Displacement analysis boat surveys Kentish Flats

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Executive summary

Boat survey data collected around Kentish Flats 2001-2010 were analysed to assess the feasibility of quantifying displacement rates of birds from the footprint of this wind farm.

- sighting and effort data were collated by BTO from survey forms,
- species-specific detection functions were fitted for five species of birds on water and birds in the air,
- adjusted counts for $1km^2$ segments along the survey transects were modelled as response variables with northing and easting used as predictors,
- the modelled relationship between adjusted counts and spatial location was used to predict bird numbers throughout the study region before and after construction of the Kentish Flats wind farm,
- for each prediction grid cell the estimated difference in bird abundance pre-construction minus post-construction was calculated,
- confidence intervals on estimated difference in bird abundance were constructed using uncertainty associated with the density surface model (not including uncertainty associated with the detection function model),
- locations where the upper confidence interval for the difference in bird abundance was negative would be indicative of a decrease in bird abundance following operation of the Kentish Flats wind farm,
- no species had areas within the wind farm footprint where these upper confidence intervals were negative, red-throated divers did display some locations in the northeastern portion of the study area where they were estimated to be in lower abundance 2005-2010 than they were in 2001-2004.

Caveats

- some discrepancies in the data (such as flock recorded as both in flight and on the water) lead to some uncertainty about the input to these analyses,
- the vast portion of the sightings (in excess of 80% for some species) were detected in flight, which challenges the concept of bird "use" in a study area that is little more than $80km^2$,
- given reservations about the data, two embellishments in the analysis were **not** performed:
  - uncertainty in the predicted number of birds in prediction grid cells were not adjusted for uncertainty associated with fitting the detection function,

  - uncertainty in fitting the density surface model did not adjust for spatial autocorrelation

Conclusions

- This model-based estimation of bird distribution within the study area adjusts counted birds for imperfect detectability. Subsequent to that, distribution of birds within the study area is modelled as a function of northing and easting. These models assume a smooth underlying process distributing birds throughout the study area. This smoothed model is less sensitive to fine spatial scale changes in bird distribution than count statistics based on the surveyed area divided into cells. The counts of red-throated divers within the wind farm footprint after construction were smaller than the counts in the same locations prior to construction. There was no evidence from our modelling of a change in distribution for the gull and cormorants and an equivocal indication of displacement out of the wind farm footprint for red-throated divers. We do not believe this to be a result that will generalise to other wind farm installations.

  A short-coming to this modelling approach is detections at the fringes of the study area can have a demonstrable effect upon the fitted model when northing and easting are used as predictors. Many of the detections in this study, particularly for red-throated divers and cormorants, were at the edges of the surveyed region. Consequently the models presume these detections are indicative of a concentration of animals outside the surveyed region. The influence of these predicted 'hot spots' are propogated into the study area because of the smooths (with cormorants being a case in point).

  A model-based approach to displacement is a useful way of measuring this phenomenon because it provides both an inferential measure and also a visual depiction of where the negative and positive displacement may be occurring within the study area. Possible benefits to consenting for offshore wind farms are a) modelling sea bird distribution pre- and post-construction may show population consequences are not necessarily mortality of animals but rather redistribution of animals and b) if explanatory covariates are included in the density surface modelling, factors other than presence of a wind farm that might explain distribution of sea birds could prevent misidentification of the wind farm as the causal agent in sea bird redistribution.

1 Introduction

This report was commissioned by the Strategic Ornithological Support Services arrangement between The Crown Estates and the British Trust for Ornithology. It constitutes scope of work 1A with the objective of "assess displacement rates" for seabird species in existing offshore wind farms in UK waters. Data from boat surveys conducted around Kentish Flats 2001-2010 (Gill et al. 2008, Percival 2010)) were analysed. Methodology to measure displacement was based upon methods described in Petersen et al. (2011).

2 Methods

2.1 Data preparation

Data from 40 boat surveys conducted October 2001 through July 2004 along with 39 boat surveys conducted after late August 2005 were used in this analysis. Data from the 18 boat surveys conducted during the construction of the Kentish Flats wind farm were not used in this analysis as the question of interest focused upon comparing seabird numbers prior to construction with numbers following construction.

Across the survey region eight set transects (T1 to T8) were sailed, together with a further four control transects (C1 to C4). These survey data were processed by the BTO to convert geo-referenced survey data into data amenable to distance sampling analysis.

Because some observations in the bird data files contained no information on transect ID, we initially matched bird observations to their nearest transect line. Using the information on GPS start and end points of transects (single straight line per transect), we then calculated segments of equal length (300 m) along each transect. Given that Distance analysis for boat data is conducted on all observations up to 300 m from the boat (observations over 300 m are excluded), fixed 300 x 300 m squares were created along each transect and all bird observations on all survey dates were binned into these respective segments.

In reality the boat did not sail a straight path. Therefore we also calculated the nearest square for all observations lying just outside the square but were apparently recorded within 300 m from the boat. A final file was provided to CREEM containing the survey date, transect, transect length, segment square ID, midpoints of all segment squares, species, flock size, distance band, and whether birds were in the sea or air. These data processing steps were carried out in R v2.14.0 (The R Core Development Team 2011)

The five species sighted most commonly were analysed in this report. Number of flocks sighted during the surveys of interest are shown in Table 1.

	Pre swim	Pre fly	Post swim	Post fly
Red-throated divers	78	184	72	75
Lesser black-backed gulls	66	197	74	340
Herring gulls	32	209	65	591
Common gulls	11	96	31	264
Cormorant	25	22	91	86

Table 1: Number of flocks detected in boat surveys for the species considered in this report. Numbers are subdivided by bird behaviour (swimming or flying) and by pre- and post-wind farm construction.

2.2 Fitting detection functions

Simple half-normal detection functions incorporating covariates of group size (natural log thereof) and pre- or post-construction phase were considered as predictors that might influence detection probability. Flock behaviour (swimming or flying) was also taken as influencing detection probability. A substantial majority of the detections with the exception of cormorants, were of birds in flight. This constitutes a threat to the veracity of the analysis (see Discussion section). Under the ESAS protocol, snapshot counts of birds in flight are to be made during boat surveys, and these counts are assumed to be censuses (complete counts) of birds seen in flight.

A Horvitz-Thomson like estimator was used to adjust the number of flocks sighted into estimated numbers of birds in each 300m segment of survey transect (see Hedley and Buckland 2004). Counts within a survey segment are divided by their detection probability to produce an estimated number of birds in a segment. These adjusted counts are summed over all surveys that were conducted pre-construction and post-construction. Data from all surveys (regardless of season conducted) were included in the analysis for all species.

2.3 Fitting density surfaces

Generalised additive models using northing and easting as predictors were fitted to the adjusted counts of birds for each species, employing a quasi-Poisson error structure. The four candidate models were

$$\begin{aligned}
\text{adjusted count} &\sim \text{s(northing, k=3)} + \text{s(easting, k=3)} \\
\text{adjusted count} &\sim \text{s(northing, easting, k=6)} \\
\text{adjusted count} &\sim \text{s(northing, k=3)} + \text{s(easting, k=3)} + \text{Phase} \\
\text{adjusted count} &\sim \text{s(northing, easting, k=6)} + \text{Phase.}
\end{aligned}$$

Note the number of knots was restricted to 3 for the one-dimensional smooths and restricted to 6 for the two-dimensional smooths to keep the fitted density surface from being too flexible, given the spatial resolution of the survey data. Generalised cross-validation score was used to select among the candidate models.

3 Results

3.1 Detection functions

Detection functions were fitted to all species and AIC was used to select among competing models. AIC scores for fitted models are shown in Table 2. Plots of the fitted detection functions are shown in Fig. 1. Note that when phase is the only covariate included, there will be only two dots for each distance bin, however, when group size is included, there will be a multitude of levels of group size within each bin.

