Evaluation of Dark-Bellied Brent Geese (*Branta bernicla bernicla)* population trends along the North Kent and Essex Coastline, and their potential application as environmental indicators

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Executive summary:

Understanding the condition of coastal wetlands within the UK is of high importance given the plethora of ecosystem services they provide. However, their ability to support biodiverse ecosystems or cycle nutrients is undermined by anthropogenic pressures. The Greater Thames Estuary is an example of a wetland area strongly associated with human activities, however the Transforming the Thames Project seascape-scale restoration project aims to improve these habitats. By analysing the population trends of Dark-Bellied Brent Geese, who heavily rely on these coastal wetland environments, it provides an opportunity to explore their use as indicators for environmental quality.

Using data from the Wetland Bird Survey (WeBS), this exploratory analysis used General Additive Models to create population indices, from which trends in percentage change of relative population size were calculated. This identified long-term declines in the majority of sites surrounding the Greater Thames Estuary, along the north Kent and Essex Coastlines. However, in the short term, relative population size showed increases. These results concur with those published by WeBS, however variations due to model systematic bias and data availability exist. As such, WeBS data should always be referred to for validated trends. A suggested trend of favouring inland sectors across the wintering period was also identified, however this highlighted the need for further research and integration of other confounding factors, such as anthropogenic disturbance, urbanisation and global climate data. This will help demonstrate vulnerable sites and high-impact external pressures, which in turn can help identify priority restoration sites. Overall, the results suggest strong application opportunities for the use of Dark-Bellied Brent Geese as environmental indicators.

Acknowledgements:

I would like to thank the Dr Chas Holt for his invaluable guidance and support throughout this project. I would also like to acknowledge and thank the work of the Wetland Bird Survey volunteers for their countless hours of bird surveying. In particular, I would like to thank Murray Orchard, Bob Knight, Nick May, Greg Godden and Peter Tyler for their time and enthusiasm. I'm also grateful for the encouragement I received from Sherece Kesner, Max Renton, Linn Wiberg and Jack Price. Finally, I would like to acknowledge the Data provided by WeBS, a partnership jointly funded by the BTO, Royal Society for the Protection of Birds and Joint Nature Conservation Committee, in association with the Wildfowl & Wetlands Trust. Please see their website to source validated population trends.

Introduction:

UK coastal wetlands contain crucial functional habitats, providing a range of ecosystem services that humans and species rely on (Robins et al., 2016). Saltmarsh, mudflat and seagrass habitats are ecologically important in supporting biodiversity-rich ecosystems, providing habitats for breeding and feeding species, contributing to nutrient cycling and storage, as well as playing a role in flood-risk management. Consequently, given their functional diversity, it is crucial to gain detailed understanding of the health of these habitats, particularly in the face of anthropogenic-driven climate change.

The Greater Thames Estuary contains a multitude of intertidal wetland habitats. Moreover, it has been historically, and continues to be, closely connected to human activities and associated with heavily urbanised areas. Anthropogenic uses of the estuarine habitats include fishing, agriculture and transport (Tinsley, 1998, pp.5–26). As a result of such activities, and subsequent disturbance and pollution, the wetland habitats have been subjected to a cyclical process of deterioration (Richardson and Soloviev, 2021).

Dark-Bellied Brent Geese (DBBG) (*Branta bernicla bernicla*) are strongly dependent on UK coastal and wetland habitats for feeding and roosting sites over their wintering period. After travelling distances of about 2500 miles from northern Siberia, DBBG remain in the UK between September and March (Trust and Chambers, 2018). In addition to Eel Grass species (*Zostera marina* and *Zostera noltii*), DBBG also feed on green algae and saltmarsh habitats across the UK (Ganter, 2000). An estimated 40-59% of the European DBBG population is hosted in Britain, with the east and south-east coastline of England sheltering the majority of the wintering populations. In particular, sites between Essex and Kent form the principal wintering locations (Salmon and Fox, 1991). However, DBBG are classified as 'Amber Listed' according to the UK Birds of Conservation Concern (British Trust for Ornithology, 2015), due to the cumulative effects of habitat degradation, loss of connectivity between stopover sites and food availability issues (Trust and Chambers, 2018).

As a result, it is evident that UK coastal wetlands and estuarine habitats are of international importance, supporting migratory species that depend upon these environments. In particular, the north Kent and Essex coastline play an important role in supporting wintering populations. However, there are knowledge gaps about the health of these habitats when considered holistically as a functionally important, interconnected area. As such, DBBG could be used as environmental indicators for the overall health of these estuarine and coastal habitats.

This has potential strong applications for the Transforming the Thames (TtT) project, a seascape-scale restoration, recovery and reconnection project within the Thames Estuary. Understanding the population trends of DBBG in this cultural and internationally, ecologically important site could help inform understanding of environmental health at a seascape-scale, as well as spotlight future habitat restoration and enhancement projects.

The British Trust of Ornithology (BTO) have conducted Wetland Bird Surveys (WeBS) since 1947, collecting monthly count data on different species at sites across the UK. DBBG are one of the 220 waterbird species monitored (British Trust for Ornithology, 2018). Consequently, this species is well-studied, providing a suitable candidate for long-term population analysis using an extensive dataset. Therefore, this underlines the strong potential for using DBBG as environmental indicators.

Although the BTO produces both national and site-specific trends, this report aims to spotlight a functionally connected seascape-scale area. As such, this analyses population trends of DBBG across different sites that make up an ecologically and culturally important interconnected area. To investigate this in fine detail, different spatial and temporal scales were used. This will be achieved by investigating the following research questions: 1) Understand and visualise DBBG population sizes at sites within the north Kent and Essex area, 2) Understand how population trends have changed over the study period (1992-2022) between the sites, 3) Understand how population size changes across a wintering period within a site and 4) Investigate he potential relationship between DBBG and habitats (saltmarsh and seagrass).

The results of this report have the potential to be a pilot study investigating the possible use of DBBG as an indicator species for environmental quality. In turn, this could help inform site management plans, inform restoration feasibility projects and support the TtT in identifying priority restoration sites.

Methods:

<u>Study Area: Sites and Sectors</u>

This report covers 10 survey sites along the north Kent and Essex coastline (figure 1), each with multiple designations on all, or sections, of the site (table 1). These sites represent good geographical coverage of wetland habitats across the coastline, as well as displaying connectivity within the Greater Thames Estuary area. Each site is split into sectors, largely for practical monitoring reasons, but this means sectors generally reflect distinctive environmental features (Woodward and Austin, 2022) .

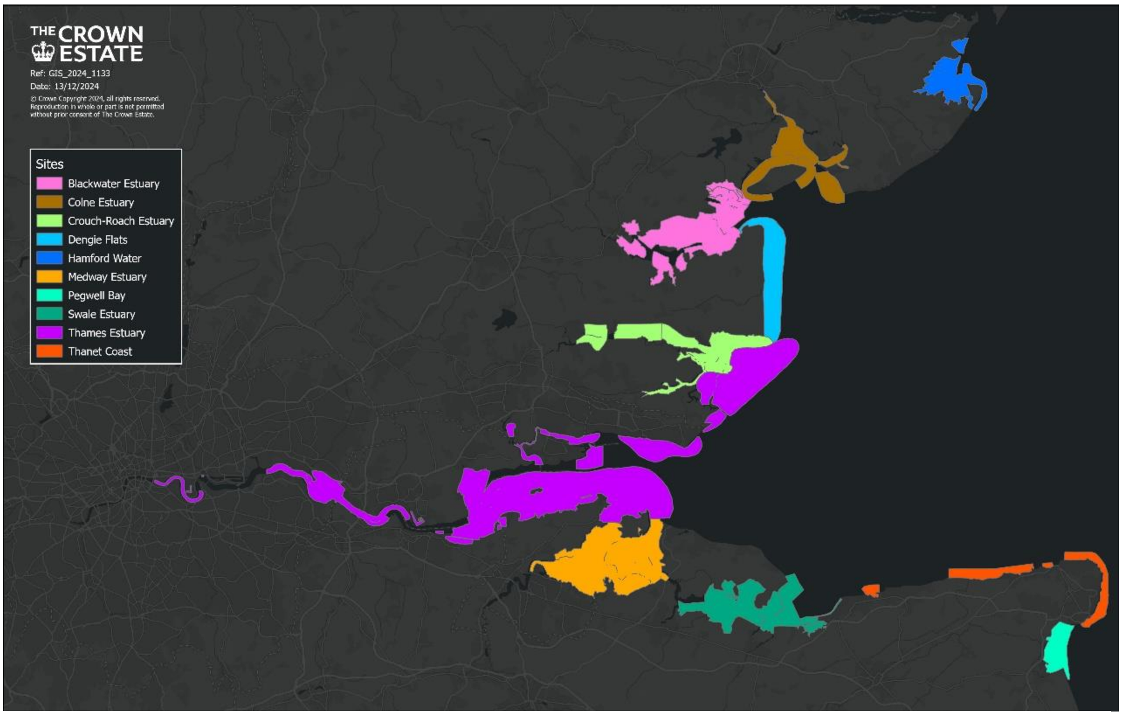

Figure 1: WeBS Site boundaries along the north Kent and Essex Coastline, with different colours representing the different sites. Created using ArcGIS.

Site Name	**Site Code**	**Designations included**
Hamford Water	25971	Ramsar, SSSI, SPA, SAC
Colne Estuary	25953	Ramsar, SSSI, SPA, SAC, MCZ
Blackwater Estuary	25948	Ramsar, SSSI, SPA, SAC, MCZ
Dengie Flats	25441	Ramsar, SSSI, SPA, SAC, MCZ
Crouch Roach Estuary	25931	Ramsar, SSSI, SPA, SAC, MCZ
Thames Estuary	25901	Ramsar, SSSI, SPA, SAC, MCZ
Medway Estuary	22460	Ramsar, SSSI, SPA, MCZ
Swale Estuary	22450	Ramsar, SSSI, SPA, MCZ
Thanet Estuary	22931	Ramsar, SSSI, SPA, SAC, MCZ
Pegwell Bay	22412	Ramsar, SSSI, SPA, SAC

Table 1: Site names, codes and designations of the WeBS sites along the north Kent and Essex coastline

Study Species

DBBG (*Branta bernicla bernicla*) is a subspecies of the *Branta* goose family, distinguished from other species (light-bellied (*B. b. hrota*) and black-bellied (*B. b. nigricans*)) by their colouring and breeding locations. DBBG breed along the coast of Siberia (Taymyr Peninsula) (Trust and Chambers, 2018) before migrating mid-September along the northern Russian, White Sea, Baltic Sea, North Sea, English Channel and French Atlantic coastlines (figure 2). As well as wintering September to March in the UK (figure 3), DBBG also have wintering sites in France and the Netherlands.

Figure 2: General migration route of DBBG from Taymyr Peninsula, Siberia, along the northern European coastline, towards the UK. Edited Google Map.

Figure 3: General habitat boundaries of the two most common *Branta* species within the UK*:* *B. b. hrota* and *B. b. bernicla*). Edited map from Wetlands International Waterbird

Being almost exclusively herbivorous and unable to dive, DBBG spend their wintering period feeding on green alga, Eelgrass (*Zostera marina* and *Zostera noltii*) and saltmarsh vegetation (Ganter, 2000). *Zostera* is the preferred food source due to its high nutritional value and easy digestibility, which are traits important for migratory species. As a result, DBBG are heavily dependent on intertidal shallow-water areas and infrequently upland pastures or cereal fields. This means that DBBG rely on different habitats within and adjacent to coastal wetland environments throughout their wintering and migration period. Further information on DBBG ecology can be found here:

- https://wpp.wetlands.org/explore/386/2056?conservation=1
- https://www.bto.org/understanding-birds/birdfacts/brent-goose#:~:text=Brent%20Geese%20are%20locally%20numerous,from%20four%20separate%20breeding%20populations.

According to the BTO WeBS online report, in 2023, the total population of DBBG in Great Britain was recorded as 86,569 individuals. However, it is acknowledged that this total includes estimated and incomplete counts. This aligns with the current national population estimate of 98000 ((Woodward et al., 2020).

WeBS data

WeBS Count data, organised by the BTO, are collected by volunteers on monthly synchronous counts at sites across the UK. This consists of site-level Core Counts, and infrequent Low Tide Counts for estuaries. Supplementary Count Data can be submitted as well, however for this report, only Core Count Data are used. Each site is also split into sectors.

