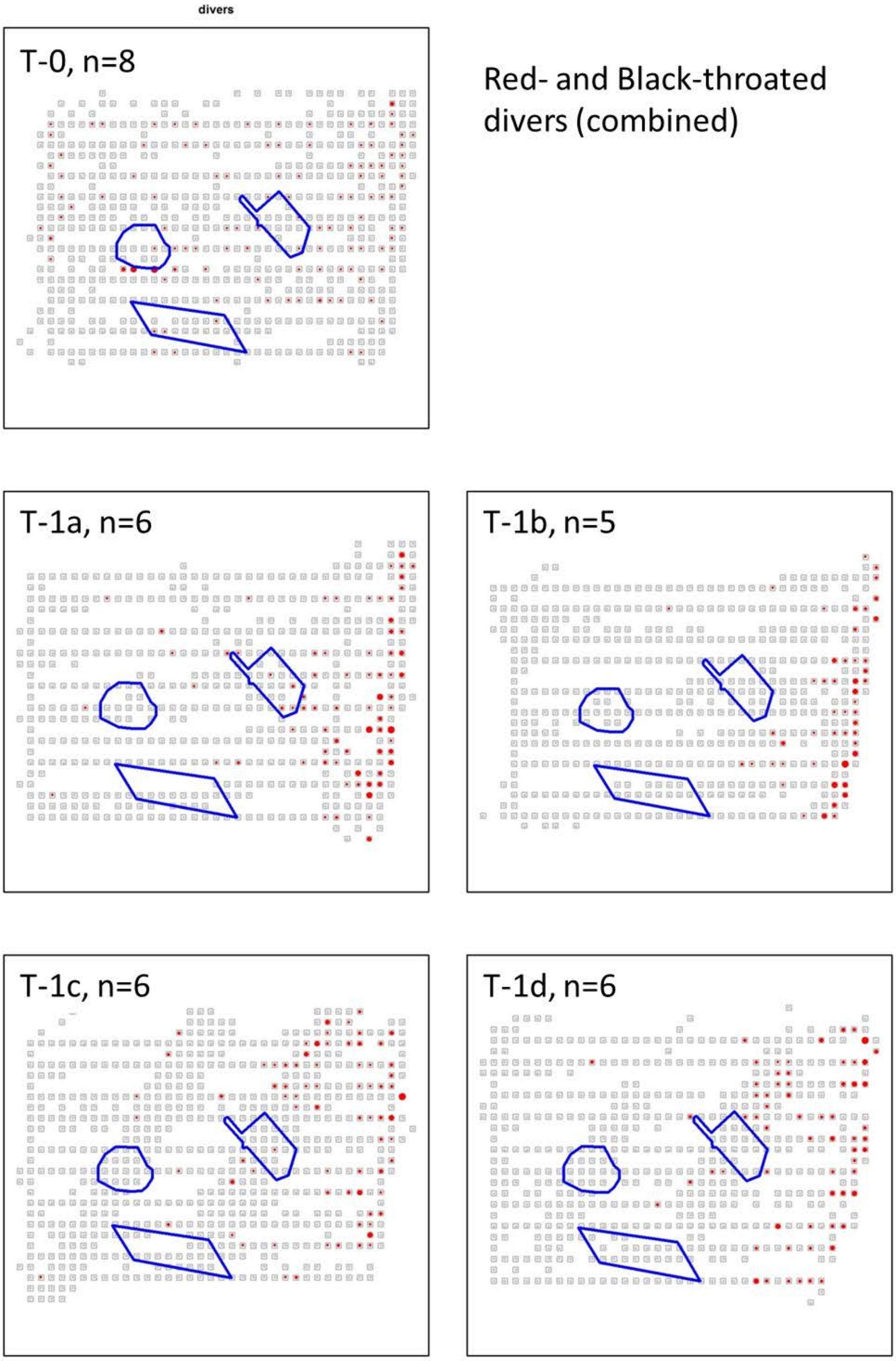

***Figure 12**. Averaged distribution patterns during the various survey phases.*

Great Crested Grebe *Podiceps cristatus*

Great Crested Grebe in winter plumage. Photo: Steve Geelhoed, IMARES.

Great Crested Grebes are often considered freshwater birds, but since the turn of the century, increasing numbers spend the winter in the North Sea coastal waters. The most important wintering site at sea, and indeed in the entire county, is a narrow coastal strip of sea between Hook of Holland and Den Helder, off the Dutch mainland coast. Total numbers in these parts have been estimated at 28,000 birds, with significant numbers due east of the wind farms (Leopold et al. 2011b). An increasing trend was also apparent in the series of OWEZ mid-winter surveys. Relatively small numbers were seen during the T-0 phase of this study and Great Crested Grebes were only seen closely inshore then (*Figure 13*). In the following years, more grebes were seen and also slightly further offshore (*Figure 14*).

OWEZ is situated on the edge of the distribution of Great Crested Grebes. Still, a significant negative effect of this wind farm was found (*Table 14*). The anchorage area and particularly PAWP however, are situated outside the distribution range of this species and hence modelling results are insignificant. Note, however, that even if Great Crested Grebes would be very reluctant to enter a wind farm, such a response would have been unlikely be detected for the two wind farms studied here, as they are located too far offshore, beyond this species' range.

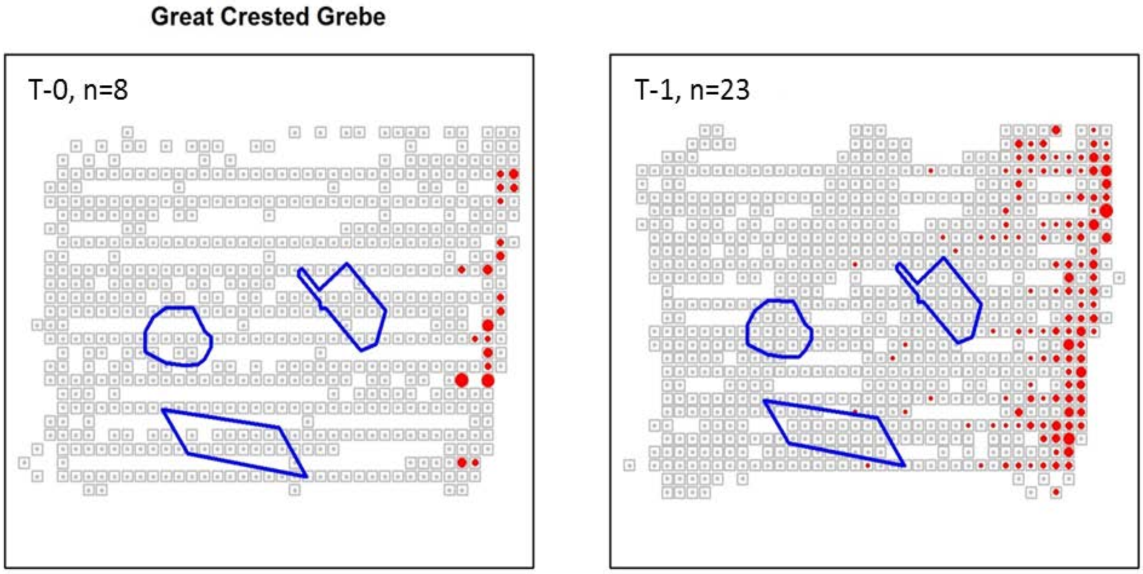

***Figure 13**. Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Because of (near) absence during most of the year (Figure 9), only data from January and February surveys were used for analysis.

Model results do not reveal significant negative effects for PAWP and for the anchorage area (*Table 8*), which may be attributable to the absence of large numbers of grebes away from a narrow nearshore strip of water within the study area.

***Table 8**. Model results of a ZIP GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-0.84	3.4	-6.6	3.7	N
OWEZ	-4.88	3.7	-11.3	-1.4	Y
IJmuiden	-2.19	3.5	-7.6	1.5	N

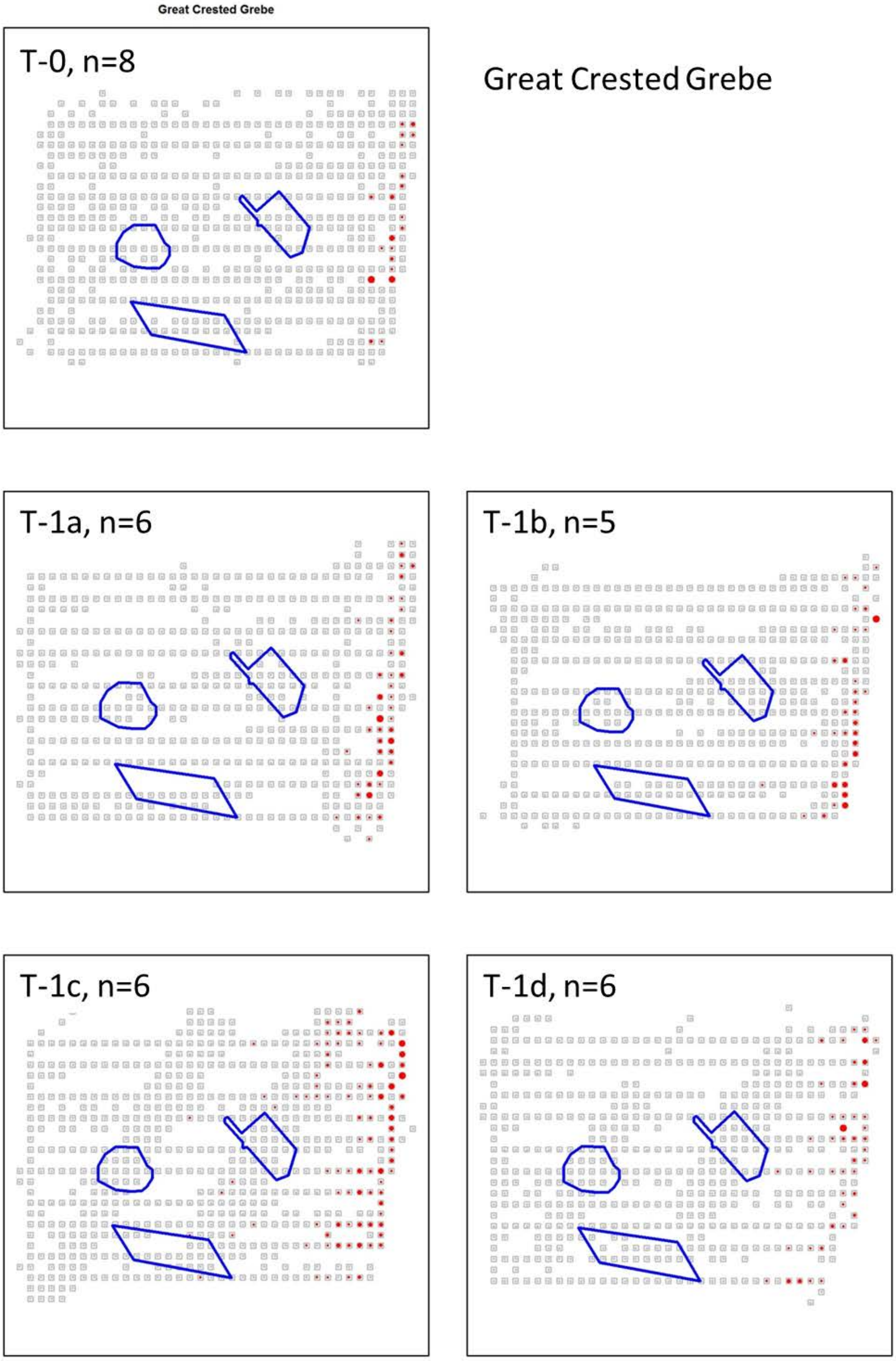

***Figure 14**. Averaged distribution patterns during the various survey phases.*

Northern Fulmar *Fulmarus glacialis*

Northern Fulmar. Photo: Steve Geelhoed, IMARES.

Northern Fulmars breed on cliff coasts and islets around the British Isles, Faroe, Svalbard, Jan Mayen, Iceland and from Norway to northern Russia (Mitchell et al. 2004), but occur abundantly in Dutch waters throughout the year (Camphuysen & Leopold 1994; Berrevoets & Arts 2001; Arts & Berrevoets 2005; Arts 2009; Poot et al. 2011). Northern Fulmars prefer clear, oceanic waters, making the Southern North Sea less suitable. Here, they mostly stay away from the mainland coastline, although influxes sometimes occur.

During the surveys conducted for this project, most Fulmars were seen at rather large distances from the shore, both during T-0 and T-1 (*Figure 15*). A remarkable drop in numbers was noted after the T-0 phase, particularly during the T-1b and T-1c years (*Figure 16*). However, even in “better” years, insufficient numbers per survey were generally seen “in transect”, for modelling purposes. Results for this species are therefore inconclusive. However, most Fulmars seen were ship-followers which were by definition classed as “not in transect” and hence not used in the models. If we plot all Fulmars seen during T-1 surveys, including those at slightly larger distances and those that flew purposefully to the ship and followed it for some time (*Figure 17*), a pattern emerges that clearly indicates avoidance of the wind farms. Although these results cannot be used for modeling, there is a strong suggestion of avoidance of the wind farms, and to a lesser extent, also of the anchorage area. Nearshore waters were generally avoided by this species, although some strays did venture closely inshore (c.f. seawatching data for the Netherlands).

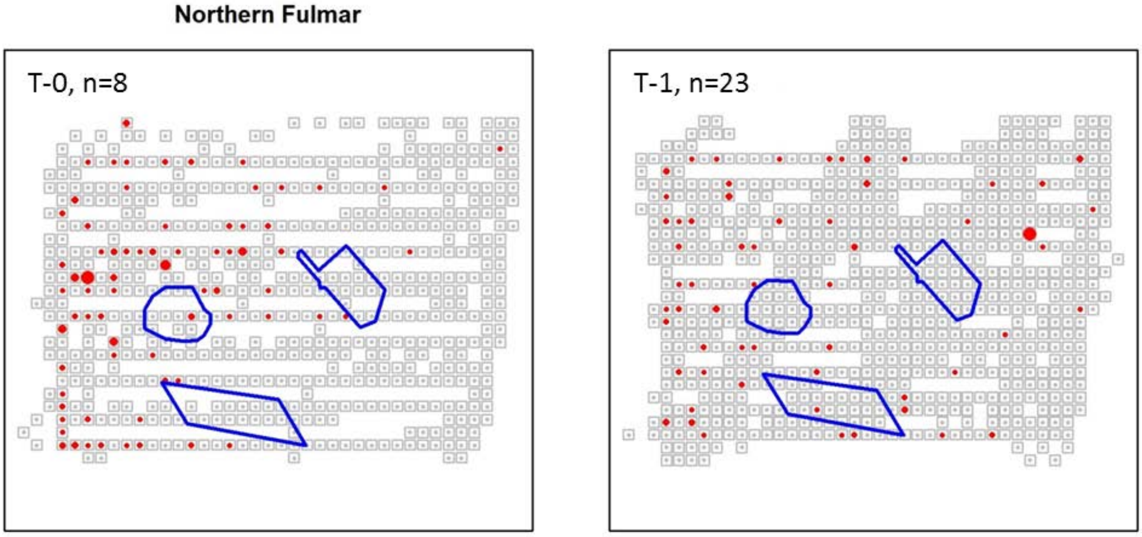

***Figure 15**. Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Northern Fulmars were seen in low numbers throughout the year. For the analysis of possible effects of PAWP, OWEZ and the anchorage area, no results were excluded (Figure 9).

Analysis did not reveal any significant effects, although the parameter estimates are highly negative for both wind farms (*Table 9*). The generally low numbers of Northern Fulmar are likely to explain this absence of significant results.

***Table 9**. Model results for a Poisson GAMM with one smoother. This model did not show overdispersion (0.36).*

Term	Coefficient	p-value
PAWP	-15.810	0.994
OWEZ	-15.006	0.992
Anchorage	0.741	0.264

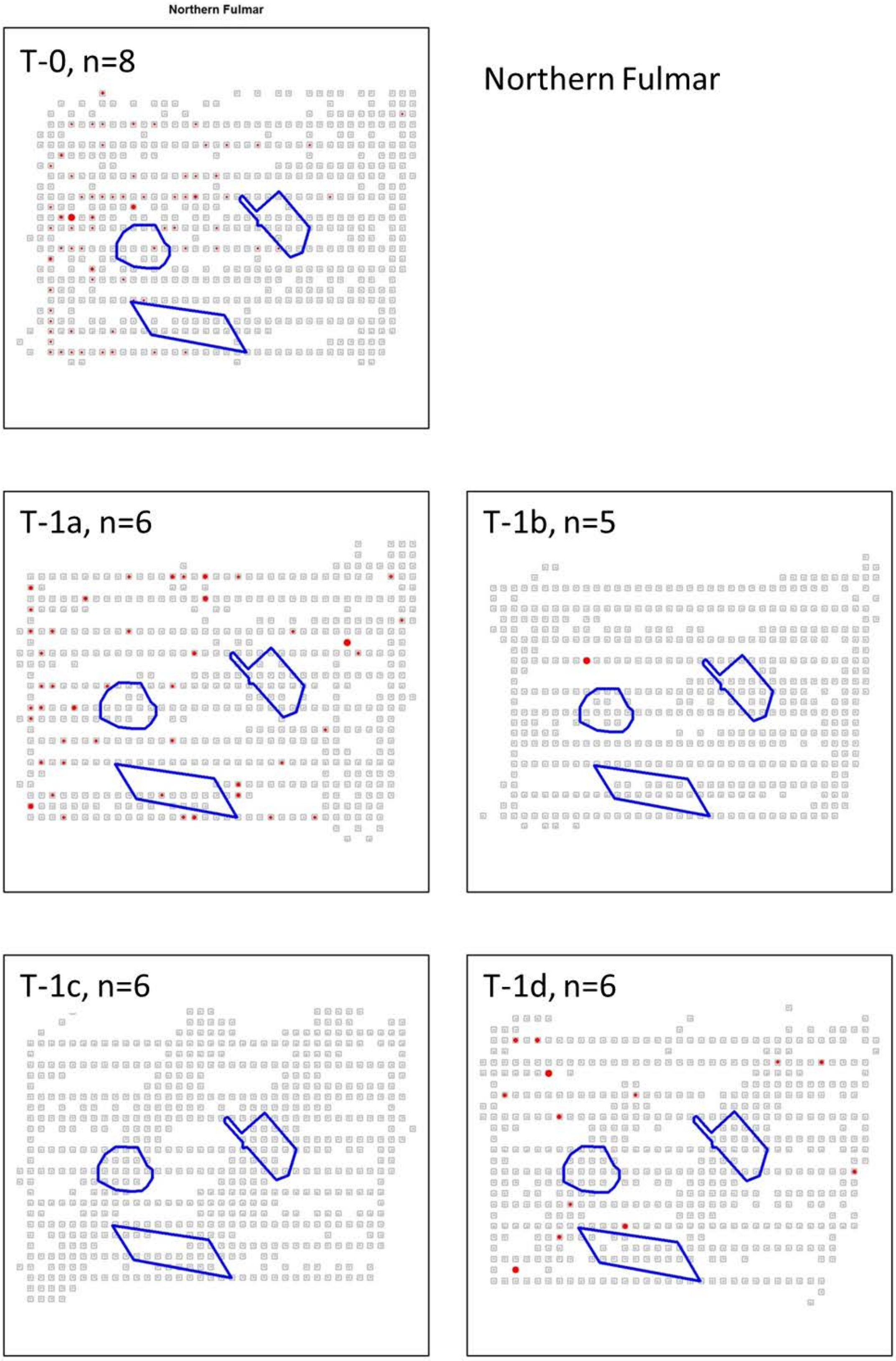

***Figure 16**. Averaged distribution patterns during the various survey phases.*

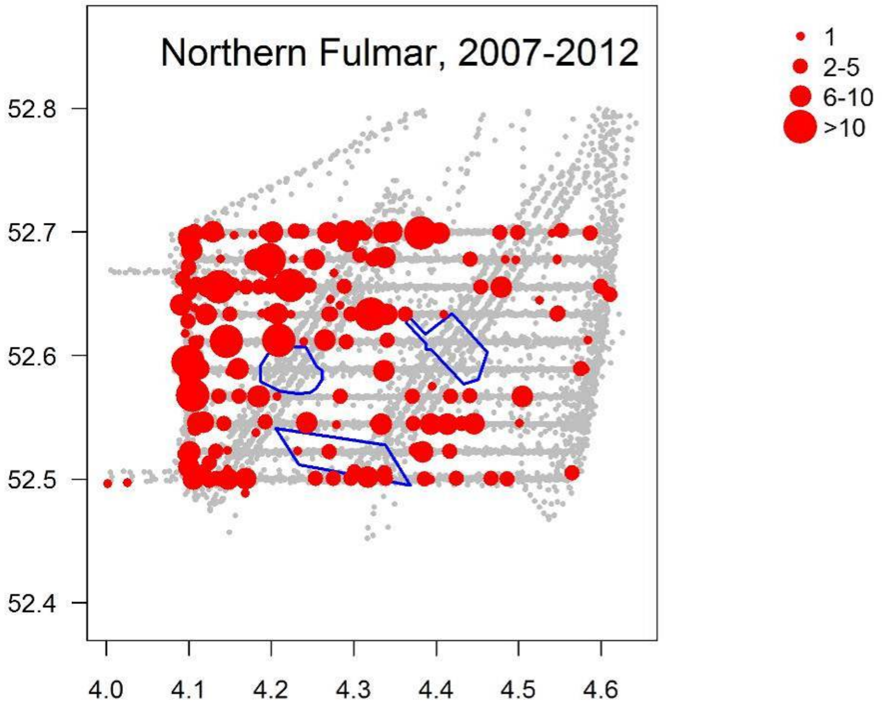

***Figure 17**. All Fulmars seen during all T-1 survey, both "in transect" and "out of transect" (mainly ship-followers).*

Northern Gannet *Morus bassanus*

Adult Northern Gannet. Photo: Hans Verdaat, IMARES.

Northern Gannets breed on rocky islands and cliff coasts in the North Sea, East en West Atlantic (Mitchell et al. 2004) but are present in Dutch waters throughout the year (Camphuysen & Leopold 1994; Arts & Berrevoets 2005; Arts 2009; Berrevoets & Arts 2001; Poot et al. 2011). In nearshore waters, their presence peaks during autumn migration, from mid-august to early November (Camphuysen & van Dijk 1983; Leopold & Platteeuw 1987; Platteeuw et al. 1994; www.trektellen.nl).