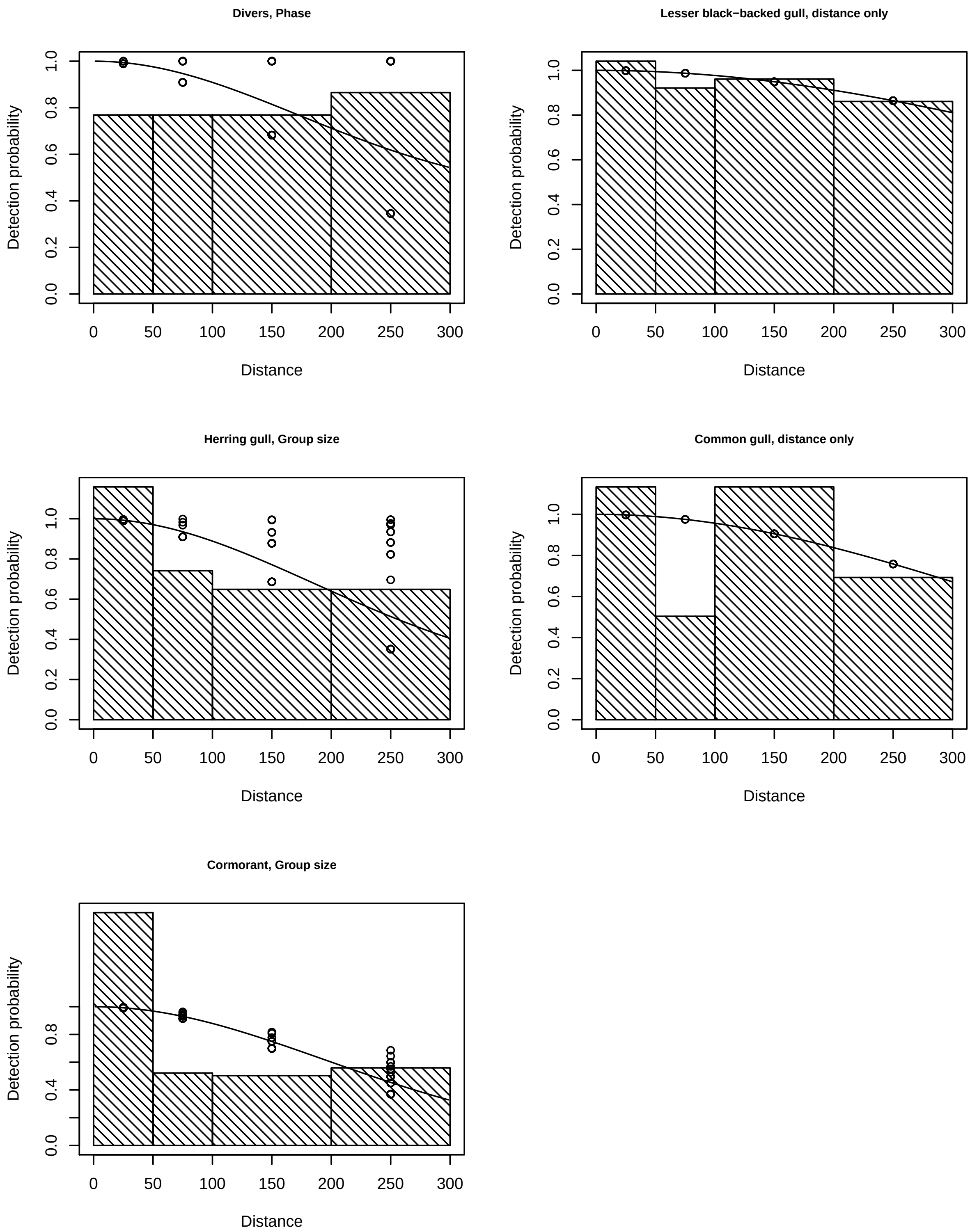


Figure 1: Fitted detection functions for birds swimming. Dots indicate numbers of detections for differing levels of the covariates included in the fitted detection functions.

	Distance only	Group size	Group size+phase	Phase
Divers swim	398.1		390.3	389.7
Lessers swim	377.1	374.6		378.7
Herring swim	269.7	265.9	267.6	271.6
Common swim	328.6	330.3	330.7	329.8
Cormorant swim	111.8	111.7	112.8	113.8

Table 2: AIC scores for fitted detection functions for each species. Model with smallest AIC used to adjust counts for imperfect detectability; with the exception of lesser black-backed gulls where the distance only detection function was used. Two detection functions failed to converge and their AIC values are not computed.

3.2 Density surfaces

3.2.1 Divers

Fitting a simple GAM to the pre- and post-construction data for the species of interest are shown below. Inference centres upon the difference between the surfaces (computed as **post-pre** for each cell in the prediction surface). If the upper confidence bound for a prediction cell is negative, there is reason to suspect there has been a detectable decrease in birds in that cell.

The fitted surfaces for divers are shown in Fig. 2, and the difference between the surfaces and the upper confidence bound for the difference in Fig. 3.

3.2.2 Lesser black-backed gulls

Fitted pre- and post-construction surfaces for lesser black-backed gulls are shown in Fig. 4, with the difference between surfaces, and the upper confidence bound for the difference in Fig. 5.

3.2.3 Herring gulls

Fitted pre- and post-construction surfaces for herring gulls are shown in Fig. 6, with the difference between surfaces, and the upper confidence bound for the difference in Fig. 7.

3.2.4 Common gulls

Fitted pre- and post-construction surfaces for common gulls are shown in Fig. 8, with the difference between surfaces, and the upper confidence bound for the difference in Fig. 9.

3.2.5 Cormorants

Fitted pre- and post-construction surfaces for cormorants are shown in Fig. 10, with the difference between surfaces, and the upper confidence bound for the difference in Fig. 11.