Counts are recorded for the UK's internationally important non-breeding waterbirds, with 220 species counted on average a year. Counts have been conducted since 1947, but this report focuses on Core Counts from 1992-2022.

The data are used to calculate population trends in abundance and distribution of individual species or communities, at both site, regional and national levels. The BTO publishes annual summary reports and "WeBS alerts" which helps monitor changes in population status over time, which can then be used to inform site management, for example.

Data were provided by WeBS, a partnership jointly funded by the BTO, Royal Society for the Protection of Birds and Joint Nature Conservation Committee, in association with the Wildfowl & Wetlands Trust. Fieldwork is conducted by volunteers. The data used consisted of count data at each sector for each site, with corresponding dates and times of recording also included. The trends subsequent calculated within this report are exploratory calculations, meaning validated population trend data should be sourced from the BTO and WeBS.

Visualising WeBS DBBG population sizes in the study area

To understand the range of population sizes across the 10 sites within the study area, the average annual maximum count was calculated for each. Data between the years 1992 and 2022 was used, over the wintering months of September to March.

This was then mapped using ArcGIS, displaying the site boundaries and graduated symbols reflecting the average maximum count size of each site.

Analysing DBBG population trends across sites between 1992-2022

The relative population change of DBBG at each of thew 10 sites was calculated for the period 1992-2022. This means that population indices were calculated for each site using a smoothed General Additive Model (GAM).

Firstly, the data were cleaned and formatted. This meant organising the data according to average monthly (September – March) count for each site, between the years 1992-2022. Herne Bay site was removed from the dataset, as this only included records over a duration of 4 non-consecutive years, meaning there was not enough data available to compare it with the other sites.

All sites included data gaps, whereby sites either had one or more missing monthly records on particular years, or an entire year of records were missing. This could be due to low volunteer numbers or difficult weather conditions that prevented surveying.

However, a complete dataset is required to calculate population trends. Therefore, the raw monthly count data were modelled using a Generalised Linear Model (GLM), following the Underhill process, to impute missing data points (Underhill and Prys-Jones, 1994). Although data points were missing, all the sites had good coverage according to BTO methodology: at least 50% of the count months hold count data. Therefore, there was sufficient data to perform a GLM. This method works under the assumption that missing data can be calculated using existing data points near to the time of the missing data. These will likely be a similar observation, mostly because the data are linked to a seasonal cycle, but also because these observations are repeated. Consequently, it makes this process ideal for ecological and animal observation studies. The GLM was performed using RStudio and the packages "tidy.verse", modelling count against Year and Month variables. A Poisson distribution was used because the missing data represents count data.

From this, population index values were calculated using formula 1 in Excel. Population indices are used to exhibit measurements of population size at a particular point within a period of study, in relation to the population size at a different selected time point (Leech, Rehfisch and Atkinson, 2002). For this report, population index values were calculated relative to the population size at the beginning of the dataset. This means that the baseline population size at each site is set to 100, with all other yearly population sizes expressed as a proportion of this baseline. Therefore, percentage differences between the population size at any point can be readily observed in comparison to the start of the study. Moreover, by indexing all sites, cross-site comparisons could be made (Kennedy et al., 2022).

Index value = (I_{ref}/I_x) x 100

I_{ref} = count value at reference time point (in this case start of study 1992)

I_x = count value at selected year

Formula 1: Formula computing index values as a proportion of the baseline year (1992)

Using these indexed values, a smoothed GAM was used. This statistical model fits a flexible, non-linear relationship between a response variable (in this case a population index value) and an explanatory predictor variable (in this case time, made up of categorical year values) using smoothing functions (Kennedy et al., 2022). These functions identify subtle, non-linear patterns in the relationship between the variables, making GAMS appropriate for modelling population dynamics. Furthermore, smoothing accounts for, and reduces the effect of, confounding factors. As a result, the GAM can control for the confounding effects or seasonal fluctuations or survey effort differences, for example. As such, GAMs are ideal for modelling and visualising ecological patterns, without them being lost in the ‘noise’ of confounding factors (Austin and Ross-Smith, 2014).

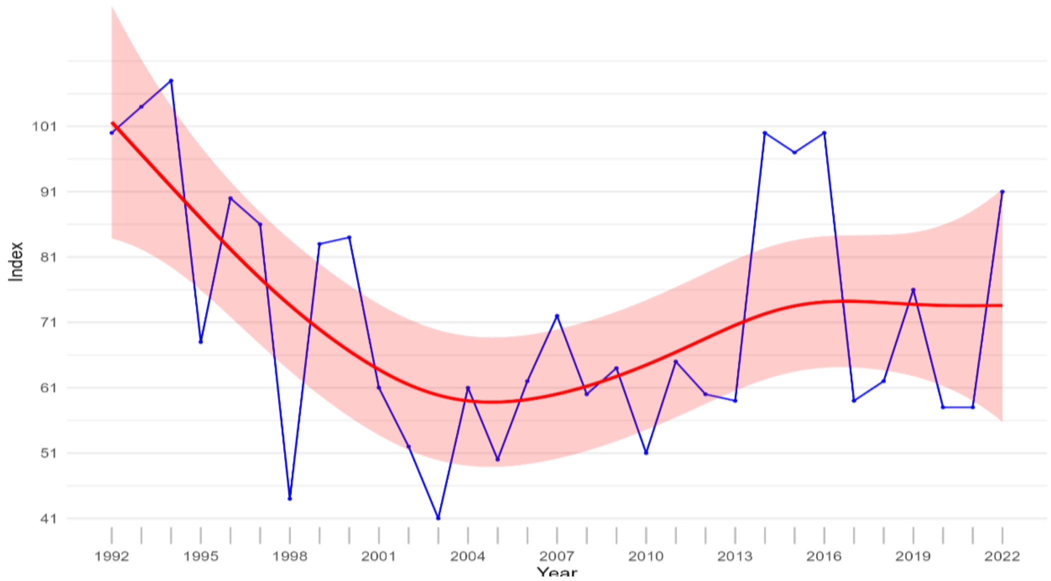

Figure 4: Example of smoothed and fitted GAM for the Blackwater Estuary. Blue line indicates index values, red line indicates fitted and smoothed relationship between the population index and time, the shaded red area indicates the confidence intervals associated with the fitted trend line.

The GAMs were performed using RStudio and the “mgcv” package. A Gaussian distribution was used for simple interpretation. Furthermore, a k value of 15 was used to appropriately fit the model, and allow a suitable amount of flexibility when modelling, according to the number of predictor values (years). These fitted values were calculated and plotted for each site, along with corresponding confidence intervals (figure 4).

From here, the relative change in population size could be calculated using the smoothed index values. Long-term, medium-term and short-term trends were calculated, reflecting relative percentage change over the whole study period, the last 10 years, and the last 5 years respectively. This is computed by the following formula 2:

Relative percentage change in population size = $((I_{ref} - I_x)/I_x) \times 100$

I_{ref} = smoothed index value at reference time point

I_x = smoothed index value at the start of the time period for which a trend is a being calculated

Formula 2: Formula computing the relative change in population size, as a

Example calculation for Medway Estuary using fitted index values:

Where $\mathbf{I_{ref}}$ = 37 and $\mathbf{I_x}$ = 87:

Relative percentage change in population size = -57%

Care should be taken when selecting I_{ref} and I_x, because as a GAM smooths an index value, it considers the preceding and following terms. Therefore, the final value in the time period will be less statistically robust, and hence it would be excluded from a calculation, and the penultimate value used instead. Similarly, the first index value (in this case 1992) is also excluded for the same reason, as there were no data values for the year 1991 in this dataset.

The subsequent percentage change values for relative population size are classified according to WeBS methodology. Table 2 indicates the different classifications for each classification type:

Trend Range	Classification
Lower than -50%	Large Decline
Between -50% and -25%	Moderate Decline
Between -25% and -1%	Intermediate Decline
Greater than -1%	Stable or Increasing

Table 2: Trend Classifications according to WeBS Trends Report Methodology

Finally, the long, medium and short-term trends were visualised using ArcGIS, according to the above trend classification, for each site, as a heatmap.

Analysing DBBG seasonal population trends within case study sites

To investigate DBBG populations at different sites in more detail, the change in relative population size over the wintering period was calculated for sectors within case-study sites.

- Case study site selection and data cleaning

The case study sites were selected with the relevance of this report in mind, therefore the Thames estuary, and surrounding Crouch Roach and Medway estuaries were chosen (appendix item 1). This helps achieve the aim of the report by focusing on the use of DBBG as environmental indicators for the TtT project, and provides an opportunity to evaluate population trends with habitat connectivity in mind spanning Kent and Essex.

The wintering period, for this section of the report, was defined between the six months of October to March, as these months contained sufficient data points. However, if a sector did not contain a minimum of two records across the years in a selected month, it was removed because no average could be calculated. According to BTO methodology, sites are excluded from annual indices calculations if they have inadequate level of coverage. This means less than 50% of possible visits have been undertaken (British Trust for Ornithology, 2017). As a result, the data for a certain year of a sector were removed if less than 3/6 months of that wintering period had been surveyed. This meant every sector of the three case study sites contained two or more records for each month of the wintering period, over the years. Furthermore, every year of the wintering period contained three or more surveyed months.

Following the methodology above, for the remaining sectors, any missing data were imputed using GLMs.

- Analysing and visualising relative population sizes over the wintering period

Using the completed datasets, an average population count for each month during the wintering period was calculated for each sector of the three case study sites. A GAM, using a Poisson distribution and k value of 5, was used to model the average population and calculate confidence intervals (figure 5). Please see appendix item 3 for more examples.

From here, the fitted values were extracted and used to calculate index values for each month over the wintering period, for each sector of the case study sites. This was done according to the formula above. A sector's index value of a selected month represented the percentage change in relative population size as a proportion of the population size within that sector at the start of the wintering period (October).

These values were then displayed on a heat map according to the selected month, meaning one map was created for each month of the wintering period. This was done using a heatmap display on ArcGIS.

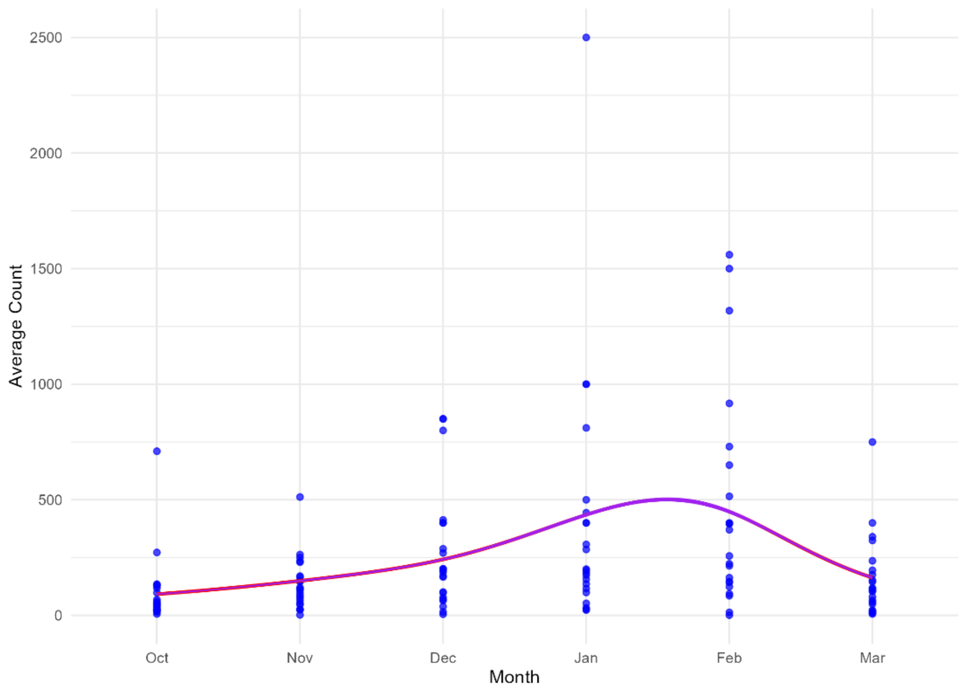

Figure 5: Example of smoothed and fitted GAM, representing average population count each month over the wintering period, for the Chetney Marshes Sector of the Medway Estuary Site. Blue dots indicate raw and imputed count values each month, the smoothed and fitted line represents the relationship between the monthly average count and time. The purple shading indicates greater uncertainty (larger confidence intervals) over a certain time period.