Gannets were seen throughout the survey area, both during the T-0 and T-1 surveys (Figure 18; Figure 19). Only the southeastern quarter of the area was generally avoided by these birds. Comparatively few birds were seen inside the PAWP and OWEZ parameters during the T-1 surveys, while the anchorage area was not apparently avoided by these birds.

Gannets mostly flew around the wind farms and those few birds that did enter, only went “one turbine deep” into the wind farm, crossing the site at its fringe (*cf*. Krijgsveld et al. 2011) or flying through it while staying low over the water (well below turbine height). Never was a Gannet seen diving into the water (foraging) in any of the wind farms. This is in contrast to Gannet behaviour outside the wind farms, where they seemed to be constantly looking for opportunities to catch prey and where diving deep down into the water was frequently observed.

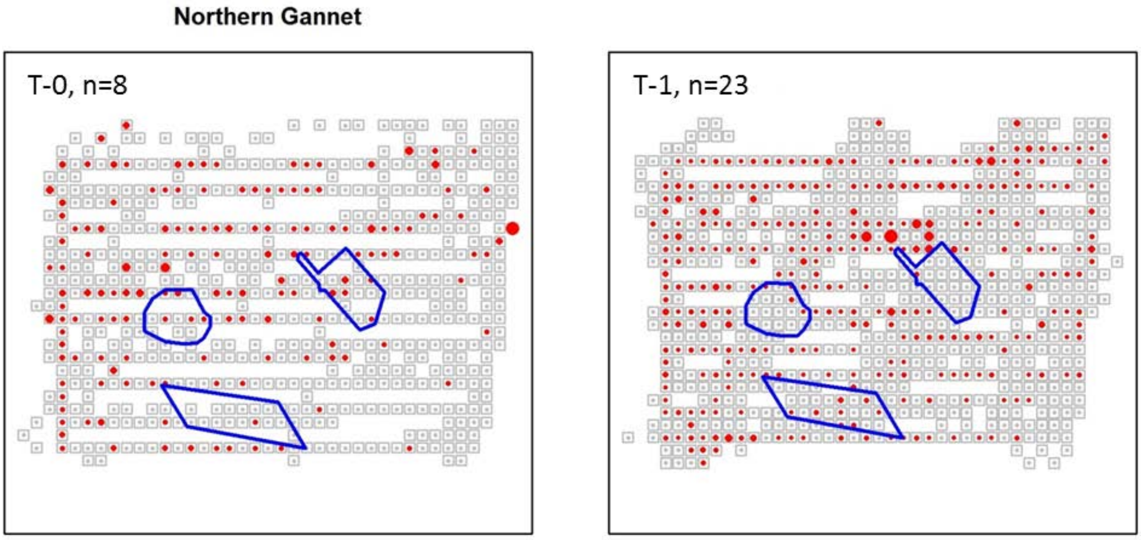

Figure 18. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Model results revealed significant negative effects of PAWP and OWEZ, but not for the anchorage area (*Table 10*, *Figure 20*). Note however that similarly small numbers were seen in both wind farms, but that background densities tended to be higher around PAWP (*Figure 18*).

Table 10. *Model results for a ZINB GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-2.60	1.70	-5.34	-1.09	Y
OWEZ	-1.36	0.52	-2.38	-0.33	Y
IJmuiden	0.28	0.50	-0.71	1.27	N

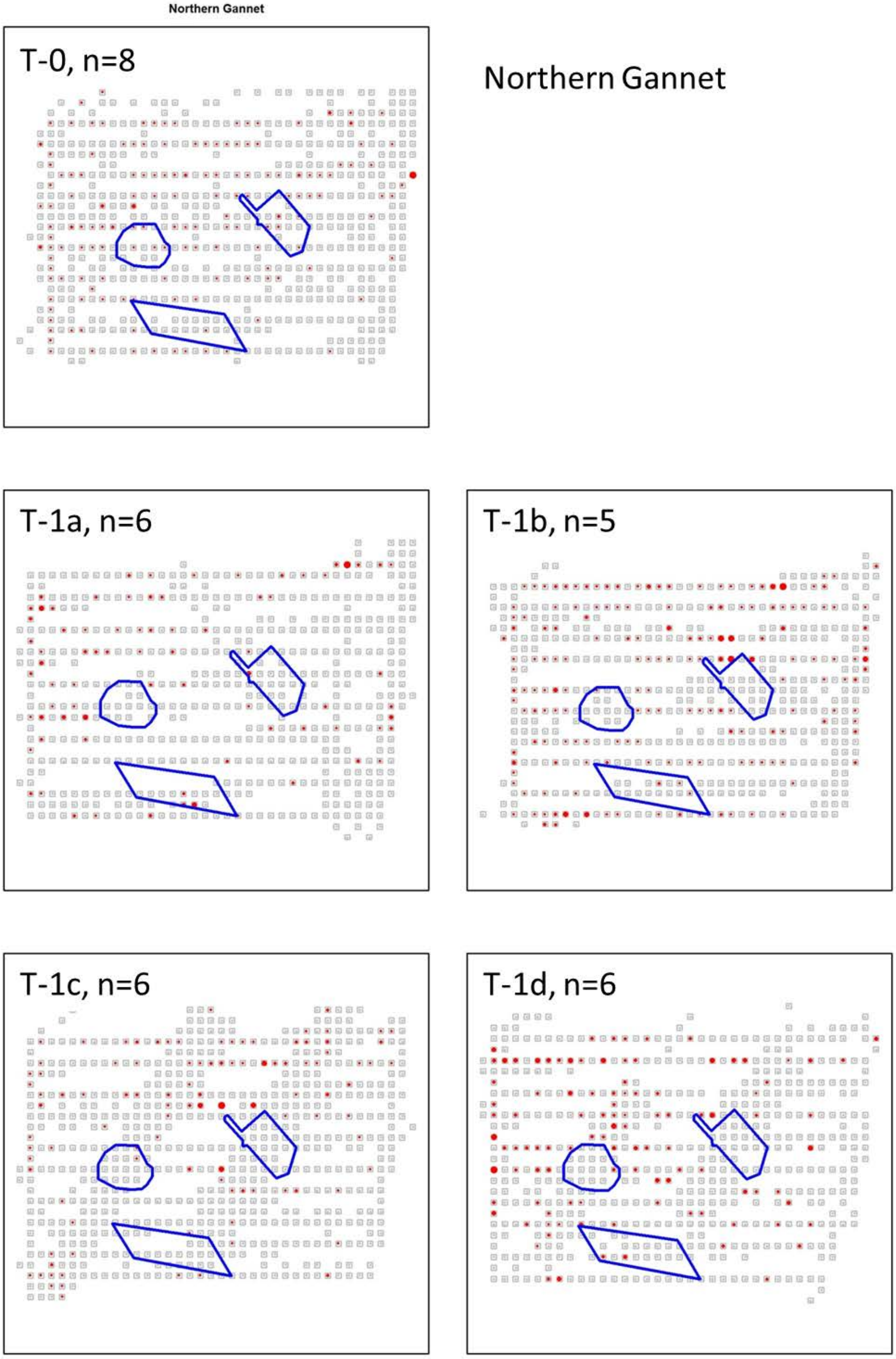

***Figure 19**. Averaged distribution patterns during the various survey phases.*

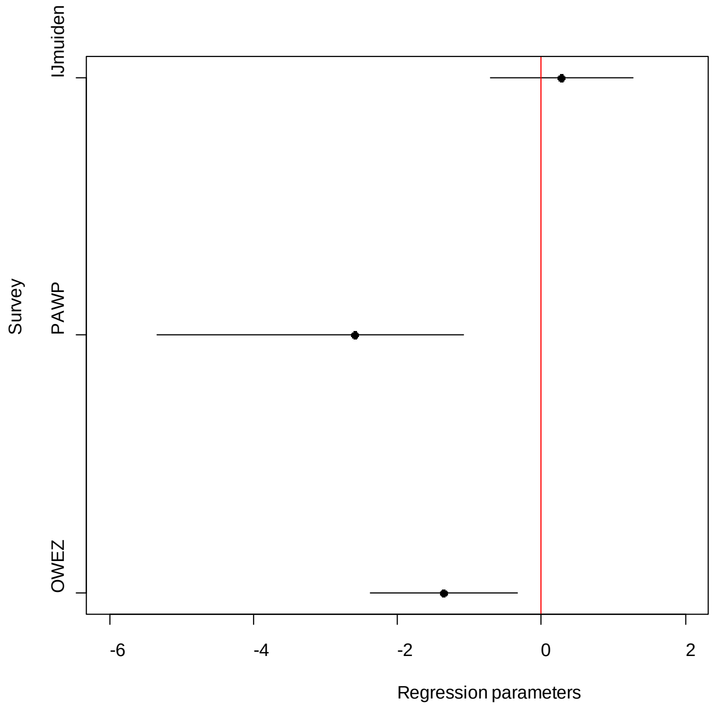

Figure 20. *ZINB GAMM regression coefficients for each ‘disturbance’ area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Great Cormorant Phalacrocorax carbo

A flock of Great Cormorants flying through PAWP in high winds. Photo: Steve Geelhoed, IMARES.

In the low countries, Great Cormorants *Phalacrocorax carbo* of the subspecies *sinensis* were long seen as freshwater birds, this in contrast to birds of the nominate subspecies *carbo*, that breed on rocky coasts, of e.g. the UK, France and Norway (van Eerden et al. 1995). Probably pushed by deteriorating feeding conditions in de-eutrophied inland waters (Noordhuis 2011), birds from Dutch inland colonies have shifted to the North Sea coast, and started breeding here. They also turned to a marine diet, feeding on the abundant flatfish, sandeel and other resources at sea (Leopold et al. 1998 and unpublished data). Cormorants, however, face the problem that their feathers are not waterproof, like in true seabirds. If they stay in the water for too long, they become waterlogged and cold, and thus need to get out the water in time, and dry their feathers. Cormorants thus spend relatively little time in the water and need dry, safe places to sit and dry. The two Dutch offshore wind farms provided such safe resting places, within sight and within reach of Great Cormorants breeding in colonies along the Dutch mainland coast and were quick to colonise OWEZ (first) and PAWP (next). Here they feed at sea and dry their feathers while perched on turbine poles (both wind farms), the OWEZ meteo mast and the PAWP transformer platform (Leopold et al. 2011a and *Figure 21*).

***Figure 21**. Roosting Great Cormorants on a turbine pole, the PAWP transformer platform (lower left) and the OWEZ meteo mast (lower right). Photo's: Hans Verdaat, taken from Leopold et al. (2011a).*

There has been a significant seaward shift in the distribution of Great Cormorants after the wind farms were constructed (Figure Corm-1 & Corm-2). During summer, OWEZ is the preferred offshore site for the Cormorants but in winter they move in larger numbers to PAWP. The reason for this seasonal shift is yet unknown, but probably food-related. The "offshore wind farm" requires further study and these issues might be brought to light in the near future.

Great Cormorant were clearly attracted to PAWP, OWEZ and the anchorage area (Table 11). The significant positive effect was most pronounced in PAWP, which can be explained by the fact that background densities are lower in these offshore parts. The actual effect of the wind farms is probably larger than shown by the modeling. Cormorants were drawn to offshore waters where they could rest in the wind farms and feed both inside and in the rather wide surroundings of the wind farms: compare the T-0 and T-1 situations (*Figure 22*)!

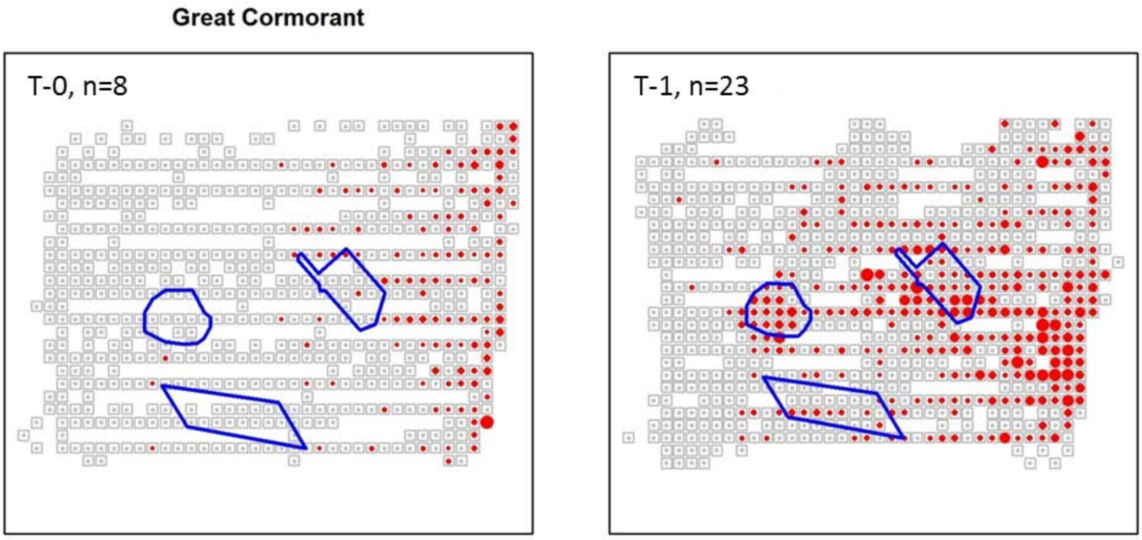

Figure 22. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 11. *Model results for a Poisson GAMM with a smoother for each survey. This model showed no overdispersion (1.34).*

Term	**Coefficient**	**p-value**
PAWP	2.338	<0.001
OWEZ	0.810	<0.001
Anchorage	0.964	<0.001

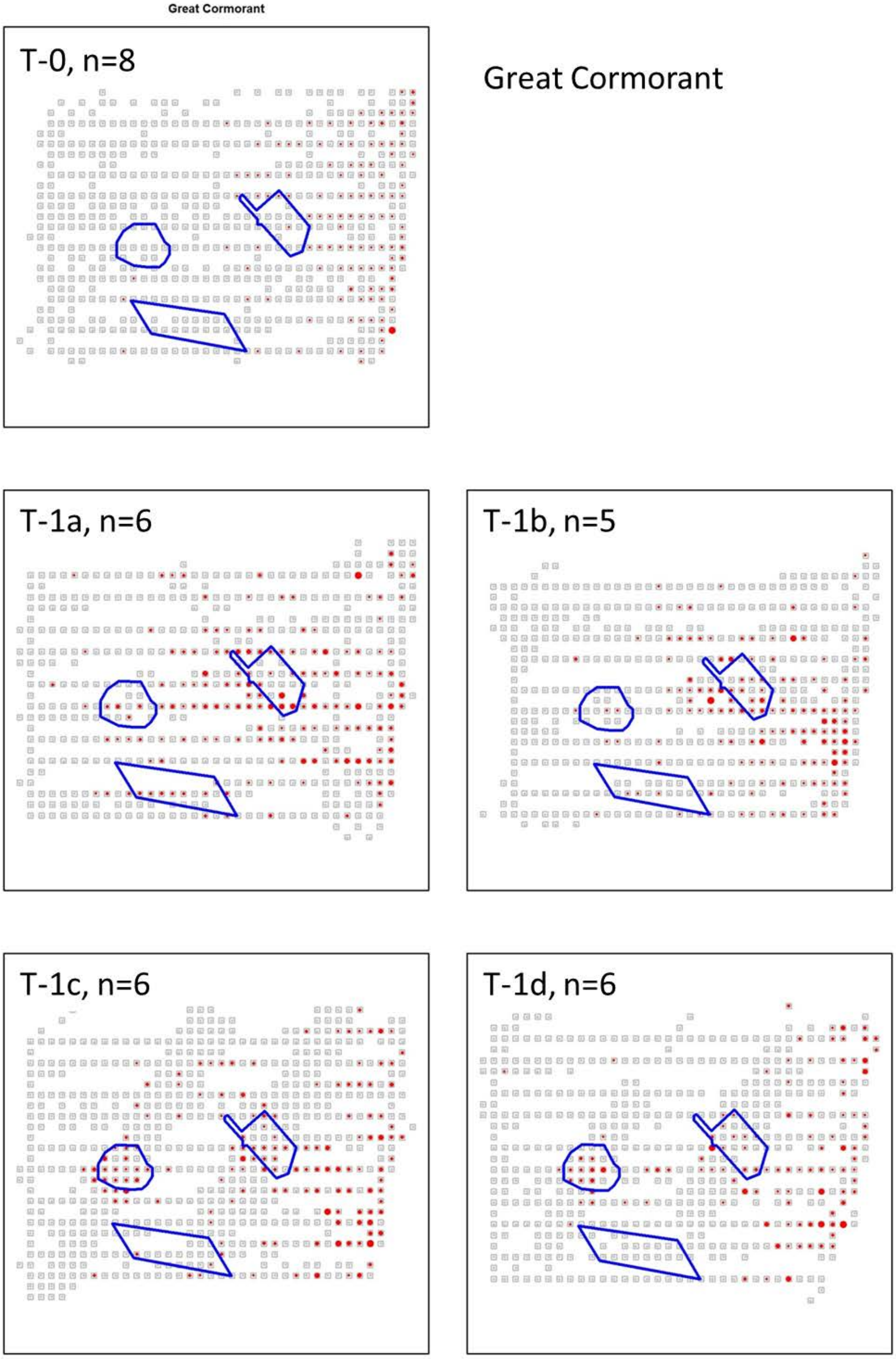

***Figure 23**. Averaged distribution patterns during the various survey phases.*

Common Scoter *Melanitta nigra*

A flock of Common Scoters migrating over the North Sea. Photo: Hans Verdaat, IMARES.

Common Scoters have used the coastal waters off Noord-Holland at times in large numbers (up to circa 100,000; Leopold et al. 1995) and because of this, the coastal waters north of the town of Bergen have been designated as a Natura 2000 site (see: Lindeboom et al. 2005).this Natura 2000 site is directly adjacent to OWEZ, but in recent years, the staple food of these ducks, *Spisula subtruncata*, was largely absent from all Dutch coastal waters and no large flocks of seaducks have been using the area since 1999 (Craeymeersch & Perdon 2006; Goudswaard et al. 2008; Baptist & Leopold 2009). When *Spisula* stocks were large off Noord-Holland, these shellfish occurred over a wide area, and the ducks, feeding on this resource were also found quite far offshore in these parts. OWEZ may have been just within the range of these ducks when *Spisula* were plentiful, although there are no records on-site. After *Spisula* numbers dwindled, the area around the wind farm was no longer of interest to the ducks. No significant numbers of scoters were encountered during any of the T-0 or T-1 surveys (Figure 24), but this may, of course, change again in future years. Surveys at sea, such as our own or aerial surveys (Poot et al. 2001; Arts 2012) have not found any offshore concentrations lately and at present, the offshore waters around the wind farms appear unattractive for seaducks. Although scoters still migrate through the study area (www.trektellen.nl), they mostly follow the coastline and pass through the corridor between the shore and OWEZ.

Increasing numbers of Common Scoters have been found wintering in UK coastal waters during the last decade, partly because of much more intensive surveys (a.o. in relation to developing offshore wind initiatives) and probably also partly because of a true increase in numbers (see e.g. Lewis et al. 2009). Most of these ducks originate from the European mainland, and must therefore cross the North Sea to reach their UK wintering quarters.

Scoters were seen in nearly all surveys, but mostly flying up and down the Dutch mainland coast, in groups ranging in size from several individuals to circa 100 birds. Such groups are mostly quite wary, and stay clear of obstacles at sea, including wind farms (Krijgsveld et al. 2011). However, groups were also seen flying across the North Sea, in westerly and southwesterly directions in autumn, most likely flying to the UK (Figure 24; Figure 25). Such a course took the birds offshore, and into the longitudes of OWEZ and PAWP. These birds were never seen flying through either PAWP or OWEZ. Birds that were offshore on a heading that would take them directly into a wind farm, typically reacted strongly when they apparently first noticed the wind farm and changed course markedly to avoid the wind farm and gained height while doing so. As most scoters were seen outside the 300 m wide counting strips, only relatively few data are available for modelling effects and significant results were not found (Table 12). This is due to low numbers residing in offshore waters and avoidance of both wind the farms and the ship from which the observations were made, at large distances. In all likelihood, Common Scoters avoid the wind farm when they fly across the North Sea but in the situations studied, this affected only a minority of the migrating birds. Scoters were dealt with in more detail by Krijgsveld et al. (2011) for OWEZ but the situation for PAWP is likely to be similar: strong avoidance.

Model results revealed a significant effect for OWEZ, but not for PAWP or anchorage area (Table 12) , which may be attributable to the low numbers of scoters generally recorded in the vicinity of PAWP and the anchorage area.