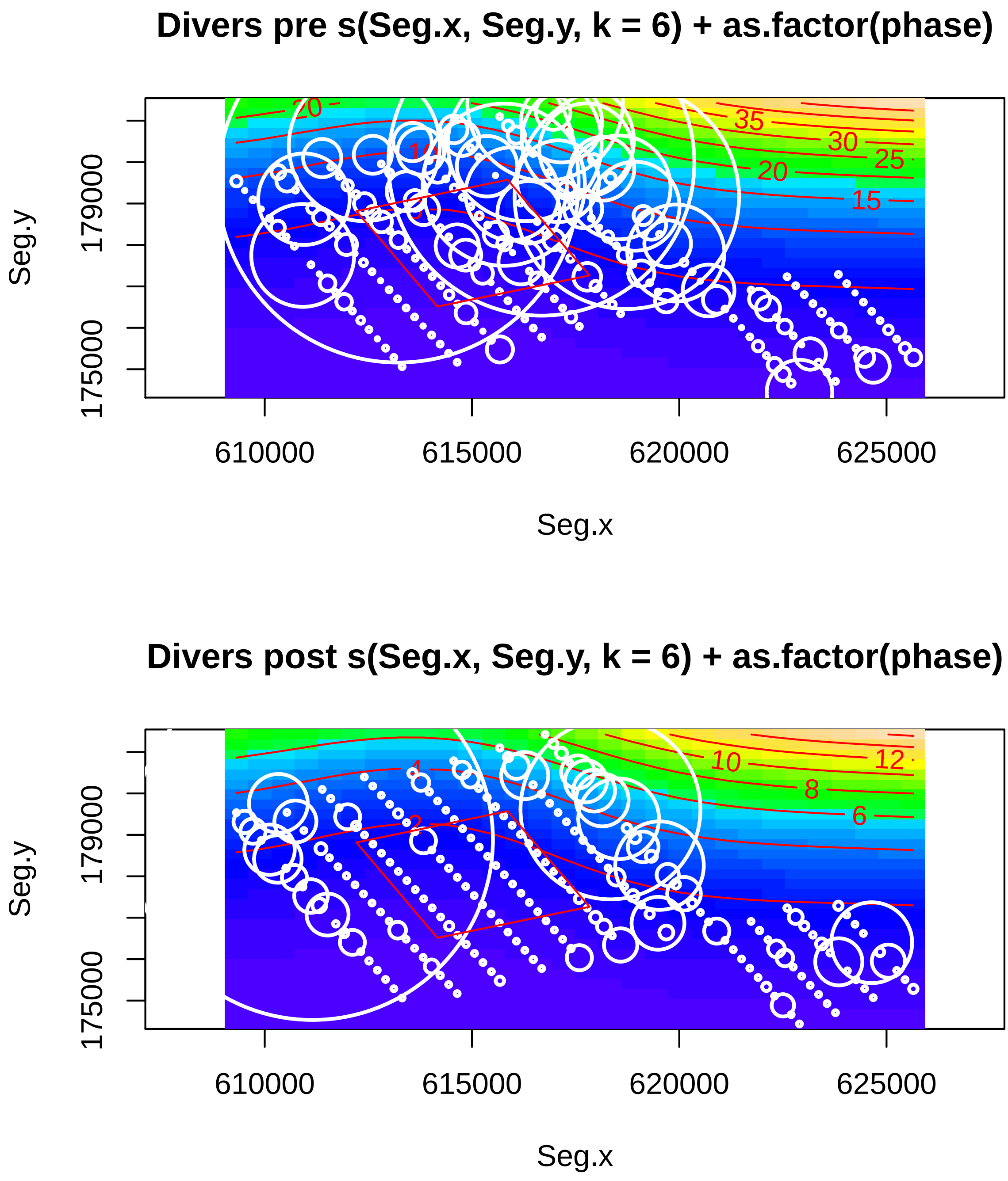


Figure 2: Density surfaces for divers fitted to pre- (top) and post-construction (bottom) data. The predictors used were northing and easting with 3 knots for each dimension. Circle radii are proportional to number of flocks seen within each 300m survey segment.

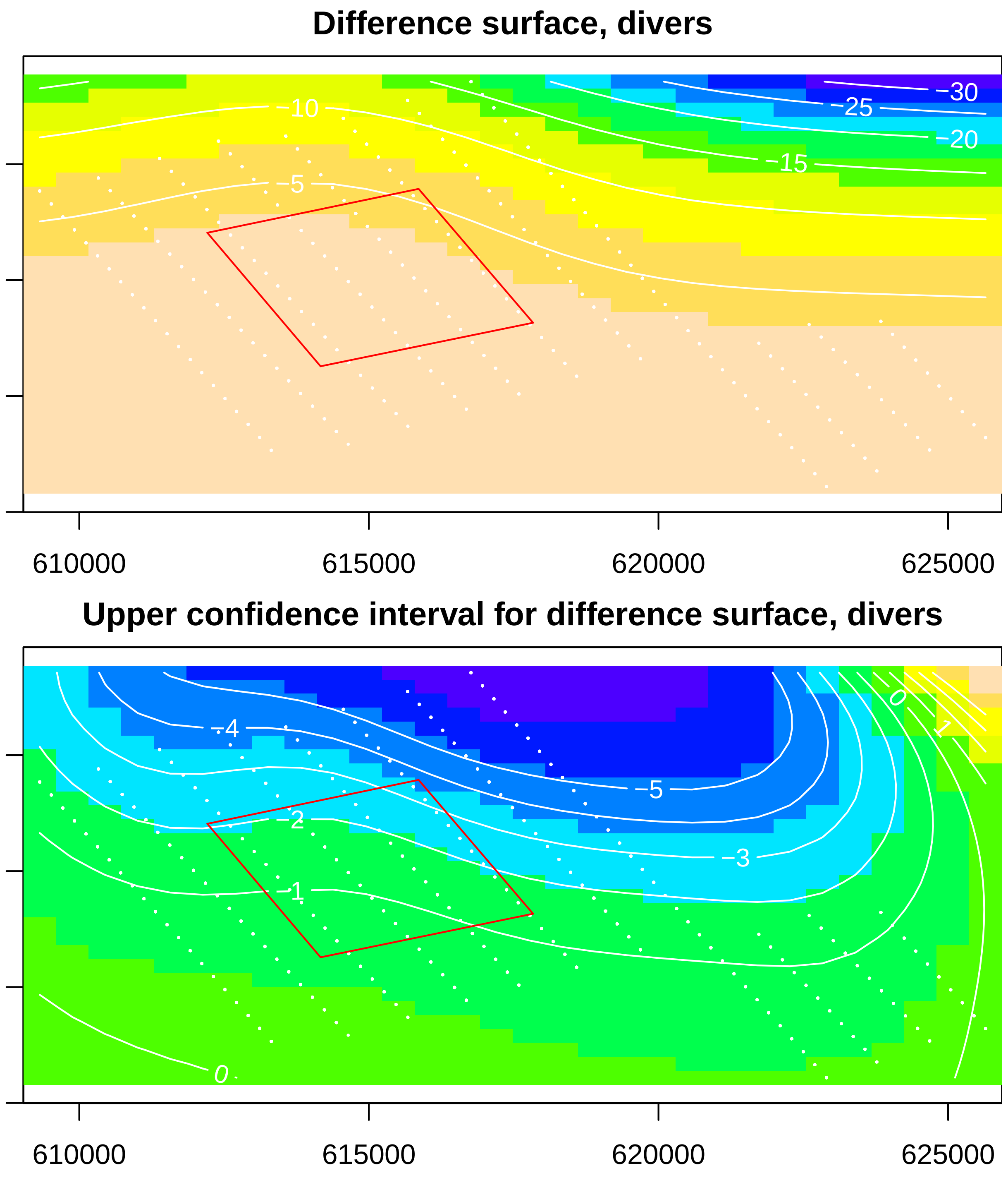


Figure 3: Difference (**post-pre**) in estimated number of divers for Kentish Flats (top). The upper confidence bound for the prediction grid cells, taking into consideration only uncertainty associated with the density surface modelling. If the upper confidence bound is negative, then the number of divers post-construction is significantly smaller than the number of divers pre-construction.