<u>Investigating the potential relationship between DBBG, Saltmarsh and Seagrass habitat</u>

To highlight habitat areas experiencing strong interactions with DBBG, the distributions of DBBG at the 10 sites were overlayed against saltmarsh and seagrass habitats. This could indicate whether there is a clear spatial relationship between DBBG habitat and the environmental habitats they rely on.

Spatial shapefiles for saltmarsh and seagrass habitat extent were sourced from Natural England. Maps were created using ArcGIS.

Results:

1. Visualising DBBG population sizes in the study area

Throughout the 10 study sites there was substantial variation between average yearly maximum population count (figure 6). The Thames Estuary displayed the largest population size with an average of 14,341 individuals, with the second largest site being Blackwater with 8,462 individuals. In contrast, Pegwell Bay and Thanet Coast displayed the smallest average population sizes of 176 and 752 individuals, respectively.

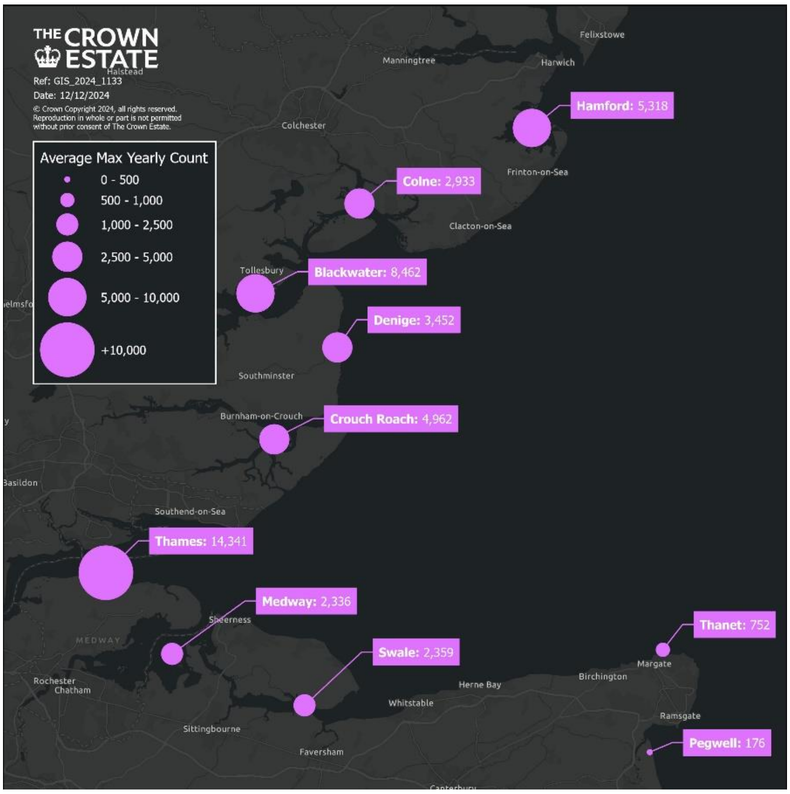

Figure 6: Map displaying average yearly maximum population count over the 10 sites. Graduated symbols reflect the relative population sizes. Map created in ArcGIS

2. Analysing DBBG population trends across sites (1992-2022)

Trends in percentage change of relative population size were calculated across the long (1992-2022), medium (last 10 years) and short (last 5 years) term (figures 7, 8, 9). Overall, the results display that the majority of sites within the study area exhibit declining trends in relative population size since the beginning of the study. Whereas, in the short-term, the majority of sites are exhibiting increases in relative population size.

Though these trends are exploratory values, they do reveal some overarching trends across the different temporal scales and between different sites. The following values are rounded, please see appendix item 2 for a list of raw values. The Hamford Water site displayed consistent declines across all three time periods, with greater declines in the short (-54%) and medium-term (-60%) compared to the long-term trend (-49%). In contrast, Pegwell Bay and Dengie Flats exhibited consistently stable or increasing population trends. In both sites however, the percentage increase in relative population size is smaller over shorter, 5-year time periods (Pegwell: 14%, Dengie: 19%) compared to the long-term trend (Pegwell: 265%, Dengie: 45%). The Thames Estuary exhibited the most stable population over the long, medium and short temporal scales, with a range of only -0.97%.

Long term spatial scale (1992-2022):

Over the long-term, 8/10 sites displayed declining trends, ranging from intermediate to large declines (figure 7). Two sites displayed large declines, two displayed moderate declines, four sites displayed intermediate declines and two displayed stable or increasing trends. Colne Estuary had the highest percentage decline in relative population size (-82%), in contrast to Pegwell Bay displaying the highest percentage increase (265%).

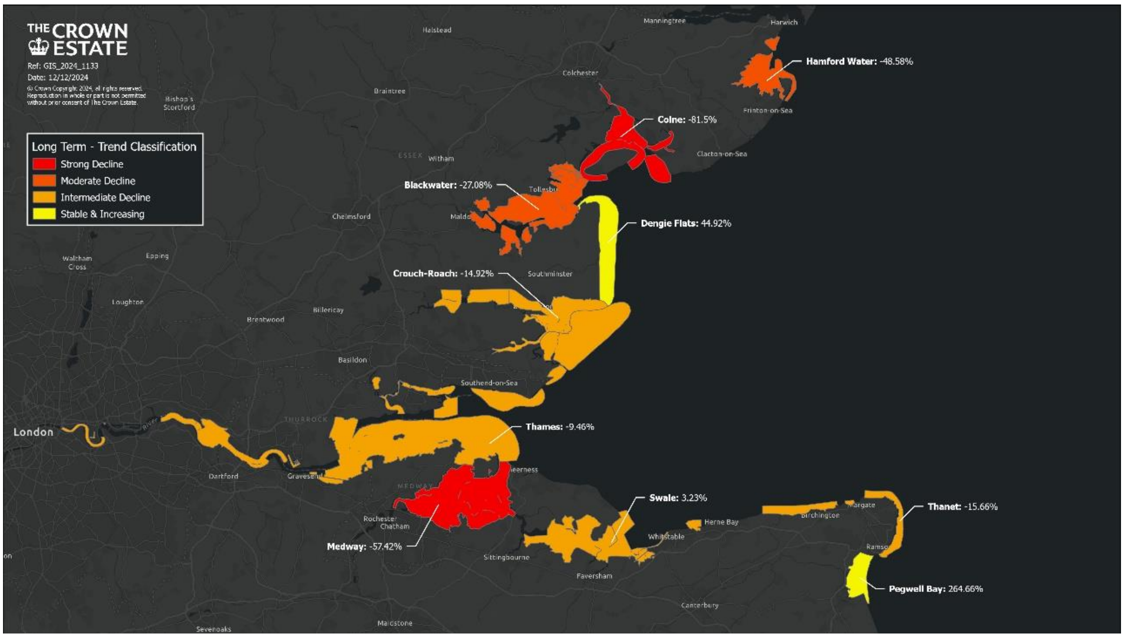

Figure 7: Heatmap displaying trends in percentage change of relative population size across the 10 sites between 1992 and 2022. Strong decline: declines of -50% or more, Moderate decline: between -50% and -25%, Intermediate declines: -25% and -1%, Stable or increasing: greater than -1%. Map made using ArcGIS

Medium term spatial scale (last 10 years: 2012-2022):

The medium-term spatial scale (2012-2022) calculated the trend in percentage change of relative population size in the last 10 years. At this scale, 4/10 sites displayed declining trends, consisting of one site showing large declines, and three sites showing intermediate declines (figure 8). Six sites exhibited stable or increasing trends, but all sites within this classification displayed positive percentage increase in relative population size. Hamford Water had the highest percentage decline in relative population size (-60%), in contrast to the Medway estuary displaying the highest percentage increase (297%). Though the Crouch Roach estuary trend is classified as an intermediate decline (-2%), it should be noted it is close to the boundary of being considered a stable or increasing population (any trend -1% or higher).

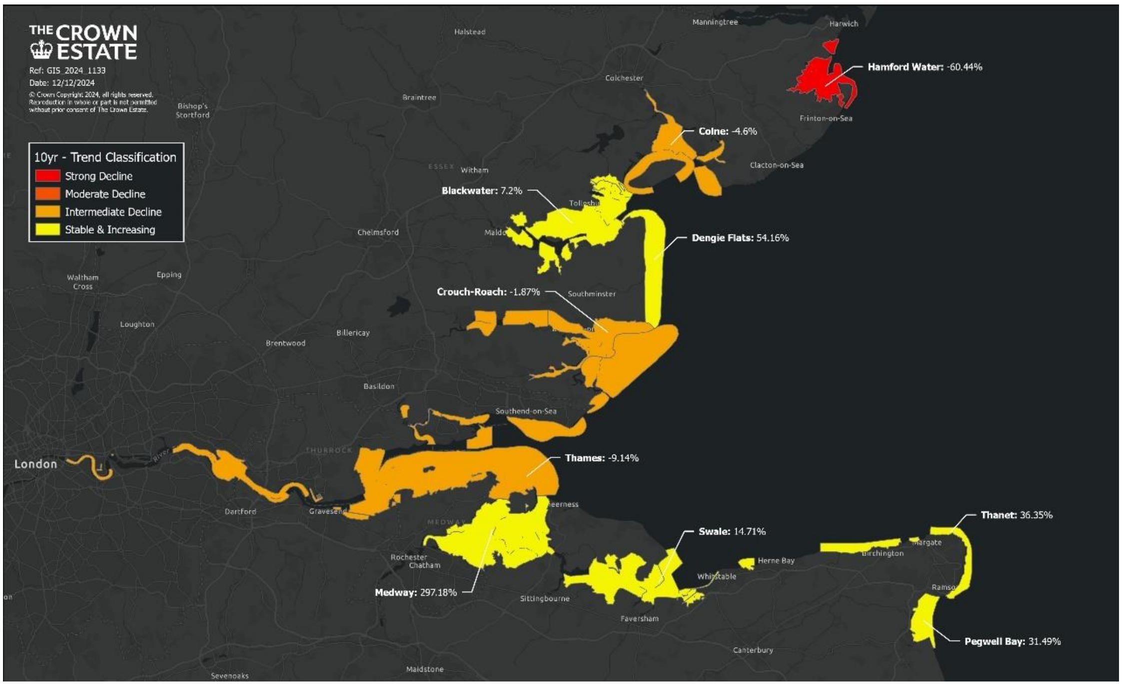

Figure 8: Heatmap displaying trends in percentage change of relative population size across the 10 sites over the last 10 years (between 2012 and 2022). Strong decline: declines of -50% or more, Moderate decline: between -50% and -25%, Intermediate declines: -25% and -1%, Stable or increasing: greater than -1%. Map made using ArcGIS

<u>Short term spatial scale (last 5 years: 2017-2022):</u>

The short-term spatial scale (2017-2022) calculated the trend in percentage change of relative population size in the last 5 years. At this scale, 8/10 sites displayed increasing trends, in addition to one site displaying large decline and one sites exhibiting intermediate declines (figure 9). Out of the six sites classified as stable or increasing populations, two sites experienced slight negative declines (Blackwater and Crouch Roach Estuaries: -0.9%). In this way, these sites were close to the classification boundary of intermediately declining populations. Hamford Water had the highest percentage decline in relative population size (-54%), in contrast to the Medway estuary displaying the highest percentage increase (75%). Both of these sites also displayed the maximum and minimum percentage changes, respectively, in the medium spatial scale trends.