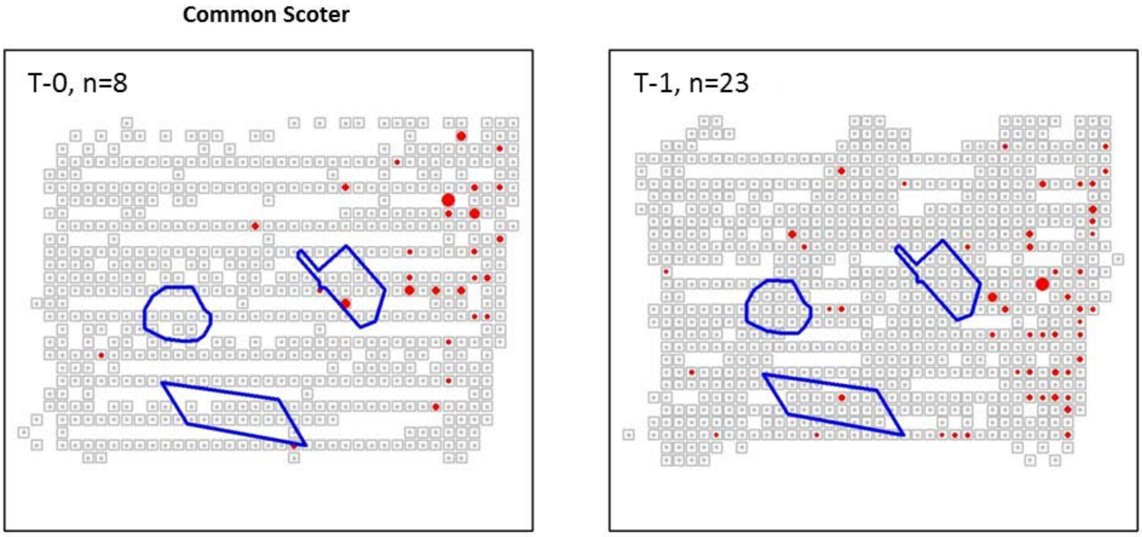

Figure 24. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 12. *Model results for a ZIP GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-0.75	4.5	-7.5	7.0	N
OWEZ	-5.17	2.1	-9.2	-1.6	Y
IJmuiden	-0.28	3.7	-5.4	6.2	N

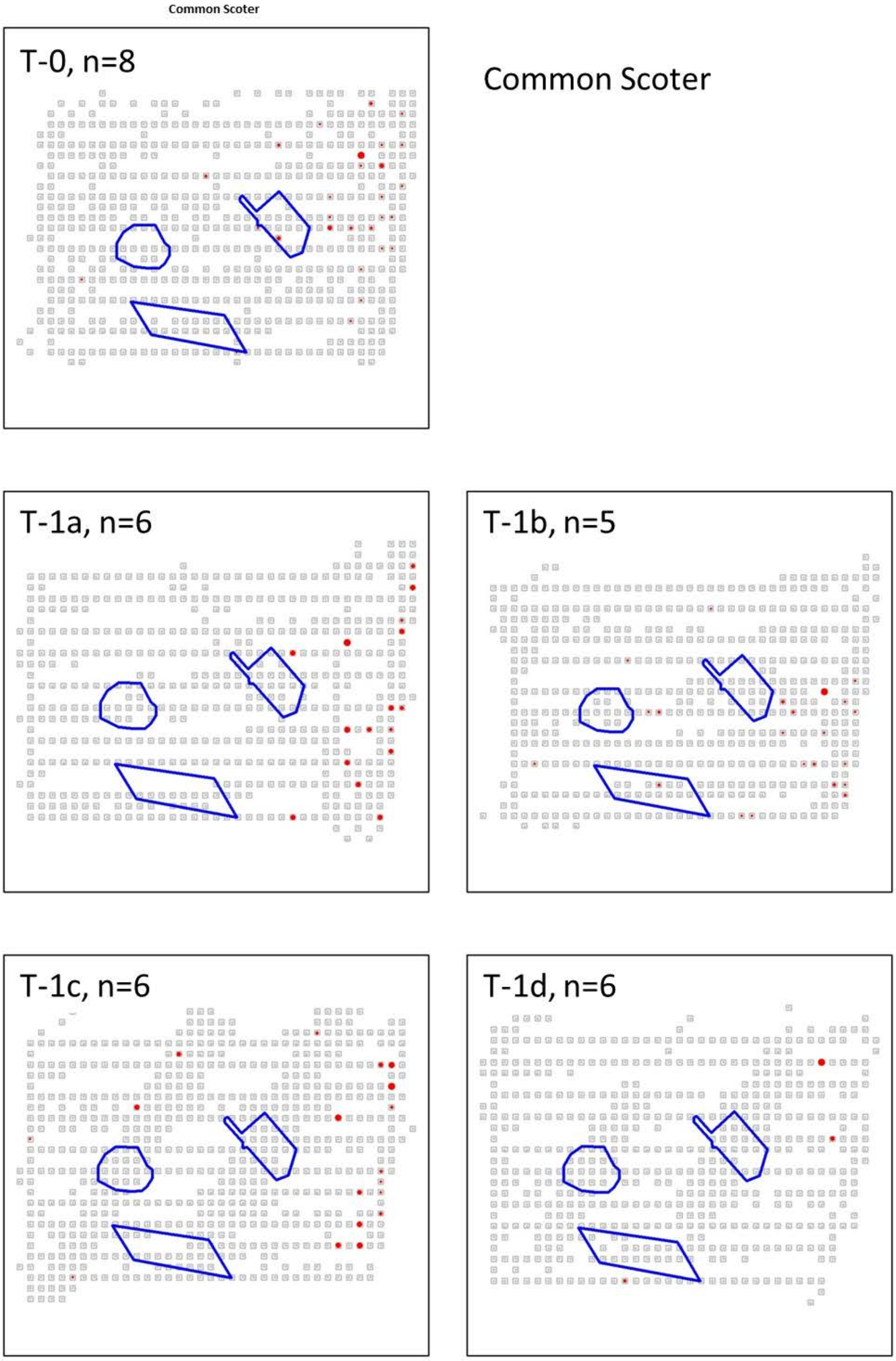

***Figure 25**. Averaged distribution patterns during the various survey phases.*

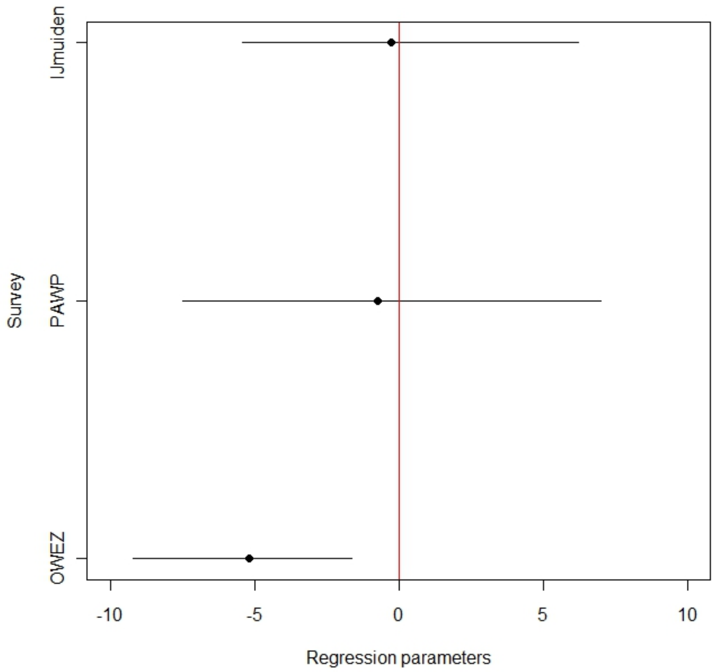

Figure 26*. ZIP GAMM regression coefficients for each ‘disturbance’ area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Little Gull *Hydrocoloeus minutus*

Adult Little Gull in winter. Photo: Steve Geelhoed, IMARES.

Little Gulls are mainly migrants through Dutch waters before and after they breed in a large area around the Baltic Sea and NW Russia (Platteeuw 1987). Some also winter off our coast (Camphuysen & Leopold 1994). Most Little Gulls are therefore seen in autumn and spring, with a spectacular migration peak in April (Camphuysen & van Dijk 1983; Platteeuw et al. 1994; www.trektellen.nl). During spring migration, nearly the entire European population of Little Gulls may pass along our mainland shoreline and thousands may stage in these waters for several weeks in April, if conditions are favourable (den Ouden & Stougie 1987, 1990; Keijl & Leopold 1997).

In accordance to this known phenology, Little Gulls were seen in largest numbers during the April surveys (Figure *8*) and these survey yielded by far the most sightings, both during T-0 and T-1 (*Figure 27*; *Figure 28*). Little Gulls may occur quite far offshore, particularly during their spring migration, but also during winter, when flocks of feeding and resting birds, several dozens to hundreds strong, were found scattered over the entire study area (cf. Keijl & Leopold 1997; Leopold et al. 2004). The distribution patterns appear rather similar between T-0 and T-1 at large (*Figure 27*). Little Gulls do not seem reluctant to enter OWEZ, but were never seen within PAWP. Indeed, significant avoidance was found for PAWP (Table 13, *Figure 29*), but no effect was found for OWEZ and a slight positive effect for the anchorage area. Hence, interpretation of this result in terms of general responses of this species to wind farms is difficult. As Little Gulls occurred throughout the study area, the difference in turbine densities might govern the willingness of Little Gulls to venture into an offshore wind farm.

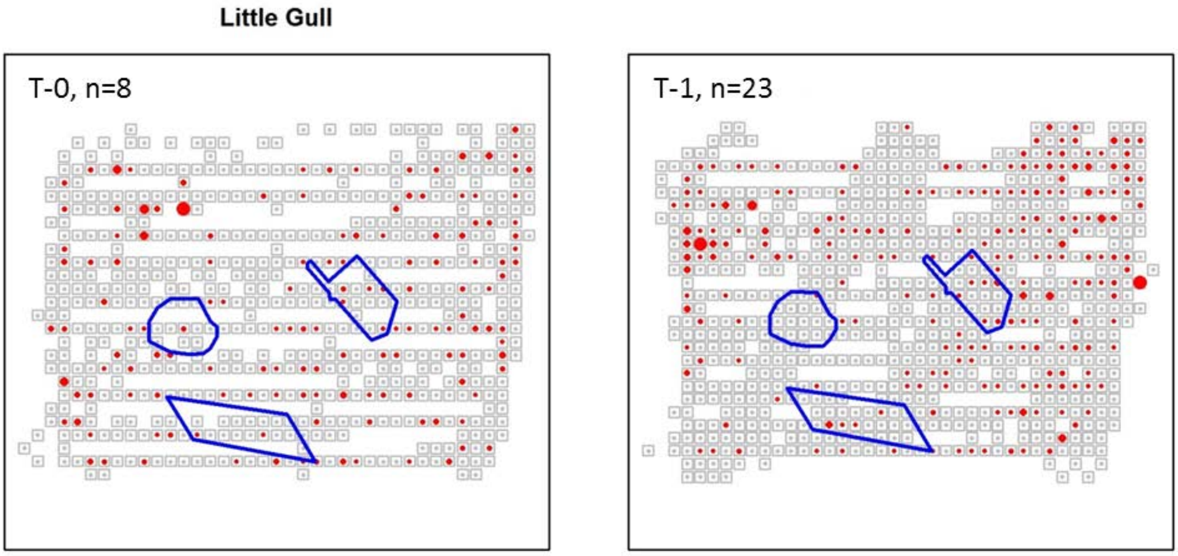

Figure 27. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 13. *Model results of a NB GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-26.13	18.52	-69.58	-2.46	Y
OWEZ	0.69	0.70	-0.63	2.11	N
IJmuiden	2.41	1.08	0.34	4.55	Y

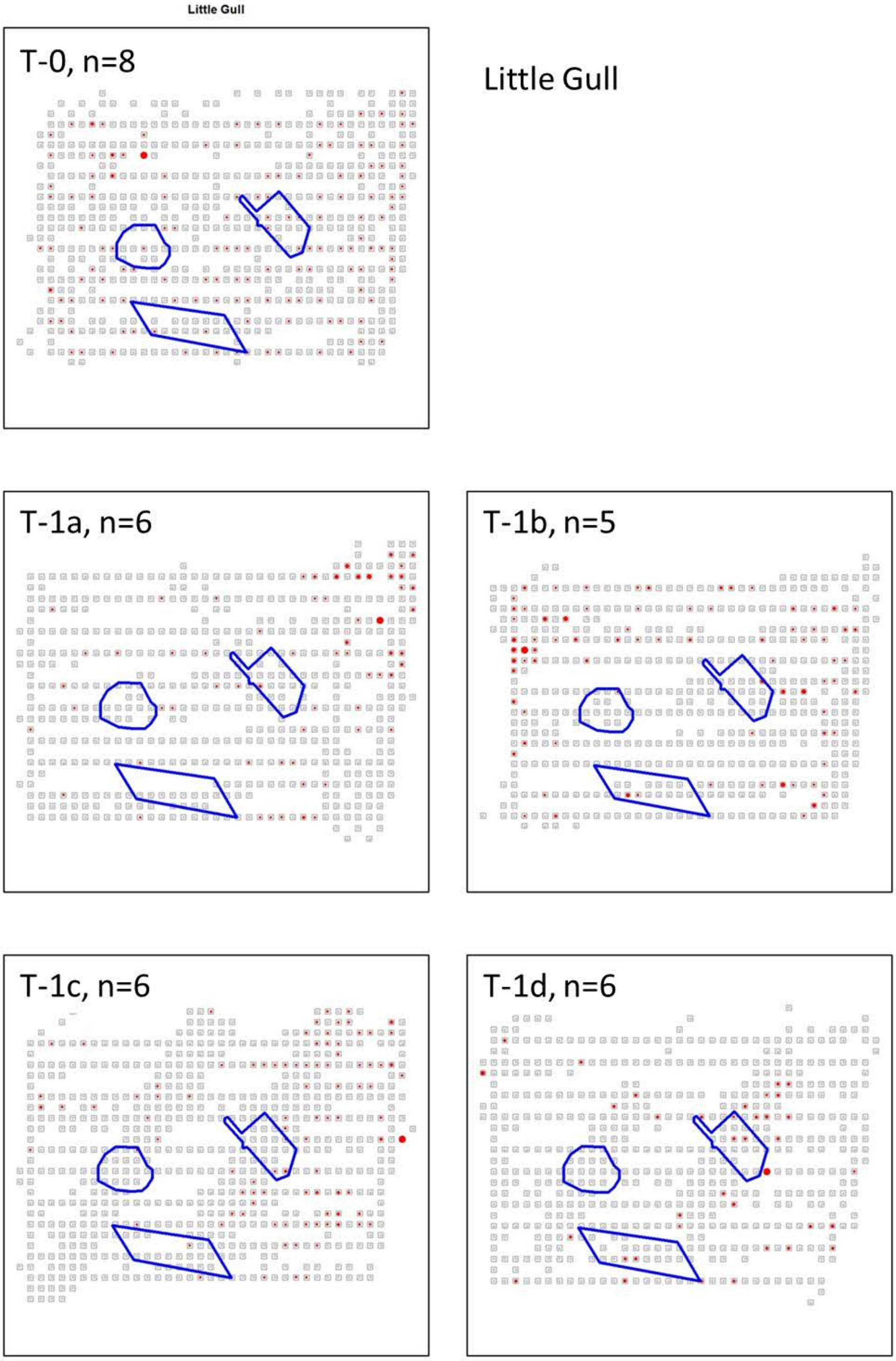

***Figure 28**. Averaged distribution patterns during the various survey phases.*

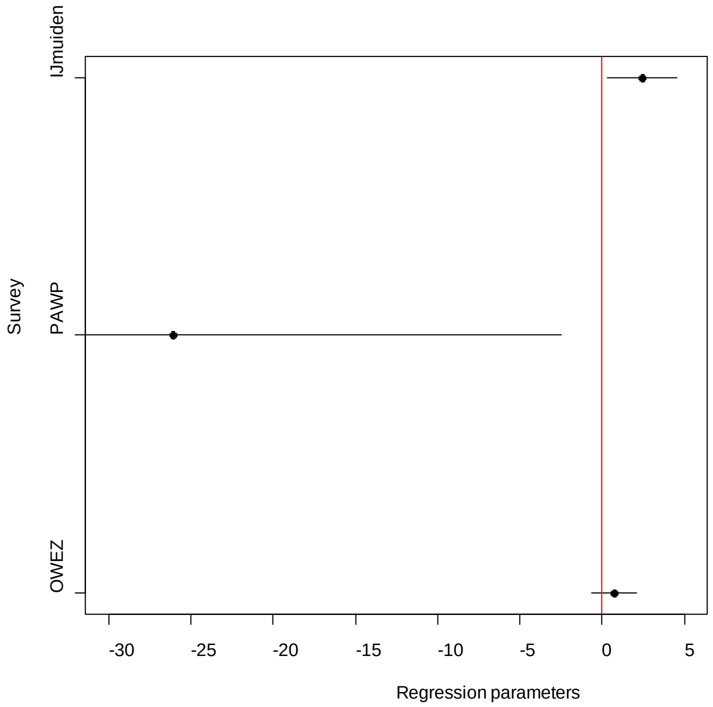

***Figure 29**. NB GAMM regression coefficients for each ‘disturbance’ area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Black-headed Gull *Chroicocephalus ridibundus*

Black-headed Gull in full breeding plumage. Photo: Hans Verdaat, IMARES.

Black-headed Gulls are mainly coastal gulls in Dutch waters but they show complex moult migrations that involve crossings to the British Isles (Camphuysen & Leopold 1994). Most Black-headed Gulls were therefore seen close to the coast, but groups of migrants might be seen anywhere in the study area, *en* route to the UK, or from there, back to mainland Europe (*Figure 30*; *Figure 31*). Black-headed Gulls were seen during nearly all surveys, in varying numbers without a clear temporal pattern. Even presence in nearshore waters appears to be rather erratic, with little consistence between years. Although dozens to hundreds were usually seen per survey, most were usually seen beyond the counting strips. The wind farms were generally too far offshore to interfere with this species' distribution. Black-headed Gulls were only once seen to (just) fly into one wind farm (OWEZ, T-1d, *Figure 31*), and with offshore densities generally too low to model any effect on this species, results for the two wind farms were insignificant (*Table 14*, *Figure 32*).

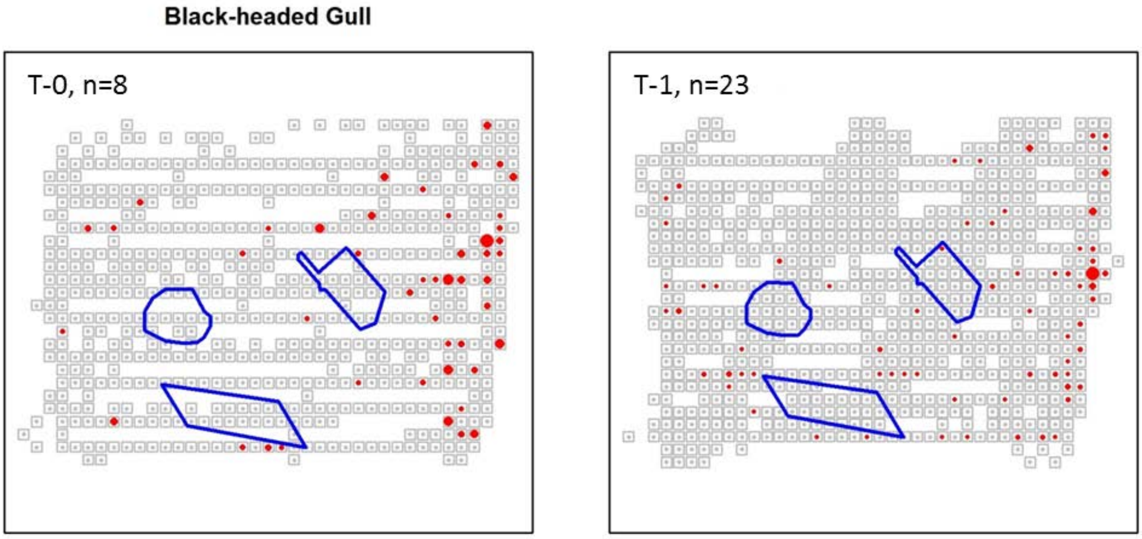

Figure 30. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 14*. Model results for a ZIP GAMM.*

Area	**Mean**	**SE**	**CI lower limit, 2.5%**	**CI upper limit, 97.5%**	**Significant?**
PAWP	-1.9	3	-8.9	1.59	N
OWEZ	-3.2	2.2	-8	0.33	N
IJmuiden	-4.9	2.2	-9.1	-1.37	Y

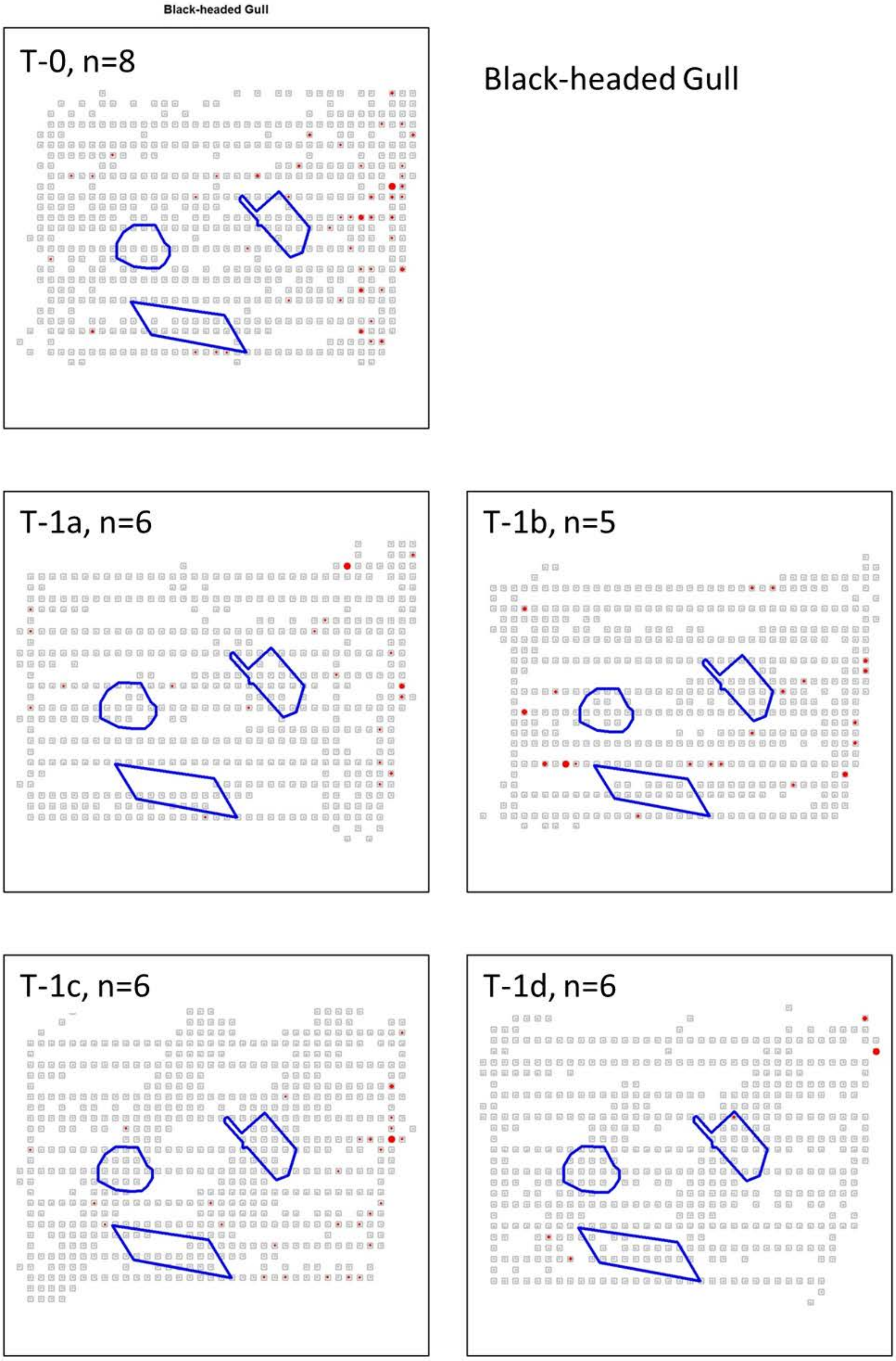

Figure 31*. Averaged distribution patterns during the various survey phases.*

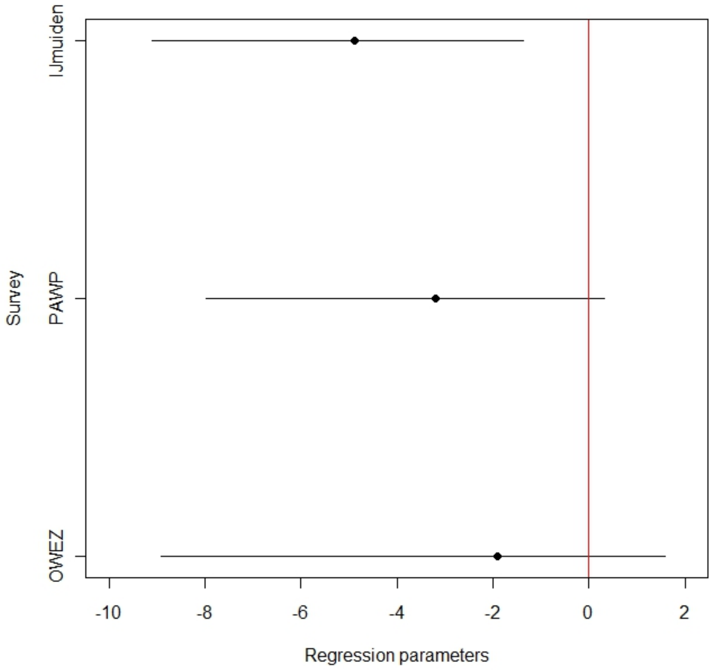

Figure 32*. ZIP GAMM regression coefficients for each ‘disturbance’ area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Common Gull *Larus canus*

Common Gull in winter. Photo: Hans Verdaat, IMARES.