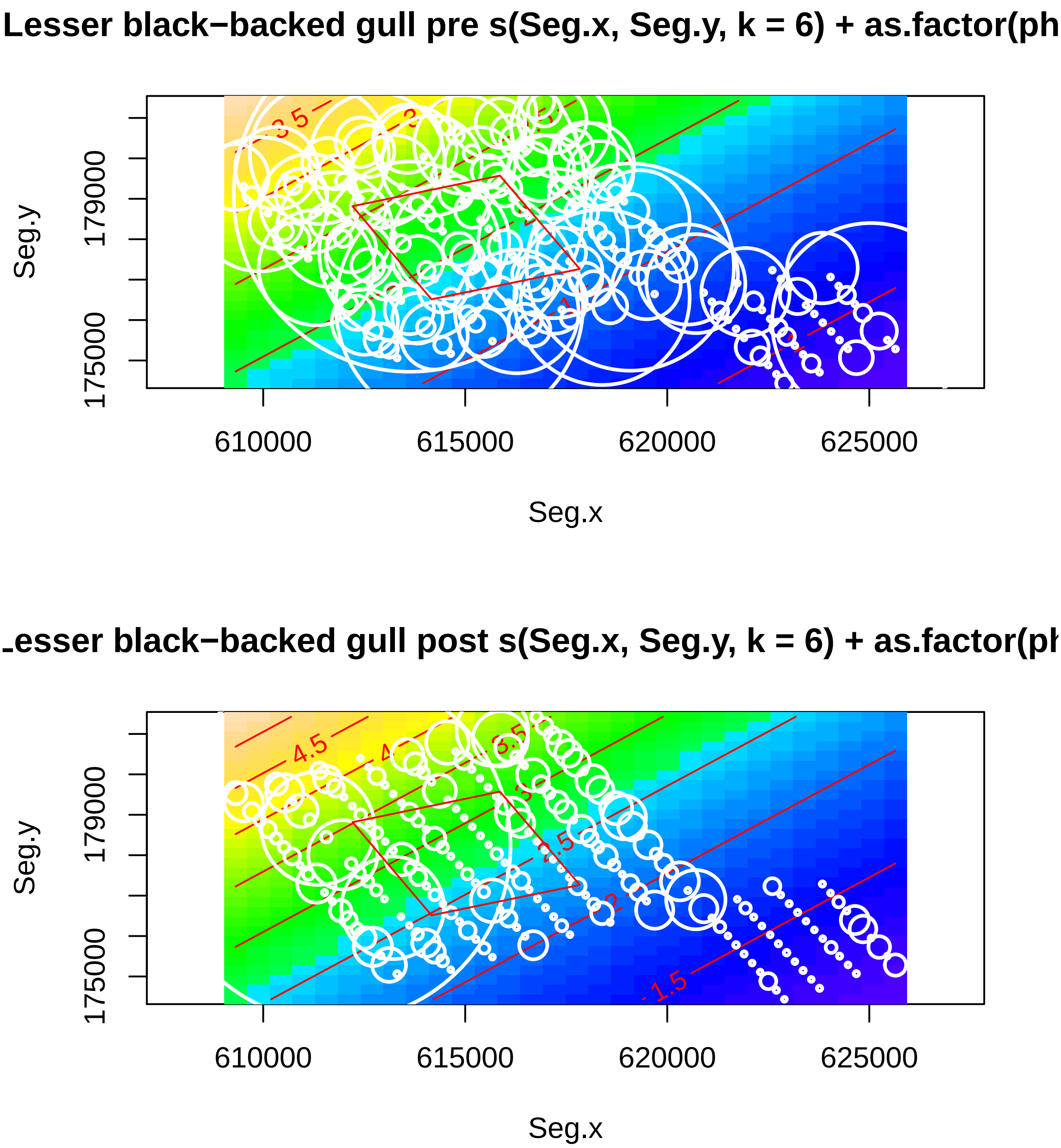


Figure 4: Density surfaces for lesser black-backed gulls fitted to pre- (top) and post-construction (bottom) data. The predictors used were northing and easting with 3 knots for each dimension. Circle radii are proportional to number of flocks seen within each 300m survey segment.

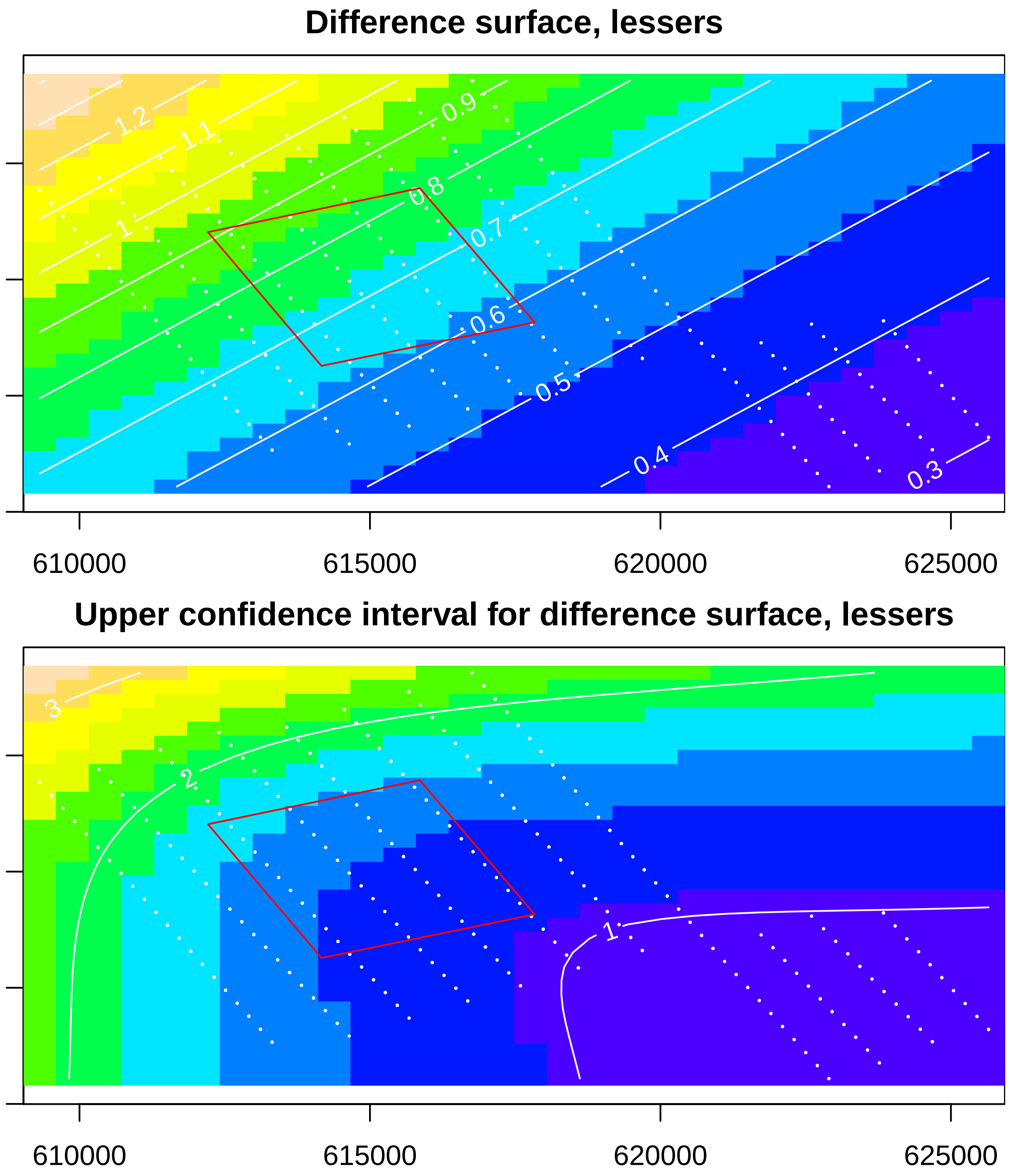


Figure 5: Difference (**post-pre**) in estimated number of lesser black-backed gulls for Kentish Flats (top). The upper confidence bound for the prediction grid cells, taking into consideration only uncertainty associated with the density surface modelling. If the upper confidence bound is negative, then the number of lesser black-backed gulls post-construction is significantly smaller than the number of lesser black-backed gulls pre-construction.