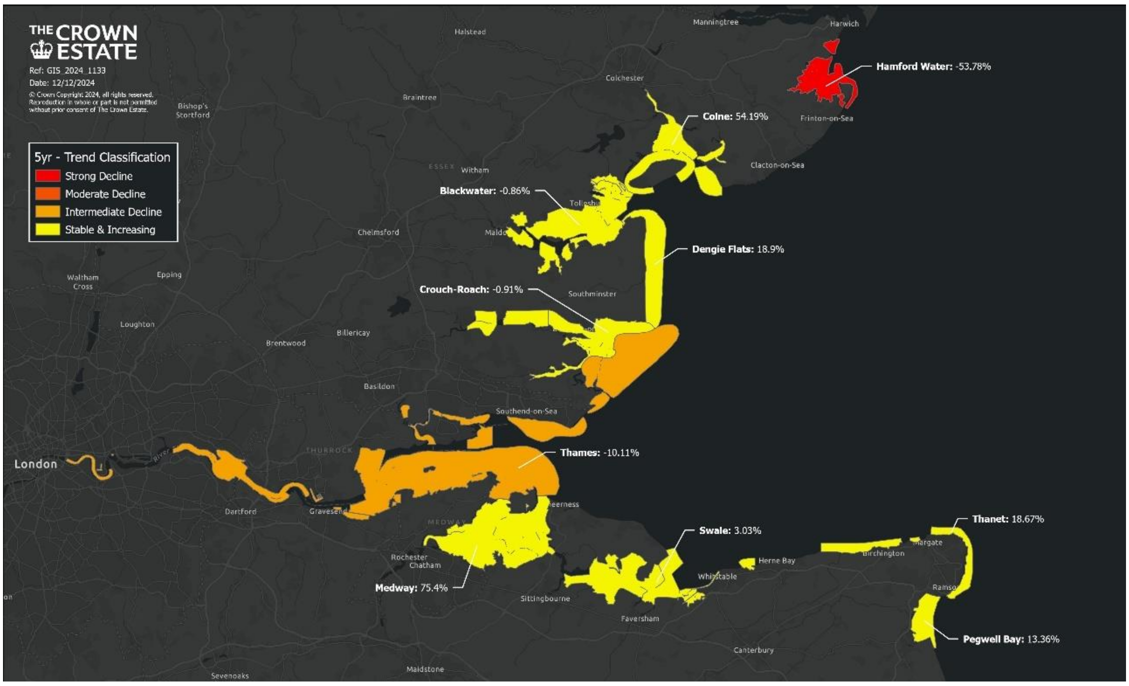

Figure 9: Heatmap displaying trends in percentage change of relative population size across the 10 sites over the last 5 years (between 2017 and 2022). Strong decline: declines of -50% or more, Moderate decline: between -50% and -25%, Intermediate declines: -25% and -1%, Stable or increasing: greater than -1%. Map made using ArcGIS

3. <u>Analysing DBBG seasonal population trends within case study sites</u>

Population indices were calculated for the sectors within three case study sites: Crouch roach estuary, Thames estuary and Medway estuary (figures 10a, b, c, d, e, f, g). This represented the relative population size between sectors each month over the defined wintering period (October-March). Overall, there is a suggested trend whereby inland sectors are favoured over the peripheral sectors of a site. Across the sites, October exhibited no difference in relative population size as this was the baseline of the indices. All sites experienced an increase in relative population size between January and March. The Thames Estuary exhibited the greatest proportion of sector coverage experiencing decreases in relative population size, relative to October. Conversely, the Crouch Roach estuary had the greatest proportion of sector coverage showing increases in relative population size.

<u>Crouch Roach Estuary</u>

All sectors within this site displayed an increase in relative population size, compared to October, each month over the wintering period. However, Paglesham Lagoon and Jubilee Marsh experienced smaller increases in relative population size, compared to all other sectors, in December. The Upper Crouch Roach, Roach Estuary, as well as Althorne to Burnham sectors, consistently displayed the biggest increases in relative population size. Upper Crouch Roach sectors exhibited the greatest relative increase out of all the sectors. The Outer Crouch Estuary and Roach Estuary sectors experienced the biggest decline in relative population size, in March, comparatively to the other sectors (figure 10g).

Thames Estuary

Almost all the sectors within the Thames Estuary site show consistent declines in relative population size each month, compared to October. Potton Island displayed the biggest relative increase out of all sectors within this site. Although decreasing in November (figure 10b), St Marys Marsh displays an increase, comparative to October, at each month thereafter over the wintering period. In January, relative population size peaked within this sector (figure 10d). Similarly, Benfleet Creek also showed increases between January (10d) and February (10e), though still being a decline in relative population size compared to October. Yantlet Beach, as well as Yantlet Beach and Allhallows sector, displayed varying relative population sizes throughout the wintering period. In each month these sectors follow the same pattern of increase or decrease, but in February (10e) and March (10f), they differ. In contrast, Coombe Bay Offshore sector experienced increases of between 100 and 500% in relative population size consistently after October. The sectors discussed are situated mostly in proximate location to one another.

Medway Estuary

The Kingsnorth Power station and Copperhouse Bay sectors consistently exhibited a smaller relative population size each month, comparative to October. Of all the sectors, Riverside Country Park 5, Ham Green, Barksore Marsh and Funton 10 displayed the greatest increase in relative population size, compared to October. Ham Green peaked between December and February, Riverside Country Park 5 only peaked in March (figure 10f), whereas Barksore Marsh and Funton 10 exhbit an increase in relative population size each month, until January. In February, Barksore Marsh displays a bigger relative population size, compared to October (10f), than Funton 10, however this swaps in March (10e). It is possible to see a decrease in relative population size, comparative to October, across two months, in one sector, whilst observing an increase in an adjacent sector. For example, Coppperhouse Bay and Barksore Marsh (Copperhouse Bay decreasing and RiversideCountry Park 5 increasing) between the months February (10f) and March (10e). Similarly, the same pattern can be seen between sectors Barksore Marsh (decreasing) and Funton 10 (increasing) across the same months.

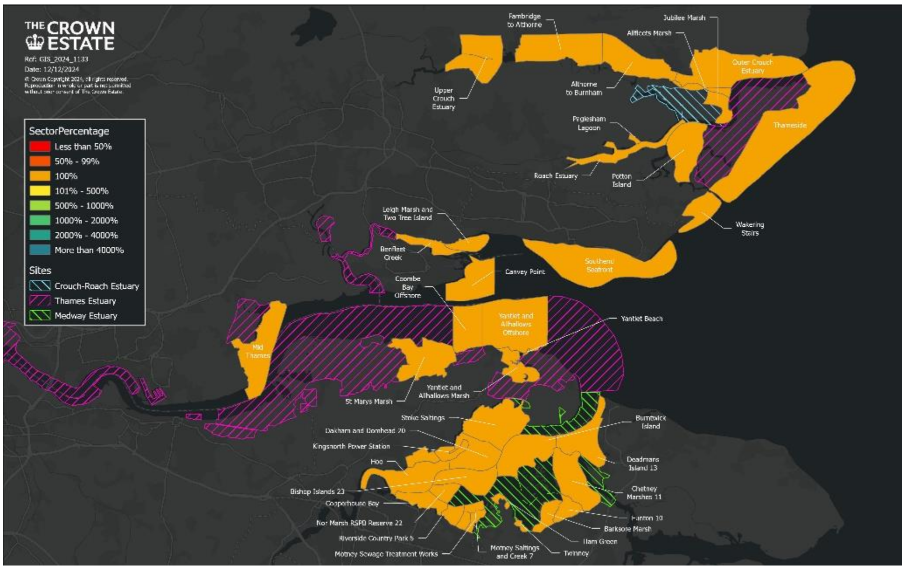

Figure 10a: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in October. Map created using ArcGIS.

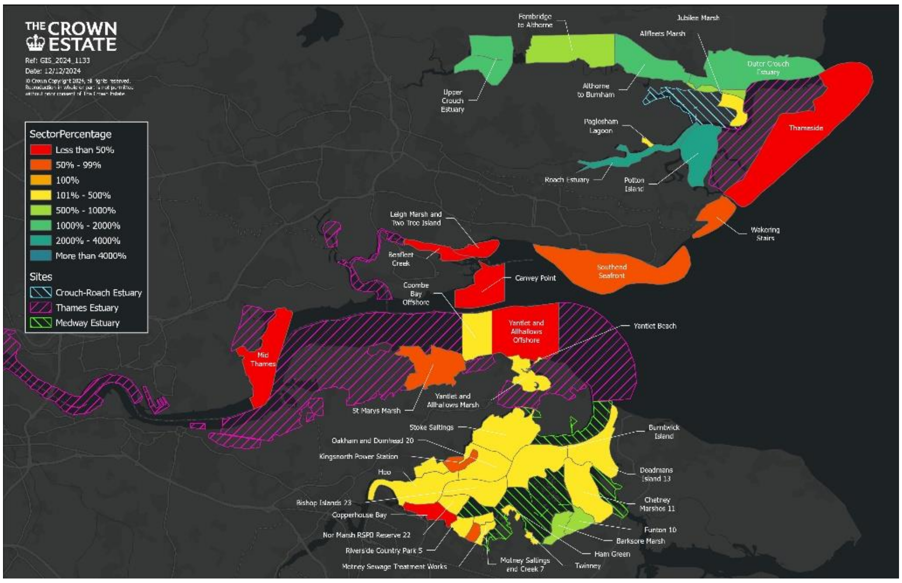

Figure 10b: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in November. Map created using ArcGIS.

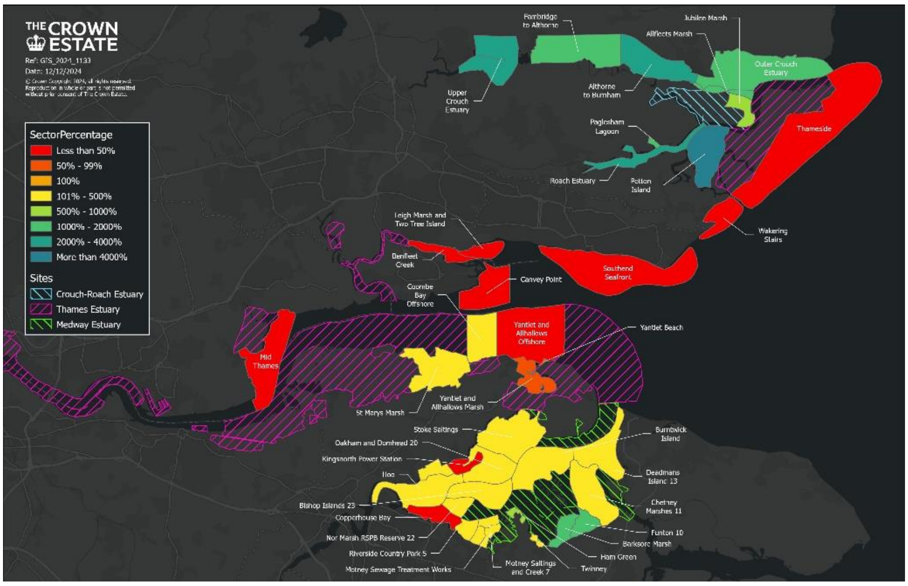

Figure 10c: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in December. Map created using ArcGIS.

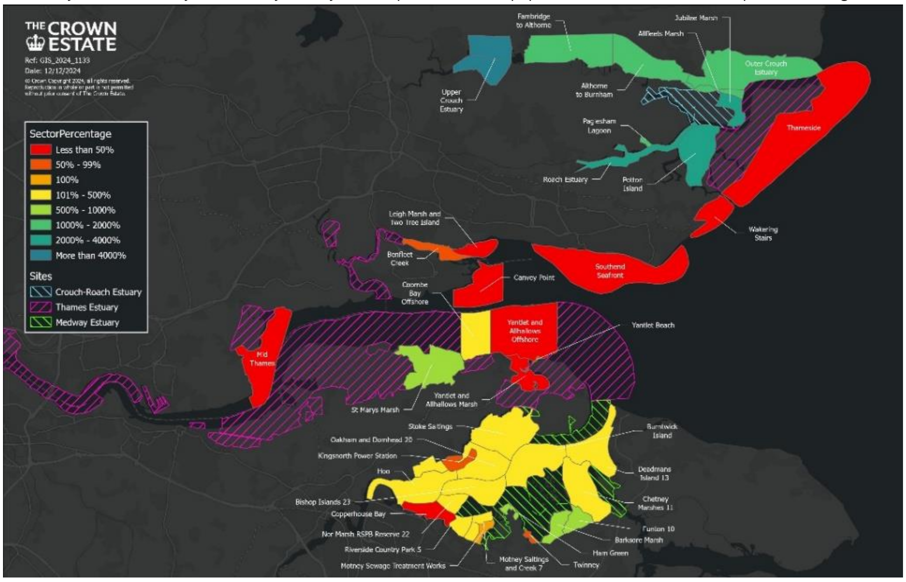

Figure 10d: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in January. Map created using ArcGIS.