Common Gulls occur in the study area throughout the year, but the highest densities occur usually in nearshore waters and in winter. However, with enough survey effort, Common Gulls might be found almost anywhere in the present study area (Figure 33).

The modeling results show no effect of either wind farm or the anchorage area (Table 15, Figure 35). This is in line with distribution maps, which do not indicate clear on-site deviations (Figure 33, Figure 34).

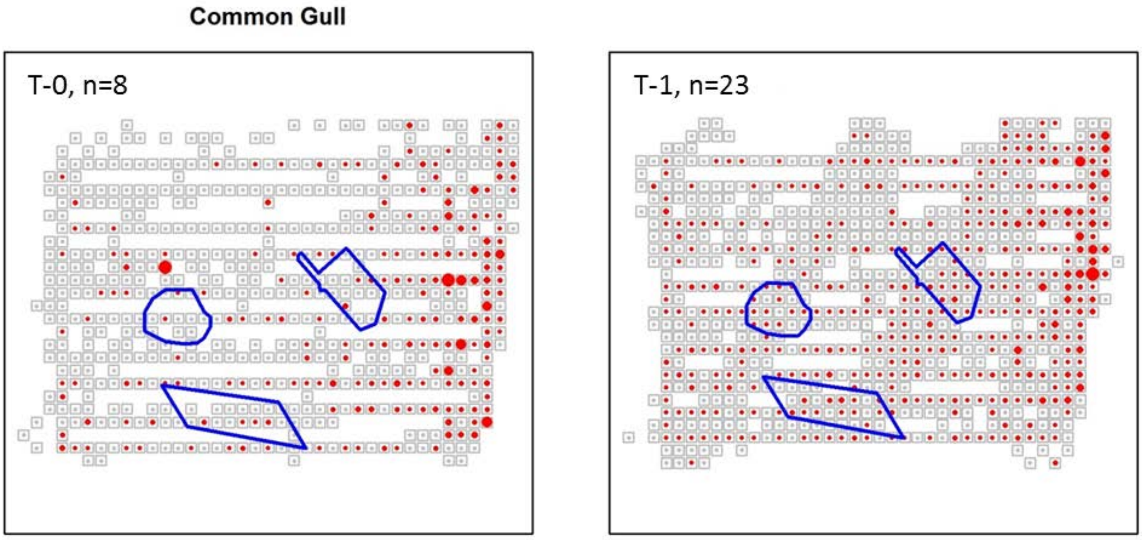

Figure 33. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 15. *Model results for a ZINB GAMM.*

Area	**Mean**	**SE**	**CI lower limit, 2.5%**	**CI upper limit, 97.5%**	**Significant?**
PAWP	-0.02	0.39	-0.80	0.72	N
OWEZ	0.16	0.26	-0.36	0.68	N
IJmuiden	0.20	0.35	-0.51	0.87	N

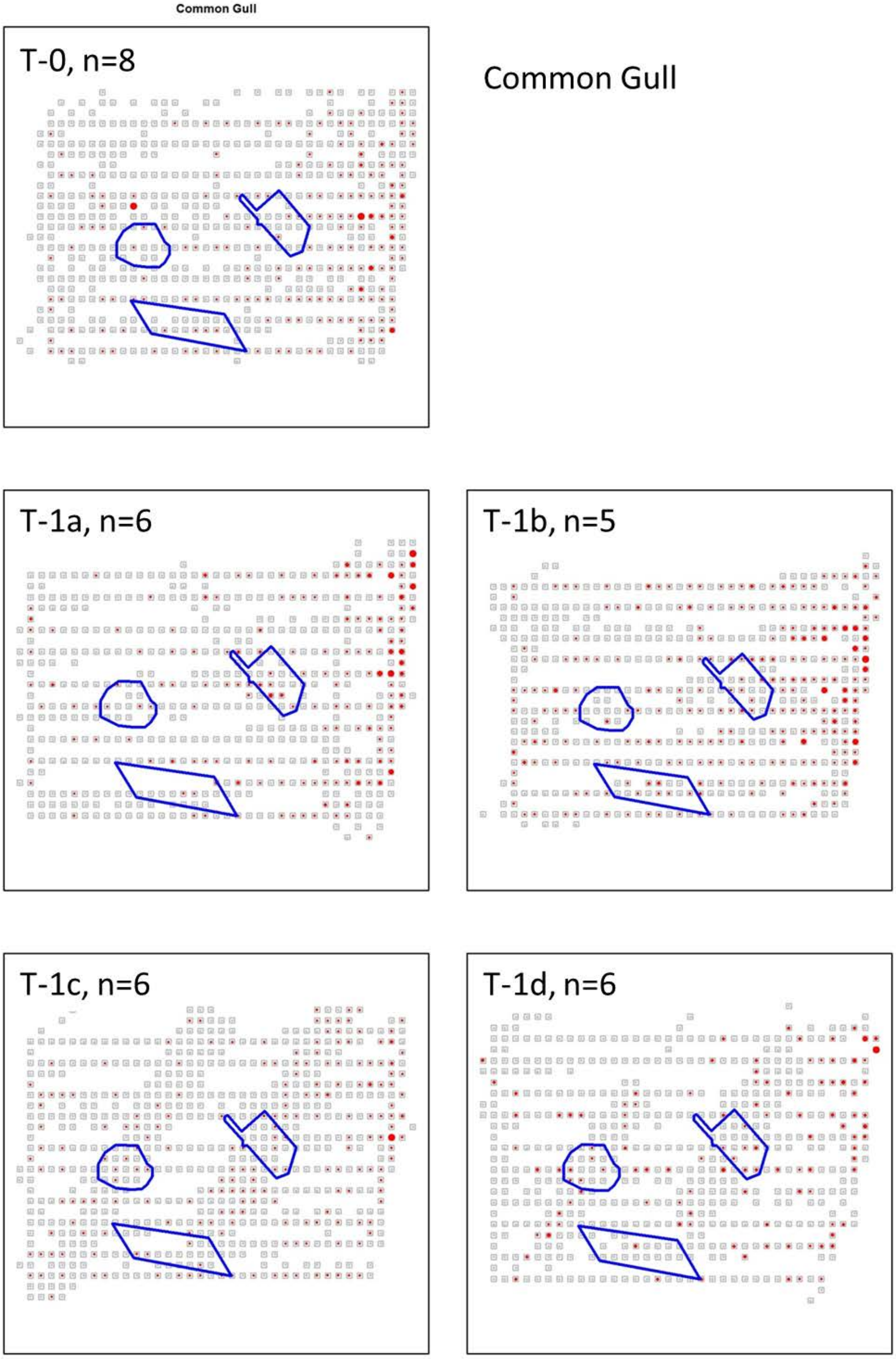

Figure 34. *Averaged distribution patterns during the various survey phases.*

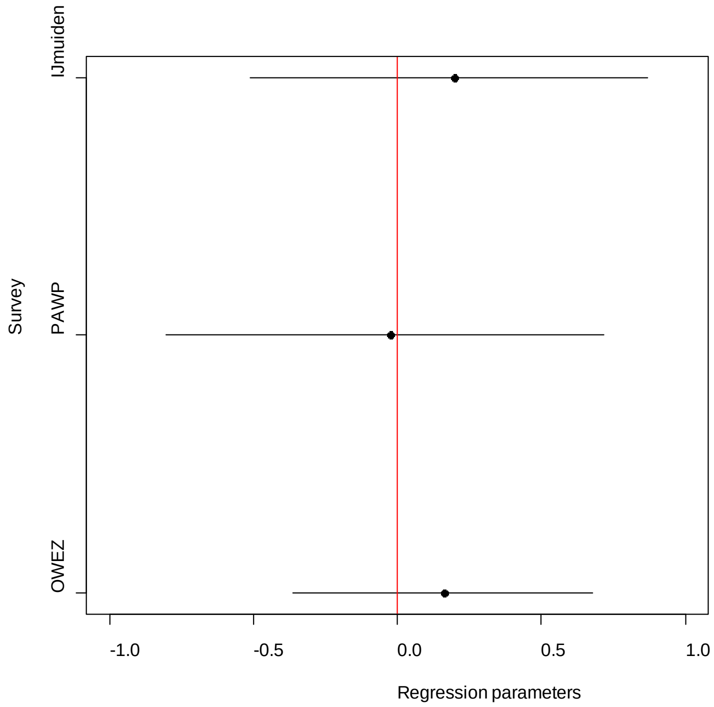

***Figure 35**. ZINB GAMM regression coefficients for each 'disturbance' area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Lesser Black-backed Gull *Larus fuscus*

Adult Lesser Black-backed Gull after breeding, in primary moult. Photo: Steve Geelhoed, IMARES.

Lesser Black-backed Gulls are sea-going birds that breed along the Dutch coastline. Colonies near Egmond are small (IJmuiden) or have become small and are now rather insignificant after Red Foxes *Vulpes vulpes* entered the area. However, PAWP and OWEZ are within foraging range of the gulls breeding on SW Texel, as shown by recent work with GPS loggers (Camphuysen 2011; *Figure 36*). Male Lesser Balck-backed Gulls in particular fly out to sea from Texel to feed, mainly in a southwesterly direction. They do not appear to fly around the two wind farms, maybe they gain some altitude while flying through the wind farms (Camphuysen 2011).

Although Lesser Black-backed Gulls are well capable of catching live fish at sea (Camphuysen et al. 2008) most birds seen during our surveys were often associated with, looking out for or resting in the wake of active fishing vessels, particularly during T-0. Concentrations of over 1000 birds have been noted in the study area against a “background density” of around 1 bird per square kilometer. Such concentrations greatly impact distribution patterns. Although Lesser Black-backed Gulls were also often seen within the perimeters of the wind farms (*Figure 37*), sometimes resting on the water or on the foundation structures, sometimes feeding in the tidal wakes of the monopoles, the largest concentrations invariably occurred around fishing vessels. From the perspective of these gulls, probably the largest impact of the wind farms is that fishing vessels never operate within their boundaries. Large, fishing-vessel related concentrations of gulls therefore by definition occur only outside the wind farms and this might result in apparent avoidance of the wind farms.

Fishing nearly collapsed after the T-0 phase of this project, at least in the western part of the study area (*Figure 37*; *Figure 38*). This was unrelated to the construction of wind farms, but greatly affected gull distribution and gull numbers: the offshore parts of the study area became much less attractive during the T-1.

Although modeling results suggest negative effects of both wind farms, this was only significant OWEZ and not for PAWP (*Table 16*, *Figure 39*).

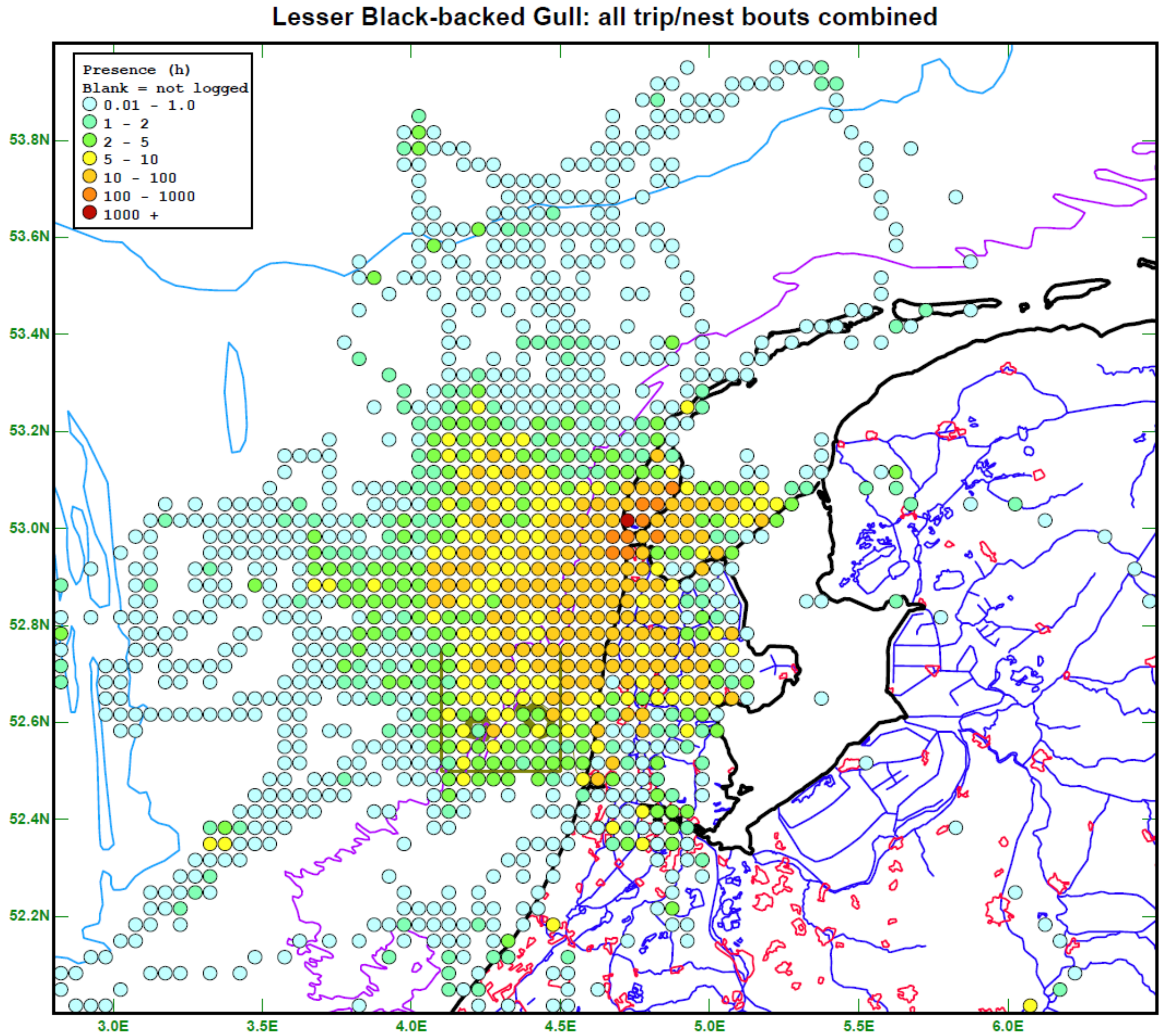

Figure 36. *Composite image of at-sea presence of Lesser Black-backed Gulls, equipped with GPS loggers in their breeding colony at Texel (red dot). On feeding trips, the birds spread out over a very large area, extending from Texel to beyond PAWP. Data: Royal Netherlands Institute for Sea Research, Texel; Figure taken from Camphuysen 2011).*

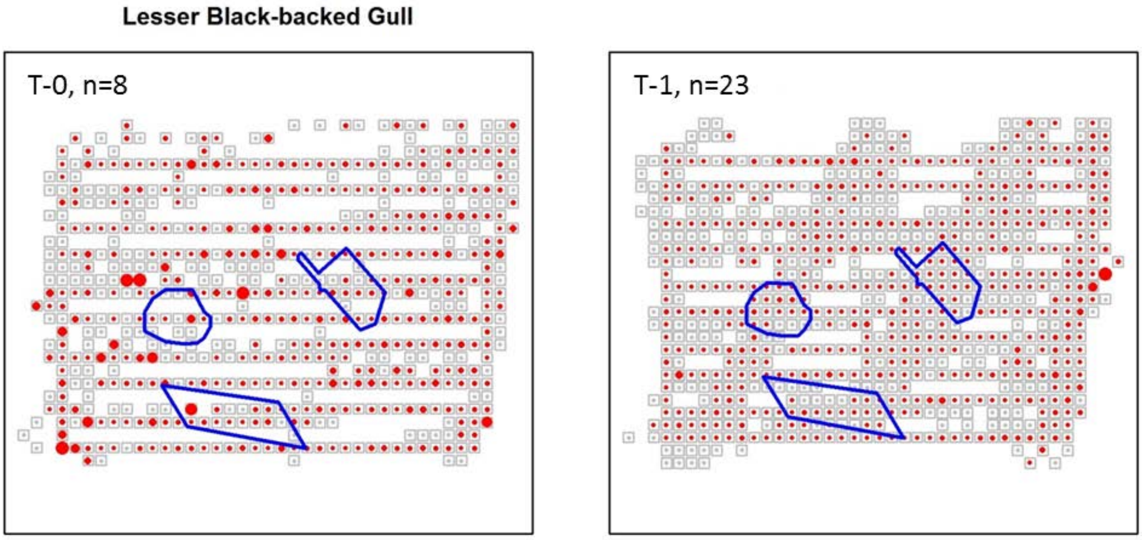

Figure 37. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 16. *Model results for a ZINB GAMM.*

Area	**Mean**	**SE**	**CI lower limit, 2.5%**	**CI upper limit, 97.5%**	**Significant?**
PAWP	-0.38	0.27	-0.90	0.16	N
OWEZ	-0.63	0.25	-1.13	-0.14	Y
IJmuiden	0.05	0.25	-0.45	0.54	N

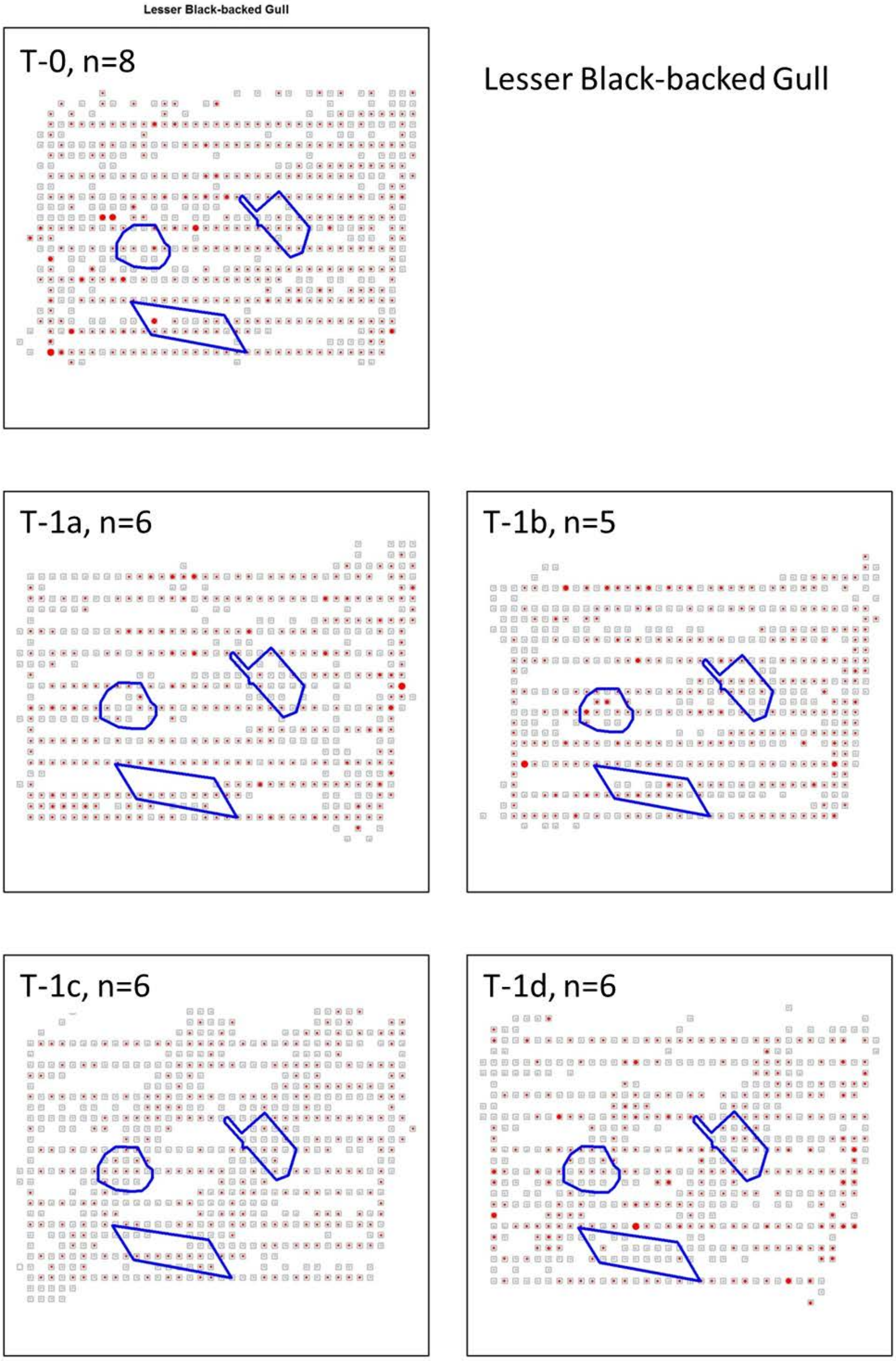

Figure 38. *Averaged distribution patterns during the various survey phases.*

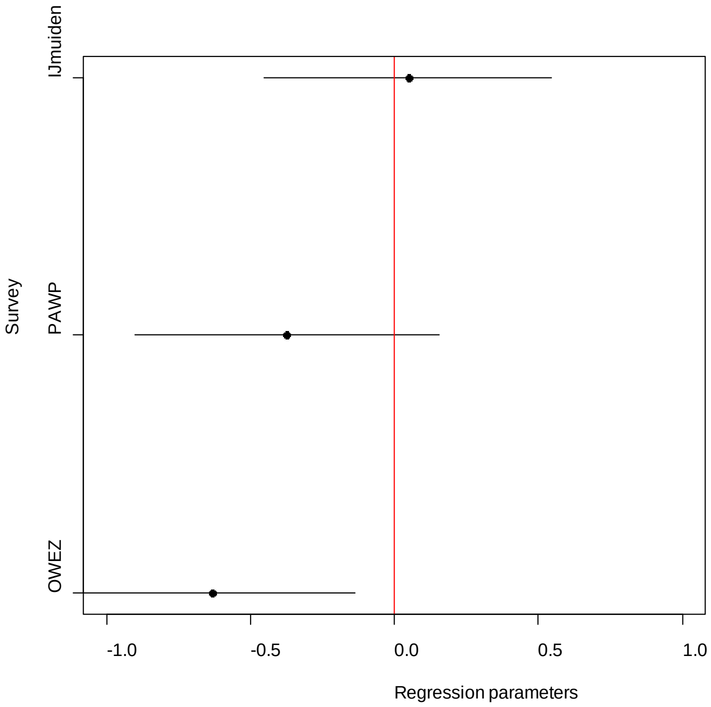

Figure 39*. ZINB GAMM regression coefficients for each 'disturbance' area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Herring Gull *Larus argentatus*

Adult Herring Gull in winter plumage. Photo: Hans Verdaat, IMARES

Herring Gulls are less sea-going and less migratory than Lesser Black-backed Gulls (Camphuysen 1995; Camphuysen et al. 2008, 2011). In the breeding season, Herring Gulls hardly take to the North Sea (Leopold et al. 2004). Also in August, Herring Gulls remain mostly nearshore. Dispersing birds in autumn and wintering birds from more northern regions however, are found throughout Dutch offshore waters (Camphuysen & Leopold 1994; Camphuysen 1995). Like the Lesser Black-backed Gulls discussed in the previous paragraph, Herring Gulls were often associated with fishing vessels. Concentrations of over 1000 birds have been noted in this species as well, mostly closely inshore, but numbers could also build up steeply offshore, around fishing fleets working these waters (during T-0, mostly:*Figure 40*).