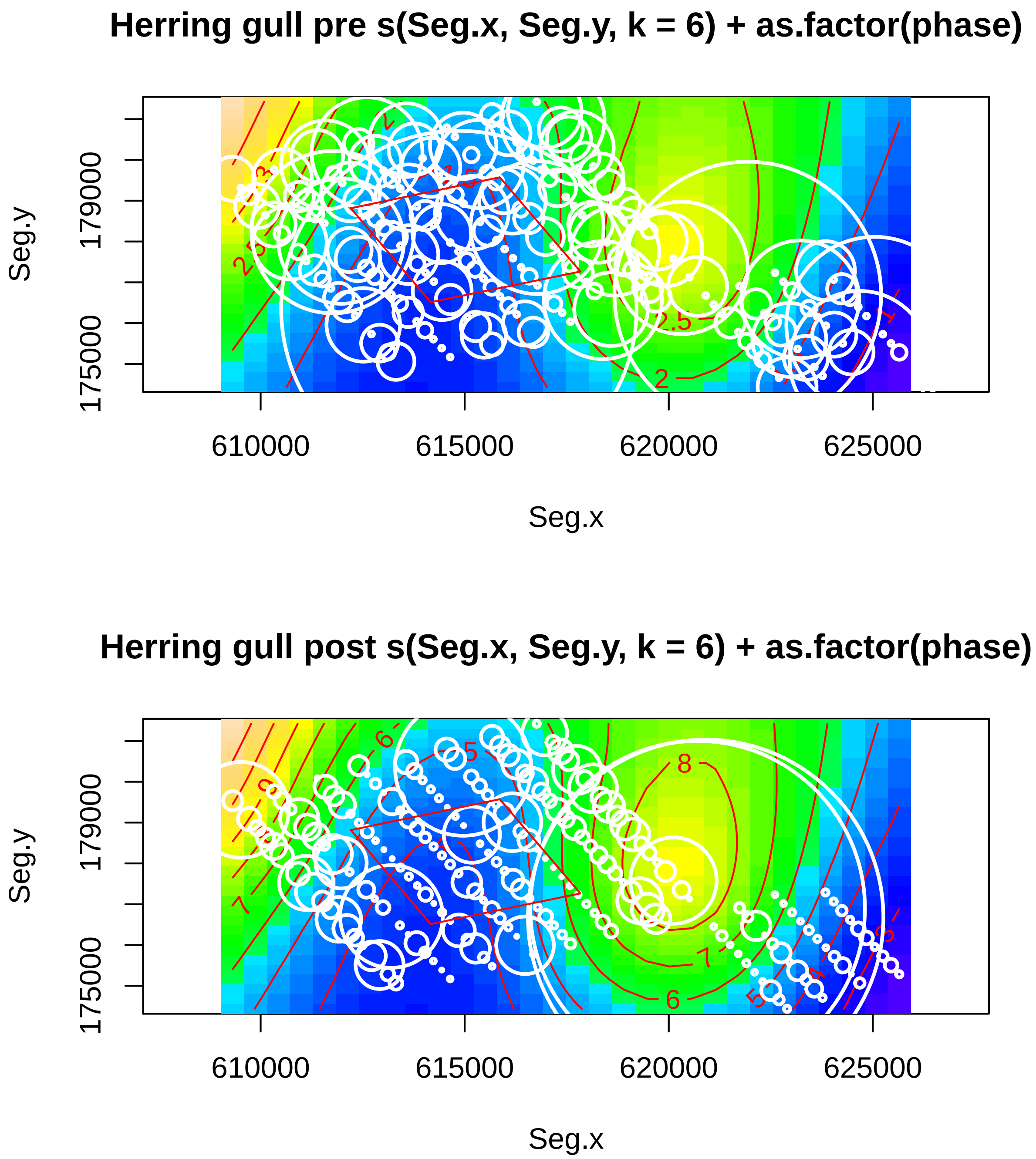


Figure 6: Density surfaces for herring gulls fitted to pre- (top) and post-construction (bottom) data. The predictors used were northing and easting with 3 knots for each dimension. Circle radii are proportional to number of flocks seen within each 300m survey segment.

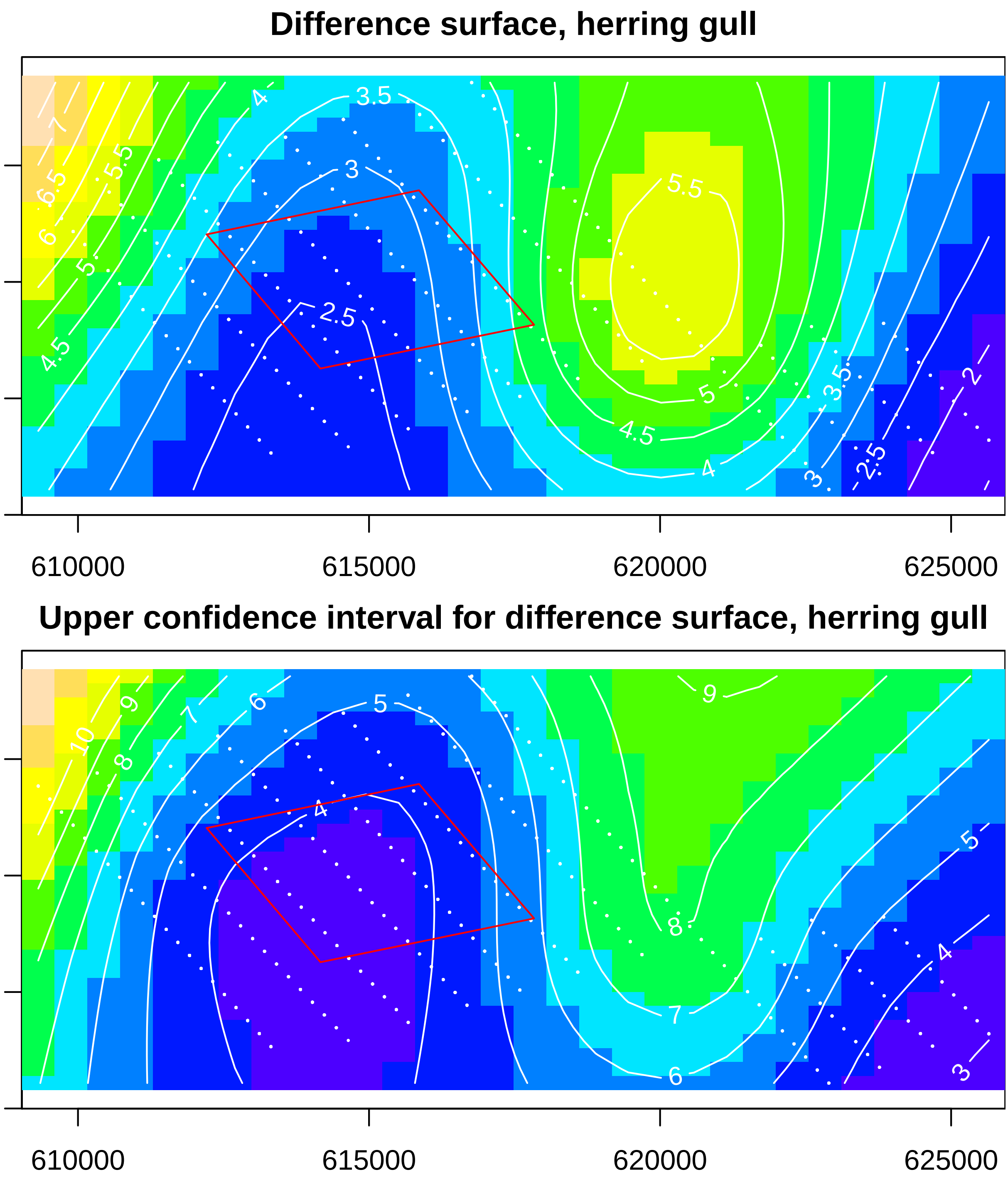
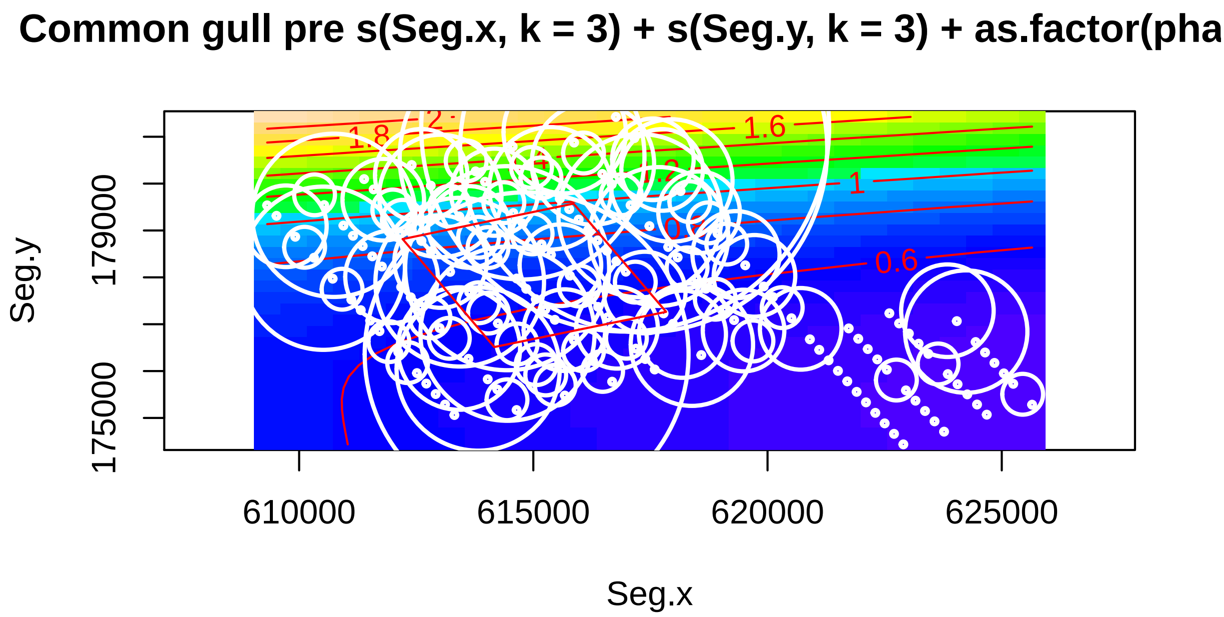


Figure 7: Difference (**post-pre**) in estimated number of herring gulls for Kentish Flats (top). The upper confidence bound for the prediction grid cells, taking into consideration only uncertainty associated with the density surface modelling. If the upper confidence bound is negative, then the number of herring gulls post-construction is significantly smaller than the number of herring gulls pre-construction.