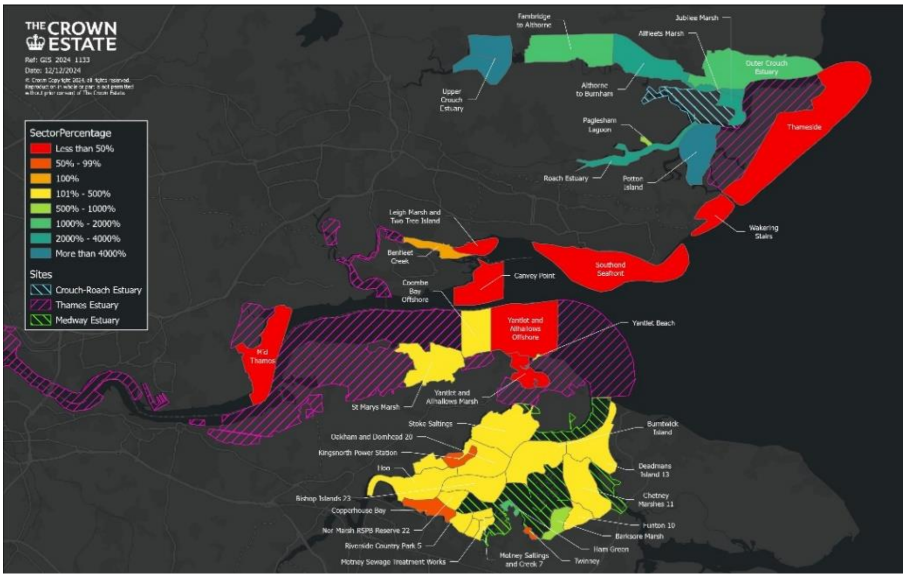

Figure 10e: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in February. Map created using ArcGIS.

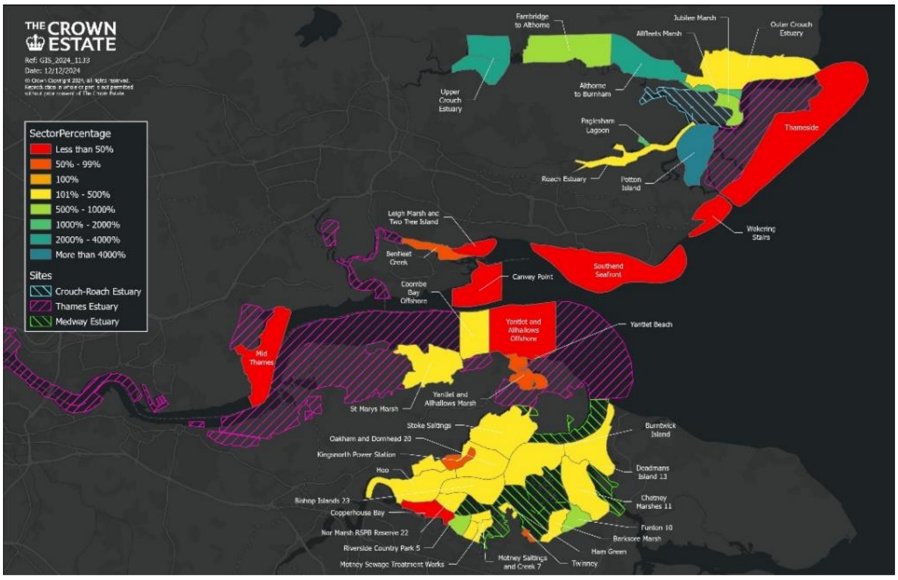

Figure 10f: Heatmap displaying percentage change in relative population sizes, compared to October, in sectors over the wintering period (October to March), across three case study sites: Crouch Roach Estuary, Thames Estuary and Medway Estuary. This map shows relative population sizes in March. Map created using ArcGIS.

Seagrass habitat

Saltmarsh:

Overall, there is considerable spatial overlap between DBBG site habitat extent and Saltmarsh habitat (figure 11). However, a few sectors from the case study sites are identified as having almost total coverage: Benfleet Creek, as well as Leigh Marsh and Two Tree Island in the Thames Estuary, Upper Crouch Estuary, in addition to Fambridge to Althorne sectors in the Crouch Roach Estuary, and finally Stoke Saltings and Burntwick sectors in the Medway Estuary. Dengie Flats, Colne Estuary and Hamford Water also disaply considerable spatial overlap, with Hamford Water exhibiting the greatest proportion of coverage of all the sites.

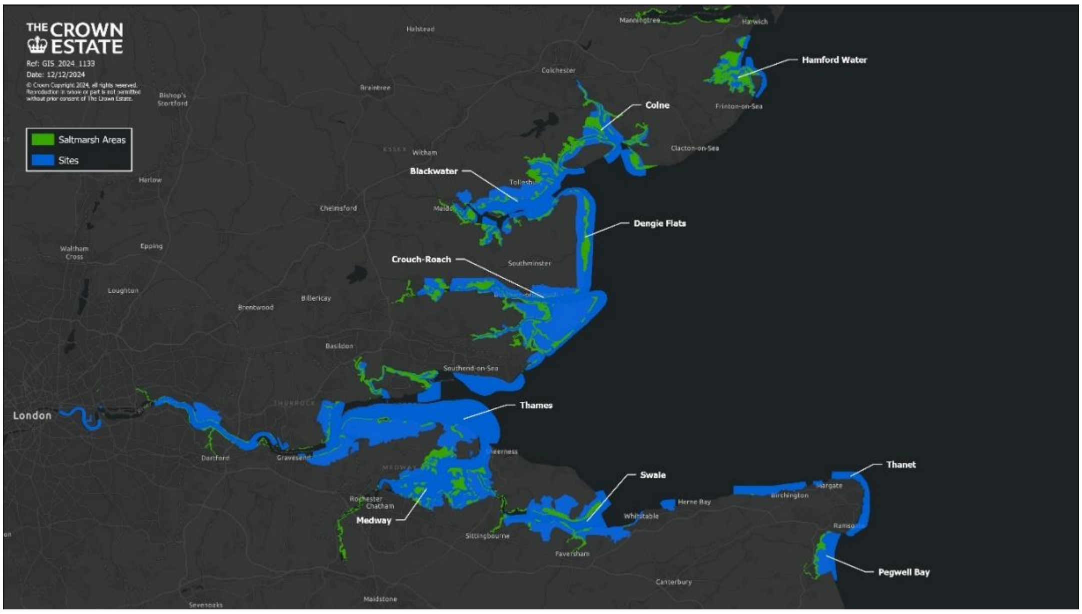

Figure 11: DBBG site spatial extents mapped over Saltmarsh habitat extents. Mapped using ArcGIS

<u>Seagrass</u>

Across the 10 sites, there was little coverage of seagrass habitat, but all seagrass habitat overlayed with DBBG spatial extent (figure 12). Sectors in which seagrass habitat can be found were identified as: Leigh Marsh and Two Tree Island, Thameside and Wakering Stairs within the Thames Estuary, as well as a small area within the Hoo sector of the Medway Estuary.

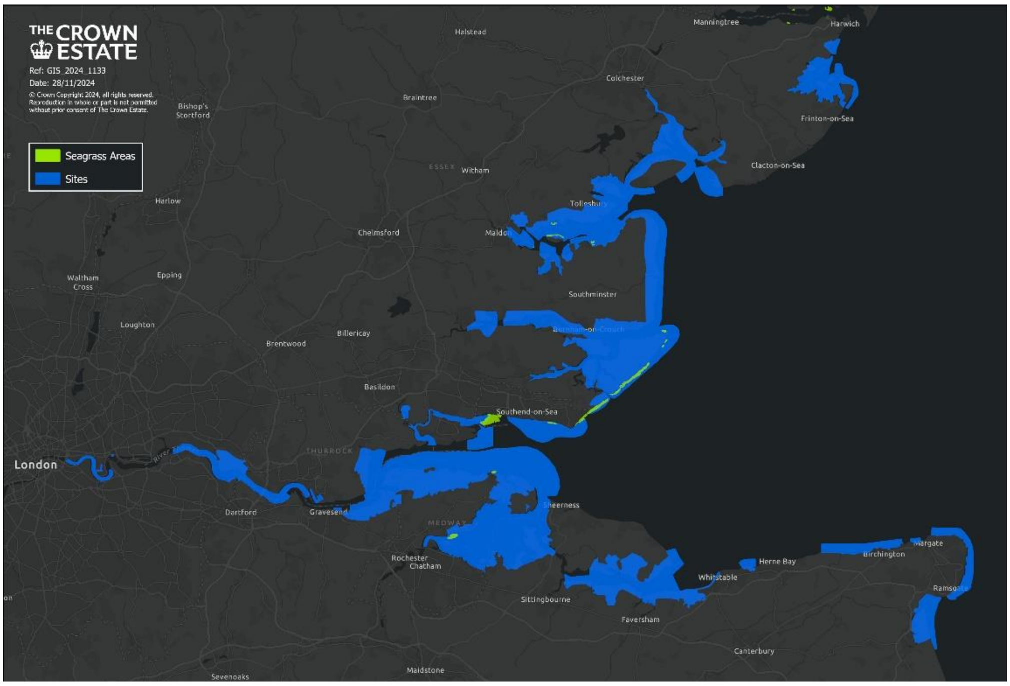

Figure 12: DBBG site spatial extents mapped over Seagrass (*Zostera*) habitat extents. Mapped using

Discussion:

The results indicate that the 10 sites within the study area exhibit varying population sizes. The majority of these sites experienced decreases trends in percentage change of relative population size in the long-term, in contrast to short-term temporal analysis, in which the majority of sites experienced a percentage increase. When analysing population trends within three case study sites over the wintering period, it is apparent that inland sites seem to be favoured. Moreover, considerable spatial overlap between DBBG habitat extent and the spatial extent of Seagrass or Saltmarsh was observed. However, specific sites and sectors exhibited greater coverage than others. Brief Summary

1. <u>DBBG population sizes within the study area</u>

There was a large range in population sizes across the 10 study sites (Thames: 14,341> Pegwell:176 individuals). This is likely largely due to the corresponding site sizes, and therefore the number of individuals each site has a capacity for. Furthermore, different sites will consist of a range of habitats. For example, Pegwell Bay comprises of habitat types like mudflats and sandy grassland, whereas Blackwater Estuary contains shingle and exposed gravel beds (Musgrove et al., 2003). As such, some sites might provide a greater amount of suitable habitat, thus supporting greater or smaller population sizes. All sites, apart from Thanet Estuary and Pegwell Bay, all surpass the 1% threshold (990) for Great Britain. This means that the remaining sites all include over 1% of the national population. Consequently, these sites are of national significance to the DBBG national population, and will have DBBG listed as an important species for that site's designation. This underlines the potential significance of using DBBG as environmental indicators, particularly for the TtT project.

2. DBBG population trends across sites between 1922 and 2022

Population trend variance

Overall, the trends in percentage change of relative population size suggested the majority (8/10) of DBBG populations experienced a decrease in relative population size in the long term, whilst the majority (8/10) have experienced an increase in the last 5 years. These trends reflect the national trends reported by WeBS: -12% decline in the long term (25 years) and 6% increase in the short term (last 5 years) (Woodward et al., 2019).

Though the overall pattern corroborates with that seen in this report, the WeBS long-term value is not as inflated as large as some of the values calculated within this report. For example, the most extreme long-term decline was reported as -81% for the Colne Estuary. Similarly, there is some variation between this report's calculated values and those reported within the WeBS Alerts, such as for Hamford Water (WeBS long term trend = 4%, Report trend = -49%). These higher values could be the result of inflation in initial index values, and thus the resulting trend, due to small sample sizes. This can exaggerate variability, whereby outliers disproportionately affect the average. Consequently, the effects of data availability should be acknowledged when interpreting the reported population trend results.

Moreover, the models used within this report could also result in variation between this report's calculated values and WeBS values. Where the flexibility, level of smoothing, weighting and type of model can be customised, this creates variation between the results a model can produce. Although models were checked for best-fit, which improves overall reliability, systematic biases can still explain, and contribute to, variations between the different reports.