An impact of OWEZ was difficult to assess during the T-1 surveys (*Figure 41*). Like in the Lesser Black-backed Gull, the data show a great deal of noise caused by fishing vessels attracting large numbers of gulls from large distances, with a smaller effect of fishing during T-1, compared to T-0. Still, all large concentrations of gulls (any species) during the T-1 phase of the project were found outside the perimeters of the wind farms, around fishing vessels. A statistical model might see this as avoidance of wind farms, while in actual fact this was attraction to fisheries banned from the wind farms. Herring Gulls were also frequently seen inside PAWP and OWEZ, e.g. resting on monopile foundations (attraction). Overall, there is no statistical evidence of an impact of the wind farm on these gulls (*Table 17*, *Figure 42*).

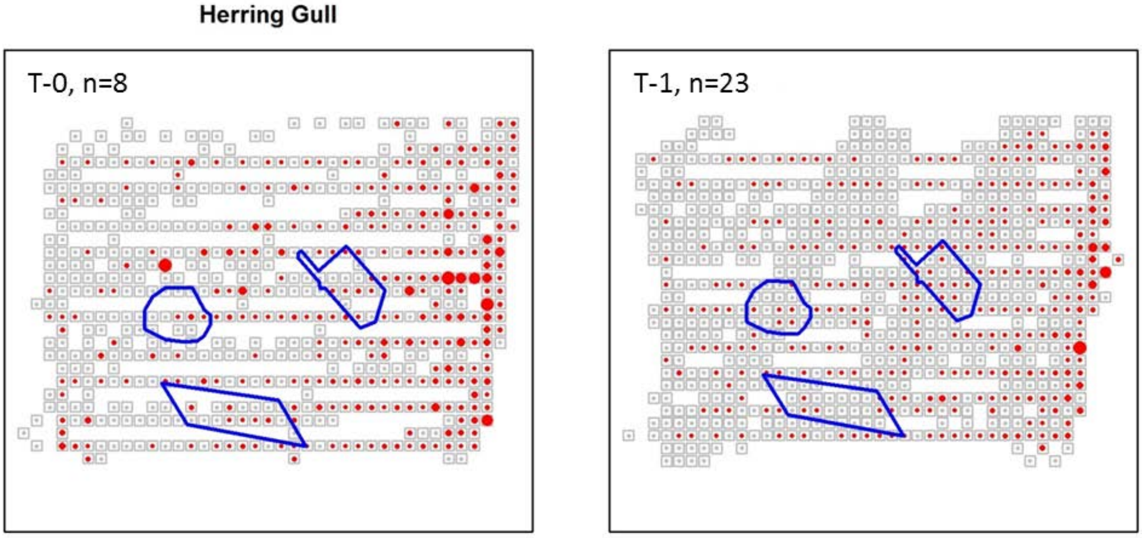

Figure 40. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 17. *Model results for a ZIP GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-0.408	0.51	-1.61	0.48	N
OWEZ	0.312	0.22	-0.12	0.75	N
IJmuiden	0.062	0.42	-0.67	0.83	N

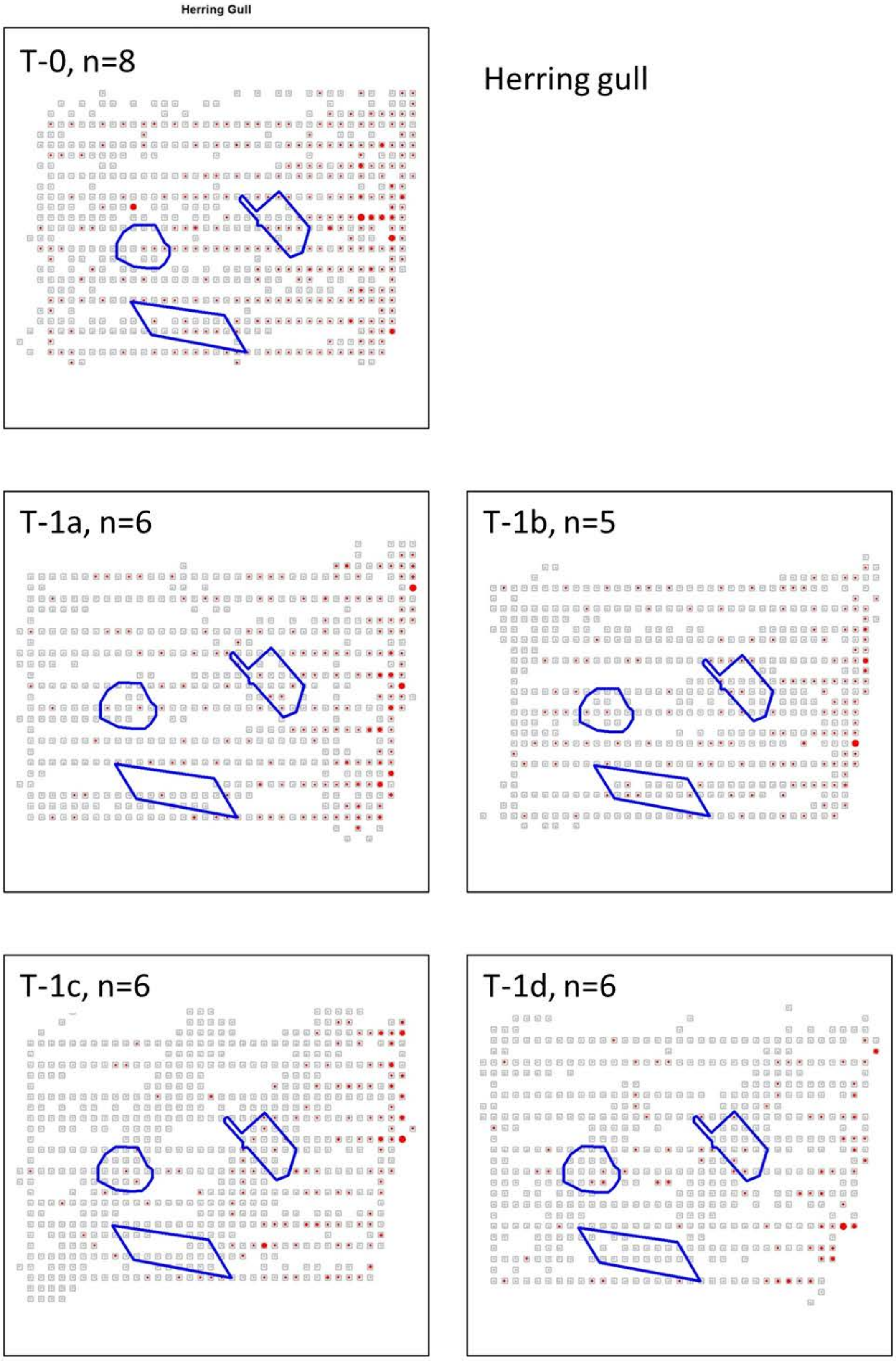

***Figure 41**. Averaged distribution patterns during the various survey phases.*

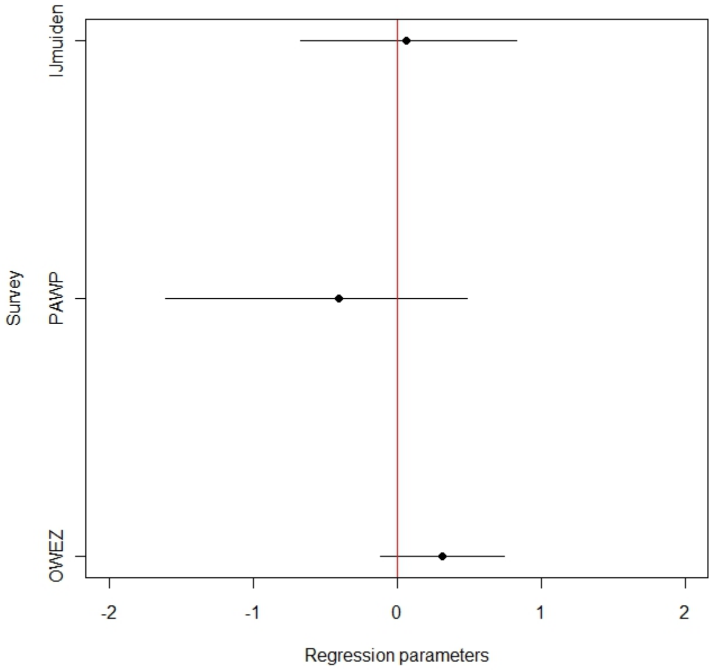

***Figure 42**. ZIP GAMM regression coefficients for each 'disturbance' area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Great Black-backed Gull *Larus marinus*

Greater Black-backed Gull – nearly adult individual. Photo: Steve Geelhoed, IMARES.

Greater Black-backed Gulls visit Dutch waters mainly in the non-breeding season and they occur dispersed over the entire southern North Sea (Camphuysen & Leopold 1994). Like the Lesser Black-backed and Herring Gulls discussed in the previous paragraphs, Greater Black-backed Gulls feed around fishing vessels but their numbers were often lower than those of other species in the associated flocks. Numbers encountered were generally largest during the autumn surveys (Figure *8*). Greater Black-backed Gulls tended to be slightly more numerous in nearshore waters, but concentrations also occurred in different parts of the study area at times (*Figure 43*; *Figure 44*).

The distribution maps provided little reason to suggest that PAPW or OWEZ had a significant impact on the distribution of this large gull (*Figure 43*; *Figure 44*). Indeed, the modelling results indicate no effect of either wind farm (Table 18, *Figure 45*).

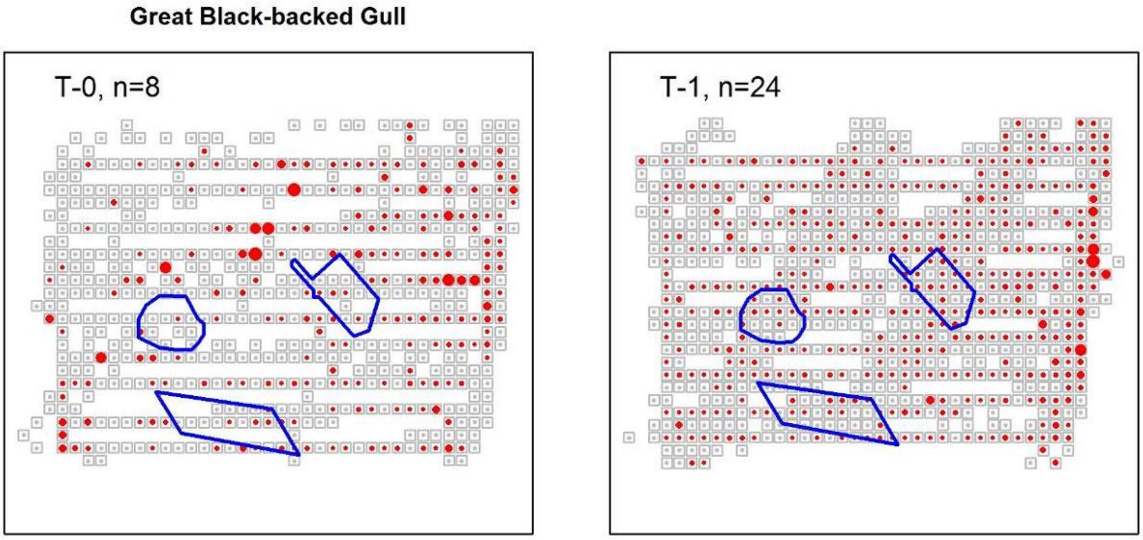

***Figure 43**. Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

***Table 18**. Model results for a ZINB GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	0.34	0.32	-0.31	0.93	N
OWEZ	0.38	0.23	-0.09	0.82	N
IJmuiden	-0.09	0.37	-0.80	0.63	N

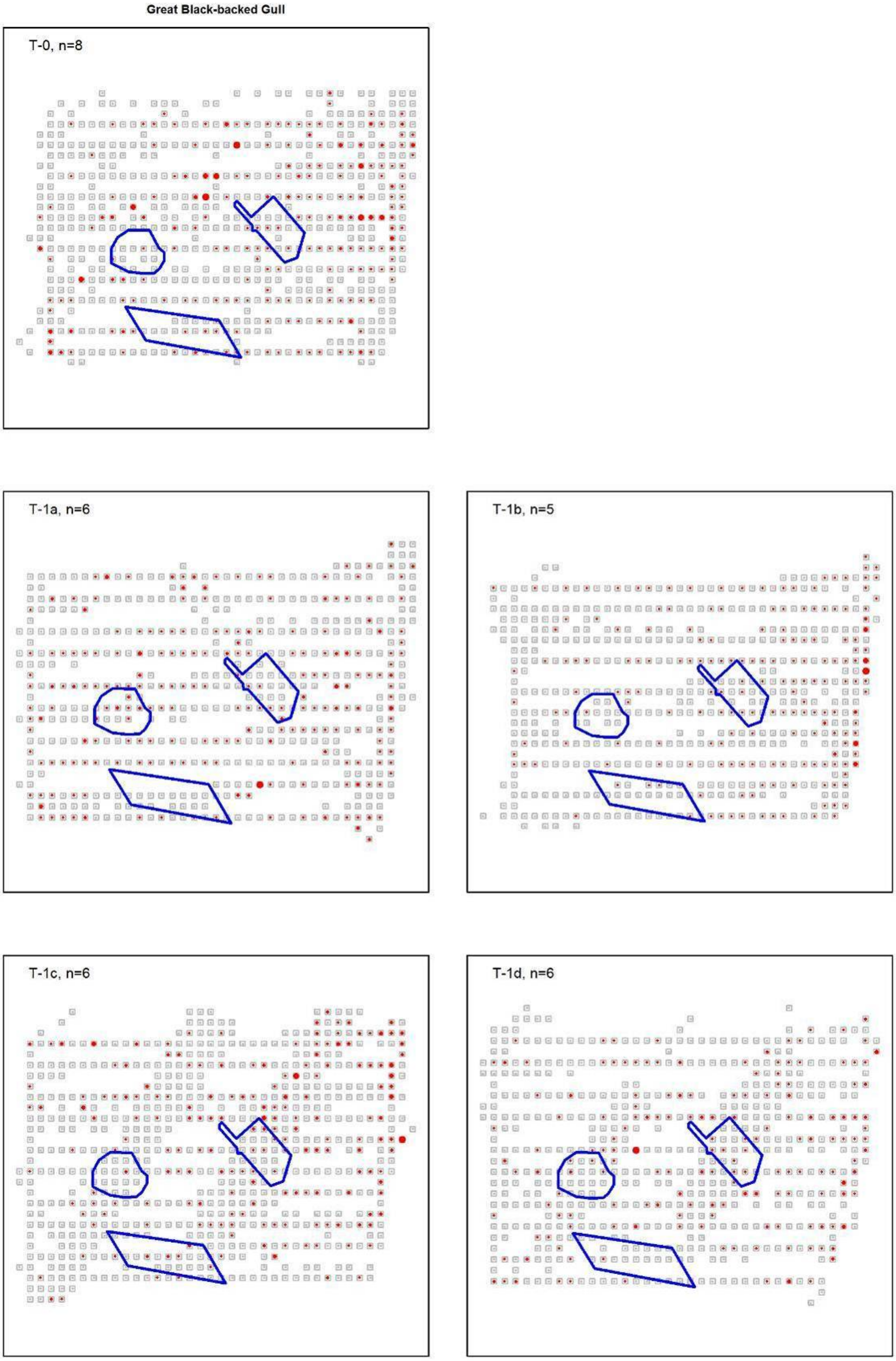

***Figure 44**. Averaged distribution patterns during the various survey phases.*

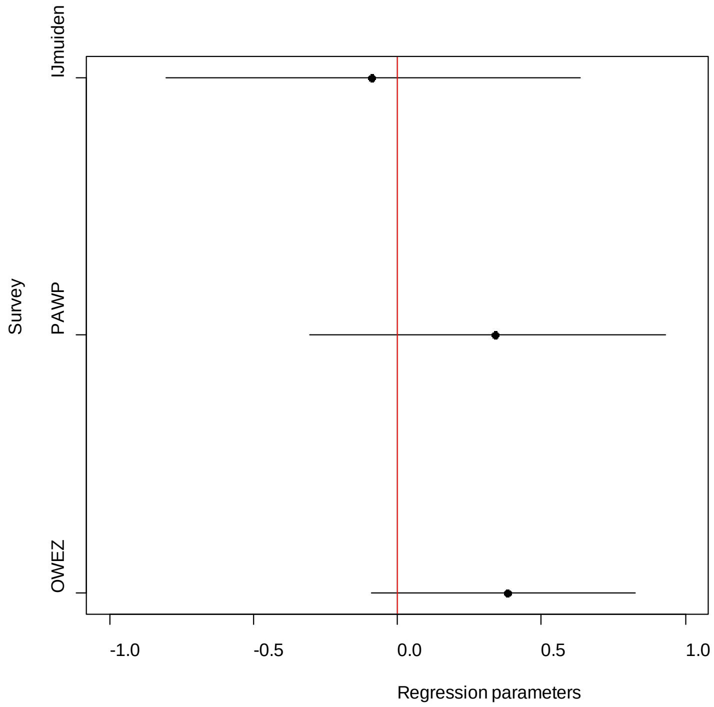

***Figure 45**. ZINB GAMM regression coefficients for each 'disturbance' area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Black-legged Kittiwake *Rissa tridactyla*

Adult Kittiwake, in winter plumage. Photo: Steve Geelhoed, IMARES.

Kittiwakes visit Dutch waters mainly in the non-breeding season, as evidenced from seawatching results (Camphuysen & van Dijk 1983; Platteeuw et al. 1994; www.trektellen.nl) and at-sea results (Berrevoets & Arts 2003; Camphuysen & Leopold 1994; Poot et al. 2011). Like other wintering gulls they occur dispersed over the entire North Sea, but unlike many other wintering gulls, they normally avoid nearshore waters and numbers in the shallow Southern North Sea vary greatly between years. Distance to coast often greatly influences distribution patterns, but apparently more so during T-0 (*Figure 46*; *Figure 47*). Kittiwakes join mixed feeding flocks with larger gulls less readily and fishing vessels probably have less impact on their general distribution, in a study area where large gulls predominate such as the current study area (Camphuysen et al. 2005). They entered both PAWP and OWEZ (*Figure 46*; *Figure 47*). Only for PAWP, a significant negative effect was found. Remarkably, a significant positive effect was found for the anchorage area (*Table 19*).