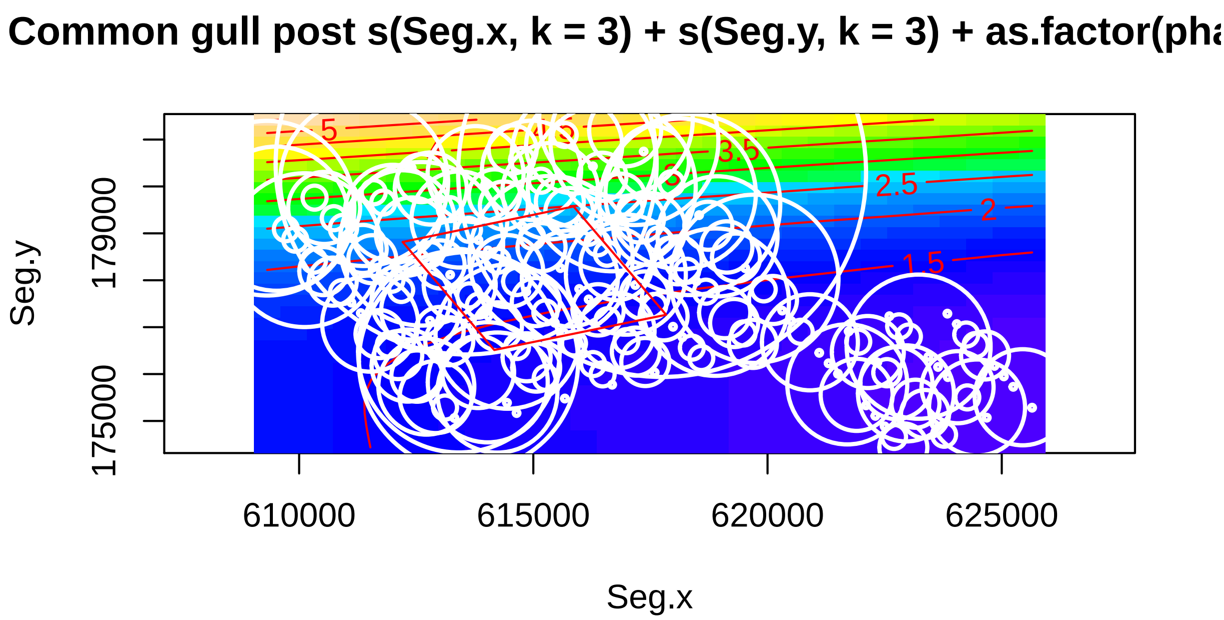


Figure 8: Density surfaces for common gulls fitted to pre- (top) and post-construction (bottom) data. The predictors used were northing and easting with 3 knots for each dimension. Circle radii are proportional to number of flocks seen within each 300m survey segment.

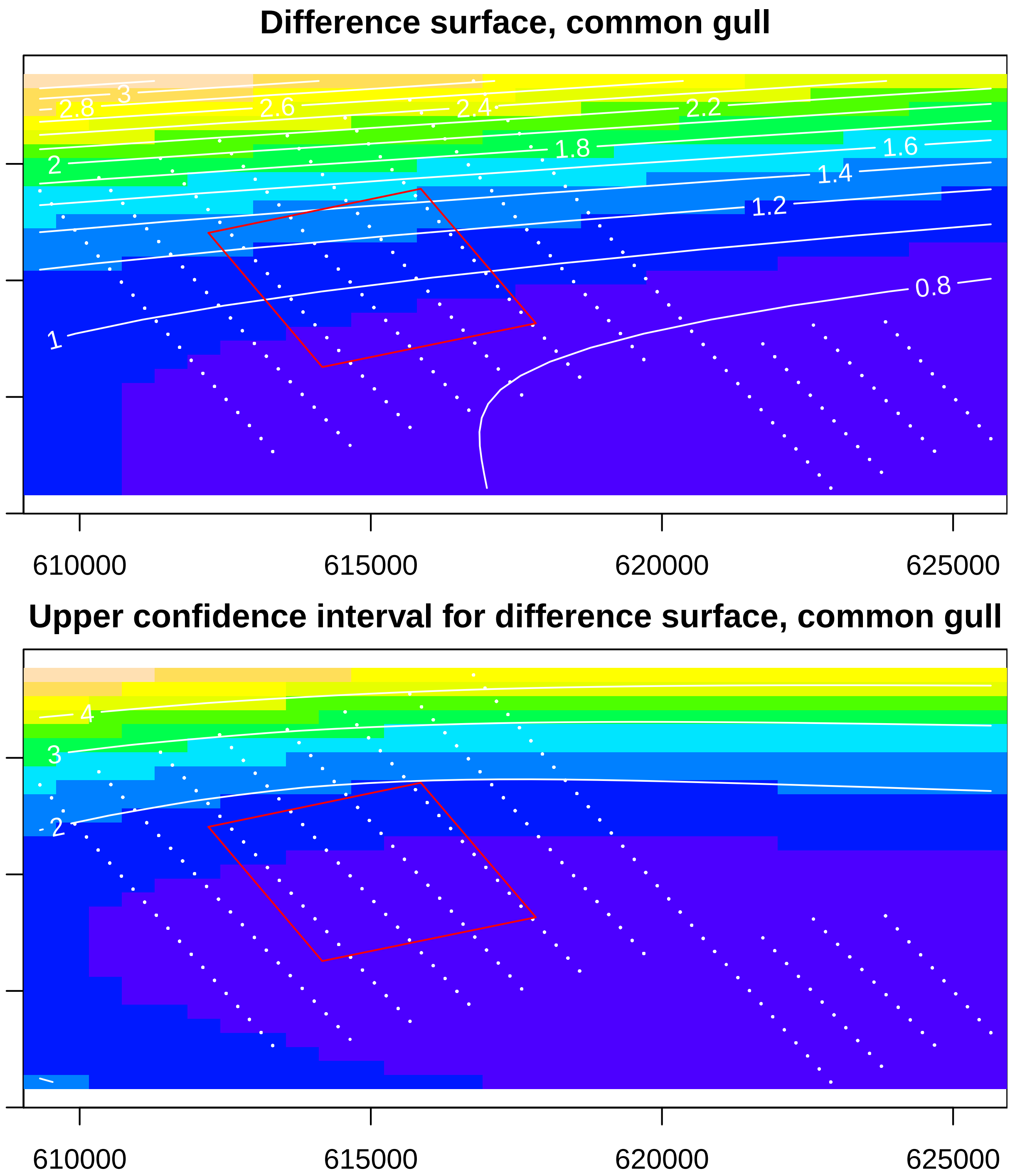


Figure 9: Difference (**post-pre**) in estimated number of common gulls for Kentish Flats (top). The upper confidence bound for the prediction grid cells, taking into consideration only uncertainty associated with the density surface modelling. If the upper confidence bound is negative, then the number of common gulls post-construction is significantly smaller than the number of common gulls pre-construction.