The percentage increase in relative population sizes within the last 5 years could be due to recent habitat creation and agri-environmental schemes that have taken place in the last 30 years (Tinsley-Marshall et al., 2022). As such, the effects of managed realignment projects for saltmarsh habitats, for example, might only recently be reflected in DBBG population trends.

Anthropogenic disturbance

The decline in the majority of habitats, comparative to relative population sizes in 1922, could largely be attributed to anthropogenic disturbance. In wetland environments, this can include dog walkers, recreational walking, joggers or water sports. Their visual presence, and any subsequent noise, can cause sudden alertness, followed by flying, from a few individuals or a whole flock. Out of 32 waterbird species studied in a bird disturbance survey in the Medway during 2021/2022 (Holt, 2022), DBBG were identified as the species exhibiting the highest response rate to disturbance. This indicates that DBBG ae particularly vulnerable to anthropogenic activities.

Previous studies calculated DBBG were prevented from feeding 11.7% of the time during busy weekends, with flight time extended as much as sevenfold (Owens, 1977). Furthermore, it has been suggested that on an exceptionally disturbed day, DBBG can experience an increased estimated hourly energy expenditure of 44 J/h (Riddington et al., 1996). Consequently, this can alter nocturnal feeding site-choice and patterns to compensate for excess energy expenditure. However, if there is low food abundance, or significant habitat fragmentation, finding abundant and easily-accessible feeding grounds might require further energy costs, which could be detrimental to population health. Overall, this anthropogenic disturbance could be indirectly driving population declines. When exposed to high levels of disturbance, resulting in higher energy costs and feeding disruptions, the extra effort and stress at the sites might deter geese habitation. The Thames Estuary, which has high levels of human activity, and has experienced consisted intermediate decline, could be an example of this. Given the sensitivity of DBBG to disturbance, this further highlights their use as indicators of environmental quality.

Urbanisation

Urbanisation, causing habitat fragmentation or coastal squeeze, might also be factors driving declines in DBBG populations. Between 1973 and 2001, an estimated 1620 ha of saltmarsh was lost in the South East of England (Natural England, 2008). This could be due to land drainage or conversion to arable and urban land. Development with the Greater Thames Estuary has resulted in a loss of 64% of habitat between the 1930s and 1980s (Tinsley-Marshall et al., 2022). Similarly, Hamford Water SPA, which displayed consistent large declining trends in relative population size, has been classed as 'unfavourable' condition due to considerable erosion (Brew and Dawks, 2018).

Habitat loss and fragmentation limits food abundance and accessibility in DBBG feeding grounds (Desmonts et al., 2009). Consequently, this additional disturbance and lower food availability could be driving population declines. This could manifest in insufficient food availability limiting a population's survival, or cause DBBG populations to settle at other, more suitable, sites. In addition to losing feeding sites, roost sites could also be affected. Furthermore, urban expansion, coupled with coastal squeeze, can result in conflict over habitat use. DBBG switch between green alga, saltmarsh and arable cereal crop land for grazing. However, the depletion of saltmarsh can result in greater reliance, and thus potentially conflict, on arable land. The cumulative effects of suitable habitat accessibility, and increased habitat-use conflict, might drive DBBG populations away.

Global climate change

It is important to also consider the effects of global factors, such as the cumulative pressures of climate change. The clearance of snow in Siberia is a crucial environmental signal for DBBG to breed, meaning alterations in this indicator could affect breeding success (Boyd, 1987). Although, earlier snowmelt has in fact been shown to enhance egg production. However, the larger populations can subsequently experience negative trends over the wintering period due to density dependent effects (Layton-Matthews et al., 2020). The additive effects of these pressures might be reflected in the long-term trends calculated within this report. Moreover, the positive effects of warmer temperatures might support predator populations, such as the Artic Fox, through indirect effects within the food web. This could also contribute to population declines.

Furthermore, climate change is also affecting global Eelgrass (*Zostera*) populations. Declining Eelgrass has forced Light-bellied Brent Geese populations in Denmark to rely more heavily on less energetically favourable foods, such as terrestrial saltmarsh or wheat. This has resulted in a winter body mass that is 122g lower than 20 years ago (Clausen et al., 2012). Consequently, this highlights how the negative effect of climate change on the habitats which DBBG rely on, can also limit population size and migratory success. Less energy and lower food availability could exacerbate short stopping, whereby migratory species do not travel to the final destination. The cumulative effect of these direct and indirect factors could explain the declines seen within this report. The reliance of DBBG on so many habitat types, and the interspecific species effects, represents the practical application of using DBBG as environmental quality indicators.

3. DBBG seasonal population trends

The analysis of DBBG relative population size in sectors over the wintering period, across three case study sites, suggested a trend of inland sectors being favoured. As previously discussed, DBBG undertake habitat switching between green algae, saltmarsh and cereal crops respectively, as the wintering period progresses. Therefore, the favoured inland sector trend observed in figures 10a-e, particularly during the months January to March, could be a reflection of this natural behaviour. However, the duration of this switching has increased, and start has become earlier, since the 1970s, and might correlate with the effects of urban expansion and habitat degradation (Rowell and Repe, 2004). The Southend Sea Front sector of the Thames Estuary, for example, is highly urbanised, and therefore would not attract large population sizes. Consequently, this additional pressure might explain the favoured inland site trend reported above. Unfortunately, there was lacking historical data allowing for evaluation of how sector-use has changed over time. Despite this early analysis calculating averages from varying time records, it still provides positive insight into the use of DBBG as environmental indicators.

4. DBBG spatial relationship with Saltmarsh and Seagrass

Given that DBBG rely heavily on saltmarsh and seagrass habitats for food resources and roosting, it is expected that their habitat extents would overlap with that of DBBG. Interestingly, although Hamford Water displayed the greatest proportional coverage of saltmarsh extent, it is the site which experienced consistent large declines. This suggests the habitat is low-quality, which is supported by its classification as 'unfavourable' (Brew and Dawks, 2018). Conversely, Benfleet Creek in the Thames Estuary displayed relatively higher population increases compared to the majority of other sectors, whilst also being a hotspot for saltmarsh. Therefore, this could suggest this area is in more favourable condition and is successfully supporting DBBG populations. Although there were isolated patches of seagrass, the sectors with large spatial overlap did not indicate positive population changes (Thameside, in addition to Leigh Marsh and Two Tree Island). This corroborates with the estimated 62% loss of seagrass since 1936 (Green et al., 2021). This early analysis of a spatial analysis is important in spotlighting important habitats under pressure, and therefore can be used to indicate restoration opportunities and priority.

Future research:

This report has been positive in underlining the strong capability of DBBG being used as environmental indicators. Nonetheless, there are many uncertainties which could be pursued in future research to help understand, in finer detail, how effective DBBG would be as an indicator species.

To further understand the effects of anthropogenic disturbance, continued site-specific disturbance surveys are critical. This can help locate priority sites needing tailored mitigation plans, as well as identify site-specific anthropogenic pressures and subsequent vulnerable behaviours. In particular, understanding how diurnal excess energy expenditure could affect feeding site-selection could help inform site management and steer stakeholder engagement.

Additionally, continued site-specific investigations into the effects of urbanisation on DBBG could help identify the most impactful pressures. In doing so, this could also highlight areas lacking functional connectivity. Consequently, this could inform urban development mitigation strategies and identify priority sites for restoration and connectivity. Integrating these findings into future population trend analyses would provide a more holistic understanding of the effect of anthropogenic activities.

Integrating global environmental data into population trend analyses would help reveal the relationship between additional factors, such as global temperature, rainfall or sea levels, and DBBG. Understanding the strength of the relationship between these environmental factors and UK DBBG population trends could deeper understanding of historic DBBG. There would also be potential to use this global data to predict future trends, which could help with habitat restoration decision-making. Researching the indirect effects of other global pressures, such as hunting, could help provide a holistic interpretation of population trends. Furthermore, it could help improve our understanding in their use as indicators of local environmental quality.

Lastly, further investigation into the spatial relationship between DBBG and saltmarsh or seagrass habitat should be continued. A long-term analysis of this relationship could help quantify how much DBBG rely on each habitat type, and how their habitat switching behaviour is natural, or potentially affected by habitat degradation. This could help prioritise habitat restoration, as well as inform DBBG management in arable land – for example the use of refugia (Owen, 1977). Greater long-term coverage of all WeBS sectors is integral to making this happen.

Concluding remarks:

Overall, this exploratory study highlights the strong feasibility of using DBBG as indicators of environmental quality. Their reliance on a multitude of habitat types, and complex interspecific interactions across the food web at a local and global scale, emphasises their ability to reflect the condition of different environments and species.

As such, this study has demonstrated that the extensive dataset can be used to evaluate DBBG population trends over varying temporal scales between different sites. Furthermore, initial analyses of seasonal population trends across sectors of a site have exemplified the possibilities of using this data to gain a deeper, finer-scale understanding of DBBG habitat use.

However, to gain more clarity on the spatial and temporal trends of DBBG movement, and thus detailed understanding of their interactions with different habitats, long-term and widespread surveying is crucial. This will enhance understanding of how DBBG interactions with the environment are affected by multiple pressures, such as anthropogenic disturbance, urbanisation and global climate change. Integration of historical records of more data types, for example environmental data, could help with this aim.

To conclude, there are multiple avenues for further research which can be pursued to build our understanding of DBBG as indicators of environmental quality. However, these exploratory results are encouraging for applications within the TtT project.

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Appendix:

1. Site and Sector List

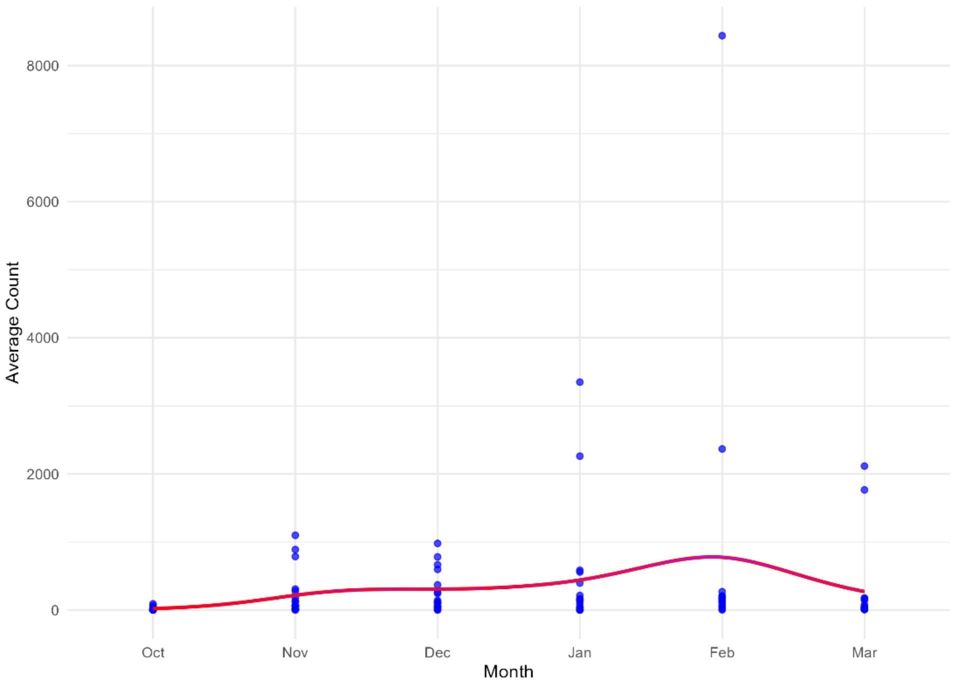
Crouch Roach Estuary	**Thames Estuary**	**Medway Estuary**
Allfleets Marsh	Benfleet Creek	Barksore Marsh
Althorne to Burnham	Canvey Point	Bishop Island 23
Bradwell	Coombe Bay Offshore	Bloors Wharf 6
Fambridge to Althorne	Crouchside	Burntwick Island
Jubilee Marsh	Leigh Marsh and Two Tree Island	Chetney Marshes 11
Middle Crouch Estuary	Mid Thames (Tilbury to Mucking)	Copperhouse Bay 3-4
Outer Crouch Estuary	Potton Island	Deadmans Island 13
Roach Estuary	Southend Seafront	Funton 10
Paglesham Lagoon	St Mary's Marsh	Ham Green
Upper Crouch Estuary	Thameside	Hoo and Nor and Bishop and Copperhouse Marshes
	Wakering Stairs	Kingsnorth
	Yantlet and Allhallows Offshore	Motney and Otterham Creek
	Yantlet Beach	Motney Saltings and Creek 7
	Yantlett and Allhallows Marsh	Motney Sewage Treatment works
		Nor Marsh RSPB Reserve 22
		Oakham and Domhead 20
		Riverside Country Park 5
		Stoke Saltings and Ooze 16-19
		Twinney