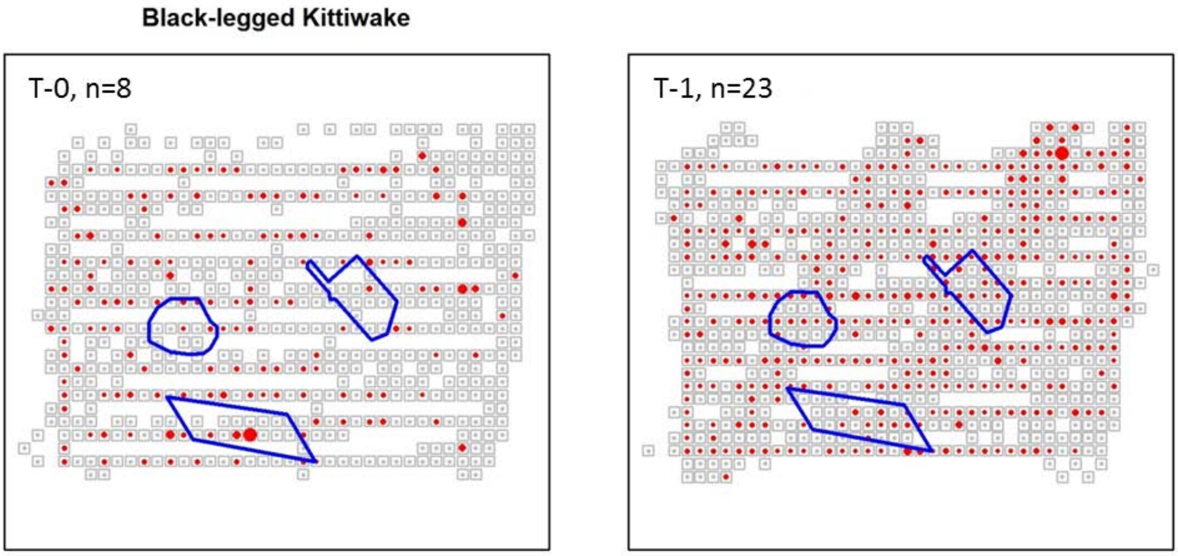

Figure 46. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 19. *Model results for a Poisson GAMM with a smoother for each survey. This model did not show overdispersion (1.09).*

Term	**Coefficient**	**p-value**
PAWP	-1.287	<0.001
OWEZ	-0.068	0.652
Anchorage	1.084	<0.001

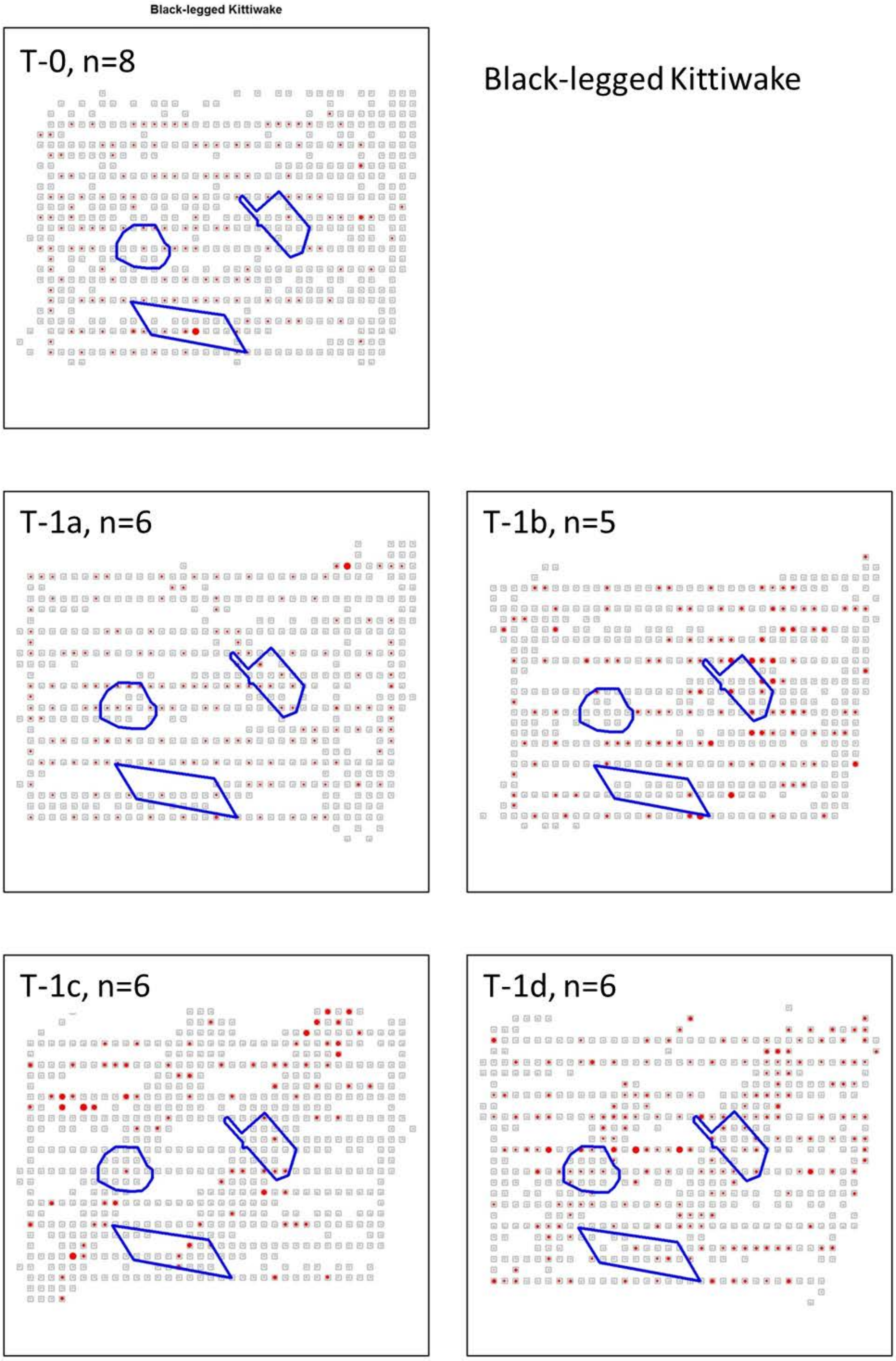

Figure 47*. Averaged distribution patterns during the various survey phases.*

Sandwich Tern *Sterna sandvicensis*

Sandwich Terns migrate south after the breeding season. Photo: Steve Geelhoed, IMARES.

Sandwich Terns are visitors to Dutch coastal waters from spring to autumn that come here to breed and to pass through, to more northerly breeding sites. Terns were therefore only seen from spring to autumn in the migration and breeding seasons. During breeding these birds are restricted to an area around their breeding colonies, but at other times, they range rather widely over the southeastern North Sea and bird that are probably not breeders at the time were seen all over the study area (*Figure 48*; *Figure 49*). Breeding birds that have nests with eggs or unfledged chicks in colonies in the Wadden Sea or in the Delta are unlikely to reach OWEZ on their foraging trips (Arends et al. 2008) but non-breeders, failed breeders, birds (parents and fledged young) after the breeding season and particularly migrants are fully capable of using the site (Leopold et al. 2011). Breeding birds remain mostly nearshore, but the study area is too far removed from the nearest colony (De Petten, at SE Texel; Baptist & Leopold 2010), to be of any importance for breeders, so numbers were very low in the study area in mid-summer. Therefore, numbers were highest during spring migration (April) and after fledging (August) (Figure 9) and modeling was only possible for April through October.

With Sandwich Terns seen only very rarely (just) inside PAWP, and never inside OWEZ during T-1, there was certainly no attraction. Indeed, no significant effect was found for either wind farm (*Table 20*). This is in contrast to work in the offshore wind farm Horns Rev (Denmark) and in Belgium where terns supposedly flocked around the outer turbines, to feed in the tidal wakes behind the monopiles (Elsam Engineering & Energi 2005; Elsam Engineering 2005; Petersen & Fox 2007; Vanermen et al. 2011). No Sandwich Terns (or any other tern species) showed this behaviour in OWEZ.

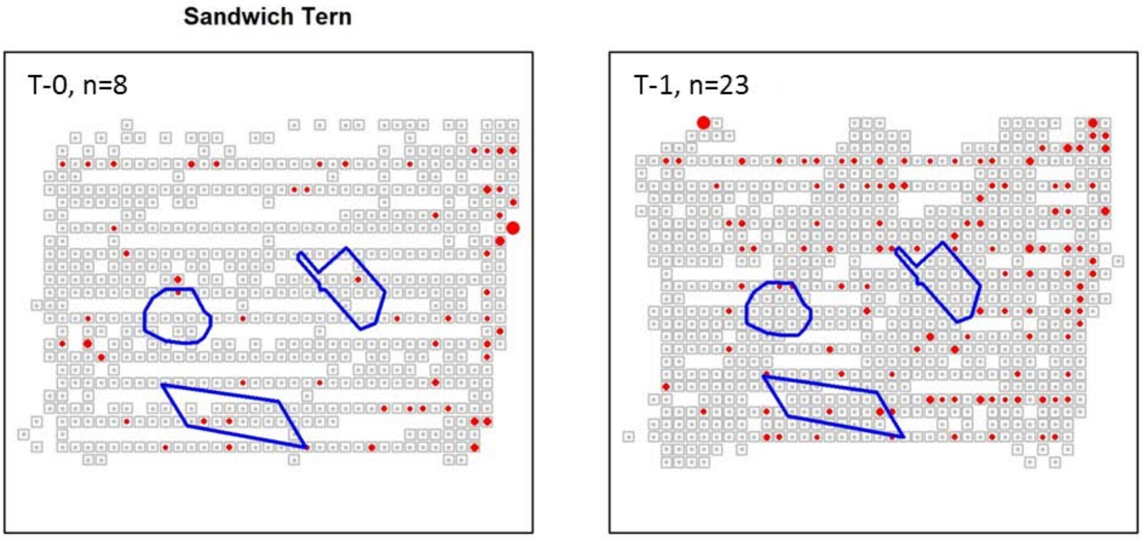

***Figure 48**. Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

***Table 20**. Model results for a Poisson GAMM with one smoother. This model did not show overdispersion (0.94).*

Term	**Coefficient**	**p-value**
PAWP	-14.946	0.986
OWEZ	-15.720	0.982
Anchorage	-1.536	0.039

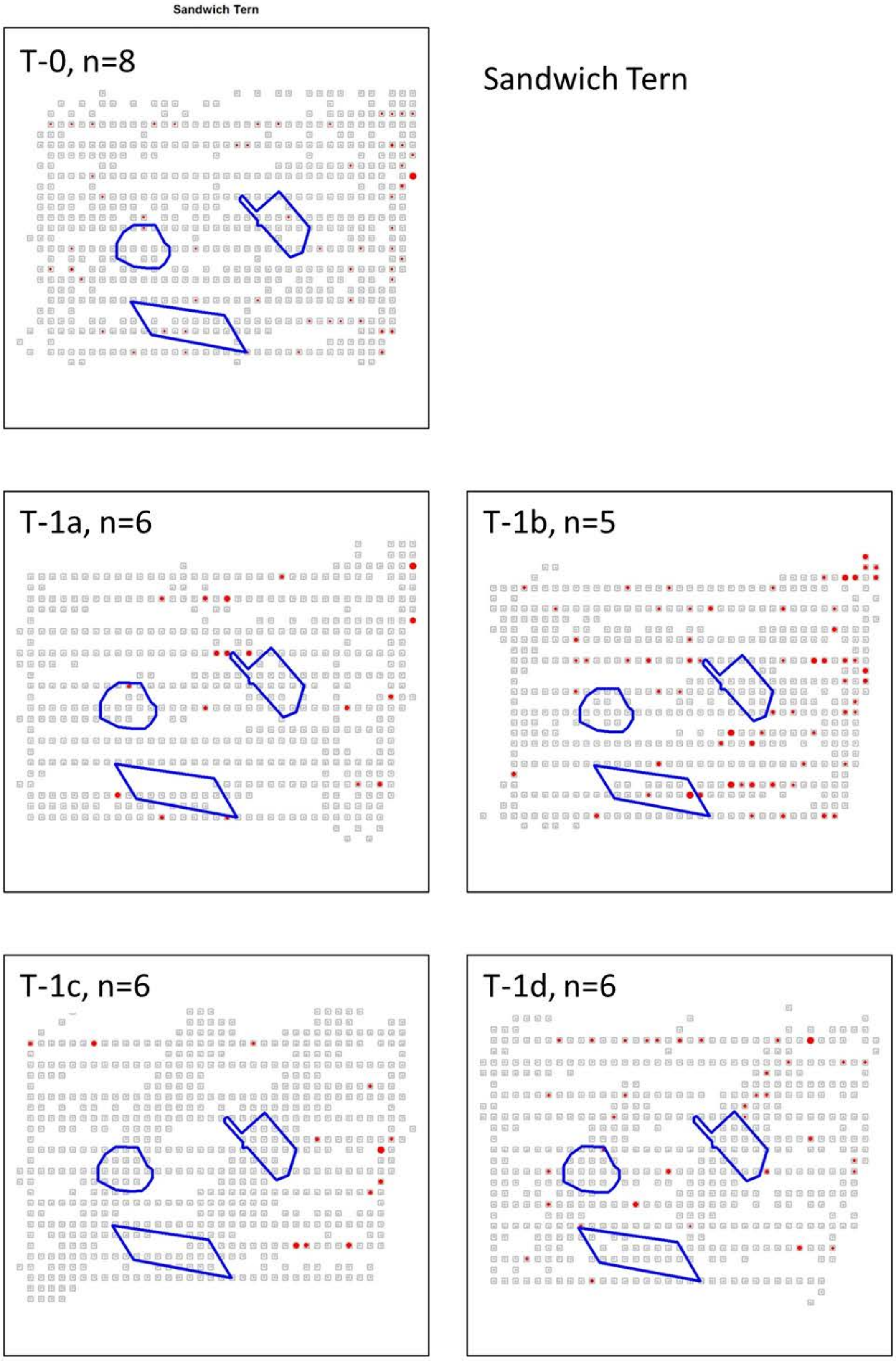

Figure 49*. Averaged distribution patterns during the various survey phases.*

‘Commic’ terns: Common Tern *Sterna hirundo* and Arctic Tern *S paradisaea*

Common Tern. Photo: Hans Verdaat, IMARES.

Common and Arctic Terns have a very similar appearance and behaviour at sea and cannot always be separated during surveys. Therefore, these two species are treated together as “Commic” terns (*cf* Leopold et al. 2004). Like the Sandwich Terns discussed above, Common and Arctic Terns are summer visitors to Dutch coastal waters. ‘Commic’ terns were only seen in significant numbers from April through October, with the largest numbers just after the breeding season, in August (Figure *8*).

Commic Terns tended to occur closer inshore than Sandwich Terns, but some reached OWEZ and PAWP latitudes (*Figure 50*; *Figure 51*), particularly during T-1b and T-1c when densities were somewhat higher than in other years. Breeding birds that are attached to colonies in the Wadden Sea or in the Delta range less far afield than Sandwich Terns and cannot reach OWEZ or PAWP on their foraging trips (Arends et al. 2008). Modeling was only possible for the results of the summer survey months (April through October; Table). After effects of distance to coast and northing were removed, no significant effect remained of the wind farms in the study area. However, densities at wind farm latitudes were so low that a meaningful analysis could in fact not be made.

Model results indicate that OWEZ had a negative effect on ‘commic’ tern densities (*Table 21*, *Figure 52*), which may be attributable to the fact that this wind farm is situated in waters were Common and Arctic Terns are relatively abundant (*Figure 50*; *Figure 51*).

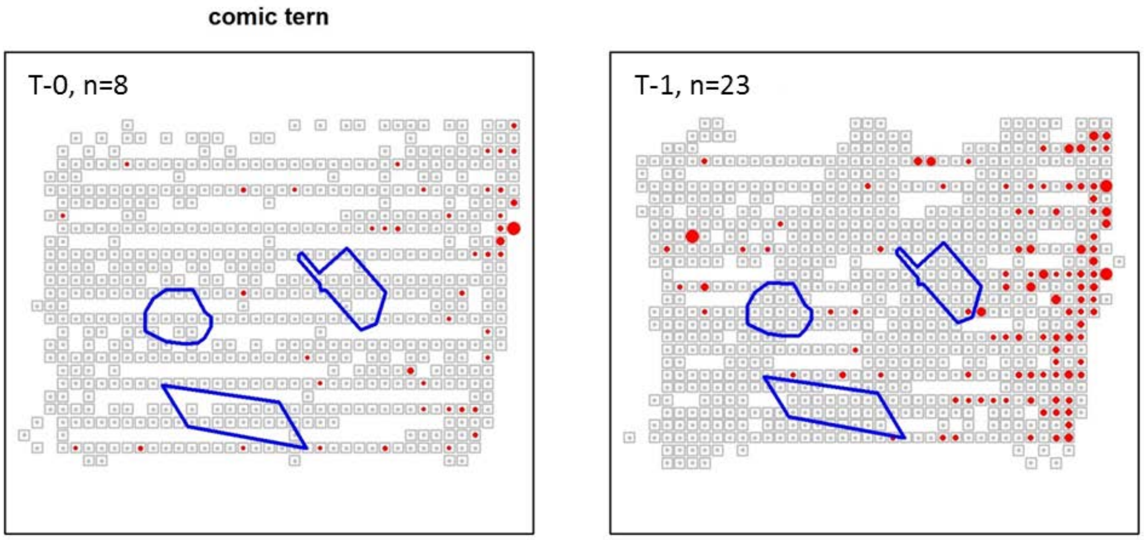

Figure 50. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 21. *Model results for a ZIP GAMM.*

Area	**Mean**	**SE**	**CI lower limit, 2.5%**	**CI upper limit, 97.5%**	**Significant?**
PAWP	-1.5	1.48	-5	0.83	N
OWEZ	-2.2	0.76	-3.7	-0.77	Y
IJmuiden	-4.4	2.32	-9.6	-1.09	Y

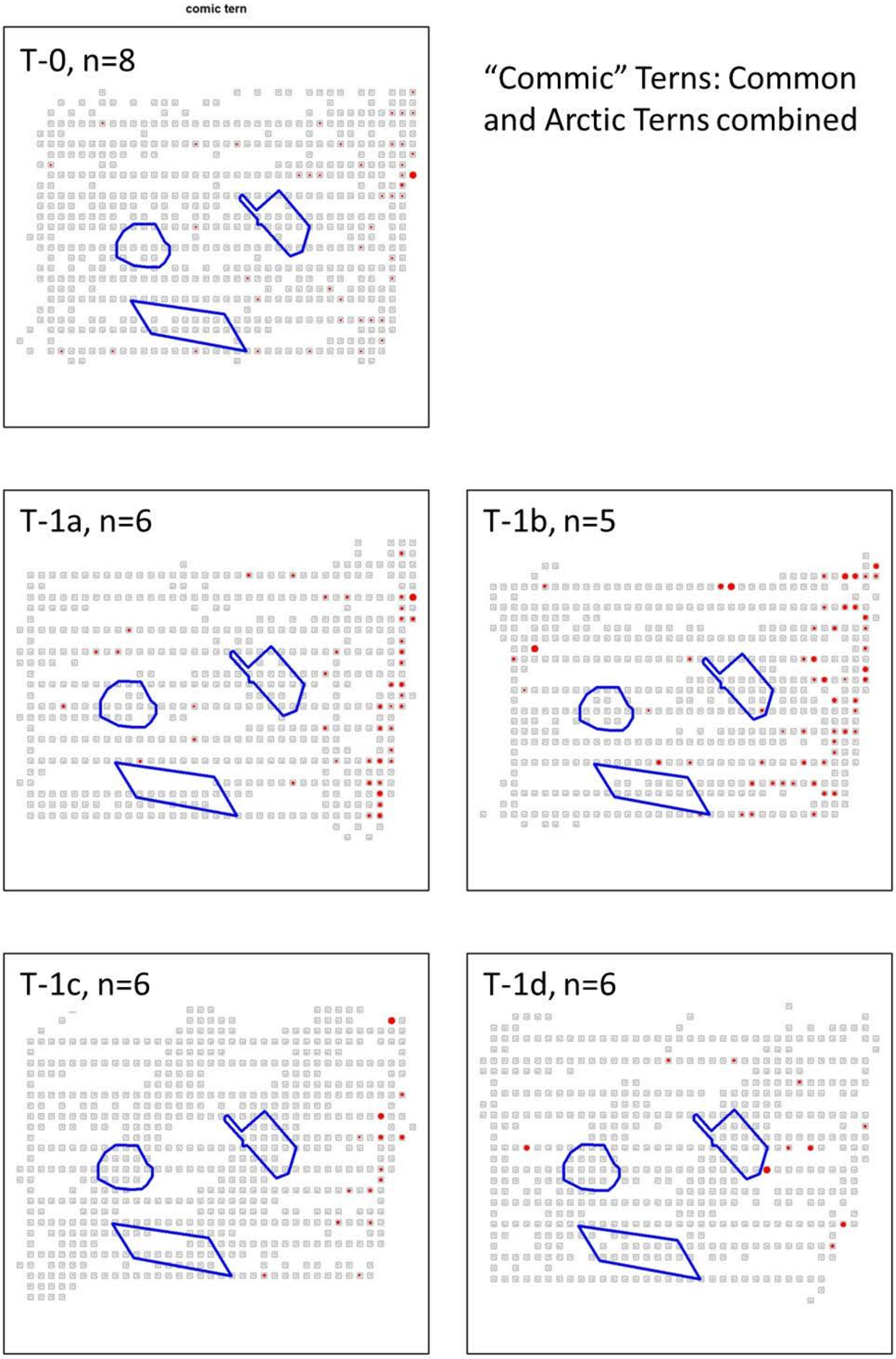

Figure 51. *Averaged distribution patterns during the various survey phases.*

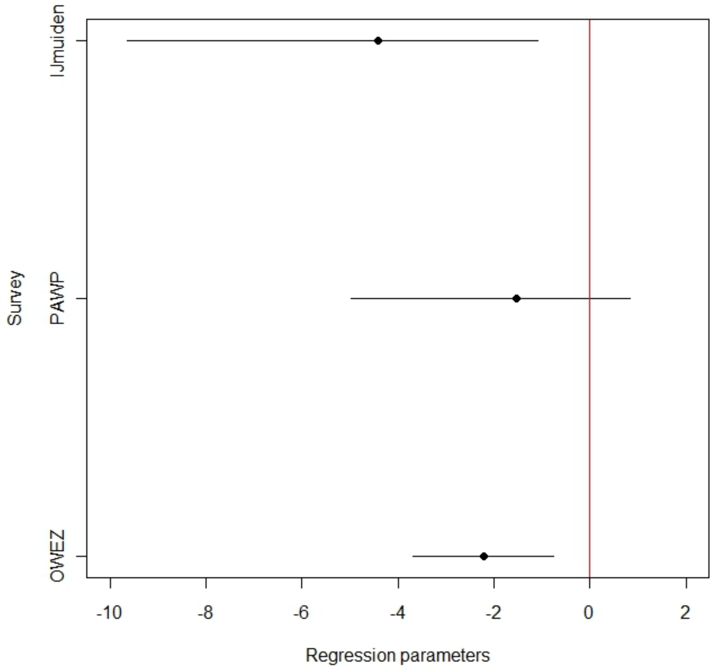

***Figure 52**. ZIP GAMM regression coefficients for each 'disturbance' area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

Common Guillemot *Uria aalge*

Two Common Guillemots in full breeding plumage, accompanied by one in active head moult, 26 January 2010, Photo: Hans Verdaat, IMARES.

Common Guillemots breed on cliff-coasts around the North Sea, the Baltic Sea, the northern Atlantic and Pacific Oceans (Nettleship & Birkhead 1985; Mitchell et al. 2004). Dutch waters are visited in large numbers in the non-breeding season (Camphuysen & Leopold 1994). Guillemots are probably the most suitable birds to study effects of wind farms on seabirds, as they occur in relatively large numbers in many water types in the North Sea (in this case both nearshore and offshore; *Figure 53*) and are not attracted to fishing vessels. These features make them ideal for spatial modeling and because Guillemots occur abundantly across wide areas within the Dutch sector of the North Sea and adjacent areas (unlike divers, grebes, seaducks, terns and some gulls), lessons learned around PAWP and OWEZ are likely to be useful for other sites. The studies at Horns Rev wind farm suggested that Guillemots avoid offshore wind farms to a large extent (Elsam Engineering & Energi 2005; Elsam Engineering 2005; Petersen & Fox 2007) but densities in those studies were much lower than in the present study area.

The first Guillemots arrive in the study area in August, shortly after the summer moult of their flight feathers, and numbers sufficient for modeling were present from August through February (Figure 9). Both their abundance and spatial pattern within the study area showed high variation between and within months and years. This variation made it necessary to estimate this spatial pattern in abundance for each survey.

Our data indicate that Guillemots avoided the wind farms PAWP and OWEZ, but also the anchorage area (Figure 56; Figure 57). Avoidance of both wind farms and the anchorage area were significant (Table *22*; Figure 56; Figure 57). However, wind farm avoidance was not 100%, as birds were seen swimming in both parks on several occasions during T-1 surveys (Figure *54*).

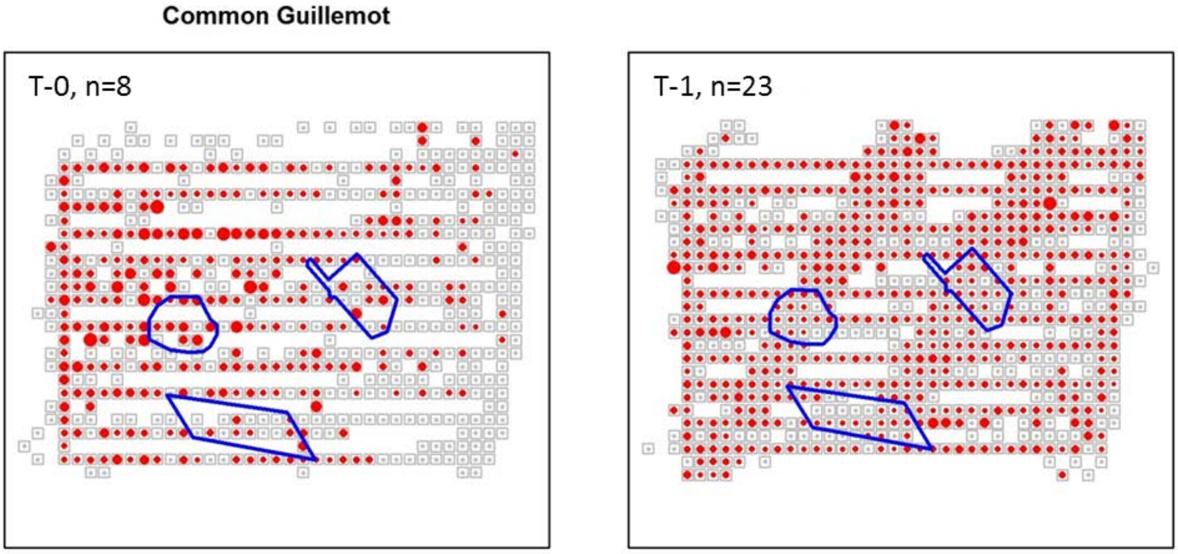

Figure 53. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 22. *Model results for a ZIP GAMM.*

Area	Mean	SE	CI lower limit, 2.5%	CI upper limit, 97.5%	Significant?
PAWP	-0.60	0.14	-0.91	-0.332	Y
OWEZ	-0.27	0.11	-0.48	-0.069	Y
IJmuiden	-0.54	0.15	-0.86	-0.273	Y

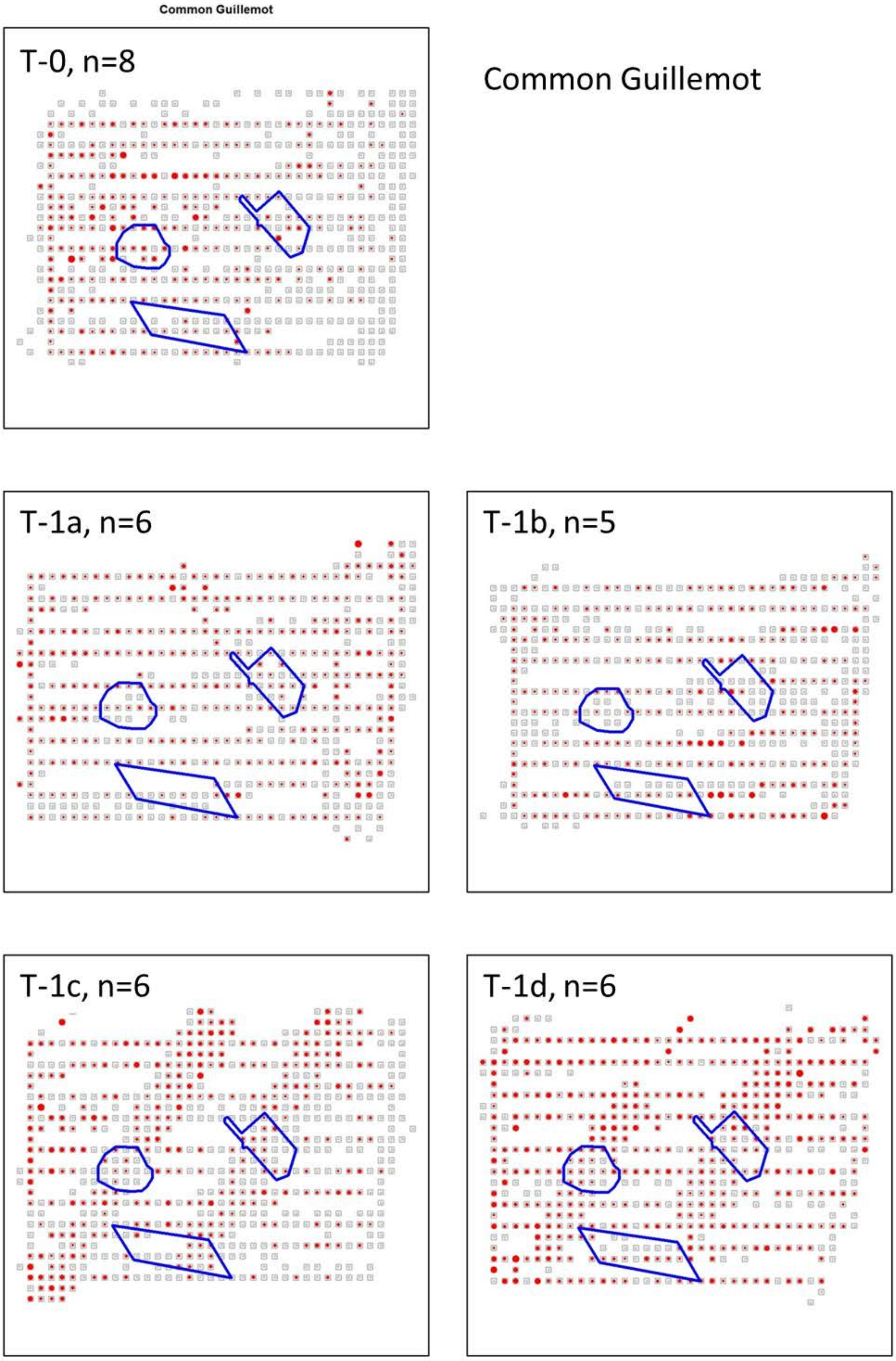

Figure 54. *Averaged distribution patterns during the various survey phases.*

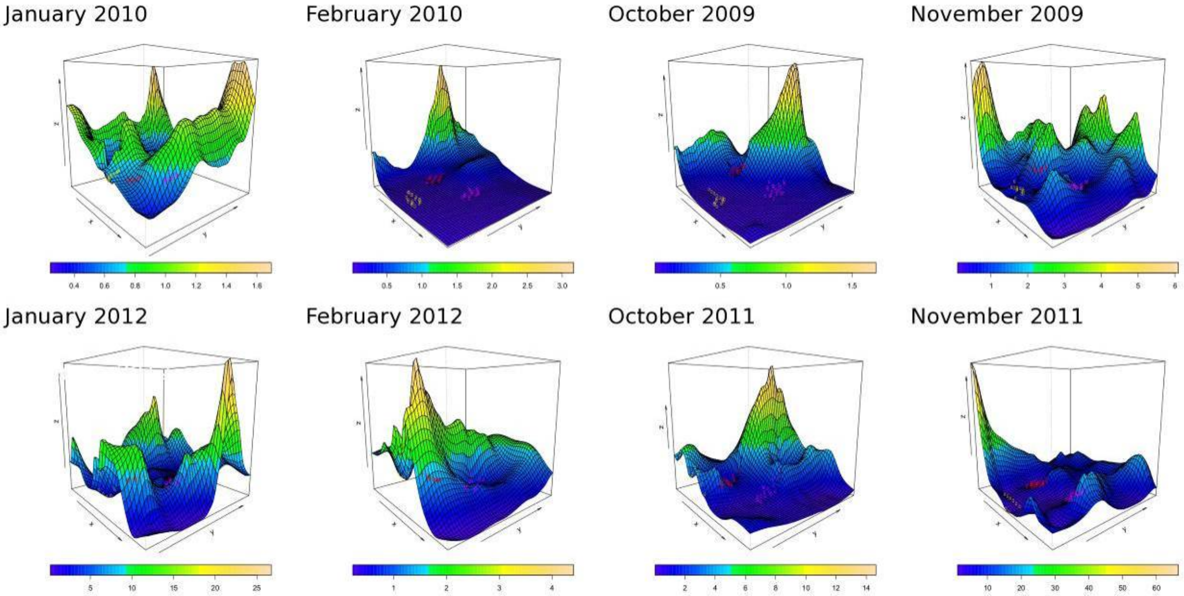

Figure 55. *Fitted model values for a number of surveys, illustrating different model predictions for several months and years. Note the large variation. The x-axis (lower left) represents longitude, the y-axis (lower right) represents latitude, and the height of the shapes (z-axis, left side) represent bird density as predicted from the model. Note that the z-axes differ in scale between figures.*

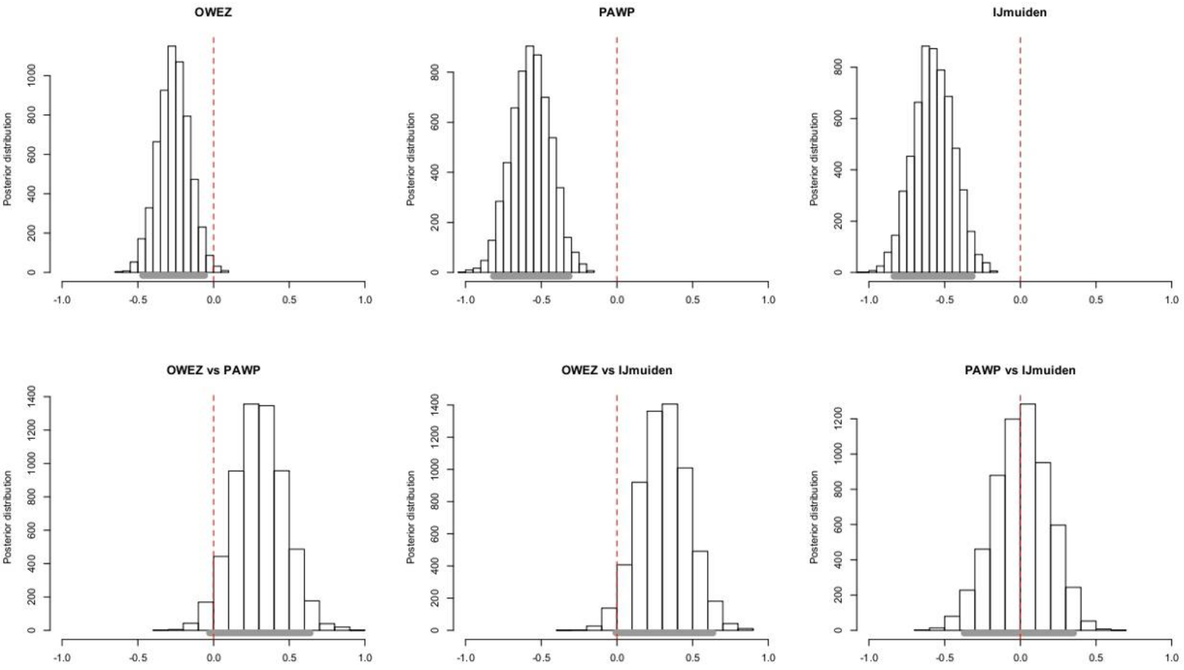

Figure 56. *Estimates of parameter coefficients for the three 'disturbance' areas, and the significance of the difference between these areas. If there is no effect of a 'disturbance area', the parameter coefficient would be zero. A significant deviation from zero is reached when zero (the red dotted line) is outside 95% of the parameter coefficient estimates (the grey bars at the bottom of the histograms).*

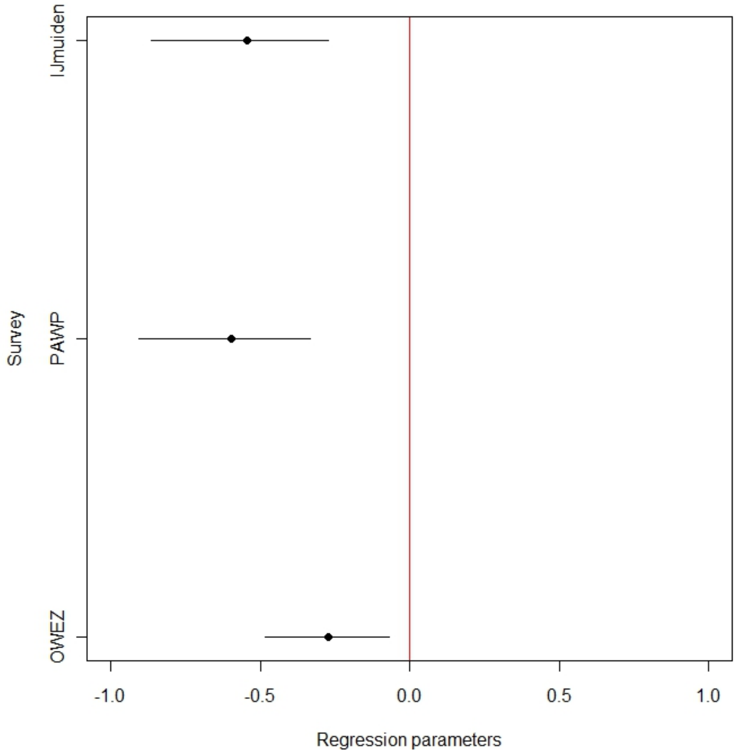

Figure 57. *Ranges of regression parameter coefficient estimates for the three 'disturbance' areas. These are the same as the grey bars under the histograms in the three upper graphs of Figure 56. If the range overlaps with zero, the effect is statistically non-significant. Note the significant negative effects of the anchorage and PAWP on the abundance of Common Guillemots, but a smaller but still significant effect of OWEZ.*

Razorbill *Alca torda*

10 januari 2012 was a remarkable day during the T-1d surveys. Razorbills came in unprecedented numbers towards the survey ship, to feed in its wake. "Full-flaps" landing of a Razorbill with all feathers and feet extended to brake, captured by Steve Geelhoed, IMARES. See also: Leopold et al. (2011).

Razorbills are often considered to be similar to Guillemots in many ways. They also visit Dutch waters only in the non-breeding season (Camphuysen & Leopold 1994; Figure 9). They are, however, more dependent on a specialised diet of small schooling fish such as herring, sprat or sandeels than Guillemots, that have a much broader diet in the general wintering area in the Southern Bight (Ouwehand et al. 2004). This may make Razorbills more susceptible to between-year differences in preferred prey stocks and variations in occurrence of suitable fish schools. Indeed, considerable year to year variation was found, e.g. in the September data (Leopold et al. 2011). Much higher numbers were seen during the T-1d than in previous years (*Figure 59*), illustrating the variability in Razorbill numbers in these parts.

Razorbills are less numerous than Guillemots (Appendix A), but like these, widely spread over the study area (*Figure 58*). Model results revealed significant negative effects of PAWP and the anchorage area, but not of OWEZ (Table 23, *Figure 60*). Some Razorbills, like some Guillemots, were found amidst the turbines of both wind farms, and particularly so in OWEZ, where background densities were relatively high (*Figure 58*).

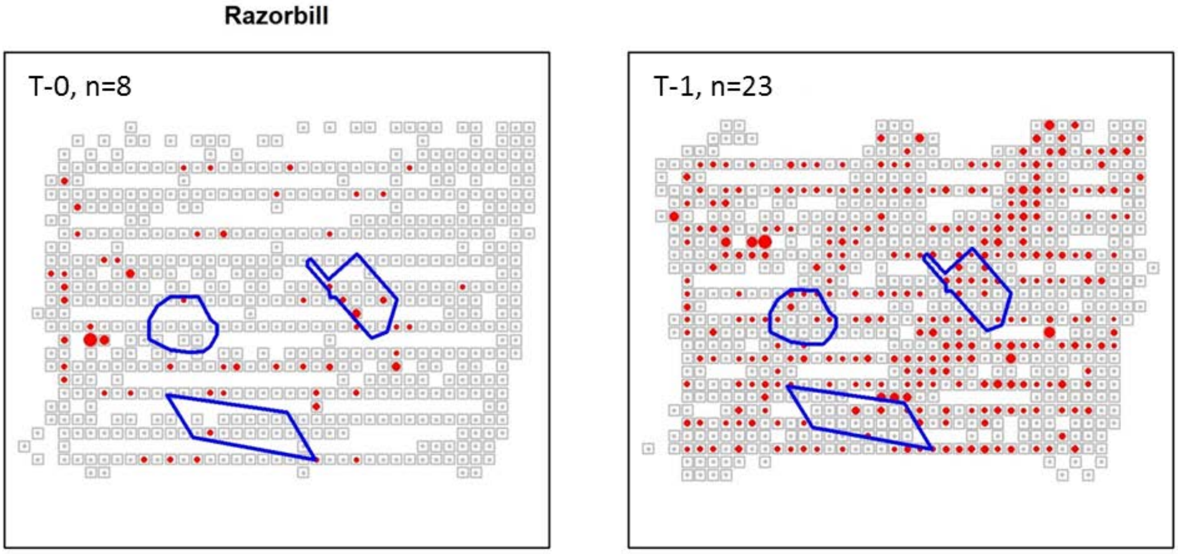

Figure 58. *Averaged distribution patterns compared for all T-0 surveys versus all T-1 surveys.*

Table 23. *Model results for a ZIP GAMM.*

Area	**Mean**	**SE**	**CI lower limit, 2.5%**	**CI upper limit, 97.5%**	**Significant?**
PAWP	-1.6	0.39	-2.37	-0.85	Y
OWEZ	-0.17	0.2	-0.54	0.23	N
IJmuiden	-0.84	0.36	-1.6	-0.18	Y

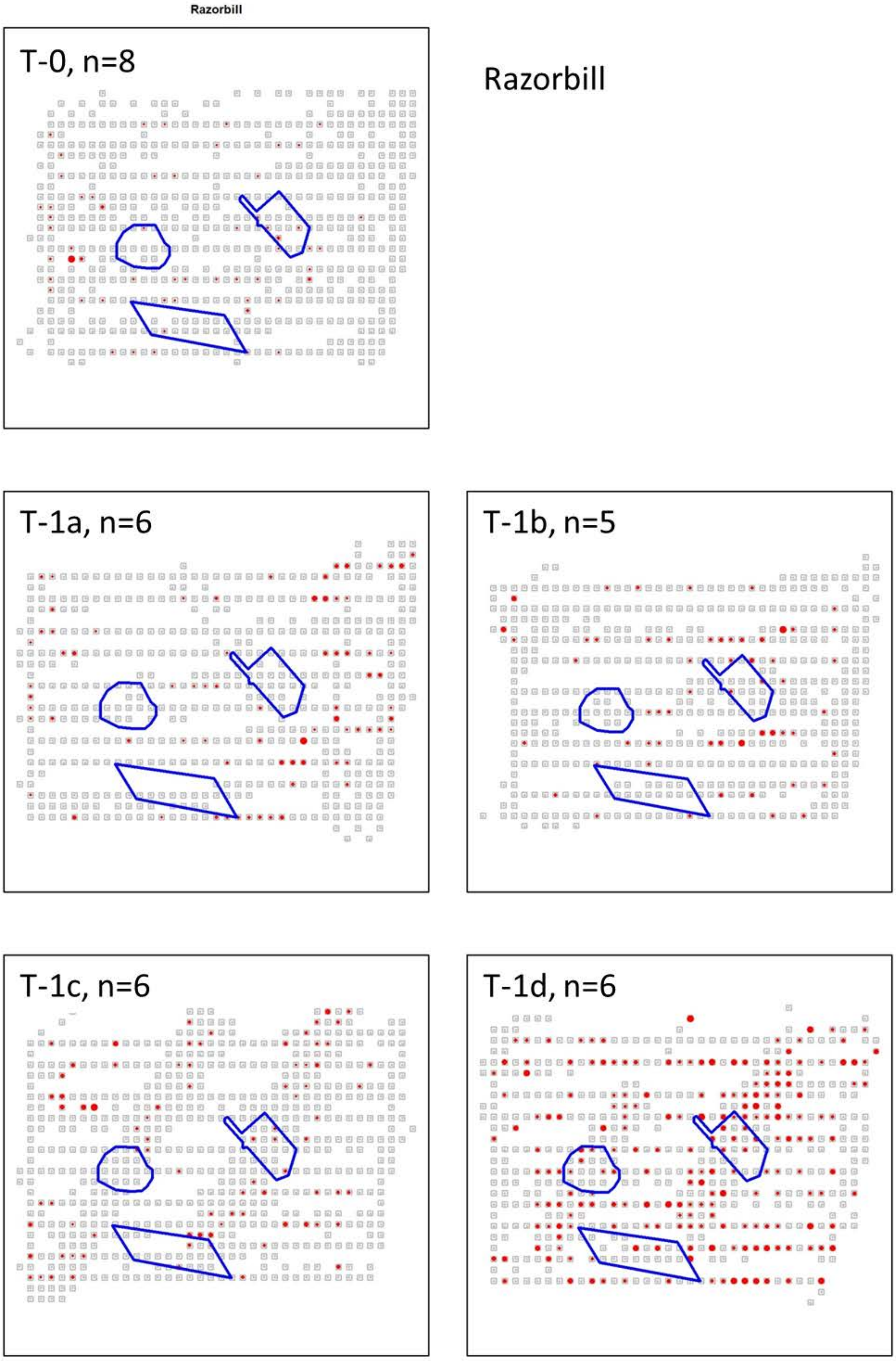

***Figure 59**. Averaged distribution patterns during the various survey phases.*

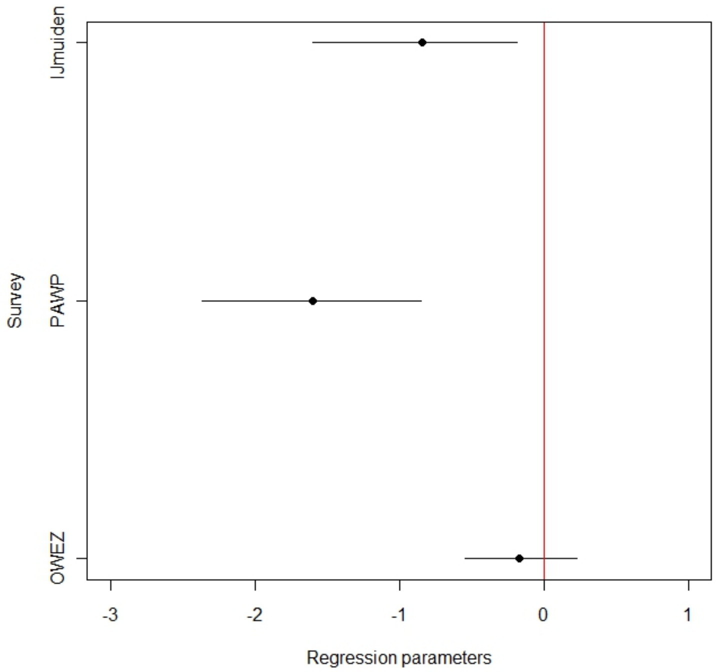

Figure 60*. ZIP GAMM regression coefficients for each ‘disturbance’ area. The black lines represent 95% credible intervals. If these overlap with 0, there is no significant effect.*

5. Conclusions and Discussion

This report describes the results of four years of T-1 Local Bird surveys around the Dutch offshore wind farms PAWP and OWEZ in comparison to the results of a one-year T-0 study. The two wind farms are situated off the Dutch mainland coast, in close proximity to each other and are owned and managed by two different parties, Eneco and NUON/Shell (now: Vattenfall). In a unique process of mutual agreements, commissioning and data sharing between these two parties, a single, large-scale, multi-year line of research has resulted in a joint approach to address the difficult question: how do local seabirds react to offshore wind farms? The long-term cooperation between the two commissioning parties is probably unique in this line of research, where all too often different wind parks are studied by different parties and different methods. Clearly, bringing together the resources of two offshore wind developers in one project has several clear advantages, for instance in the longevity of the project and its consistency. This does not mean that this project has known exactly the same methodology throughout. The project has been a learning process for all involved, certainly also for the biologists and analysts carrying out the field work, analyses and reporting. This has resulted in two major changes in the course of the project. First, after two years of T-1 surveys it was realised that more count data were required from within the wind farms themselves and the survey set-up was adjusted accordingly, introducing new survey lines running through the two wind farms and parallel to the isobaths in the general study area. Second, and the core of this report, was the development and deployment of new statistical analysis methods. In an earlier report, Leopold et al. (2011a) used only presence/absence data to look for evidence that birds avoided the wind farms, or were attracted to them. In the current report we modeled the effects of the wind farms on bird densities, using more sophisticated Poisson or Negative Binomial Generalized Additive Mixed Models (Poisson GAMMs and NB GAMMs) or Zero-Inflated models (ZIP GAMMs and ZINB GAMMs).

The analyses allow a comparison of the effects of both wind farms. This is highly relevant, because the two wind farms have a different lay-out and might thus have different effects on local seabirds. PAWP has a much higher turbine density (4.3 turbines / km^2) than OWEZ (1.3/km^2). Should there be consistent differences in effects between the two wind farms that cannot be attributed to other factors, such as the exact location of either wind farm within the planes of local seabird densities, this could provide important lessons for future wind farms designs. The main difference between PAWP and OWEZ is turbine size, and following from that, turbine density. The turbines deployed in PAWP (n=60) are Vestas V80 - 2 MW, at 59 m above mean sea level (amsl), with a rotor diameter of 80 m. Those in OWEZ (n=36) are Vestas V90 - 3MW turbines at 70 m amsl, with a rotor diameter of 90 m. Other than this difference, PAWP was built in slightly deeper waters (19-24 m versus 18-20 m) and further offshore (ca 23 km versus ca 15 km) than OWEZ.

Although the distances from the coast of the wind farms may seem trivial on this relatively small scale, this turned out to have important consequences on the impact on local seabirds, simply because PAWP is situated just outside the realm of a suit of coastal seabirds (divers, grebes, seaduck, and to a lesser extent, several terns and gulls), while OWEZ is just touching this zone of coastal avifauna. Indeed, significant negative effects were found for a suite of coastal seabirds: divers, Great Crested Grebe, Common Scoter and 'commic' terns (*Table 24*). Effects on these species further offshore, i.e. of PAWP, were not detected, likely due to low background densities. For these species, PAWP is thus ecologically better placed than OWEZ.

These results (avoidance) of offshore wind farms by divers, grebes and seaduck corroborate similar work in other offshore wind farms in Denmark (Petersen et al. 2006).

Gulls represent a problematic species group for evaluating the effects of offshore wind farms, considering the ambiguous results obtained. Several statistically significant negative effects were found, but within a species, these were never found for both wind farms (*Table 24*). Most gull species were regularly seen in both wind farms in considerable numbers. Clearly, some gulls were attracted to the wind farms where they were seen resting and feeding. On the other hand, large numbers may have been attracted to fishing vessels, which were by definition outside the wind farms. This may be the reason for the found avoidance of Lesser Black-backed Gulls.

The most suitable seabirds for testing the effect of offshore wind farms are species that show a wide distribution and that occur in relatively high densities. In this study, this was true for Northern Gannet, Black-legged Kittiwake, Common Guillemot and Razorbill. For all species, significant negative effects were found for PAWP, but only for two species, the Common Guillemot and the Northern Gannet, also for OWEZ (Table 24). The larger effect of PAWP may have resulted from the farm being less ‘open’ than OWEZ, thereby eliciting a significant reaction by the birds.

The only species that showed unambiguous attraction to both wind farms was the Great Cormorant. Compared to the T-0 situation, this species has greatly enlarged its marine range aided by the presence of resting platforms within the two offshore wind farms. At the onset of this project, the behavioural shift of the local cormorants had not been foreseen and it had not been expected that these birds would take hold of the two wind farms after these had been successively built. It is yet unclear until how far offshore Great Cormorant will follow offshore wind farm development.

Table 24. *Summary of results for all tested species, showing the model used and the effect on seabird densities of both wind farms. Statistically significant effects are denoted as ‘avoidance’ or ‘attraction’, while non-significant results are denoted as ‘NS’. A statistically significant effect of a wind farm means that the density within the wind farm differs from the expected density based on the density pattern in surrounding waters. Models represent Poisson Generalized Additive Mixed Models (P GAMMs), Negative Binomial Generalized Additive Mixed Models (NB GAMMs), Zero-Inflated Poisson Generalized Additive Mixed Models (ZIP GAMMs) and Zero-Inflated Negative Binomial Generalized Additive Mixed Models (ZINB GAMMs), see the chapter on statistical analysis for explanation of these model (p.18).*

Species (group)	**Model**	**PAWP**	**OWEZ**	**Comments**
Divers	P GAMM	NS	**avoidance**	PAWP largely of out range.
Great Crested Grebe	ZIP GAMM*	NS	**avoidance**	PAWP out of range.
Northern Fulmar	P GAMM	NS	NS	Avoidance expected, but densities too low.
Northern Gannet	ZIP GAMM	**avoidance**	**avoidance**	
Great Cormorant	P GAMM	**attraction**	**attraction**	Similar numbers in both parks, background density lower in PAWP.
Common Scoter	ZIP GAMM*	NS	**avoidance**	PAWP largely out of range.
Little Gull	NB GAMM*	**avoidance**	NS	
Black-headed Gull	ZIP GAMM	NS	NS	Both wind farms largely out of range.
Common Gull	ZINB GAMM	NS	NS	
Lesser Black-backed Gull	ZINB GAMM	NS	**avoidance**	
Herring Gull	ZIP GAMM	NS	NS	
Greater Black-backed Gull	ZIP GAMM	NS	NS	
Black-legged Kittiwake	P GAMM	**avoidance**	NS	Possibly, densities too low around OWEZ.
Sandwich Tern	P GAMM	NS	NS	Both wind farms largely out of range.
“Commic” terns	ZIP GAMM	NS	**avoidance**	PAWP in lower density area.
Common Guillemot	ZIP GAMM	**avoidance**	**avoidance**	
Razorbill	ZIP GAMM*	**avoidance**	NS	

Overall, the results of this study are largely in line with the earlier evaluation based only on presence/absence data (Leopold et al. 2011): attraction in Great Cormorants, avoidance in most other seabirds, while results for some gull species remain ambiguous.

For future wind farms, likely to be built further offshore, studying effects on coastal seabirds, although expected to be vulnerable to disturbance, does not seem to need further study. Other species will likely to be impacted more by future offshore developments. The most important conclusion of this study probably is, that the Common Guillemot would seem to be the most promising seabird for future studies of disturbance by offshore wind farms, considering that this species occurs all over the North Sea, occurs often in substantial numbers that would allow for a useful analysis and show some, but not 100% avoidance of wind farms. These properties make the Common Guillemot a suitable species for comparisons of the effects of different wind farms. In the present, first inter-wind farm comparison, admittedly based on only two wind farms, a lay-out with larger, but more spaced-out turbines, disturbed the birds to a lesser extent than a wind farm with smaller but more densely packed turbines. Bigger is better, it would seem, al other things being equal.

However, as pointed out above, other factors might be important co-variates, particularly where a wind farms is built in relation to local seabird densities. The difference in location between PAWP and OWEZ may seem trivial, but did influence the scope for disturbing seabirds considerably. For many seabird species, effects could not be demonstrated for both wind farms – for lack of sufficient numbers present in certain parts of the study area. This is of course a good quality of the two current Dutch offshore wind farms, and every effort should be made to identify other local lows in seabird density for future sites. After a site has been chosen, the choice of turbines might further help to reduce effects on local seabirds.

A final caution concerns several seabird species for which the potential effects of offshore wind farms could not be evaluated properly in this study. Fulmars were present in low numbers around PAWP and OWEZ and while the summed distribution patterns suggested avoidance of the wind farms, responses to the wind farms could not be demonstrated convincingly. Moreover, other species that might be impacted by future development, for instance the Atlantic Puffin *Fratercula arctica*, could not be tested here at all. Given that future wind farms will generally be built offshore, i.e. in the realm of fulmars and puffins, this is a reason for concern, even if no effects could be demonstrated in the current study.

In conclusion, most local seabird species avoided the wind farms to a certain extent. One species, the Great Cormorant was clearly attracted to the wind farms and two species, the Common Guillemot and the Northern Gannet, clearly avoided both wind farms, but not fully. Both Common Guillemots and Northern Gannet showed a stronger (negative) reaction to PAWP than to OWEZ, with its lower density of turbines. For several other species, a negative effect could be shown only for PAWP. Here, avoidance was found for Black-legged Kittiwake and Razorbill, whereas for OWEZ, avoidance was found for divers, Great Crested Grebe, Common Scoter and 'commic' terns. The skewed distribution patterns of nearshore species, prevented significant results to be found in the more offshore wind farm, PAWP. Our data suggest that we should be concerned mostly about seabirds with a more offshore distribution for future developments. The Common Guillemot should probably be selected for future comparative studies of the possible effects of offshore wind farms of a different build and at different locations.

6. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

7. Justification

Rapport number C151/12
Project Number: 4306119301

The scientific quality of this report has been peer reviewed by experts on bird distribution and ecology of SOVON (J. Stahl , H. Schekkerman & W.A. Teunissen: Review of the report ‘Responses of Local Birds to the Offshore Wind Farms PAWP and OWEZ off the Dutch mainland coast’ IMARES report number C151/12. Sovon-notitie 13-101), by J.F. Bakker of Rijkswaterstaat for the Dutch government, by J. Dam (Ecofys) for the Commissioner of this study and by the Head of the Ecosystems Department of IMARES.

Approved: Drs. J. Asjes
Head of Department Ecosystems

Signature:

Date: October 14th 2013

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9. Appendix A. Species list

Species		number
Red-throated Diver	***Gavia stellata***	**2709**
Black-throated Diver	***Gavia arctica***	**67**
Great Northern Diver	*Gavia immer*	2
unidentified diver	***Gavia spec.***	**277**
Great Crested Grebe	***Podiceps cristatus***	**19995**
Red-necked Grebe	*Podiceps grisegena*	27
Slavonian Grebe	*Podiceps auritus*	11
Black-necked Grebe	*Podiceps nigricollis*	2
Northern Fulmar	***Fulmarus glacialis***	**700**
Sooty Shearwater	*Puffinus griseus*	27
Manx Shearwater	*Puffinus puffinus*	13
Balearic Shearwater	*Puffinus mauretanicus*	4
Leach's Storm-petrel	*Oceanodroma leucorhoa*	13
Northern Gannet	***Morus bassanus***	**7641**
Great Cormorant	***Phalacrocorax carbo***	**17147**
North Atlantic Cormorant	*Phalacrocorax carbo carbo*	1
European Shag	*Phalacrocorax aristotelis*	5
Grey Heron	*Ardea cinerea*	40
Spoonbill	*Platalea leucorodia*	11
Tundra Swan	*Cygnus bewickii*	40
Bean Goose	*Anser fabalis*	3
Pink-footed Goose	*Anser brachyrhynchus*	2145
Greater White-fronted Goose	*Anser albifrons*	84
Greylag Goose	*Anser anser*	413
unidentified goose	*Anser spec.*	48
Barnacle Goose	*Branta leucopsis*	533
Brent Goose	*Branta bernicla*	1402
Dark-bellied Brent Goose	*Branta bernicla*	3
unidentified goose	*Anser/Branta spec.*	225
Egyptian Goose	*Alopochen aegyptiaca*	5
Common Shelduck	*Tadorna tadorna*	149
Eurasian Wigeon	*Anas penelope*	1434
Gadwall	*Anas strepera*	41
EurasianTeal	*Anas crecca*	297
Mallard	*Anas platyrhynchos*	37
domestic duck	*Anas domesticus*	2
Northern Pintail	*Anas acuta*	149
Garganey	*Anas querquedula*	7
Northern Shoveler	*Anas clypeata*	116
Common Pochard	*Aythya ferina*	2
Tufted Duck	*Aythya fuligula*	38
Greater Scaup	*Aythya marila*	118
Common Eider	*Somateria mollissima*	1696
Long-tailed Duck	*Clangula hyemalis*	3
Common Scoter	***Melanitta nigra***	**10567**
Velvet Scoter	*Melanitta fusca*	86
Common Goldeneye	*Bucephala clangula*	6
Red-breasted Merganser	*Mergus serrator*	130
unidentified duck	*unidentified duck*	5
Eurasian Marsh Harrier	*Circus aeruginosus*	2
Hen Harrier	*Circus cyaneus*	4
Northern Goshawk	*Accipiter gentilis*	1
Eurasian Sparrowhawk	*Accipiter nisus*	6
Common Kestrel	*Falco tinnunculus*	2

Peregrine Falcon	*Falco peregrinus*	9
Common Coot	*Fulica atra*	1
Eurasian Oystercatcher	*Haematopus ostralegus*	28
Ringed Plover	*Charadrius hiaticula*	11
Kentish Plover	*Charadrius alexandrinus*	1
European Golden Plover	*Pluvialis apricaria*	233
Grey Plover	*Pluvialis squatarola*	89
Northern Lapwing	*Vanellus vanellus*	68
Red Knot	*Calidris canutus*	77
Sanderling	*Calidris alba*	21
Purple Sandpiper	*Calidris maritima*	2
Dunlin	*Calidris alpina*	103
Ruff	*Philomachus pugnax*	1
Jack Snipe	*Lymnocryptes minimus*	1
Snipe	*Gallinago gallinago*	37
Eurasian Woodcock	*Scolopax rusticola*	10
Bar-tailed Godwit	*Limosa lapponica*	66
Whimbrel	*Numenius phaeopus*	17
Eurasian Curlew	*Numenius arquata*	97
Common Redshank	*Tringa totanus*	41
Common Greenshank	*Tringa nebularia*	5
Green Sandpiper	*Tringa ochropus*	1
Common Sandpiper	*Actitis hypoleucos*	2
Ruddy Turnstone	*Arenaria interpres*	20
Grey Phalarope	*Phalaropus fulicarius*	3
unidentified wader	*unidentified wader*	14
Pomarine Skua	*Stercorarius pomarinus*	66
Arctic Skua	*Stercorarius parasiticus*	56
Long-tailed Skua	*Stercorarius longicaudus*	1
Great Skua	*Stercorarius skua*	167
skua	*Stercorarius spec.*	6
Mediterranean Gull	*Larus melanocephalus*	12
Little Gull	***Larus minutus***	**12301**
Sabine's Gull	*Larus sabini*	4
Black-headed Gull	***Larus ridibundus***	**2958**
Ring-billed Gull	*Larus delawarensis*	1
Common Gull	***Larus canus***	**22763**
small gull	*Larus / Rissa spec.*	100
Lesser Black-backed Gull	***Larus fuscus***	**86500**
Herring / Lesser Black-backed gull	*L. fuscus / L. argentatus*	1850
Herring Gull	***Larus argentatus***	**45823**
Pontic Gull	*Larus cachinnans*	3
Yellow-legged Gull	*Larus michahellis*	19
Common / Herring Gull	*L. canus / L. argentatus*	53
Glaucous Gull	*Larus hyperboreus*	6
Great Black-backed Gull	***Larus marinus***	**17595**
large gull	*Larus spec.*	8495
Black-legged Kittiwake	***Rissa tridactyla***	**7610**
gull	*Larus spec.*	3645
Sandwich Tern	***Sterna sandvicensis***	**2489**
Common Tern	***Sterna hirundo***	**2751**
Arctic Tern	***Sterna paradisaea***	**197**
Common / Arctic tern	***S. hirundo / S. paradisaea***	**478**
Little Tern	*Sterna albifrons*	9
Black Tern	*Chlidonias niger*	43
Common Guillemot	***Uria aalge***	**15991**
Common Guillemot / Razorbill	*Alca torda / Uria aalge*	97
Razorbill	***Alca torda***	**1928**

Little Auk	*Alle alle*	1
Atlantic Puffin	*Fratercula arctica*	5
domestic pigeon	*Columba livia*	67
Eurasian Collared Dove	*Streptopelia decaocto*	4
Long-eared Owl	*Asio otus*	2
Short-eared Owl	*Asio flammeus*	4
Common Swift	*Apus apus*	122
Wood Lark	*Lullula arborea*	4
Sky Lark	*Alauda arvensis*	791
Barn Swallow	*Hirundo rustica*	23
House Martin	*Delichon urbica*	14
Meadow Pipit	*Anthus pratensis*	306
Rock Pipit	*Anthus petrosus*	1
Yellow Wagtail	*Motacilla flava*	2
Grey Wagtail	*Motacilla cinerea*	2
White Wagtail	*Motacilla alba*	15
Pied Wagtail	*Motacilla yarrellii*	3
Bohemian Waxwing	*Bombycilla garrulus*	1
Winter Wren	*Troglodytes troglodytes*	5
European Robin	*Erithacus rubecula*	16
Black Redstart	*Phoenicurus ochruros*	2
Northern Wheatear	*Oenanthe oenanthe*	5
Common Blackbird	*Turdus merula*	274
Fieldfare	*Turdus pilaris*	576
Song Thrush	*Turdus philomelos*	32
unidentified thrush	*Turdus spec.*	1
Redwing	*Turdus iliacus*	501
Mistle Thrush	*Turdus viscivorus*	3
Common Chiffchaff	*Phylloscopus collybita*	7
Common Chiffchaff / Willow Warbler	*P. collybita / P. trochilus*	3
Willow Warbler	*Phylloscopus trochilus*	1
Goldcrest	*Regulus regulus*	11
Pied Flycatcher	*Ficedula hypoleuca*	1
Eurasian Jackdaw	*Corvus monedula*	3
Rook	*Corvus frugilegus*	8
Carrion Crow	*Corvus corone corone*	2
Common Starling	*Sturnus vulgaris*	20084
Chaffinch	*Fringilla coelebs*	106
Brambling	*Fringilla montifringilla*	14
Common Linnet	*Carduelis cannabina*	2
Reed Bunting	*Emberiza schoeniclus*	3

In total, summed over all surveys, 153 different bird species were seen, totalling 326,493 individuals. The (seabird) species marked in **bold** are further analysed in this report.