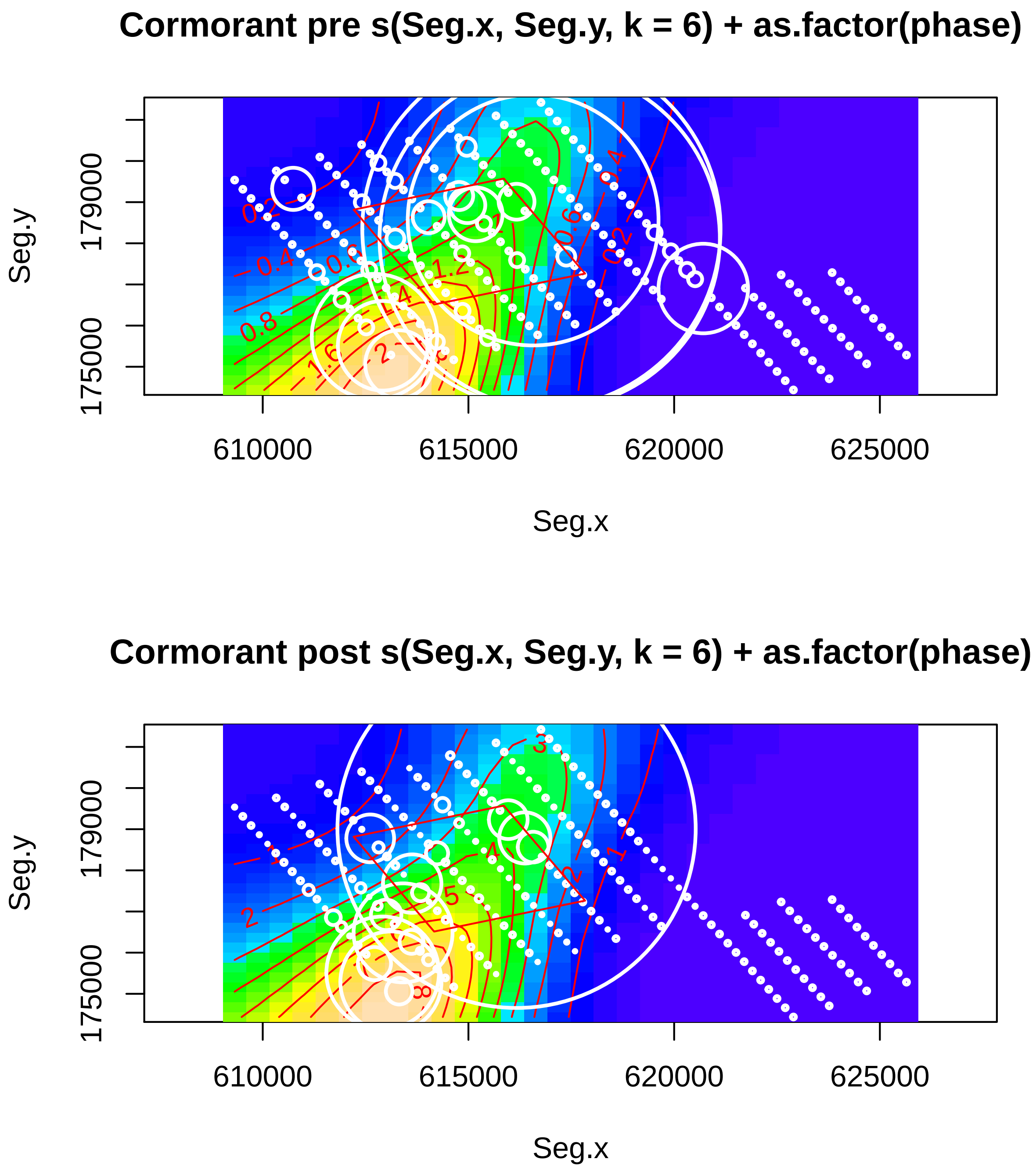
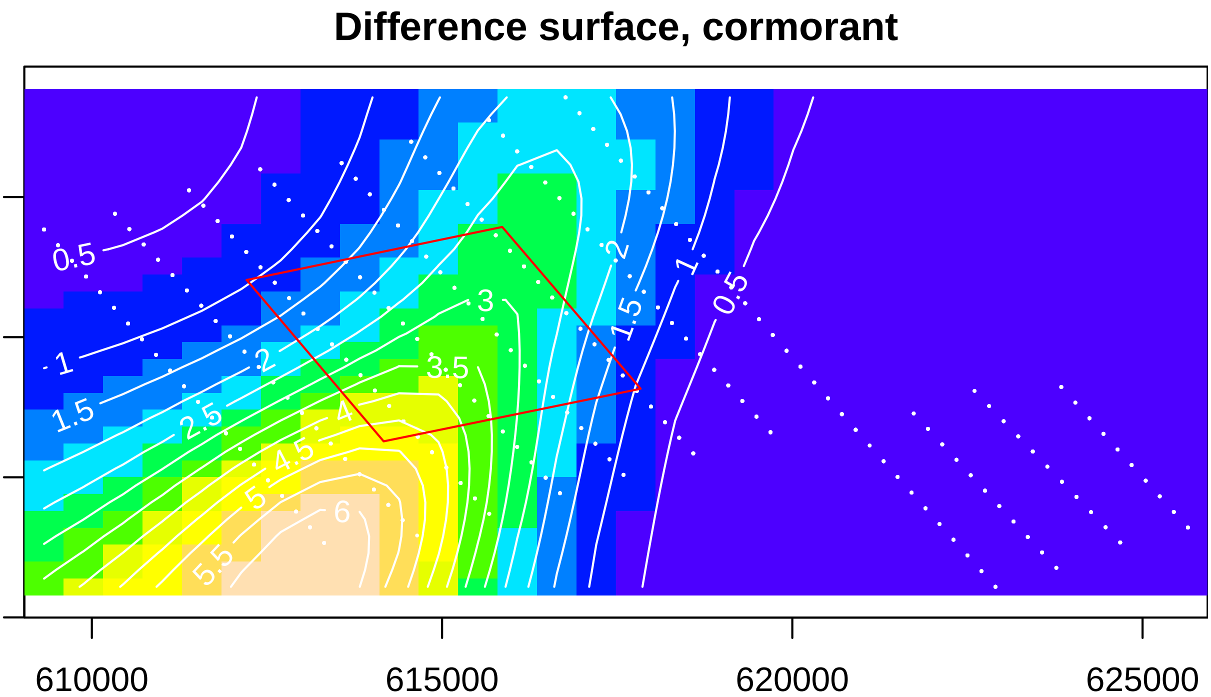


Figure 10: Density surfaces for cormorants fitted to pre- (top) and post-construction (bottom) data. The predictors used were northing and easting with 3 knots for each dimension. Circle radii are proportional to number of flocks seen within each 300m survey segment.



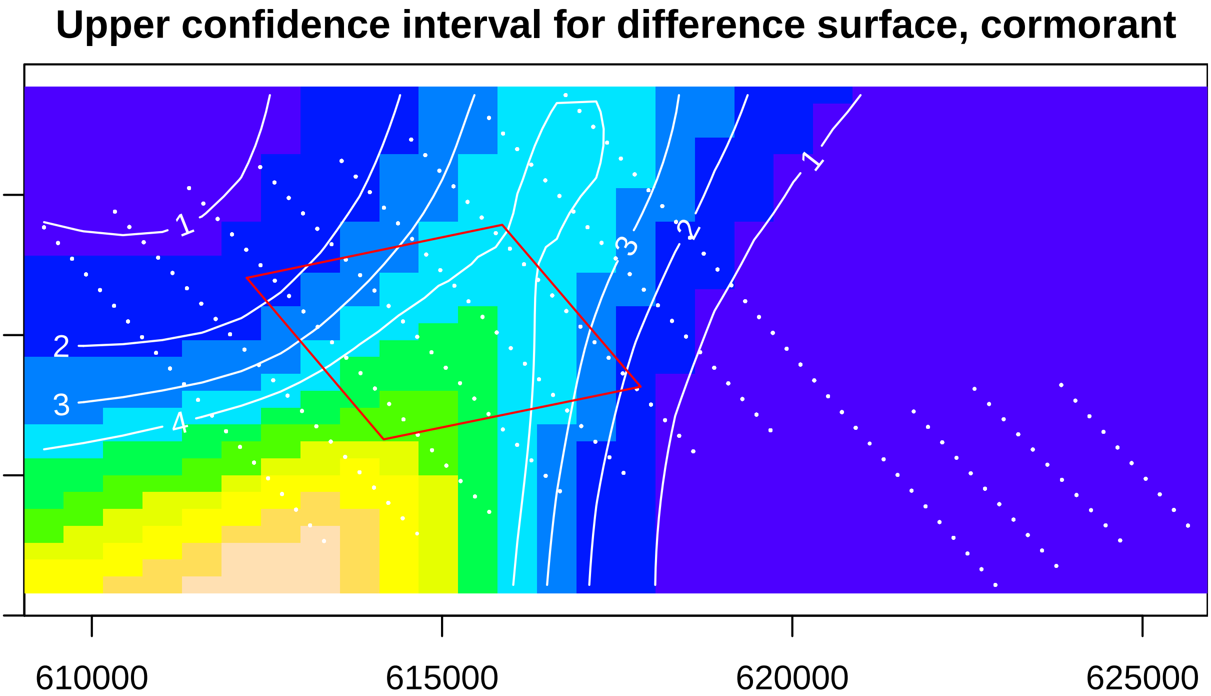


Figure 11: Difference (**post-pre**) in estimated number of cormorants for Kentish Flats (top). The upper confidence bound for the prediction grid cells, taking into consideration only uncertainty associated with the density surface modelling. If the upper confidence bound is negative, then the number of cormorants post-construction is significantly smaller than the number of cormorants pre-construction.

4 Discussion

4.1 Birds detected in flight

We were unable to recreate information about the snapshot procedure for counting birds in flight from the original data, hence we are unable to determine the potential for overestimating birds in flight. It is unsettling that birds in flight constitute the dominant source of data for this study; 90% of the detections for herring gulls. Rather than eliminating the dominant data from the analysis, we retained the bird in flight sightings, and fitted detection functions to these data recognising the birds may be in flight in response to the boat. Because sightings of birds in flight were treated identically for the pre- and post-construction period, we are of the opinion that this will not heighten or diminish the magnitude of displacement measured in this report.

The fitted detection functions shown in Fig. 1 are a bit surprising, given what we know about seabird behaviour; e.g. sharp drop off in detection function for swimming cormorants with scarcely any drop off in detection of red-throated divers. Such unusual features of the detection functions make us reluctant to make strong inferences about the resulting density surfaces that depend upon these detection functions.

4.2 Adjustment for uncertainty and spatial autocorrelation

Given the uncertainties in the recreation of the sighting data, an exhaustive analysis of the data was not warranted. In the modelling of the density surface, we did not take into account the correlated nature of the adjusted counts between adjacent transect segments. Furthermore the uncertainty associated with the predicted number of individuals throughout the study area does not take into account uncertainty in the detection function models, only uncertainty in the density surface model. Therefore assessment of "significance" of the estimated pre- and post-construction distribution cannot be assessed. We are comfortable with this situation because to assess "significance" in the face of the uncertainty in the recreation of the data seems unwarranted.

4.3 Definition of displacement rate

Beyond the data management and statistical challenges of this assessment of displacement rate, there is also the scientific question of the definition of displacement. Much of the discussion of displacement with regard to licensing of offshore wind farms has been in the context of quantifying collision risk. In that context, a scalar value (proportion of birds previously inhabiting wind farm footprint displaced from that footprint) is needed to incorporate into collision risk models. However, in a context broader than collision risk, displacement is in reality a four-dimensional quantity: response variable (number of birds) moved in both an x-dimension and a y-dimension (because there is no reason to presume displacement is symmetric around the wind farm footprint) over time (with that displacement perhaps attenuating with time as a result of habituation). The long-term fitness consequences of displacement to less optimal habitats, and the knock-on consequences of displacement for seabird populations are impacts that ought also be measured; but these impacts cannot be condensed into a single number.

4.4 Recommendations

This attempt to assess displacement of seabirds at Kentish Flats from boat-based surveys has been enlightening in several respects. The search for wind farms with sufficient data to attempt an analysis was prolonged and resulted in only two wind farms with sufficient data to investigate. After identifying the data sets of interest, moulding the data (some of which had been collected more than a decade ago) for analysis was difficult. Finally with the data in hand, the ability to make concrete statements about the magnitude of seabird displacement was minimal.

4.4.1 Study area boundaries

The study design of Kentish Flats was undertaken to the recommended standard at the time the study was initiated (2001). Apparent from the fitted density surfaces, particularly for the divers, is that bird concentrations (as predicted from the models) were outside the surveyed region. That makes interpretation of these surfaces ambiguous. If animals were displaced away from the wind farm footprint, the only circumstance in which they could be displaced and detected would be for them to relocate southeast by a few kilometres. This study design was created under the premise of "treatment and control," which in the absence of replicate treatments or controls makes inference about changes in abundance or distribution difficult. For the purpose of measuring displacement, the survey design was only able to detect birds generally displaced less than 1.5km, as this was the size of the surveyed buffer around the wind farm footprint (except for the 'control' area to the southeast of the main study area).

Going forward, if displacement was indeed a necessary metric to come from wind farm surveys, then the spatial scope of the survey would have to be increased so as to permit detection of displaced animals. It is also the case that the size of Kentish Flats was small to the point that a) few birds were detected in a single survey (hence data from 30-40 surveys were pooled for each phase of the project) making it impossible to look for attenuation of displacement and b) potential environmental covariates such as bottom depth appear from nautical charts to vary only slightly within the study area, and are unlikely to explain much variability in the spatial distribution of the seabirds. The estimated number of birds within the treatment area could be calculated from the pre- and post-construction density surfaces to measure change within the surveyed region without respect to spatial rearrangement. We did not produce these estimates because we did not know the biological rationale underlying the surveyed region boundary. From the sightings, it would seem that birds were detected to the edges of the surveyed region, giving little reason to suspect this boundary is something respected by the birds. The analysis performed by Percival (2010) looked for spatial changes in concentric bands centred upon the wind farm footprint.

For Round 3 potential sites, prospects might be brighter for being able to collect data so as to measure displacement. Many of the Round 3 areas being surveyed are larger than the size of the installations potentially being constructed. This may make it possible to have a buffer out with the wind farm footprints that are of sufficient size to detect seabirds that may be displaced from these installations. However surveys will need to occur for sufficient periods post-construction such that possible temporal aspects of displacement could be measured.

4.4.2 Site-based measurement of displacement

The recommendations of Camphuysen et al. (2004) suggested surveyed areas be six times the size of the wind farm footprint. Totalling the size of the 'buffer' surrounding the footprint plus the 'control' site resulted in a surveyed region 5.5 times the size of the proposed wind farm (Maclean et al. 2009). It is our opinion that this area is small for the purpose of describing the spatial redistribution of seabirds as a consequence of wind farm construction and operation. Also as noted in Maclean et al. (2007) the use of covariates that may afford some explanatory power in the spatial distribution of seabirds can also prove useful in deducing whether perceived displacement might be caused by changes in environmental regimes as opposed to disturbance associated with the wind development.

Existing site-based studies of displacement can be enhanced if a model-based approach is taken. Using a small number of explanatory covariates that are influential to the sea birds of interest, e.g., water depth for diving sea birds can enhance the value of field data collected and potential tease apart displacement effects of wind farms from displacement effects of changing prey resources for example.

4.4.3 Broad scale studies of displacement

It is not known at what spatial scale displacement occurs. If the displacement takes place over short distances, then perhaps those redistributions can be detected by small scale studies. However if displacement occurs over large distances, studies that are small in scale will not detect the redistribution and will conclude population-level change in abundance. Increasing the size of the surveyed region will ameliorate that effect. In addition a larger surveyed region will also expand the range in the explanatory covariates observed. This will enhance the explanatory capability of a model-based investigation of displacement. There will be more explanatory power in covariates that are measured over a greater range. Furthermore cumulative impacts of successive wind farm developments can be assessed by examining whether potential displacement exhibited in one phase of a development is altered when a later phase of development takes place. These compound effects cannot be examined unless the survey region is of sufficient size to incorporate multiple wind farm developments.

4.5 Benefits to consulting

A model-based approach to displacement is a useful way of measuring this phenomenon because it provides both an inferential measure and also a visual depiction of where the negative and positive displacement may be occurring within the study area. Possible benefits to consenting for offshore wind farms are a) modelling sea bird distribution pre- and post-construction may show population consequences are not necessarily mortality of animals but rather redistribution of animals and b) if explanatory covariates are included in the density surface modelling, factors other than presence of a wind farm that might explain distribution of sea birds could prevent misidentification of the wind farm as the causal agent in sea bird redistribution.

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