2. Raw percentage change in relative population size values

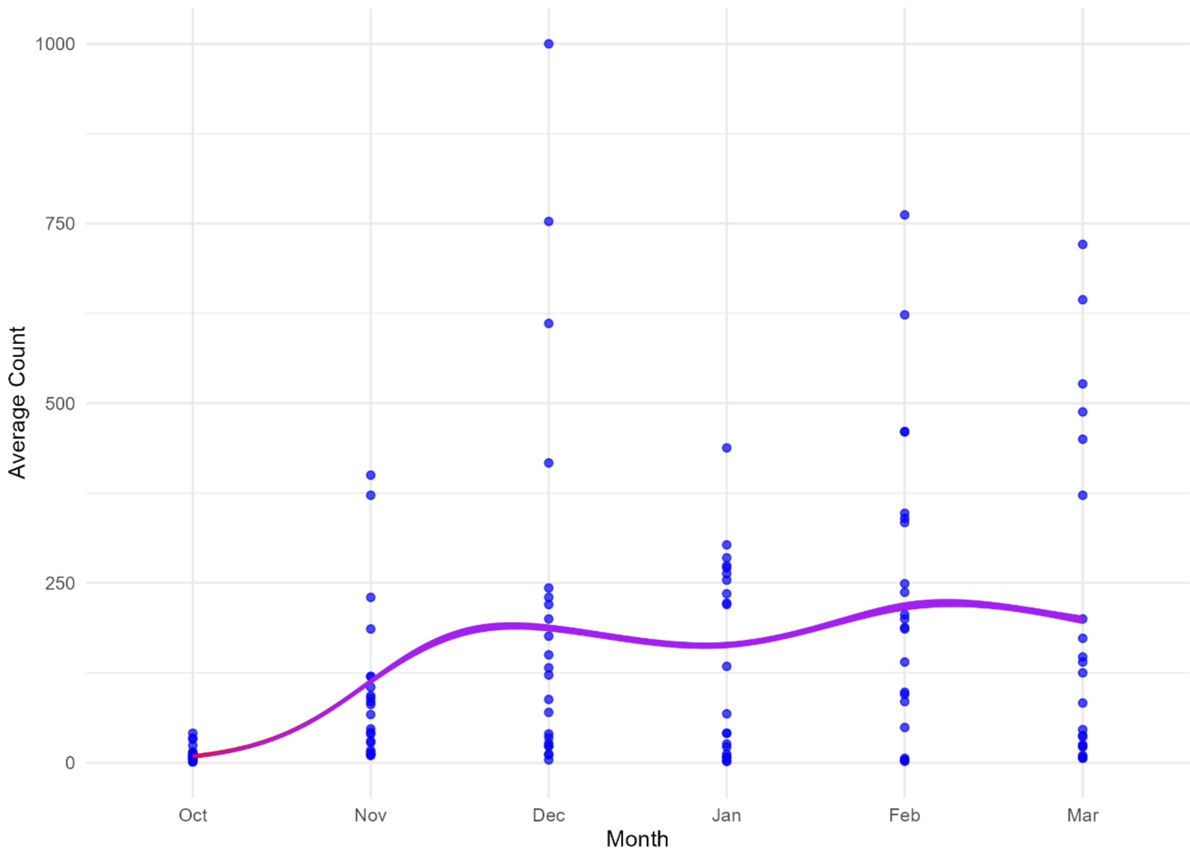
Site Name	Long-term trend (%): 30 years (1992-2022)	Medium-term trend (%): last 10 years (2012-2022)	Short-term trend (%): last 5 years (2017 -2022)
Blackwater Estuary	-27.08	7.20	-0.86
Colne Estuary	81.50	-4.60	54.19
Crouch Roach Estuary	-14.92	-1.87	-0.91
Dengie Flats	44.92	54.16	18.90
Hamford Water	-48.58	-60.44	-53.78
Medway Estuary	-57.42	297.18	75.40
Pegwell Bay	264.66	31.49	13.36
Swale Estuary	-3.23	14.71	3.03
Thames Estuary	-9.46	-9.14	-10.11
Thanet Estuary	-15.66	36.35	18.67

3. Crouch Roach Estuary modelled average monthly count for sectors

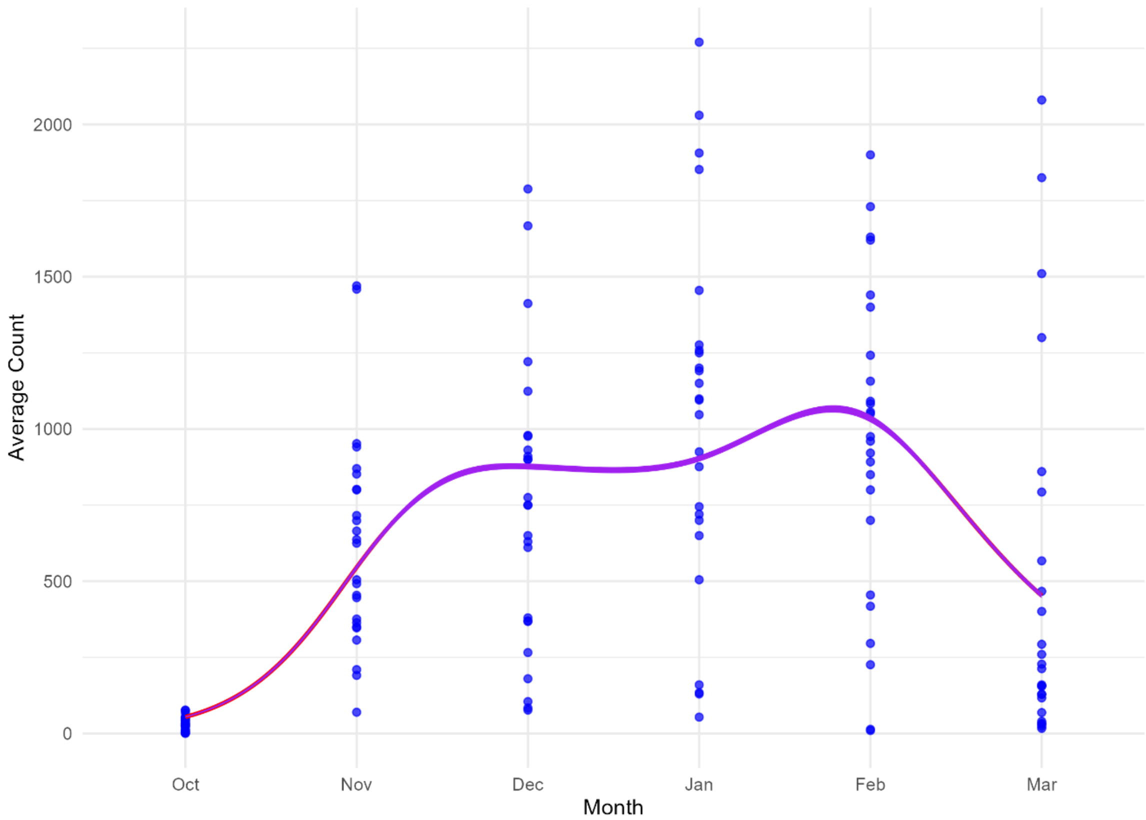
Allfleets Marsh:



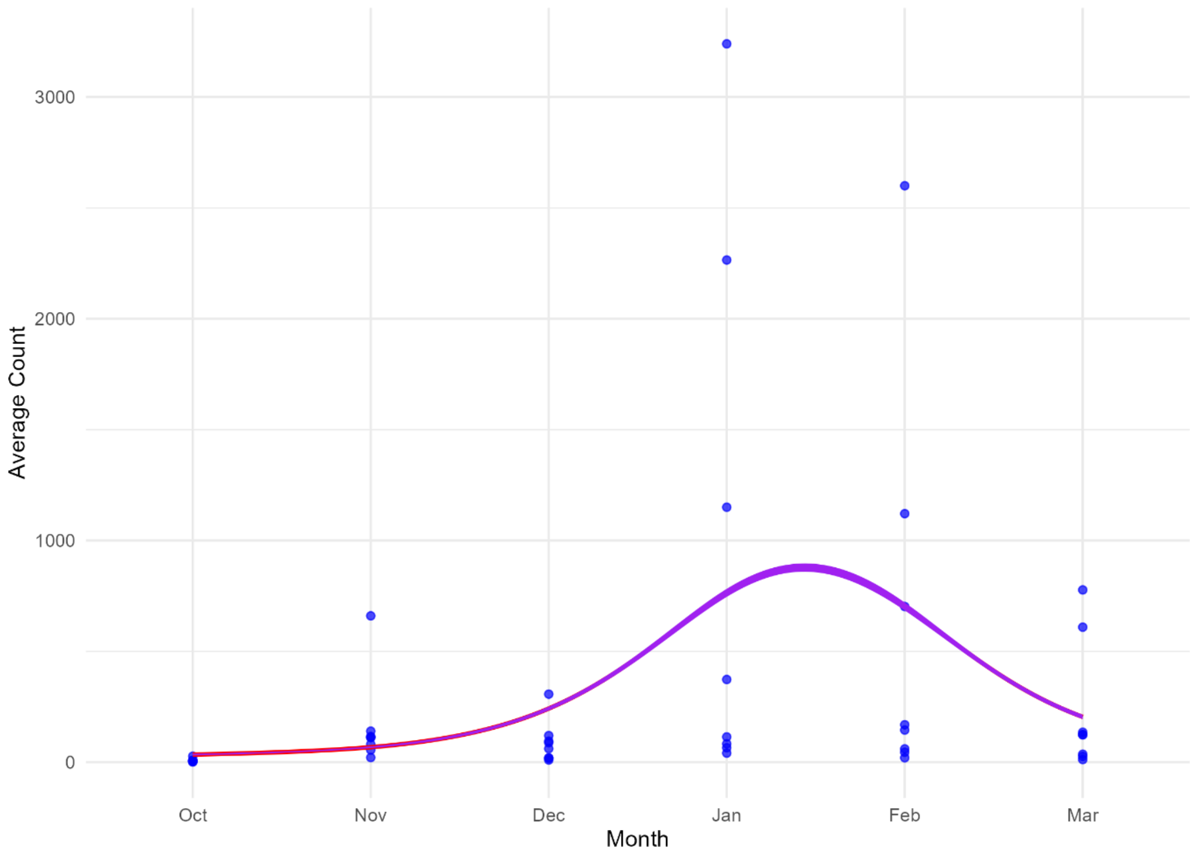
Althorne to Burnham:



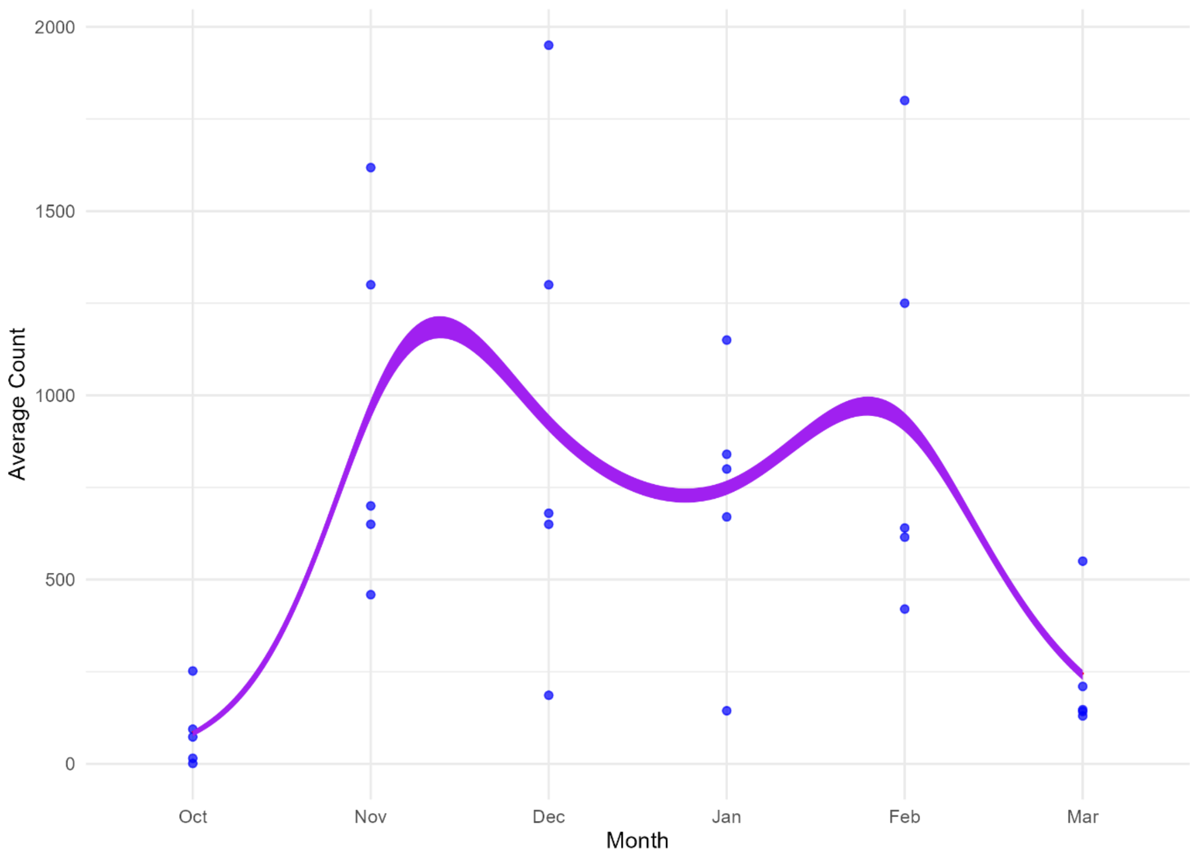
Fambridge to Althorne:



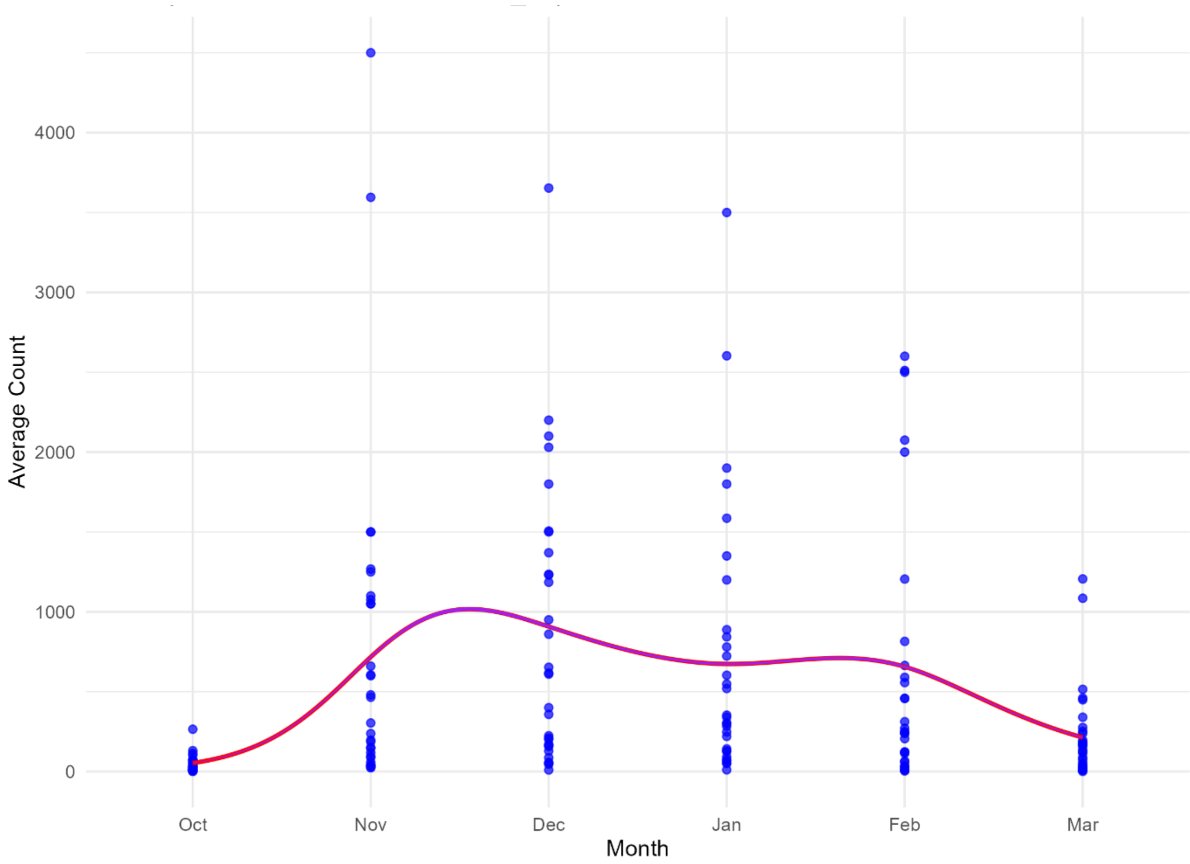
Jubilee Marsh:



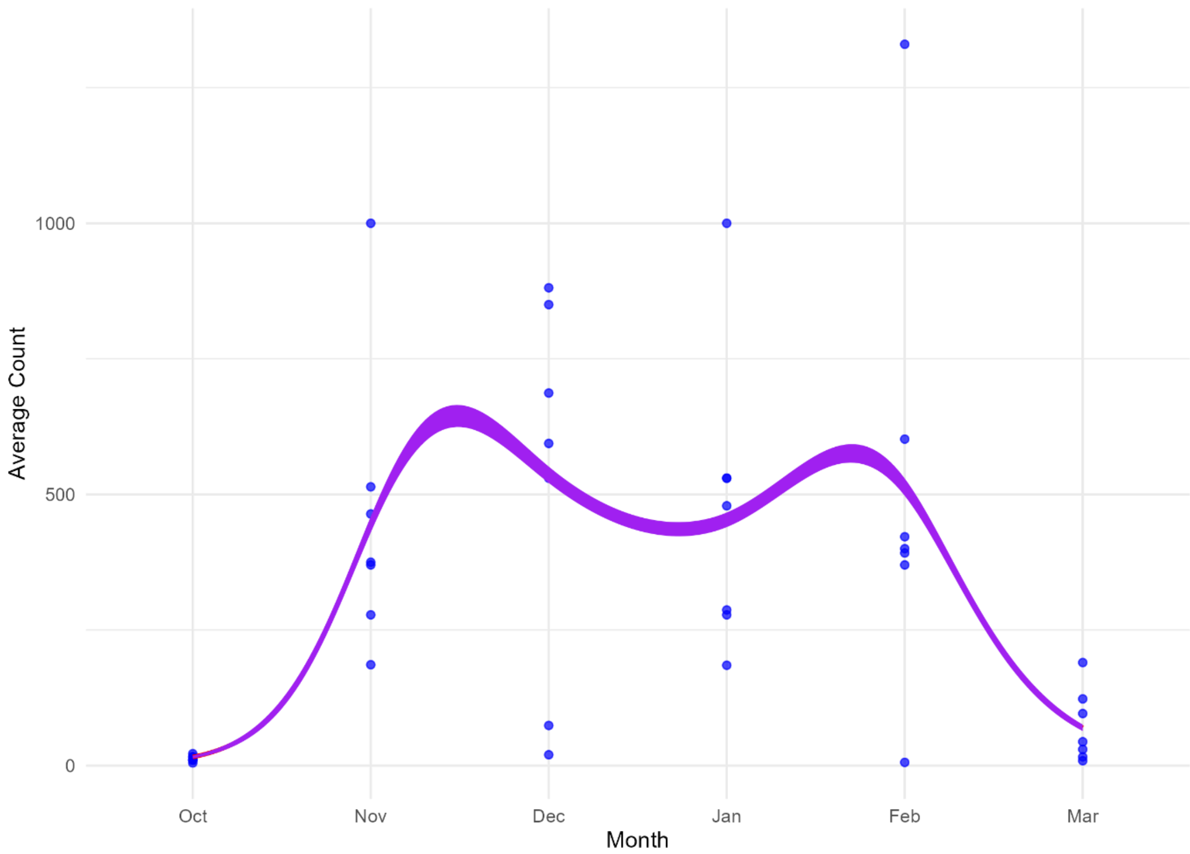
Middle Crouch Estuary:



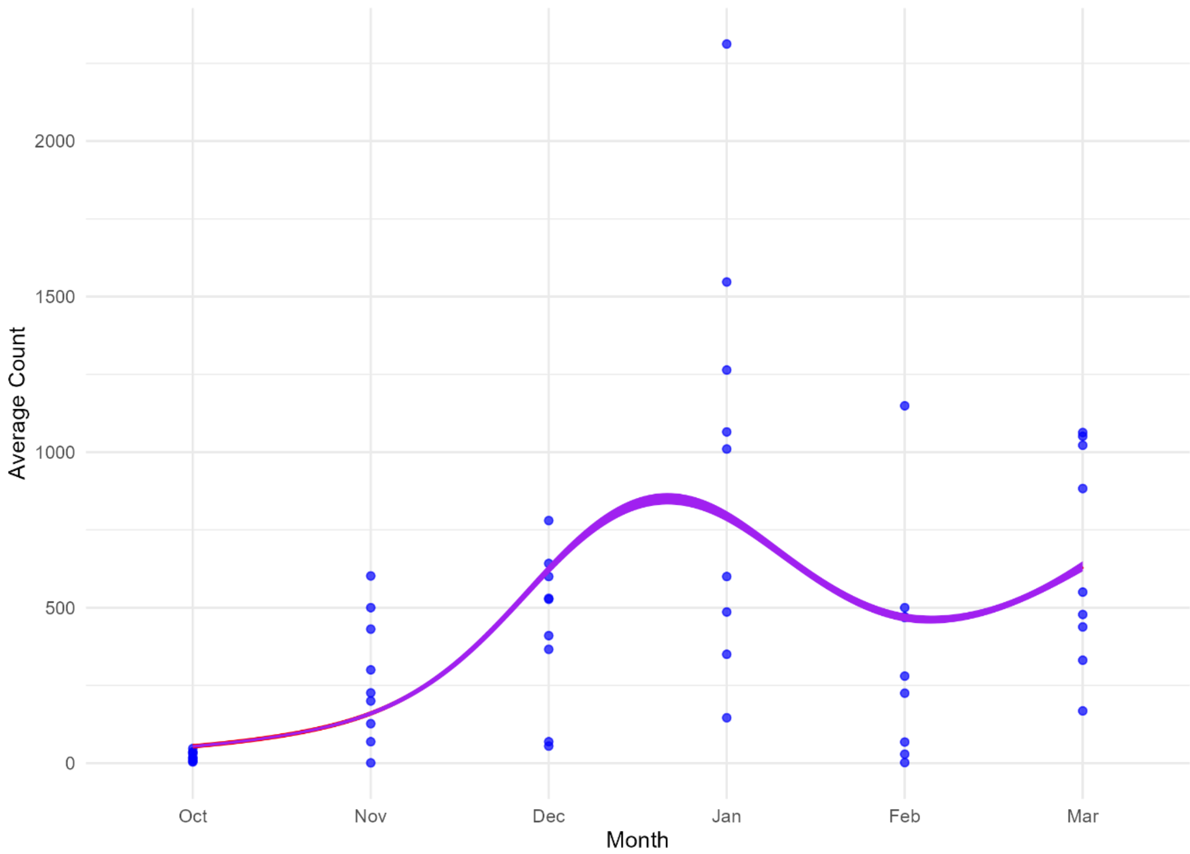
Outer Crouch Estuary:



Roach Estuary:



Paglesham Lagoon:



Upper Crouch Estuary: