BTO Research Report No. 443

Surveying waterbirds in Morecambe Bay for the Wetland Bird Survey (WeBS) Low Tide Count Scheme

Editor

A.N. Banks

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Report of work carried out by
The British Trust for Ornithology
on behalf of
the WeBS partnership
under contract to English Nature

May 2006

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EXECUTIVE SUMMARY

1. Morecambe Bay, north west England, is situated at the confluence of four major rivers (Kent, Leven, Lune and Wyre) and holds the largest continuous area of intertidal habitat in the UK. It is designated as a Special Protection Area (SPA) and Ramsar site on the basis of its non-breeding waterbird interest.

2. The Wetland Bird Survey (WeBS) is divided into two schemes: Core Counts, which aim to quantify bird numbers when aggregated at roost sites, and Low Tide Counts (LTCs), which aim to elucidate distribution of waterbirds across likely feeding areas.

3. Large sites such as Morecambe Bay are often difficult to survey at low water, owing to problems such as the range of visibility, access to potentially dangerous areas of intertidal habitat, and attracting numbers of volunteers necessary to achieve full coverage.

4. A first attempt was made to undertake co-ordinated counts of the four Sites of Special Scientific Interest (SSSIs) within the bay, including five main estuarine channels covered using standard methodology. The remainder of the bay was covered by aerial survey. Four counts were made in total, one during each winter month (November – February).

5. Bird distribution data were plotted on pre-defined sectors on the estuarine areas, and assigned to cells of a 1 km^2 grid for the aerial survey counts. Relative density of birds at low water across the whole of Morecambe Bay could thus be determined for the winter. Important areas for each species found in nationally or internationally important numbers at the site are considered.

6. Cluster analysis revealed significant ‘hot spots’ of Oystercatcher and small waders within the bay. Although mean distributions of these species sometimes overlapped with high densities of cockles and *Macoma* bivalves, no relationship was found between mean bird densities and mean bivalve densities.

7. Disturbance events appeared to occur where recorded bird density was comparatively low, but there are likely to be issues with the resolution of bird data.

8. No obvious patterns in temporal use of different parts of the bay were evident, with mean centres of both Oystercatcher and small waders tending typically towards the east and middle of the bay.

9. Estimates of counter error were made from aerial survey simulations, with an estimated overall mean error of –31%. At this level of error, corrected aerial survey counts would still represent underestimates of Core Count figures from 2004/05.

10. Further ground-truthing of aerial survey counts was not possible to any degree of accuracy, but broad comparison of counts of one area made by standard and aerial survey suggested again that aerial surveys returned lower counts.

11. The suitability of aerial survey for use in WeBS LTCs at Morecambe Bay and at other large sites is discussed. Refinements to standard ground survey practice at Morecambe Bay are also suggested.

12. Further research necessary to more closely determine feeding behaviour and distribution of waterbirds within Morecambe Bay is considered.

13. Preliminary analysis of digital images of intertidal habitat taken at another large site with internationally important numbers of waterbirds (The Wash), obtained through collaboration with RAFOS, is outlined, as are recommendations for the advancement of this approach.

1. INTRODUCTION

1.1 Birds and Morecambe Bay

The area known as Morecambe Bay (also referred to as ‘the bay’) encompasses a vast area of the coastline of north-west England. Much of the intertidal and saltmarsh habitat within the bay is afforded Ramsar site and Special Protection Area (SPA) status on the basis of the waterbird interest. The SPA includes the estuaries of the four major rivers converging at Morecambe Bay (Leven, Lune, Kent and Wyre), plus the mouth of the River Keer, Foulney Island and the eastern section of Walney Island, plus enormous intertidal mud- and sandflats stretching as far as 7 km offshore from the coastline. Morecambe Bay holds the largest continuous area of such intertidal habitat in the UK.

The variety of sediments and resulting infauna within the bay enables it to support large numbers of wintering waterbirds. The diversity of species using the bay during winter includes internationally important numbers of Curlew *Numenius arquata*, Dunlin *Calidris alpina*, Grey Plover *Pluvialis squatarola*, Knot *Calidris canuta*, Oystercatcher *Haematopus ostralegus*, Pink-footed Goose *Anser branchyrhynchus*, Pintail *Anas acuta*, Redshank *Tringa totanus*, Shelduck *Tadorna tadorna* and Turnstone *Arenaria interpres*, plus nationally important numbers of Bar-tailed Godwit *Limosa lapponica* and Golden Plover *Pluvialis apricaria*. Furthermore, 12 other waterbird species contribute to the site qualification as a wetland of international importance (Stroud *et al.* 2001).

1.2 WeBS counts at Morecambe Bay

The primary aim of the WeBS Low Tide Counts (heretofore WeBS LTC) scheme is to describe the relative distribution of waterbirds across estuarine habitats at low tide. The accurate enumeration of these birds, whilst desirable, is a secondary aim as this information is, in general, provided by the WeBS Core Counts. Morecambe Bay is an extremely important wintering and passage site for many species of waterbirds (the yearly site average totalling just over 238,000 birds; Collier *et al.* 2005) and is covered routinely and comprehensively by the latter scheme, but relatively poorly covered by the companion WeBS LTC scheme. The nature of the two methods therefore means that trends in quantitative estimates of birds at roost are well understood; the distribution of such birds using the bay to feed or loaf at low water much less so.

1.3 Restrictions to WeBS counts at large sites and solutions

The WeBS LTC method presents a particular problem at Morecambe Bay, in that much of the site consists of very extensive intertidal flats. By virtue, such sites are often the most difficult to survey as visibility becomes limited, numbers of volunteer counters may be insufficient, and there are access and Health & Safety issues to consider owing to the size and hazardous nature of the flats. These are notoriously dangerous as they may become rapidly and unexpectedly inundated on a rising tide, and in many places contain sinking sands. Additionally, at such large sites there may be less natural geographical and topographical breaks along which to draw sector boundaries, and there may be few landmarks to use as boundary guide posts far offshore. Finally, the enormous (ca. 10.5 m) tidal range and rapidity of tidal movements can serve to further restrict visibility and alter bird behaviour (for instance, limiting the available time for foraging). The major problems therefore are;

- Visibility from shore: impossible to survey full extent of flats
- Safety: volunteers placed at risk if venturing out onto flats
- Access: some areas may be difficult to reach
- Size: problems securing enough volunteers with such a big site
- Tidal range: birds feeding at water edge are often too far to see as tide retreats along deep channels
- Sector definition: difficult to segregate huge site into meaningful sectors for counting purposes

- Representativeness of bird distribution: local knowledge suggests that low tide distribution may not always reflect best feeding sites

The seemingly most attractive solution to these problems is to conduct an aerial survey over the entire area. This method allows relatively rapid coverage of a large area in a short space of time and circumvents many of the Health & Safety issues involved with ground-based counts. As counts are assigned to individual locations along a transect, there is also no requirement to sectorise the site in question; this can be done *post hoc* if necessary.

One major disadvantage of aerial survey of birds is that it is sometimes considered to be less accurate than ground-based survey (Frederick *et al.* 1996; Banks *et al.* 2004; Rodgers *et al.* 2005). As the aims of this project were to ascertain low tide distribution of waterbirds, quantitative accuracy is less of a concern than identifying 'hot spot' areas where waterbirds are concentrated. However, where possible, it was decided that ground counts should be the preferred method, with aerial survey used for inaccessible and hard to view locations. Subsequently, a combination of the two methods was employed to survey the entirety of the bay at low tide.

2. METHODS

2.1 Ground counts of estuarine channels

Morecambe Bay SPA is composed of four constituent Sites of Special Scientific Interest (SSSIs); South Walney & Piel Channel Flats, Lune Estuary, Morecambe Bay, and Wyre Estuary. The boundaries of these designated sites are outlined in the Appendix (Appendix 1: figures 1.1a –d). The major estuarine channels containing intertidal habitat and feeding into Morecambe Bay do not in all cases correspond to convenient SSSI boundaries, however, and here each estuarine area is treated in isolation. These areas were suitable for survey using the preferred ground count method (Collier *et al.* 2005), as the channels are typically narrow enough for visibility to be acceptable, are accessible by road or footpath and are mostly near population centres, where volunteer counters may be found.

2.1.1 South Walney & Piel Channel Flats

This area includes the southern section of Walney Island, plus the area to the south of Barrow-in-Furness, including Cavendish Dock (Figure 2.1.1). Part of the area has been regularly covered in the past as an adjunct to the WeBS LTC scheme by a small team of dedicated volunteers, although the counts were carried out at mid-tide when birds are closer to shore (Figure 2.1.2). It was possible to extend the area of these sectors to include the remaining intertidal habitat exposed at low tide. At the widest point, the largest mudflats at Roosecote Sands are 2.6 km from the east shore, and so these were counted from the land. Elsewhere this area is also abbreviated to 'Piel Channel'.

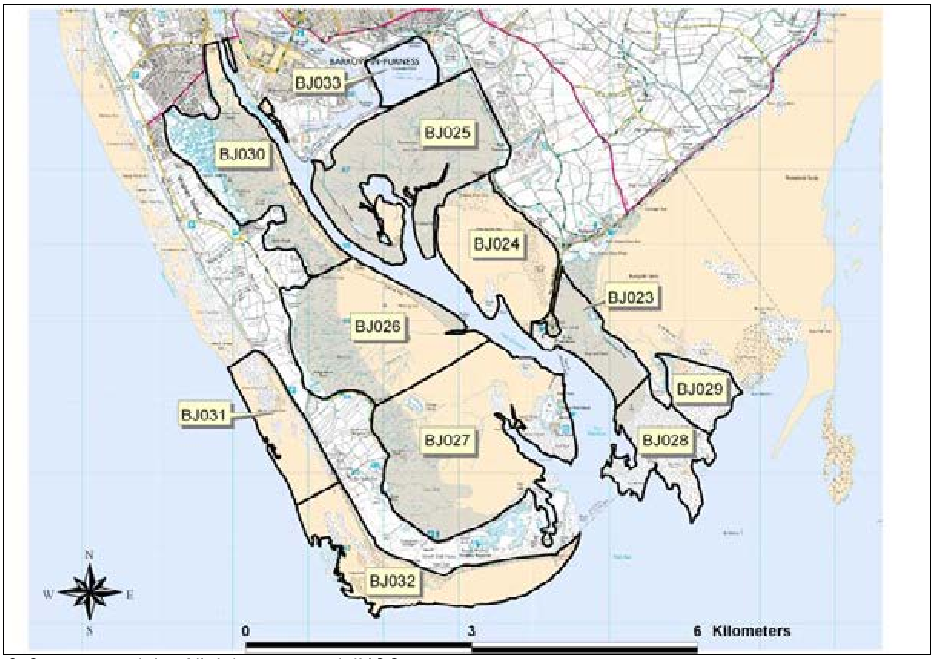


Figure 2.1.1 South Walney & Piel Channel Flats WeBS Low Tide Count sectors. Labels denote WeBS sector codes.

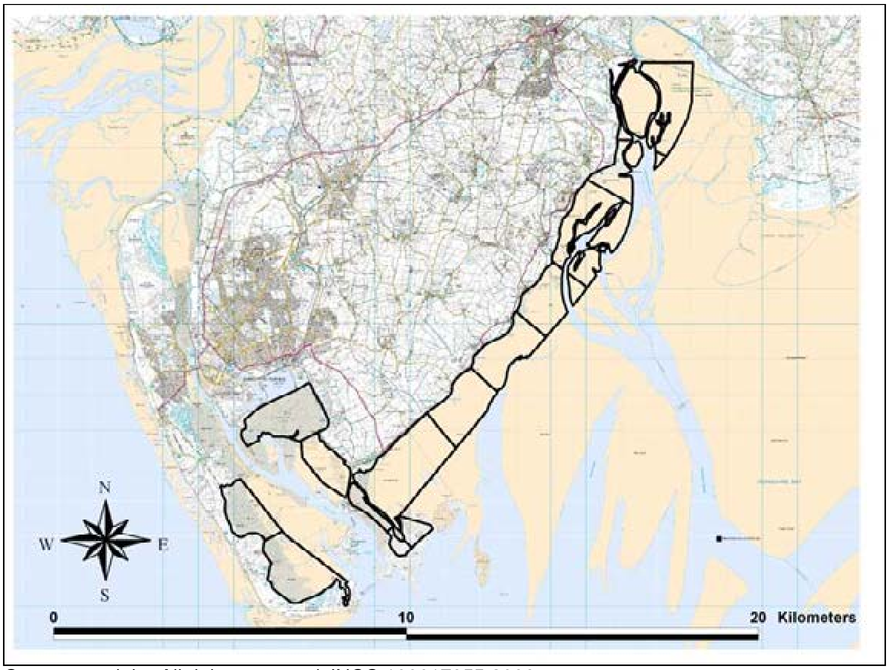


Figure 2.1.2 South Walney & Piel Channel Flats, showing WeBS sectors counted at mid-tide in previous years.

2.1.2 Wyre Estuary

The Wyre Estuary is heavily urbanised along its west bank, with Fleetwood at the head and various suburbs of Blackpool further upriver (Figure 2.1.3). It is therefore possible to count up to the mouth from the shore; there are few access or visibility restrictions, and as there exists a group of enthusiastic WeBS counters in the area, counts were feasible.

The remaining part of the SSSI is known as the North Wharf. These sandflats extend up to 3.2 km offshore and therefore in theory should be mostly visible through a telescope. In practice, land-based counts of North Wharf were not attempted. Counters indicated that at low tide, most birds are too far from shore to count accurately. However, they were included within the aerial survey of the main bay (see below).

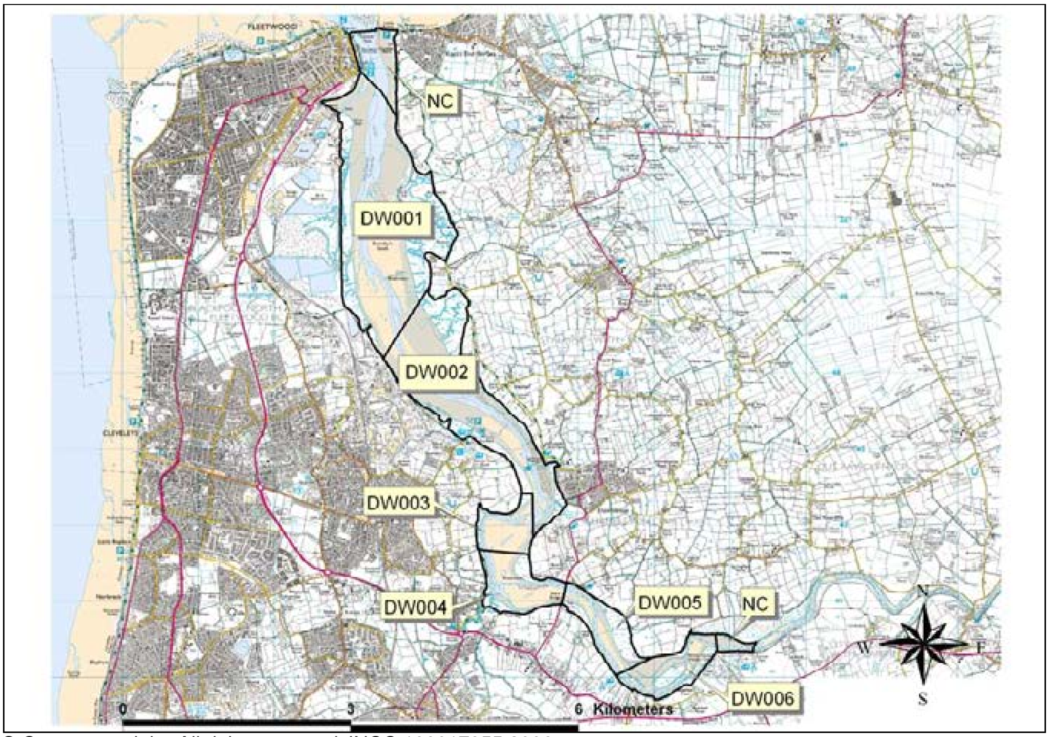


Figure 2.1.3 Wyre Estuary WeBS Low Tide Count sectors. Labels denote WeBS sector codes. NC=Not Counted.

2.1.3 Lune Estuary

The River Lune runs through Lancaster before draining into Morecambe Bay, and the estuary includes a substantial area of intertidal habitat at the mouth, including Middleton Sands, Bernard Wharf, Cockerham Sands and Pilling Sands (Figure 2.1.4). This area could only be partly covered by counts from the shore as flats extend 6 – 7 km offshore. Coverage of the riverine area was possible from the ground, with three additional sectors on the foreshore at Middleton, Morecambe and Half Moon Bay designed to fill in gaps in aerial survey coverage. As no volunteers could be sourced, BTO counters surveyed the area.

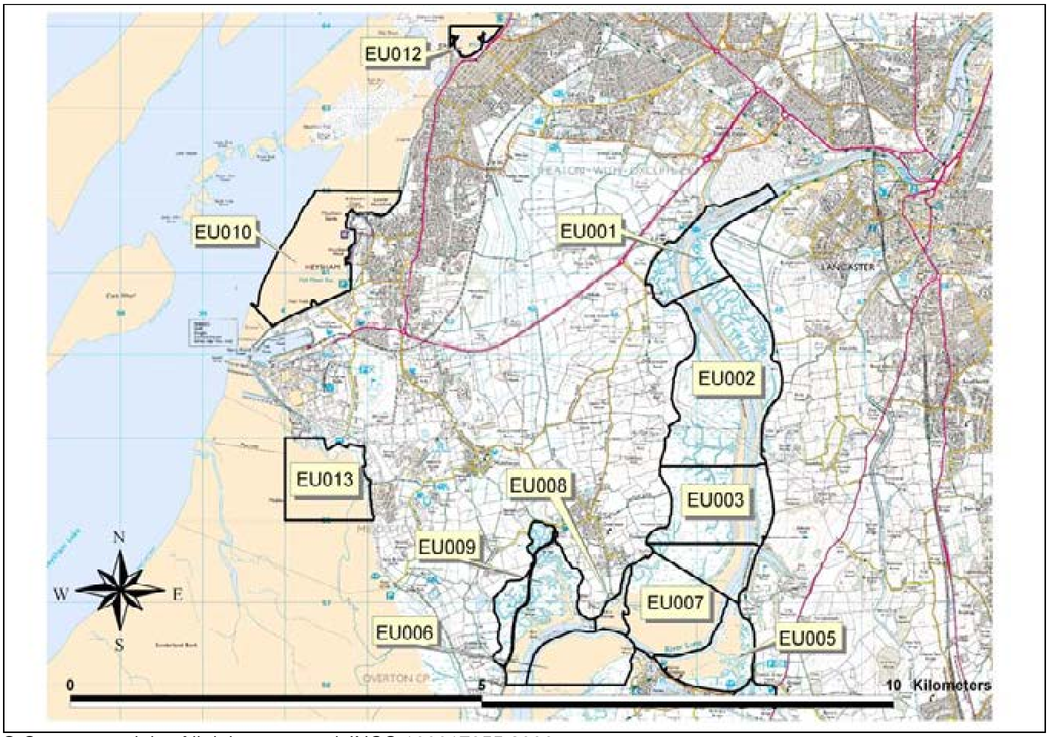


Figure 2.1.4 Lune Estuary WeBS Low Tide Count sectors. Labels denote WeBS sector codes.

2.1.4 Kent Estuary

The Kent Estuary, in the north east corner of Morecambe Bay, receives inflow from much of the Lake District, but lies near no major population centres except the town of Kendal. Counts of the Kent Estuary were organised by staff from RSPB Leighton Moss. It was thus possible to cover the area from Grange-Over-Sands north to Milnthorpe Marsh (Figure 2.1.5). The area south of the OS grid northing 277000 was surveyed using aerial methods.

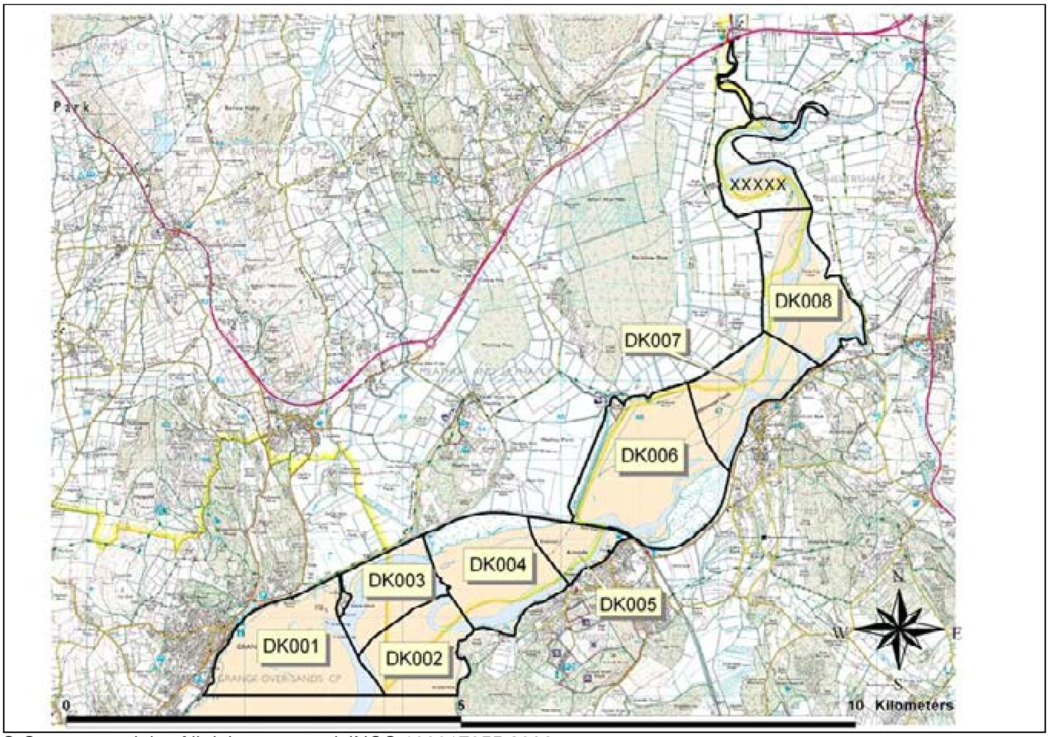


Figure 2.1.5 Kent Estuary WeBS Low Tide Count sectors. Labels denote WeBS sector codes. XXXXX=Not Counted.

2.1.5 Leven Estuary

From its source in the Lake District, the estuary of the river Leven includes some considerable areas of intertidal habitat, including Cartmel Sands (Figure 2.1.6). Ulverston is the nearest town, with Barrow-in-Furness a relatively short distance away. Counts from both shores covered all mudflats up to the river mouth, from north of Bardsea to Cowpren Point. Of the remainder of the extensive intertidal flats, a fraction of the area is potentially visible from the shore, and aerial survey was used for such areas.

As volunteers previously having surveyed this area were involved in LTCs at Piel Channel, BTO surveyors covered the Leven Estuary.

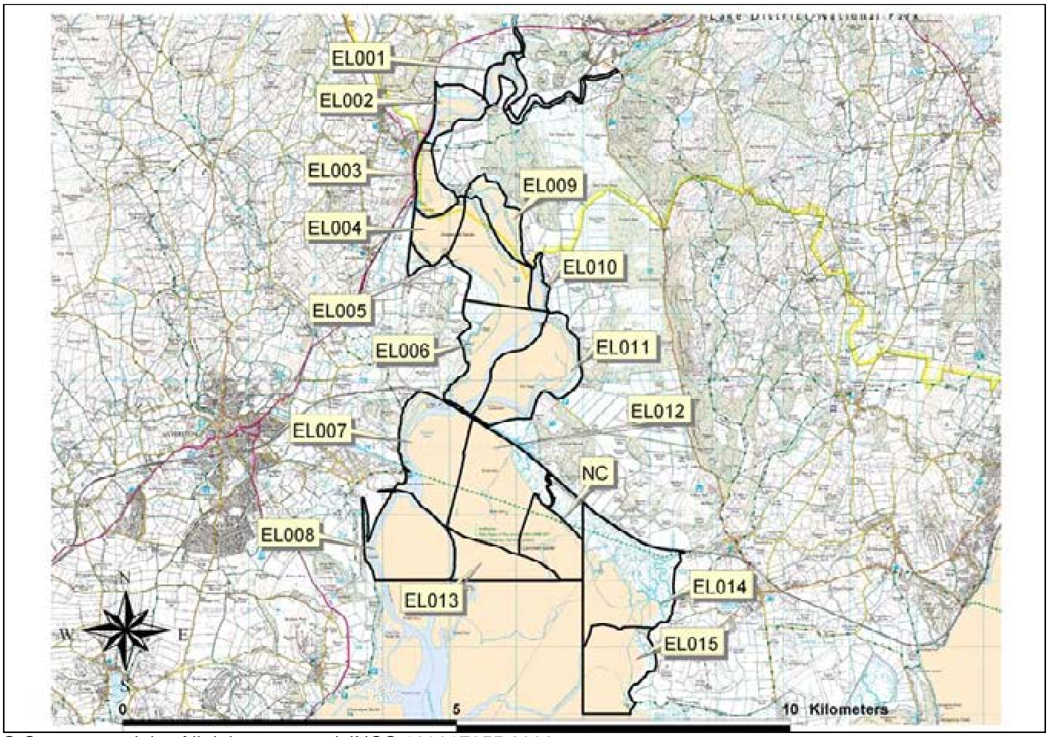


Figure 2.1.6 Leven Estuary WeBS Low Tide Count sectors. Labels denote WeBS sector codes. NC=Not Counted.

2.1.6 Coverage achieved

Weather conditions, restricted periods of temporally suitable low tides and volunteer availability meant that not all areas could be covered in each month. However, through a combination of volunteer and BTO counters, it was possible to cover all of the estuarine areas listed at least once during the winter of 2005/06 (Table 2.1.1).

Estuary	Counters	Month			
		Nov	Dec	Jan	Feb
S. Walney Flats & Piel Channel	Volunteers	Full	Partial	Partial	None
Wyre Estuary	Volunteers	Full	Partial	Full	Full
Lune Estuary	BTO	Full	Full	Full	Full
Kent Estuary	RSPB	Full	Full	Full	Full
Leven Estuary	BTO	Full	Partial	Full	Full

Table 2.1.1 Coverage of Morecambe Bay estuary channels. Full coverage = all sectors counted in all four months. Partial = some sectors not counted. None = no sectors counted. For list of counters, see Acknowledgements.

2.2 Aerial survey of remainder of Morecambe Bay

The remainder of the bay was covered using aerial survey methods. These were based on standard procedures for surveying birds from aircraft (Komdeur *et al.* 1992; Camphuysen *et al.* 2004), but as the aim of the survey was to ascertain relative bird density and distribution, and not quantify numbers of birds, no correction was made for the likely proportion of birds missed by observers. Instead, a grid of 1 km squares was imposed on the survey area *post hoc*, allowing areas of comparatively high bird density to be elucidated.

2.2.1 Aircraft, equipment and observers

All aircraft and pilots were supplied by Ravenair of Liverpool. On all surveys, the aircraft used was a Partenavia PN68. This high-winged, twin engine aeroplane is ideal for aerial bird surveys, allowing observers an unrestricted view to the surface of the sea or ground. The cockpit of the aeroplane carried up to three passengers in addition to the pilot. All observers were equipped with headsets, in order to communicate with each other and with the pilot, and lifejackets. Where possible, a navigator sat alongside the pilot, to record times at waypoints and to assist the pilot in maintaining constant flight speed (185 km^{-h}) and altitude (75 m). A handheld GPS (Garmin 12XL) was connected to a laptop computer with live feed to a Microsoft Access database, in order to record position and time. Some aircraft used had external aerials to which the GPS was connected. On these flights, input to the GPS enabled full flight tracks to be generated; in some other cases, known start and end points of transects were used to infer position. Where suitable personnel were unavailable, the pilot was able to act as navigator, using an on-board GPS system with pre-entered waypoint co-ordinates marking flight paths. All pilots were familiar with piloting on wildlife surveys.

On all surveys, two observers were seated in the rear of the aircraft, one looking to port and one to starboard. Observers were equipped with handheld inclinometers that enabled them to check the limits of their count area, and with handheld digital voice recorders (Olympus WS200S). One voice track was recorded for each transect, that could subsequently be downloaded to computer for analysis. These devices prevented problems with micro-cassettes, which were too short to run for the entire survey. Timers, taped to the inside of the plane, were used to announce start and end times of transects as a cross-check to GPS data.

Observers had all experienced training on aerial surveys before acting as counters, and all were skilled field ornithologists. One observer (Richard Schofield: RS) had participated in hundreds of hours of aerial survey, and acted as starboard counter for two surveys. Alex Banks (AB) had taken part in ten aerial bird surveys before the present survey, and acted as port counter on all surveys. Steve Holloway (SH) and Ilya Maclean (IM) had experienced two and five surveys respectively before the present survey, and took part in one survey each in the absence of RS (starboard counts). Each of the latter three observers had undergone instruction from RS at some point.

2.2.2 Recording methods and survey details

A series of transects was designed to facilitate aerial survey of the entirety of Morecambe Bay not covered from the ground, with special dispensation to enter restricted airspace at Heysham Power Station. The aircraft flew along transects spaced 2 km apart, and observers counted up to 1 km from the plane, enabling the whole bay to be covered. Following the first survey, some transects were truncated for subsequent surveys, on the advice of the pilot.

Surveys were planned to take place once during each of the winter months November – February, in accordance with standard WeBS LTC methodology (*e.g.* Collier *et al.* 2005). Surveys only took place in weather conditions with visibility up to 3 km and wind speeds below 15 mph. Owing to the nature of low tides at Morecambe Bay, an extremely restricted period each month was available for survey. Table 2.1.2 shows details of all surveys attempted.

Date	Start	End	LT	Pilot	Navigator	Observer	Observer	Notes
09.11.05	0956	1130	1102	DN	IM*	AB	SH	Overcast
11.12.05	1232	1405	1417	DN	IM*	AB	RS	Sunny
08.01.06	1117	1247	1219	NS		AB	RS	Overcast
05.02.06	1115	1140	1039	OP		AB	IM	Aborted due to adverse weather
21.02.06	0950	1126	1028	JG		AB	IM	Sunny spells

Table 2.1.2 Aerial survey details. LT = time of Low Tide (at Barrow). Pilots: DN = Dave Naylor, NS = Nick Schofield, OP = Ollie Price, JG = Justin Gore. *IM training and recording waypoints.

Wherever possible, observers assigned bird counts to species level. For some species, such as Shelduck and Oystercatcher, this was a straightforward task. However, for other species, it was often difficult to discriminate between birds of similar appearance (*e.g.* Dunlin and Knot). Camphuysen *et al.* (2004) suggest that in such cases birds should be identified "to the best level of identification, *i.e.* small gull, small diver, auk, etc.". As such, Table 2.1.3 shows the species categories used by observers.

Category	Species included
Small waders	Dunlin, Knot, Purple Sandpiper, Ringed Plover, Sanderling, Turnstone
Medium waders	Golden Plover, Greenshank, Grey Plover, Lapwing, Redshank
Large waders	Bar-tailed Godwit, Black-tailed Godwit, Curlew, Oystercatcher
Unidentified waders	Any wader where no confident impression of size is formed
Small wildfowl	Teal, Long-tailed Duck, Tufted Duck, Goldeneye, Scaup, Wigeon, Shoveler, Common Scoter, Gadwall, others not 'Large wildfowl'
Large wildfowl	Mallard, Pintail, Eider, Shelduck, geese
Unidentified wildfowl	Any duck where no confident impression of size is formed
Small gulls	Black-headed Gull, Common Gull
Large gulls	Herring Gull, Lesser and Great Black-backed Gull
Unidentified gulls	Any gull where no confident impression of size is formed

Table 2.1.3 Categories used for unidentified waterbirds.

2.2.3 Data resolution

For ease of determining species density distributions, the transects were divided into 1 km^2 grid cells. Each observation could be assigned to a discrete grid cell, based on the time of observation and corresponding plane position. This allowed observers to concentrate on identification and quantification, removing the burden of having to judge distance from the plane to the birds observed and thus generate a separate x-coordinate. Figure 2.1.7 shows the grid cells and frequency of visit to each cell derived from the four complete surveys.

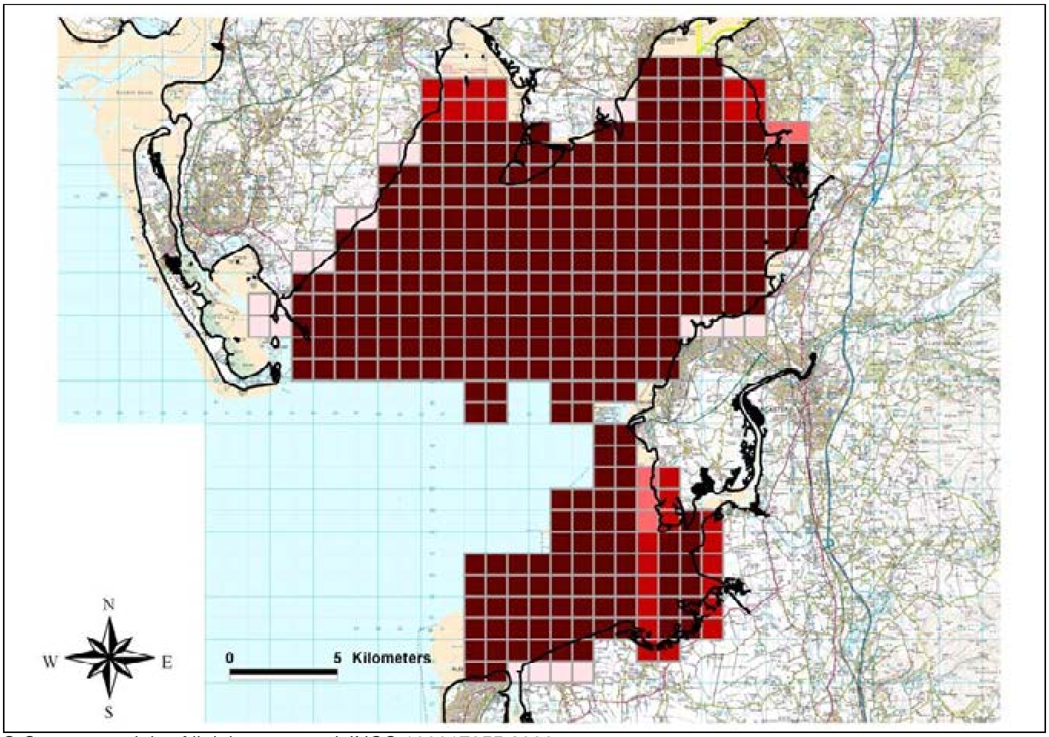


Figure 2.1.7 Frequency of visit to aerial survey grid squares. Darkest squares indicate a maximum four visits, decreasing in tone to the lightest squares visited once.

2.3 Data Processing and Analysis

2.3.1 Data

In addition to bird distribution data collected on aerial survey, disturbance events were also recorded. Potentially disturbing factors were noted on January and February surveys. These were attributable to two different categories; cockling activity, and leisure activity. The former involved people on the mud, raking for cockles or performing another activity related to cockle fishing (arbitrarily including bait-digging). Typically, small teams of people were observed, usually with associated vehicles. Leisure activities were restricted to walking, either with or without dogs. Dogs were always unleashed when observed. Only those people walking on the mud / sandflats were recorded (*i.e.* not people on promenades or on other habitat bordering the bay).

Data on the distribution of shellfish (cockles and *Macoma*) were kindly supplied by Bill Cook (NWNWSFC). Shellfish surveys were all performed before aerial surveys took place; data collected during the winter of 2005/06 for one sample station were not considered. Sample stations and visit times were as follows: Aldingham, August – September 2005; Flookburgh, September 2005; Middleton, July 2005; Pilling, July 2005; Warton, August 2005. Data on total numbers of adult shellfish were collected as point samples. In order to make these data comparable, average values were calculated for the grid cells used to display bird data. Not all grid cells contained a shellfish sample point. Cockle density refers to total numbers of adults (i.e. > one year old). *Macoma* data are total numbers of all size classes; these data were not collected systematically, but depended on manpower available.

Data on sediment types within Morecambe Bay were provided by Bart Donato (English Nature Cumbria Office). These data were collected by Royal Haskoning as part of a survey to English Nature. Data were again collected as point samples. However, owing to the categorical nature of the data, it was not possible to calculate sediment type scores for individual 1 km^2 grid cells.

2.3.2 GIS approaches

All maps and spatial statistics were produced using either ESRI ArcView 3.3 or ArcMap 9 Geographical Information Systems (GIS), with OS backdrops used under the JNCC license (details in Acknowledgments).

2.3.2.1 Cluster analysis

In order to determine bird-rich areas within Morecambe Bay, cluster analysis was performed. This technique highlights ‘hot spots’ and ‘cold spots’ of a given distribution. The Getis-Ord Gi* statistic was used to determine statistical significance of clusters (Mitchell 2005), based on the similarity of values in adjacent 1 km^2 grid cells (*e.g.* Figure 3.1.6a), calculated using the Spatial Statistics toolbox in ArcMap 9. The local search neighbourhood specified in the procedure used a fixed distance of 2000 m, which was considered appropriate to encounter for the potential of birds to move between cells. A Euclidean distance function was specified, and row-standardized weights were used to minimise edge effects (Mitchell 2005). The significance of the resulting Gi* statistics was assessed using the related Z-score at the 95% level.

Similar analyses were used to discover clusters of cockle and *Macoma* distribution.

2.3.2.2 Spatial statistics

Changes in monthly distributions were analysed to examine temporal trends in bird distribution. The spatial mean centre of each distribution was calculated, weighted by mean winter counts of the species in question. Comparison of the means for each month allowed judgment of shifts in distribution, and included a spatial component. The standard deviation from the spatial mean was also calculated and displayed as a circle, the diameter of which encompassed all cells within one standard deviation (*e.g.* Figure 3.2.13). This provided a spatial analysis of the nature of dispersal in the distribution. All analyses were performed using the Spatial Statistics toolbox in ArcMap 9.

2.3.3 Regression analysis

Relationships between mean winter bird distribution and shellfish density were examined using linear regression. Initially, spatial autocorrelation was tested for using Moran’s *I* test and other related tests within the GeoDa 0.9.5i spatial statistics package (Anselin/University of Illinois, 2004). To undertake regression analysis, a generalised linear model was used within SAS (SAS Institute Inc., Cary, NC). The model related mean bird counts to mean shellfish density and a measure of clustering to control for spatial autocorrelation (Z-scores from Gi* statistics), and specified a log link function and Poisson distribution. It was important to control for spatial autocorrelation, as this phenomenon violates the assumption that regression is based on independent observations and can lead to unreliable coefficient estimates.

2.4 Analysis of Count Accuracy

The program “Wildlife Counts” (Lucid Reverie LLC; Juneau, Alaska) was used in order to obtain estimates of counter accuracy. The program simulates images of variable numbers of birds, and calculates count error based on the comparison of actual numbers to counter estimates. It is not possible to judge the ability of observers to identify birds accurately using this program, but it does provide a measure of likely quantitative bias, and as different arrays resemble different bird groups, it is possible to obtain error estimates for a variety of likely species encountered.

Three different set-ups were used to equate roughly to three different field scenarios. Firstly, the ‘snow geese in flight’ image set was used to roughly correspond to counts of large, conspicuous birds, such as Shelduck, Lapwing or geese (minimum number displayed 3, maximum 200). Secondly, the ‘overflight of geese’ image set was used to simulate snapshot counts of large numbers of birds where the target objects are transient and move over the visual field (minimum 200, maximum 1,000). Thirdly, the ‘ducks on a pond’ image set was used to mimic counts of small, cryptic waders, as the target images are somewhat difficult to detect (minimum 3, maximum 550).

Each image set was run for 20 iterations per observer, with a typical exposure time of <10 seconds, depending on the scenario. Three observers participating in aerial surveys (AB, SH and IM) each performed the 20 iterations for each of the three image sets. A naive counter (Emma Davis; ED), with no experience of bird counts of any sort, was used as a control subject against which to compare performance.

3. RESULTS

3.1 Bird distribution and density

For each estuarine area, dot-density maps (at sector level resolution, not in exact locations seen) for every species counted are shown in Appendix 2. Within the text, distribution maps for those species for which Morecambe Bay SPA is important (section 1.1) are also shown where densities are high enough to highlight relative spatial differences within each discrete estuarine site. Notable densities of these species are described in the text. As WeBS Low Tide Count methodology no longer requires a distinction between feeding and roosting birds to be made, counts including all birds observed.

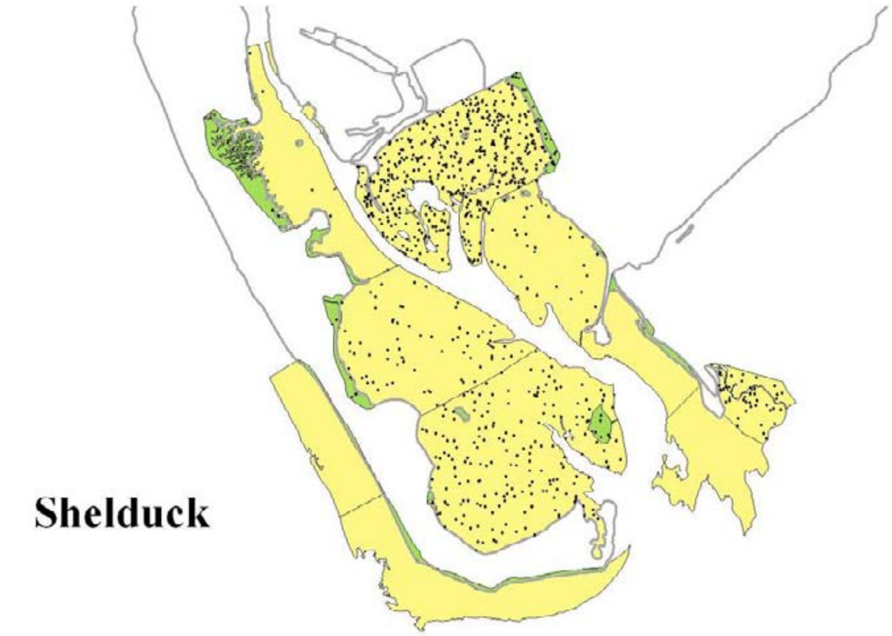
3.1.1 Mean winter density: estuaries

3.1.1.1 South Walney Flats & Piel Channel

Two species of wildfowl, Tufted Duck and Coot, showed high site densities (Table 3.1.1), mostly because of relatively high counts in Cavendish Dock. Relatively high mean counts of Shelduck were thinly spread within the site, at a density of 0.36 birds ha^{-1} (Table 3.1.1; Figure 3.1.1a).

Golden Plover were recorded at similar densities to Shelduck (Table 3.1.1), but were restricted to the Roosecote Sands area (Figure 3.1.1b). Knot were limited to the large mudflats at Haws Bed and Pike Stones (Figure 3.1.1c), at an average density of 0.14 birds ha^{-1} (Table 3.1.1). Oystercatcher densities were comparatively large (Table 3.1.1d), with a fairly even distribution through much of the site, except for an increased density of birds at Foulney Island; these are likely to be associated with the mussel-rich skears found in nearshore areas here. Dunlin were thinly and evenly distributed, up to the Walney Channel but not on the west side of Walney Island (Figure 3.1.1e). Most Curlew were recorded on the same sectors as the highest Oystercatcher densities, the rocky skears at Foulney Island (Figure 3.1.1f). By contrast, Redshank were thinly spread with highest densities found at Roosecote Sands (Figure 3.1.1g).

a



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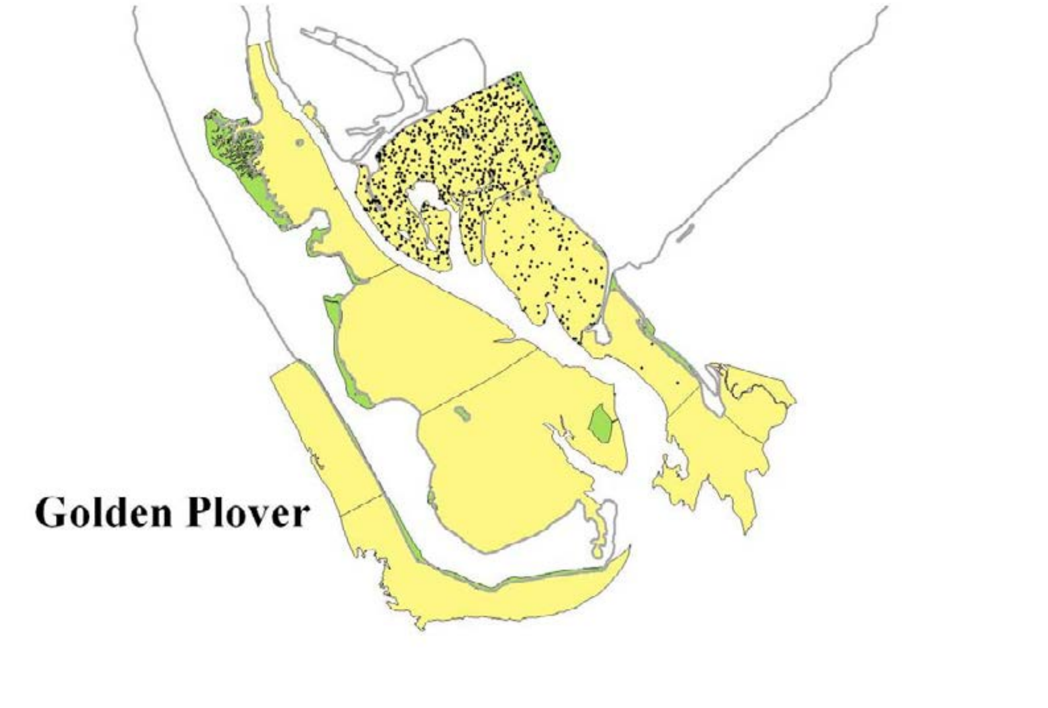

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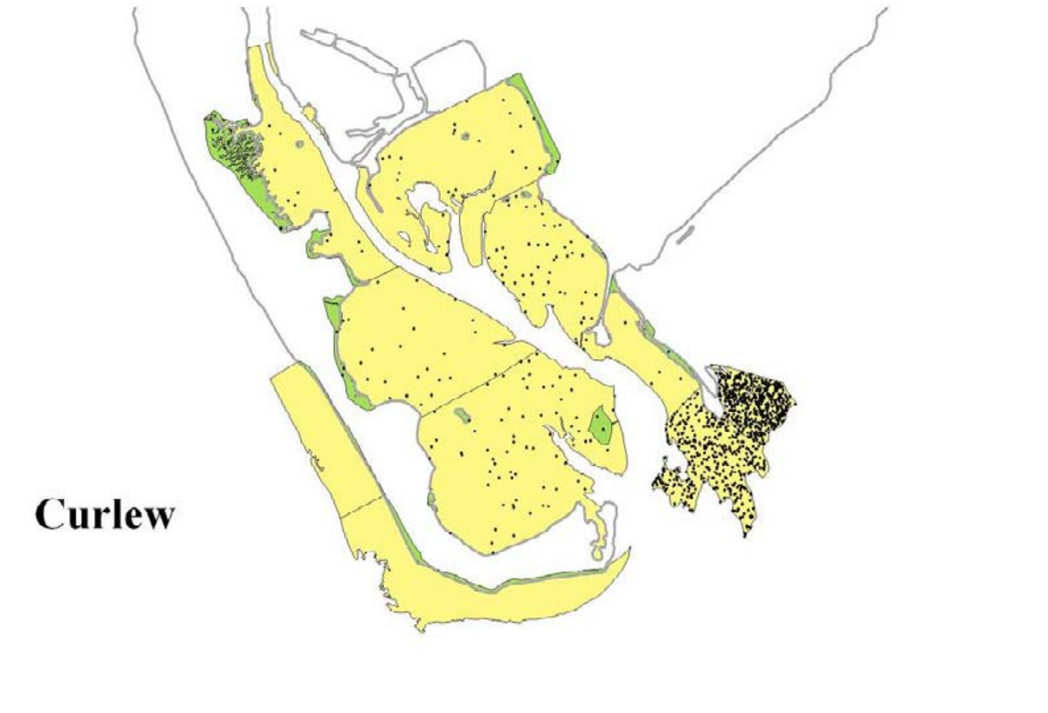

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Figure 3.1.1 a - g Mean winter distributions of Shelduck, Golden Plover, Knot, Oystercatcher, Dunlin, Curlew and Redshank at South Walney & Piel Channel Flats. One dot = one bird.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Little Grebe	Sub-tidal	62	10	0.16
Great Crested Grebe	Sub-tidal	62	19	0.31
Cormorant	Sub-tidal	62	52	0.84
Shag	Sub-tidal	62	12	0.19
Little Egret	Intertidal & non-tidal	2231	2	0.00
Grey Heron	Intertidal & non-tidal	2231	5	0.00
Mute Swan	Sub-tidal	62	9	0.15
Greylag Goose	All habitats	2293	1	0.00
Dark-bellied Brent Goose	All habitats	2293	19	0.01
Light-bellied Brent Goose	All habitats	2293	10	0.00
Shelduck	All habitats	2293	834	0.36
Wigeon	All habitats	2293	336	0.15
Gadwall	All habitats	2293	1	0.00
Teal	All habitats	2293	2	0.00
Mallard	All habitats	2293	40	0.02
Pintail	All habitats	2293	1	0.00
Pochard	Sub-tidal	62	25	0.40
Tufted Duck	Sub-tidal	62	296	4.77
Eider	Sub-tidal	62	459	7.4
Goldeneye	Sub-tidal	62	20	0.32
Red-breasted Merganser	Sub-tidal	62	3	0.05
Coot	Sub-tidal	62	389	6.27
Oystercatcher	Intertidal	2094	5146	2.46
Ringed Plover	Intertidal	2094	44	0.02
Golden Plover	Intertidal & non-tidal	2231	829	0.37
Grey Plover	Intertidal	2094	8	0.00
Lapwing	Intertidal & non-tidal	2231	1369	0.61
Knot	Intertidal	2094	293	0.14
Sanderling	Intertidal	2094	25	0.01
Dunlin	Intertidal	2094	720	0.34
Jack Snipe	Intertidal & non-tidal	2231	0	0.00
Snipe	Non-tidal	137	8	0.06
Curlew	Intertidal & non-tidal	2231	1102	0.49
Redshank	Intertidal & non-tidal	2231	1155	0.52
Greenshank	Intertidal & non-tidal	2231	2	0.00
Turnstone	Intertidal	2094	103	0.05

Table 3.1.1 Species recorded at South Walney & Piel Channel Flats. Areas in hectares.

3.1.1.2 Wyre Estuary

Relatively similar mean densities of a number of wildfowl species were recorded on the Wyre, notably Pink-footed Goose (Figure 3.1.2a), Shelduck (Figure 3.1.2b), Wigeon, Teal and Mallard (Table 3.1.2). Shelduck were fairly evenly spread across the area counted, whilst Pink-footed Geese were largely restricted to the mouth of the river. This area also supported the greatest densities of Oystercatcher, which were found in sizable numbers (Figure 3.1.2c). Golden Plover (Figure 3.1.2d) and Lapwing (Figure3.1.2e) were found in largest aggregations further down the Wyre, unsurprising in that these plovers may also feed on adjacent farmland. Dunlin, Curlew and Redshank were distributed relatively evenly throughout the estuary (Figures 3.1.2f, g, h).

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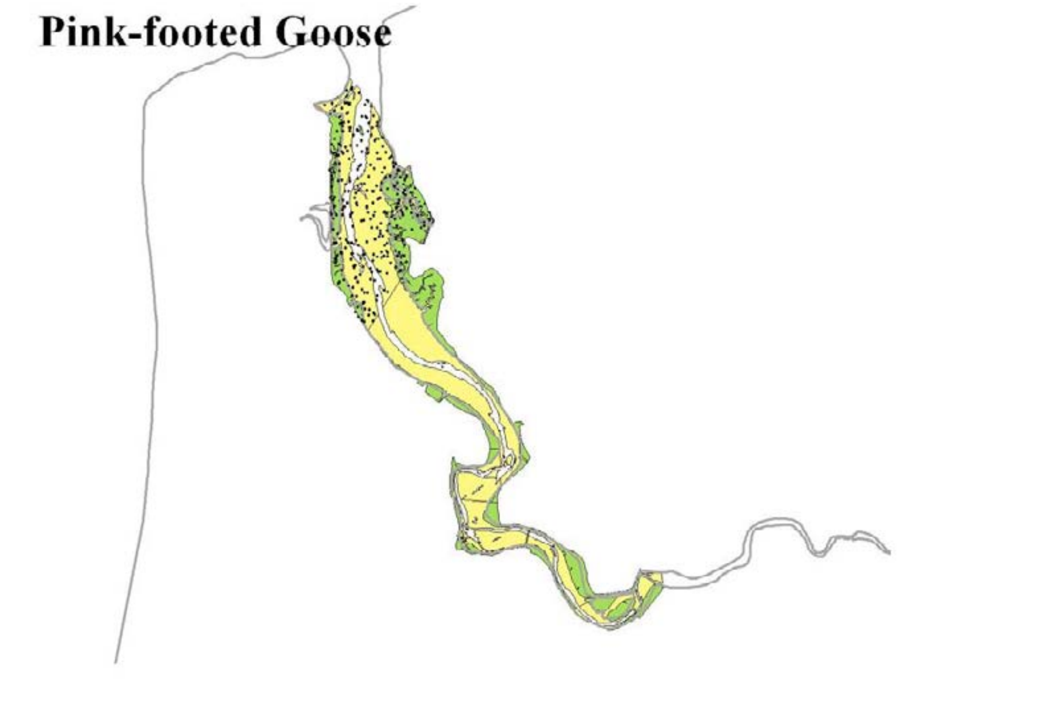

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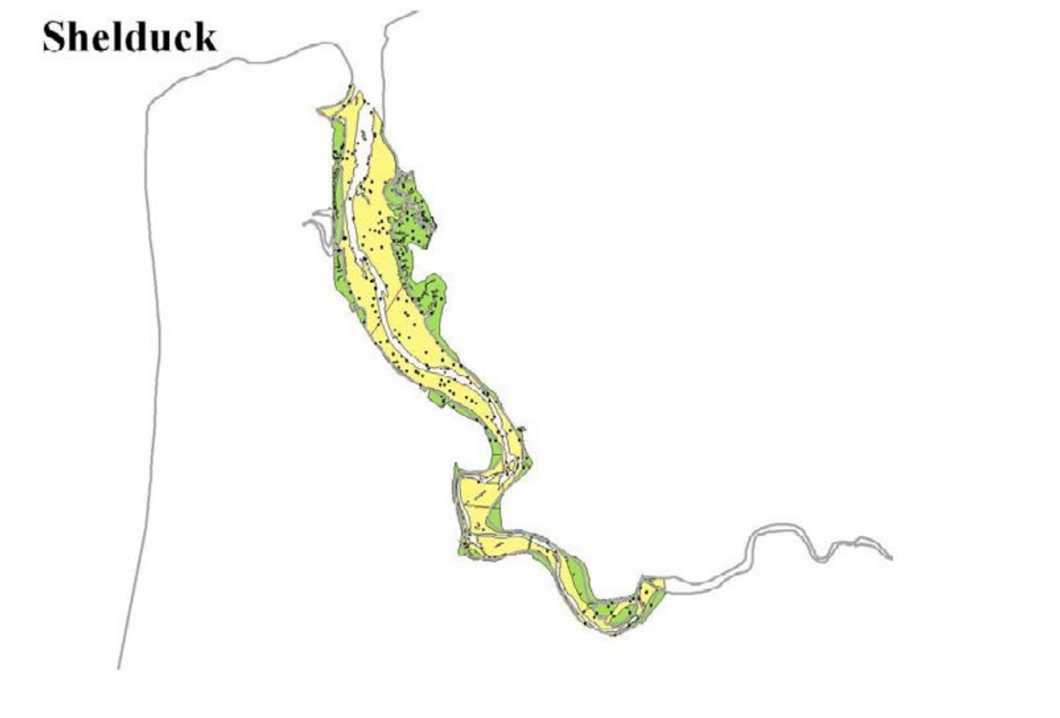

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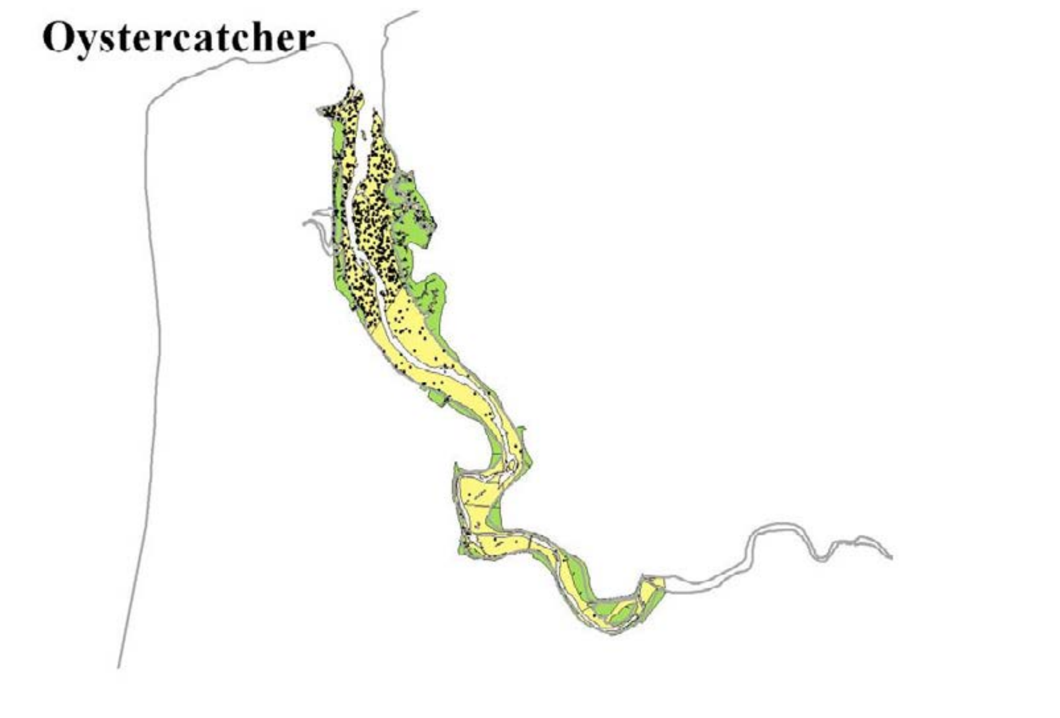

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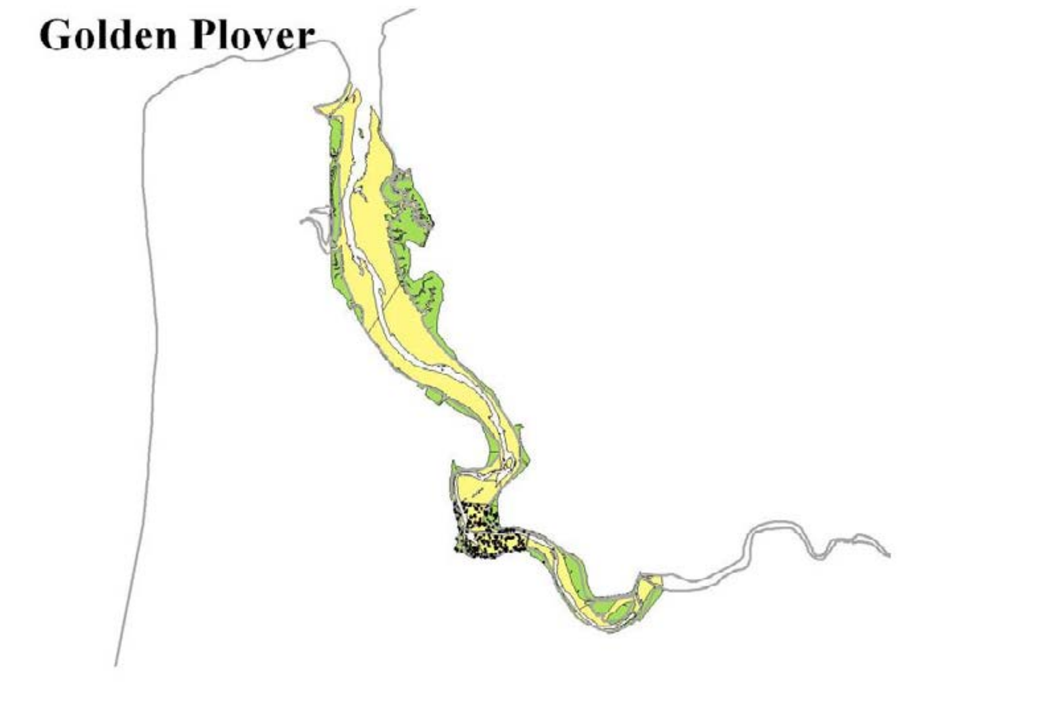

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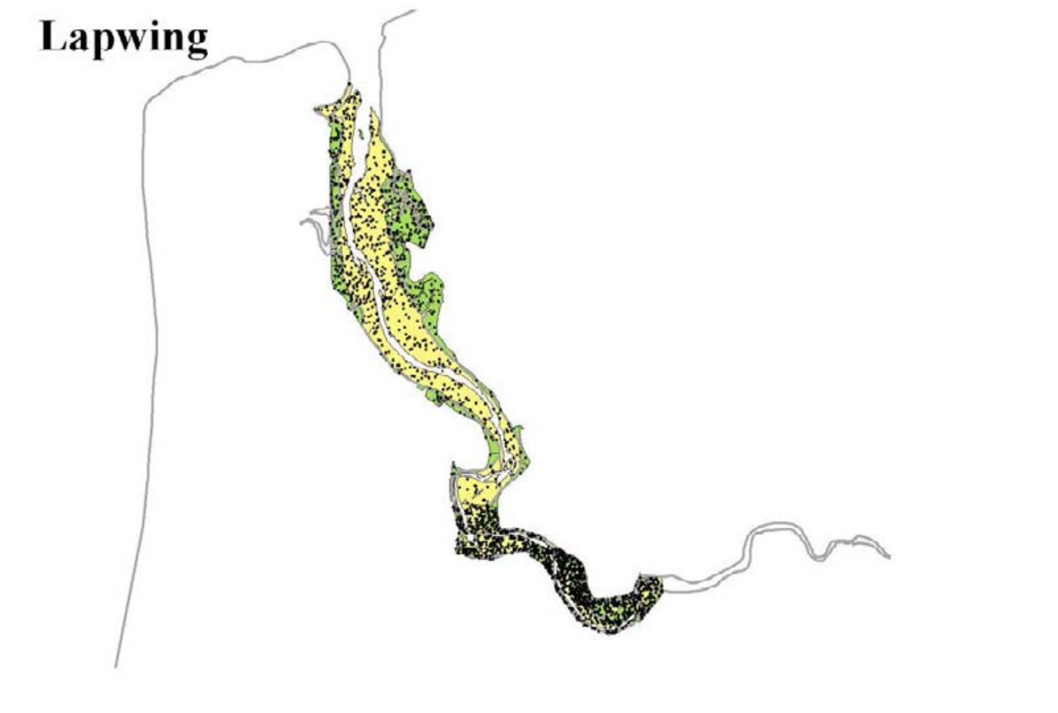

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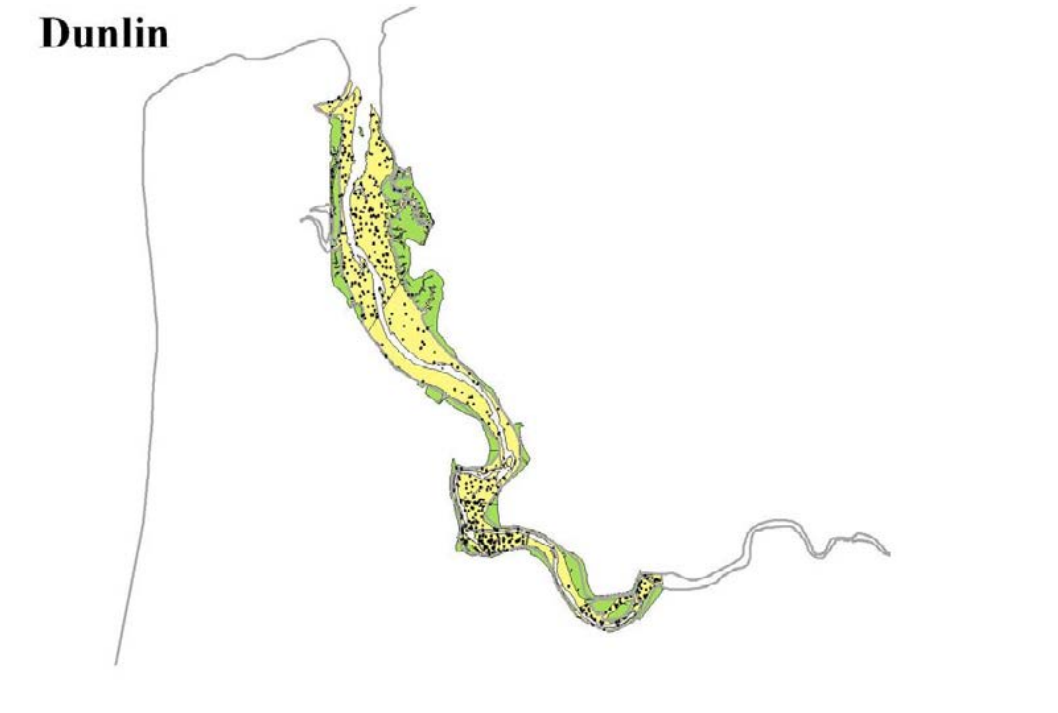

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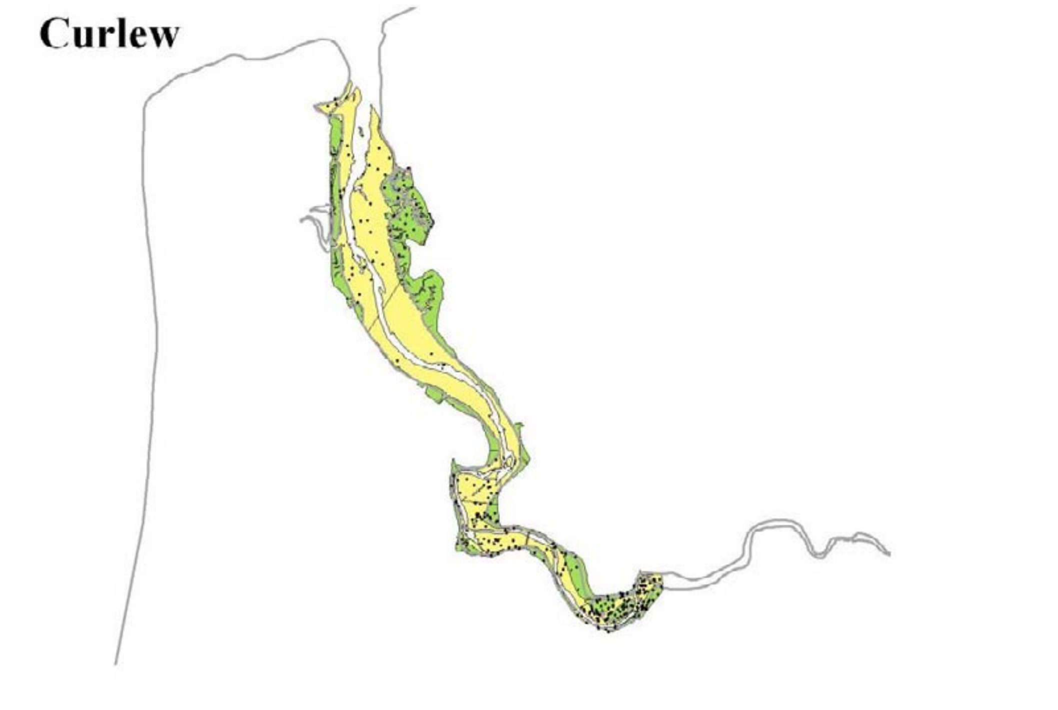

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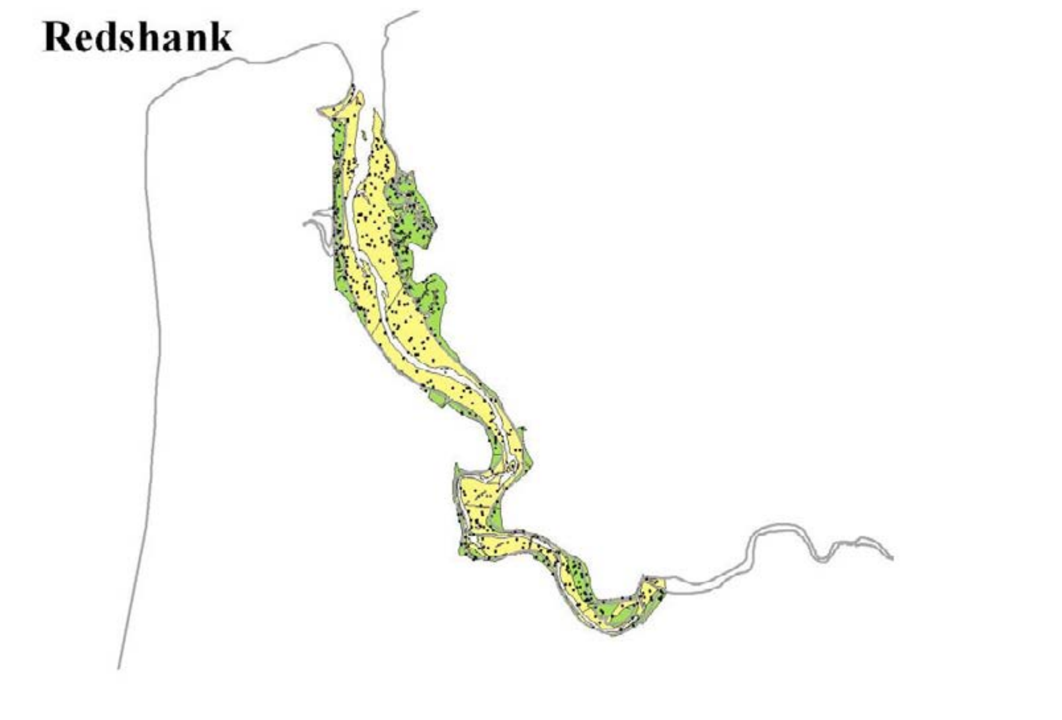

Figure 3.1.2 a - h Mean winter distributions of Pink-footed Goose, Shelduck, Oystercatcher, Golden Plover, Lapwing, Dunlin, Curlew and Redshank on the Wyre Estuary. One dot = one bird.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Great Crested Grebe	Sub-tidal	116	1	0.01
Cormorant	Sub-tidal	116	14	0.12
Little Egret	Intertidal & non-tidal	679	0	0.00
Grey Heron	Intertidal & non-tidal	679	3	0.00
Mute Swan	Sub-tidal	116	13	0.12
Bewick's Swan	All habitats	795	1	0.00
Whooper Swan	All habitats	795	4	0.00
Pink-footed Goose	All habitats	795	300	0.38
Greylag Goose	All habitats	795	0	0.00
Canada Goose	All habitats	795	18	0.02
Shelduck	All habitats	795	217	0.27
Wigeon	All habitats	795	206	0.26
Teal	All habitats	795	293	0.37
Mallard	All habitats	795	254	0.32
Pintail	All habitats	795	6	0.01
Shoveler	All habitats	795	1	0.00
Eider	Sub-tidal	116	3	0.02

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Goldeneye	Sub-tidal	116	1	0.01
Red-breasted Merganser	Sub-tidal	116	7	0.06
Oystercatcher	Intertidal	444	786	1.77
Ringed Plover	Intertidal	444	4	0.01
Golden Plover	Intertidal & non-tidal	679	336	0.50
Lapwing	Intertidal & non-tidal	679	2348	3.46
Knot	Intertidal	444	127	0.29
Dunlin	Intertidal	444	554	1.25
Snipe	Non-tidal	235	1	0.00
Black-tailed Godwit	Intertidal & non-tidal	679	84	0.12
Bar-tailed Godwit	Intertidal	444	4	0.01
Curlew	Intertidal & non-tidal	679	268	0.39
Redshank	Intertidal & non-tidal	679	490	0.72
Greenshank	Intertidal & non-tidal	679	0	0.00
Common Sandpiper	Intertidal & non-tidal	679	0	0.00
Turnstone	Intertidal	444	11	0.03

Table 3.1.2 Species recorded on Wyre Estuary. Areas in hectares.

3.1.1.3 Lune Estuary

The highest densities of wildfowl recorded were of Mute Swan (1.43 birds ha^{-1}) and Wigeon (0.94 birds ha^{-1}), but no wildfowl of international or national importance were recorded in such high densities (Table 3.1.3). Most Oystercatcher recorded were on the sectors along the Heysham shore, principally at Half Moon Bay and Morecambe where rocky skears are likely to hold quantities of mussels (Figure 3.1.3a). Densities of two plover species, Golden Plover and Lapwing, were notably high (Table 3.1.3). The former species was mostly found at Conder Green, whereas Lapwing were evenly distributed at high density (Figure 3.1.3c). The extremely high density of Knot was largely determined by the estimate of 14,000 birds made in December 2005 at Half Moon Bay (Figure 3.1.3d; photographs of the flock are in Appendix 3). Bar-tailed Godwit were also recorded at comparatively high density, with the majority of birds concentrated near the mouth of the river (Figure 3.1.3e).

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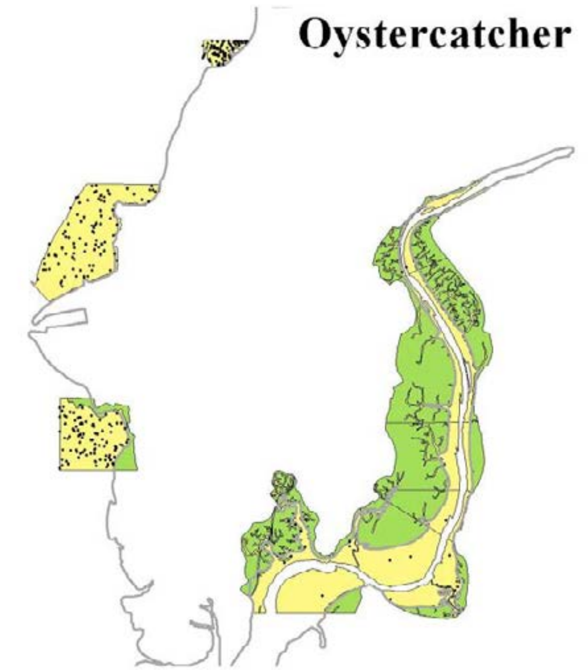

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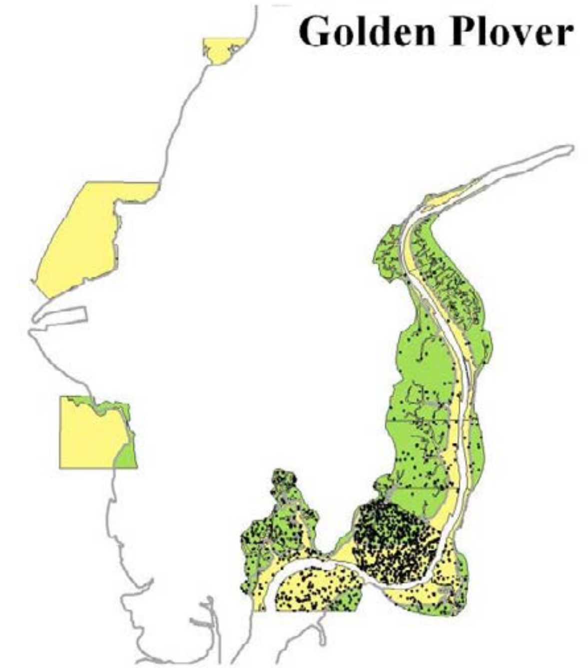

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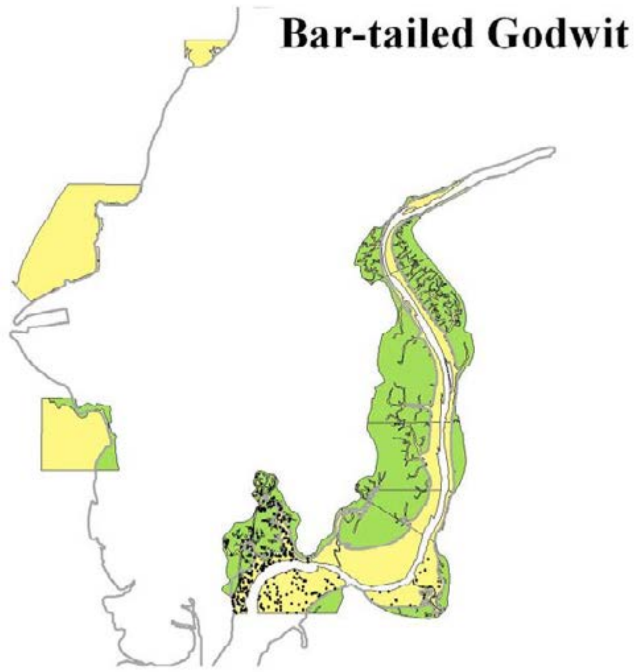

Figure 3.1.3 a - e Mean winter distributions of Oystercatcher, Golden Plover, Lapwing, Knot, and Bar-tailed Godwit on the Lune Estuary. One dot = one bird.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Great Crested Grebe	Sub-tidal	91	1	0.01
Cormorant	Sub-tidal	91	17	0.18
Little Egret	Intertidal & non-tidal	1037	1	0.00
Grey Heron	Intertidal & non-tidal	1037	8	0.01
Mute Swan	Sub-tidal	91	130	1.43
Pink-footed Goose	All habitats	1128	0	0.00
Greylag Goose	All habitats	1128	63	0.06
Canada Goose	All habitats	1128	84	0.07
Shelduck	All habitats	1128	123	0.11
Wigeon	All habitats	1128	1062	0.94
Teal	All habitats	1128	72	0.06
Mallard	All habitats	1128	220	0.20
Shoveler	All habitats	1128	1	0.00
Pochard	Sub-tidal	91	3	0.04
Tufted Duck	Sub-tidal	91	7	0.08
Scaup	Sub-tidal	91	0	0.00
Eider	Sub-tidal	91	1	0.01

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Goldeneye	Sub-tidal	91	49	0.54
Red-breasted Merganser	Sub-tidal	91	2	0.02
Goosander	Sub-tidal	91	3	0.03
Oystercatcher	Intertidal	559	291	0.52
Ringed Plover	Intertidal	559	1	0.00
Golden Plover	Intertidal & non-tidal	1037	1278	1.23
Grey Plover	Intertidal	559	0	0.00
Lapwing	Intertidal & non-tidal	1037	5324	5.13
Knot	Intertidal	559	3581	6.41
Dunlin	Intertidal	559	20	0.04
Snipe	Non-tidal	478	0	0.00
Bar-tailed Godwit	Intertidal	559	288	0.51
Curlew	Intertidal & non-tidal	1037	157	0.15
Spotted Redshank	Intertidal & non-tidal	1037	2	0.00
Redshank	Intertidal & non-tidal	1037	333	0.32
Turnstone	Intertidal	559	2	0.00

Table 3.1.3 Species recorded on Lune Estuary. Areas in hectares.

3.1.1.4 Kent Estuary

A relatively low diversity of species was recorded on the Kent Estuary, but three species of international importance were recorded in noteworthy densities. Pintail numbers neared an average of 500, at a density of 0.39 birds ha^{-1} (Table 3.1.4). This species was concentrated in the lower reaches of the estuary (Figure 3.1.4a). Oystercatchers, occurring at a mean density of 0.56 birds ha^{-1} (Table 3.1.4) were largely restricted to the intertidal area south of the Kent viaduct, an area also favoured at higher concentrations by Dunlin (Figures 3.1.4b, c). Curlew were also found in this area, though smaller concentrations occurred further upriver towards surrounding farmland (Figure 3.1.4d).

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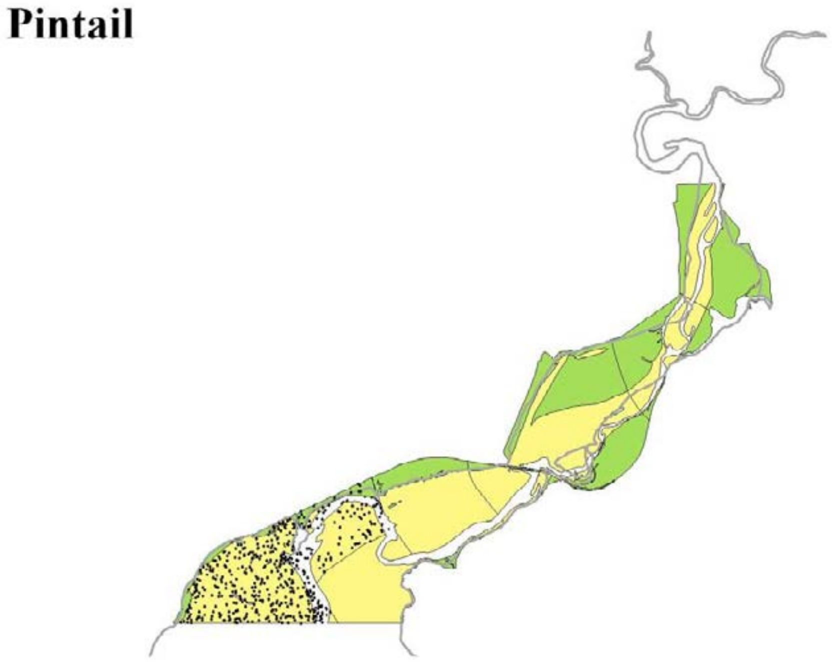

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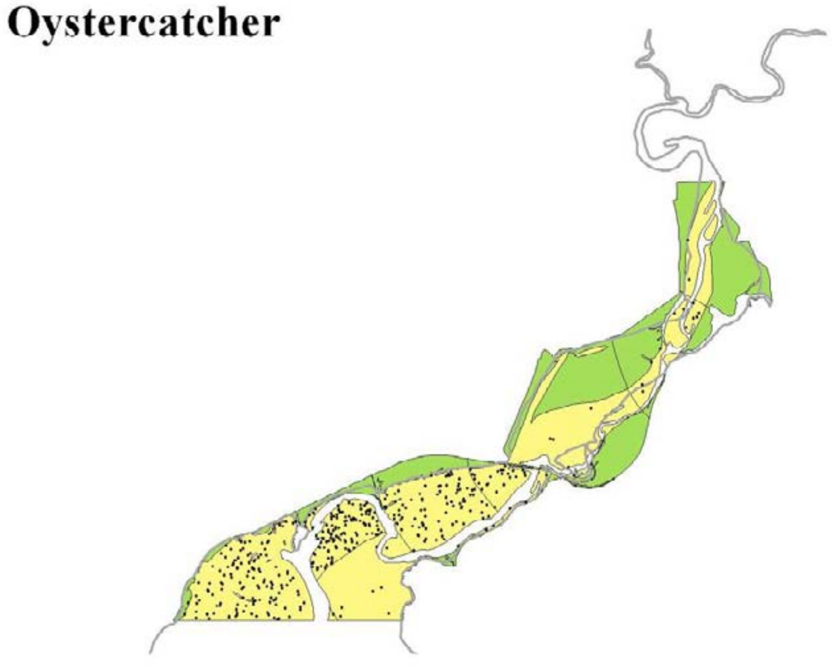

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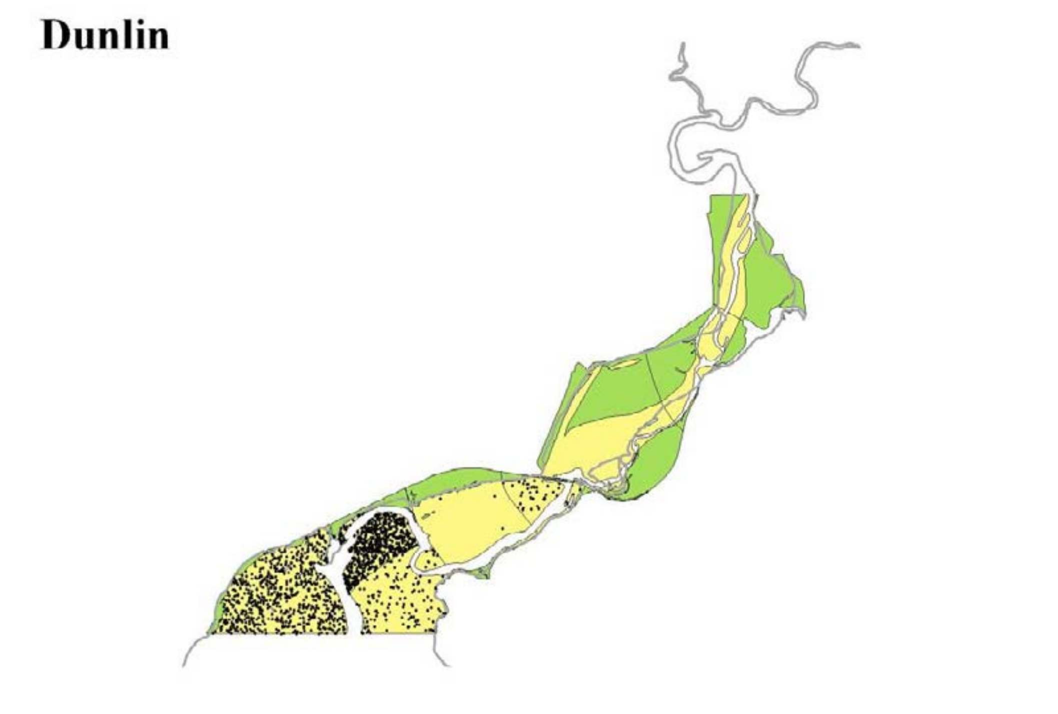

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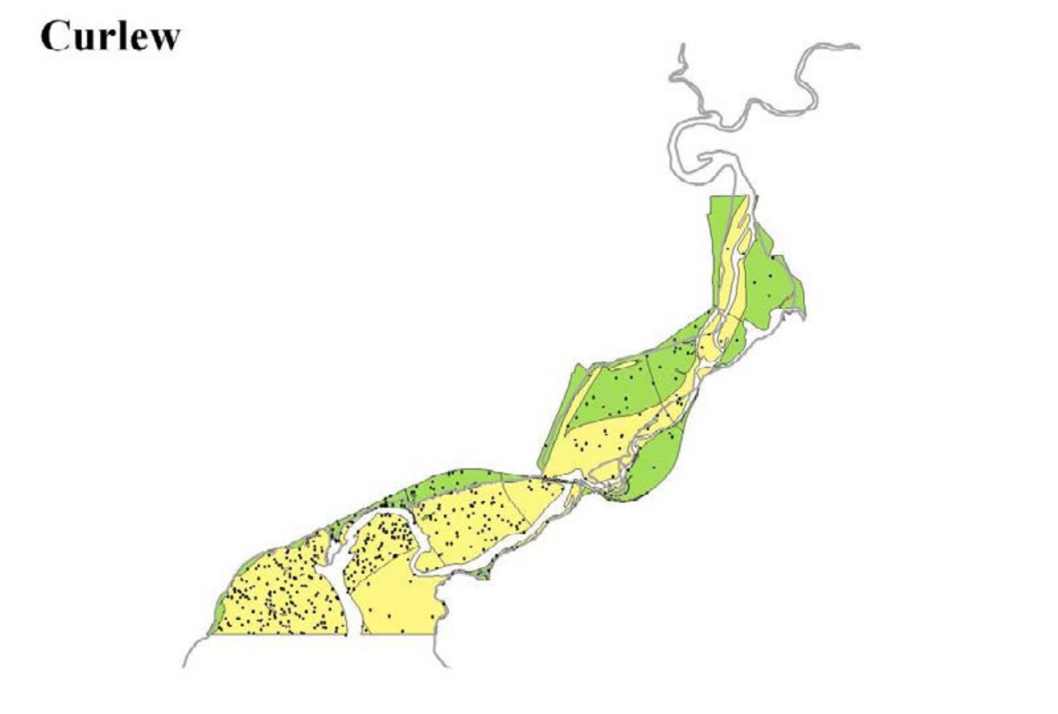

Figure 3.1.4 a - d Mean winter distributions of Pintail, Oystercatcher, Dunlin and Curlew on the Kent Estuary. One dot = one bird.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Cormorant	Sub-tidal	153	10	0.07
Grey Heron	Intertidal & non-tidal	1106	4	0.00
Mute Swan	Sub-tidal	153	1	0.00
Greylag Goose	All habitats	1259	72	0.06
Shelduck	All habitats	1259	215	0.17
Wigeon	All habitats	1259	157	0.12
Teal	All habitats	1259	85	0.07
Mallard	All habitats	1259	238	0.19
Pintail	All habitats	1259	497	0.39
Goldeneye	Sub-tidal	153	7	0.05
Red-breasted Merganser	Sub-tidal	153	1	0.01
Goosander	Sub-tidal	153	3	0.02
Oystercatcher	Intertidal	717	399	0.56
Ringed Plover	Intertidal	717	10	0.01
Golden Plover	Intertidal & non-tidal	1106	5	0.00
Lapwing	Intertidal & non-tidal	1106	19	0.02
Knot	Intertidal	717	30	0.04
Dunlin	Intertidal	717	1522	2.12
Curlew	Intertidal & non-tidal	1106	441	0.40
Spotted Redshank	Intertidal & non-tidal	1106	0	0.00
Redshank	Intertidal & non-tidal	1106	252	0.23

Table 3.1.4 Species recorded on Kent Estuary. Areas in hectares.

3.1.1.5 Leven Estuary

The Leven is a large estuary, comprising extensive areas of saltmarsh and intertidal habitat. However, bird numbers were comparatively low, and no species was found at particularly high density. Oystercatcher, Dunlin and Redshank were all present in average densities of 0.21 birds ha^{-1} , whereas Lapwing occurred at 0.11 birds ha^{-1} (Table 3.1.5). Additional numbers of Lapwing (ca.700) and Golden Plover (ca.100) were counted in areas slightly beyond the boundaries of count sectors in December, so it is possible that these plovers also appear on the intertidal and saltmarsh areas of the Leven at times. Most waders were observed in densest aggregations on intertidal areas south of Greenodd Sands, such as Cartmel Sands and the area near Ulverston (Figure 3.1.5a - d).

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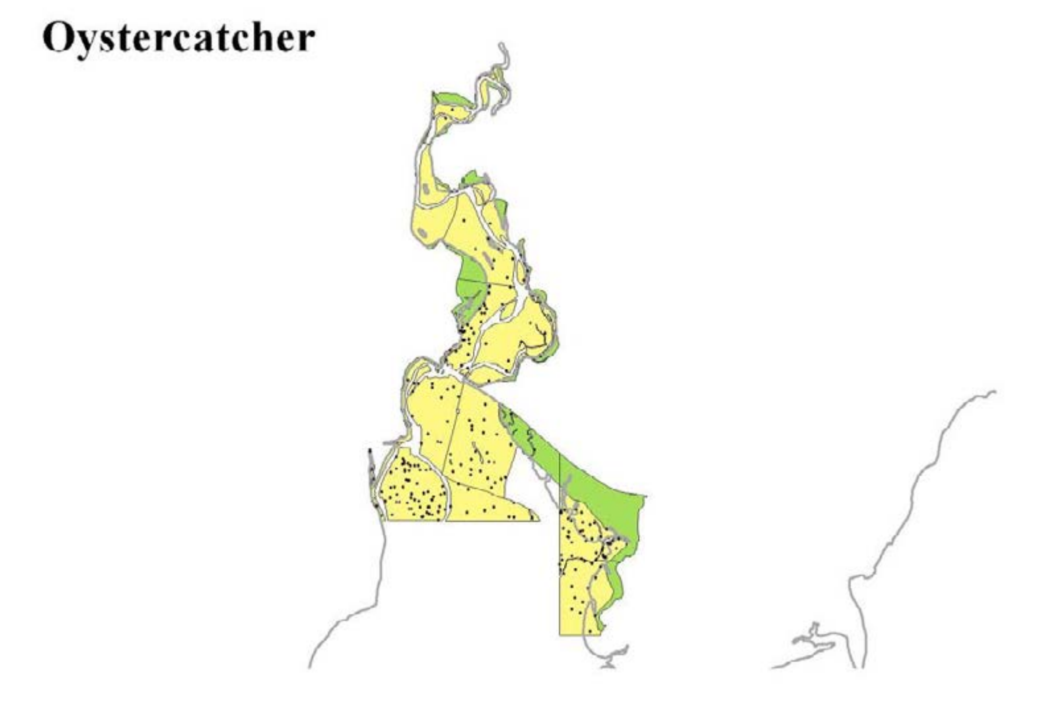

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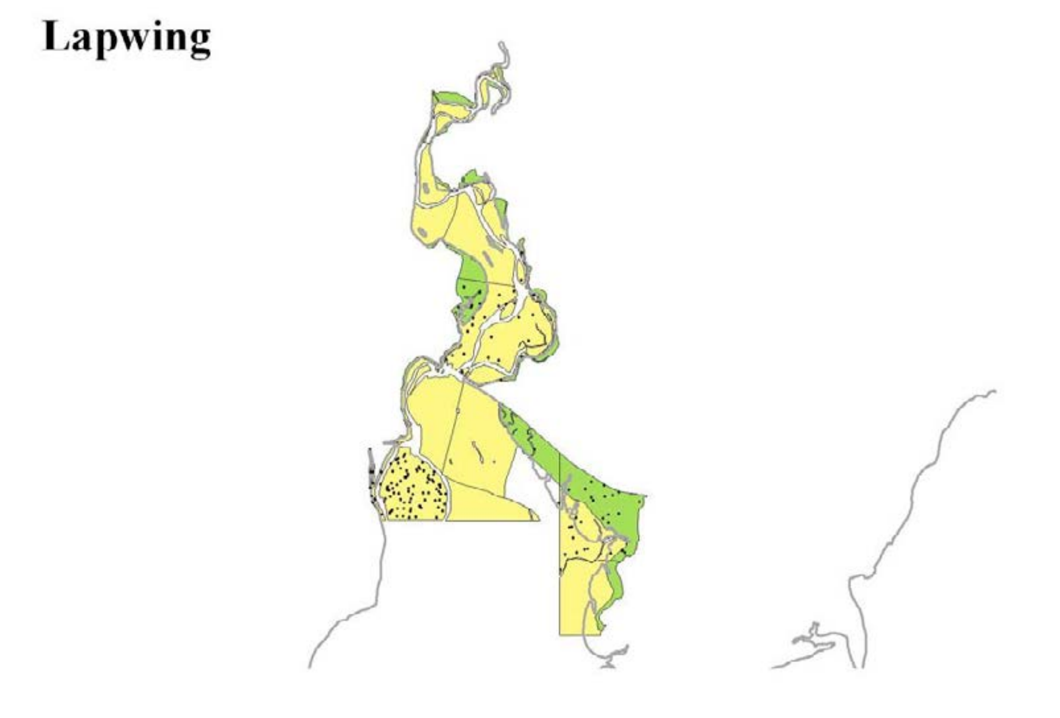

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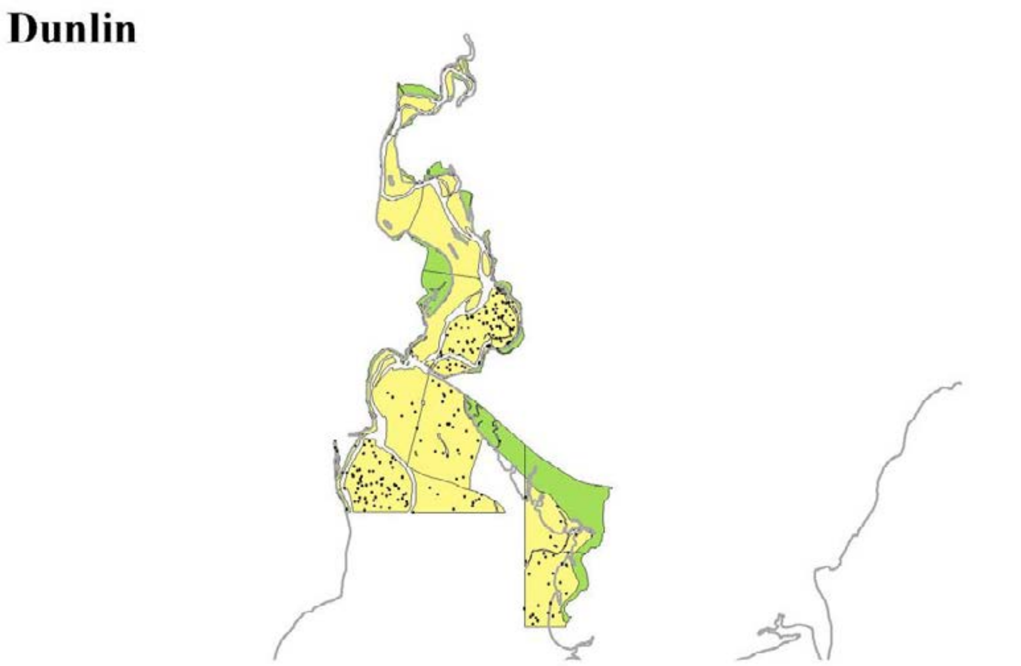

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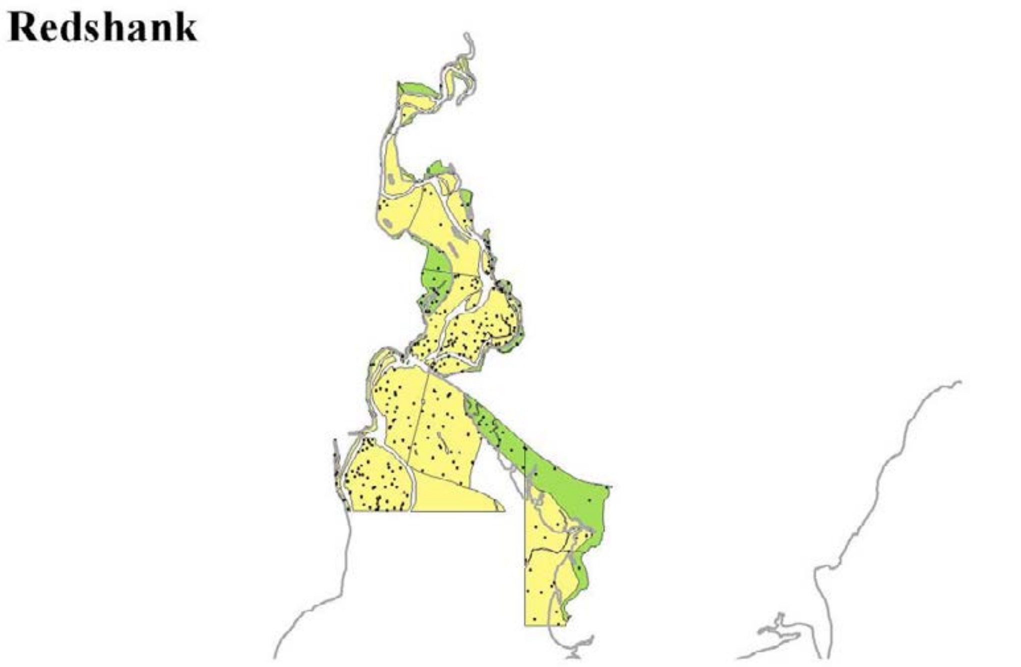

Figure 3.1.5 a - d Mean winter distributions of Oystercatcher, Lapwing, Dunlin and Redshank on the Leven Estuary. One dot = one bird.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Great Crested Grebe	Sub-tidal	150	1	0.00
Cormorant	Sub-tidal	150	9	0.06
Grey Heron	Intertidal & non-tidal	1342	5	0.00
Mute Swan	Sub-tidal	150	2	0.01
Whooper Swan	All habitats	1492	0	0.00
Pink-footed Goose	All habitats	1492	5	0.00
Shelduck	All habitats	1492	84	0.06
Wigeon	All habitats	1492	235	0.16
Teal	All habitats	1492	41	0.03
Mallard	All habitats	1492	152	0.10
Pintail	All habitats	1492	8	0.01
Eider	Sub-tidal	150	0	0.00
Goldeneye	Sub-tidal	150	14	0.09
Red-breasted Merganser	Sub-tidal	150	3	0.02
Goosander	Sub-tidal	150	11	0.08
Oystercatcher	Intertidal	1054	221	0.21
Ringed Plover	Intertidal	1054	3	0.00
Golden Plover	Intertidal & non-tidal	1342	37	0.03
Grey Plover	Intertidal	1054	1	0.00
Lapwing	Intertidal & non-tidal	1342	147	0.11
Knot	Intertidal	1054	58	0.06
Dunlin	Intertidal	1054	220	0.21
Snipe	Non-tidal	288	1	0.00
Black-tailed Godwit	Intertidal & non-tidal	1342	1	0.00
Bar-tailed Godwit	Intertidal	1054	1	0.00
Curlew	Intertidal & non-tidal	1342	117	0.09
Redshank	Intertidal & non-tidal	1342	283	0.21
Turnstone	Intertidal	1054	1	0.00

Table 3.1.5 Species recorded on Leven Estuary. Areas in hectares.

3.1.2 Mean winter density: aerial surveys

3.1.2.1 Wildfowl and waders

Table 3.1.6 shows mean site counts and mean site density for all species recorded on aerial surveys. As the area involved was so great, and as aerial surveys are prone to underestimating numbers of birds, even large bird counts led to most site densities being very low. Three notable exceptions are those of Eider, Oystercatcher and ‘unidentified small waders’. The latter category is largely comprised of Knot and Dunlin, and it is unsurprising that densities of these four species should be high, given that they are known to be very abundant within Morecambe Bay (e.g. Collier *et al*. 2005).

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Red-throated Diver	Sub-tidal	900	5	0.01
Cormorant	Sub-tidal	900	36	0.04
Little Egret	Intertidal & non-tidal	36400	0	0.00
Grey Heron	Intertidal & non-tidal	36400	0	0.00
Mute Swan	Sub-tidal	900	46	0.05
Pink-footed Goose	All habitats	37300	2	0.00
Shelduck	All habitats	37300	771	0.02
Wigeon	All habitats	37300	65	0.00
Teal	All habitats	37300	58	0.00
Mallard	All habitats	37300	44	0.00
Pintail	All habitats	37300	6	0.00
Eider	Sub-tidal	900	206	0.23
Long-tailed Duck	Sub-tidal	900	1	0.00
Red-breasted Merganser	Sub-tidal	900	0	0.00
Oystercatcher	Intertidal	35100	10253	0.29
Lapwing	Intertidal & non-tidal	36400	832	0.02
Knot	Intertidal	35100	97	0.00
Dunlin	Intertidal	35100	150	0.00
Black-tailed Godwit	Intertidal & non-tidal	36400	2	0.00
Bar-tailed Godwit	Intertidal	35100	13	0.00
Curlew	Intertidal & non-tidal	36400	620	0.02
Redshank	Intertidal & non-tidal	36400	113	0.00
Unidentified small wader	Intertidal & non-tidal	36400	5961	0.16
Unidentified large wader	Intertidal & non-tidal	36400	111	0.00
Unidentified medium wader	Intertidal & non-tidal	36400	728	0.02
Unidentified duck	All habitats	37300	292	0.01
Unidentified diver	Sub-tidal	900	1	0.00
Unidentified wader	Intertidal & non-tidal	36400	403	0.01

Table 3.1.6 Species recorded on aerial surveys within Morecambe Bay. Areas in hectares.

It is instructive to consider in more detail the relative distribution of a greater number of species; although densities may be low, absolute numbers may be high in comparison to those counted on the associated estuaries. Therefore, Figures 3.1.6a - l show the relative densities of those species with mean site counts of greater than 50 birds. Where species identification was not possible and birds were classified as 'unidentified', mean counts have been combined with counts of the species positively identified to give an overall distribution for the various categories (*e.g.* counts of unidentified small waders were combined with counts of Dunlin and Knot to provide the distribution of small waders). Readily identifiable species (Eider, Shelduck, Oystercatcher, Lapwing and geese) were excepted from these calculations, as it was extremely unlikely that observers would fail to recognise such birds when encountered. Thus such species would not be assigned to any of the 'unidentified' categories. A map was also produced detailing the distribution of all unidentified waders (*i.e.* combined counts of unidentified waders and unidentified small, medium and large waders). As relatively few wildfowl were counted on the surveys, a map is presented showing the distribution of all ducks, excluding the readily identifiable Eider, Shelduck and any geese recorded.

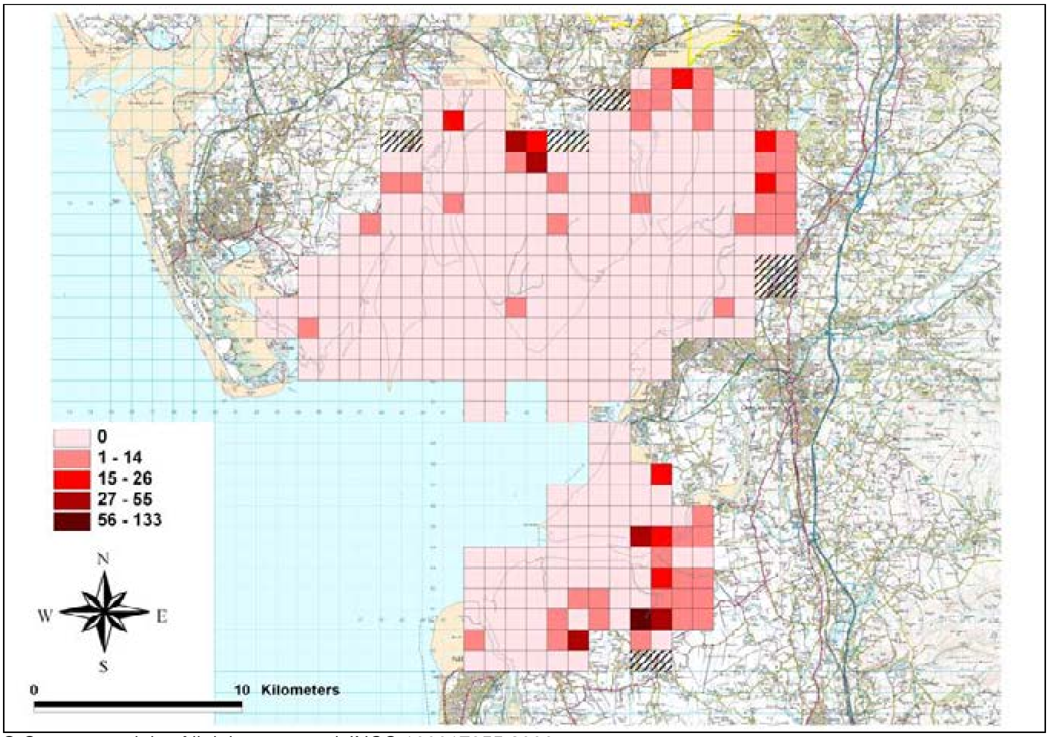

Figure 3.1.6a Mean winter distribution of Shelduck, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

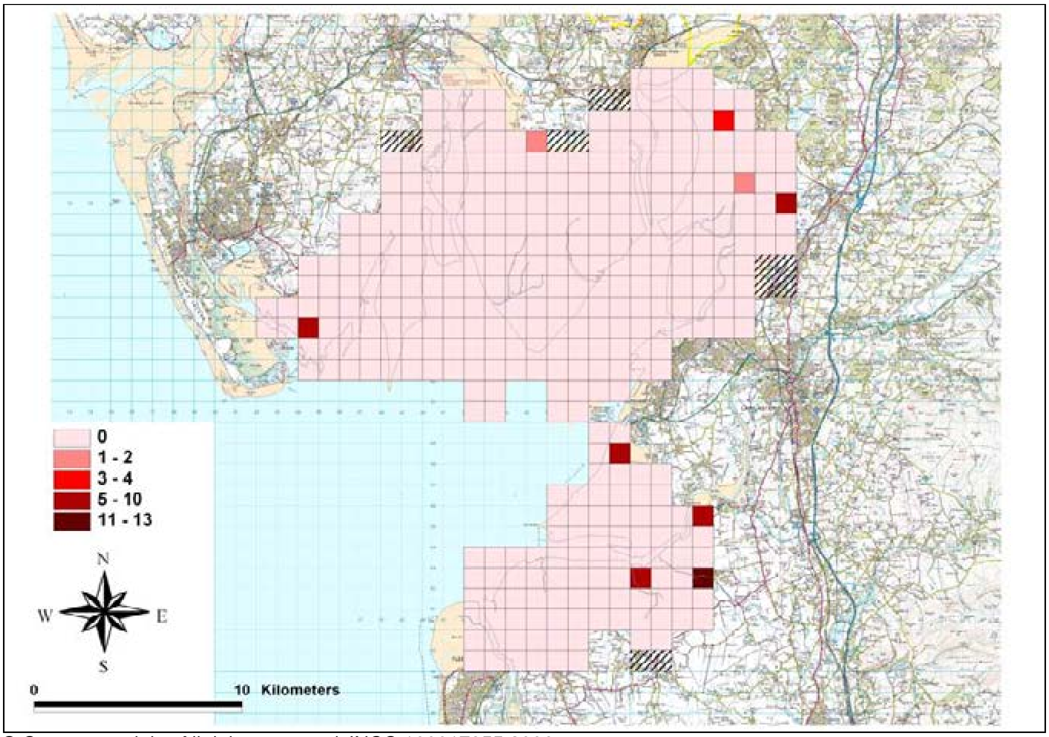

Figure 3.1.6b Mean winter distribution of Wigeon, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

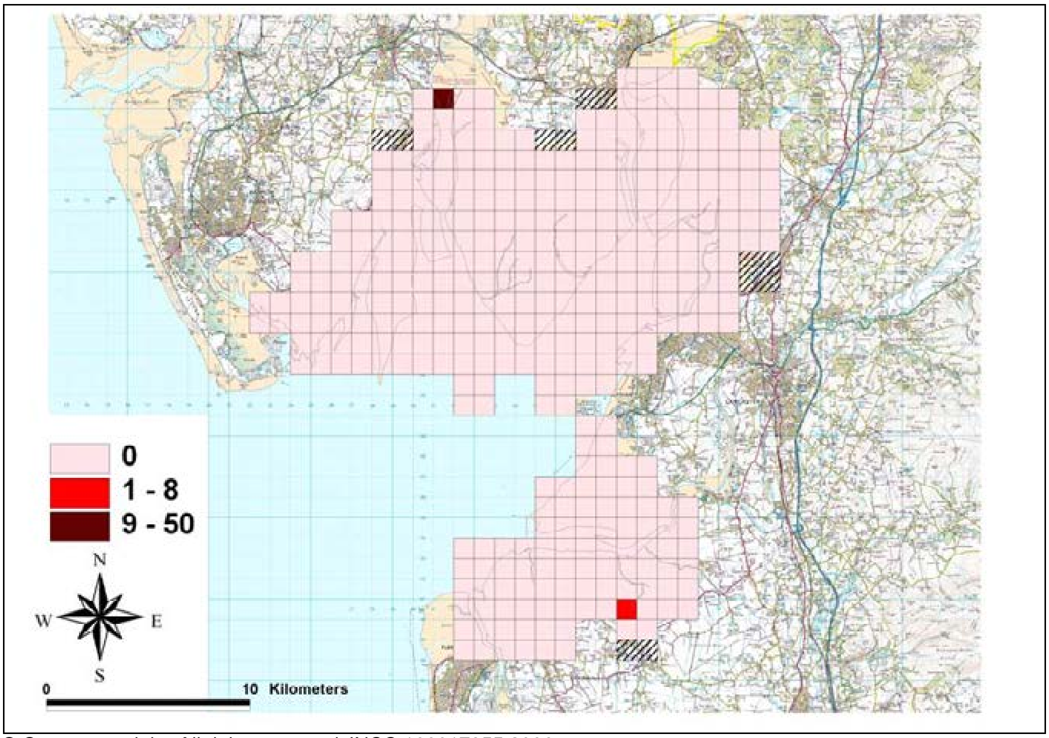

Figure 3.1.6c Mean winter distribution of Teal, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

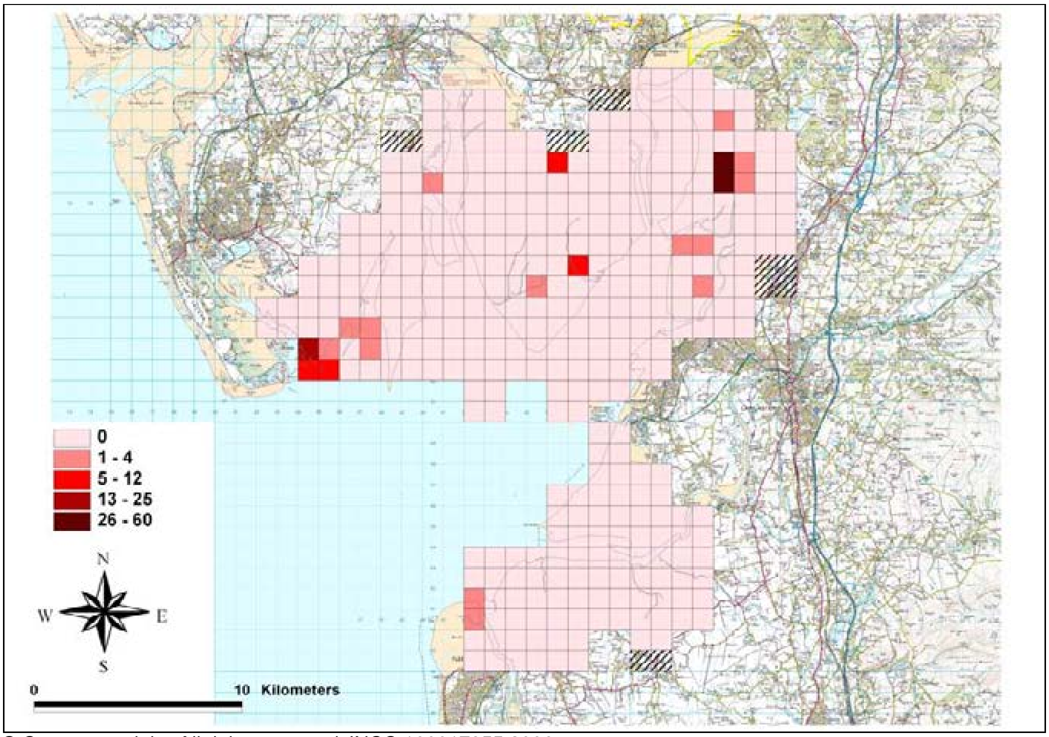

Figure 3.1.6d Mean winter distribution of Eider, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

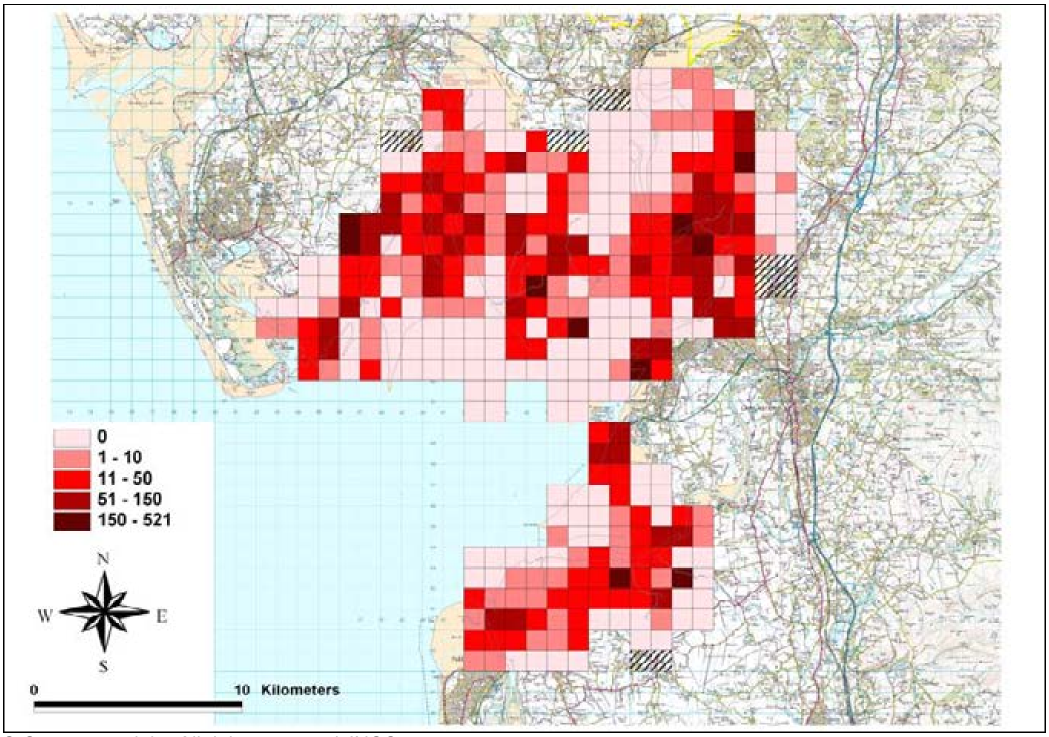

Figure 3.1.6e Mean winter distribution of Oystercatcher, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

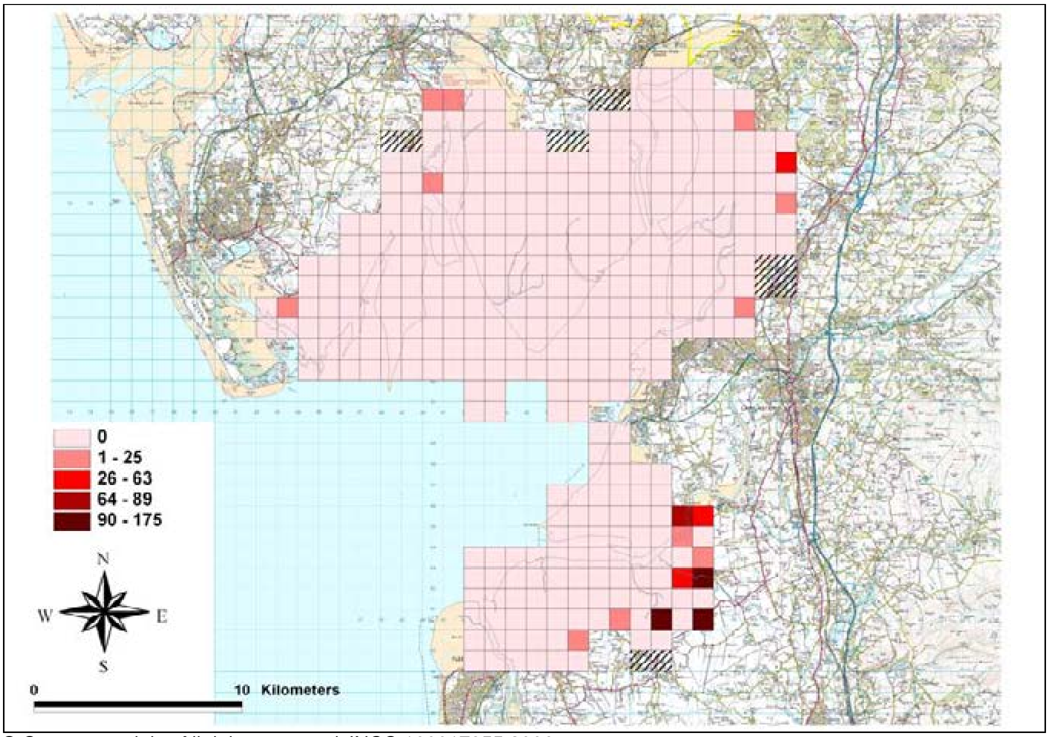

Figure 3.1.6f Mean winter distribution of Lapwing, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

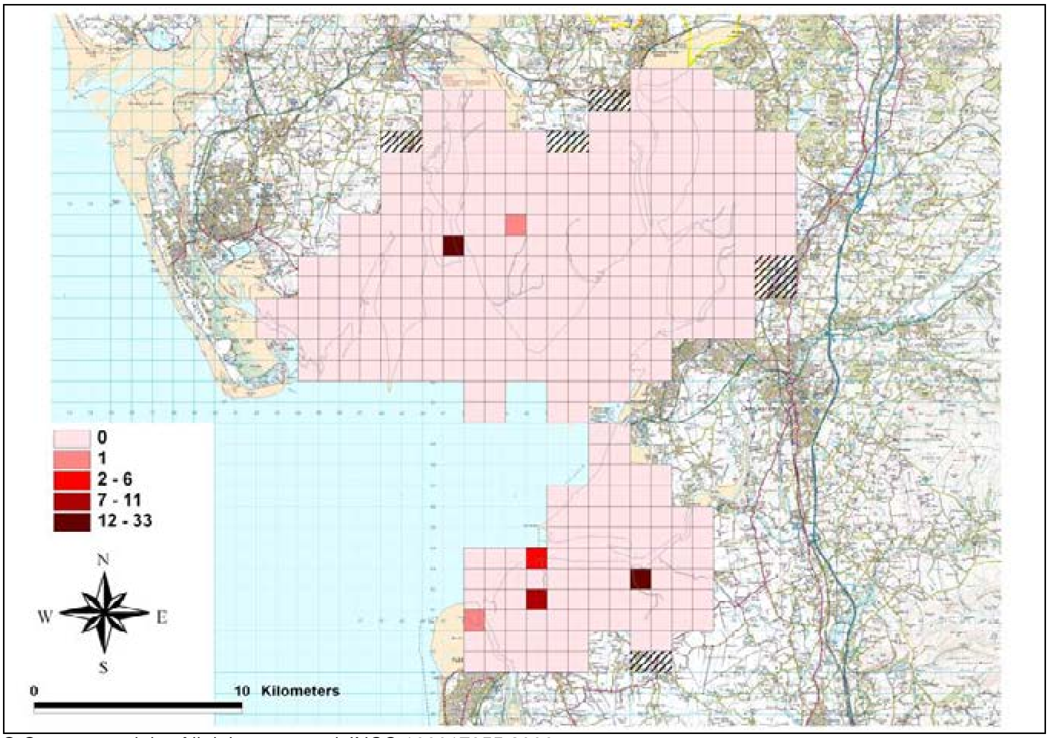

Figure 3.1.6g Mean winter distribution of Knot, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

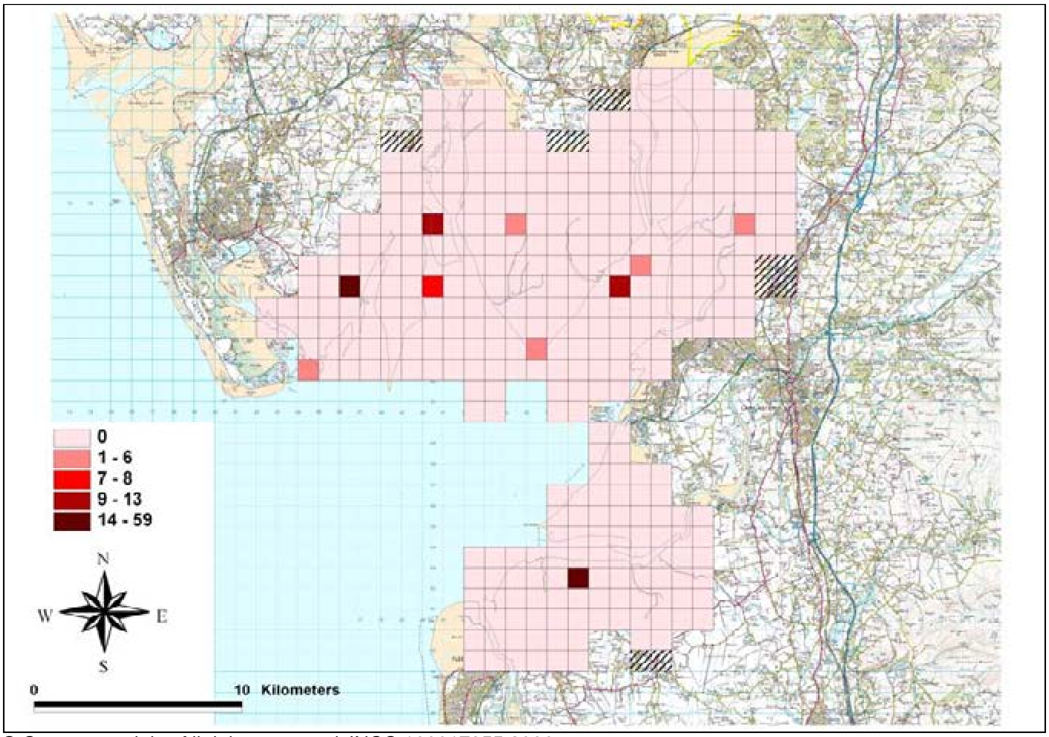

Figure 3.1.6h Mean winter distribution of Dunlin, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

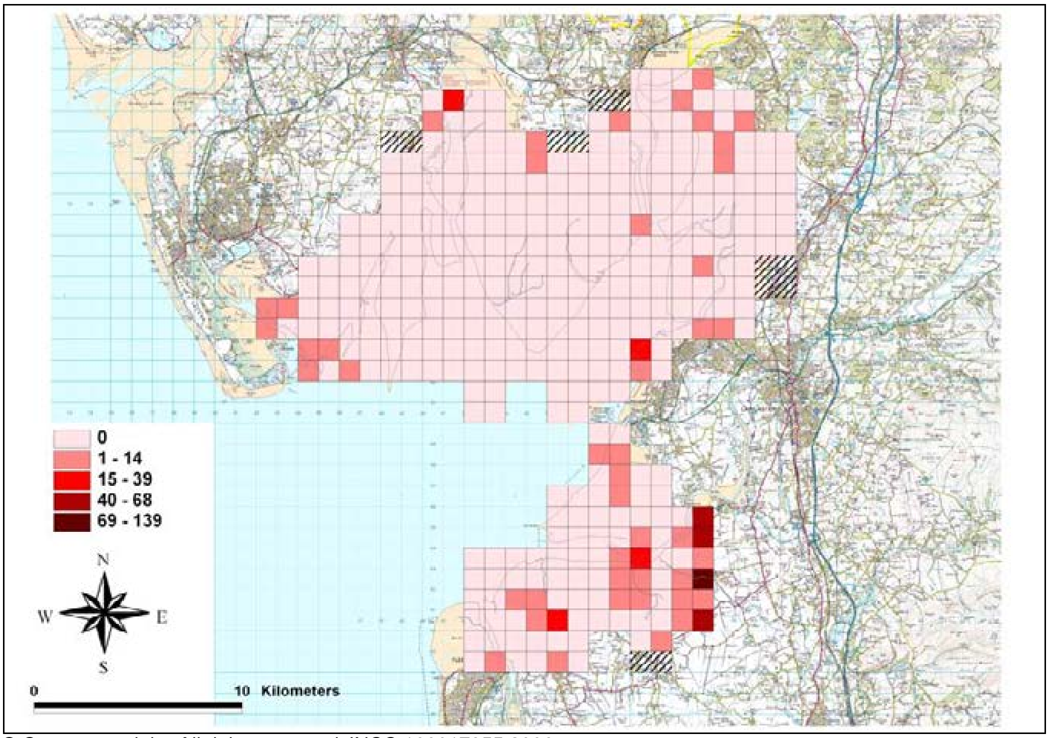

Figure 3.1.6i Mean winter distribution of Curlew, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

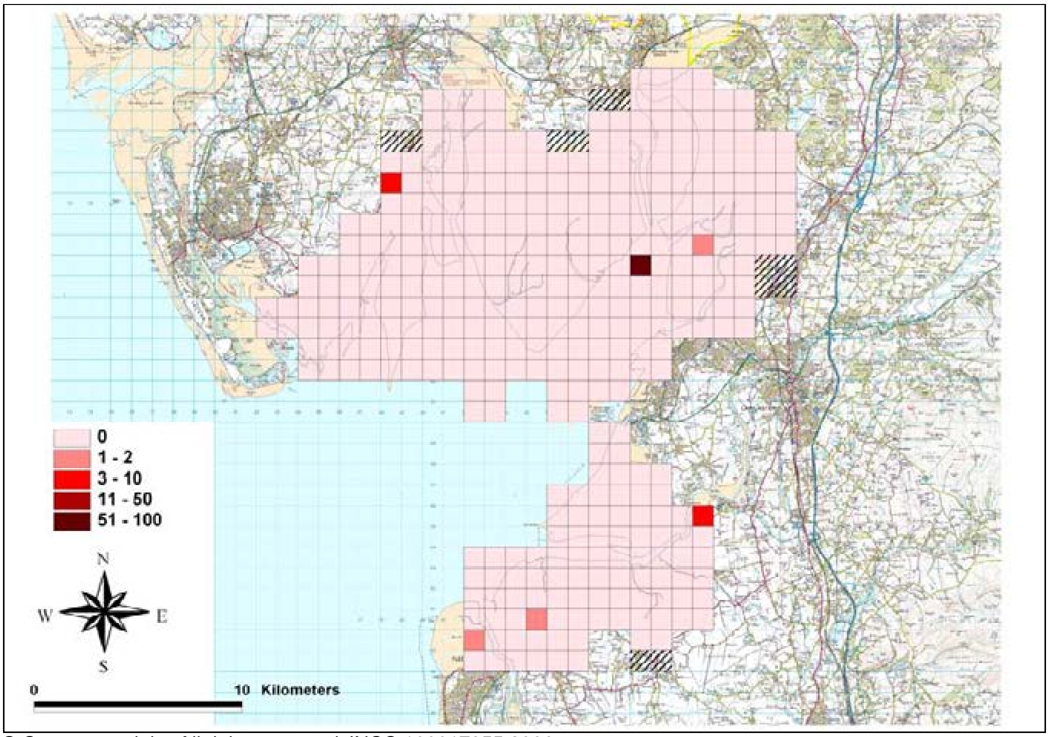

Figure 3.1.6j Mean winter distribution of Redshank, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

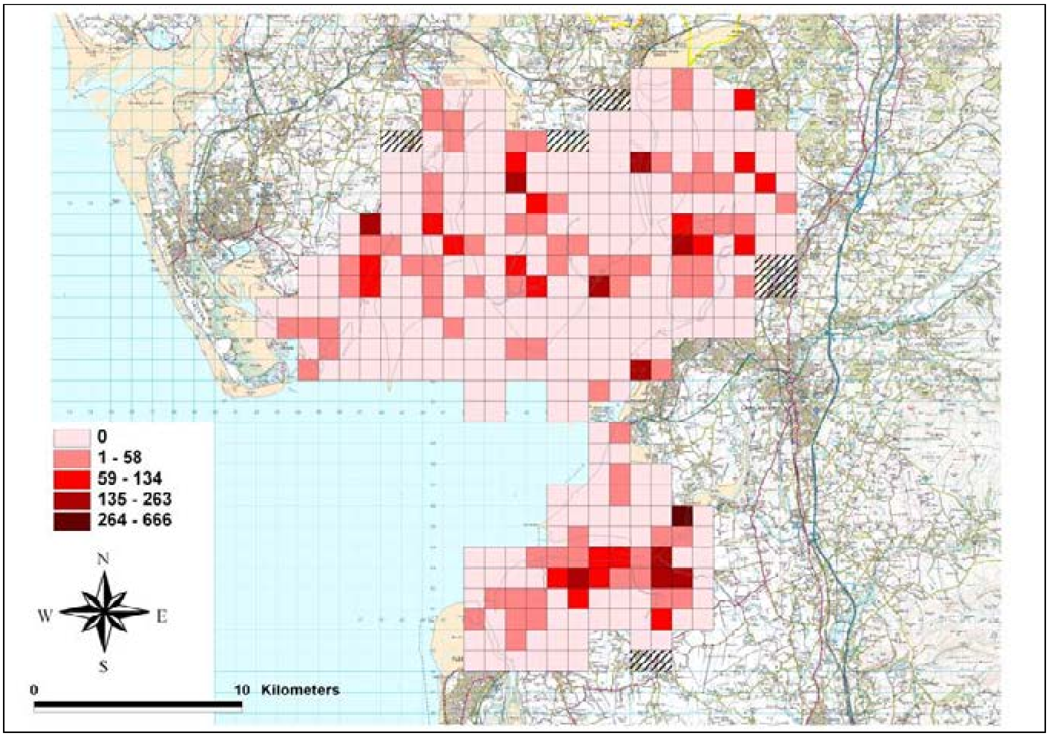

Figure 3.1.6k Mean winter distribution of small waders (all small waders, plus counts of the identified species in Table 2.1.3), as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

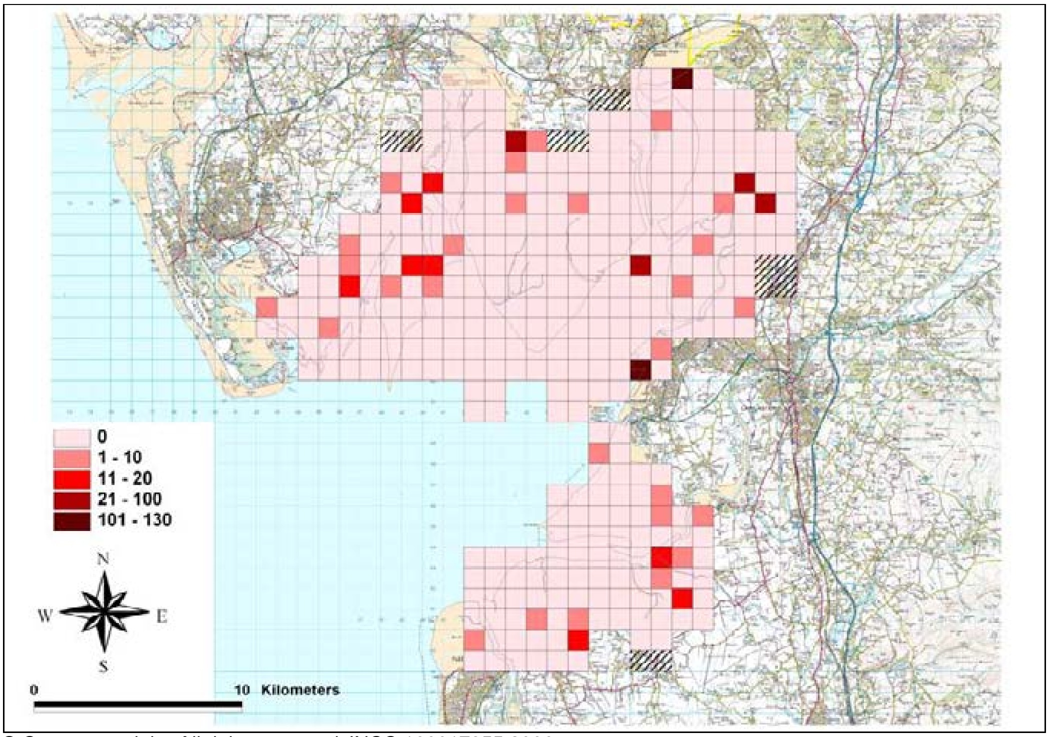

Figure 3.1.6l Mean winter distribution of medium waders (all medium waders, plus counts of the identified species in Table 2.1.3, excluding Lapwing), as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

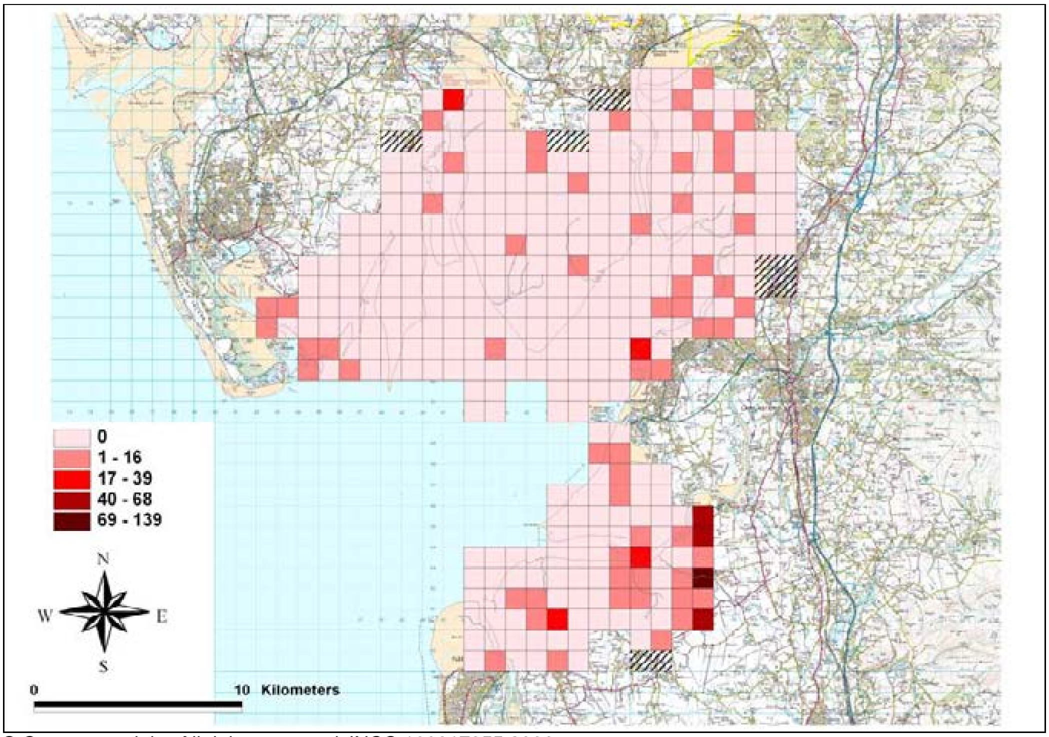

Figure 3.1.6m Mean winter distribution of large waders (all large waders, plus counts of the identified species in Table 2.1.3, excluding Oystercatcher), as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

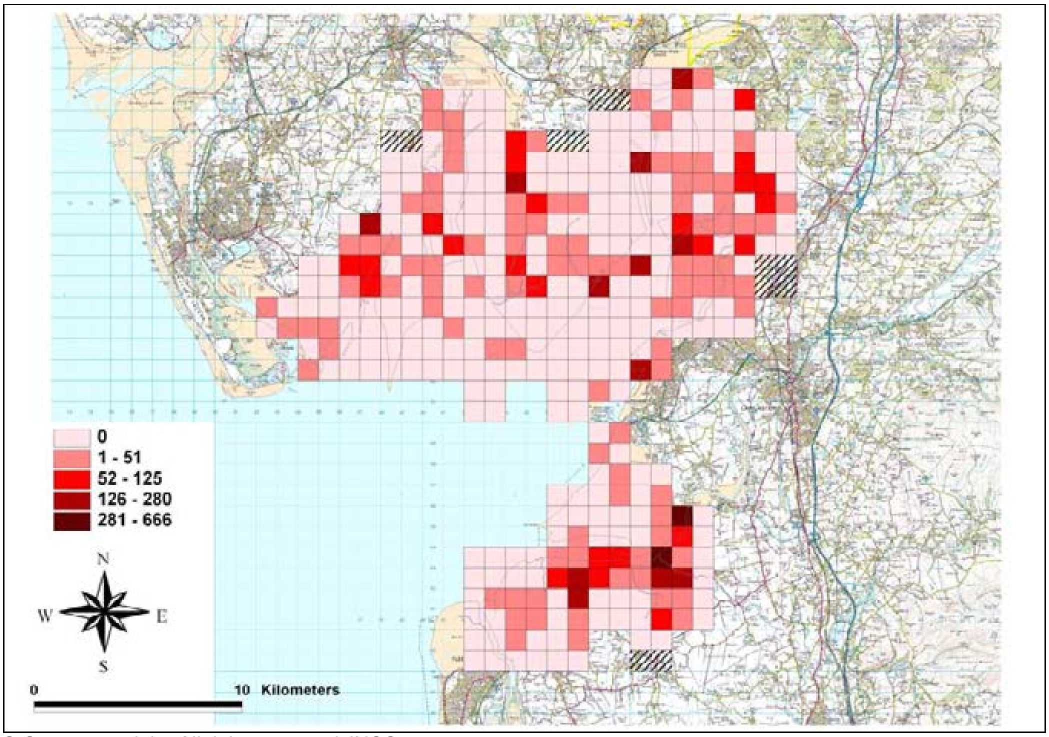

Figure 3.1.6n Mean winter distribution of all unidentified waders, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

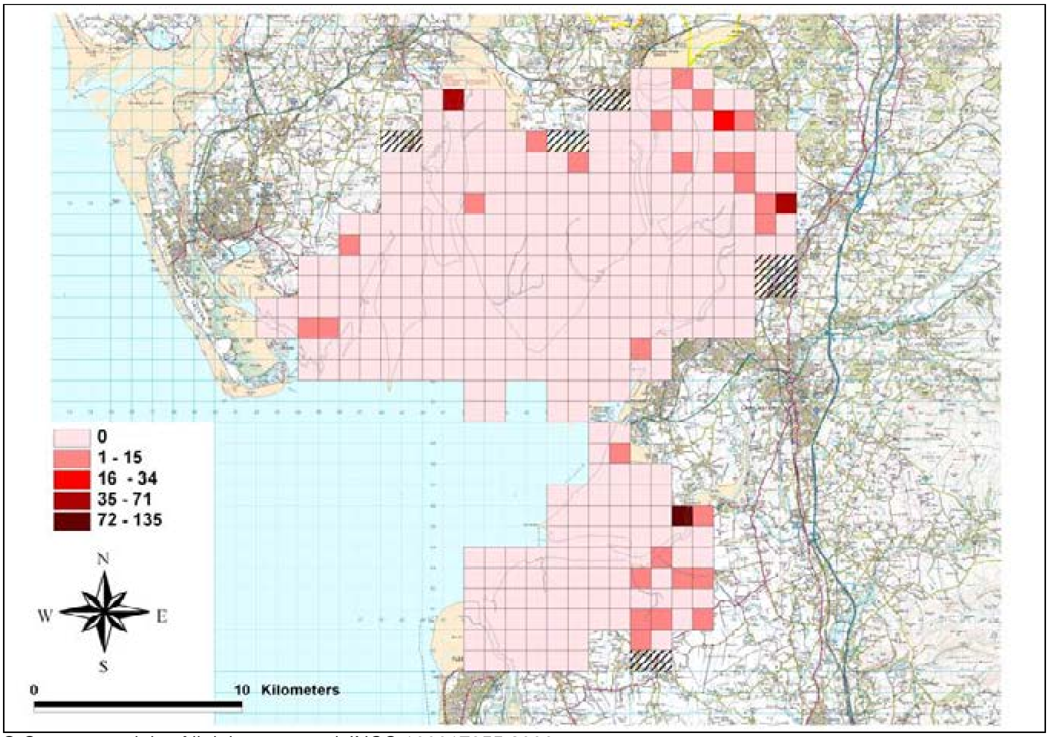

Figure 3.1.6o Mean winter distribution of all ducks, excepting Eider and Shelduck, as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

3.1.2.2 Gulls

Efforts were made to count gull species during aerial surveys, but gulls were considered of secondary priority to waders and wildfowl due to time constraints on identification and counting. Effort was thus focused on counting the latter, and gulls were counted to size class or recorded as 'unidentified' where closer identification detracted from this task. However, where gulls were detected without the presence of other waterbirds, identification to species, or at least size, was usually possible.

As gulls are an optional count species for WeBS, and as the above caveat means that individual species distributions may be affected by the presence of other species, three maps of gull distribution are presented. These relate to the distribution of small gulls (Black-headed, Common and unidentified small gulls), large gulls (Herring, Lesser Black-backed, Great Black-backed and unidentified large gulls), and all gulls (all of the above, plus unidentified gulls). Mean counts and densities for the individual gull species and categories are presented in Table 3.1.7.

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Black-headed Gull	All habitats	37600	530	0.01
Common Gull	All habitats	37600	26	0.00
Lesser Black-backed Gull	All habitats	37600	23	0.00
Herring Gull	All habitats	37600	123	0.00
Great Black-backed Gull	All habitats	37600	58	0.00

Species	Preferred habitat	Total area of preferred habitat	Mean site count	Mean site density
Unidentified large gull	All habitats	37600	213	0.01
Unidentified small gull	All habitats	37600	756	0.02
Unidentified gull	All habitats	37600	520	0.01

Table 3.1.7 Gull species recorded on aerial surveys within Morecambe Bay. Areas in hectares.

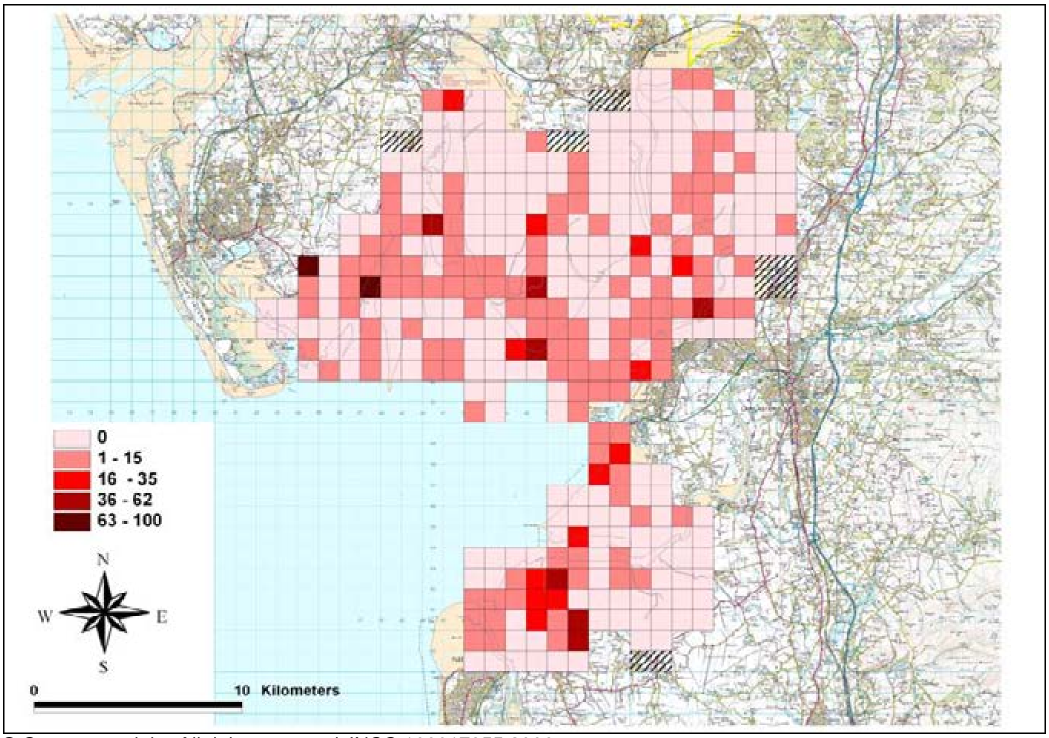

Figure 3.1.7a Mean winter distribution of small gulls (Black-headed, Common and unidentified small gulls) as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

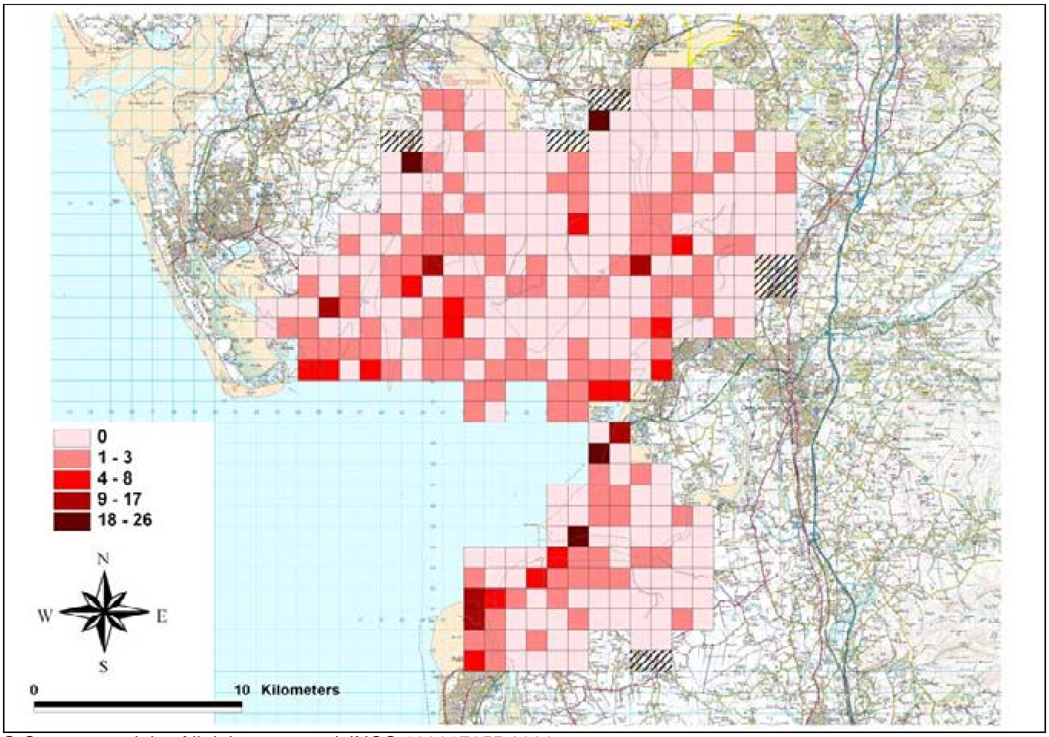

Figure 3.1.7b Mean winter distribution of large gulls (Herring, Lesser Black-backed, Great Black-backed and unidentified large gulls) as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

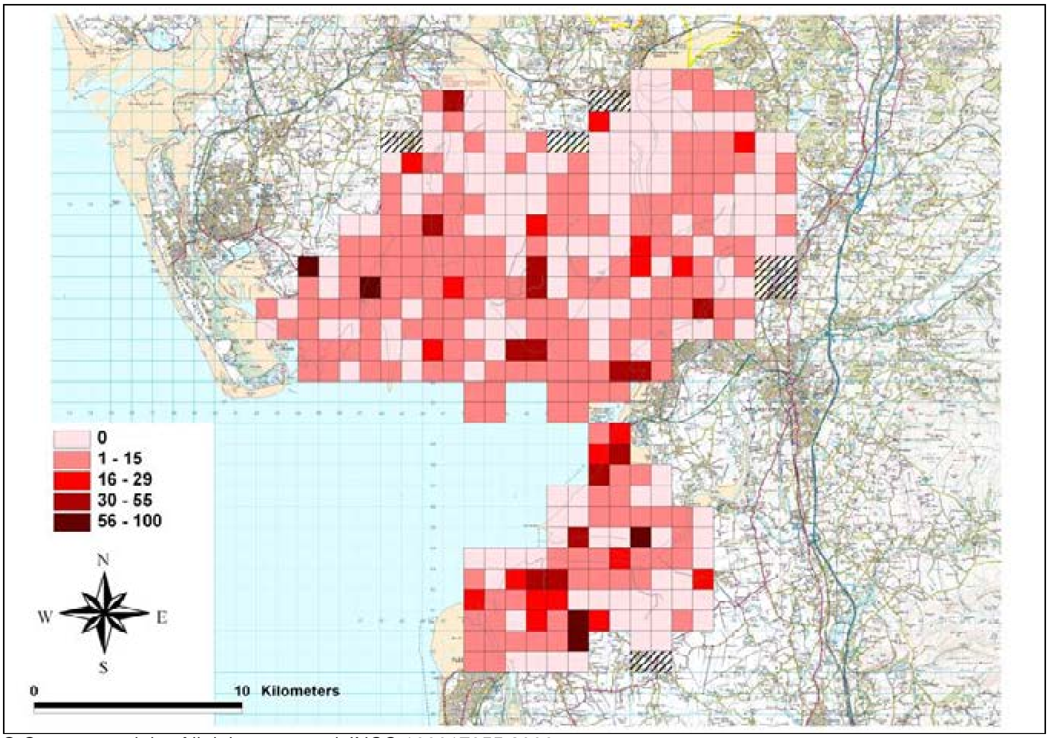

Figure 3.1.7c Mean winter distribution of all gulls (all identified and unidentified gulls) as recorded on aerial survey. Hatched squares not visited. Mean low tide mark outlined in grey.

3.2 Bird Distribution Analysis

3.2.1 'Hot spots' and 'cold spots' of bird distribution

Density maps generated from aerial surveys provide an idea of bird distribution, and which areas are important for birds. However, it is not possible by eye to determine where significant 'hot spots' (and, conversely, 'cold spots') of bird distribution are. For many of the species considered, distribution is patchy or restricted to isolated areas. However, for others, notably Oystercatcher and the small wader group, bird distribution is widespread enough to facilitate analysis of hot spots. In order to determine areas important for birds other than these, average winter counts for all waders (Bar-tailed Godwit, Black-tailed Godwit, Curlew, Dunlin, Knot, Oystercatcher, Redshank, all unidentified waders), plus Eider, which may feed on some of the same prey as waders (Cramp & Simmons 1983), were pooled.

Cluster analysis using the Getis-Ord Gi* statistic (section 2.3.2.1) was undertaken on the mean winter distribution of Oystercatcher, small waders and all waders (heretofore taken to include Eider). Maps show significant Z-scores at the 95% level thus highlighting statistically significant clusters of birds (hot spots), or significant clusters lacking birds (cold spots). Figures illustrating these clusters appear below (Figures 3.2.1 – 3.2.3).

Oystercatcher hot spots were recorded in a number of locations (Figure 3.2.1). A large cluster block was found at Warton Sands, another at Cockerham Sands at the mouth of the Lune and a further cluster at Newbiggin, presumably on the scars found on the shore there. Smaller clusters were recorded between Middleton Sands and Heysham Harbour, Heysham Sands (including rocky scars off Morecambe), and at Scalestones Point. All cells were significantly clustered at the 95% level (Z-score >1.96, P <0.05). Although, no cold spots were statistically significant (Z-scores > -1.96, P >0.05), trends for low bird densities were seen at the mouth of the Kent Estuary, the outermost cells between Walney Island and Heysham (often including little or no intertidal habitat) and the outer sands between the Lune and Wyre.

Small waders were significantly clustered around the mouth of the Lune, at Cockerham Sands, Pilling Sands and towards the Wyre at Preesall Sands, with another significant cluster along the Kent channel off Hest Bank (Z-score >1.96, P <0.05). However, the latter area was found to represent much less of a hot spot for small waders than for Oystercatcher. Other clusters tending towards hot or cold spots were also revealed, including a non-significant cluster off the mouth of the Kent, also found to be a cold spot for Oystercatcher (Figure 3.2.2).

The distribution pattern for all waders is dominated to some extent by the distribution of Oystercatcher and small waders, as relatively few other waders were counted. As such, the hot spots identified are similar to those identified previously. However, no new hot spots were found, suggesting that the contribution of other waders to clustering of count values was relatively low (Figure 3.2.3).

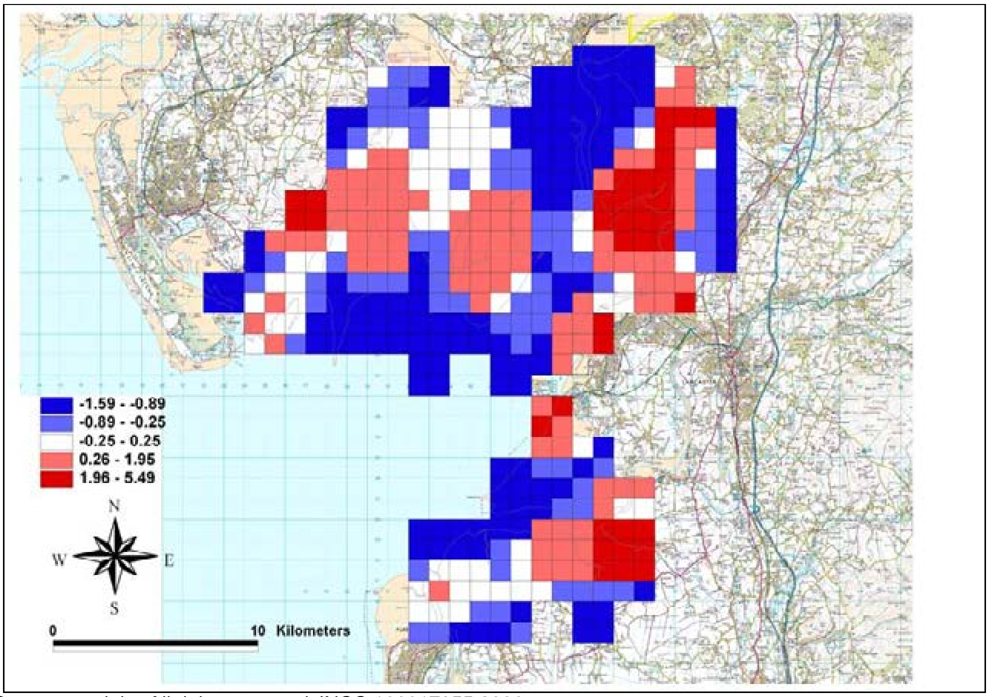

Figure 3.2.1 Significant hot spots (dark red) of Oystercatcher distribution. Intermediate non-significant values shown on scale on map, with blue cells tending towards lack of clustering of birds. White cells indicate no relationship with surrounding cells.

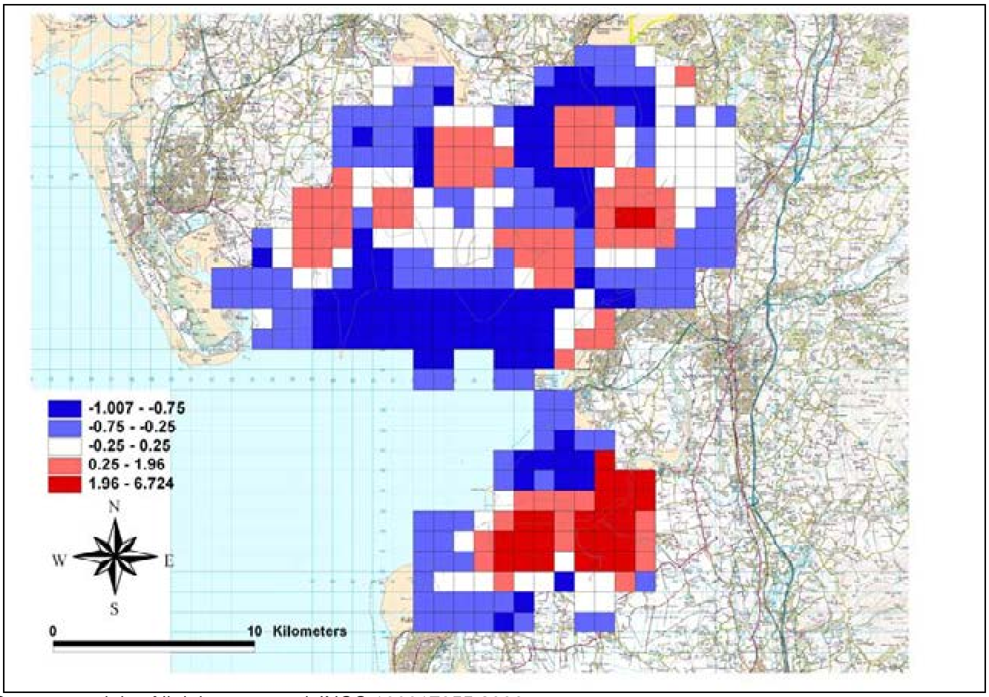

Figure 3.2.2 Significant hot spots (dark red) of small wader distribution. Intermediate non-significant values shown on scale on map, with blue cells tending towards lack of clustering of birds. White cells indicate no relationship with surrounding cells.

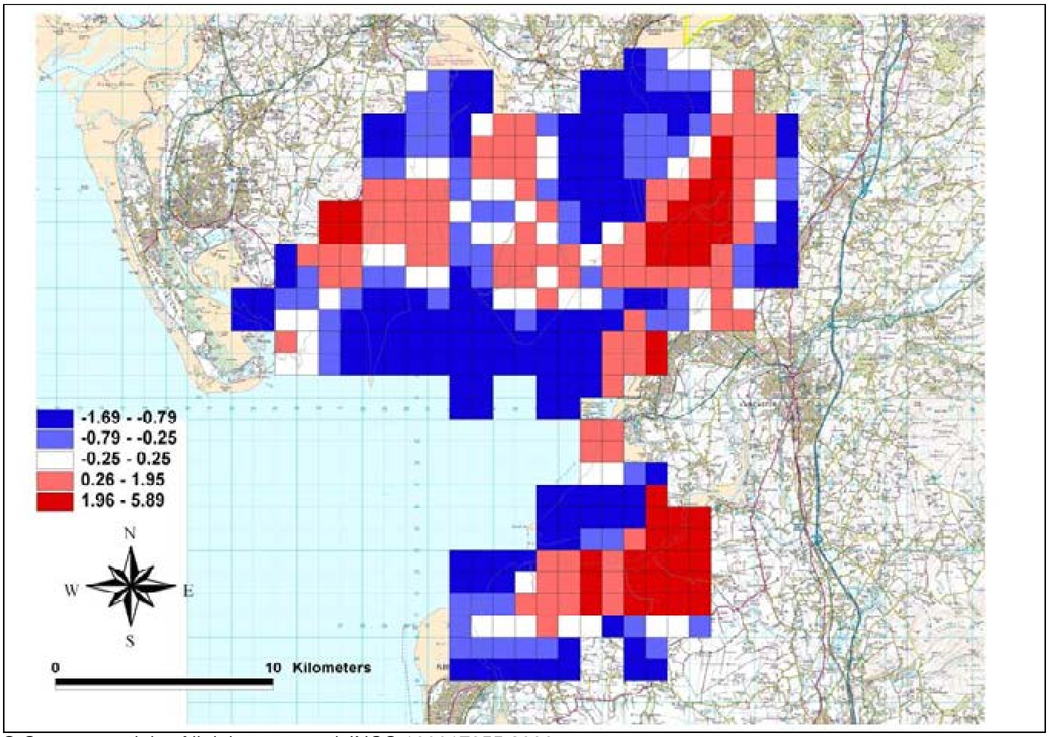

Figure 3.2.3 Significant hot spots (dark red) of all wader distribution. Intermediate non-significant values shown on scale on map, with blue cells tending towards lack of clustering of birds. White cells indicate no relationship with surrounding cells.

3.2.2 Disturbance

Incidences of disturbance were plotted overlaid on bird distribution for the relevant month, for all waterbirds excepting gulls, to examine the effect of the disturbance.

Cockle pickers were observed in five locations in January, and dog walkers in two locations (Figure 3.2.4). One dog walker coincided with an area of high bird density, one with relatively low density. Cockle pickers were seen on the Aldingham and Pilling beds, cells containing cocklers also containing birds recorded at relatively low density.

One dog walker and one team of cocklers were recorded in February, the former near to the shoreline at Hest Bank, the latter on Middleton Sands (Figure 3.2.5). No birds were recorded in the cells containing these events, nor any neighbouring cells within 1 km.

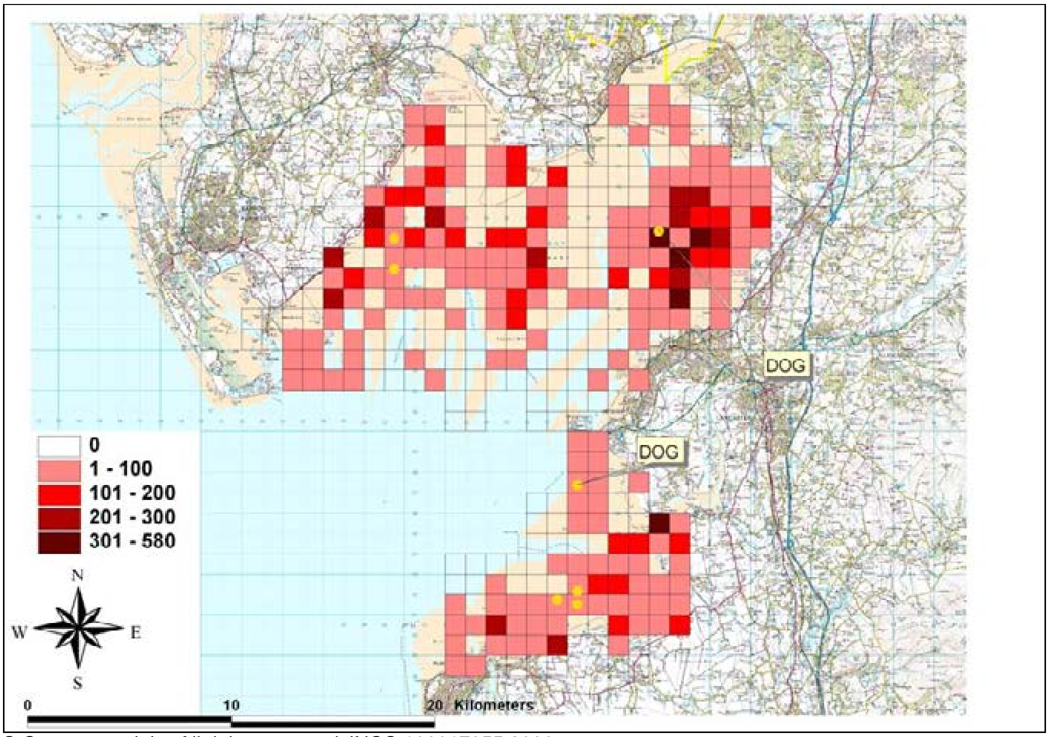

Figure 3.2.4 Disturbance events and total waterbird distribution January 2006. Disturbance events indicated by dots; all events are records of cockle pickers, except where indicated on the map.

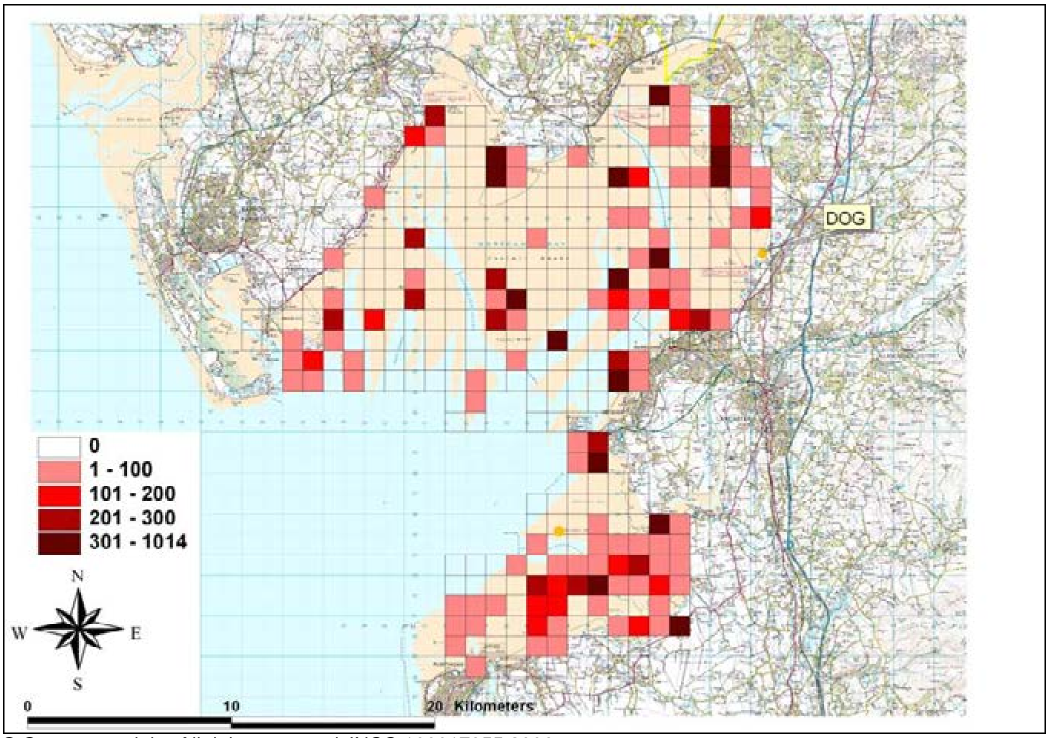

Figure 3.2.5 Disturbance events and total waterbird distribution February 2006. Disturbance events indicated by dots; all events are records of cockle pickers, except where indicated on the map.

3.2.3 Bivalves

The distribution of cockles recorded within the bay prior to the winter of 2005/06 is plotted (Figure 3.2.6). Excepting a notable absence in the mouth of the Kent River, cockles were found at variable density on all beds sampled, with greatest densities at inland of Foulney Island, Middleton Sands, Warton Sands and Pilling Sands (Figure 3.2.6). Significant hot spots ($Z > 1.96$, $P < 0.05$) were detected at Foulney, Middleton and Pilling, with significant cold spots ($Z < -1.96$, $P < 0.05$) on the Flookburgh bed in the mouth of the Kent Estuary (Figure 3.2.7). As the data contained a high degree of spatial autocorrelation (Moran's I=5.39, P<0.00001), the regression model included cockle density Z-score as a measure of non-independence. Despite the spatial coincidence of some of these areas with corresponding densities of birds, no relationship was found between mean Oystercatcher distribution and mean cockle distribution ($F_{1,109} = 0.01$, $P = 0.94$) after controlling for the highly clustered nature of the cockle data ($F_{1,109} = 3.70$, $P = 0.05$). The level of spatial autocorrelation means that the latter relationship could exist because of the features underlying the average cockle density and not the values themselves. A similar lack of relationship was found between small wader distribution and cockle density ($F_{1,109} = 0.01$, $P = 0.94$).

In some areas, *Macoma* distribution represents almost the inverse of cockle distribution (Figure 3.2.8), with high densities especially noteworthy in the mouth of the Kent and Leven Estuaries. Cluster analysis reveals that significant hot spots for *Macoma* occur at the mouth of the Kent and at Warton Sands (Figure 3.2.9). The former coincides with a hot spot for cockles; furthermore, areas tending toward representing cold spots for *Macoma* often tended toward hot spots for cockles. No relationships were found between mean *Macoma* and mean Oystercatcher density ($F_{1,109} = 0.93$, $P = 0.33$) or small wader density ($F_{1,109} = 0.88$, $P = 0.35$), despite this bivalve forming a crucial part of the diet of Knot (Cramp & Simmons 1983).

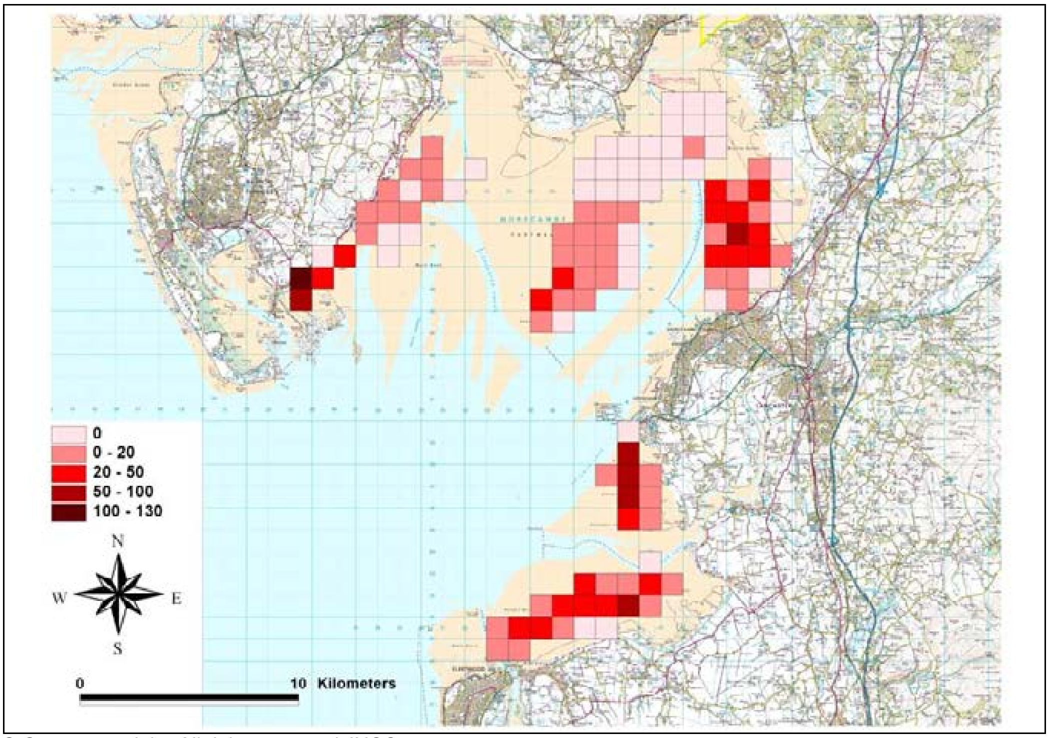

Figure 3.2.6 Mean cockle distribution July – September 2005. Data from NWNWSFC.

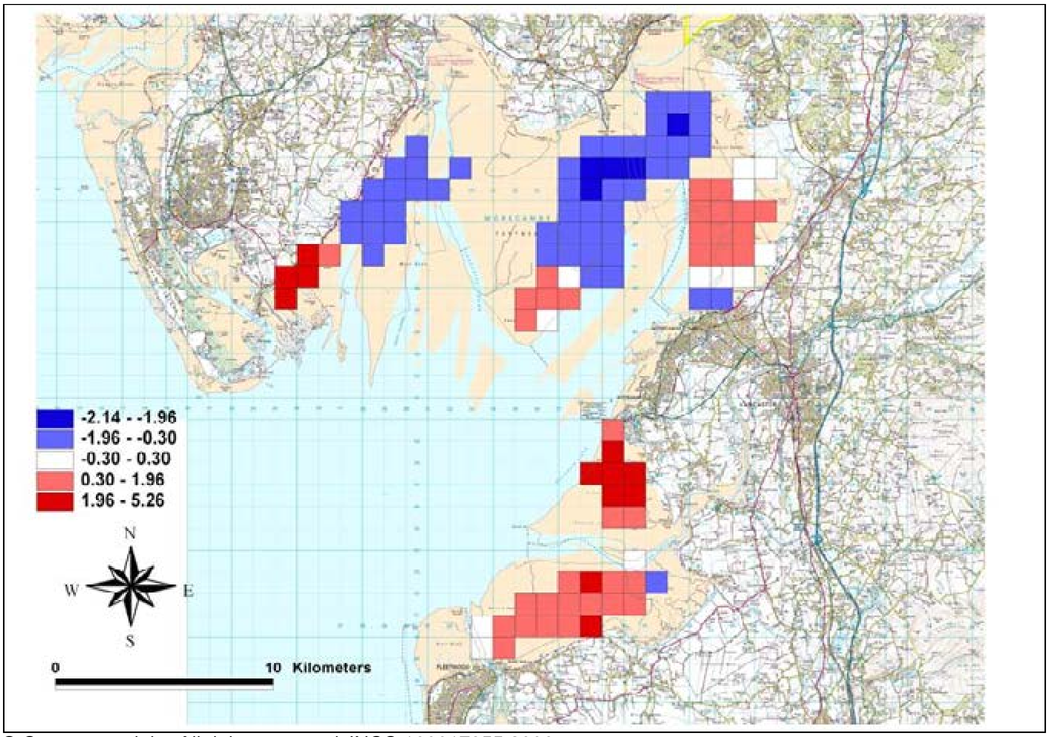

Figure 3.2.7 Significant hot spots (dark red) and cold spots (dark blue) of cockle distribution. Intermediate non-significant values shown on scale on map. White cells indicate no relationship with surrounding cells.

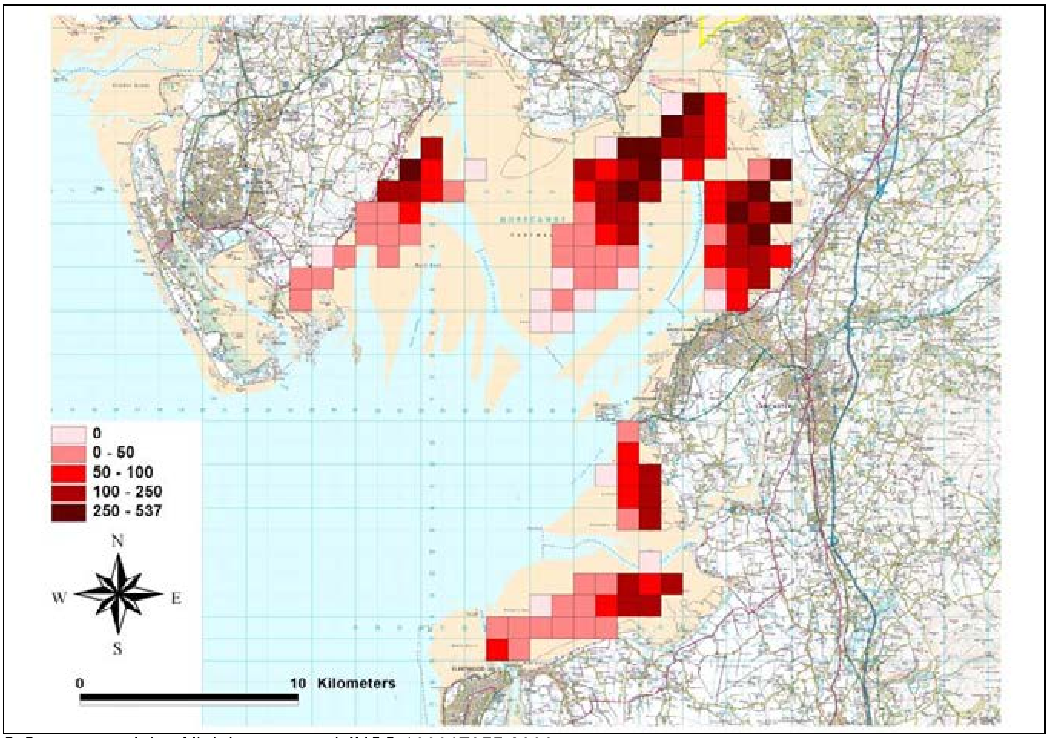

Figure 3.2.8 Mean *Macoma* distribution July – September 2005. Data from NWNWSFC.

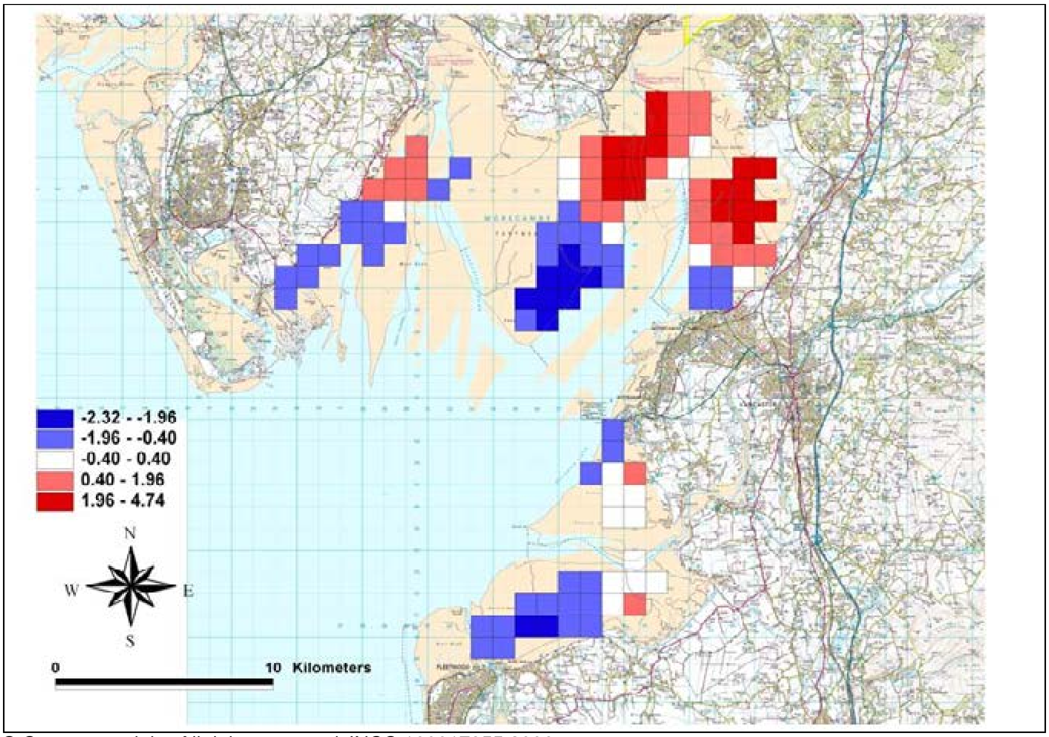

Figure 3.2.9 Significant hot spots (dark red) and cold spots (dark blue) of *Macoma* distribution. Intermediate non-significant values shown on scale on map. White cells indicate no relationship with surrounding cells.

3.2.4 Sediment

Attempts to relate bird density to sediment type were unsuccessful. Bird density was recorded to a resolution of birds per square kilometre, whilst data obtained on sediment type were collected from surveys using a point sample method. Thus, within any given 1 km^2, a number of different sediment types could be recorded. As these data were categorical, it was not possible to calculate an ‘average’ sediment score for each cell. Thus, it was unfortunately not possible to perform an analysis on the relationship between bird distribution and sediment distribution. However, the likely influence of this variable is considered in the discussion.

3.2.5 Temporal trends in bird distribution

Owing to the time-consuming nature of the analysis, it was decided to investigate variation in bird distribution for the two species (groups) with greatest mean site density: Oystercatcher and small waders. Maps displaying relative bird density on each month of aerial survey are shown (Figures 3.2.10, 3.2.12). The mean centre of each distribution, weighted by bird numbers per cell, is shown, as is a circle representing one standard deviation from the mean (Figures 3.2.11, 3.2.13).

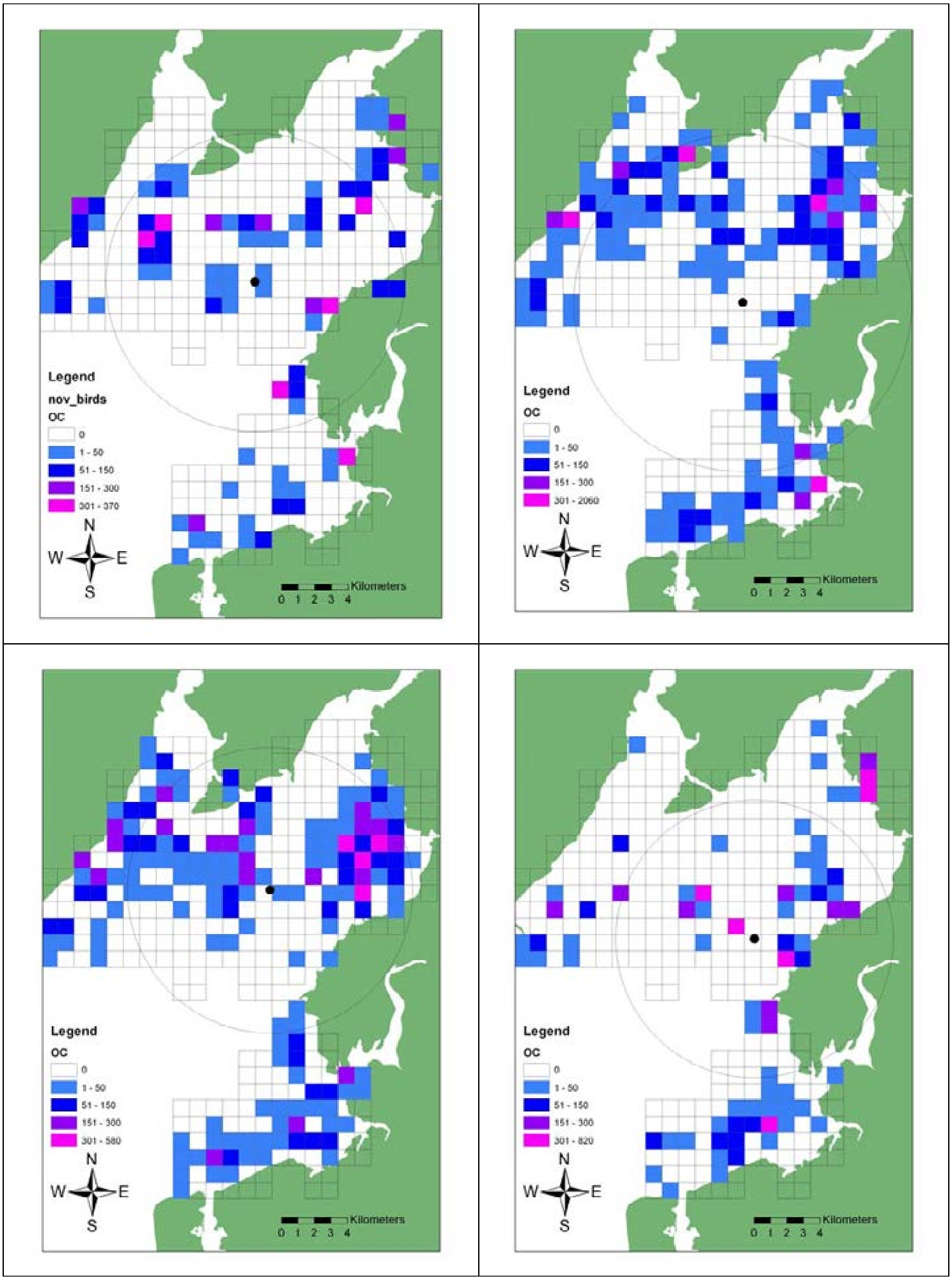

Figure 3.2.10 Temporal trends in Oystercatcher distribution. Maps show (from top left, across page) distributions for November, December, January and February. Black dot represents mean of the distribution, weighted by abundance per cell. Circle represents spatial extent of one standard deviation.

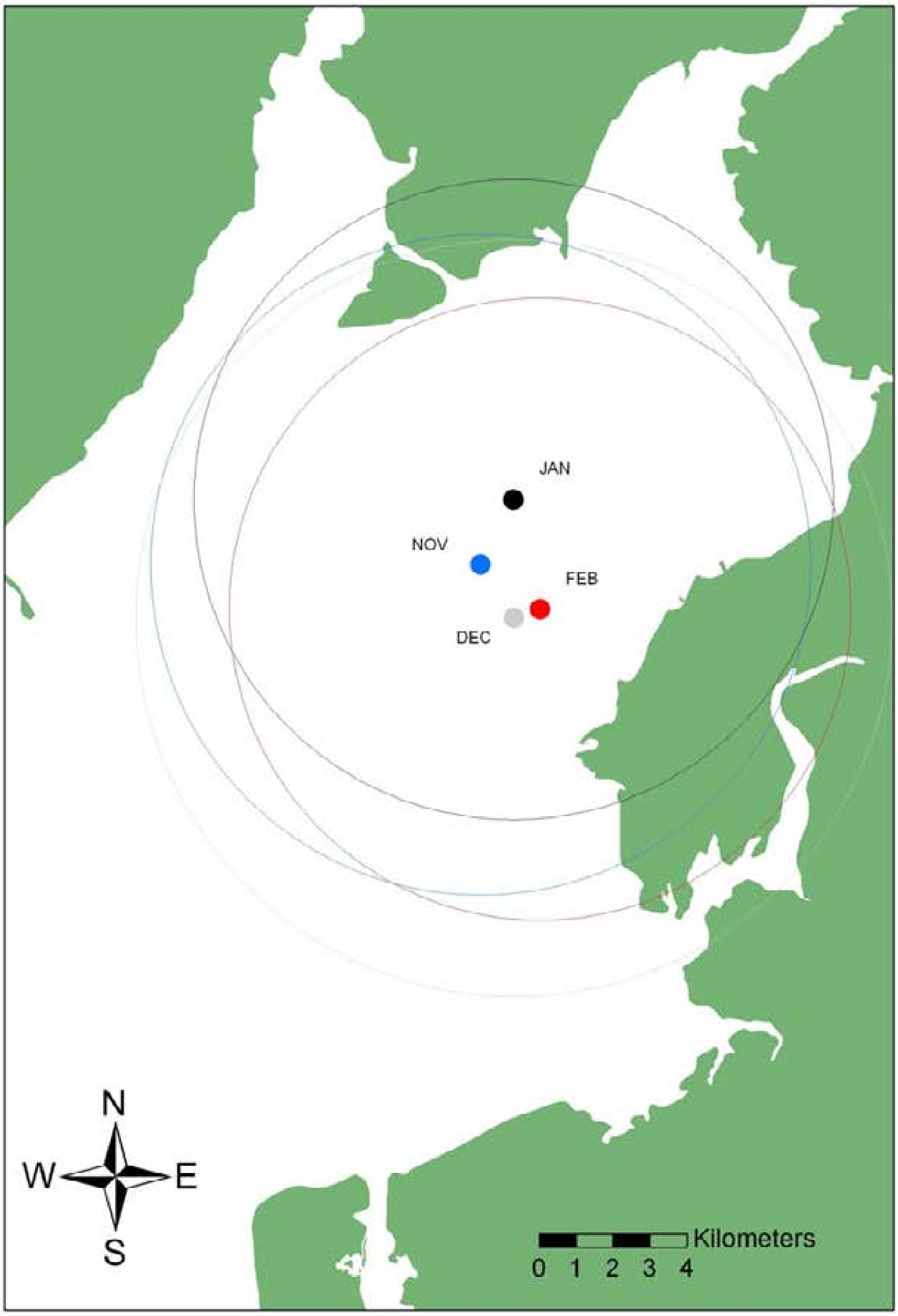

Figure 3.2.11 Mean weighted centres and standard deviations of monthly Oystercatcher distribution. Where colour: blue=November, grey=December, black=January, red=February.

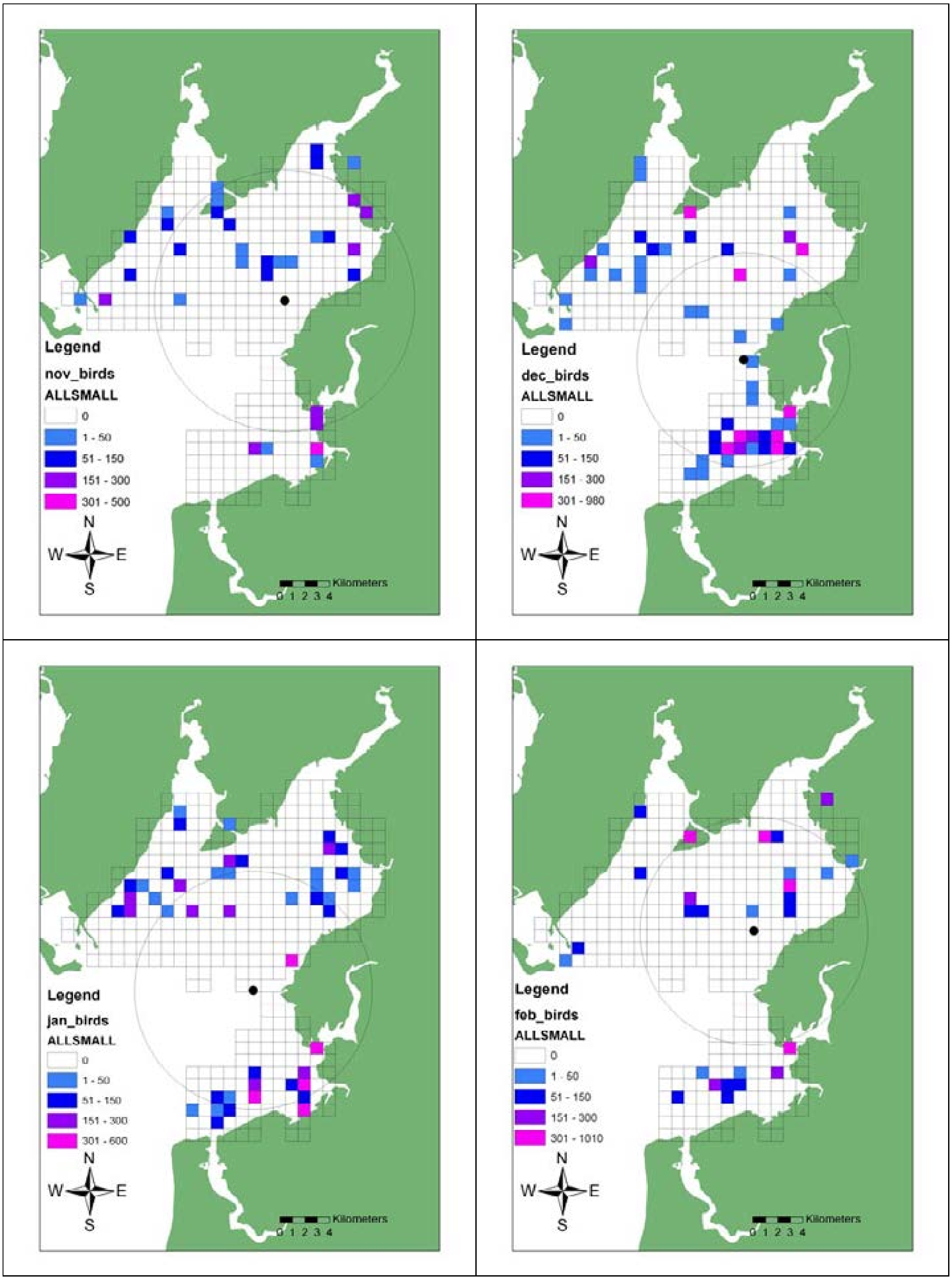

Figure 3.2.12 Temporal trends in small wader distribution. Maps show (from top left, across page) distributions for November, December, January and February. Black dot represents mean of the distribution, weighted by abundance per cell. Circle represents spatial extent of one standard deviation.

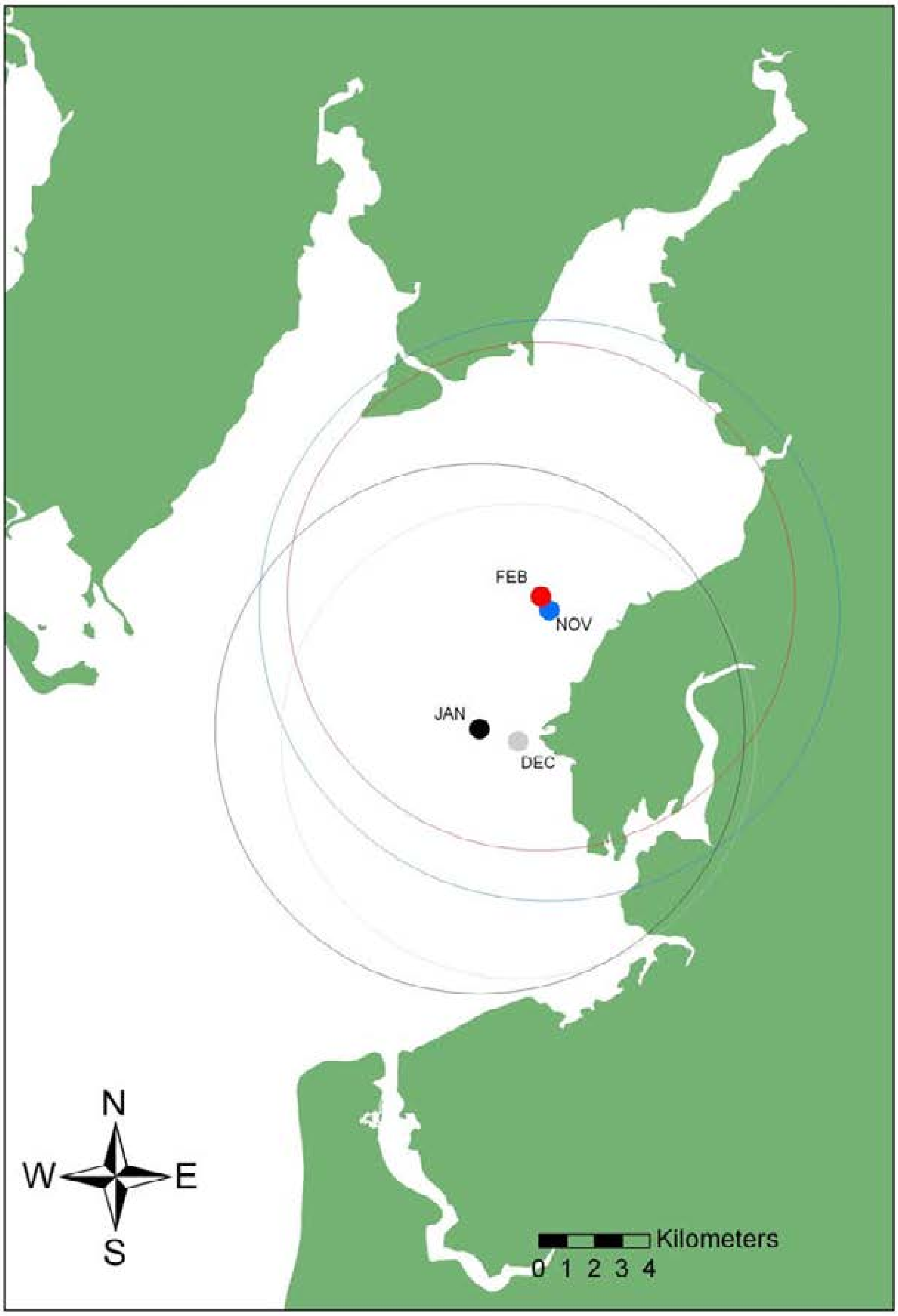

Figure 3.2.13 Mean weighted centres and standard deviations of monthly small wader distribution. Where colour: blue=November, grey=December, black=January, red=February.

Mean distribution centres of small waders were weighted towards the east shore of the bay in every month. In November and February, the centre was situated further north than in December or January, with the limits of one standard deviation stretching south to the mouth of the Lune, north to the mouth of the Kent and west to the edge of the Leven. In December, the somewhat restricted distribution of small waders led to a smaller radius encompassing cells within one standard deviation, and the weighted mean centre lay off Half Moon Bay, corroborating large numbers of Knot observed from the ground in this month. The distribution in January was characterised by a mean centre in a similar location, but with larger standard deviation.

3.3 Count accuracy

3.3.1 Assessment of counter error

Figures 3.3.1 – 3.3.3 show the trendlines of the counters tested on the Wildlife Counts program, for the three different image sets, and Figure 3.3.4 summarises performance. On the 'snow geese' image set, AB and SH were close to the actual number presented (-4% and -1% error respectively), whilst IM was surprisingly similar in error to ED, the control (-20% and -17% error). Counters AB and IM performed similarly on the 'overflying geese' simulation, with -19% and -21% respectively. The -33% error recorded for SH was comparable with that for ED (-35%). IM was unique in over-estimating the numbers of 'ducks on a pond' (12%); other counters made underestimates (AB: -17; SH: -21; ED: -32).

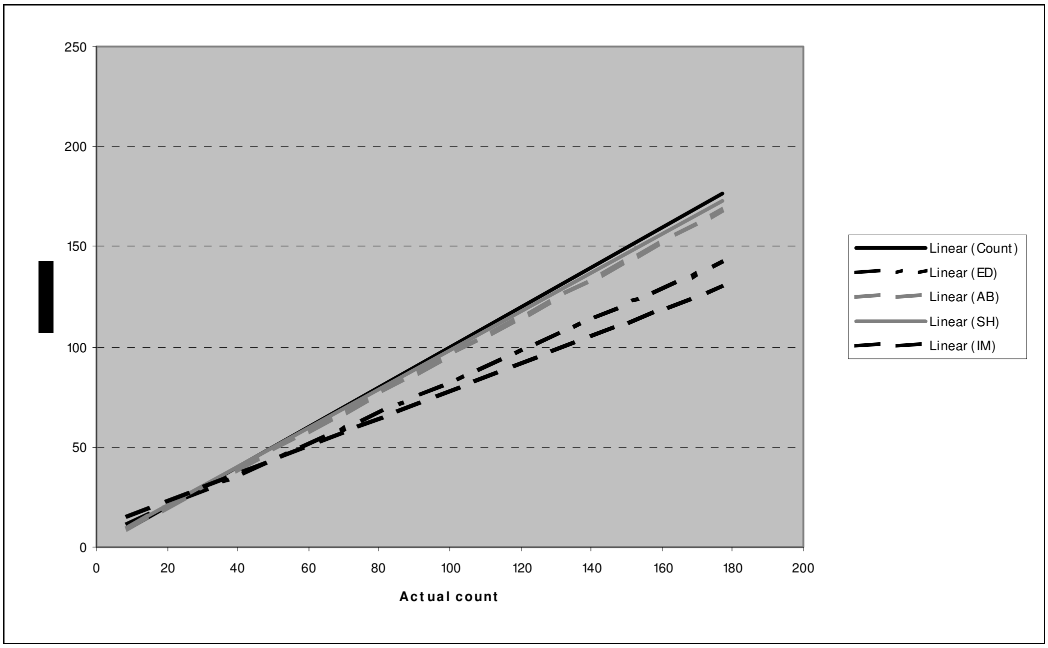

Figure 3.3.1 Performance of counters on 'Snow Goose' simulation. Linear (Count) line = actual count.

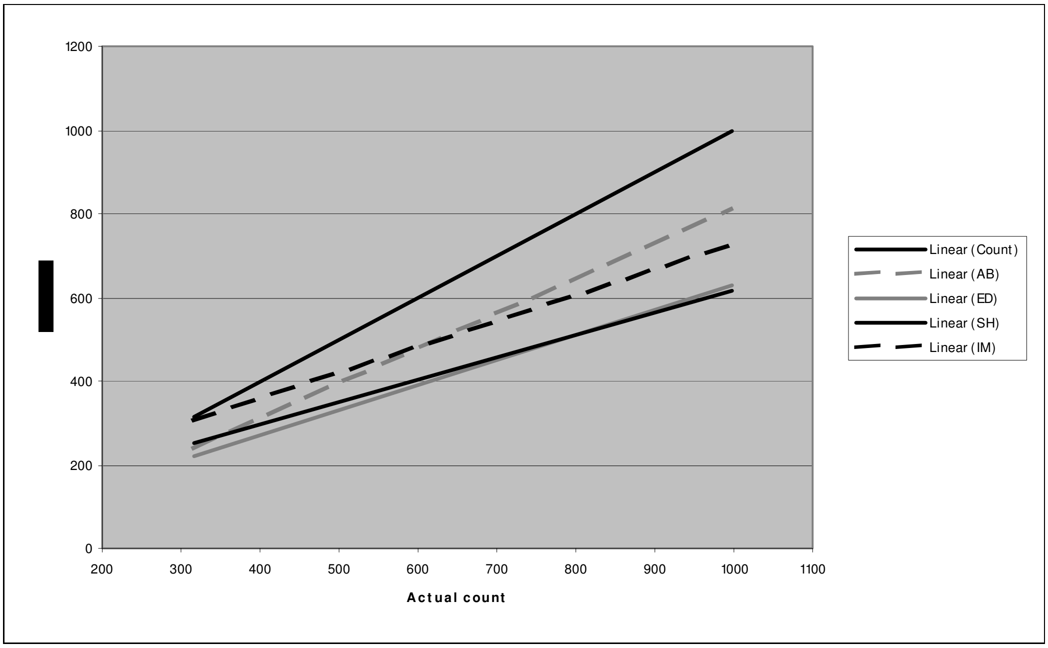

Figure 3.3.2 Performance of counters on ‘overflying geese’ simulation. Linear (Count) line = actual count.

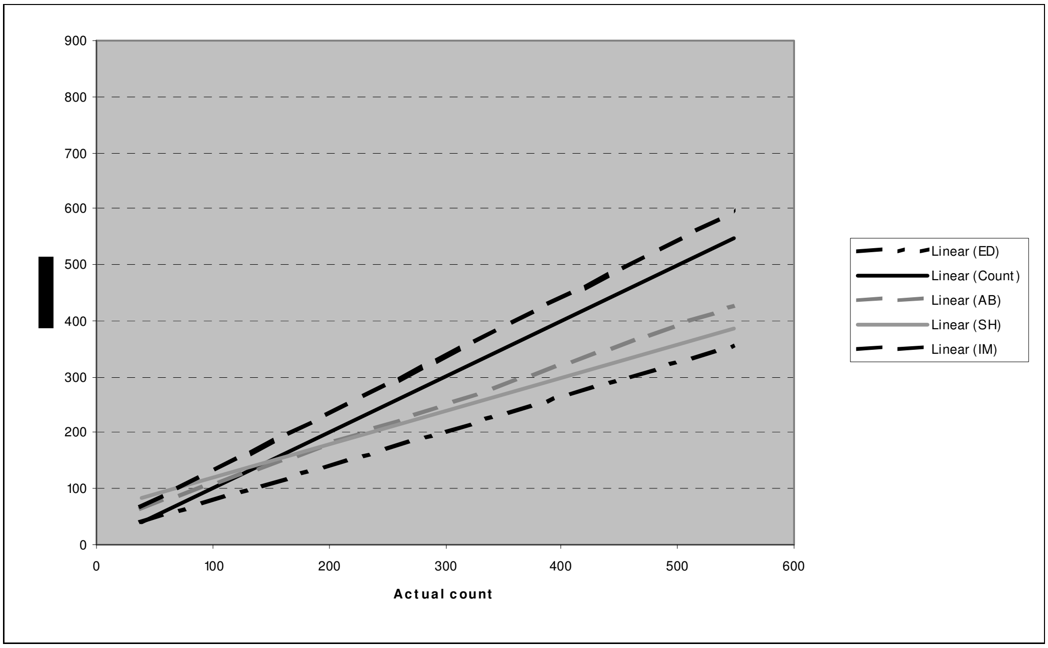

Figure 3.3.3 Performance of counters on ‘ducks on a pond’ simulation. Linear (Count) line = actual count.

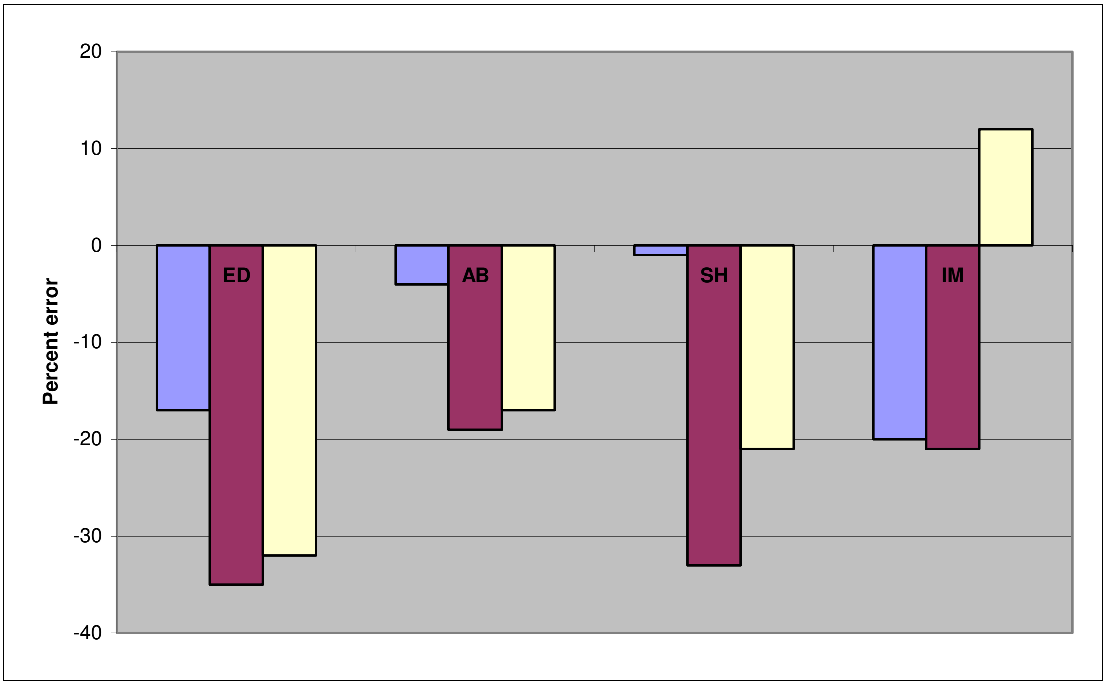

Figure 3.3.4 Summary of counter error on bird count simulation. Columns represent simulations, from left to right: ‘Snow Geese’, ‘Overflying geese’, ‘Ducks on a pond’.

3.3.2 Comparison of WeBS Low Tide and Core Counts

Comparing counts made using WeBS LTC and Core Count methods is inherently problematic (see Discussion section 4.2.3). However, in an attempt to estimate roughly what proportion of the Core Count totals were surveyed by the LTC method, whole bay figures were compared.

Sum total Core Counts for the most recent winter available (2004/05) provide a quantitative baseline number of birds roosting around Morecambe Bay. Monthly totals were then compared with monthly totals obtained from LTCs (Table 3.3.1), heeding the caveats in section 4.2.3. Low Tide Count totals were found to be less than half of the corresponding monthly Core Count totals. Where LTC coverage was maximal (November 2005), the total for Morecambe Bay reached 53,810, or 46.6% of the total recorded on Core Counts in the previous November. Despite partial coverage of some estuarine sections, the December 2005 LTC total represented a similar proportion, 43.5% of the Core total for December 2004. In January and February 2006, some areas were not covered at low water, and as such the figures of 34.8% and 27.1% respectively are perhaps underestimates of the totals in comparison to the previous winter’s corresponding monthly Core Count totals.

	November	December	January	February
Core Count total 2004/05	115,569	162,050	164,124	137,137
LTC total 2005/06	53,810	70,535	57,142	37,186
Proportion of Core	46.6%	43.5%	34.8%	27.1%

Table 3.3.1 WeBS Core Count and Low Tide Count monthly totals for Morecambe Bay.

In an attempt to infer whether particular species were more likely to be undercounted on LTCs, further comparisons were made of mean winter totals for each species with a Core Count winter mean of more than 50 birds (Table 3.3.2).

Species	Core Count winter mean	LTC winter mean	%LTC of Core
Great Crested Grebe	68	8	11.7%
Cormorant	308	87	28.2%
Mute Swan	302	193	63.9%
Pink-footed Goose	2,787	306	11.0%
Greylag Goose	398	136	34.0%
Canada Goose	178	102	57.2%
Shelduck	4,772	1,628	34.1%
Wigeon	6,546	1,833	28.0%
Teal	2,515	530	21.1%
Mallard	1,301	881	67.7%
Pintail	2,161	516	23.9%
Shoveler	121	2	1.4%
Scaup	78	0	0.3%
Eider	528	321	60.9%
Goldeneye	165	75	45.3%
Red-breasted Merganser	126	15	11.9%
Coot	91	97	107.5%
Oystercatcher	40,555	12,323	30.4%
Ringed Plover	254	28	11.0%
Golden Plover	3,043	1,770	58.2%
Grey Plover	697	3	0.5%
Lapwing	12,777	8,756	68.5%
Knot	22,621	4,010	17.7%
Sanderling	178	6	3.5%
Dunlin	17,034	2,789	16.4%
Snipe	152	8	5.3%
Black-tailed Godwit	505	68	13.5%
Bar-tailed Godwit	1,072	302	28.2%
Curlew	5,241	1,778	33.9%
Redshank	6,634	1,748	26.3%
Turnstone	591	39	6.6%
Black-headed Gull	4,829	2,744	56.8%
Common Gull	1,717	531	30.9%
Lesser Black-backed Gull	279	125	44.8%
Herring Gull	3,585	2,248	62.7%
Great Black-backed Gull	214	194	90.9%
Unidentified gull	142	481	338.9%

Table 3.3.2 WeBS Core Count and LTC mean winter counts for selected species.

It is clear that most of the key species present in Morecambe Bay are counted in much lower numbers on LTCs than on Core Counts. On average, less than 20% of the Knot and Dunlin recorded at roost in 2004/05 were recorded on LTC surveys in 2005/06. Some of these birds will have been classified as small waders, but a winter mean of 5,309 still leaves a large discrepancy. Similarly, 70% less Oystercatchers were counted on LTCs than Core Counts. Species such as Grey Plover and Turnstone were particularly scarce on LTCs, though may have been included as unidentified waders on aerial surveys. Only Coot and unidentified gulls were more numerous on LTCs; the former by only six birds, the latter by virtue of the difficulty of identification of gulls from aerial surveys.

4. DISCUSSION

4.1 Bird Distribution Within Morecambe Bay

For the first time under the jurisdiction of the WeBS Low Tide Count scheme, and possibly ever, a co-ordinated low water survey of the entirety of Morecambe Bay SPA has been undertaken. Combining standard land-based counts with those made from the air, all of the significant intertidal habitat was surveyed at least once between November 2005 and February 2006. This integrated survey represents a significant achievement for WeBS and will help to inform English Nature's programme of Common Standards Monitoring.

Forty-nine species of waterbird were recorded within Morecambe Bay. In the following discussion, attention will be focused on the most abundant species, principally those for which the site is designated (section 1.1).

4.1.1 Spatial distribution

4.1.1.1 Pink-footed Goose

This species was recorded in very small numbers on most estuaries on which it occurred, and few were noted on aerial surveys. The Wyre Estuary held the highest site density for the winter, possibly as a result of the expanse of farmland to the east of the river, upon which the geese may be foraging.

4.1.1.2 Shelduck

Shelduck were widespread within the bay, occurring on all estuaries and all aerial surveys. The highest densities were recorded on South Walney & Piel Channel Flats, and aerial data indicated that most of the fringe habitat contained some Shelduck. Although mean site density on the Leven was low, the area around Cark Point at the river mouth held comparatively high density on aerial surveys.

4.1.1.3 Pintail

Few Pintail were detected on aerial surveys, although some may have been included in the unidentified wildfowl category. Pintail were scarcely recorded on any of the estuaries counted, with the exception of the Kent, where sectors at the river mouth supported the species in relatively high densities.

4.1.1.4 Eider

Unsurprisingly, this sea duck was largely absent from most estuarine areas. The high density of birds recorded on aerial surveys at Foulney Island was corroborated by a similar distribution recorded by ground counters at the corresponding sectors of South Walney & Piel Channel Flats. This site held a mean site density of 7.4 birds ha^{-1}, and confirms it as important for the species, where it is likely to exploit the mussel beds found on the rocky skears. Although another concentration of Eiders was detected off Warton Sands during aerial surveys, the greatest numbers, depending on tidal state, were often seen when flying between the south of the bay and Walney Island. This area is sub-tidal and was therefore not included in transect counts.

4.1.1.5 Oystercatcher

Although all estuarine areas held at least some Oystercatchers, with notably high densities on the Wyre, the major concentrations of the species were at South Walney & Piel Channel

Flats (especially at Foulney Island, see 4.1.1.4) and in the main bay. Aerial surveys showed that significant clusters of Oystercatcher were located at Middleton Sands, Warton Sands and Aldingham, although other areas also contained high densities of Oystercatcher. It is possible that birds feeding at these mussel and cockle-rich sites originate from the closest wader roosts (Appendix 1) and do not travel across the bay to feed.

4.1.1.6 Golden Plover

Golden Plover was never recorded during aerial surveys, possibly because the species was not readily identifiable, or because it typically forages on farmland and not intertidal habitat. The Lune Estuary was notable for holding a particularly great mean site density, and the hinterland of the estuary contains much low-lying farmland which may contain suitable habitat for the species, possibly supplementing feeding at high tide. Additional concentrations of Golden Plovers were recorded on South Walney & Piel Channel Flats and the Wyre Estuary.

4.1.1.7 Grey Plover

Grey Plover was recorded on extremely few occasions in any location. It is possible that the species was overlooked on aerial survey and classified as an unidentified wader; this would perhaps explain the apparent absence of the species, known to roost at Morecambe Bay in its hundreds (Collier *et al.* 2005), on these surveys.

4.1.1.8 Lapwing

This species was ubiquitous on estuarine and coastal fringe areas. Aerial surveys recorded greatest aggregations on cells near to the mouth of the Lune Estuary, and this estuary also returned high densities from standard ground counts, as did the Wyre Estuary to a lesser extent. It seems likely that the species, often associated with Golden Plover, exploits feeding habitat on the margins of the bay whilst also profiting from the flat and low-lying flood pastures at its southern extent.

4.1.1.9 Knot

Small numbers of Knot were counted on the northernmost Kent and Leven Estuaries, with higher densities on the Wyre, Lune and at Piel Channel. The presence of an enormous flock of Knot at Half Moon Bay, included with the Lune Estuary, increased the mean site density. It was on these muddy bays that most Knot were expected, and although Knot were commonly indistinguishable from other small waders on aerial surveys, significant clusters of small waders were calculated to occur at Cockerham and Middleton Sands at the mouth of the Lune, with further non-significant hot spots at Warton Sands and Aldingham.

4.1.1.10 Dunlin

By contrast to Knot, the Lune Estuary and associated coastal count sectors held very few Dunlin. Highest densities of the species were found on the Wyre Estuary, and especially on the Kent Estuary. The flats off Grange-Over-Sands in particular held large numbers of Dunlin at high density. Counts of Dunlin on aerial survey were subject to the same difficulties as Knot (4.1.1.9) and thus the comments on small waders recorded are generic to both species.

4.1.1.11 Bar-tailed Godwit

The only notable concentrations of Bar-tailed Godwit were registered in the mouth of the Lune Estuary, where a mean site count of 288 birds was recorded. Thousands of these birds are known to roost at Morecambe Bay (Collier *et al.* 2005), although the trend is for a decline (Maclean *et al.* 2005), but even the disparate counts of large waders made on aerial surveys could not fully compensate for the lack of numbers. As Bar-tailed Godwits may be comparatively unresponsive to aircraft (Smit & Visser 1993), they may be more difficult to detect against a cryptic background than birds which 'pop-out' to an observer when flushing. It is therefore unclear from these surveys which areas of Morecambe Bay are used by foraging Bar-tailed Godwits.

4.1.1.12 Curlew

Curlew were present in reasonable densities on all estuaries surveyed, the largest concentrations at Piel Channel (especially Foulney Island), the Kent Estuary and downstream on the Wyre. Scatterings of Curlew were relatively commonplace on aerial surveys, but the major concentrations were observed near to the shore at Cockerham Sands, on the skears off the Morecambe shore and in the mouth of the Leven. Large numbers of Curlew were also frequently observed in the wet pasture to the south of Morecambe Bay, when approaching aerial survey transects.

4.1.1.13 Redshank

As a bird favouring muddy creeks and channels, Redshank were unsurprisingly recorded on all estuaries surveyed. Densities were similar on the Lune, Kent and Leven Estuaries, with highest densities on the Wyre Estuary and at Piel Channel. The species was occasionally recorded on aerial surveys, but it is probable that many of the birds identified as medium waders were Redshank. The distribution of these birds was fairly scattered, but they were frequently recorded on the main river channels.

4.1.1.14 Turnstone

Substantial numbers of Turnstone were seldom recorded, the most prevalent area being the sectors at Foulney Island in the Piel Channel. It is likely that the birds here were foraging on the rocky substrate offered by the near offshore skears. No Turnstone were positively identified on aerial surveys; see comments pertaining to small waders (4.1.1.9).

4.1.1.15 Wildfowl

Three species of swan were recorded within the bay, Bewick's and Whooper Swan restricted to very low densities on the Wyre Estuary, and Mute Swan occurring on all estuaries and on aerial surveys with highest densities on the Lune. Wigeon, Teal and Mallard were also present on all estuaries, with densities of Wigeon especially high on the Lune. Regular sightings of Goldeneye and Red-breasted Merganser were made on estuarine areas, as were occasional records of Shoveler, Scaup and Goosander. Cavendish Dock at Barrow-in-Furness, part of South Walney & Piel Channel Flats SSSI, contained relatively high numbers of some waterfowl, including Gadwall, Pochard and Coot and Tufted Duck at high density. Aerial surveys typically recorded ducks as unidentified, although one sighting of a Long-tailed Duck was notable. No other sea duck apart from Eider were observed.

4.1.1.16 Gulls

Description of gull distribution is confounded by a number of factors. Firstly, as gulls are an optional count group for WeBS, we cannot be confident that all gulls were accurately counted on standard counts. Secondly, for this reason, attention on aerial survey was focused on counting waders and wildfowl, and so many gulls were classed as unidentified, meaning species-specific distributions are difficult to generate. Thirdly, the short space of time available for identification and counting on aerial survey meant that large flocks of gulls were often classed as unidentified, especially where obviously of mixed species, and positive identification was often restricted to small groups. All five regularly occurring winter gulls (Black-headed, Common, Herring, Lesser-black Backed and Great Black-backed Gull) were found on all estuaries, and maps from aerial surveys for all gulls suggest a thinly and widely spread distribution, with some potential hot spots in coastal areas; this could be a result of additional foraging in urban or agricultural areas.

4.1.1.17 Other waterbirds

Occasional records of other waterbirds were made both on standard and aerial surveys. Little Grebe, Great Crested Grebe, Shag, Little Egret and Grey Heron were recorded sporadically on estuarine areas (the herons also on aerial surveys), and Red-throated Diver were seen on aerial surveys. Cormorants were present in relatively high densities at Piel Channel, were recorded on every estuary surveyed, and were common on aerial surveys.

4.1.2 Temporal distribution

Temporal analysis was undertaken for aerial counts of Oystercatcher and small waders, as these birds had the widest and most dense distributions. No analysis was performed on estuarine data, principally because of the smaller scale of these areas.

The mean weighted centre of Oystercatcher distribution was similar in each of the four winter months, never greater than 4 km distant. Each of the main feeding areas in Morecambe Bay, containing either mussel beds and / or intertidal habitat suitable for other invertebrate prey (principally cockles and Baltic tellin bivalves: Dare & Mercer 1973; Cramp & Simmons 1983; Wilson & Marsh 1987) exerts an influence on the mean centre. The main feeding areas can be considered to be between Foulney Island and the Leven, between the Kent and Heysham, and between Heysham and the Wyre, and thus the centre of distribution is typically at some point between the intersection of these areas. In November, the Oystercatcher distribution was fairly patchy, possibly as numbers had not built up to peak winter levels, and the centre of distribution and standard deviation suggest most birds were concentrated in key feeding areas north of the Lune. By December, the mean centre shifted towards the skears between Heysham and Morecambe, and the wider standard deviation suggests a more scattered distribution. Although Oystercatcher were also widespread in January, the mean centre lay further to the north, and the standard deviation radius did not encompass birds found south of Heysham. This implies that at the time of survey, more Oystercatcher favoured the north of the bay. Numbers of Oystercatcher declined in February, as birds dispersed, and this may have led to a distribution restricted to fairly localised clusters. The mean centre was similar to that in December, shifted towards the Morecambe shore; this suggests that more birds were located in the southern extent of the bay in late winter.

Mean centres of small wader distribution were broadly similar to those for Oystercatcher, but occurring closer to the Morecambe and Heysham shore. This pattern, and that of the standard deviation circles, suggests that the majority of small waders tended more to the east and south of the bay than Oystercatchers. It is tempting to speculate that the close proximity of mean centres in November and February, and those in December and January, reflects a wider dispersal of birds in peak count months, possibly through a density dependent process such as competitive exclusion. It is apparent that fewer cells in the sandier area between the Wyre and Lune were occupied by small waders in November and February; these months may be expected to contain comparatively fewer Knot and Dunlin, and thus it is possible that increased numbers in mid-winter led to increased foraging in the south of the bay.

Overall, however, there is little convincing evidence to suggest that there are large-scale movements of waders between feeding grounds throughout the winter. Should such an analysis be repeated at a smaller resolution, for instance within approximate feeding areas, trends may become more apparent.

4.1.3 Determinants of distribution

It is likely that many factors influenced the distribution of birds recorded on both standard and aerial surveys. An obvious factor that would determine bird distribution is food resource location, which in turn is influenced by habitat and sediment type. However, it is debatable to what extent a low tide survey of Morecambe Bay accurately reflects a feeding distribution for some species, as local experts have consistently observed that many birds begin foraging as the tide turns, exploiting the gradually exposed mussel beds and intertidal substrate, and finish feeding before the lowest tide when birds form roosting or pre-roosting flocks (*e.g.* Oystercatcher are often thought to cease feeding by mid-tide, Wilson & Marsh 1987; Mower 2004; Jack Sheldon, *pers. comm.*). Therefore it is feasible that counts made within the bounds of the WeBS Low Tide Count method do not entirely reflect the distribution of the key feeding sites. The lack of a relationship between cockle density and Oystercatcher or small wader density may have been influenced by this issue; however, it is probable that the spatial resolution of the data and preferential feeding on mussels are equally important.

A relationship between bird distribution and sediment characteristics (and, by implication, associated prey types) may have indicated the behaviour of birds at low tide. If, for example, high bird densities had corresponded with sediments known to be rich in the preferred prey of certain species, then it would be likely that the area was used for feeding at some stage of the tidal cycle. Unfortunately it was not possible to undertake such an analysis. Morecambe Bay is known to be dominated by two sediment types, and *Macoma balthica* was found to be prevalent within the bay (Royal Haskoning 2006). As no relationship was found between small wader and *Macoma* distributions, it is perhaps questionable whether a relationship with sediment would have been revealed.

Some disturbance events were recorded, predominantly cocklers but also dog walkers. It was difficult to establish the direct influence of these events, largely due to the spatial resolution of the bird data; a dog walker 900 m away from a flock of birds may be ignored, but one at 100 m probably less so. However, there was a general trend for low densities of birds in cells containing disturbance events. This is somewhat unsurprising, given that it is established that waterbirds will frequently take flight in the presence of people (*e.g.* Kirby *et al.*1993). On the Wadden Sea, Oystercatcher were estimated to take flight when people were at a distance of 25 – 300 m, Dunlin at a distance of 100 – 300 m (Smit & Visser 1993). Short-lived disturbance events, such as dog walking, may simply cause a temporary vacation of the immediate area or relocation nearby (Kirby *et al.*1993). However, continuous, intense activity such as large-scale cockling may cause birds to desert certain areas (Goss-Custard & Verboven 1993). It is therefore important that cockling activity should not take place simultaneously on many beds, as the likely impact will be to disturb birds from feeding and deprive them of secondary resources that would otherwise have been used in reserve. At Morecambe Bay, one small study found that Warton Sands cockle bed was exploited by Oystercatcher before the area was reachable by humans, and that birds had moved off the bed before cockling began (Mower 2004). This would suggest that some fishery areas are not used at temporally coincident periods by birds and humans, but to what extent the phenomenon extends to other areas of the bay, or to other winters, is unclear.

4.2 Count Bias and Abundance Adjustment

4.2.1 Aerial survey

Although currently the most feasible method of covering large sites at low tide, aerial survey is not without associated problems that can influence results. Environmental conditions on surveys were similar in all cases, and it is unlikely that these influenced counter experience. Visibility, however, was subject to change not only between surveys but also within surveys. Komdeur *et al.* (1992) suggest that dull light conditions can lead to underestimation of flock sizes, though most observers preferred counting in such conditions than when glare from the sun existed.

Differences between counters, in terms not only of experience but also inherent differences in eyesight, alertness and so on, will also have introduced bias, as different counters were used on the starboard side of the plane for three of the four surveys. To some extent, the bias in counts on the port side should have been consistent, as the same counter was present on all surveys. Estimates of individual count bias revealed that mean count error was fairly consistent for the three counters tested (AB: 13%; SH: 18%; IM: 18%), compared to the control (ED: 28%). Most observers underestimated true numbers (with only one exception on one simulation), as has been found elsewhere (*e.g.*Frederick *et al.* 2003). If a mean combined error of –31% is assumed (-13% from the port counter plus -18% from the starboard), then total abundance would still represent less than approximately 50 – 80% of the Core Count total for 2004/05 (section 3.3.2). It is usual for some LTCs to exceed Core Counts when using standard methods (Collier *et al.* 2005), and so it is probable that these aerial surveys did not include some of the birds recorded at Morecambe Bay on Core Counts.

The effects of the aircraft itself are likely to have influenced count numbers. Although during flights it was evident that certain species (*e.g.* Oystercatcher, Eider, gulls) showed little response to the aircraft, flocks of small waders and other species were often seen to flush. This is considered a particular problem for Knot and Dunlin; the former have been noted to undergo heavy disturbance in response to low-flying light aircraft (Koolhaas *et al.* 1993). It is also probable that underestimates of these flocks were particularly prevalent; as well as the inherent difficulty of counting large flocks of small birds by any method, once in flight a two-dimensional view of a three-dimensional flock can create the impression of far fewer birds than are actually present.

The combination of aircraft disturbance, counter error and influence of light conditions will undoubtedly have contributed to underestimates of abundance. However, as the aim of WeBS LTCs is to determine spatial distribution of waterbirds, some of the pitfalls discussed are not necessarily problematic. Despite potential counter error, it is considered that the relative distribution of birds recorded is largely accurate. Even when birds reacted to the aircraft, it was usual to record them in the location from which they flushed; it was very unusual to record a flock of birds in flight without knowledge of origin. Perhaps the greatest drawback is the unknown proportion of birds disturbed in response to the approaching aeroplane which were not recorded at all. Based on the behaviour of birds observed it is not considered likely that this was a widespread phenomenon, but simultaneous counts from air and ground may help to elucidate further.

4.2.2 Standard counts

Coverage of the five main estuaries of Morecambe Bay was extensive. Full counts of each sector on each estuary were possible in at least one month during the winter. Partial counts of some sites resulted mainly from weather disruption and the small number of days available when low tide fell within daylight hours. Difficulties with counts at South Walney & Piel Channel Flats meant that complete coverage was only possible in one month, and that no counts occurred in February. This area is regularly counted by the same volunteers at mid-tide, when the majority of birds are more easily visible. At low water, however, many birds move offshore where they are no longer visible in gutters and river channels, leading to undercounts (Jack Sheldon, *pers. comm.*). Of the sectors that were counted in both the winters of 2004/05 (mid-tide, thus smaller areas) and 2005/06 (low tide, wide expanses of mudflats), the former method returned 1,500 more birds, including more Oystercatcher and Knot. Future surveys should therefore include provision for the trade-off between detectibility of birds and extent of habitat viewed.

A similar situation exists at North Wharf, the flats north of Fleetwood. Hopes to count the whole of North Wharf from the ground, with the possibility for comparison of counts with aerial survey, were not realistic in practice. Counters could not accurately estimate numbers of birds far offshore, and thus the counts for the area, anticipated to be of higher precision than could be made from aerial surveys, could not be undertaken. In future it will be necessary to include the small section left uncovered on aerial surveys.

In general, the use of standard WeBS LTC methods to cover the five main estuaries was successful. There is indeed no reason why repeat surveys of these areas, whether co-ordinated with aerial surveys or otherwise, should not be repeated if volunteers are keen to do so. Further consideration of the difficulties of viewing birds on large mudflats should be included.

4.2.3 Ground-truthing

Originally, it was hoped to be able to compare ground and aerial count totals between North Wharf and some of Piel Channel. However, ground counts of these areas were impossible or limited, and aerial surveys of the latter were only possible in one month, on the advice of the pilot. Further complications arose from the degree of overlap between count sector boundaries and aerial survey grid cells. However, a rough comparison was possible of those counts made in November at Foulney Island, which was surveyed from both the ground and air. Sector boundaries for ground counts are not drawn along grid cell lines and thus did not exactly correspond to aerial survey cells covered, but assuming that all of the birds counted from the air in cells containing at least part of the standard sector boundaries were likely to be those counted on the skears from ground counts, aerial counts recorded considerably fewer birds, including 4% of the Curlew counted from the land, 10% of the Oystercatcher and 5 % of the Eider. Marginally more small waders were recorded on aerial surveys; thus it is possible that for some species, the aircraft induces disturbance allowing detection which is otherwise not possible. Comparison of aerial counts with ground counts of waterbirds has produced similar general patterns of lower totals from the air in other studies (*e.g.* Musgrove & Holloway 1997; Banks *et al*. 2004).

Despite the great likelihood of underestimation, comparisons of count totals with those from WeBS Core Counts should be interpreted somewhat cautiously. No allowance has been made for sector coverage in the calculations, and so, for instance, some LTCs may be lower because of partial coverage in some months. The same may be true of Core Count totals. Also, roost site sectors and LTC sectors do not overlap in many cases, and so the birds roosting at Morecambe Bay may feed elsewhere, and *vice versa*. Finally, the LTC method is less preferred for making quantitative estimates, as the aims of the scheme are to measure relative distribution; birds scattered across a large area may be harder to quantify than those restricted to a small roost site, and may make more movements between sectors (Collier *et al*. 2005).

4.3 Future Directions

4.3.1 Morecambe Bay

The suite of counts undertaken in 2005/06 at Morecambe Bay will help to fill gaps in current knowledge regarding species distribution and density, and to inform English Nature's programme of Common Standards Monitoring. Undoubtedly, the scope of this survey is sufficient to address some questions; the experience can also be used to refine and improve future low water distribution surveys within the bay.

It is recommended that future counts on the rivers Leven and Kent be undertaken in the same fashion as in 2005/06. Birds on these estuaries generally occur at low densities, and visibility does not seem to be a major problem. Access to some count areas may, however, be difficult, and if volunteers are to become involved it would be worth a preliminary visit to the sites accompanied by an experienced counter, or at least close liaison with the WeBS Office to explain previous approaches.

Counts on the Wyre Estuary are already regularly made by volunteers, and will hopefully continue. Counts of the estuary at present are made in one visit, and it is possible that counts of the later visited sectors are made outside the 2-hour post low tide window used for WeBS LTCs. The Wyre is considered to be something of a closed system within Morecambe Bay, with little movement of birds from feeding or roosting birds into or out of the estuary (Paul Ellis, *pers. comm.*), and so in this case the normal method is not violated unduly. The prospect of including North Wharf (part of the Wyre Estuary SSSI) in these counts seems unrealistic, unless some mid-tide counts can be arranged; even then it is unclear whether birds will be fully visible from the shore. Another approach will be necessary to cover the entire area, with an extension to the current aerial survey area the most likely candidate at present.

Counts at South Walney & Piel Channel Flats are due to continue, thanks to the enthusiasm of the volunteer counters in the area. These will be made at mid-tide, as they have been for many years in the past. It is debatable if it would ever be possible, or indeed worthwhile, to obtain a 'true' low tide distribution for some of this area (*e.g.* Snab Sands, Roosecote Sands). Full visibility and detectibility from the land seems impossible on the lowest tides, and counters may be deterred. Aerial survey is not desirable, due to the areas of habitation and industrialisation that cannot be flown over at low-level. Perhaps one solution would be to conduct a survey from a boat, sailing along the Piel Channel and surveying the widest mudflats and scars from the vessel. This would also allow survey of offshore feeding areas such as South America scar and Conger Stones.

Counts of the Lune Estuary were largely successful. A major advantage on future surveys would be to extend counts north along the shore between Sunderland Point and Morecambe Pier, part of which has been done in conjunction with private commercial surveys (Peter Marsh, *pers. comm.*). Some counts were made on the present surveys, and some stretches were covered by aerial survey. The presence of an estimated 14,000 (probably roosting) Knot in Half Moon Bay in December 2005 confirms that detection and / or accurate quantification of such flocks is not possible with aerial survey, as no estimated flock size approached that figure, and as the inner bay contains many rocky skears upon which birds are likely to feed, finer scale resolution would be obtained from land surveys.

Ideally, the aim should be to conduct 'through the tide cycle' counts for the estuarine areas, in order to fully understand movements and distribution patterns. However, such surveys require large amounts of time and effort and so initially it may be worth selecting one or two areas for trial. Regardless, the issue of bird behaviour in response to tidal movements is pertinent. Local experts insist that most birds feed three or four hours post-high tide, and that at low tide aggregations form in locations that do not necessarily reflect feeding areas. An alternative approach would be for a radio-tracking programme that would allow movements of birds to be continuously recorded throughout a longer period. Depending on what the data are to be used for, it may be necessary to refine the WeBS LTC method at Morecambe Bay, as a feeding distribution and low tide distribution may not be mutually exclusive.

Aerial surveys of Morecambe Bay were effective at recording the gross low water distribution of a number of species and species groups, notably Oystercatcher and small waders. Refinements to the transect routes may be necessary for any future surveys to avoid pilots flying at low level over habitation. This strengthens the argument to survey the near-shore from the ground, and to reserve aerial survey for inaccessible and invisible areas of the bay. Until technology permits high quality images of birds to be obtained, aerial survey would seem a desirable option for surveying the large expanses of outer Morecambe Bay.

4.3.2 WeBS Low Tide Counts

The experience at Morecambe Bay can be used to inform future decisions regarding the survey of birds at low tide on other large estuaries that are not easily counted with standard methods. Banks *et al.*(2005) identified a number of estuarine sites that fall into this category, such as The Wash. Although costly, the method allowed a large area to be covered in a short space of time. Hot spots of bird distribution could be identified, although spatial resolution is less than normally used on standard surveys of smaller estuaries. It is possible that this could be increased, but could necessitate more transects, and thus more time in the air, and thus more expense. Sites with high levels of urbanisation would seem to be somewhat unsuitable for aerial surveys, as pilots have difficulty remaining on transect routes when these overlap inhabited areas, due to CAA regulations. Similarly, transects at low level cannot be flown if there is sharply rising high ground at the end of the route.

It is recommended that aerial surveys continue to be used, at least where site conditions allow. Careful planning can ensure the method is only needed to fill in gaps at sites where standard methods cannot be used. In the meantime, there would seem an urgent need for biologists and policy makers to fully explore the burgeoning satellite and image technologies. Any opportunity to obtain remote images of bird distributions will avoid many of the disadvantages currently associated with aerial survey, not least disturbance from the aircraft itself and underestimation of bird numbers.

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References

Banks, A.N., Bolt, D., Bullock, I., Haycock, B., Musgrove, A., Newson, S., Fairney, N., Sanderson, W., Schofield, R., Smith, L., Taylor, R. & Whitehead, S. (2004). *Ground and aerial monitoring protocols for in shore Special Protection Areas*. CCW Marine Monitoring Report No: 11, 89pp.

Banks, A.N. Handschuh, M., Musgrove, A.J. & Rehfisch, M.M. (2005). *Review of Spatial and Temporal Coverage of Coastal English SSSIs by The Wetland Bird Survey Low Tide Count Scheme.* BTO Report to English Nature. BTO, Thetford.

Camphuysen, C.J., Fox, A.D., Leopold, M.F. & Petersen, I.K. (2004). Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K. Report to COWRIE in conjunction with NIOZ.

Collier, M.P., Banks, A.N., Austin, G.E., Girling, T., Hearn, R.D. & Musgrove, A.J. (2005). *The Wetland Bird Survey 2003/04: Wildfowl and Wader Counts*. BTO/WWT/RSPB/JNCC, Thetford.

Cramp, S. and Simmons, K. E. L., eds (1983). *The birds of the western Palearctic: waders to gulls, III*. Oxford: Oxford University Press (Handbook of the birds of Europe the Middle East and North Africa).

Dare, P.J. & Mercer, A.J. (1973). Foods of the Oystercatcher in Morecambe Bay Lancashire. *Bird Study* **20**, 173-184.

Frederick, P.C., Towles, T., Sawicki, R.J. & Bancroft, T. (1996). Comparison of aerial and ground techniques for discovery and census of wading bird (Ciconiiformes) nesting colonies. *Condor* **98**, 837-841.

Goss-Custard, J.D. & Verboven, N. (1993). Disturbance and feeding shorebirds on the Exe Estuary. *Wader Study Group Bull.* **68**: 59-66.

Kirby, J.S., Clee, C. & Seager, V. (1993). Impact and extent of recreational disturbance to wader roosts on the Dee Estuary: some preliminary results. *Wader Study Group Bull.* **68**: 53-58.

Komdeur, J., Bertlesen, J. & Cracknell, G., eds (1992). *Manual for Aeroplane and Ship Surveys of Waterfowl and Seabirds*. IWRB Spec. Publ. 19, Slimbridge. 37pp.

Koolhaas, A., Dekinga, A. & Piersma, T. (1993). Disturbance of foraging Knots by aircraft in the Dutch Wadden Sea in August-October 1992. *Wader Study Group Bull.* **68**: 20-22.

Maclean, I.M.D., Austin, G.E., Mellan, H.J. and Girling, T. (2005) WeBS Alerts 2003/2004: Changes in numbers of wintering waterbirds in the United Kingdom, its Constituent Countries, Special Protection Areas (SPAs) and Sites of Special Scientific Interest (SSSIs). BTO Research Report No. 416 to the WeBS partnership. BTO, Thetford.

Mitchell, A. (2005). *The ESRI Guide to GIS Analysis. Volume 2: Spatial Measurements and Statistics*. ESRI Press, California.

Mower, D. (2004). The impact of cockle fishing on Oystercatcher numbers and feeding patterns, Warton Sands, November and December 2003. Unpublished RSPB data.

Musgrove, A.J. & Holloway, S.J. (1997). *Counting Waterfowl on Large Estuaries at Low Tide.* BTO Research Report 178, Thetford.

Rodgers, J.A. Jr., Kubilis, P.S. & Nesbitt, S.A. (2005). Accuracy of aerial surveys of waterbird colonies. *Waterbirds* **28**, 230-237.

Royal Haskoning (2006). Maritime Monitoring Intertidal Survey of North West England 2005-2006. Report to English Nature. Haskoning UK Ltd., Exeter.

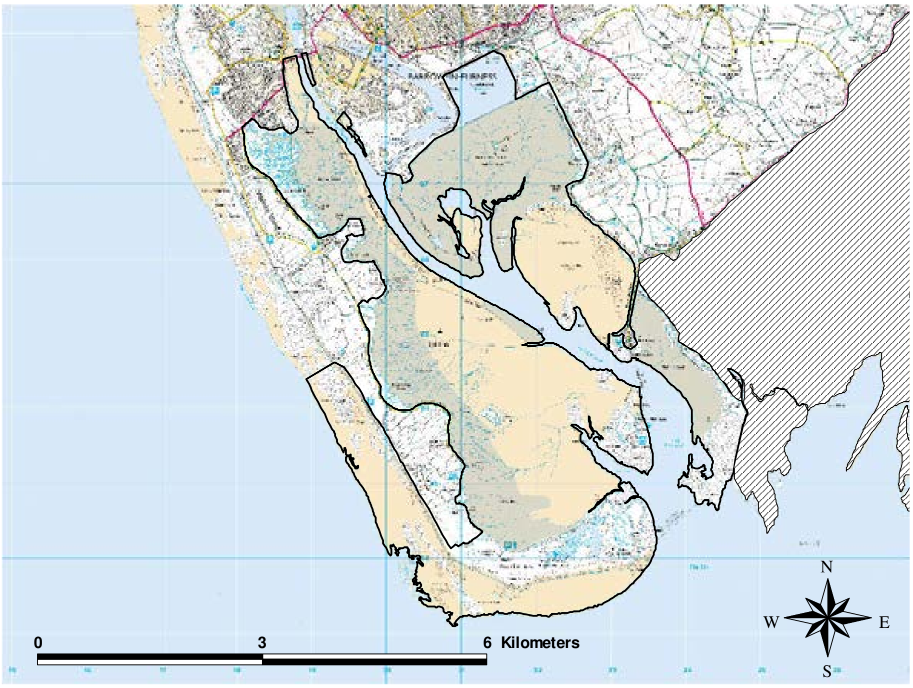
Smit, C.J. & Visser, J.M. (1993). Effects of disturbance on shorebirds: a summary of existing knowledge from the Dutch Wadden Sea and Delta area. *Wader Study Group Bull.* **68**: 6-19.

Stroud, D.A., Chambers, D., Cook, S., Buxton, N., Fraser, B., Clement, P., Lewis, P., McLean, I., Baker, H. & Whitehead, S. (2001) *The UK SPA network: its scope and content.* JNCC, Peterborough, UK.

Wilson, J. & Marsh, P.J. (1987). Birds. In: Robinson, N.A. & Pringle, A.W. (eds.) (1987) *Morecambe Bay: An Assessment of Present Knowledge*. CNRS/MBSG, Lancaster.

Appendix 1 SSSI maps & site map.

a



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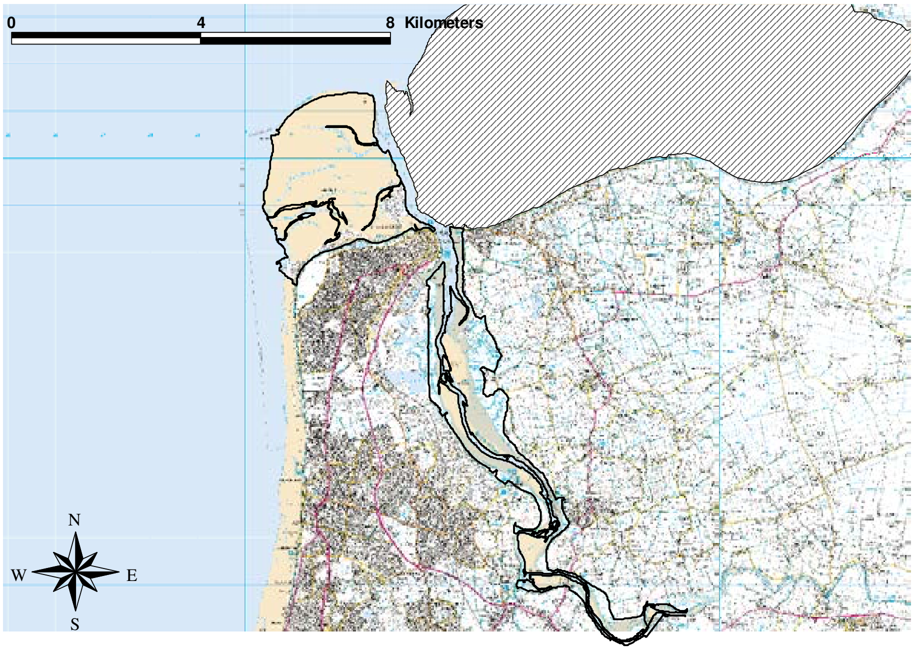

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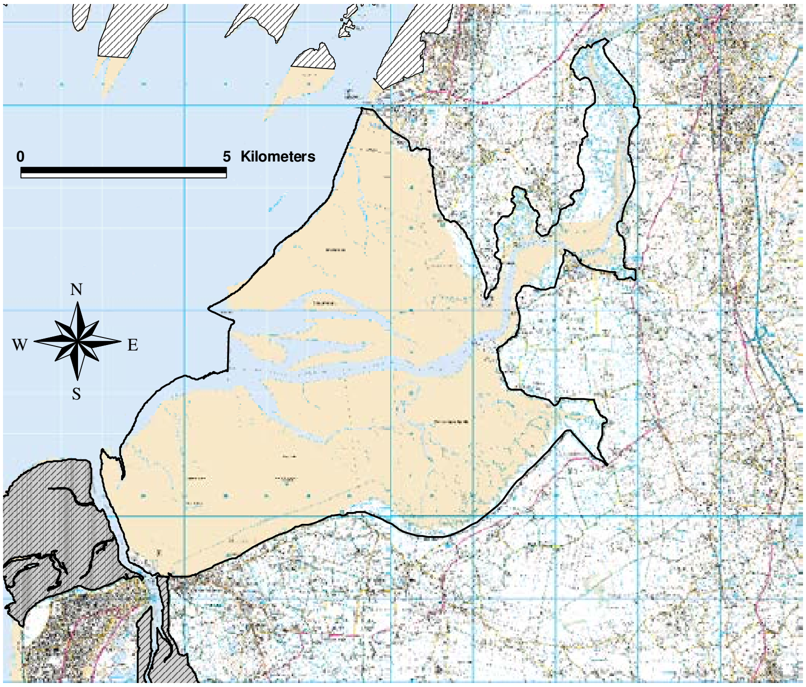

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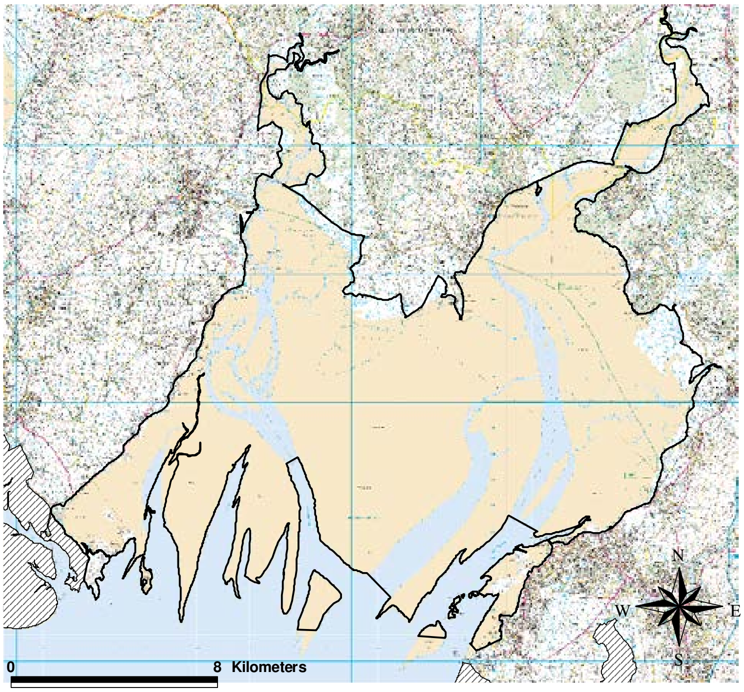


Figure 1.1 Constituent SSSIs of Morecambe Bay SPA. a. South Walney & Piel Channel Flats SSSI; b. Wyre Estuary SSSI; c. Lune Estuary SSSI; d. Morecambe Bay SSSI. Hatched areas, where shown, are areas of bordering SSSIs.

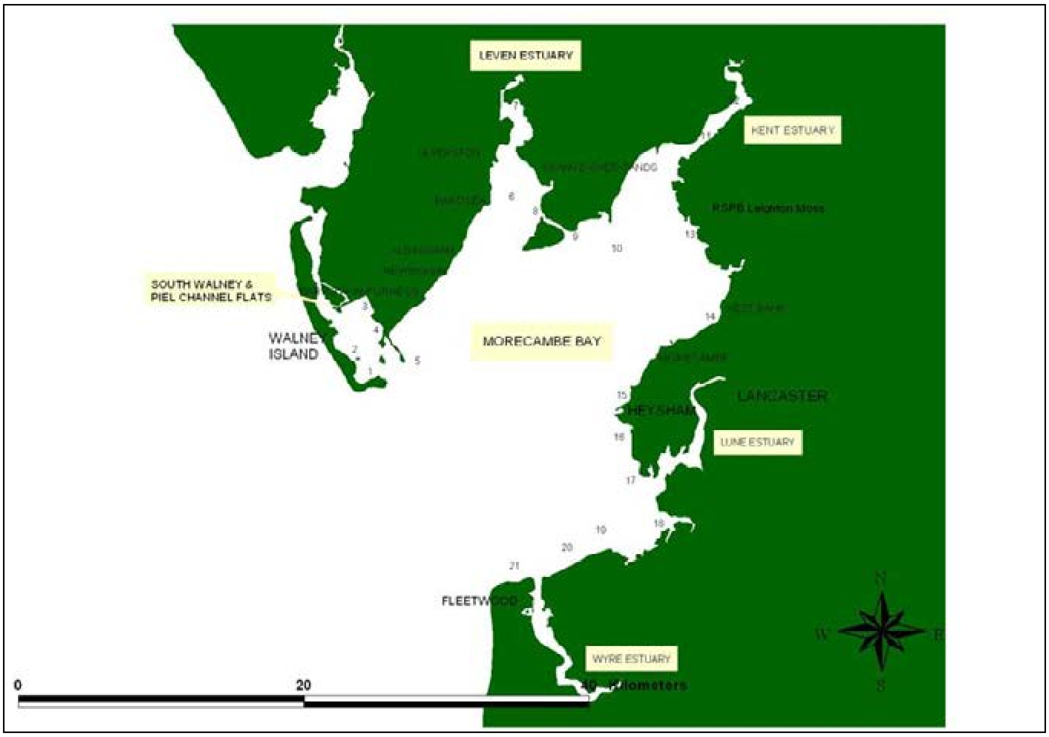


Figure 1.2 Morecambe Bay. 1=Haws Bed; 2=Snab Sands; 3=Roosecote Sands; 4=Pike Stones; 5=Foulney Island/South America scar/Conger Stones; 6=Cartmel Sands; 7=Greenodd Sands; 8=Cowpren Point; 9=Cark Point; 10=Flookburgh Mussel bed; 11=Kent Viaduct; 12=Milnthorpe Marsh; 13=Warton Sands; 14=Scalestones Point; 15=Half Moon Bay; 16=Middleton Sands; 17=Sunderland Point; 18=Cockerham Sands; 19=Pilling Sands; 20=Preesall Sands; 21=North Wharf.

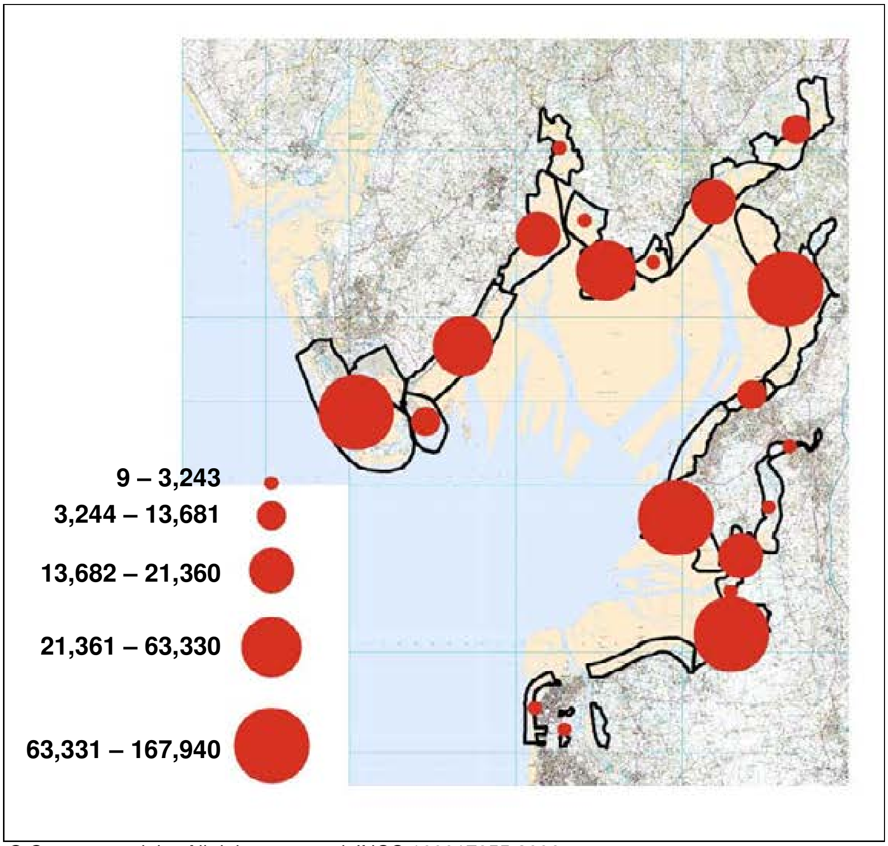


Figure 1.3 Main wader roosts from WeBS Core Count data 2004/05. Black outline shows WeBS Core Count sectors.

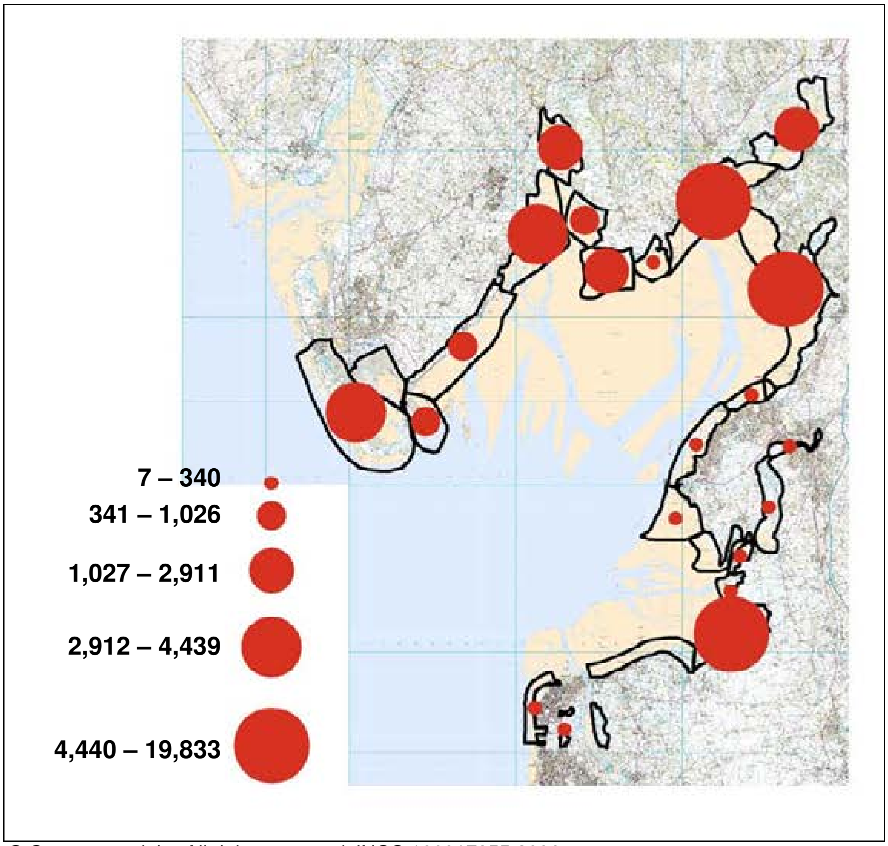
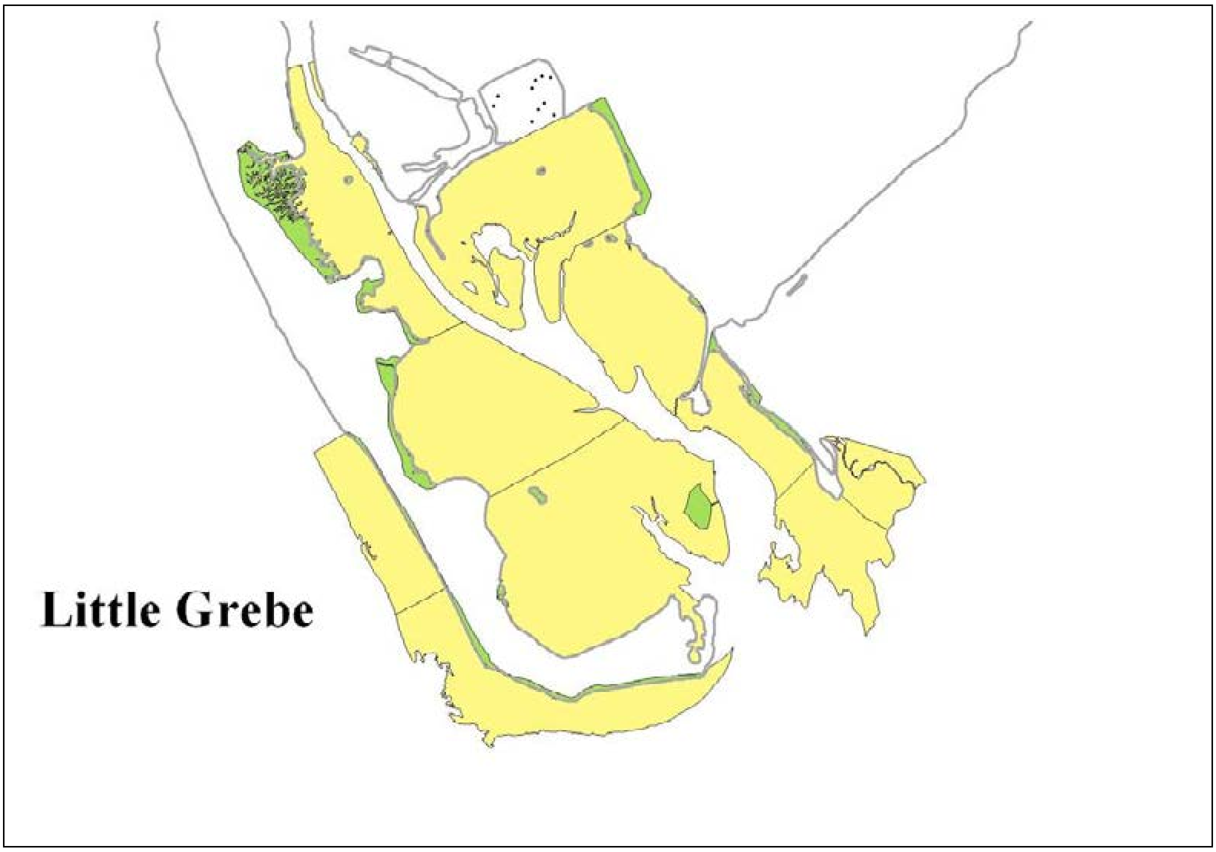
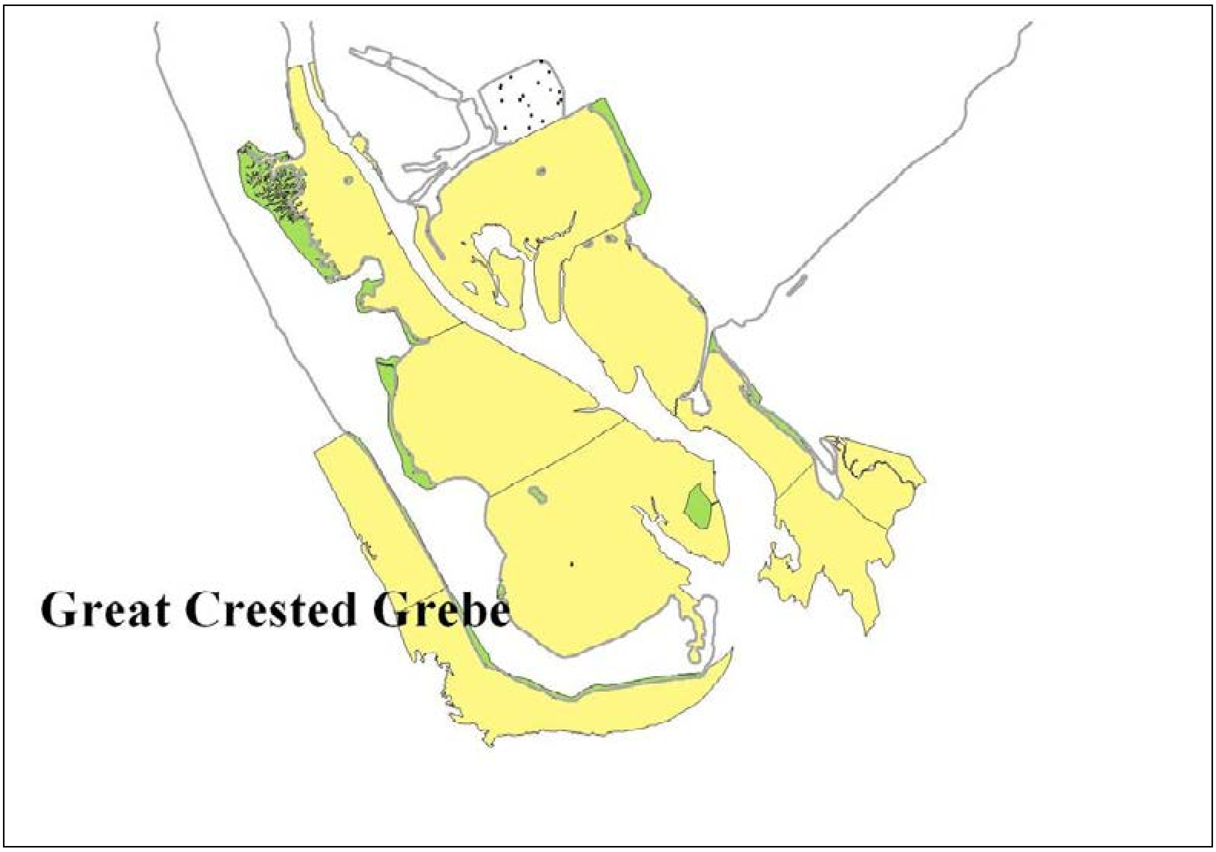


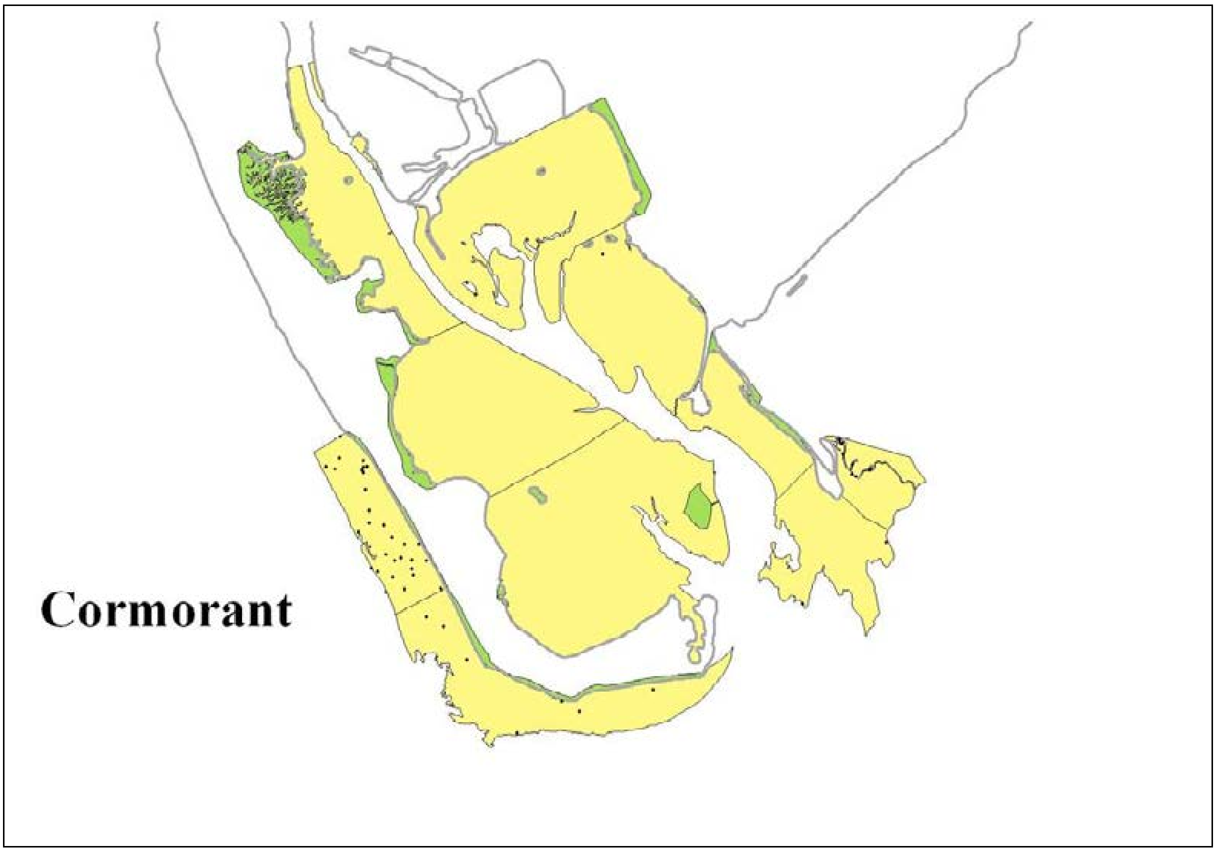
Figure 1.4 Main wildfowl roosts from WeBS Core Count data 2004/05. Black outline shows WeBS Core Count sectors.

Appendix 2 Dot density maps for estuarine data.

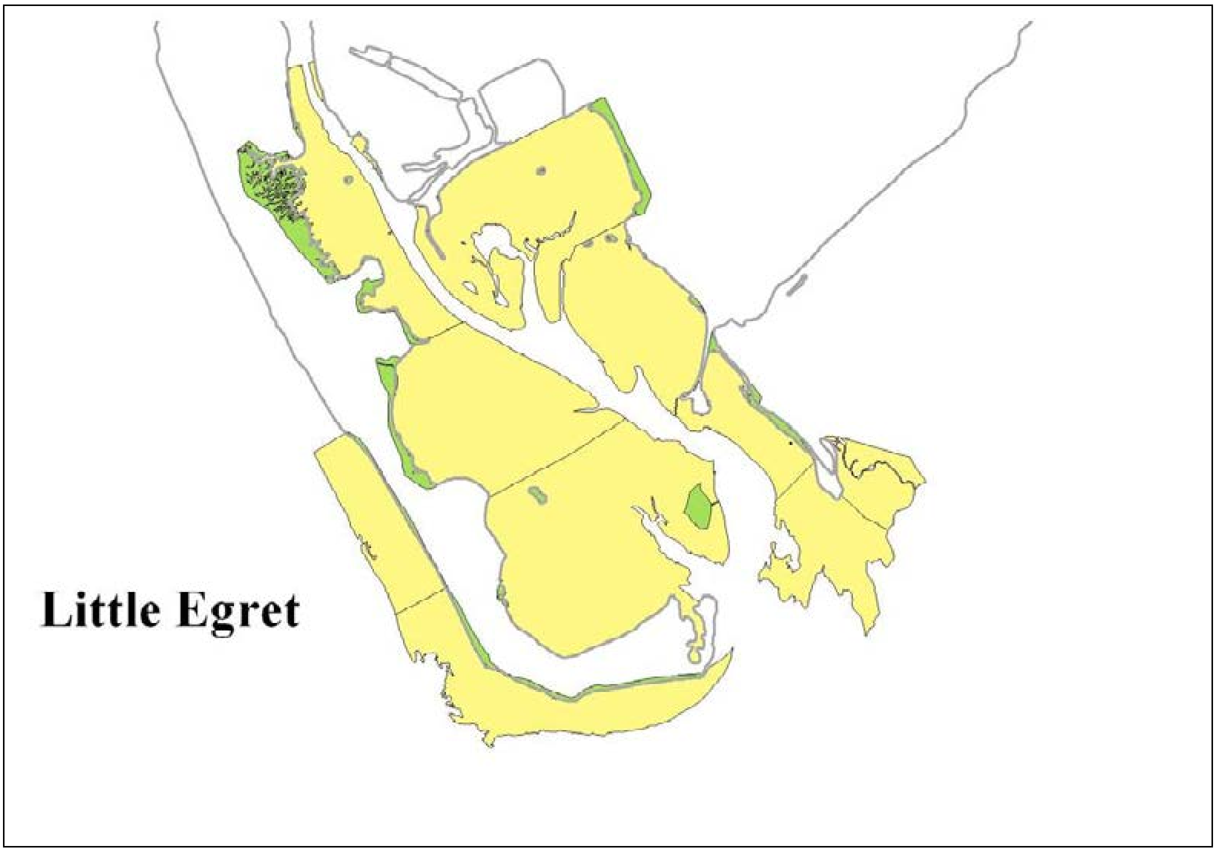
Piel Channel

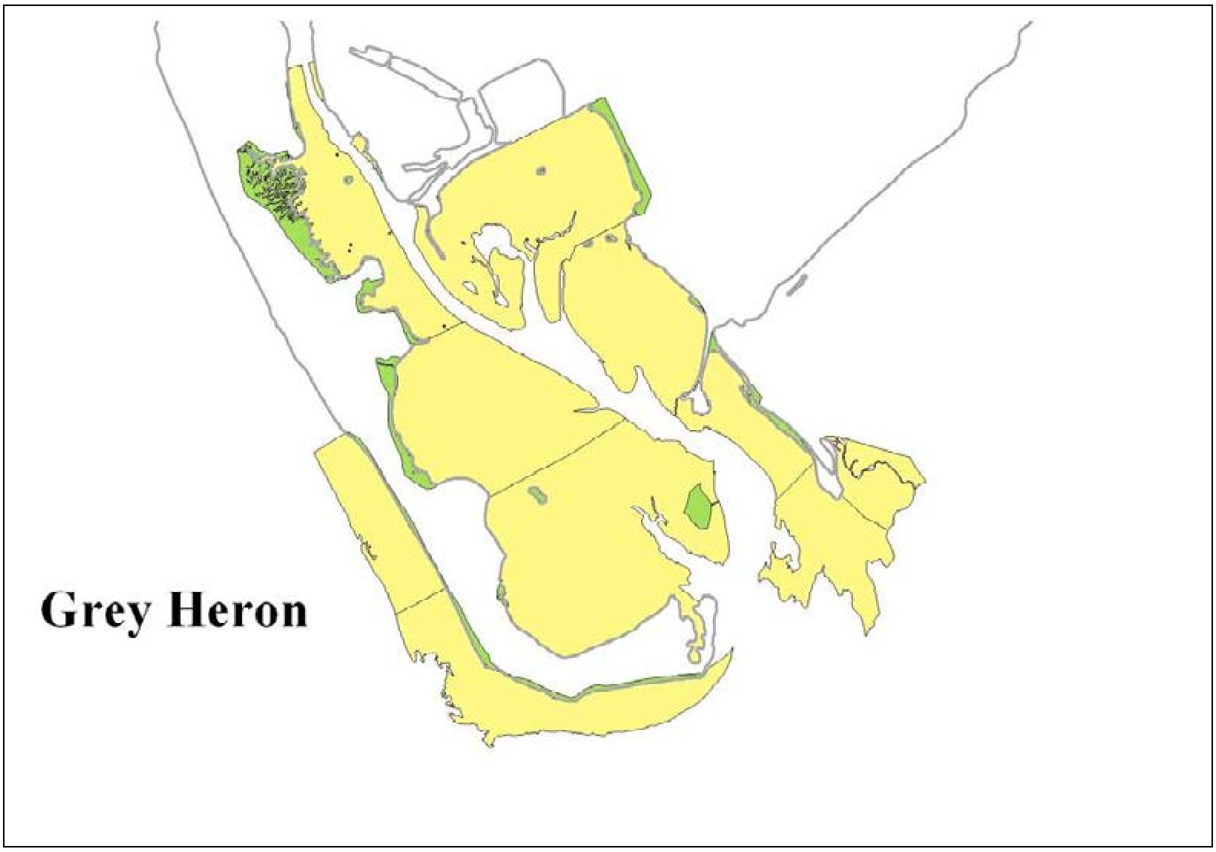


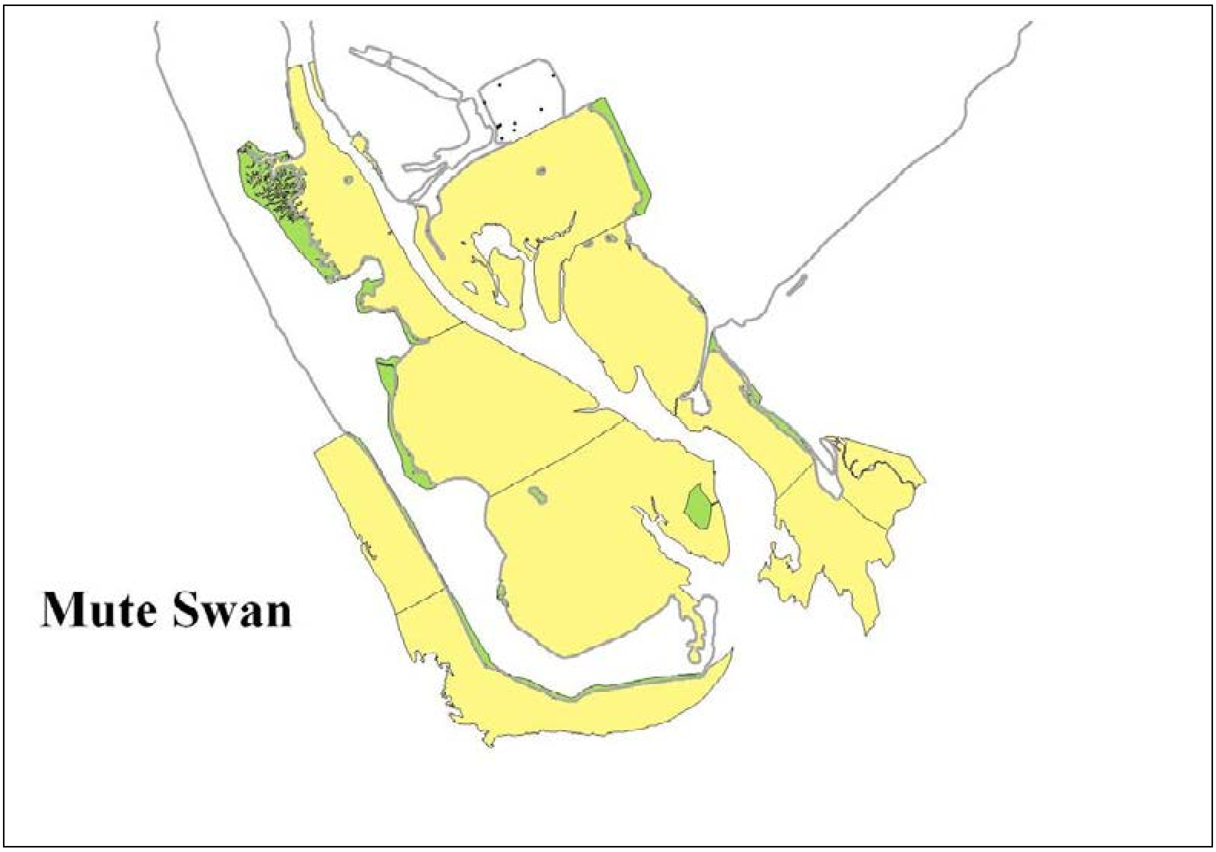


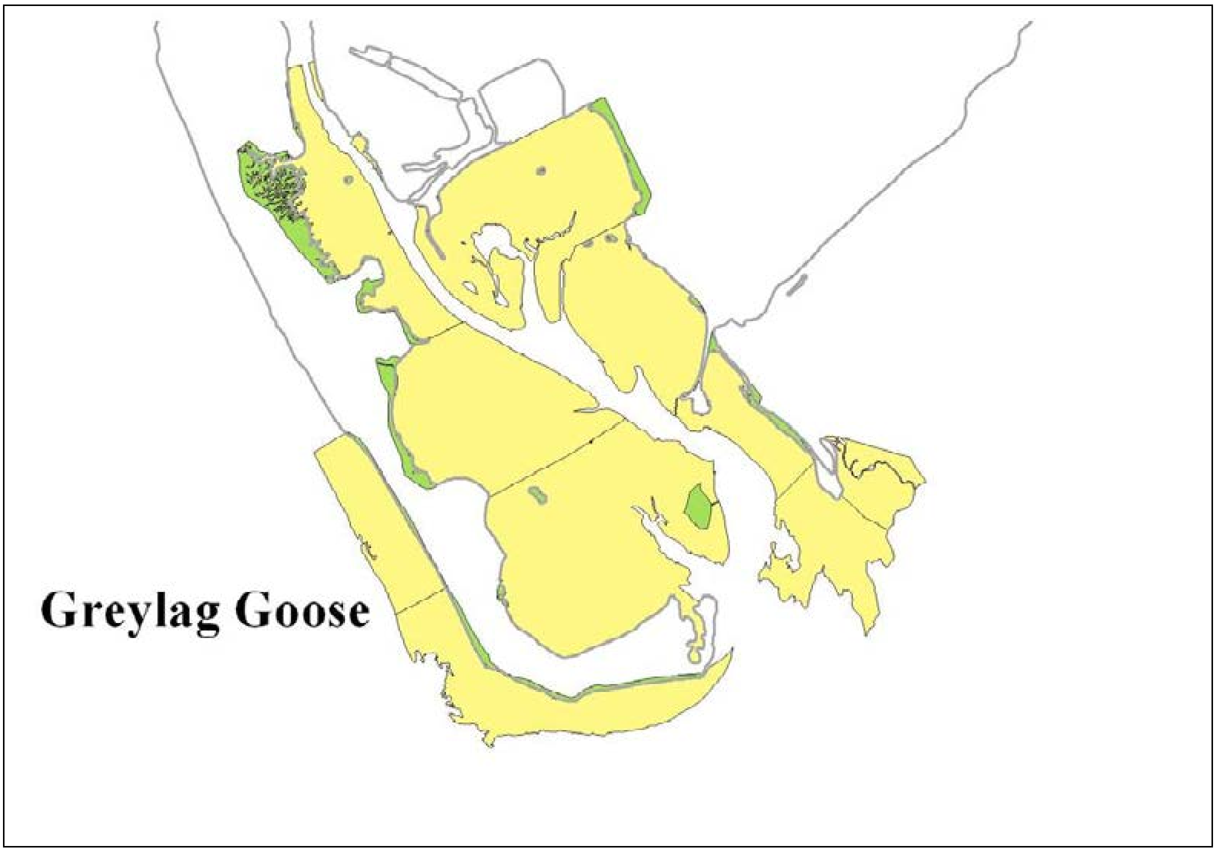

Cormorant

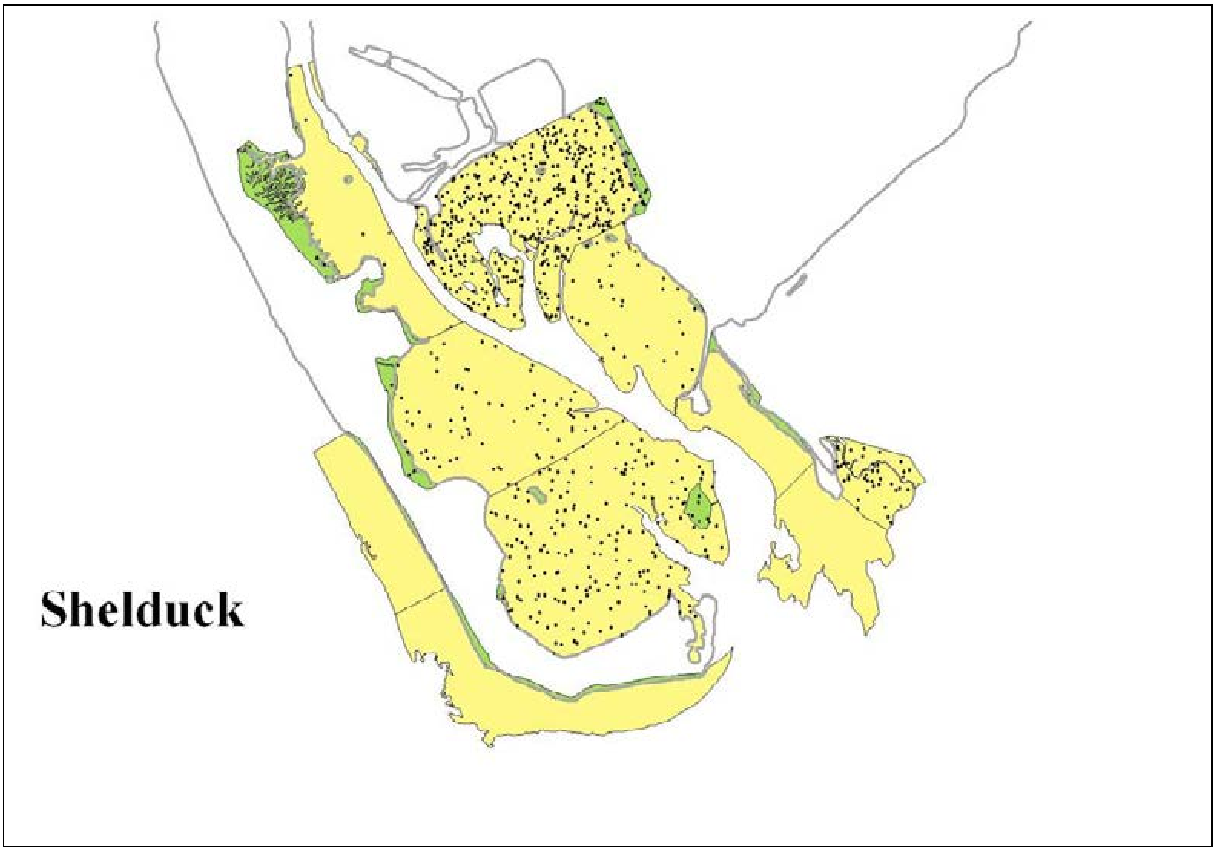

Shag

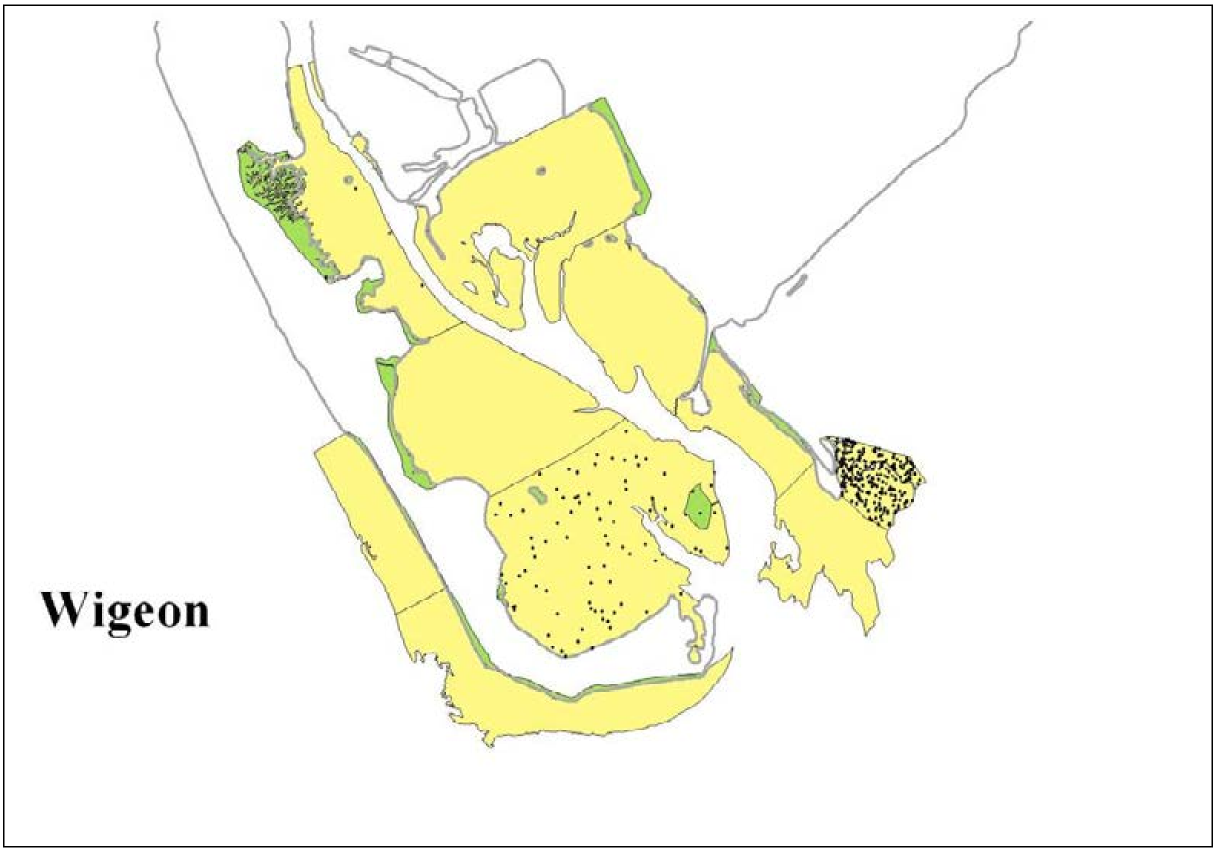

Little Egret

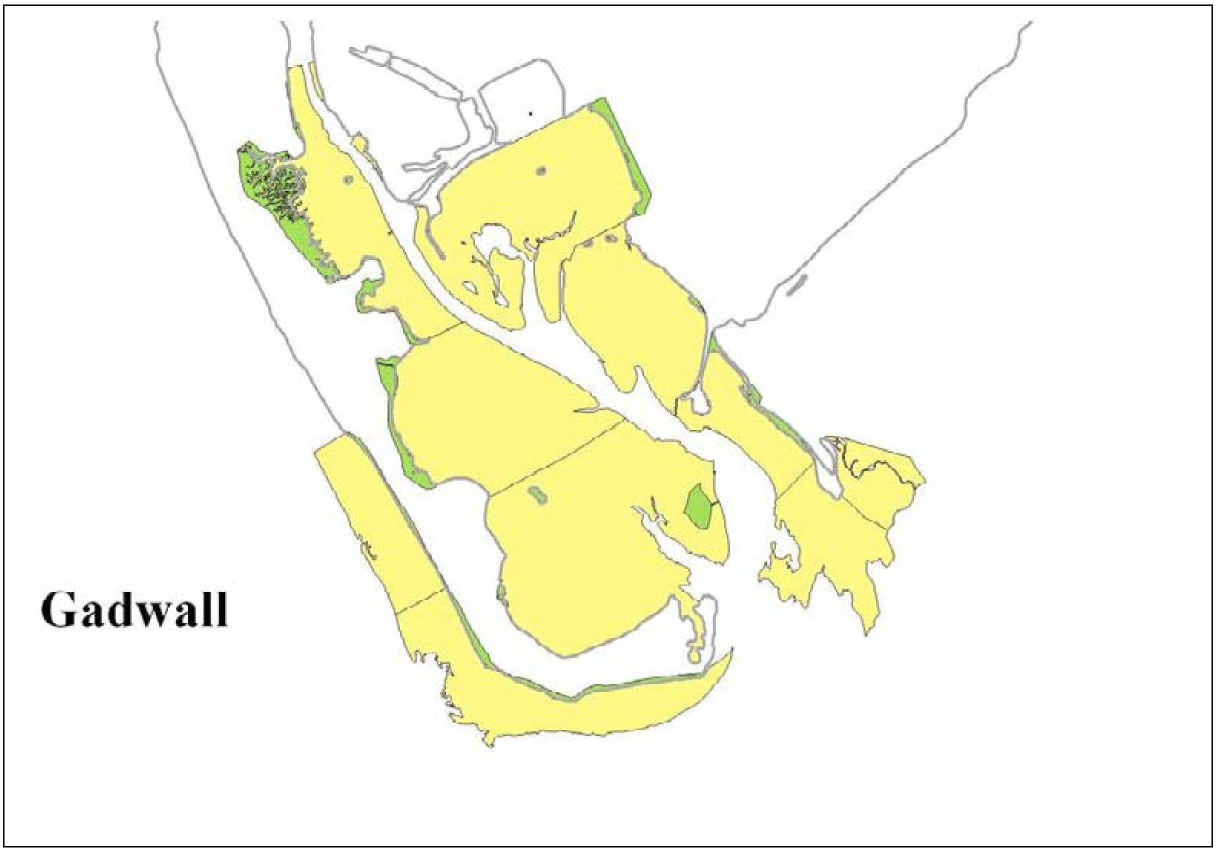

Grey Heron


Mute Swan


Greylag Goose


Shelduck


Wigeon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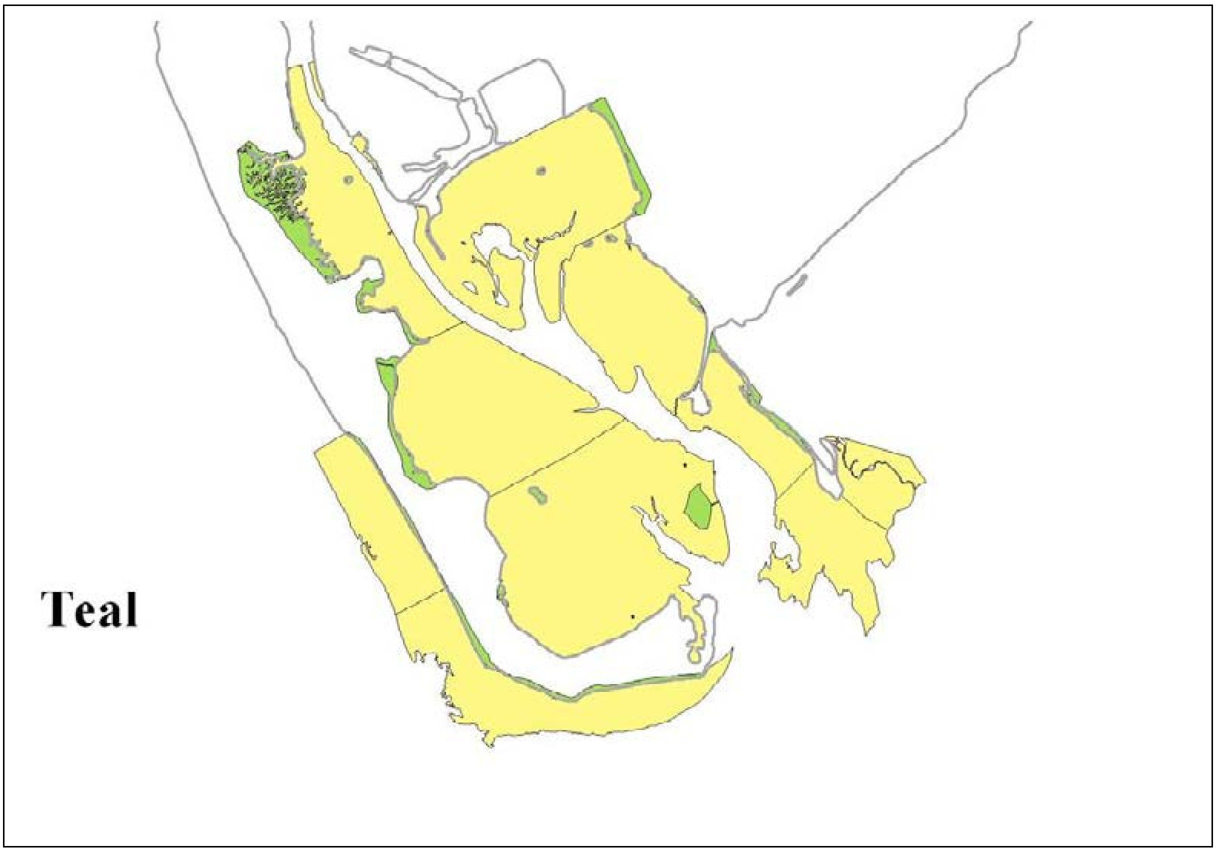
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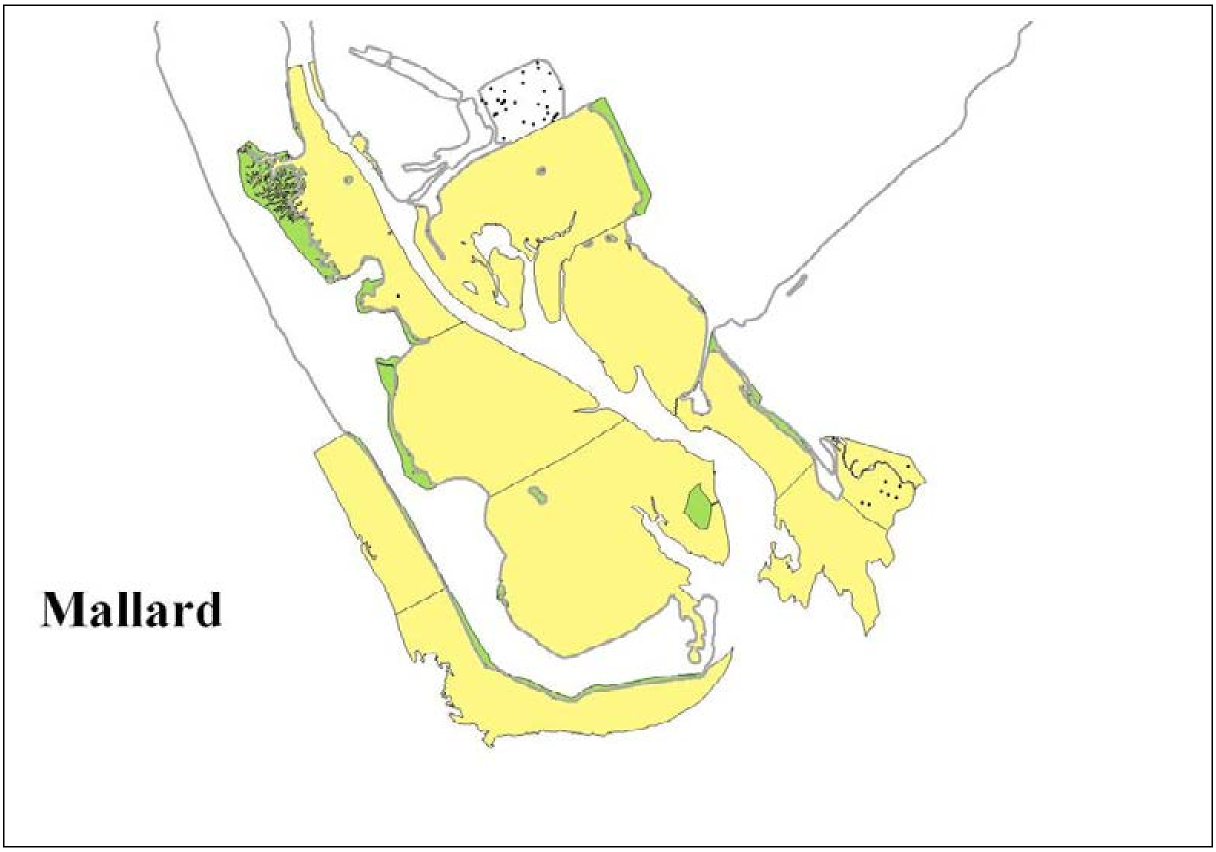
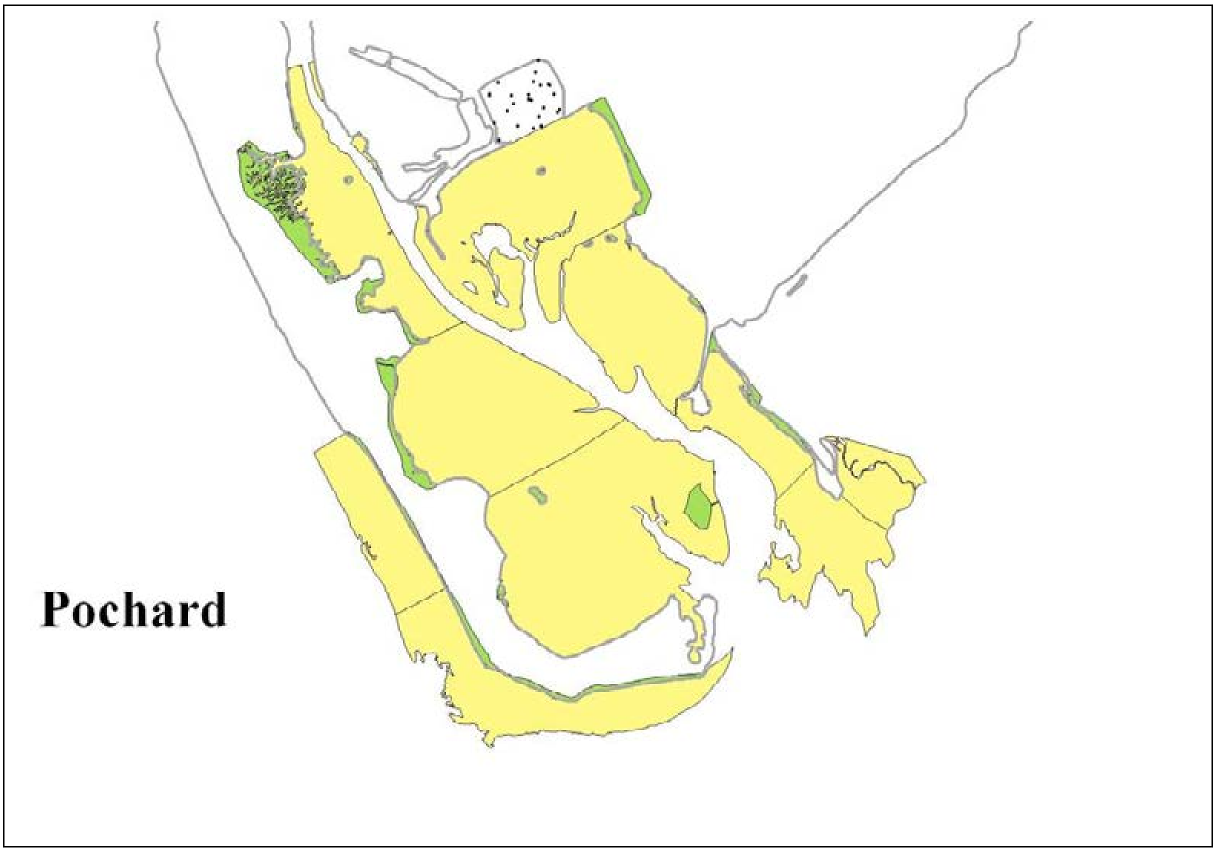

Mallard


Pintail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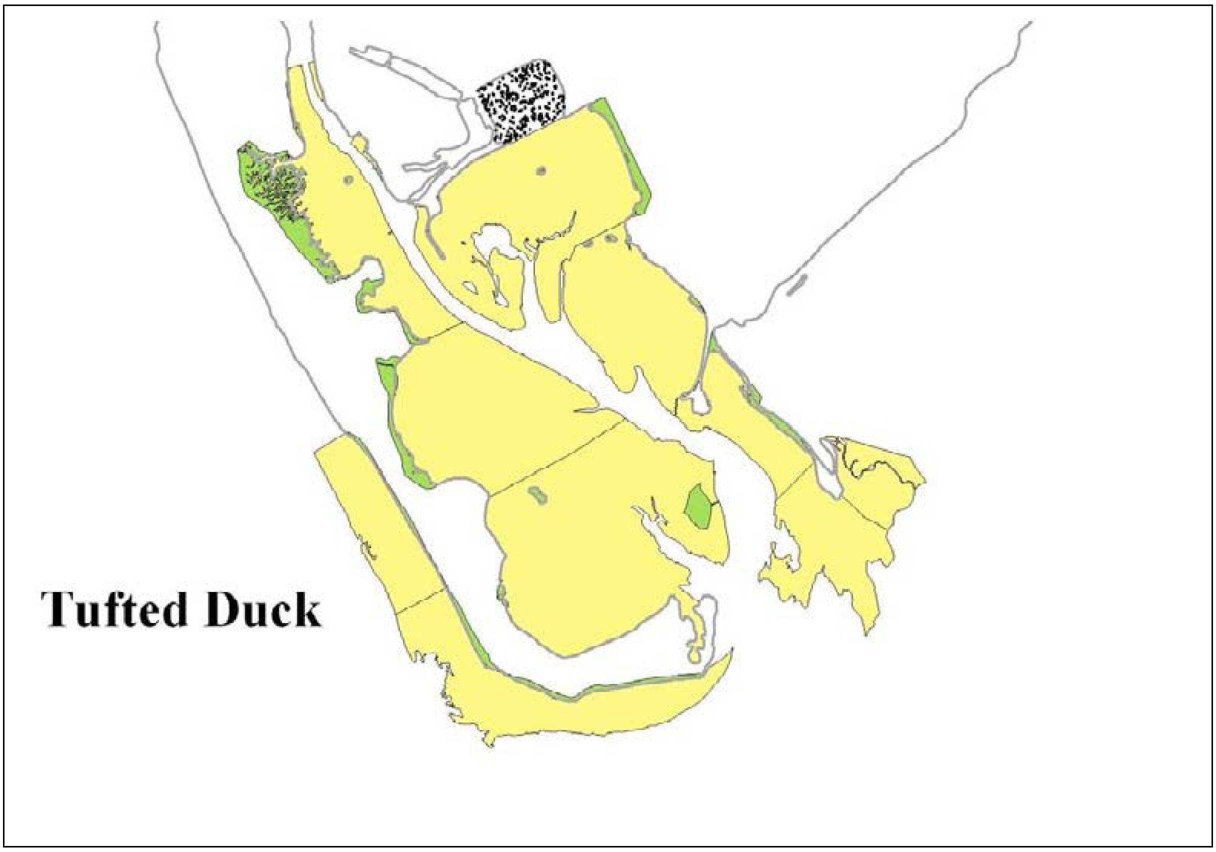
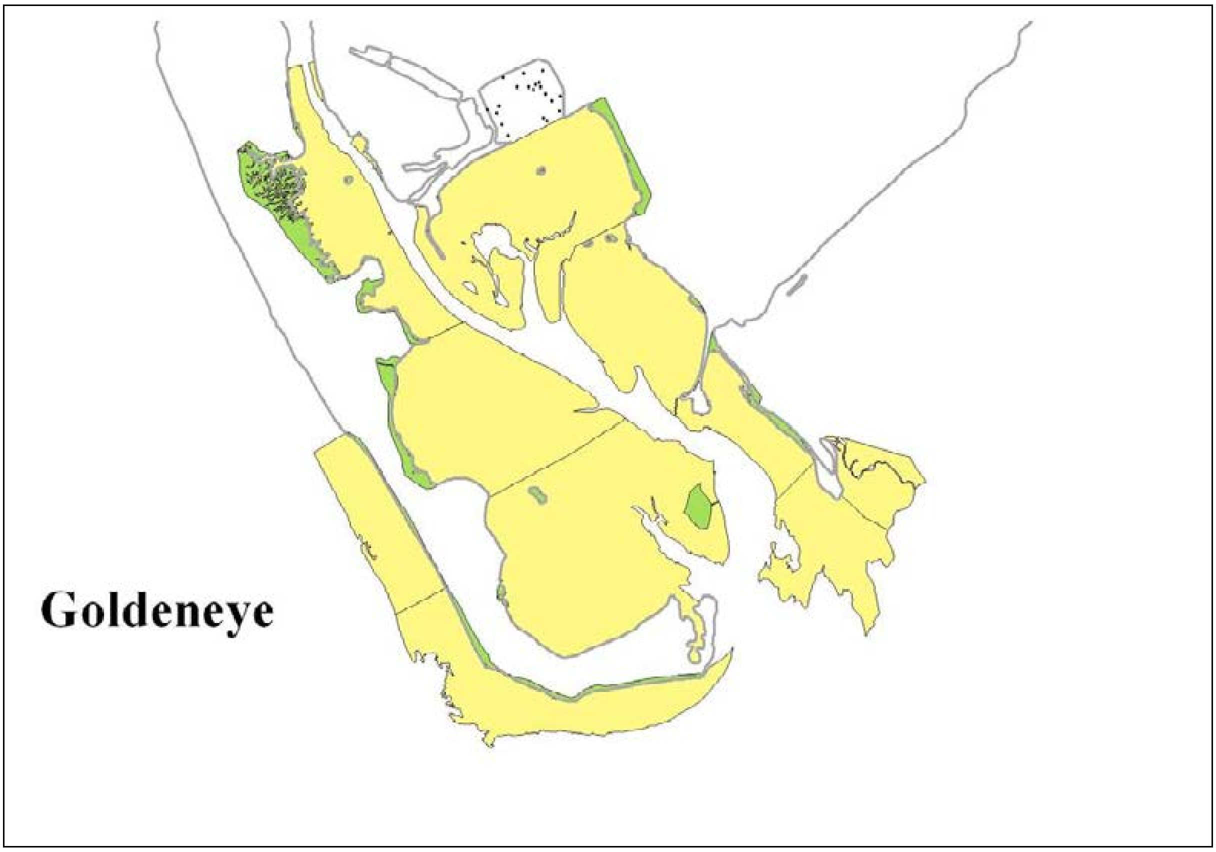

Tufted Duck


Eider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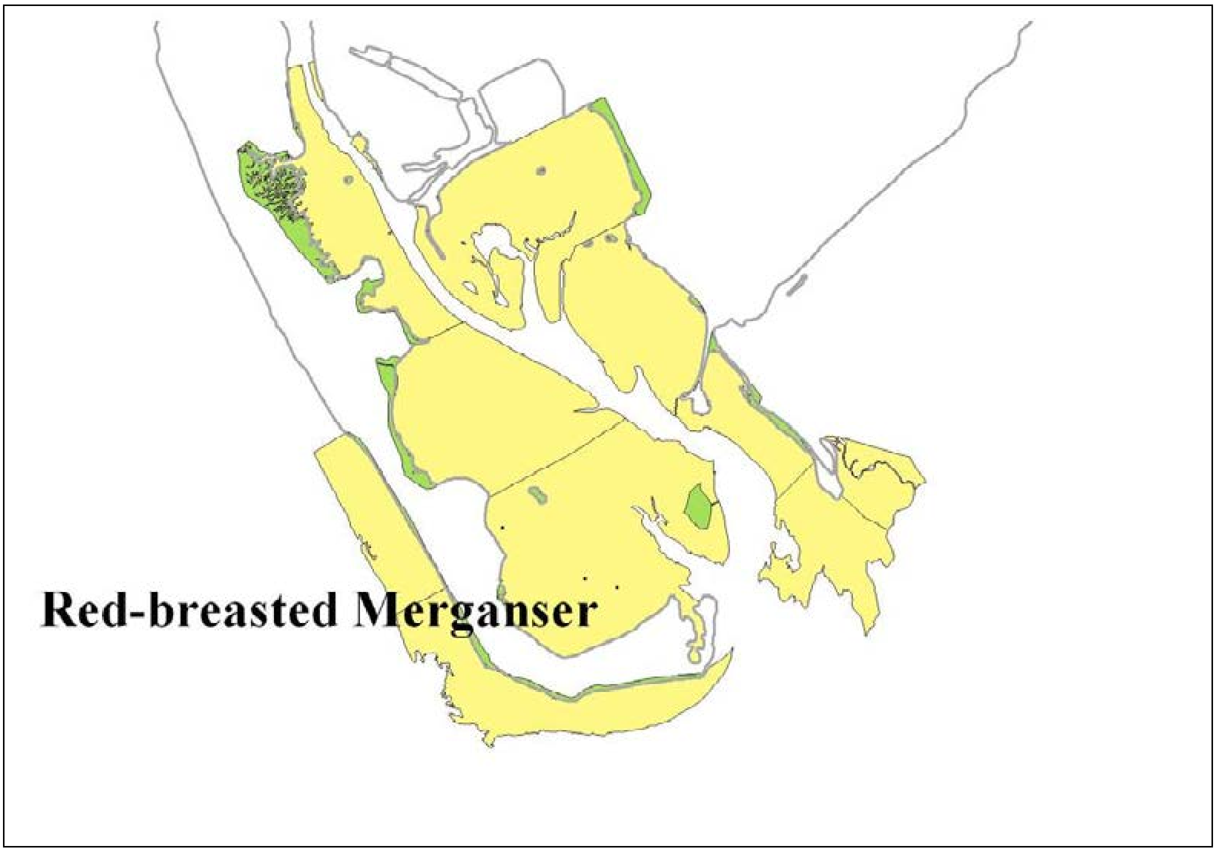
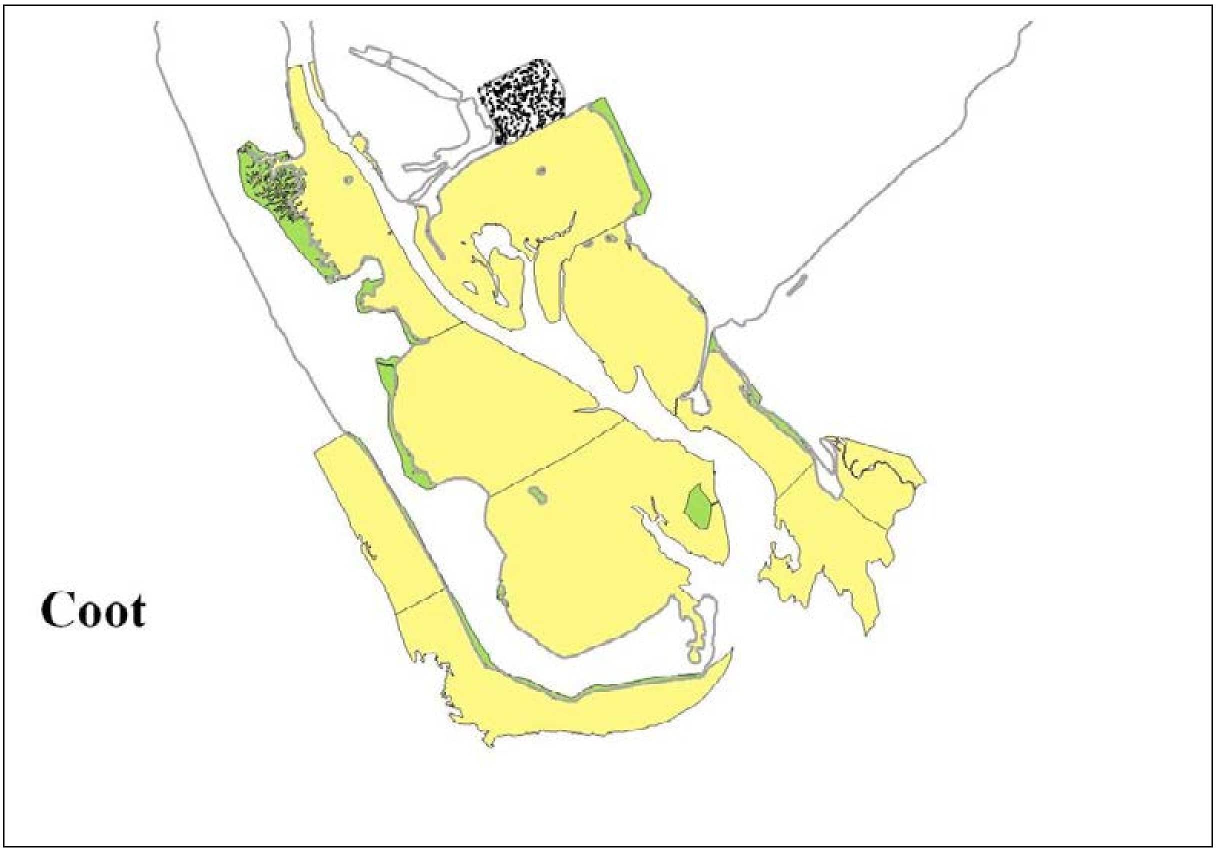
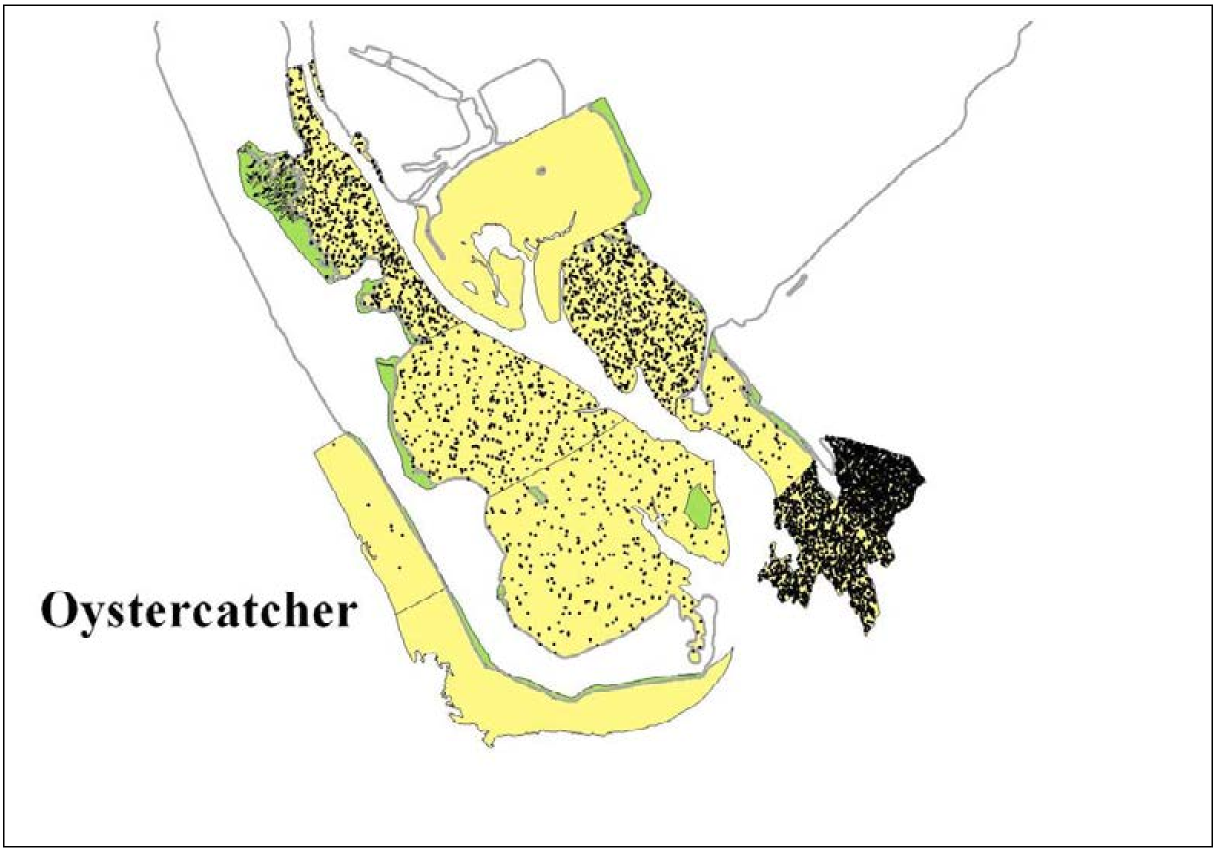

Red-breasted Merganser


Coot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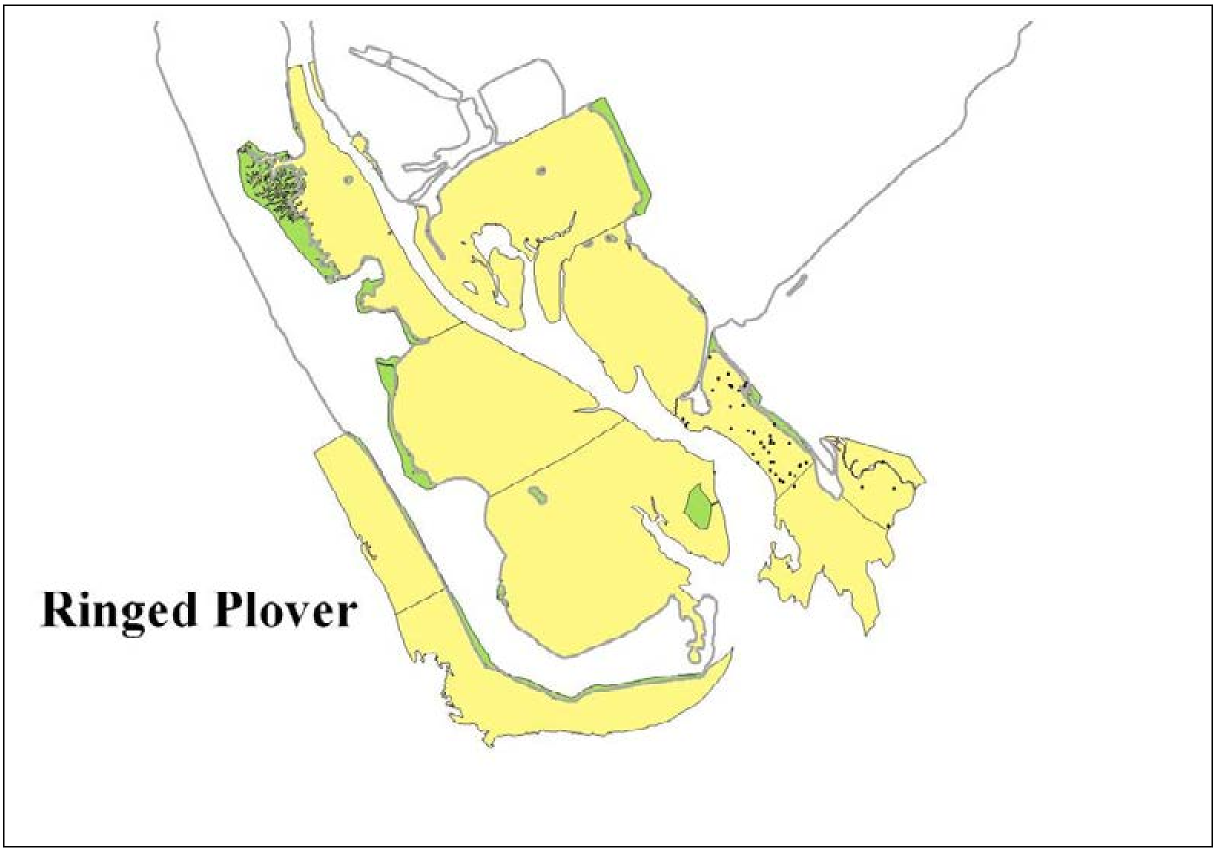
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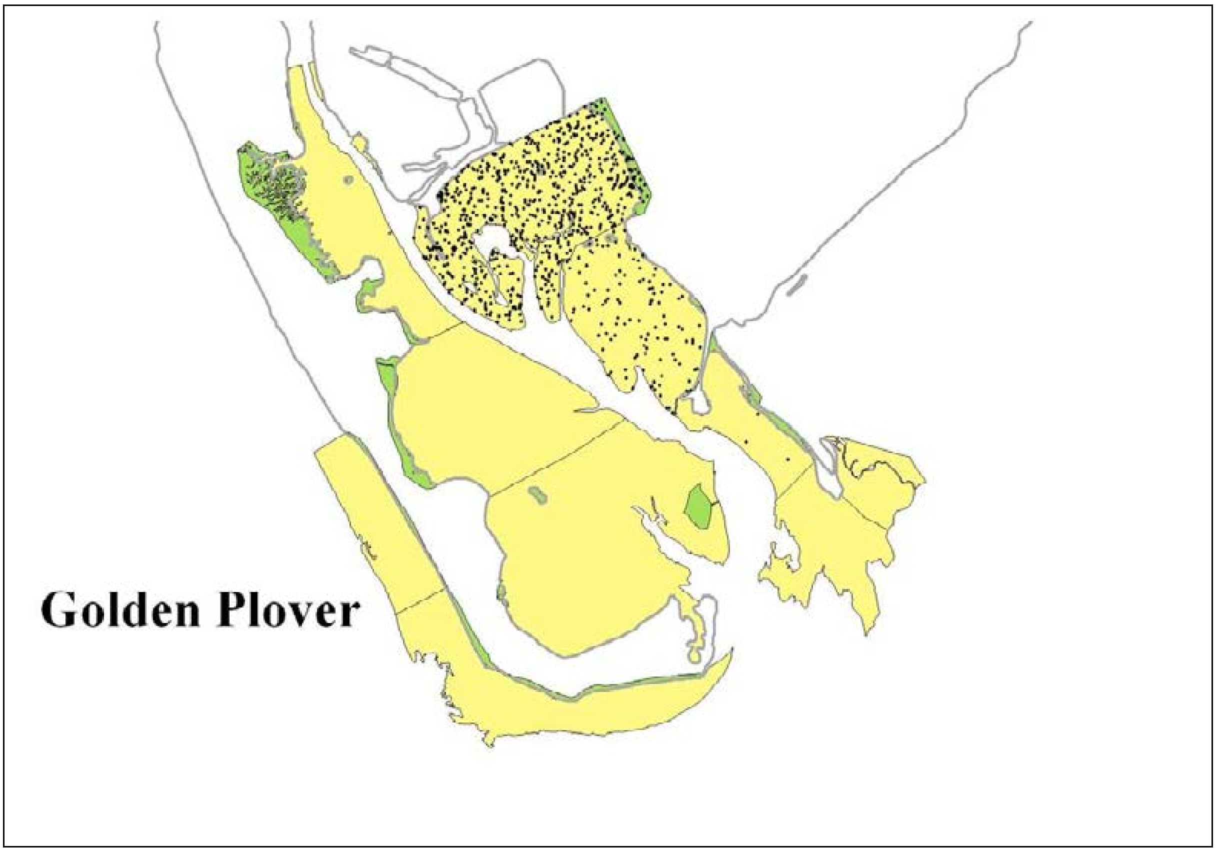
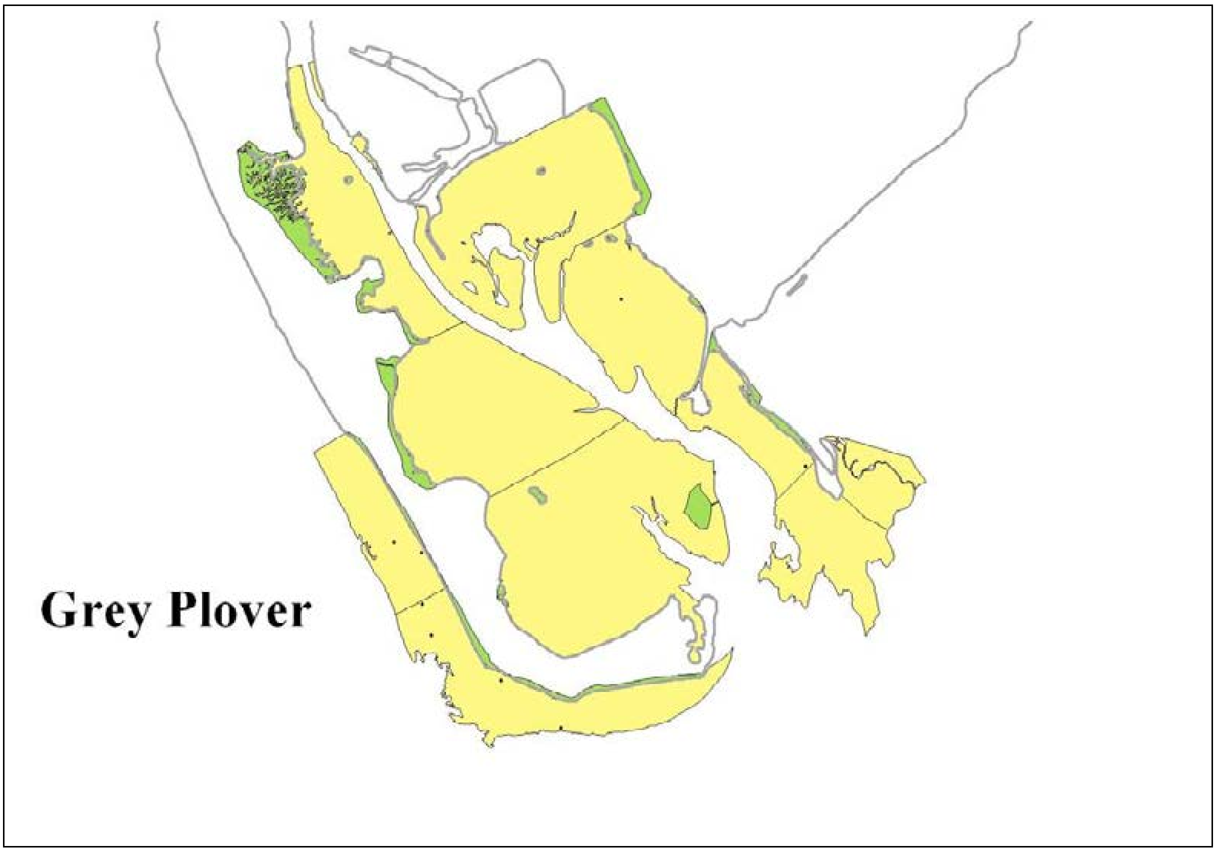
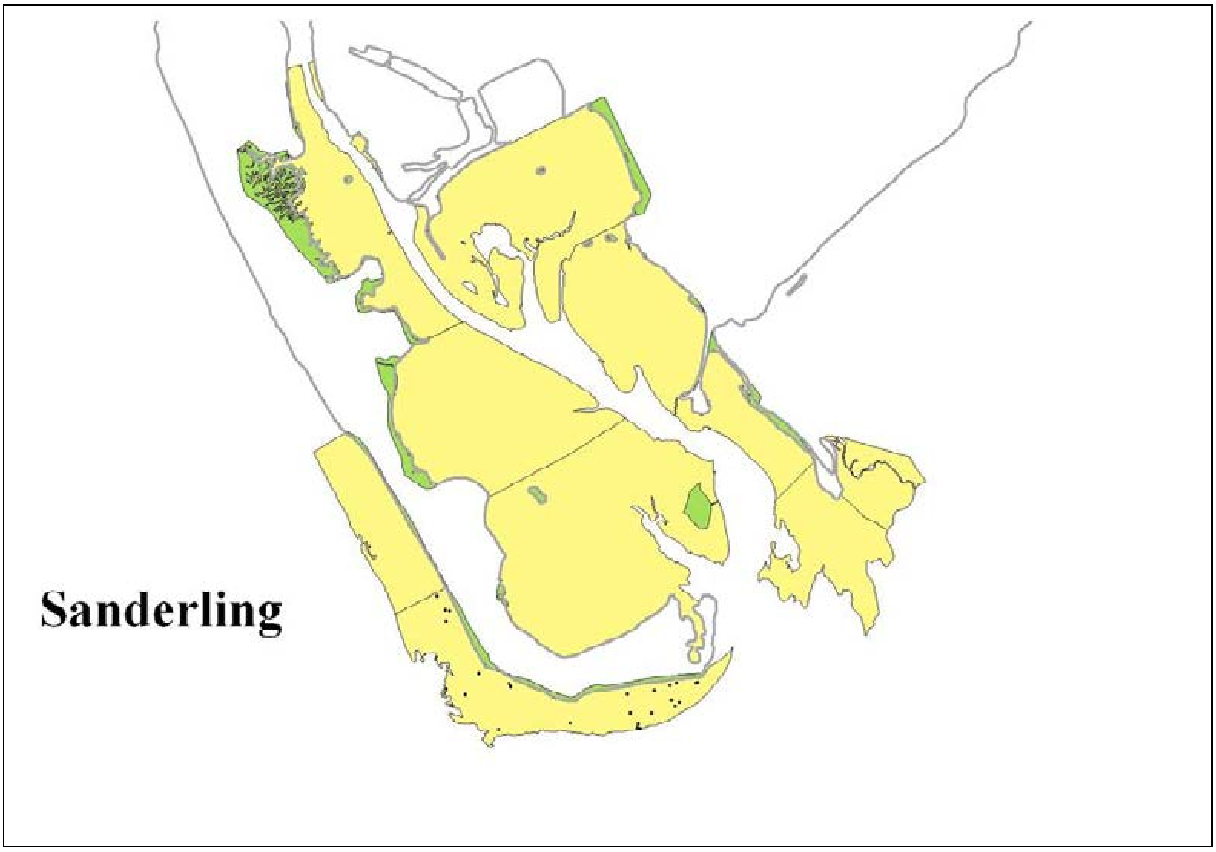

Golden Plover

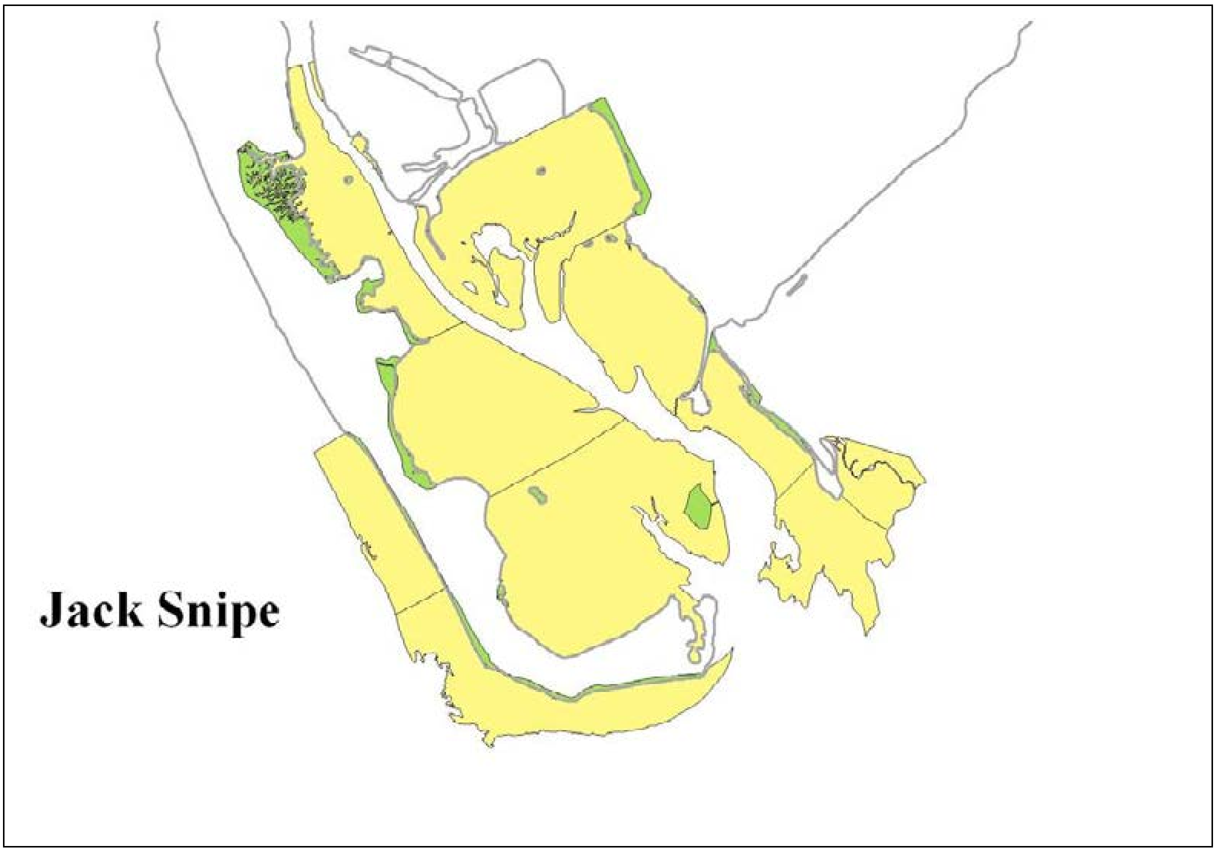

Grey Plover

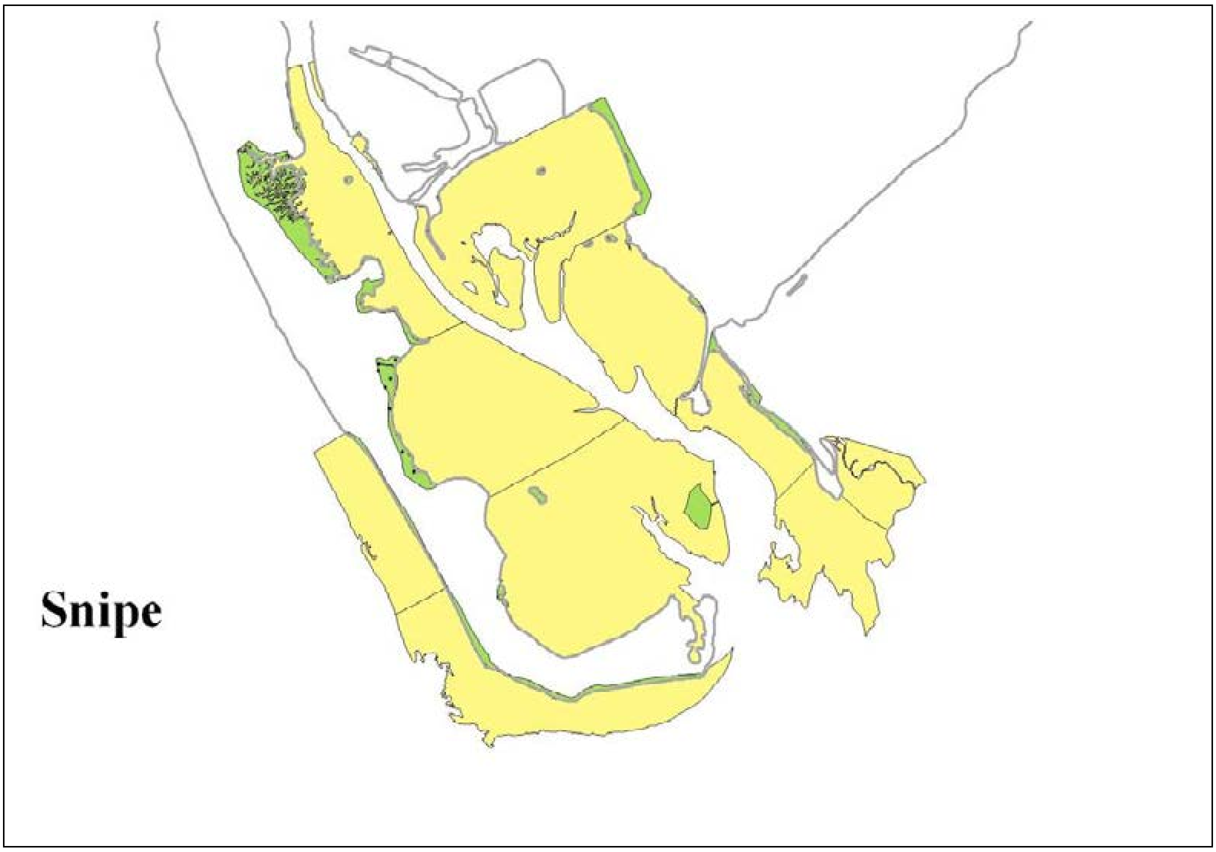

Lapwing


Knot

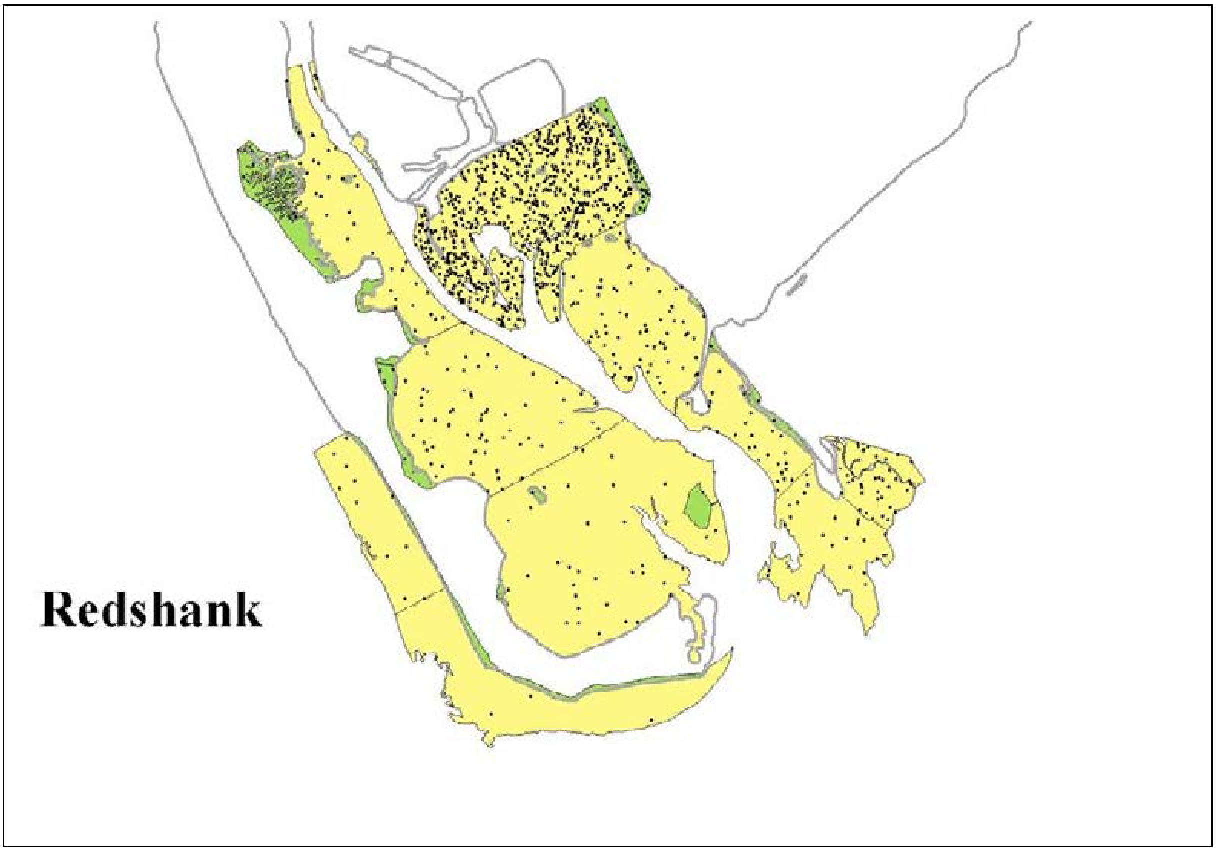

Sanderling


Dunlin


Jack Snipe


Snipe


Curlew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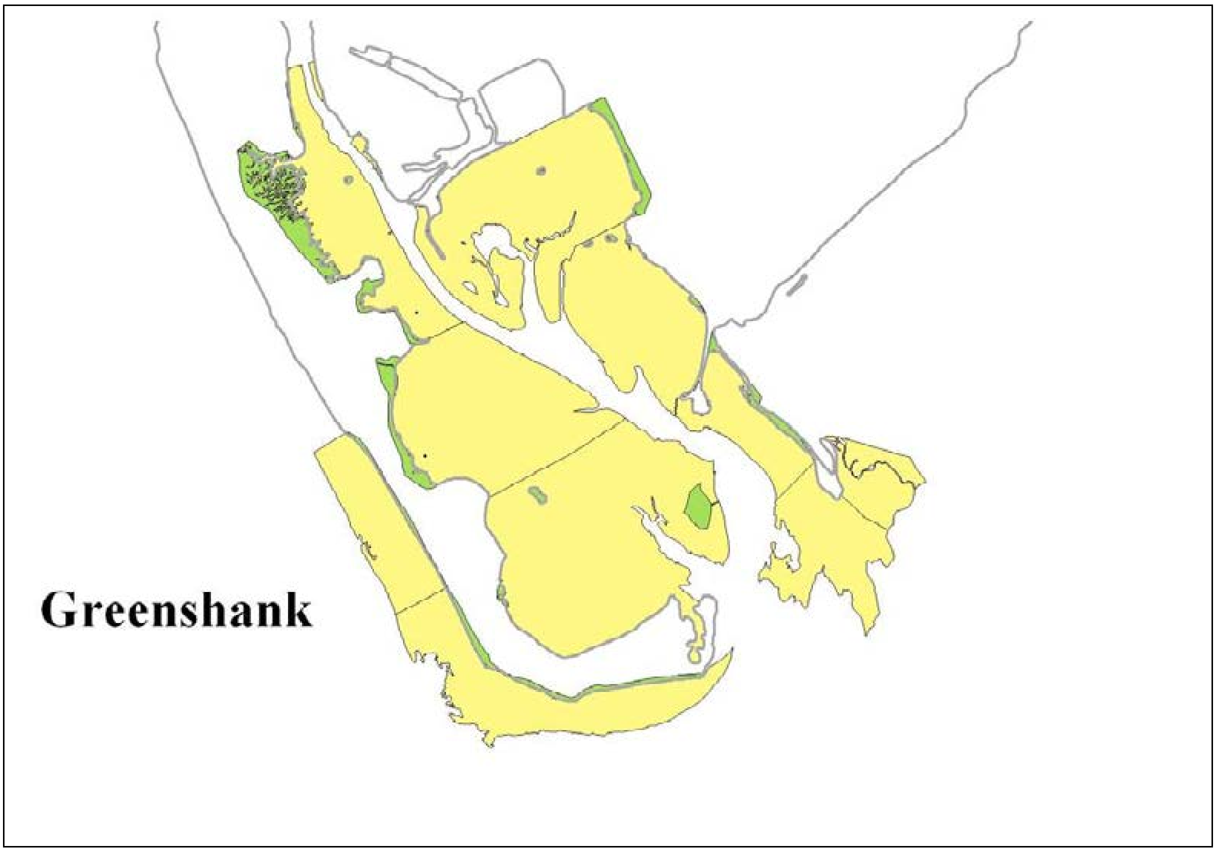
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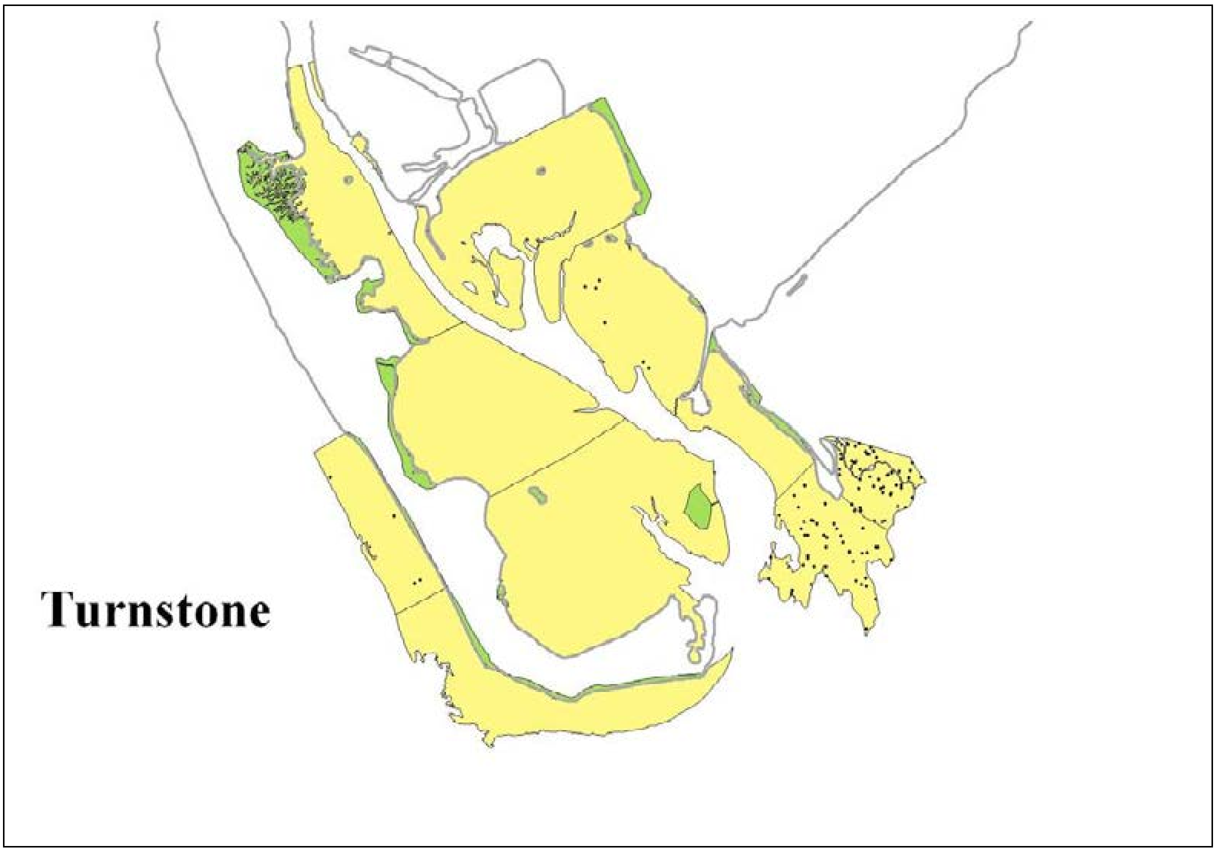
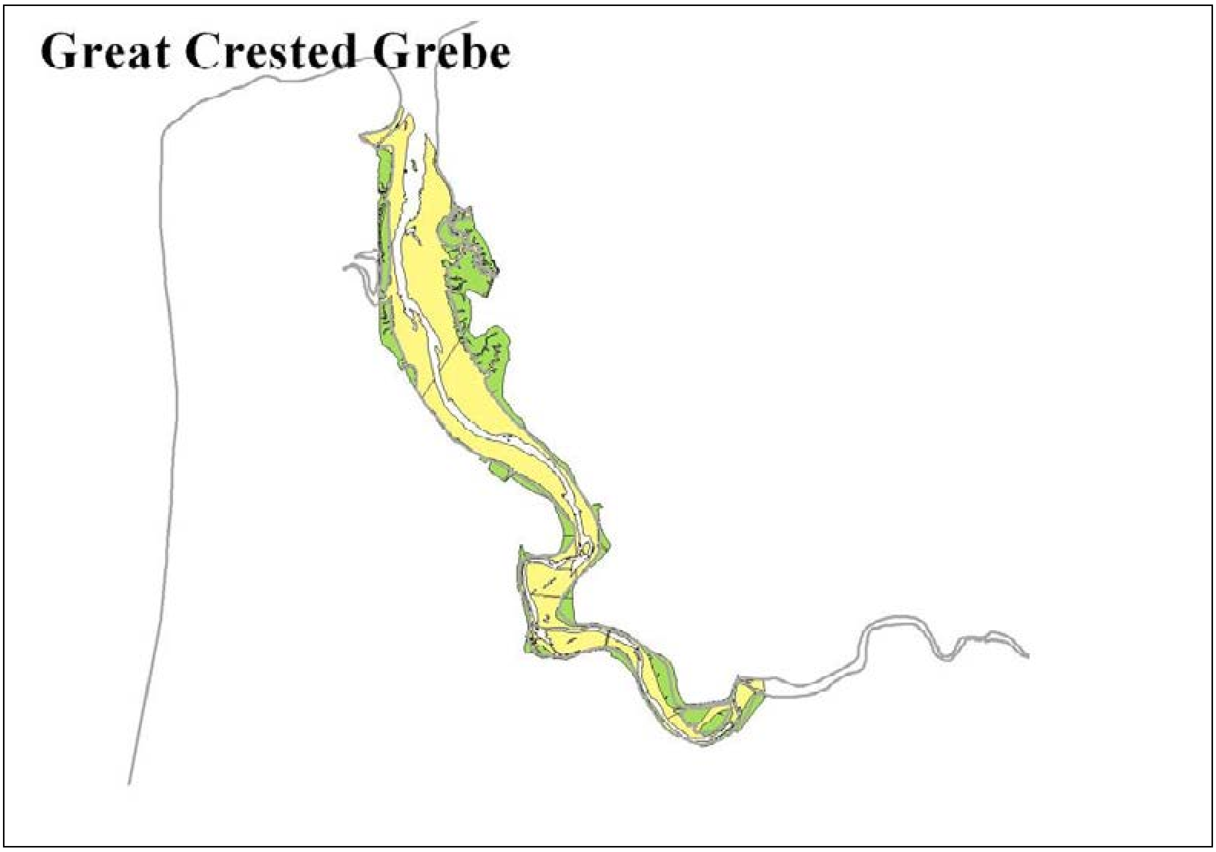
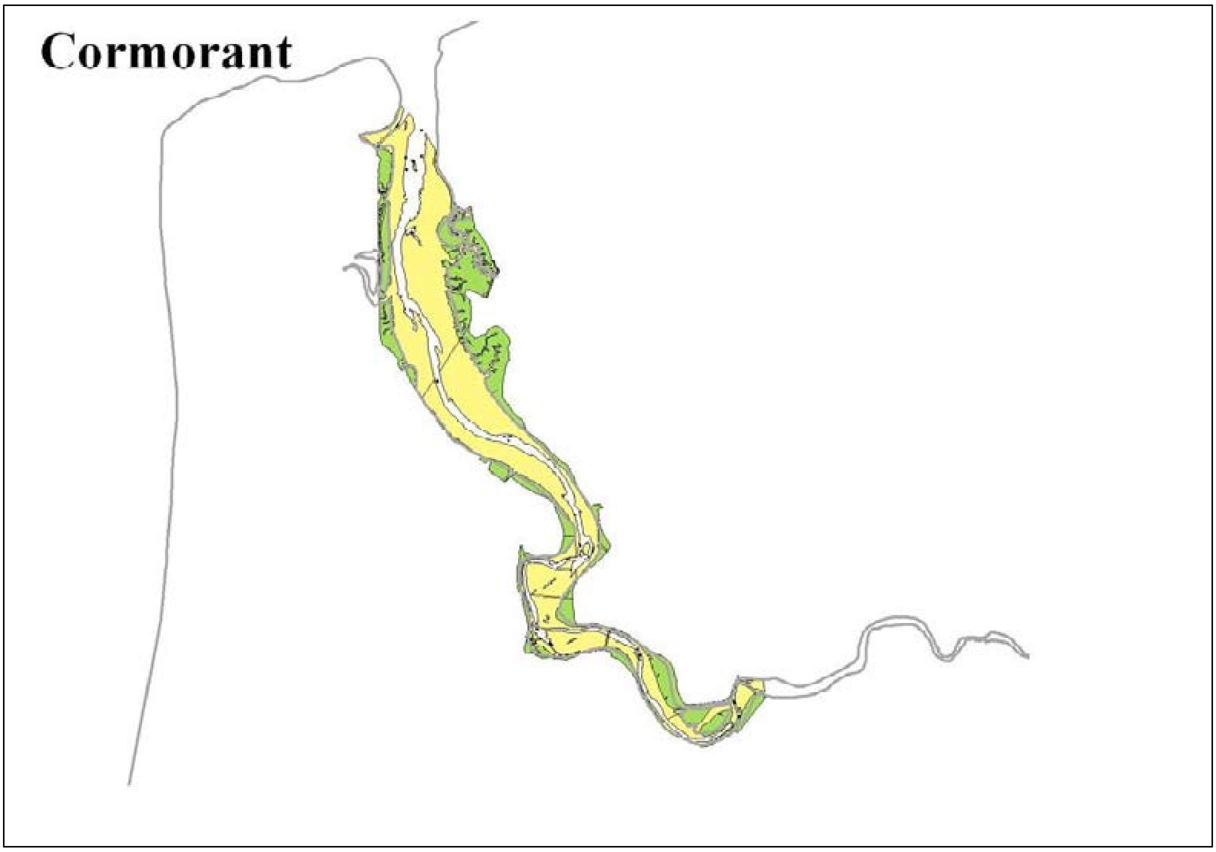
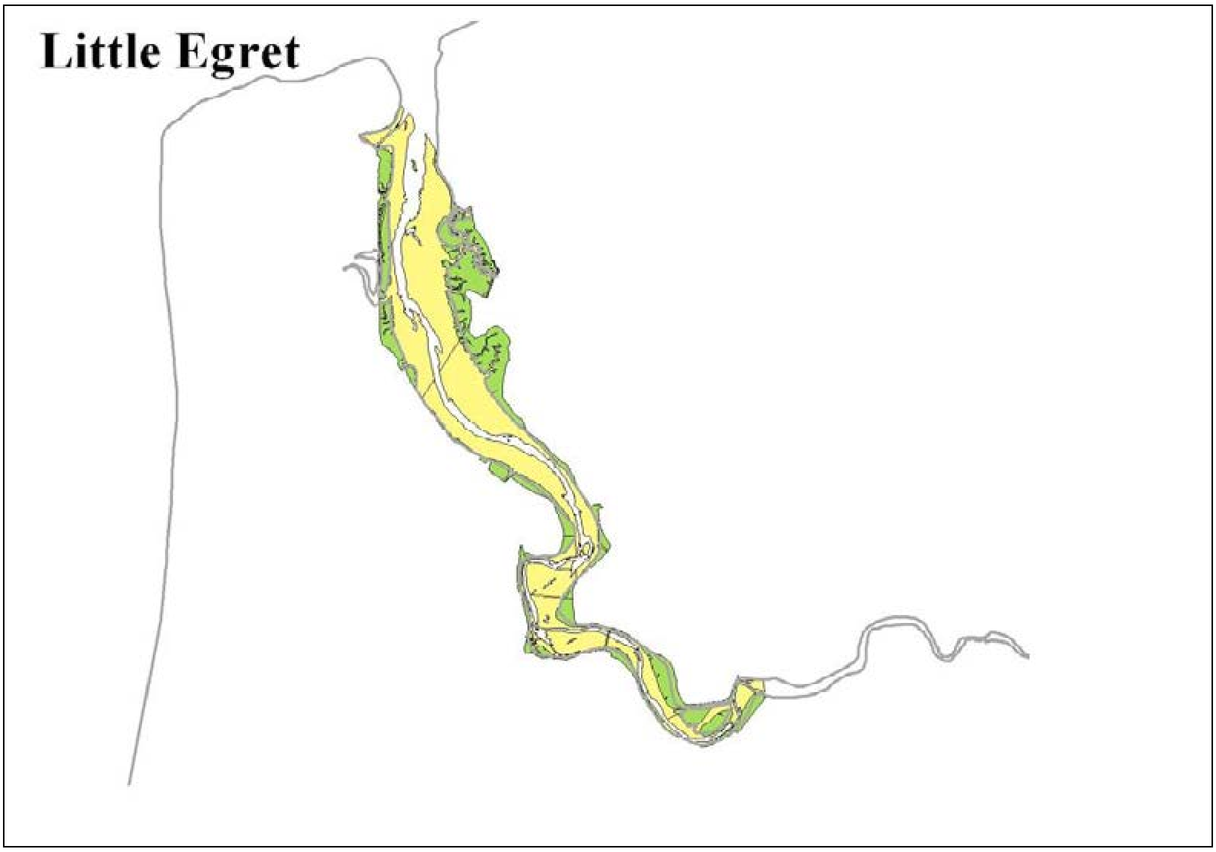

Turnstone

Wyre Estuary



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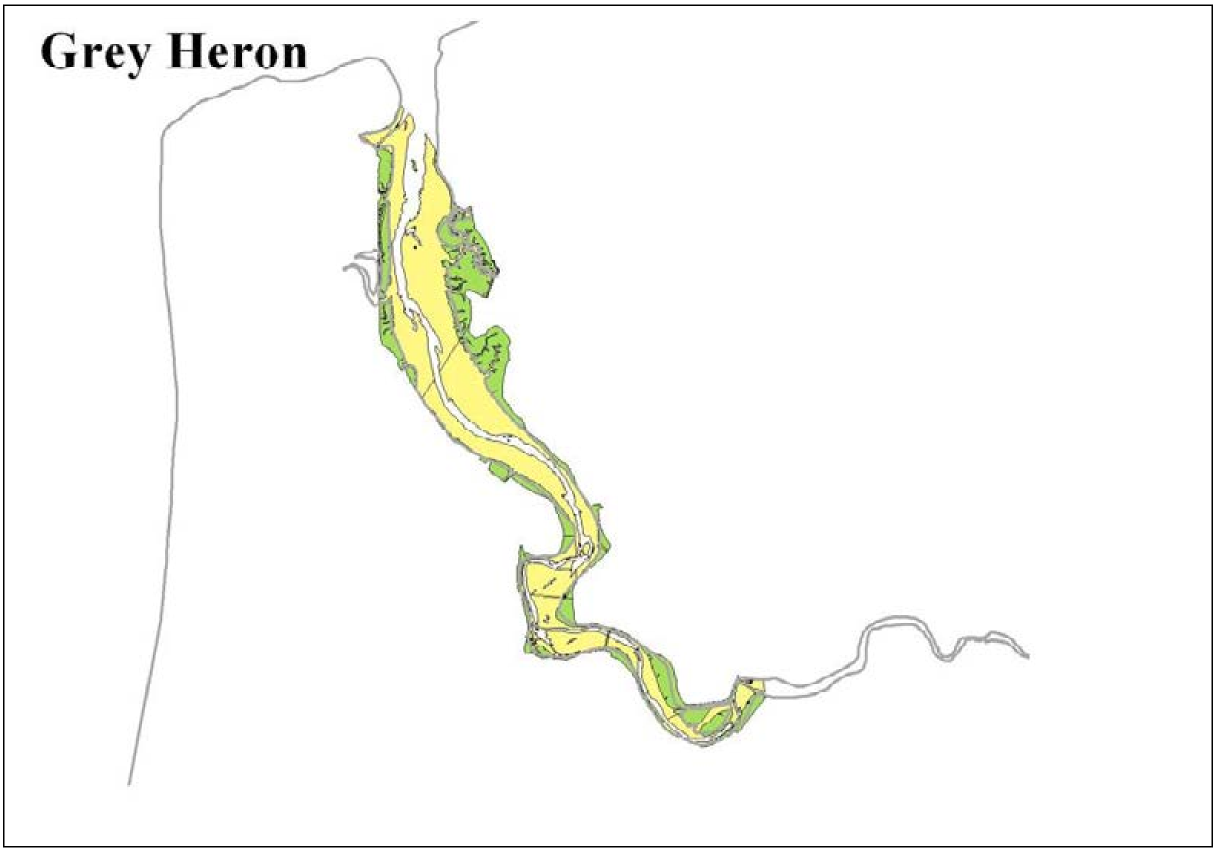
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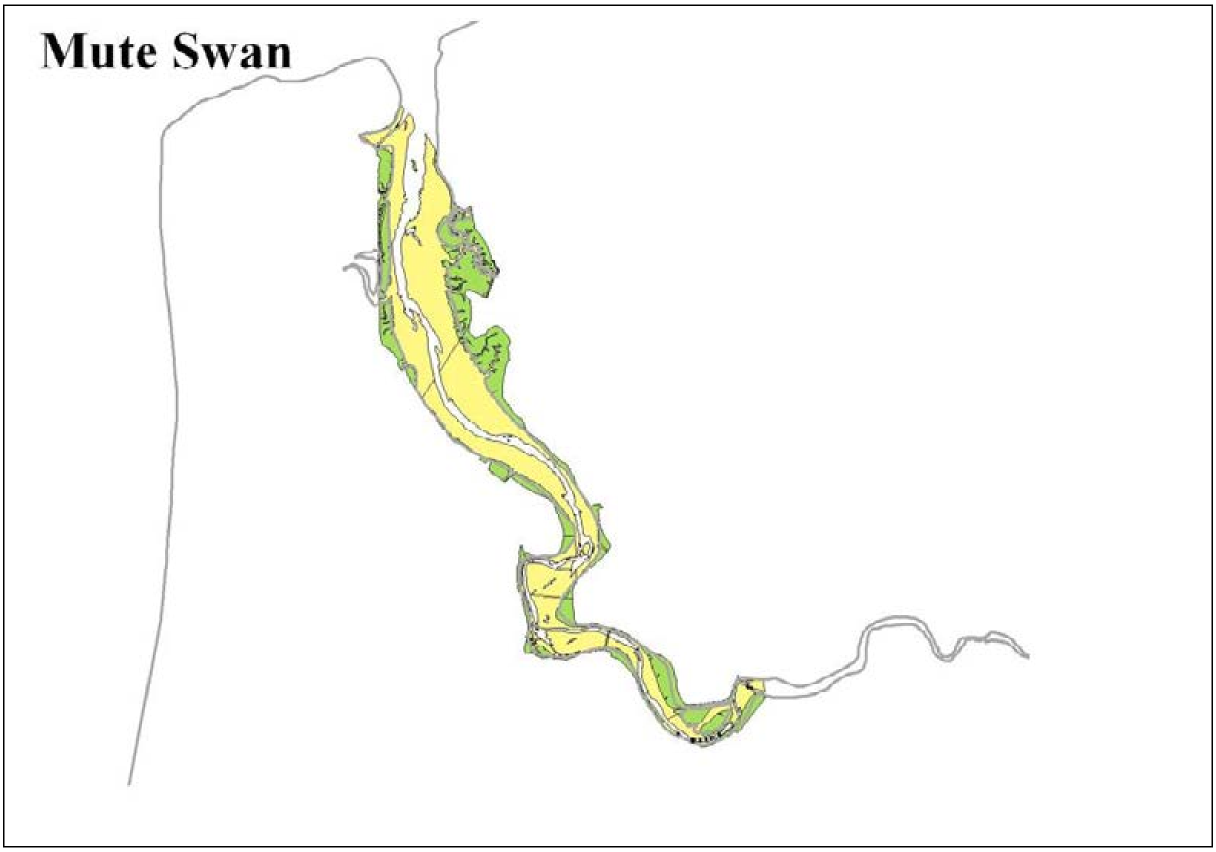
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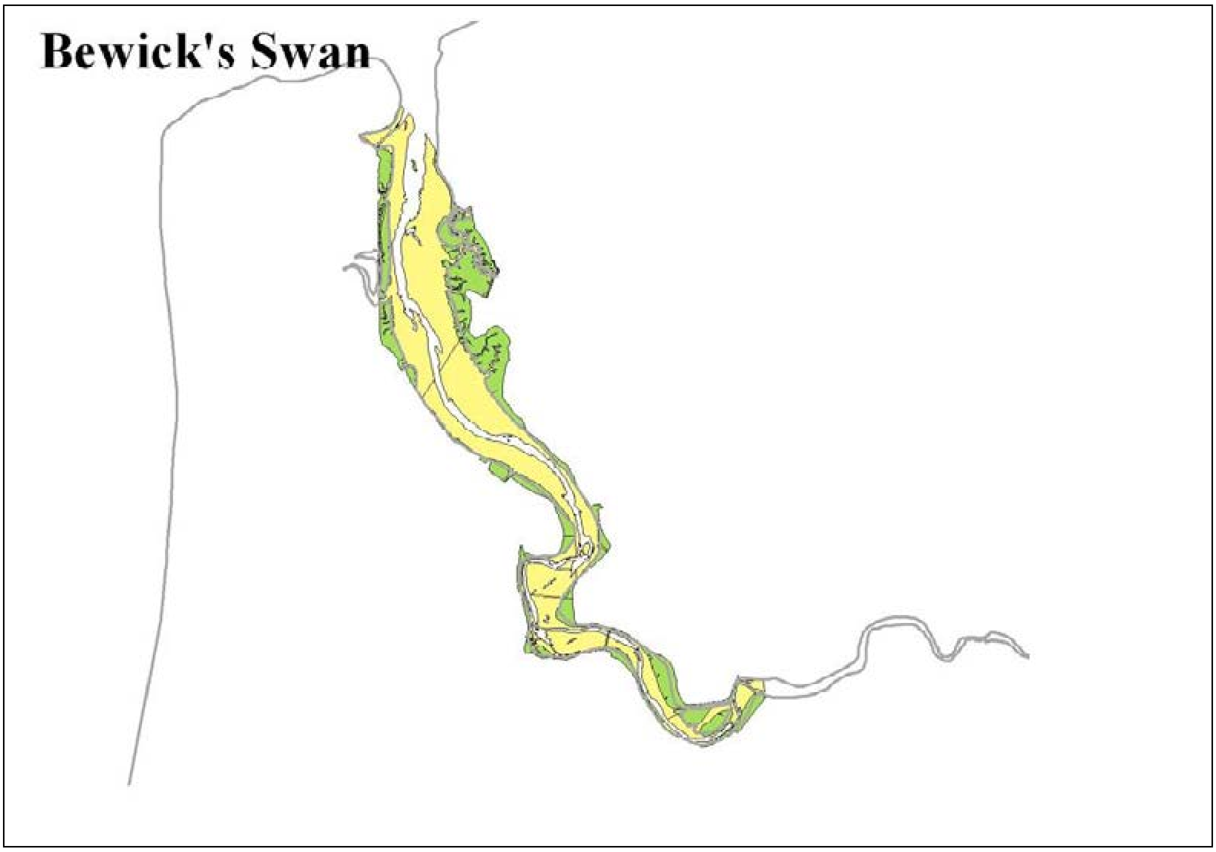
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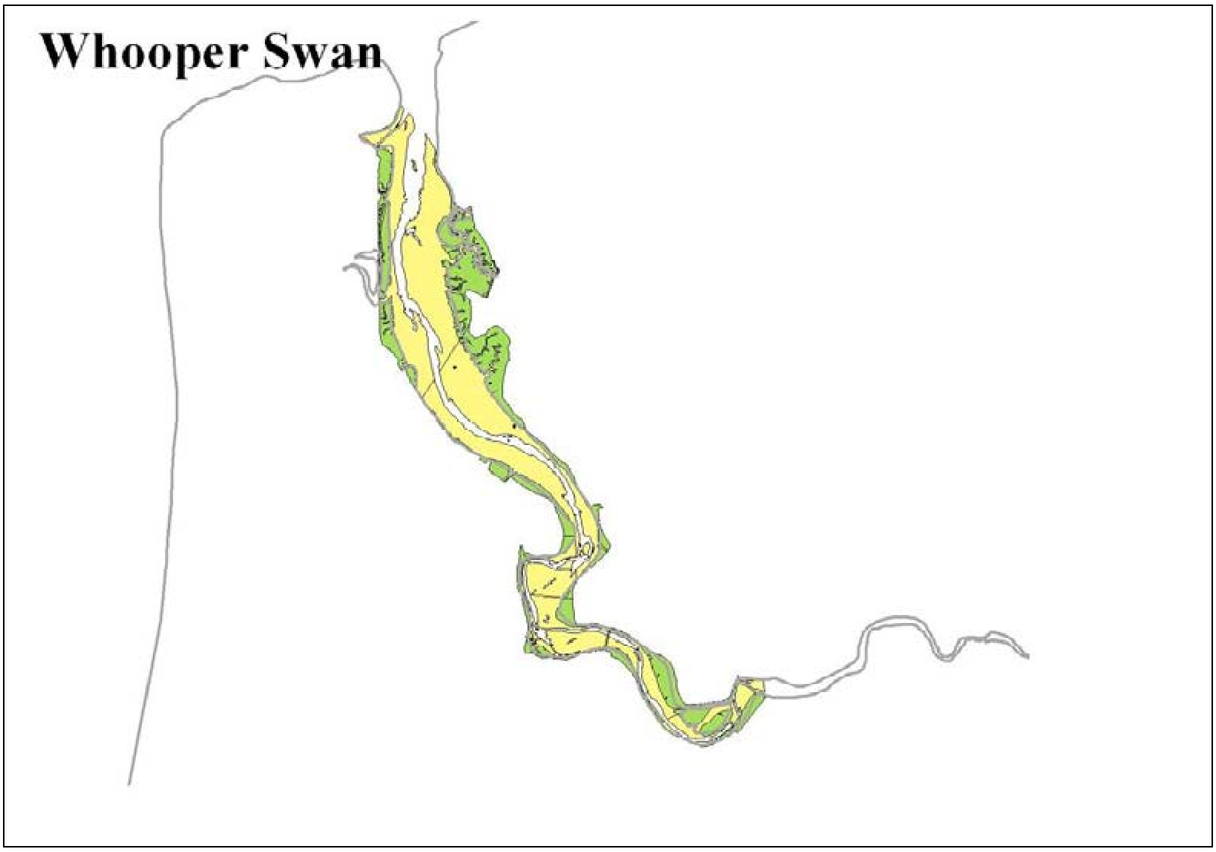
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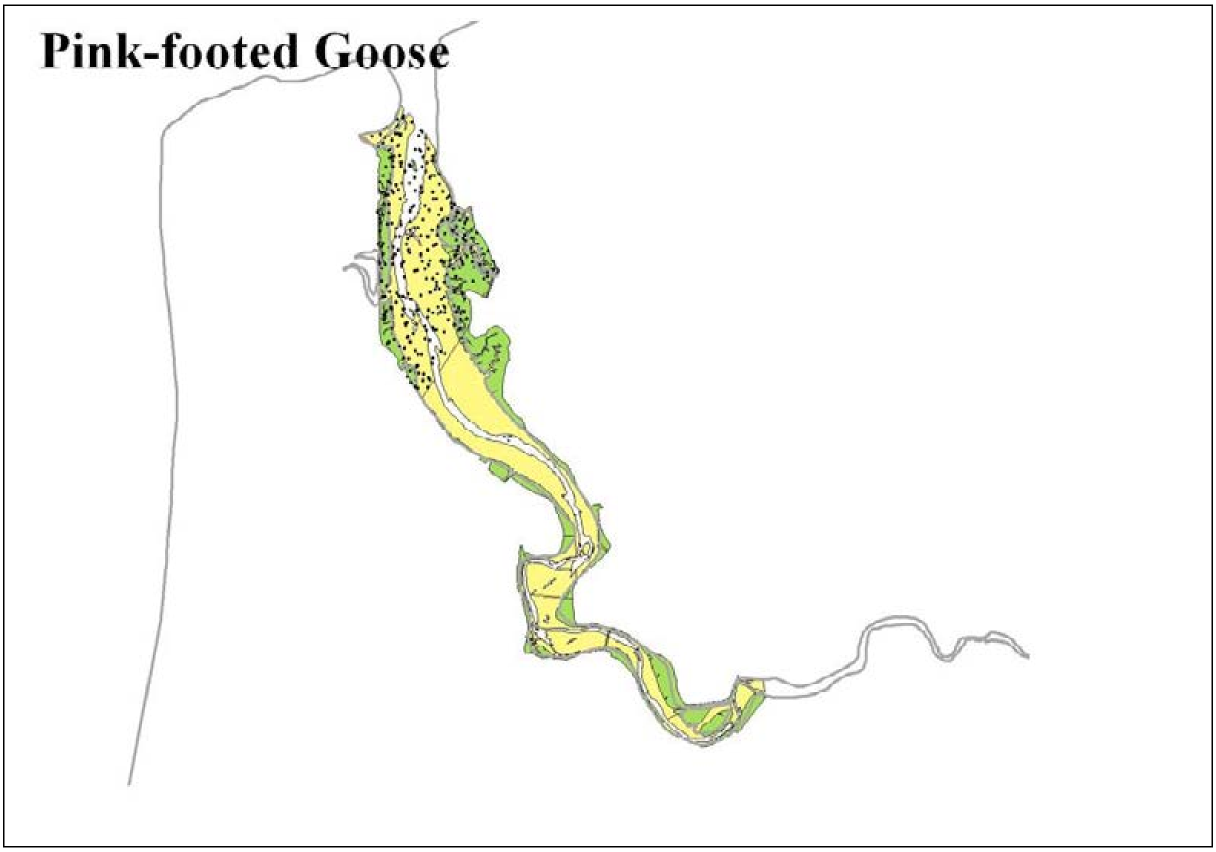
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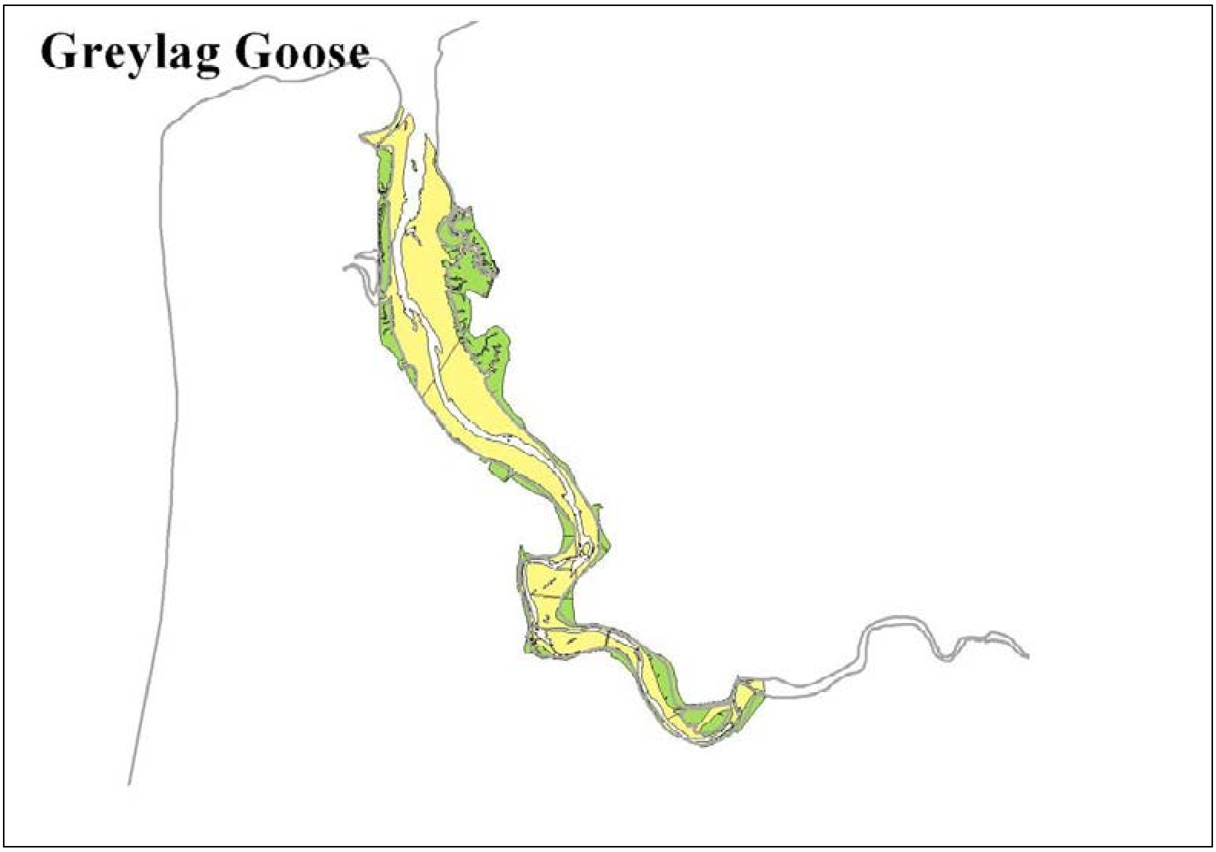
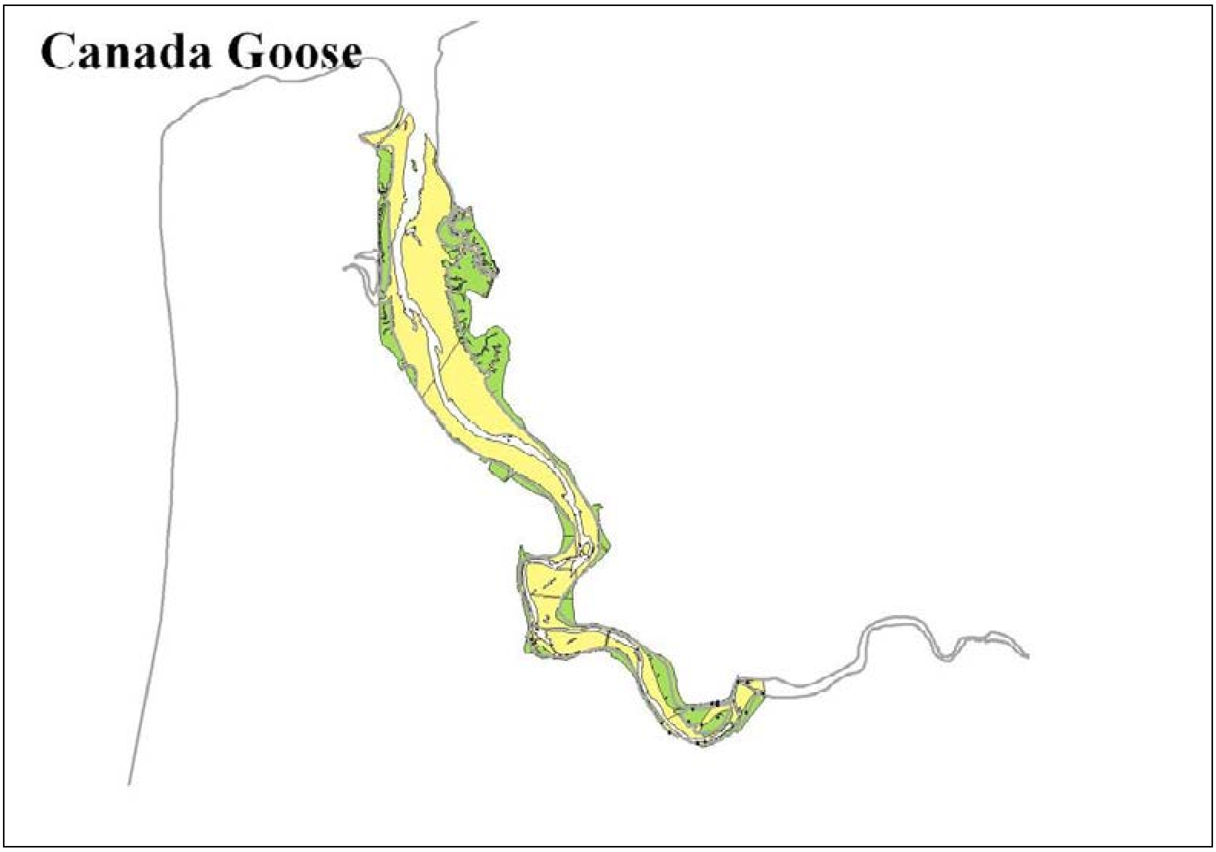

Greylag Goose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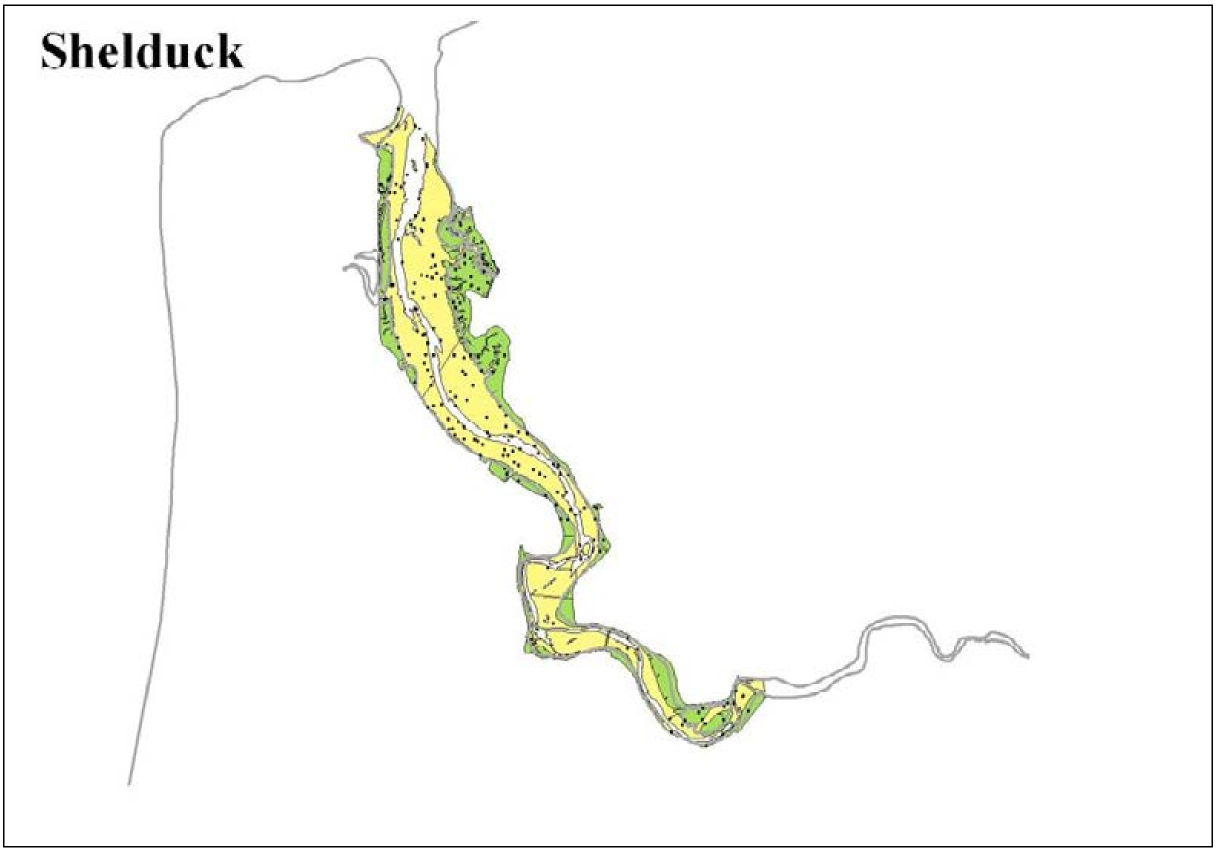
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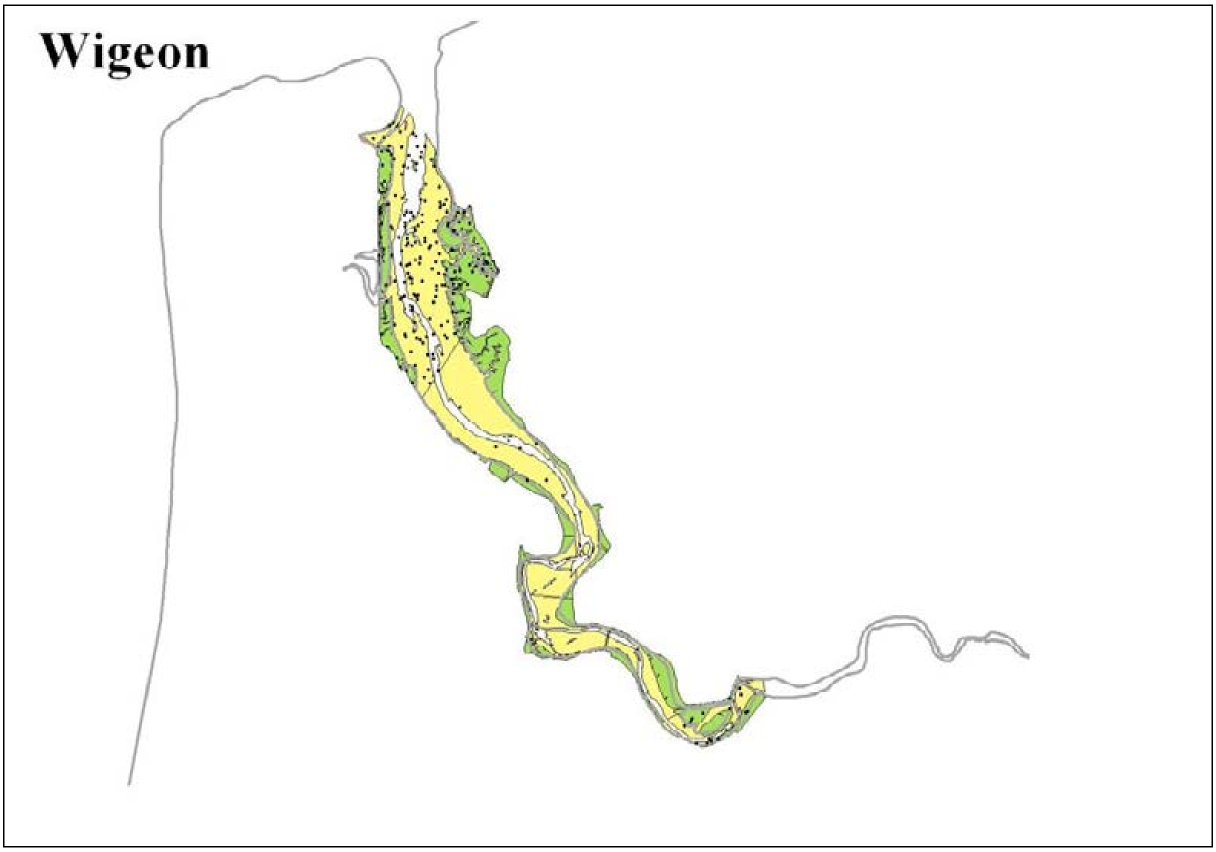
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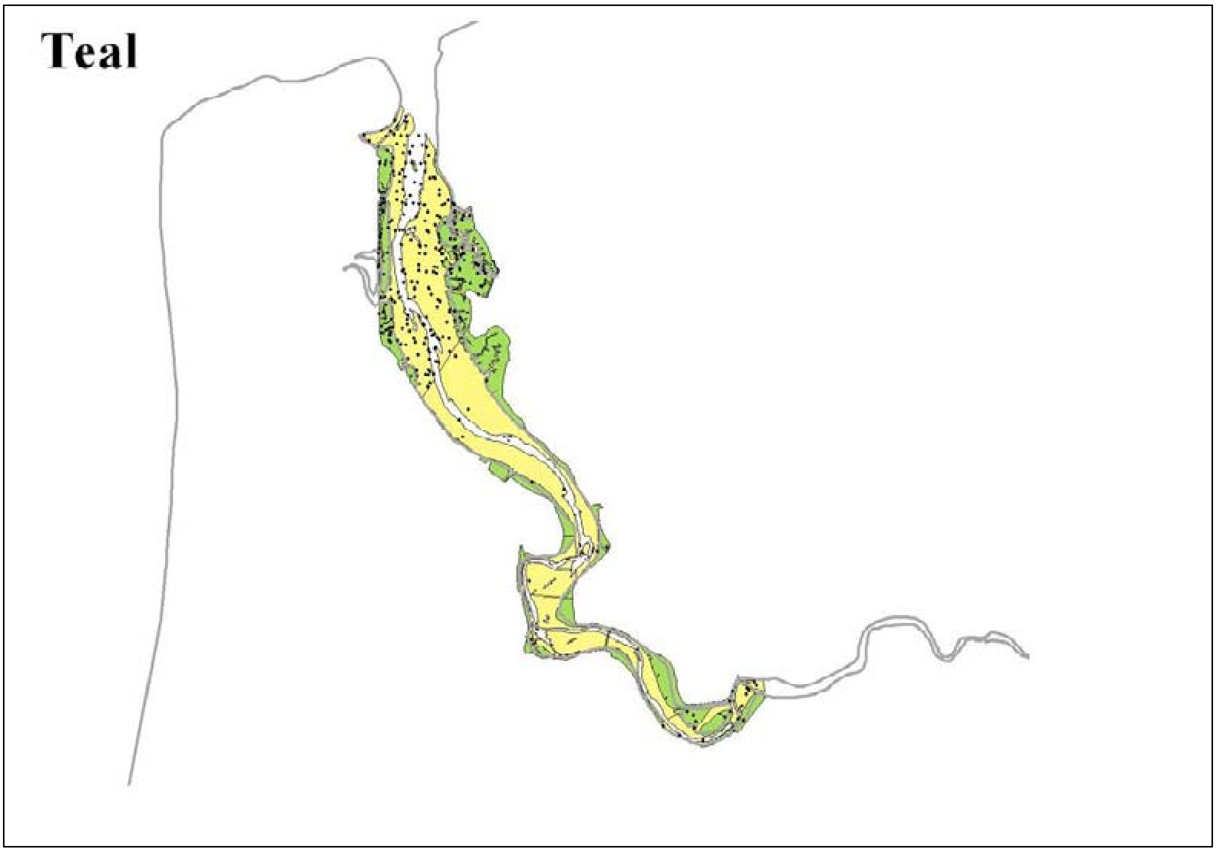
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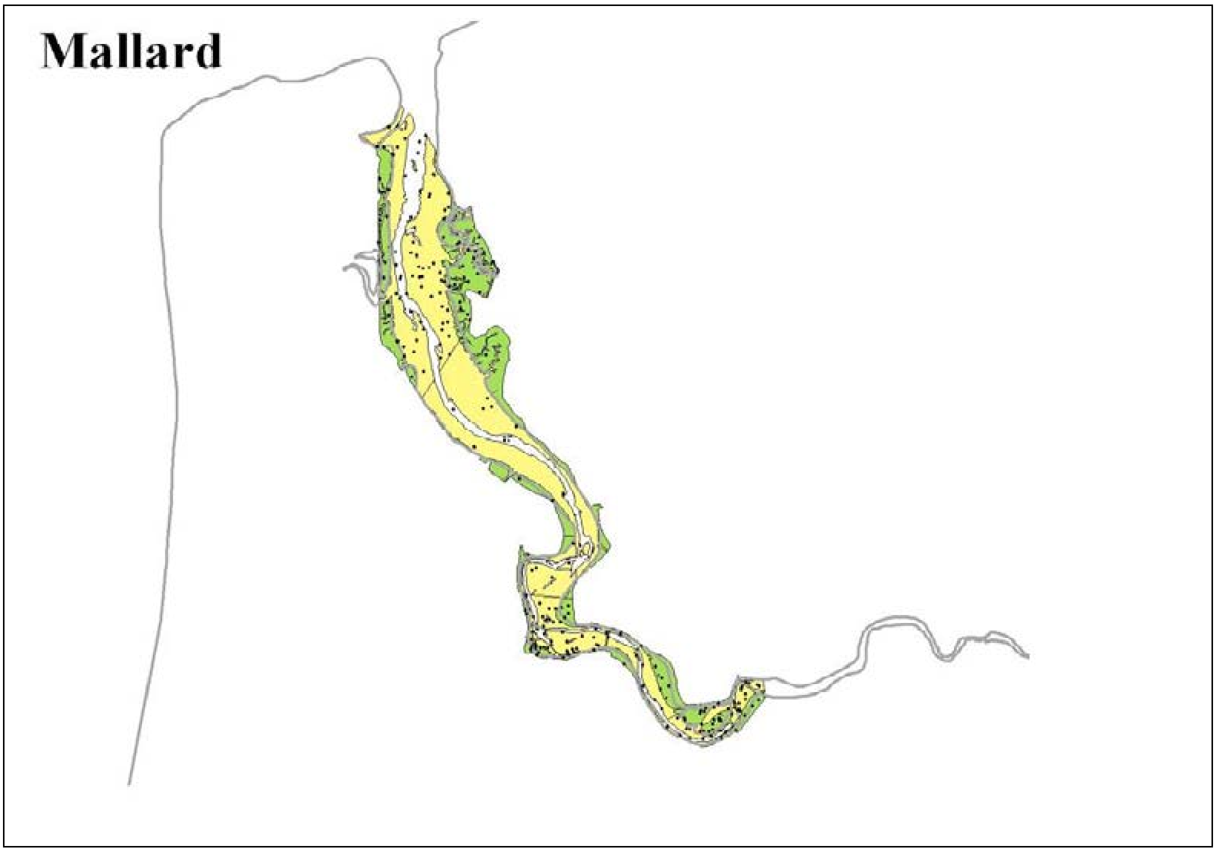
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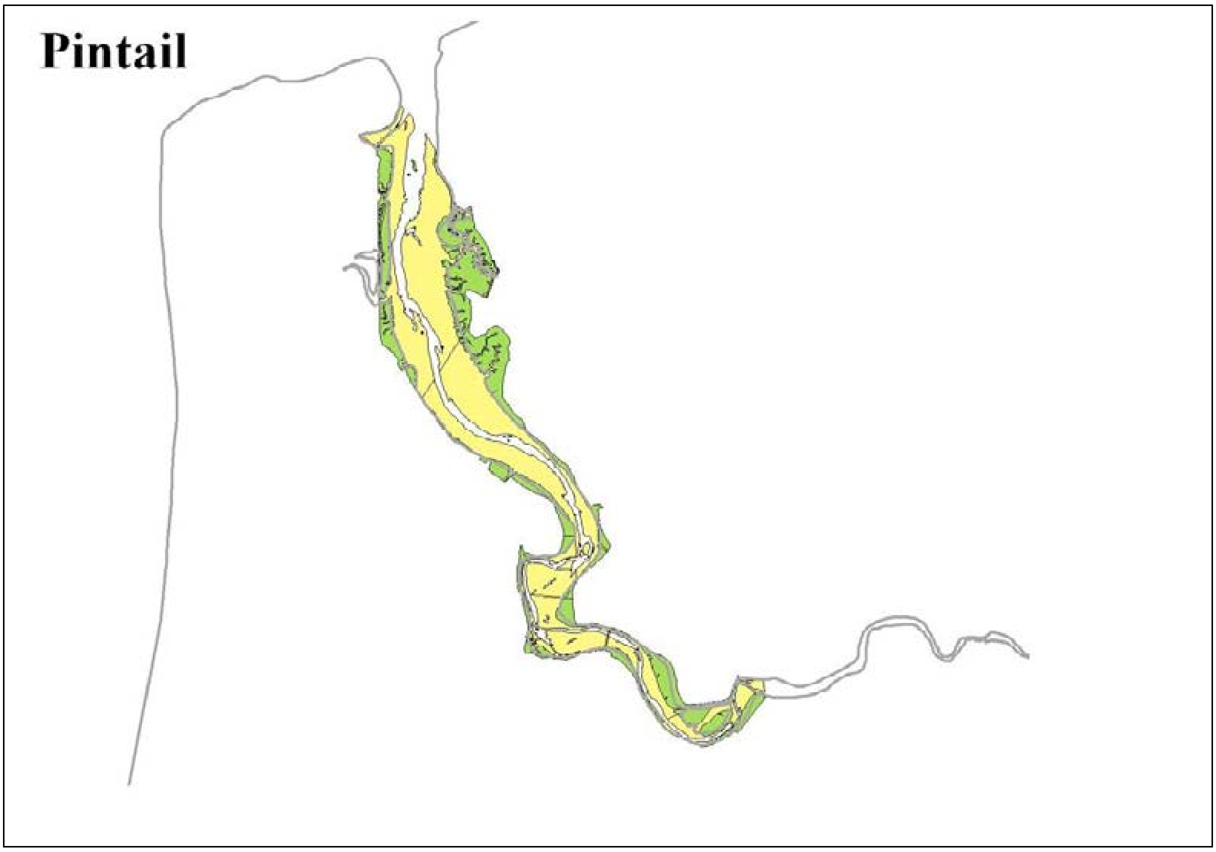
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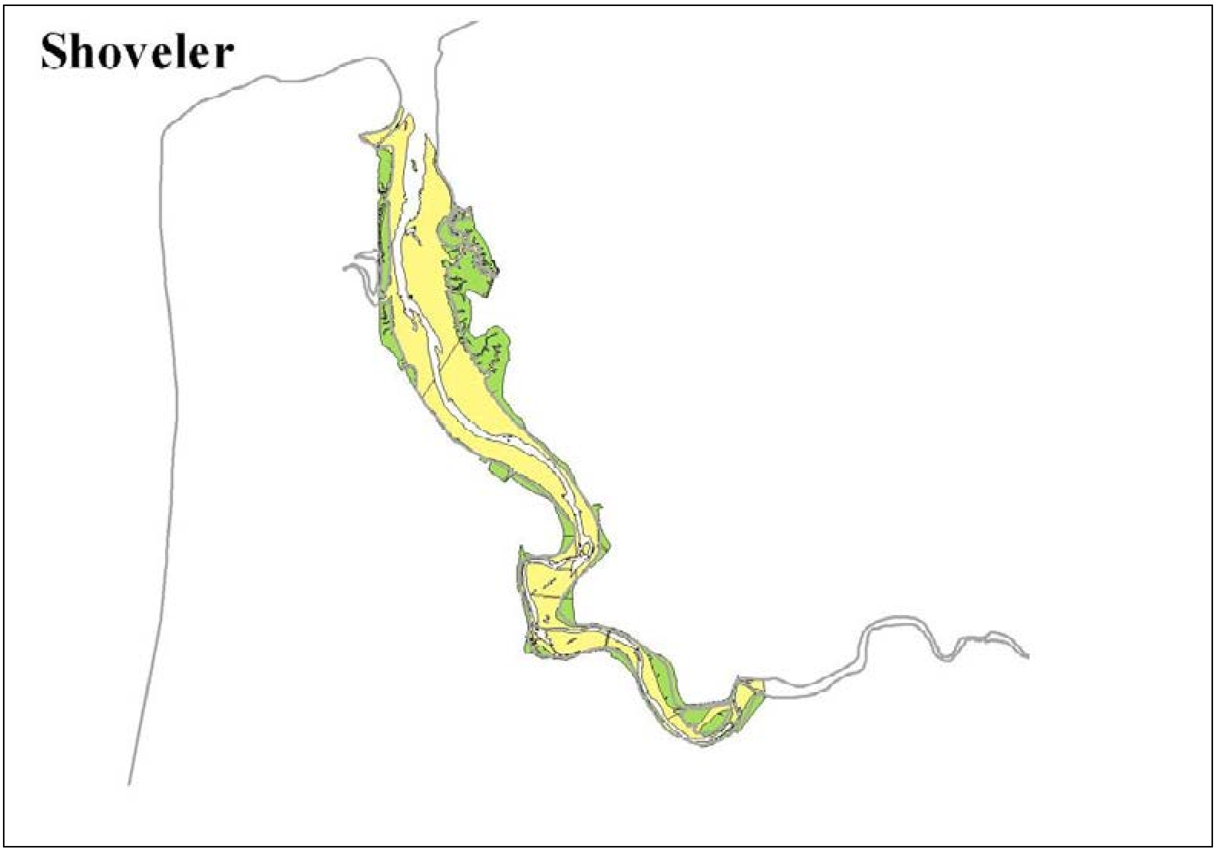
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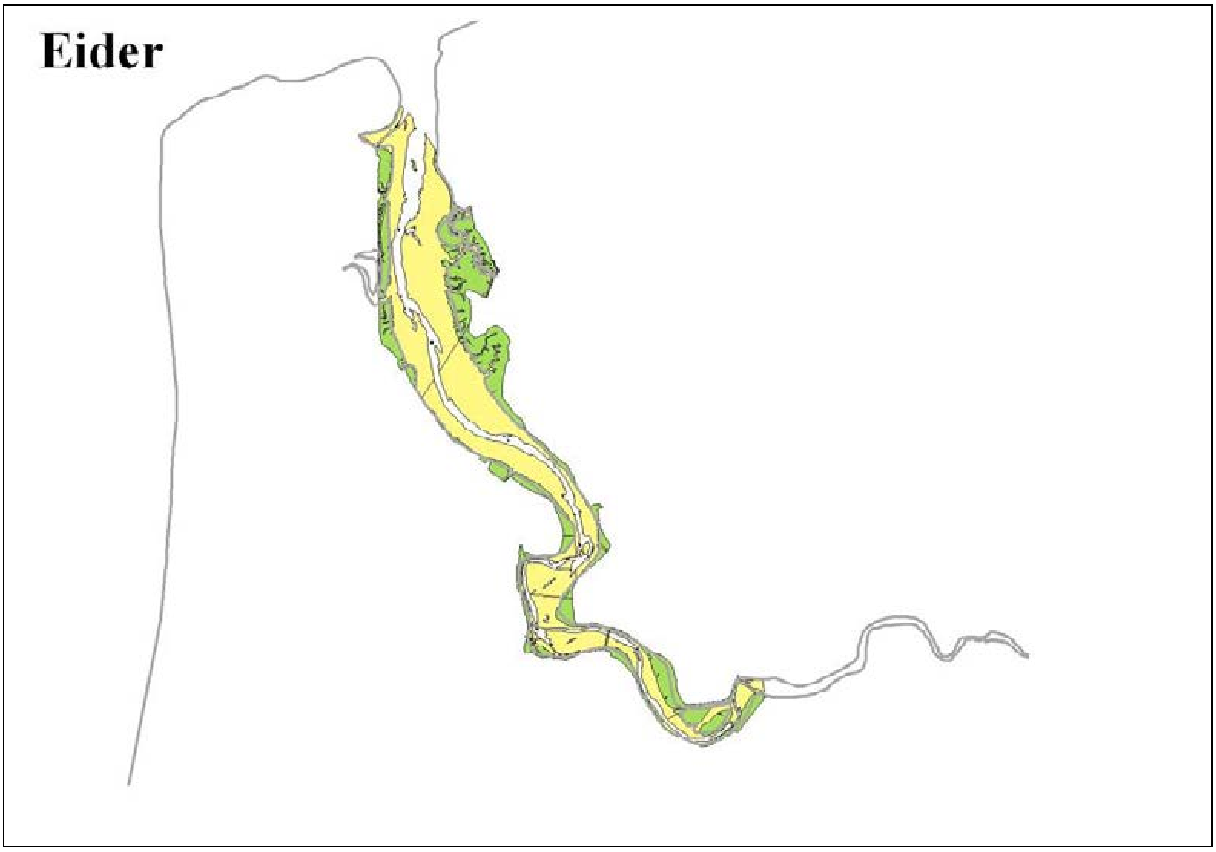
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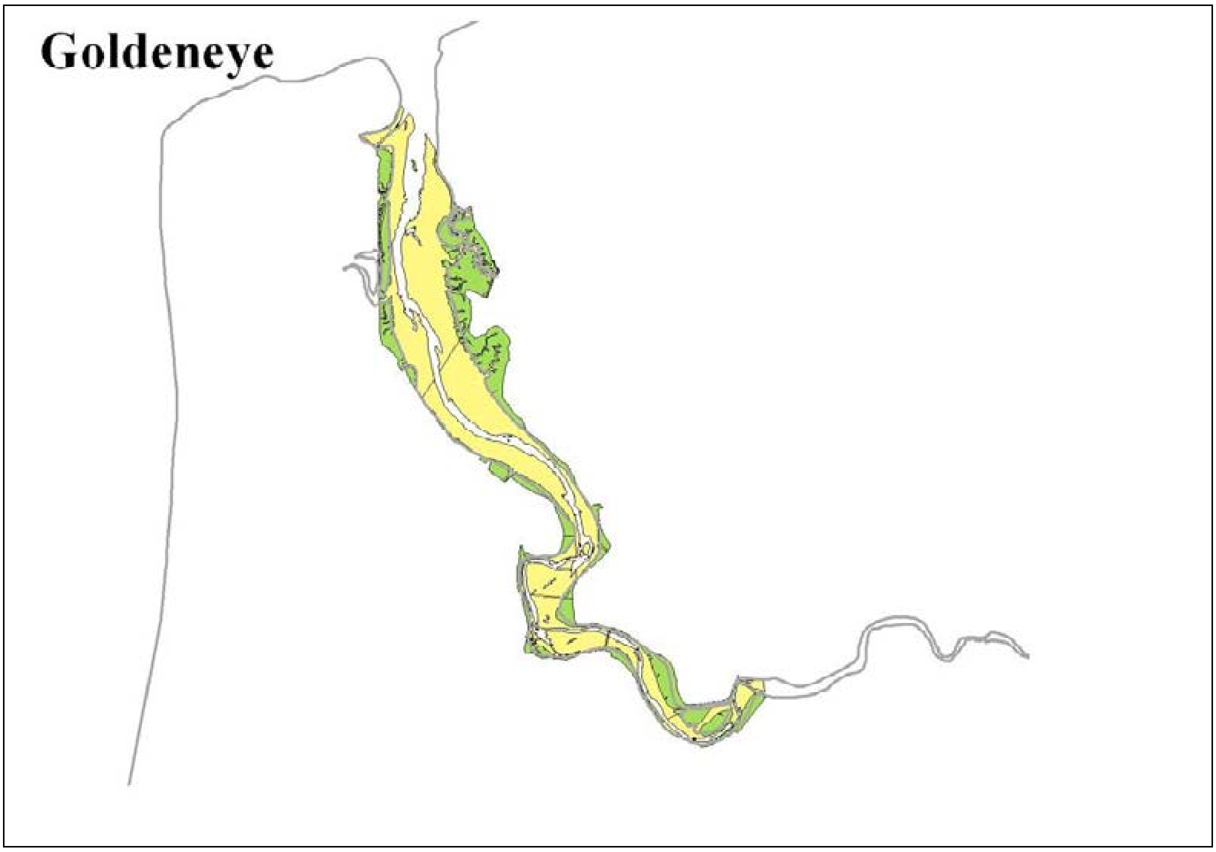
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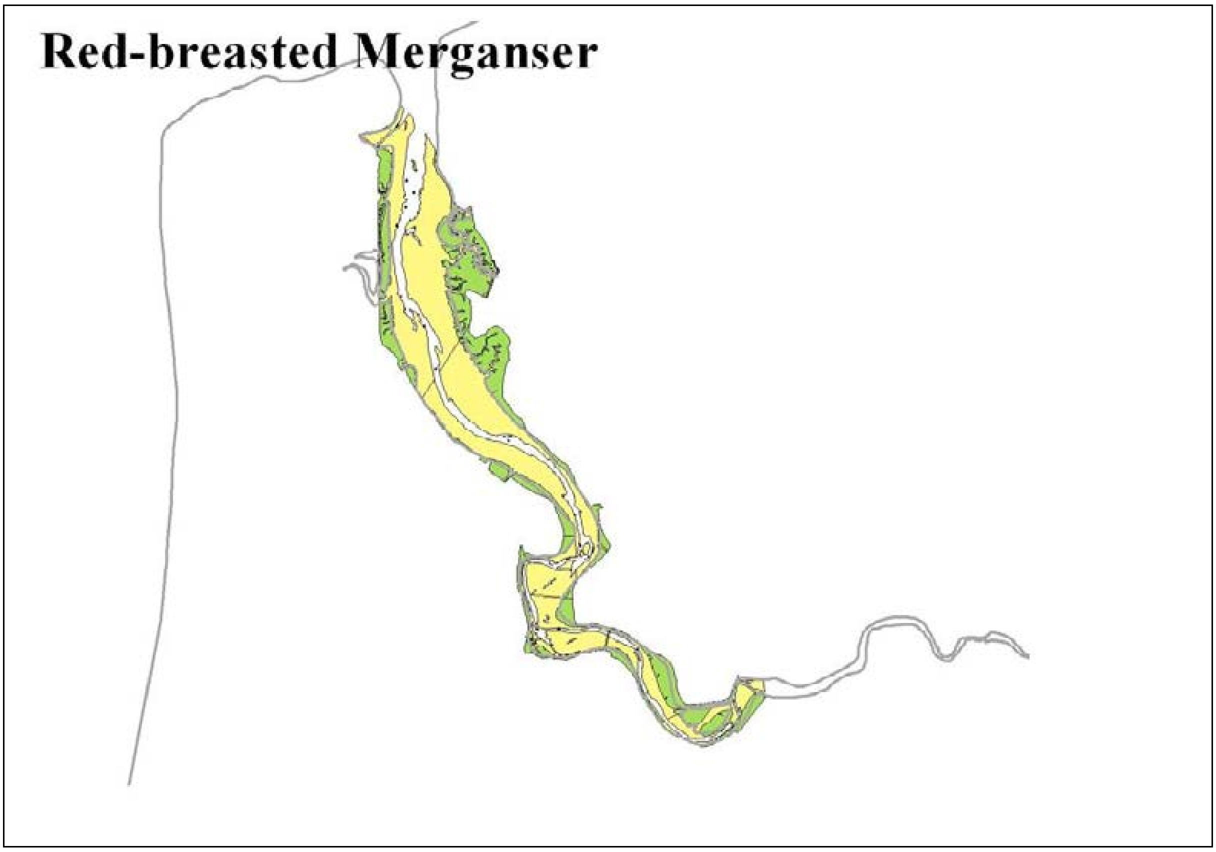
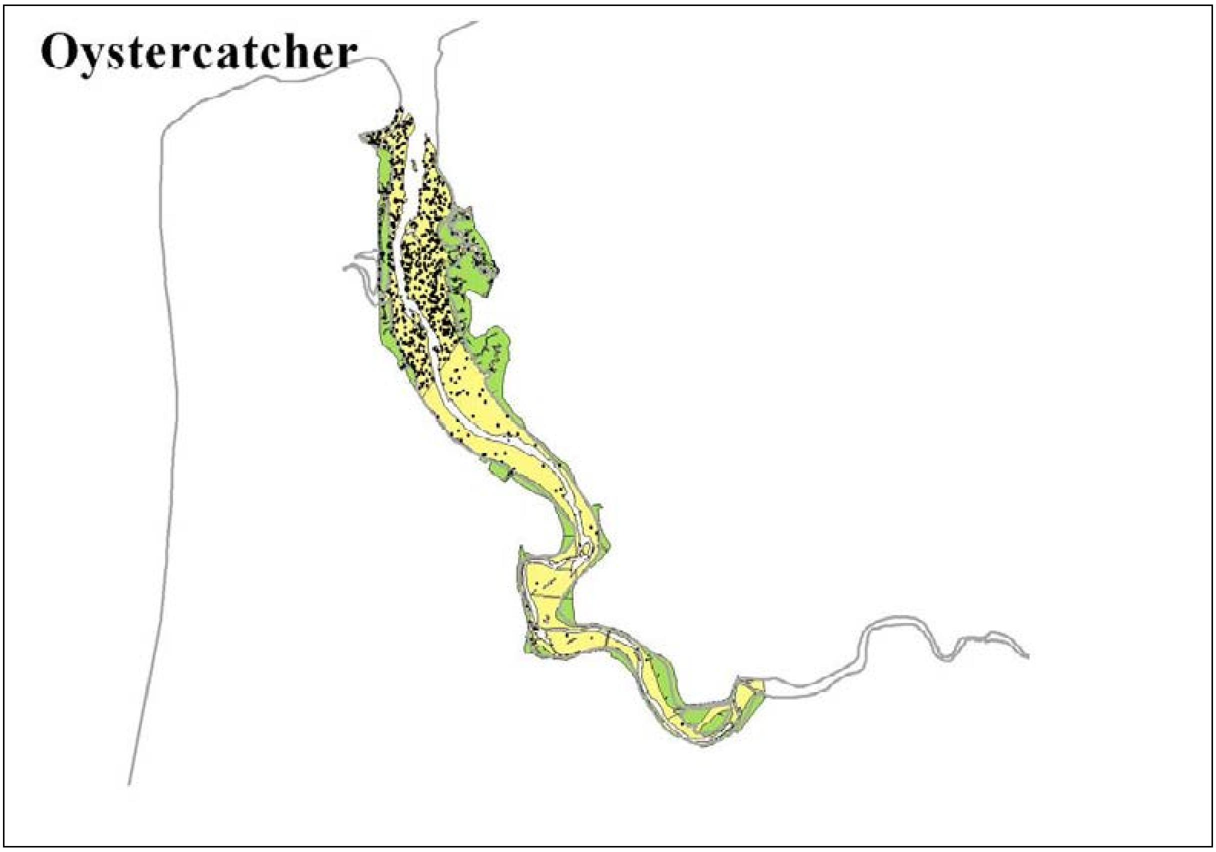
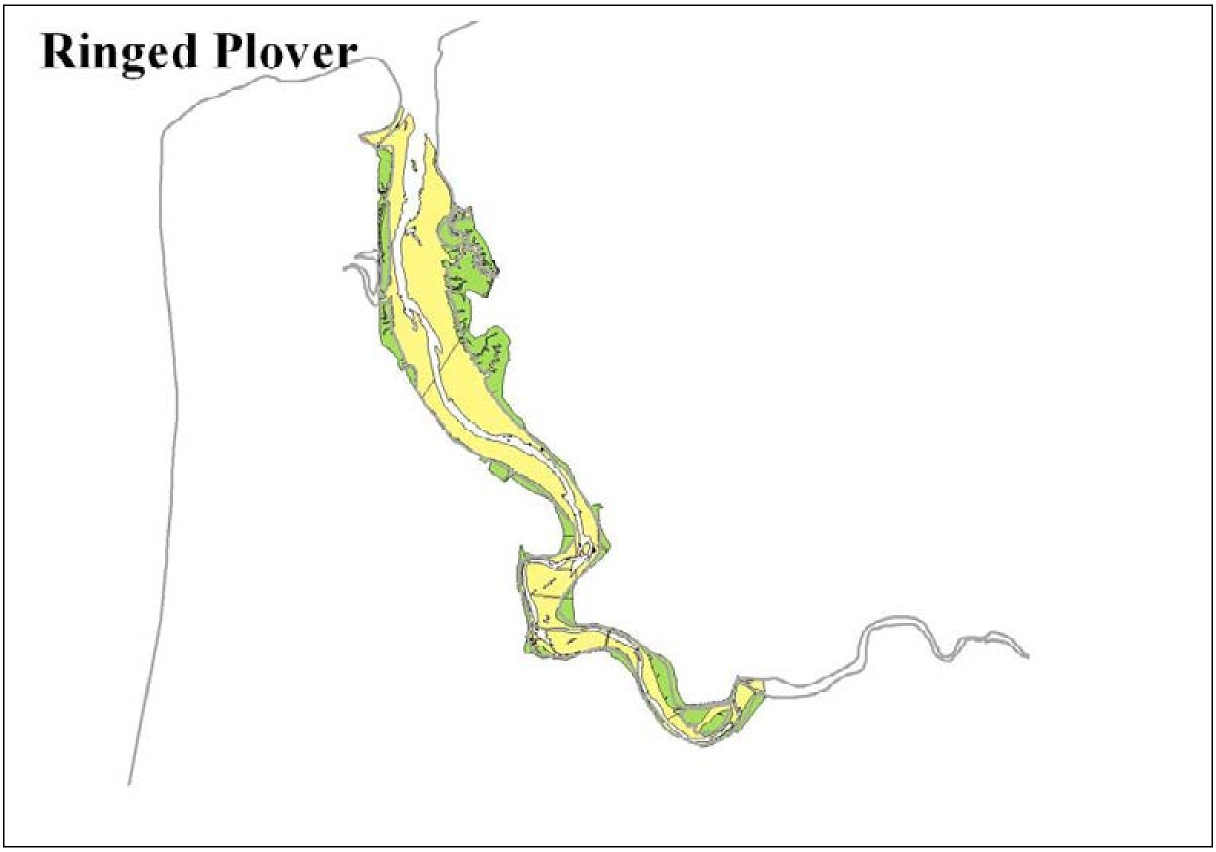
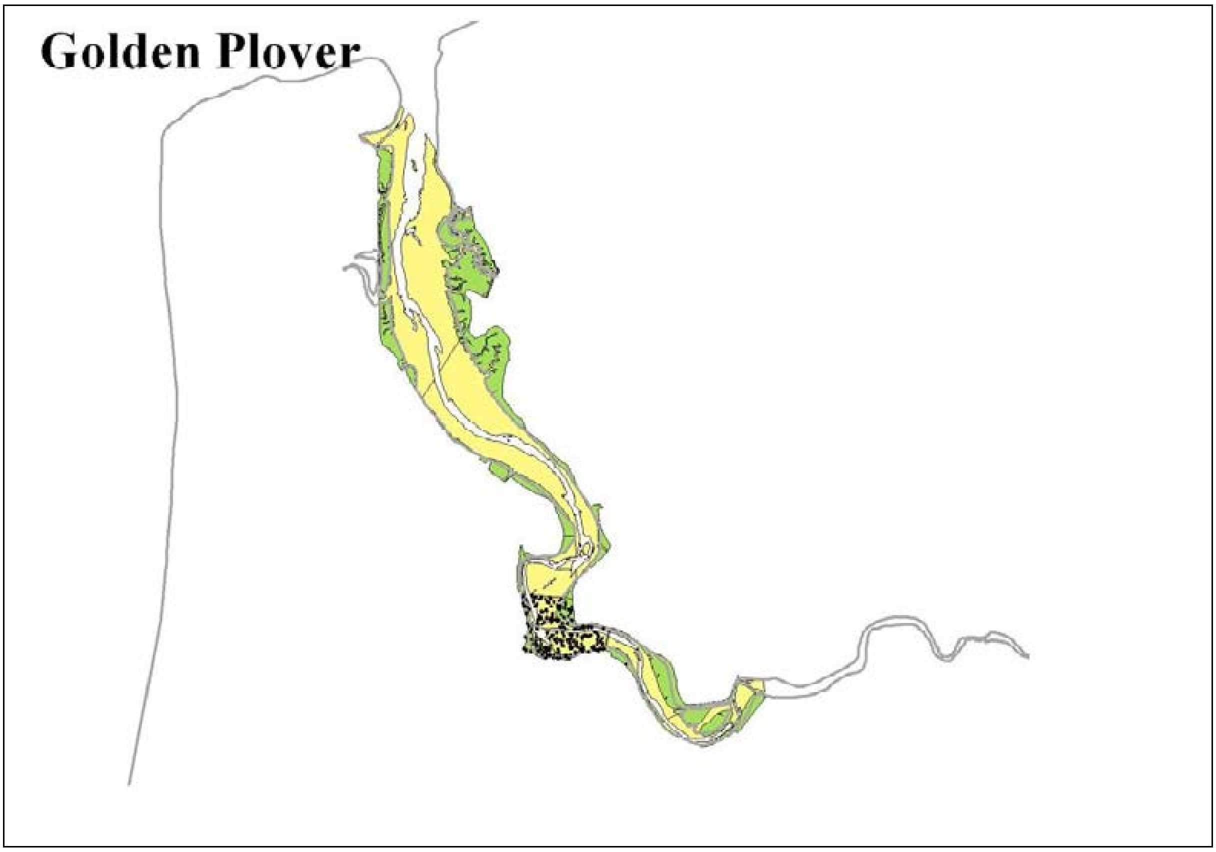
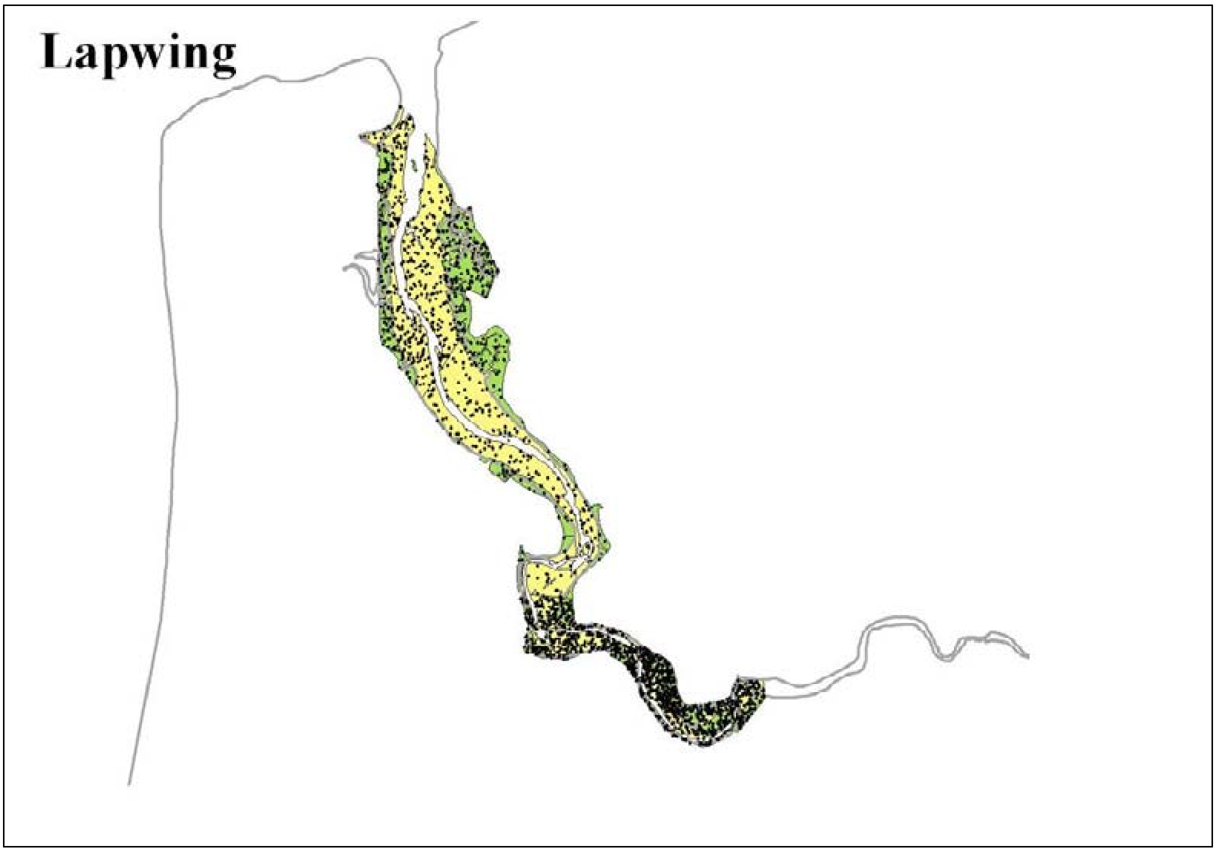
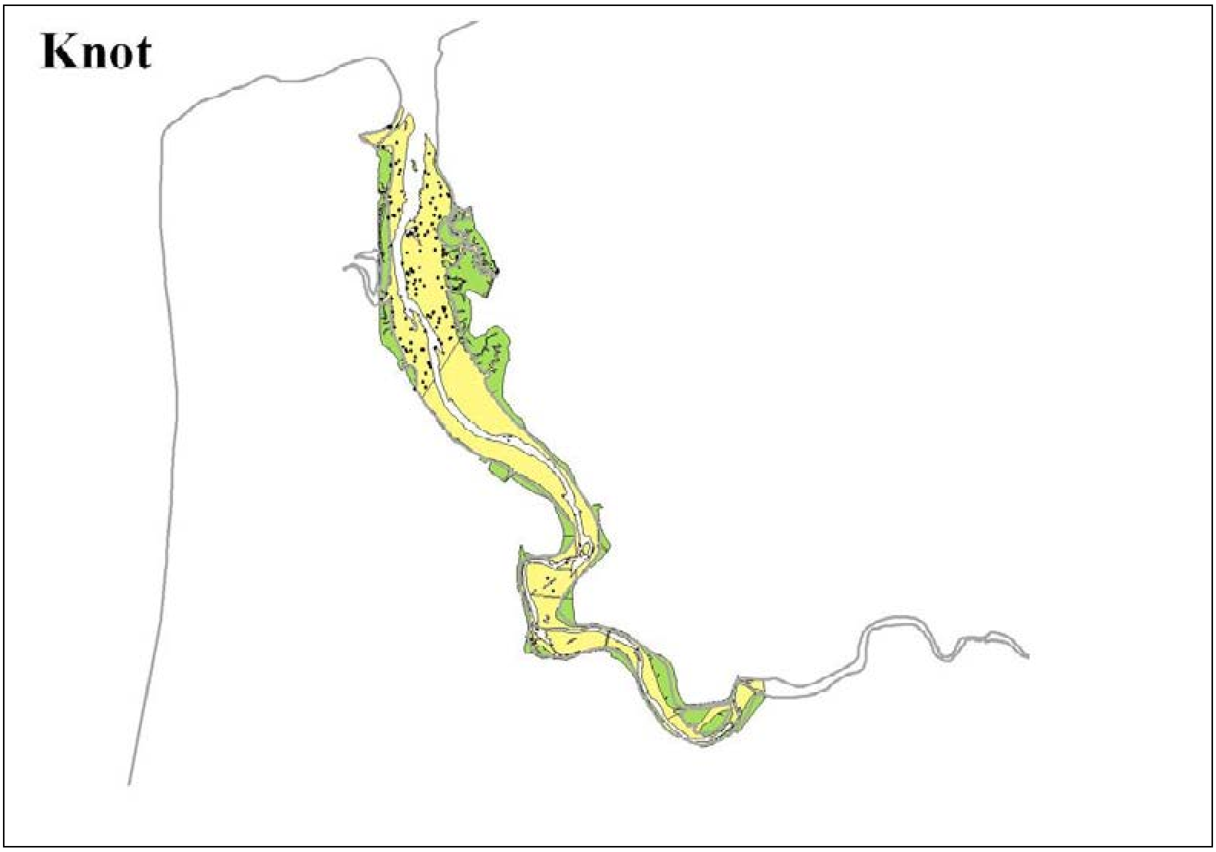

Red-breasted Merganser

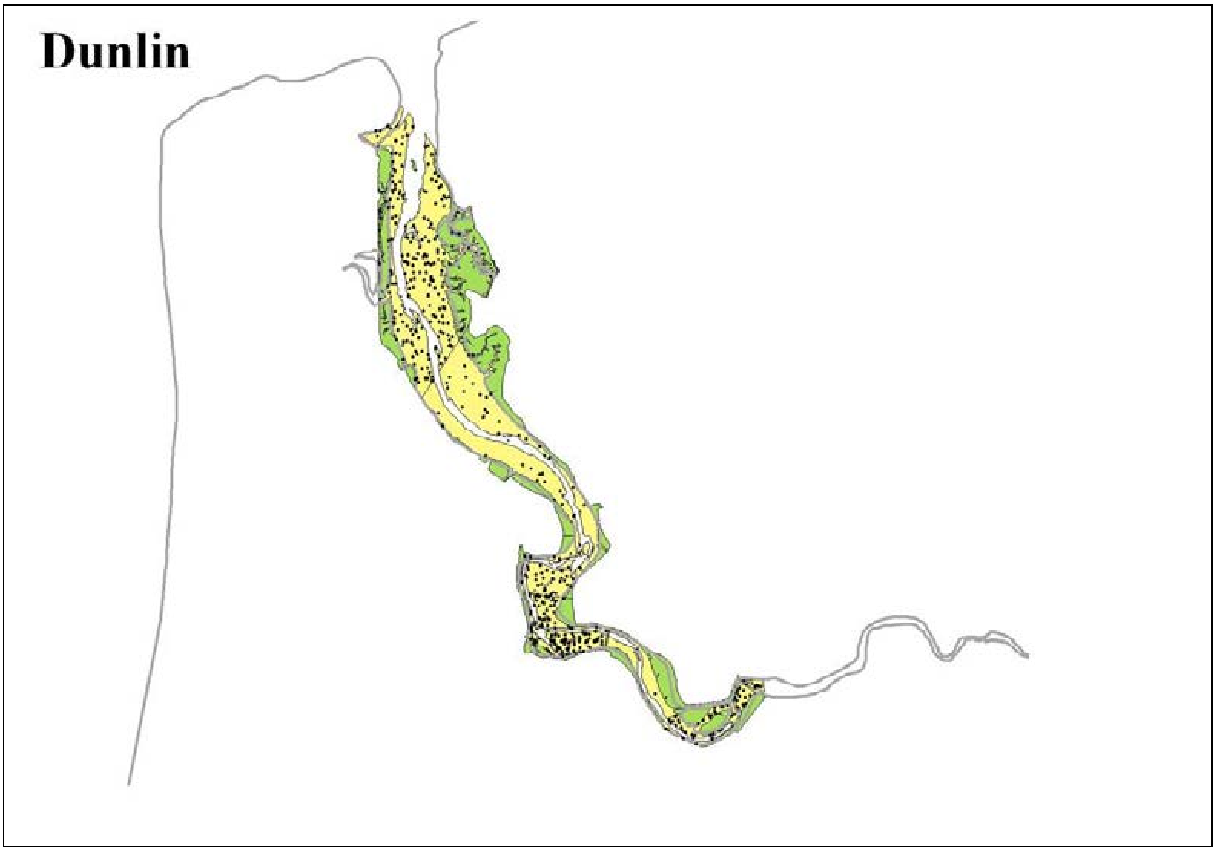

Oystercatcher

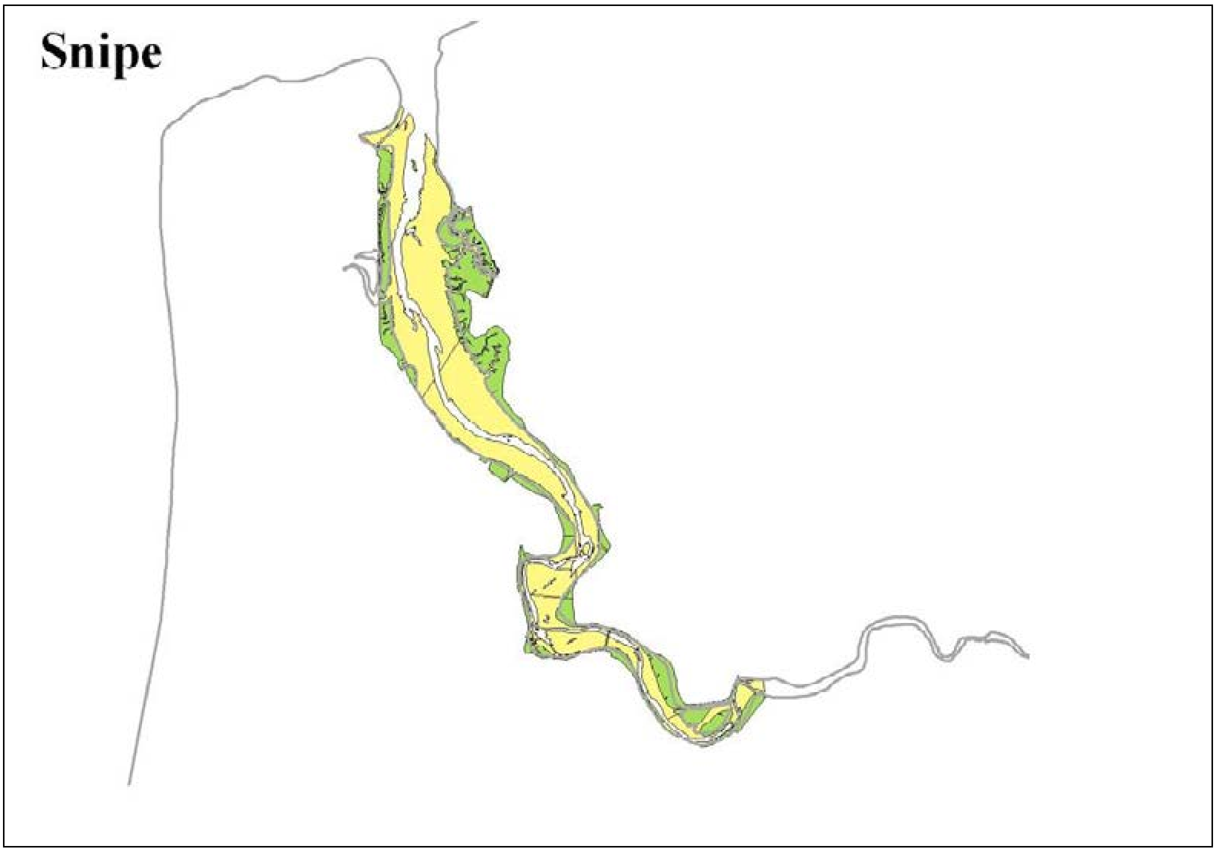

Ringed Plover

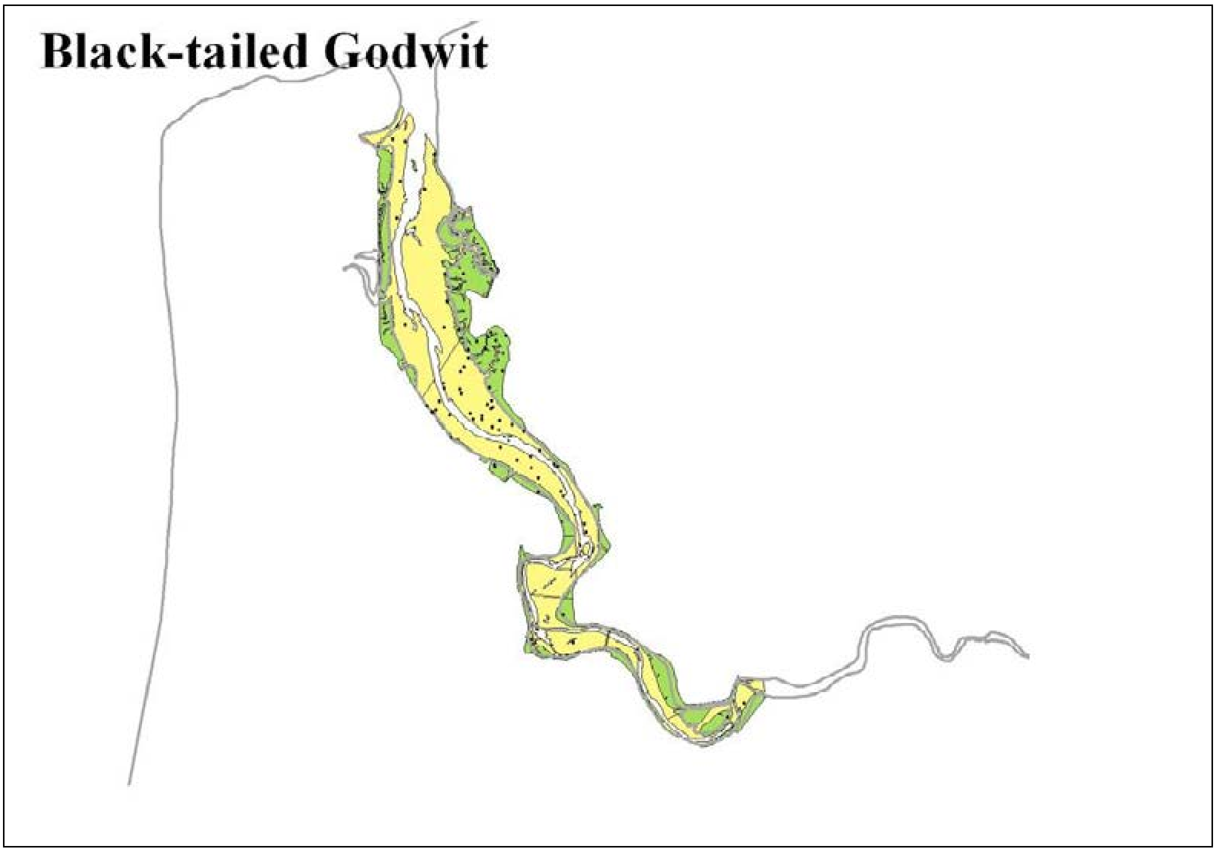

Golden Plover


Lapwing


Knot


Dunlin


Snipe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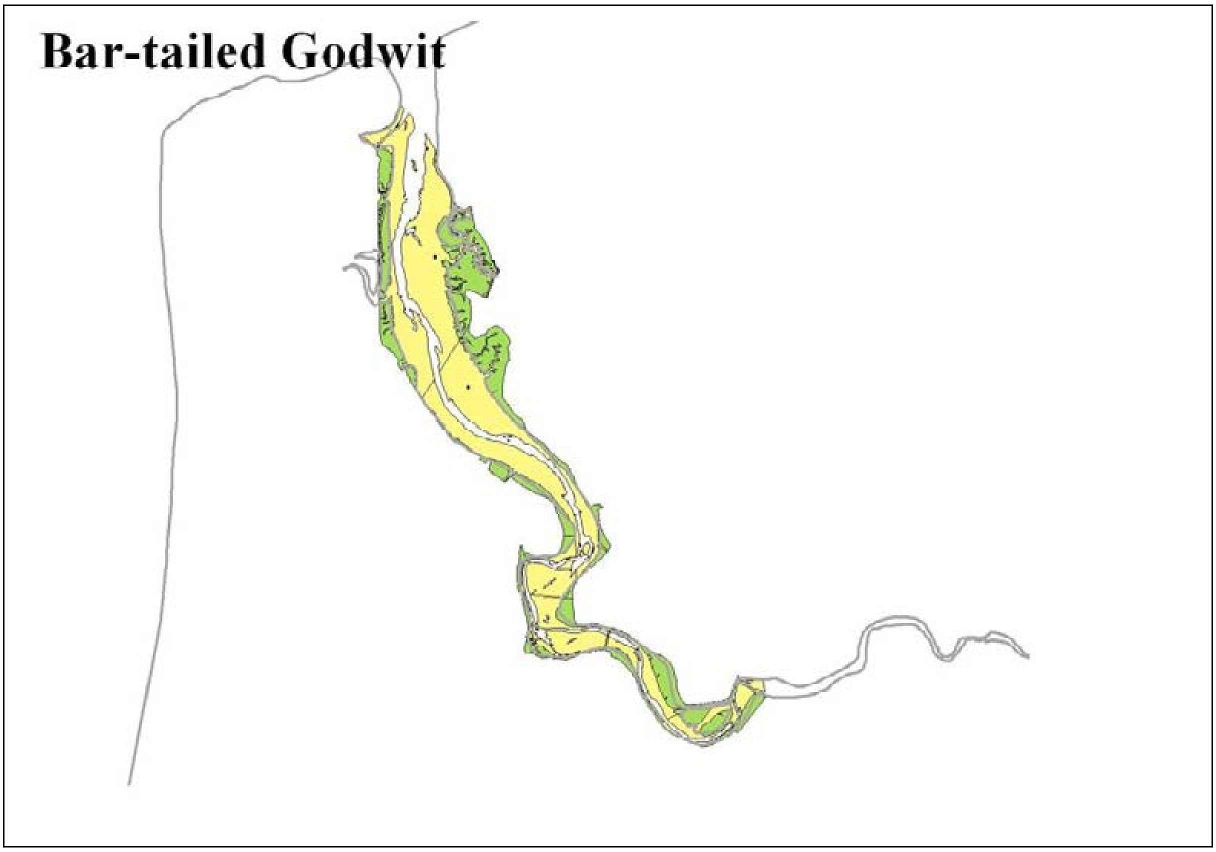
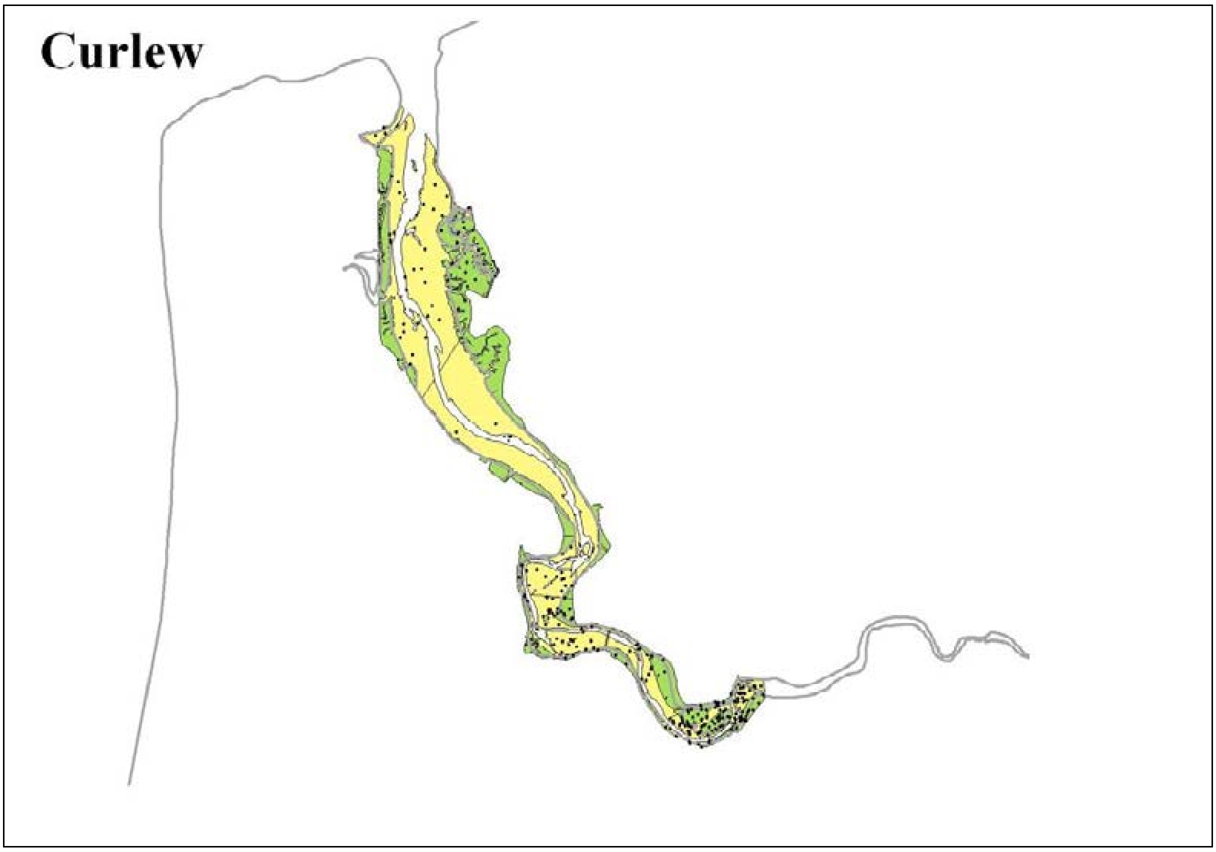

Bar-tailed Godwit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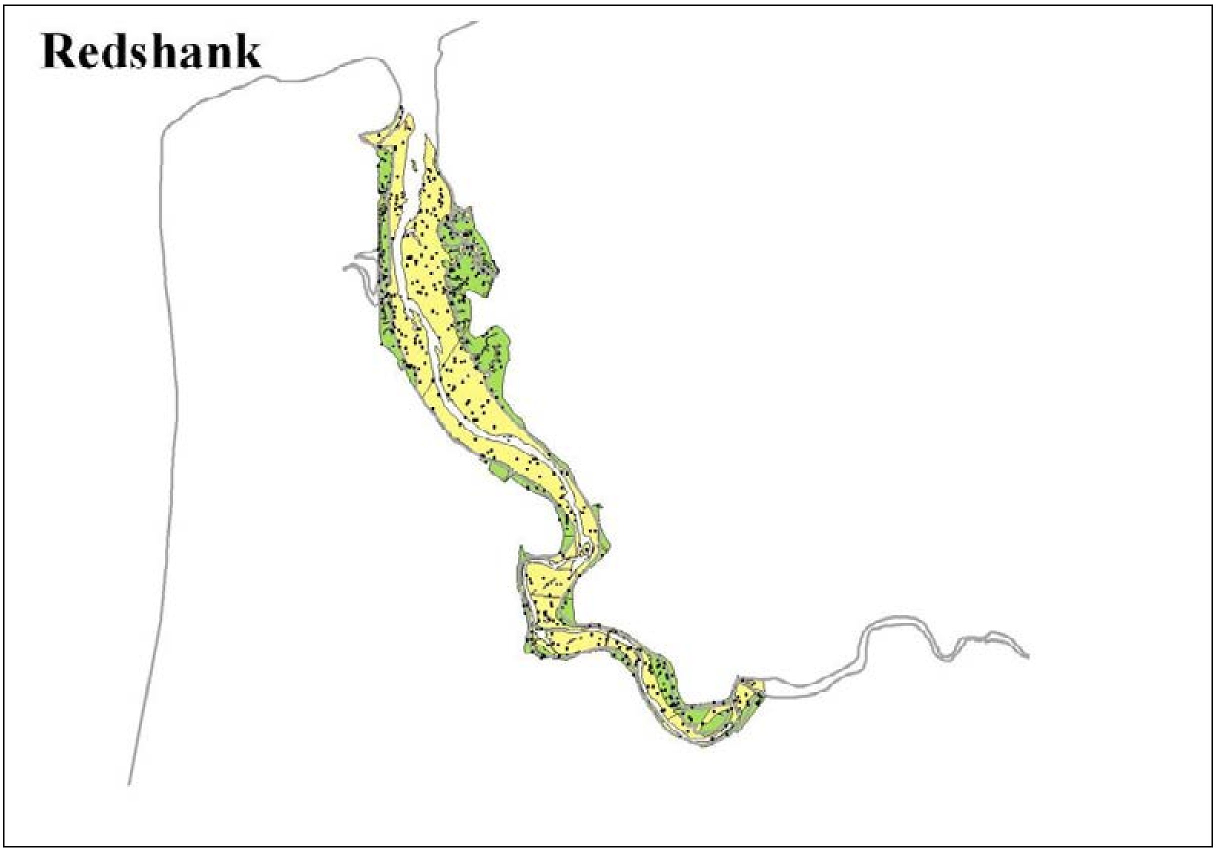
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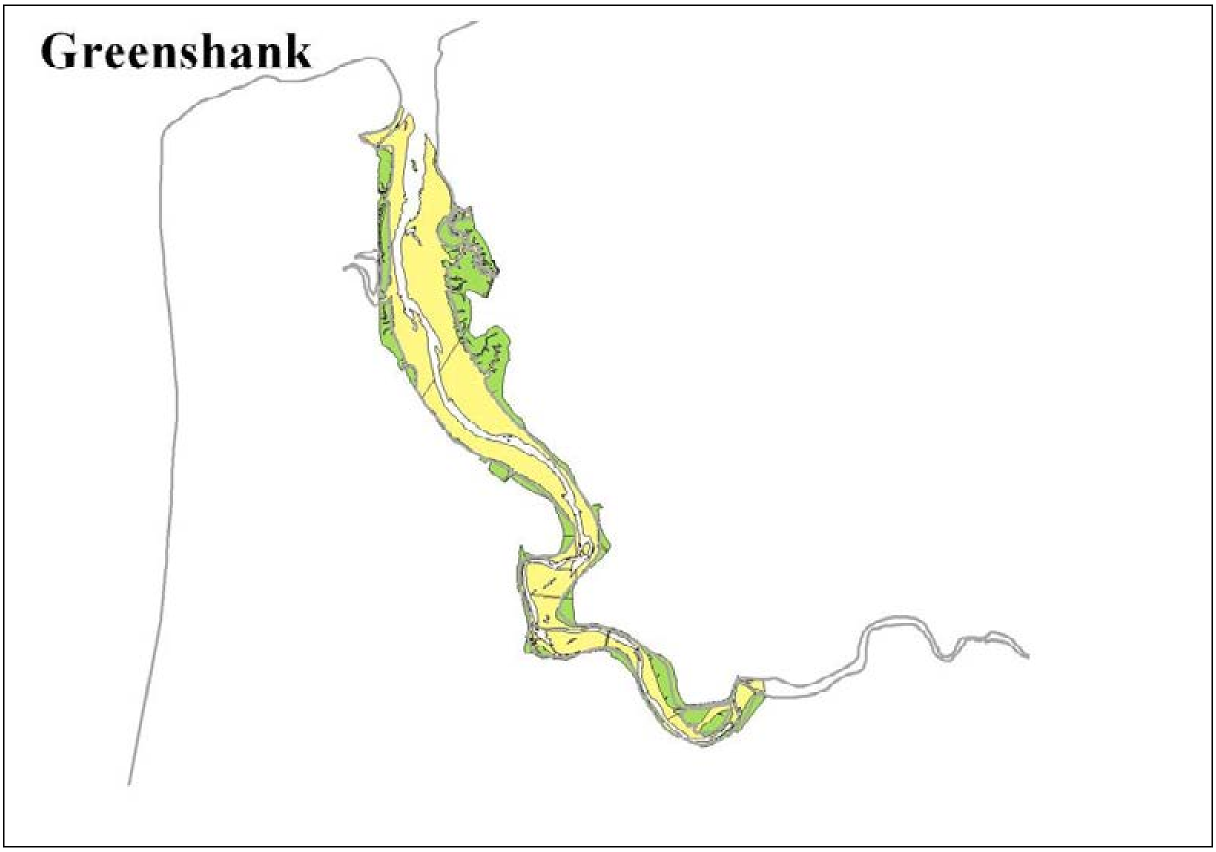
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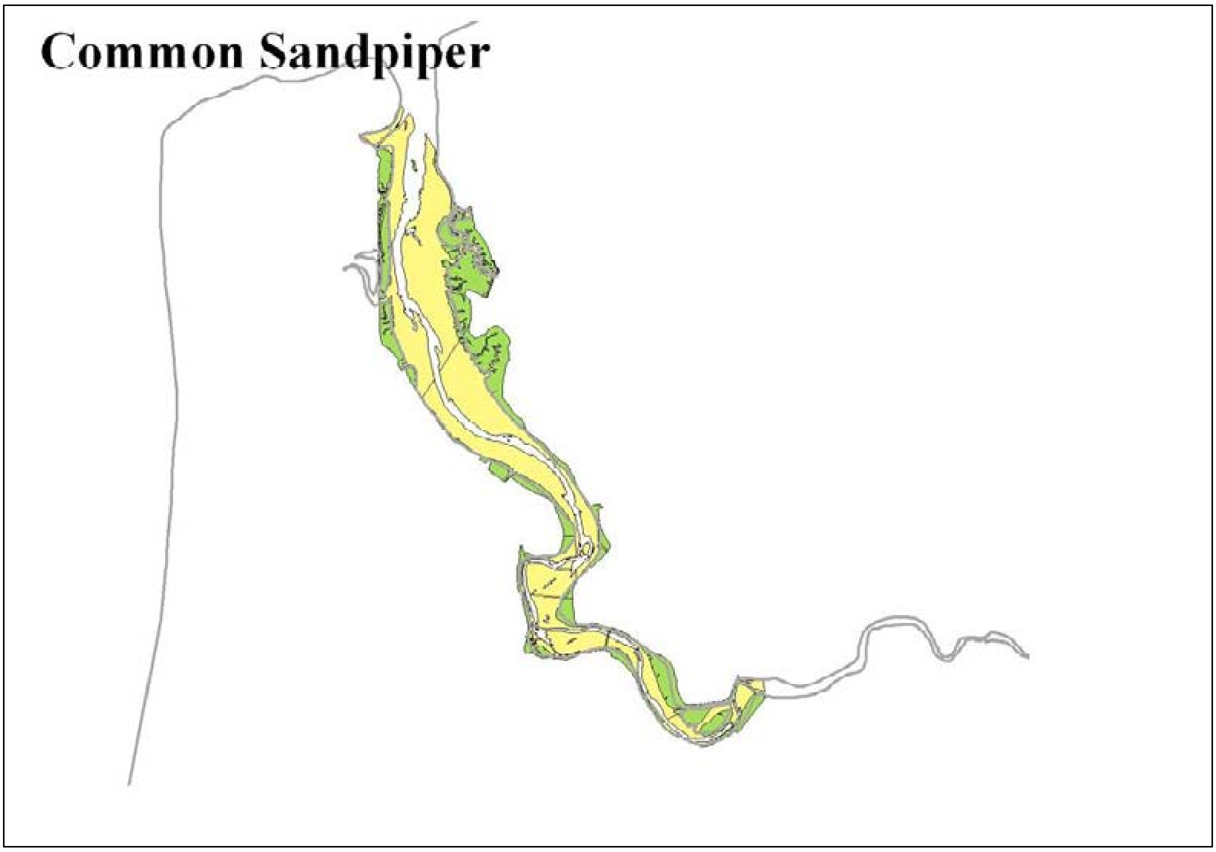
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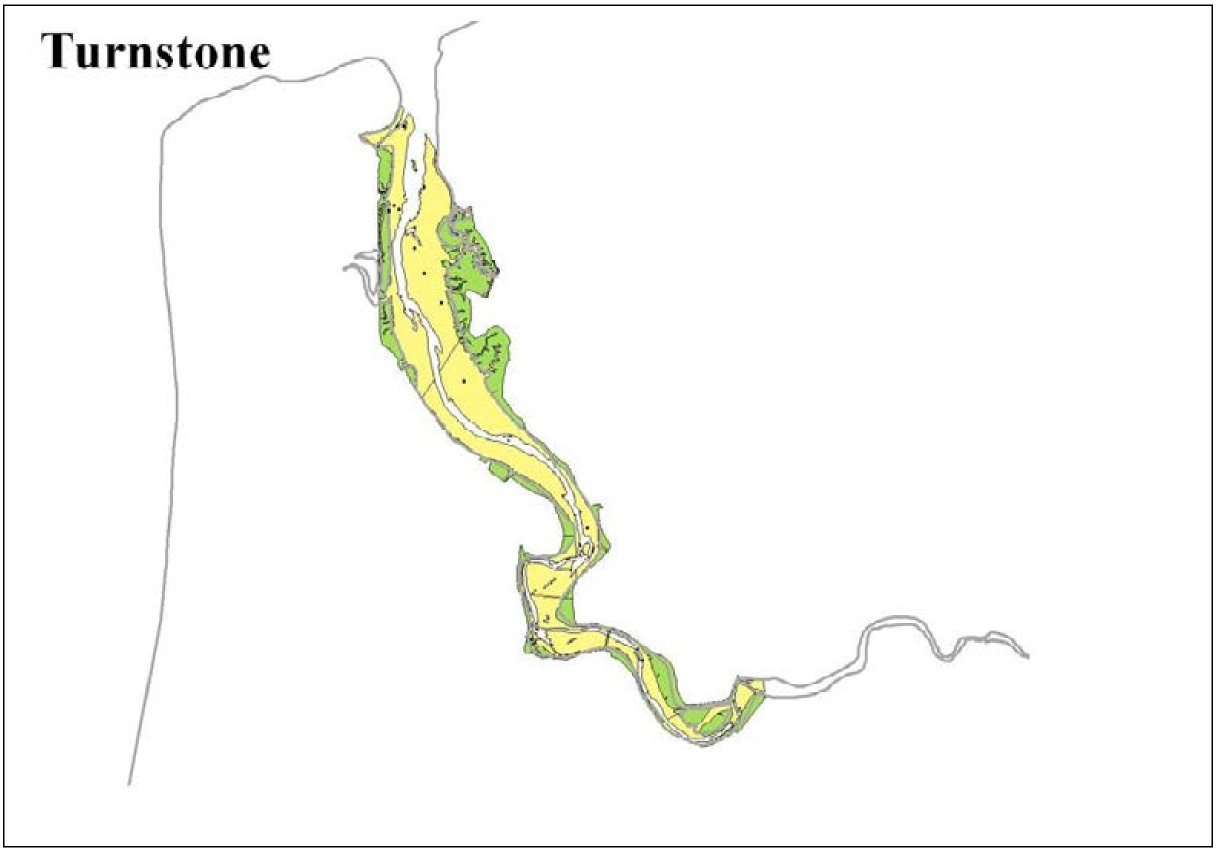
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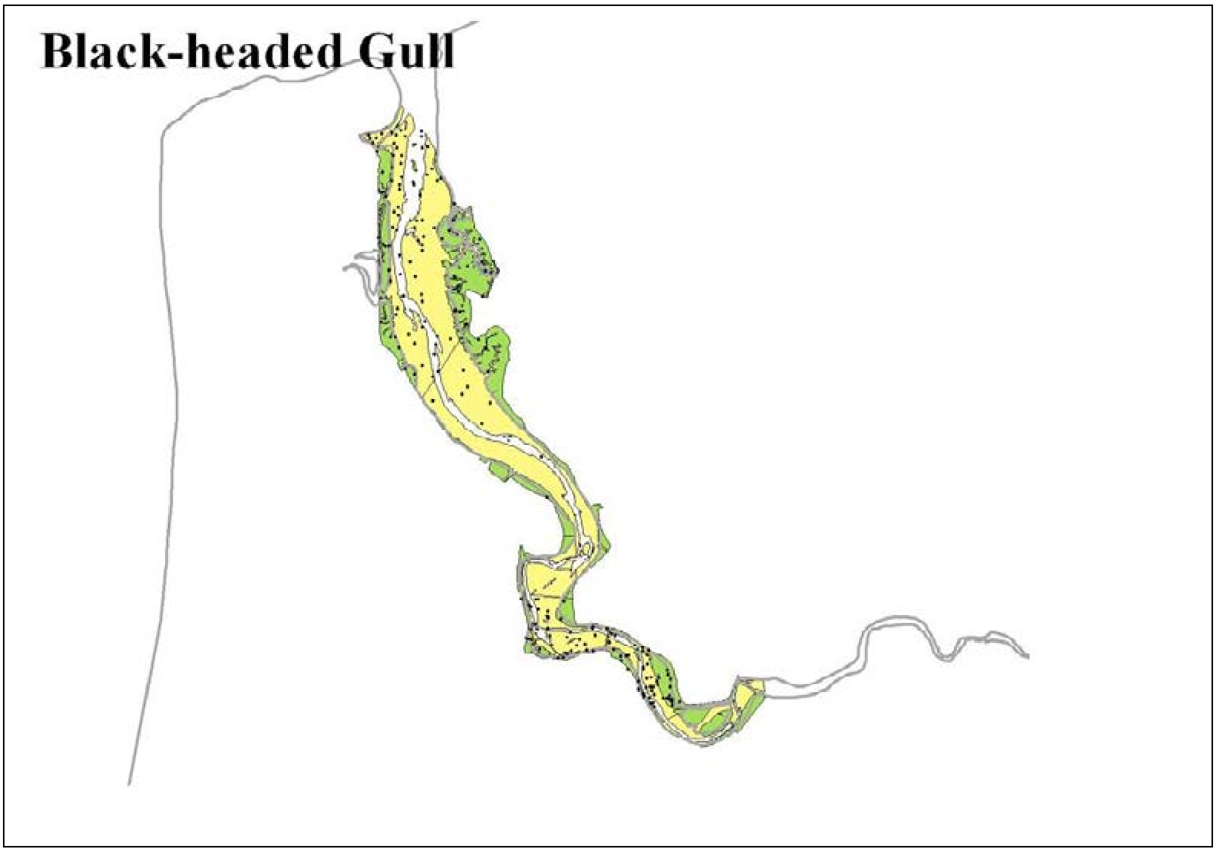
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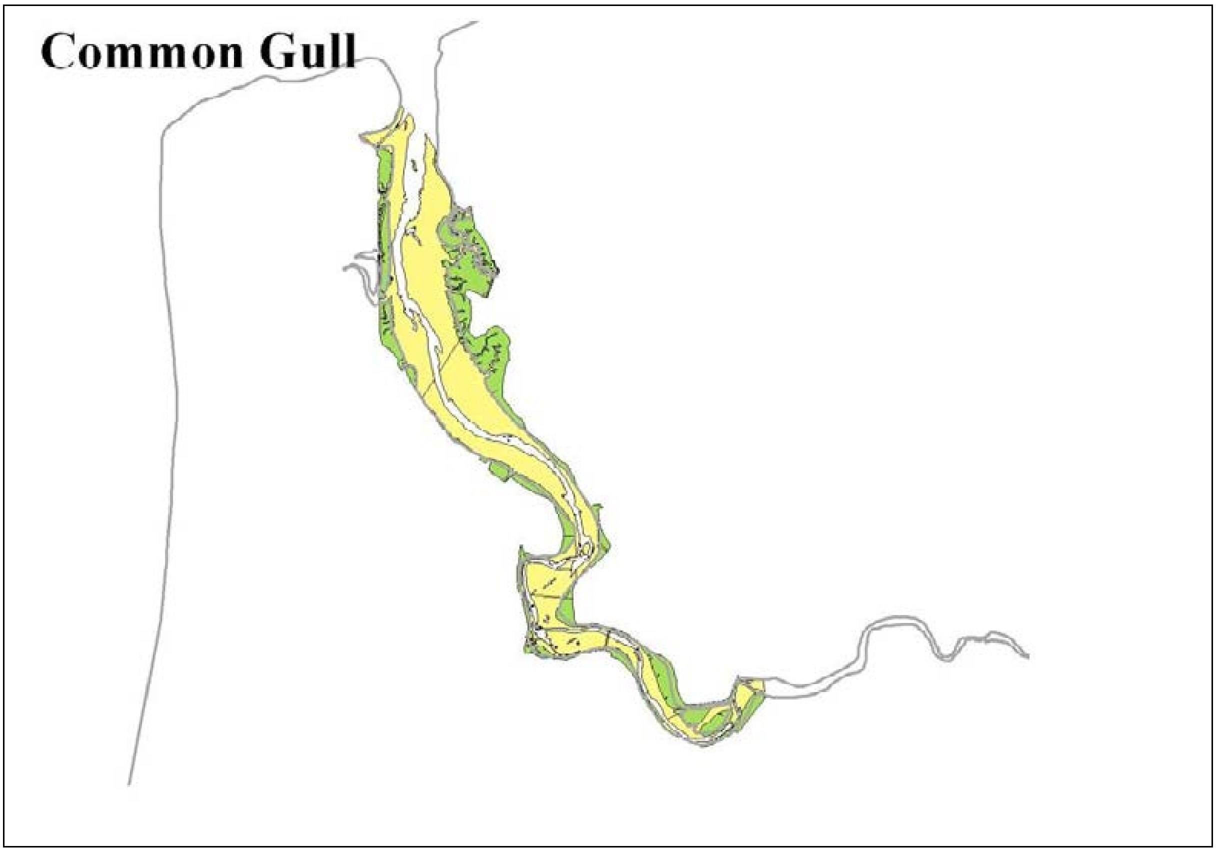
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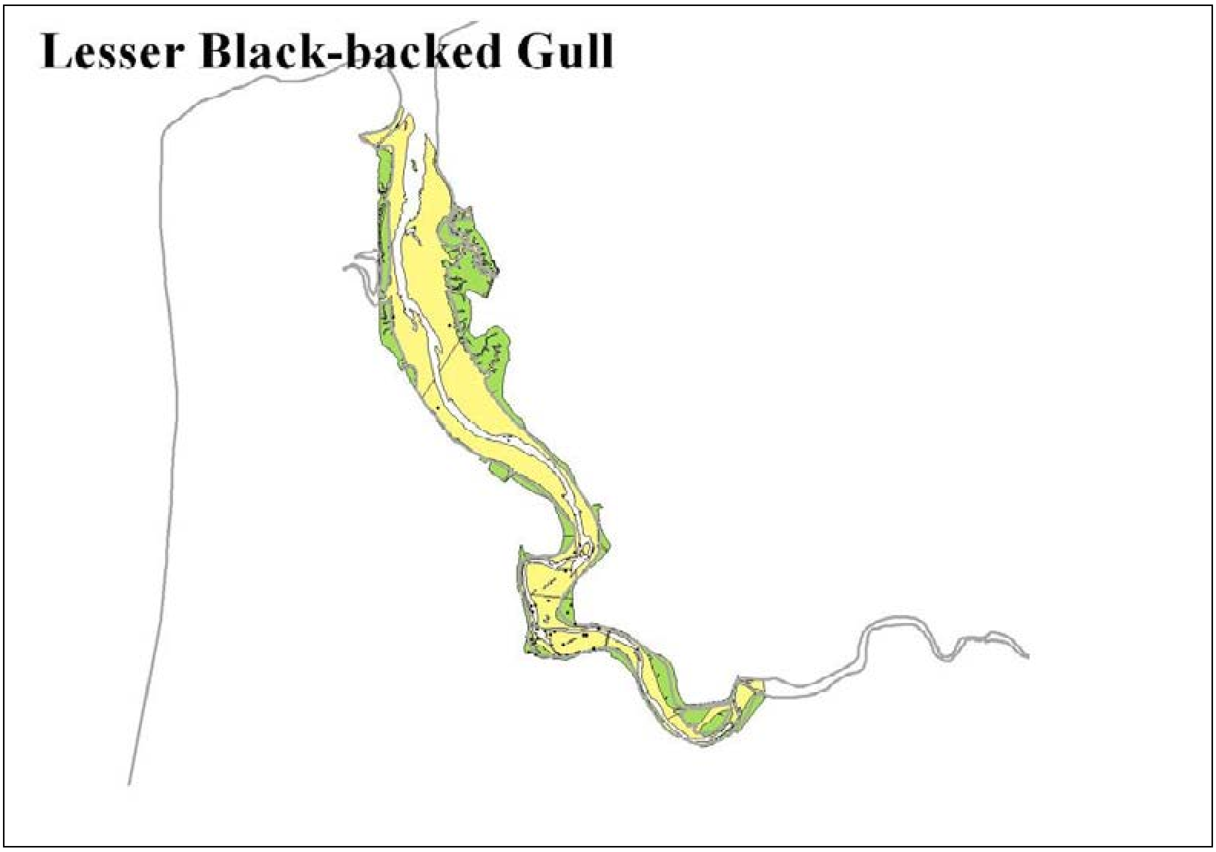
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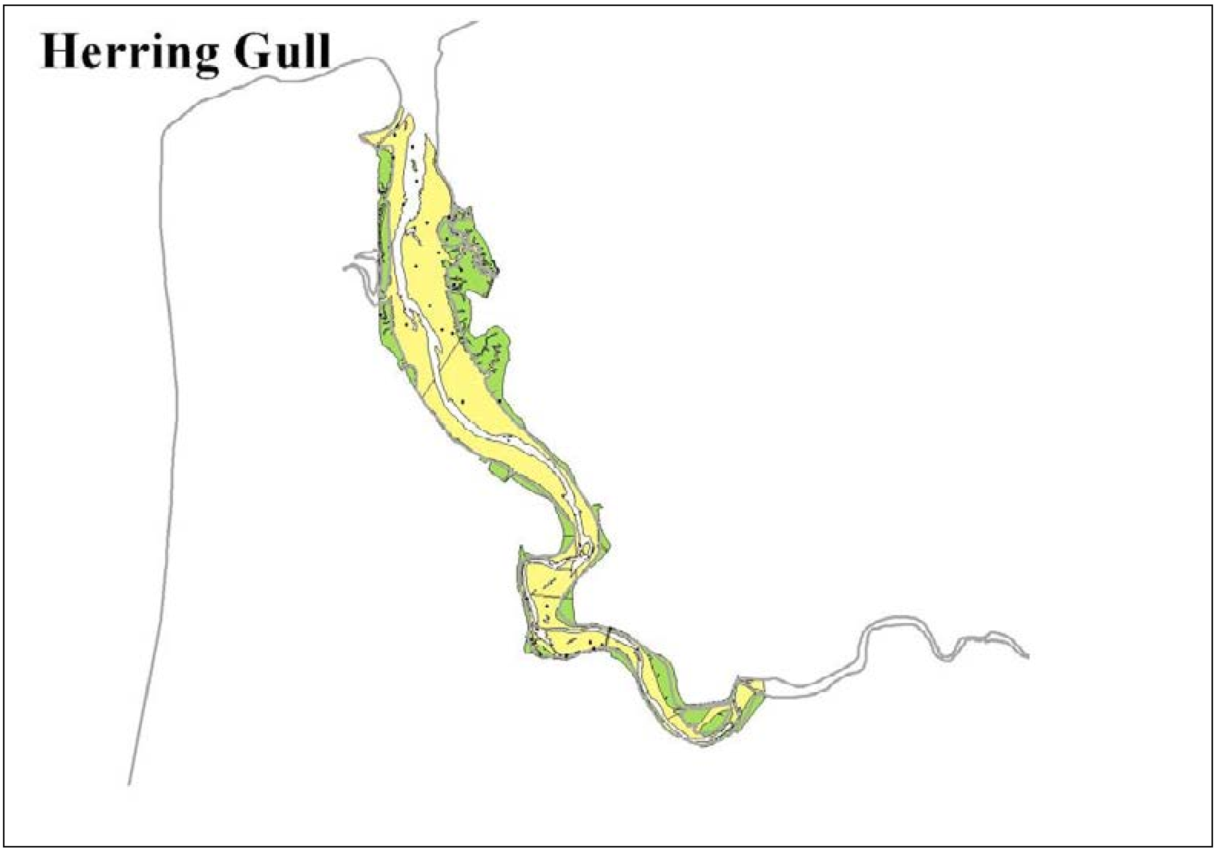
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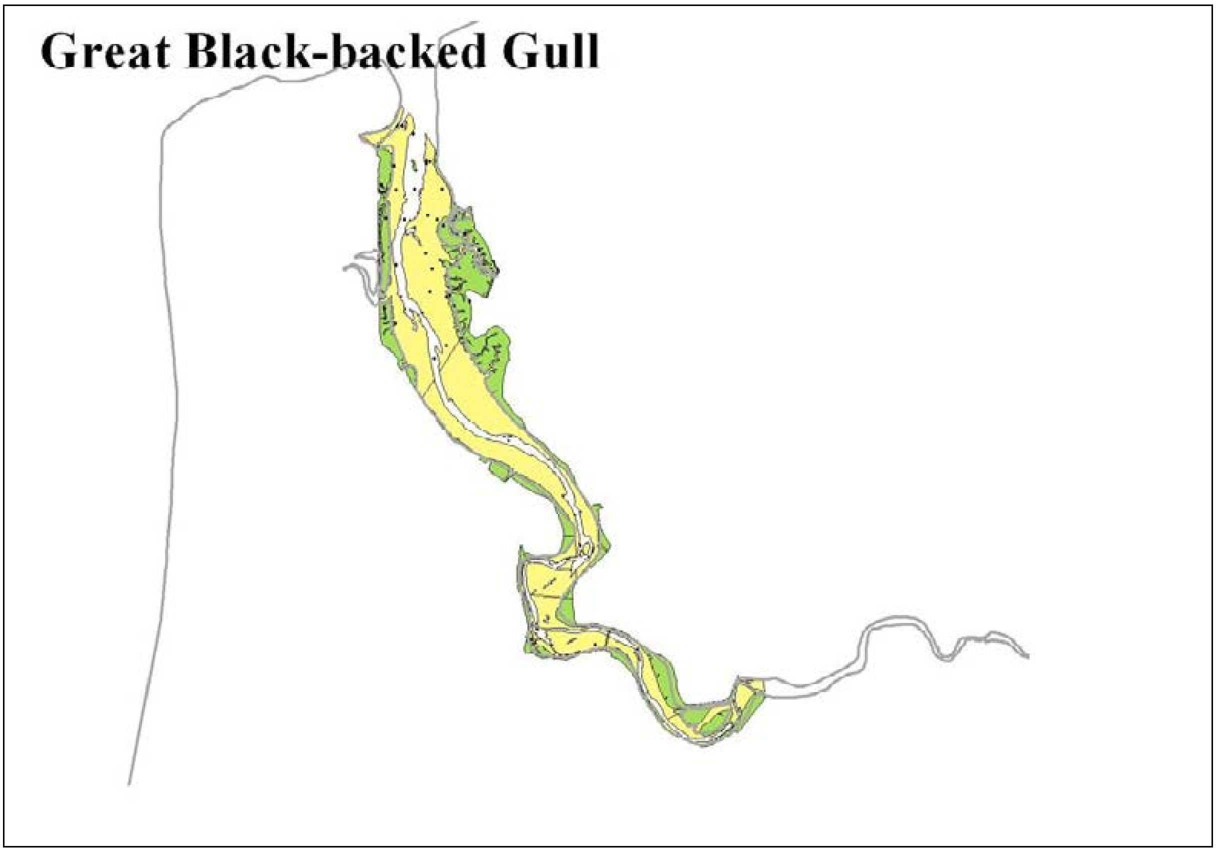
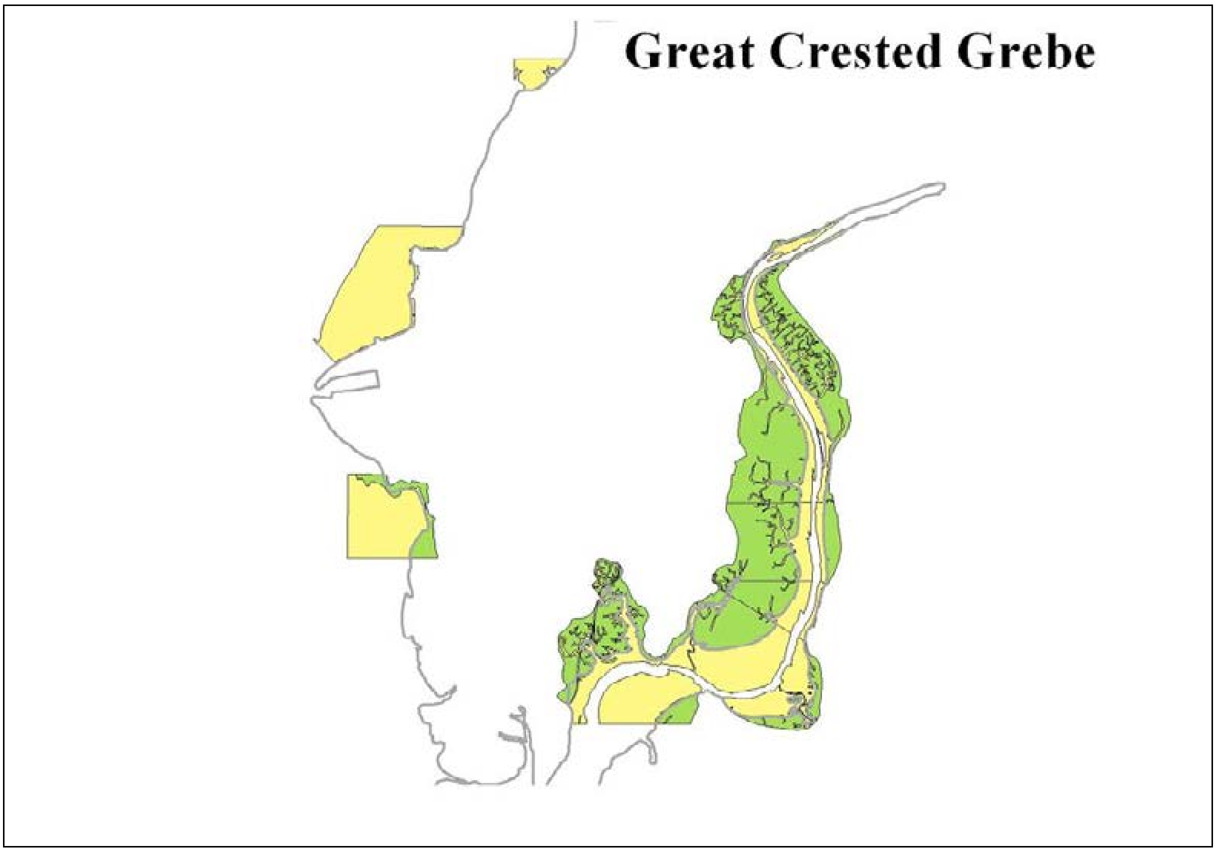
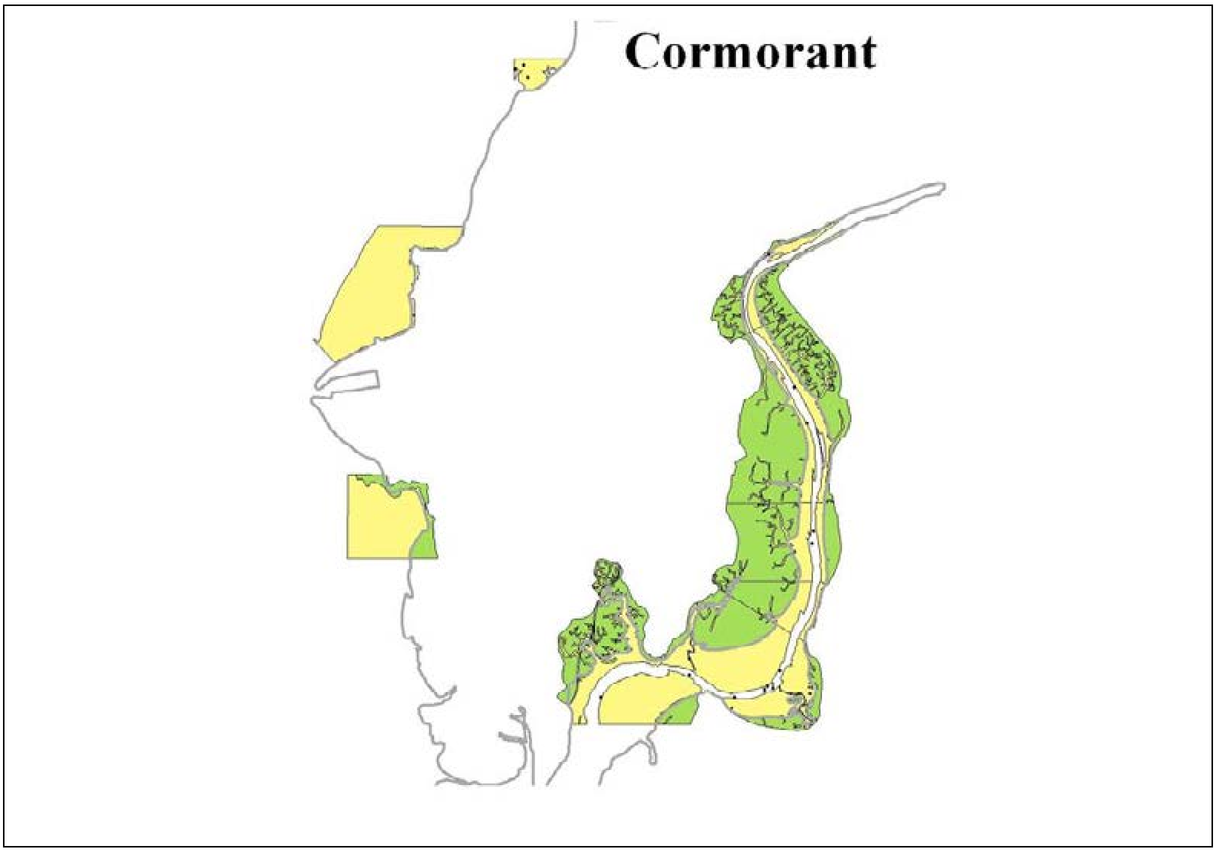
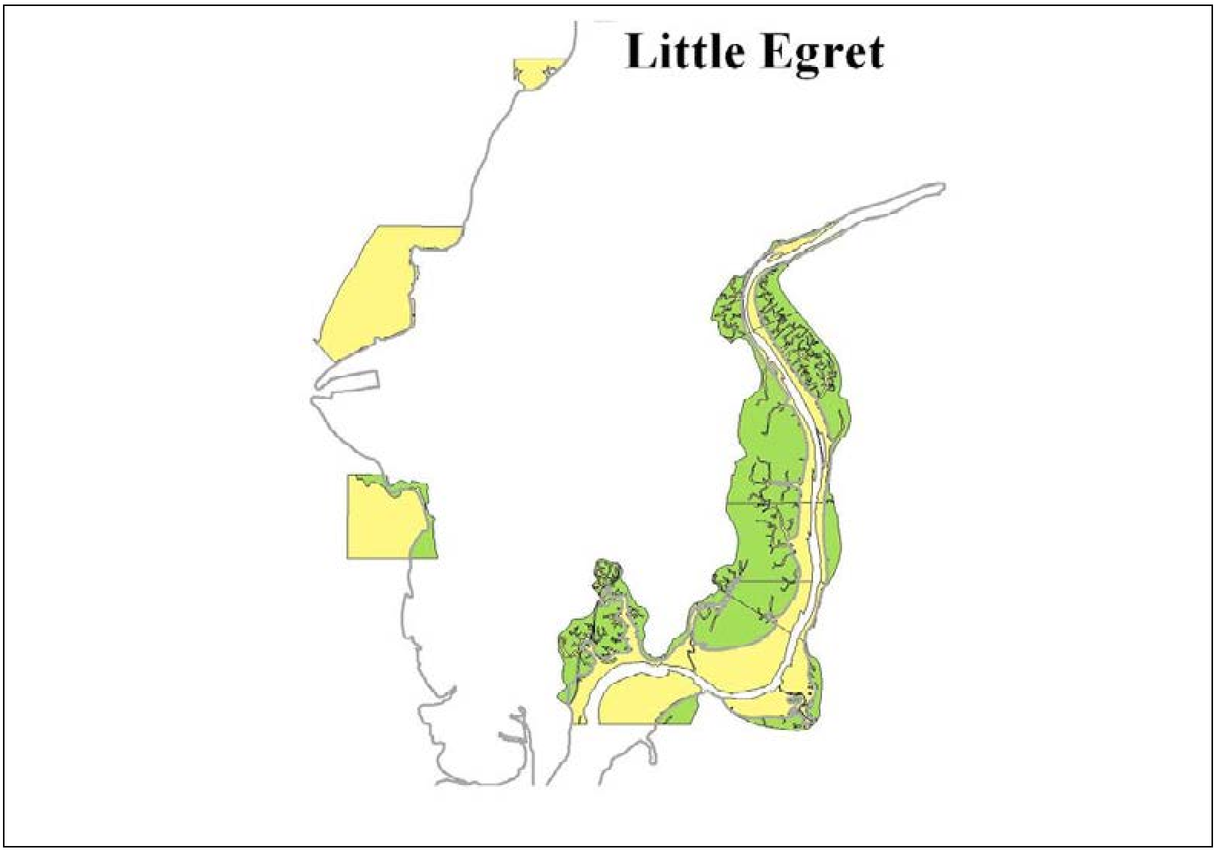

Great Black-backed Gull

Lune Estuary



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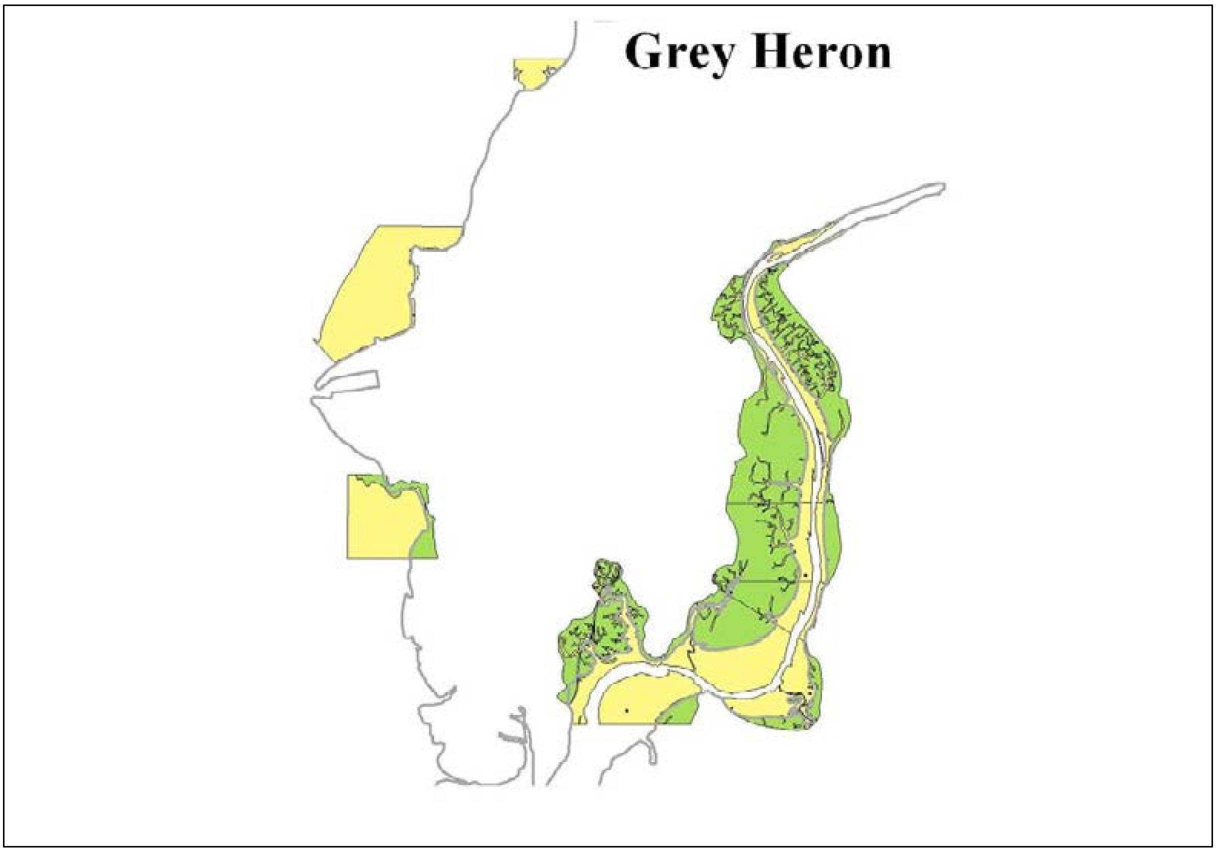
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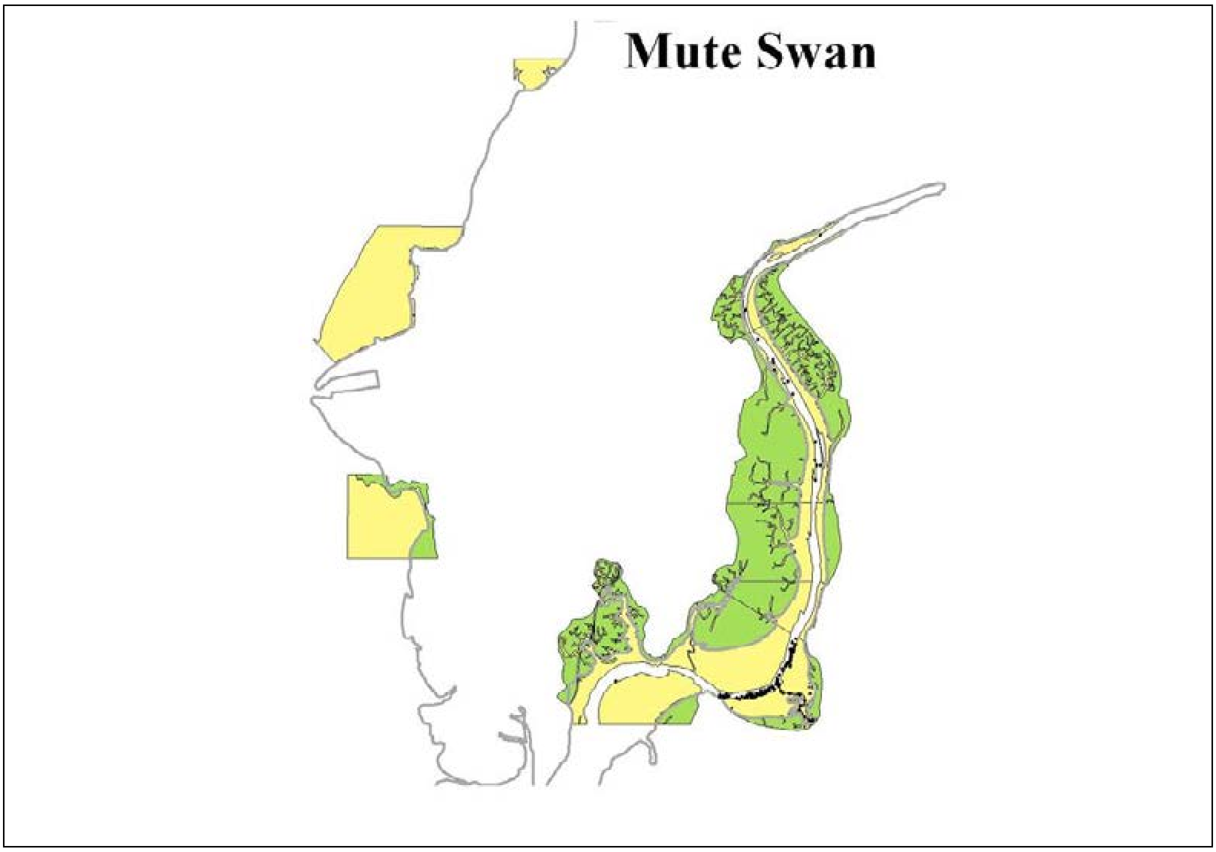
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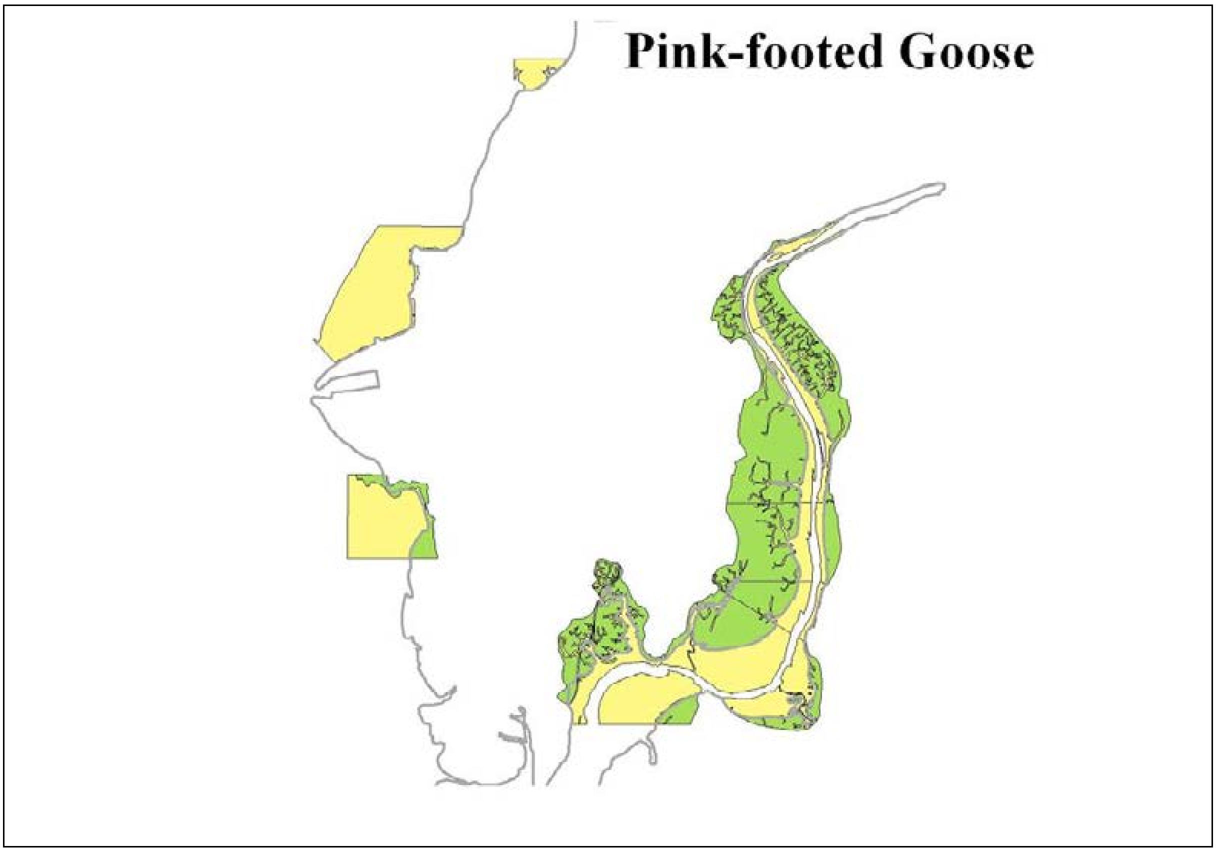
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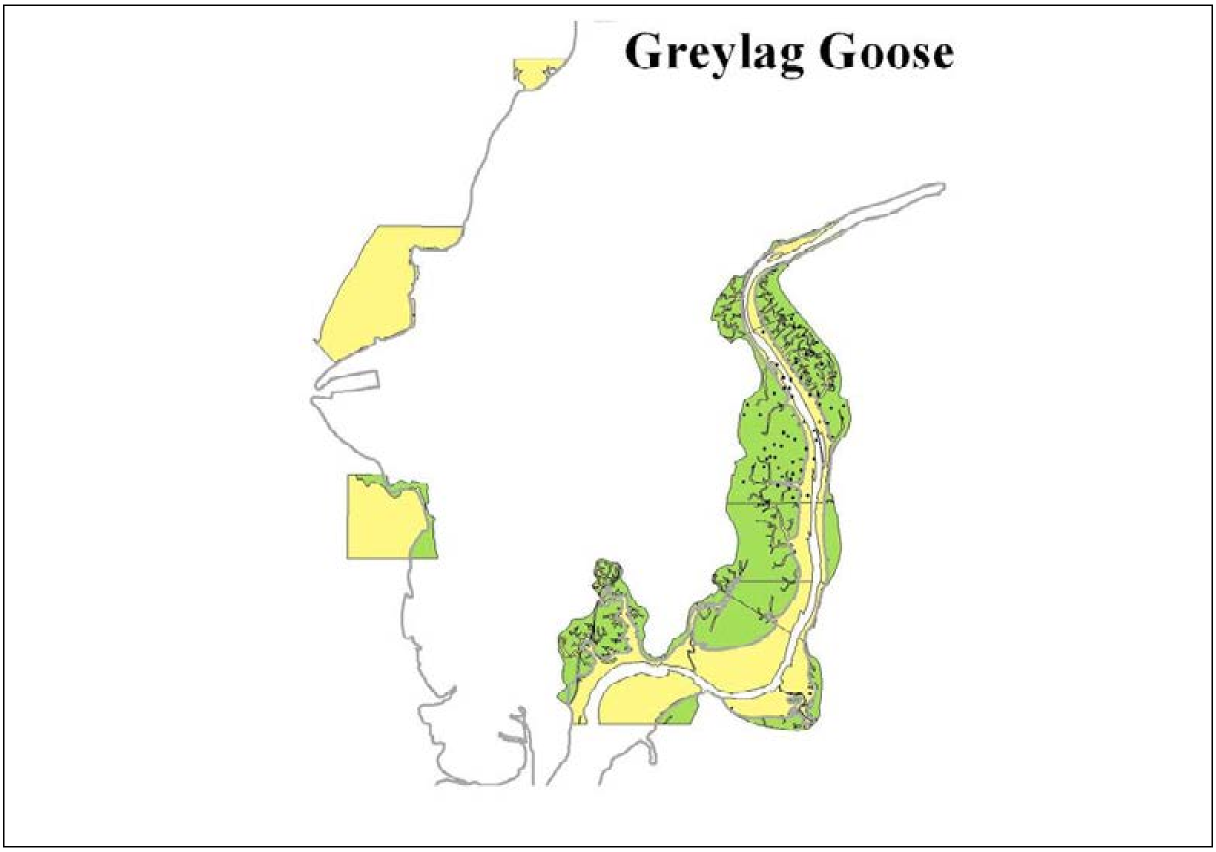
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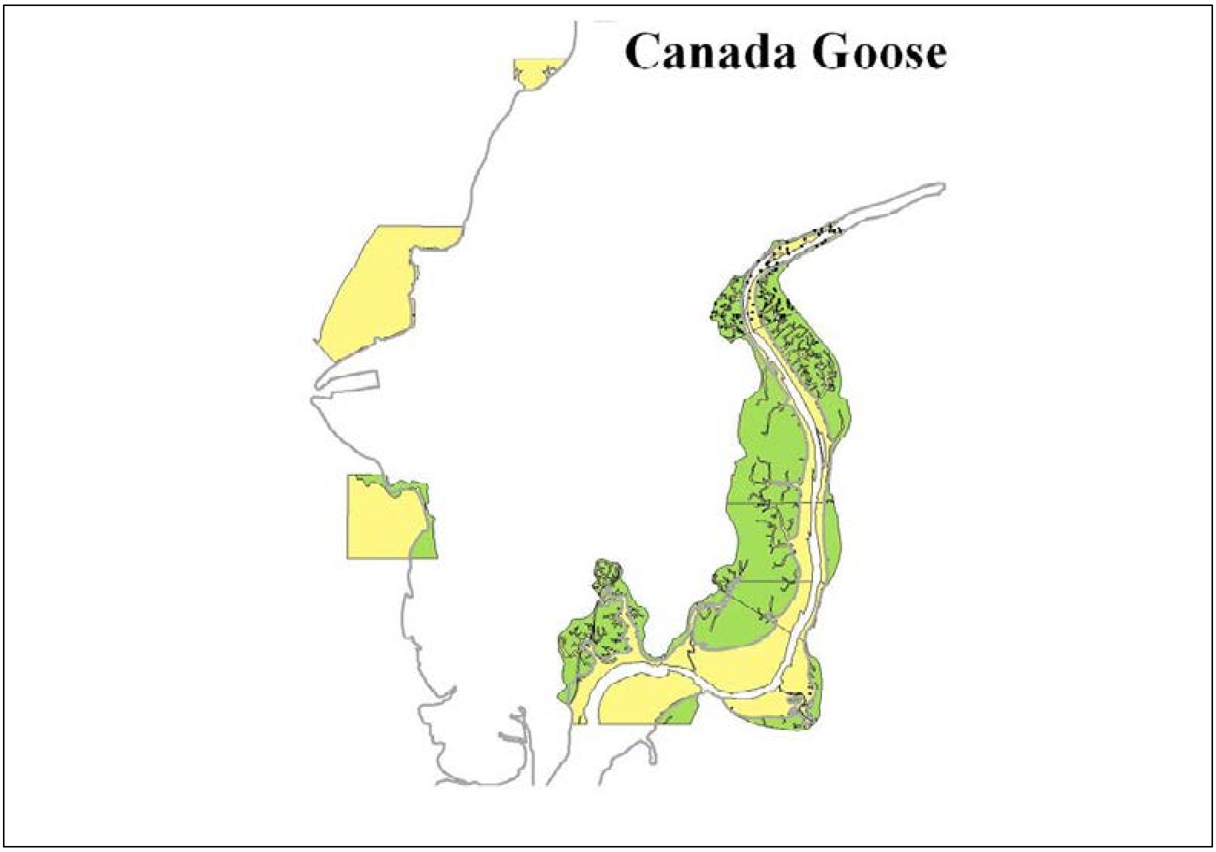
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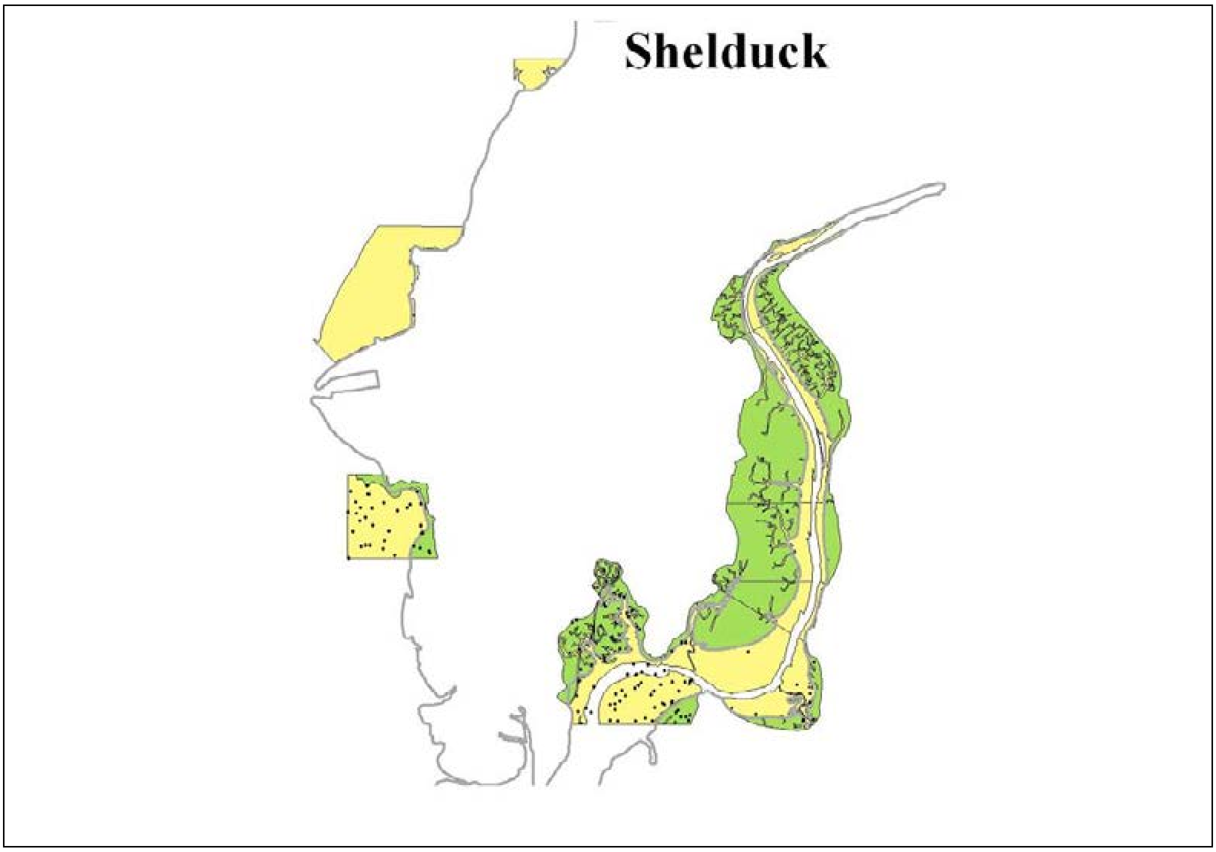
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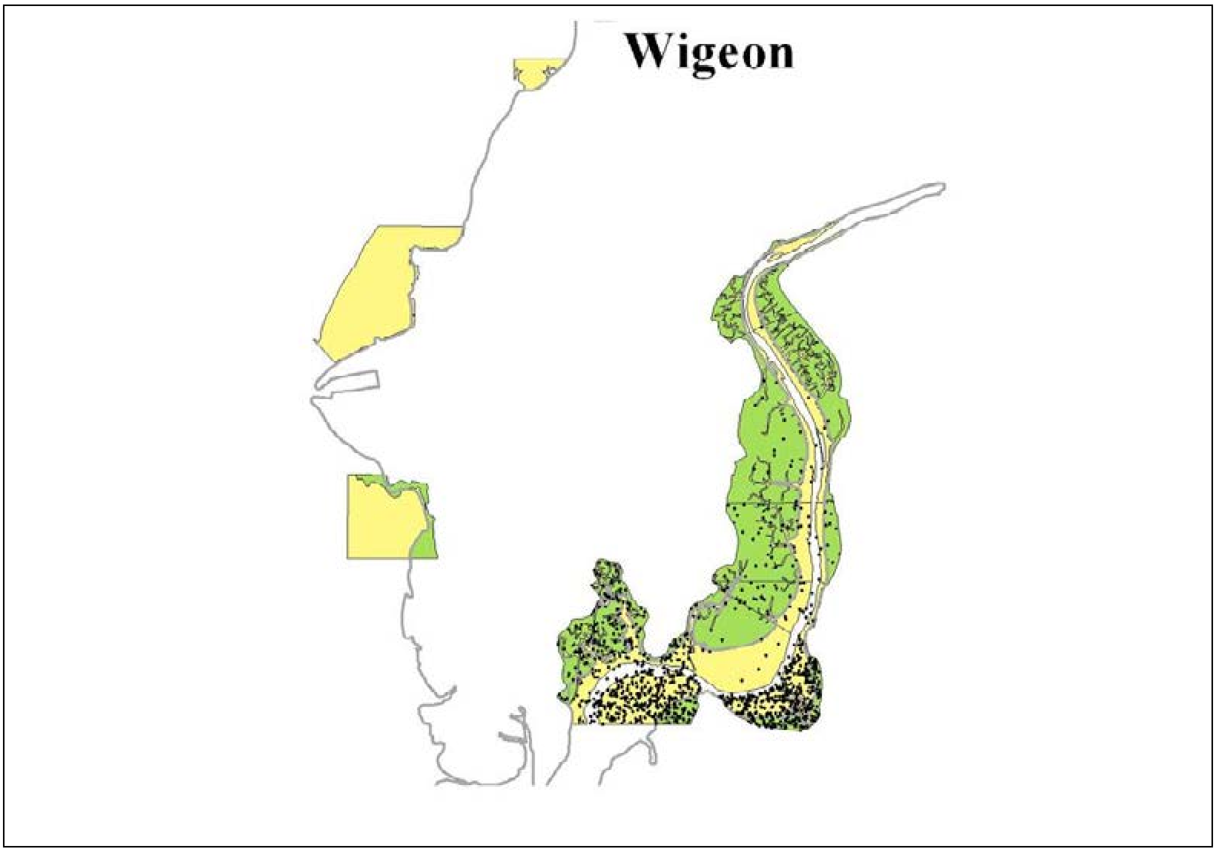
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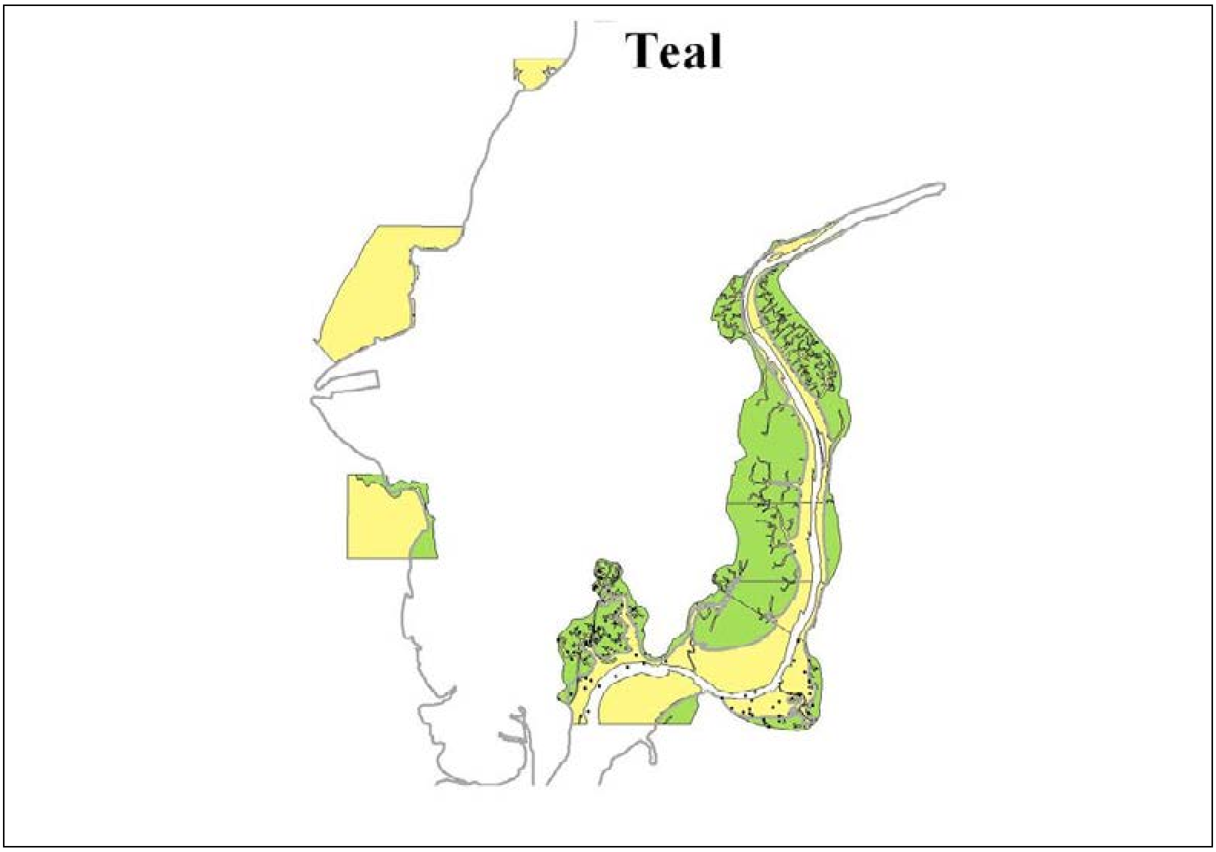
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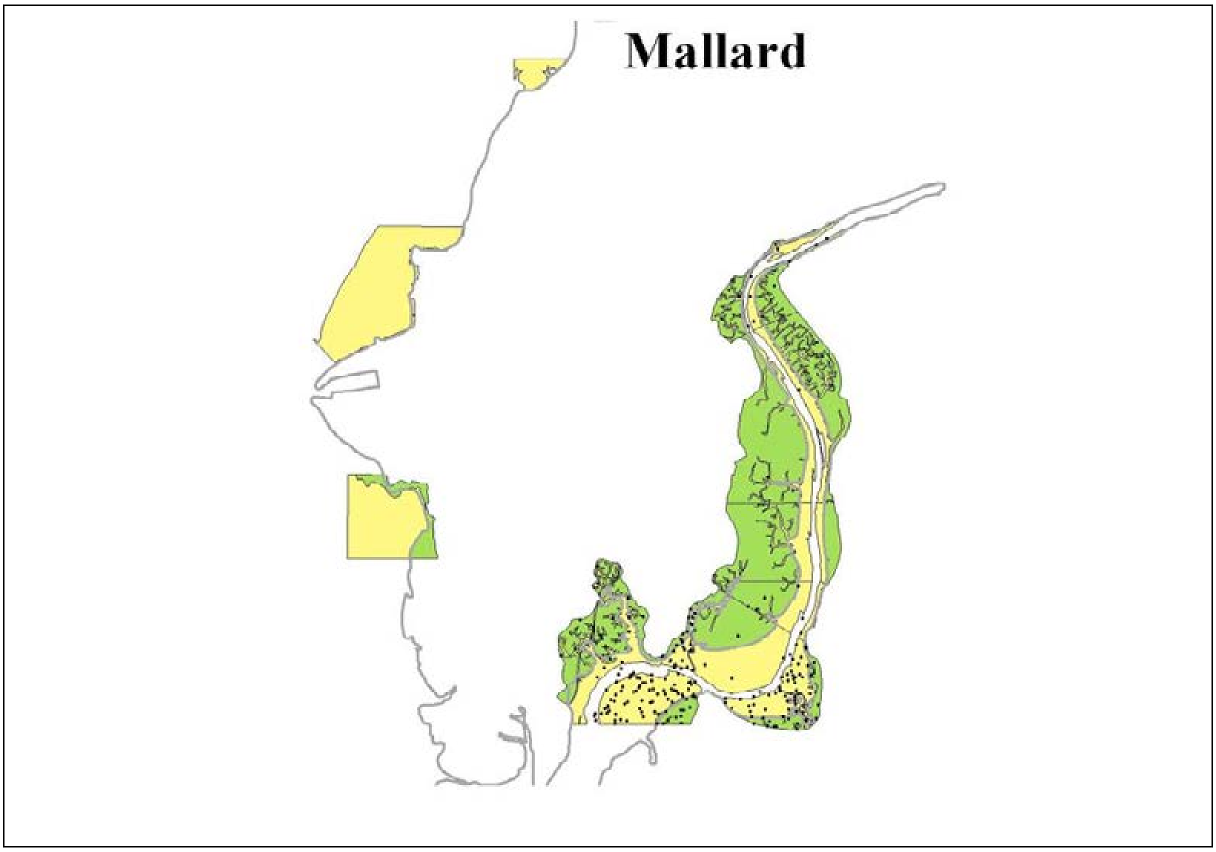
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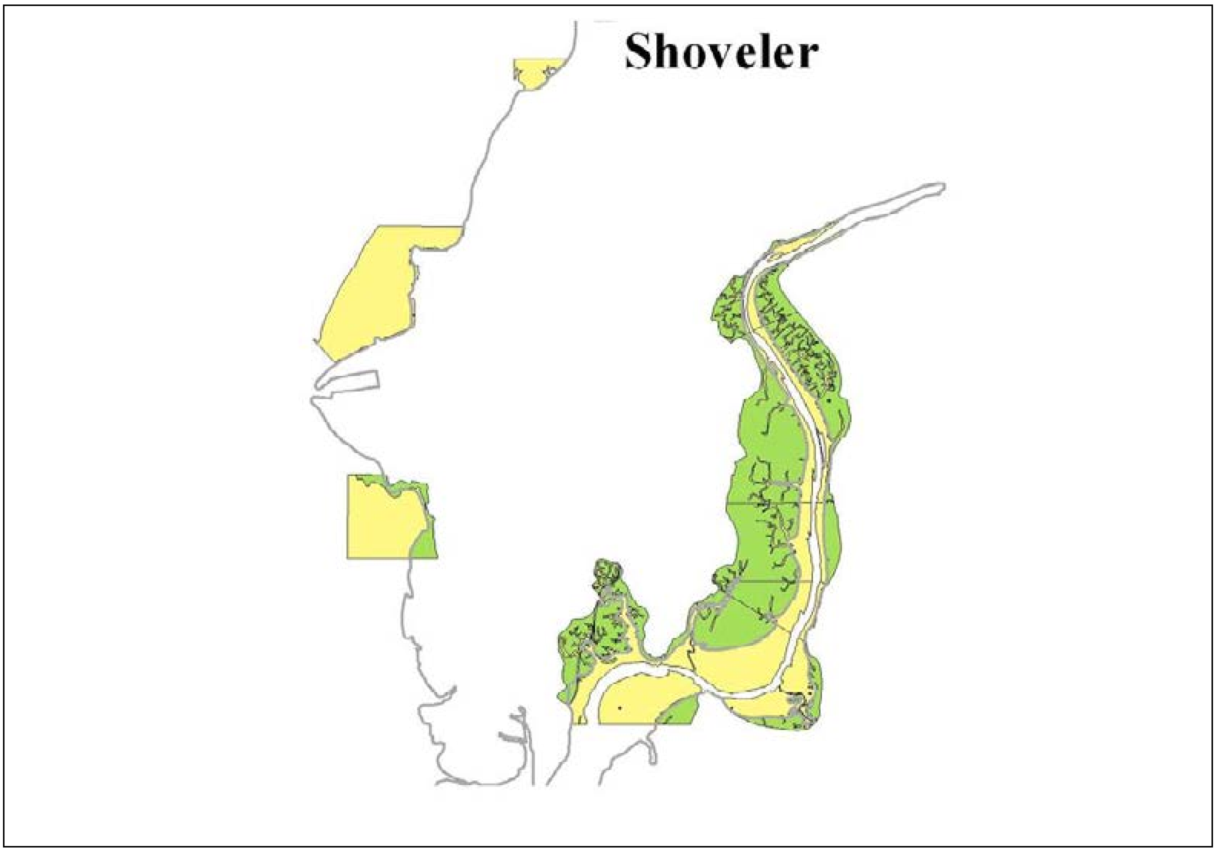
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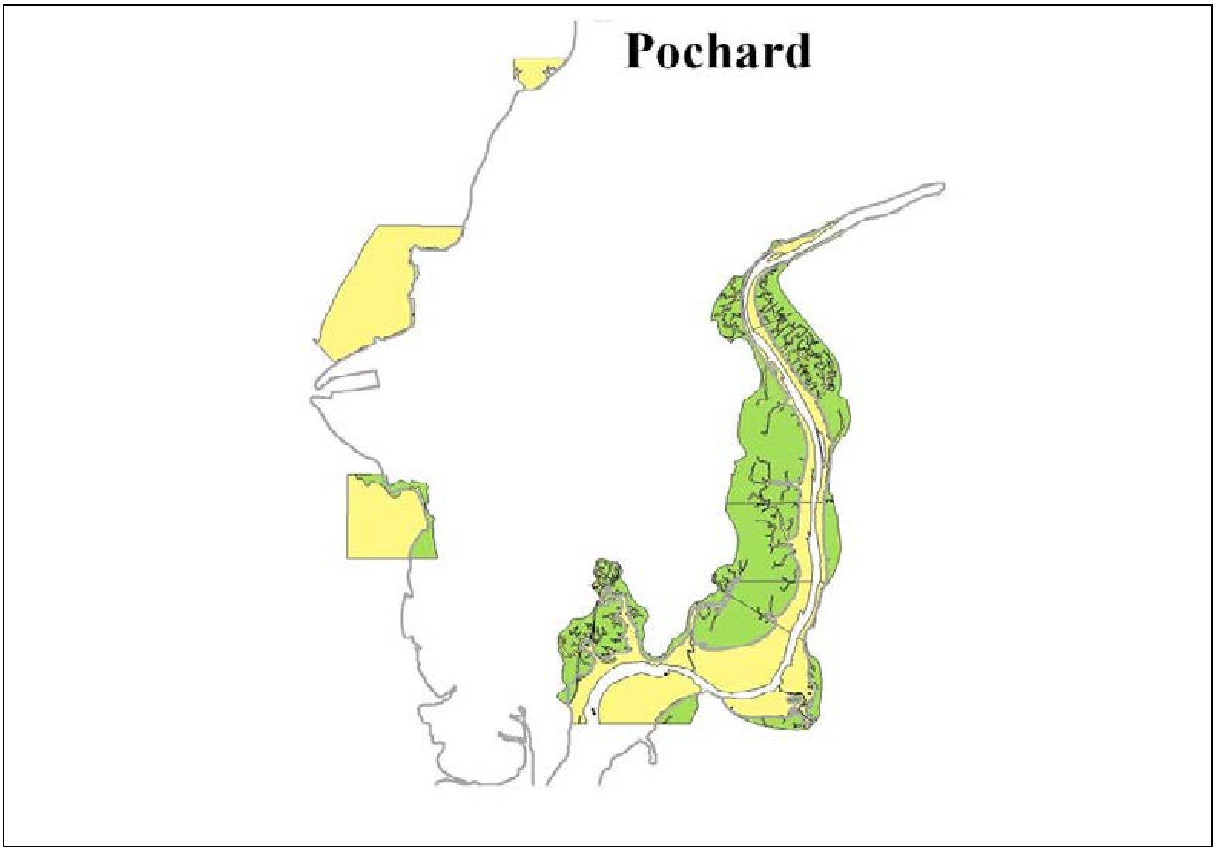
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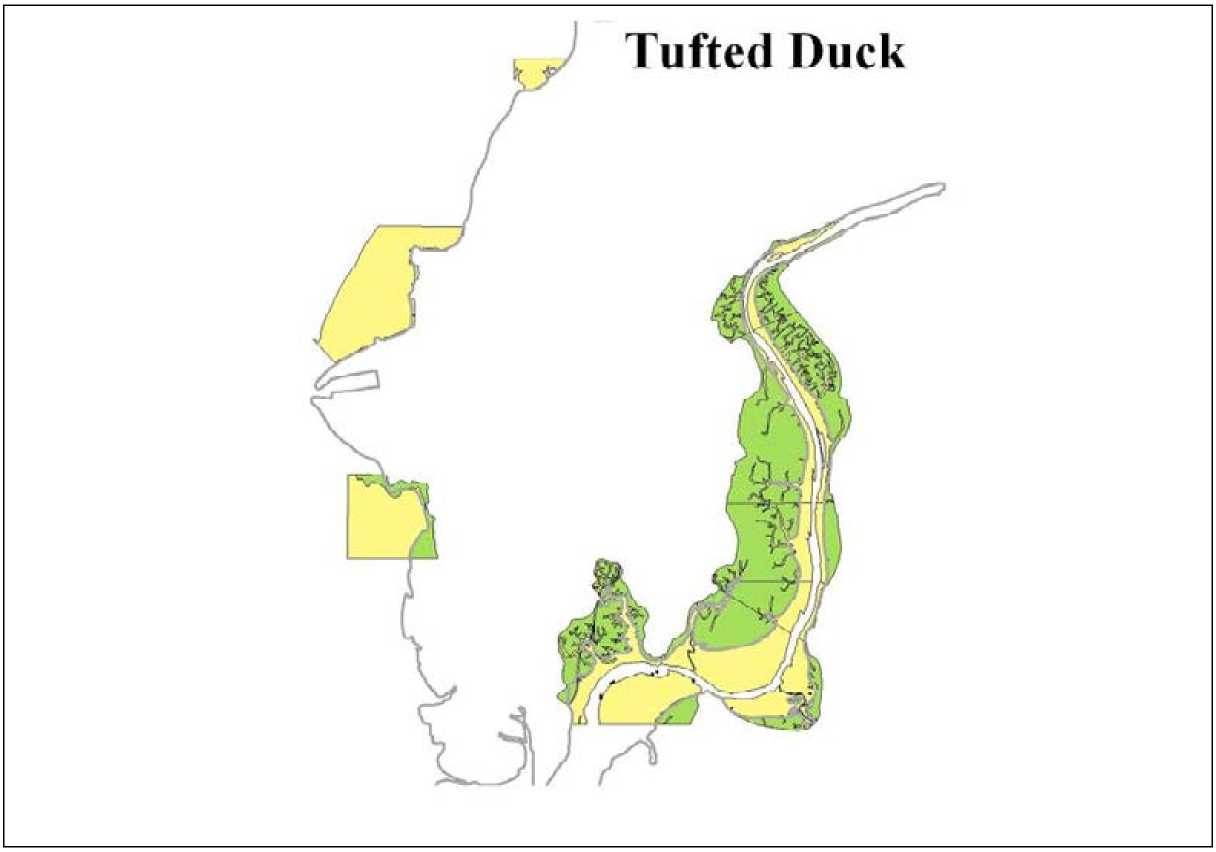
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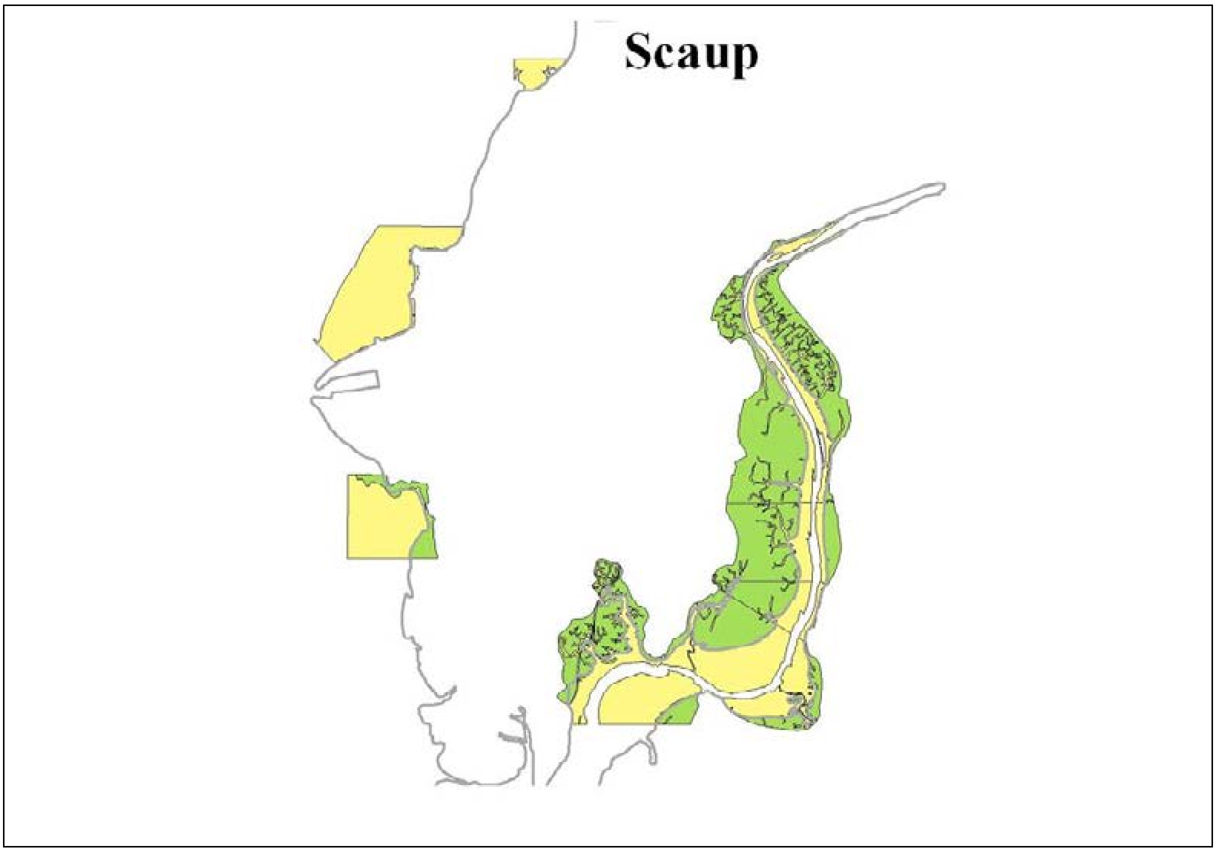
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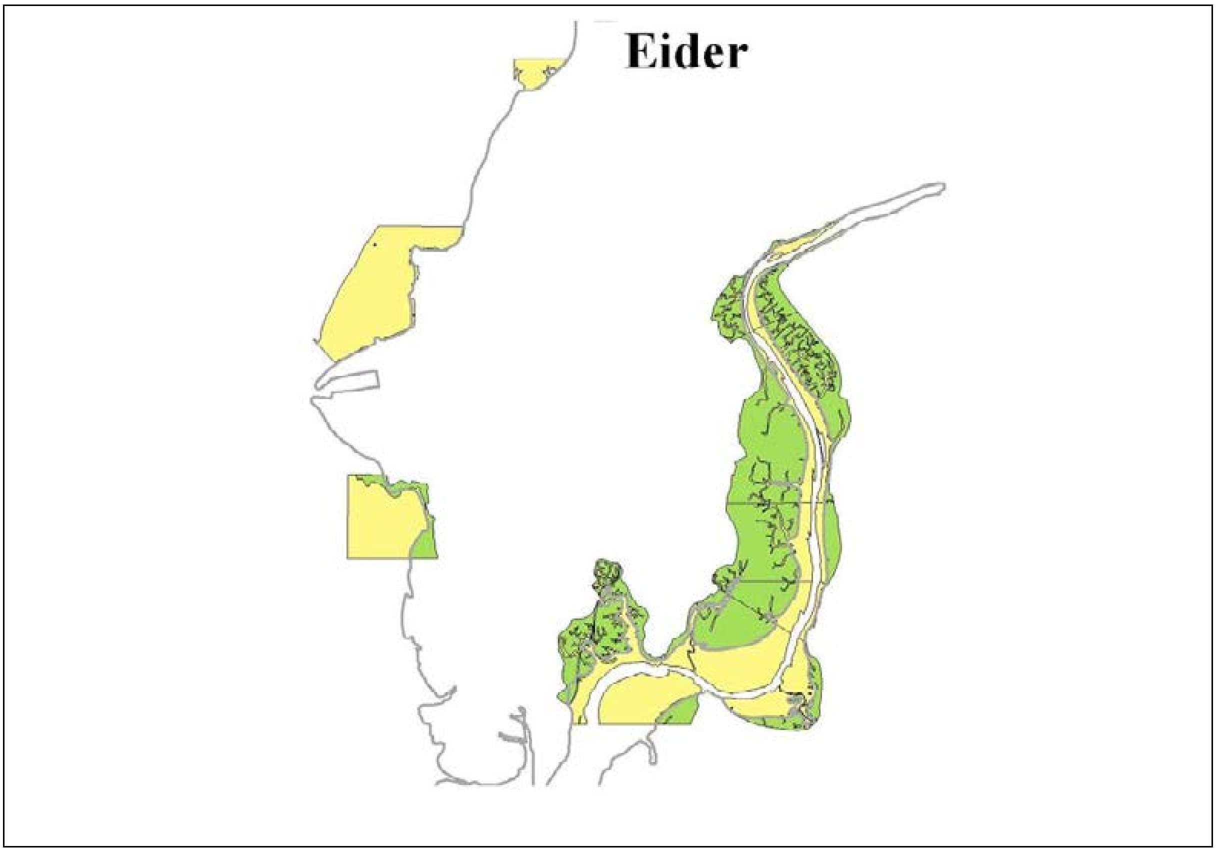
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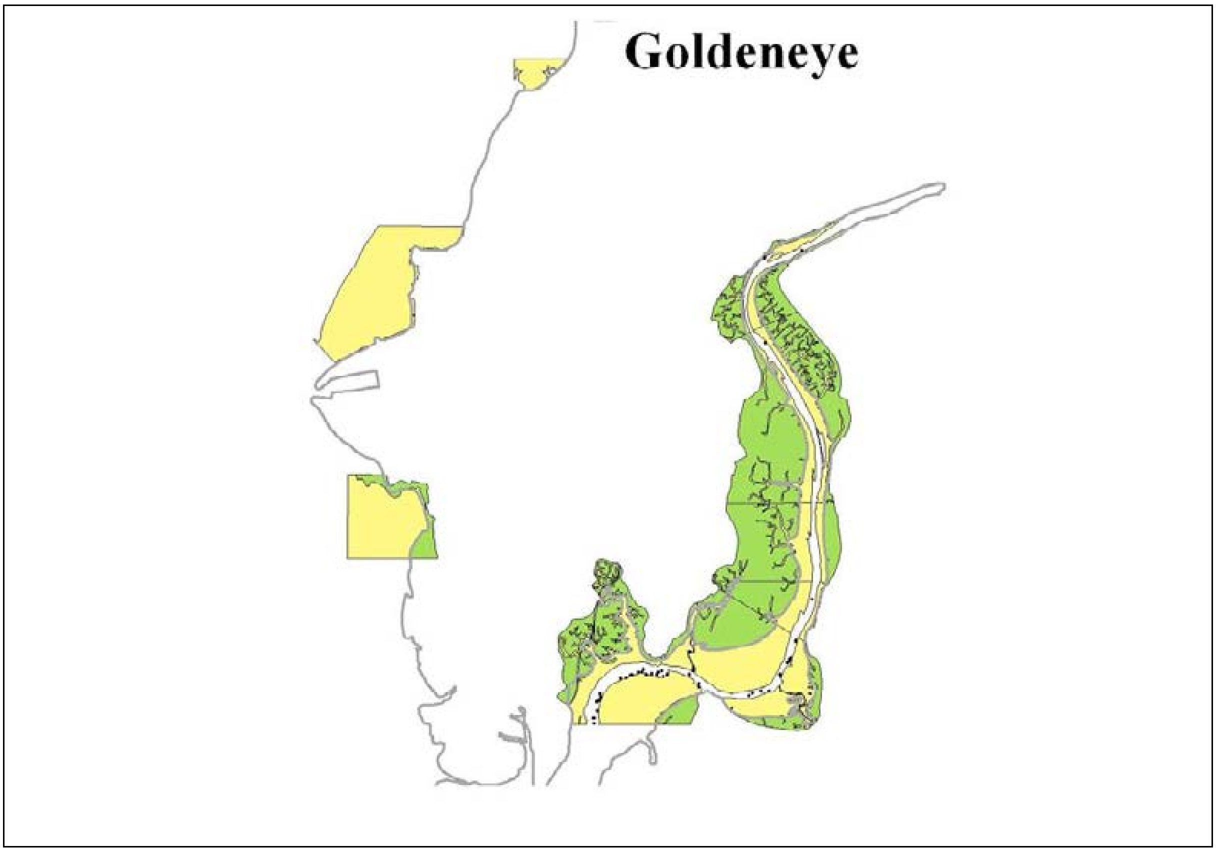
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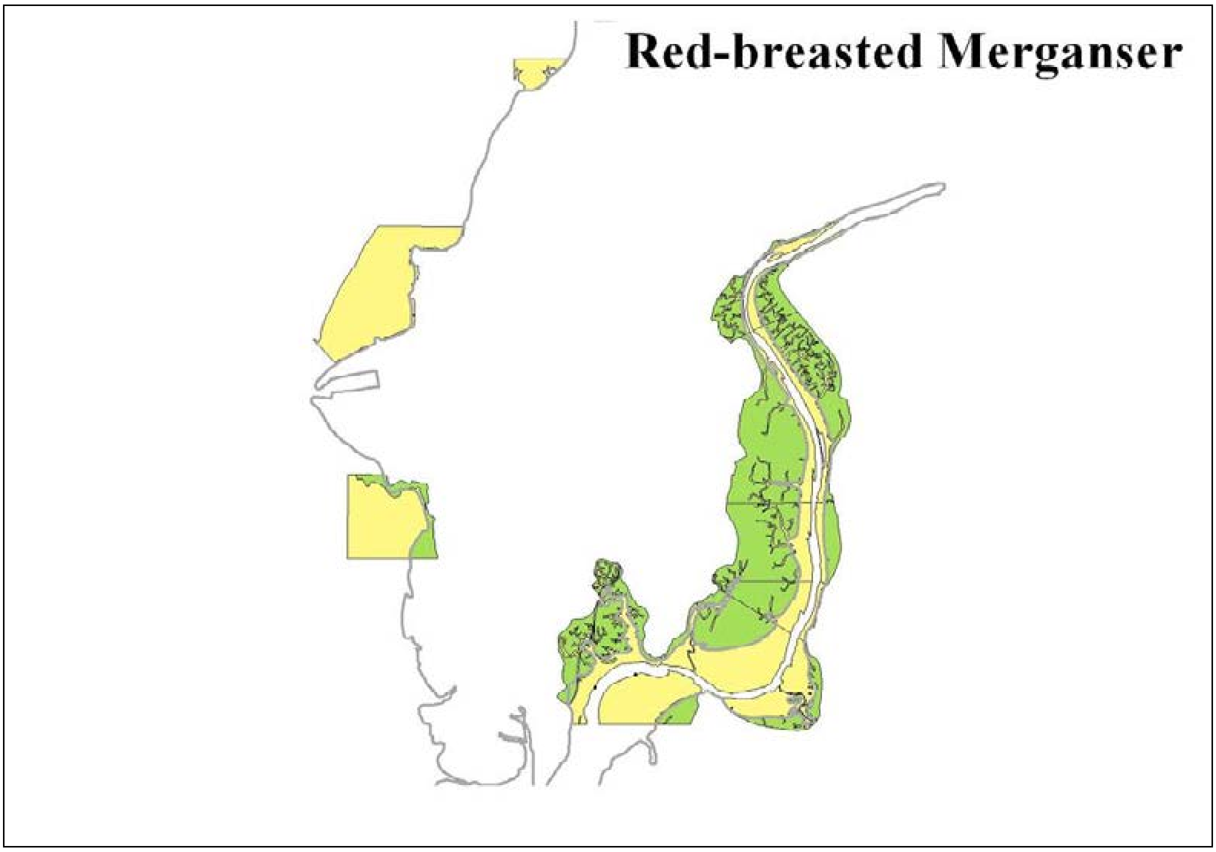
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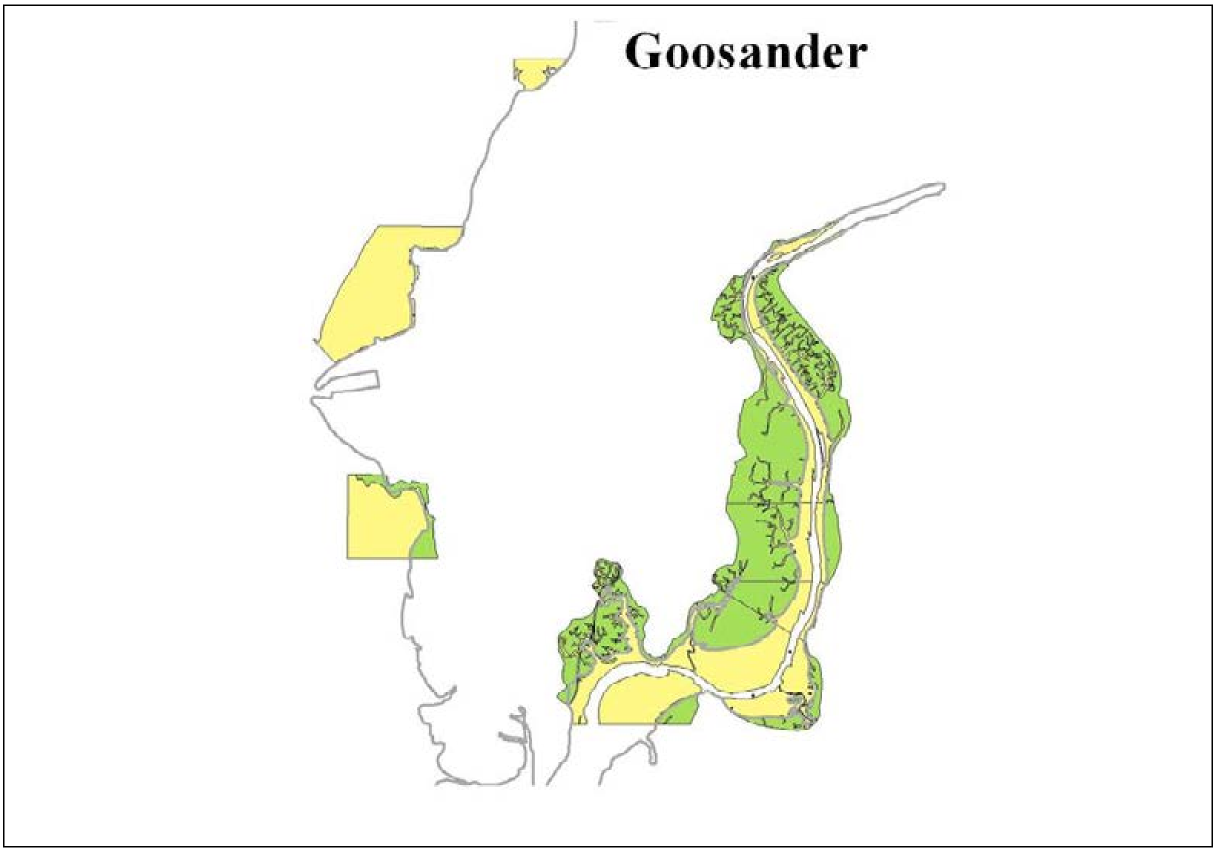
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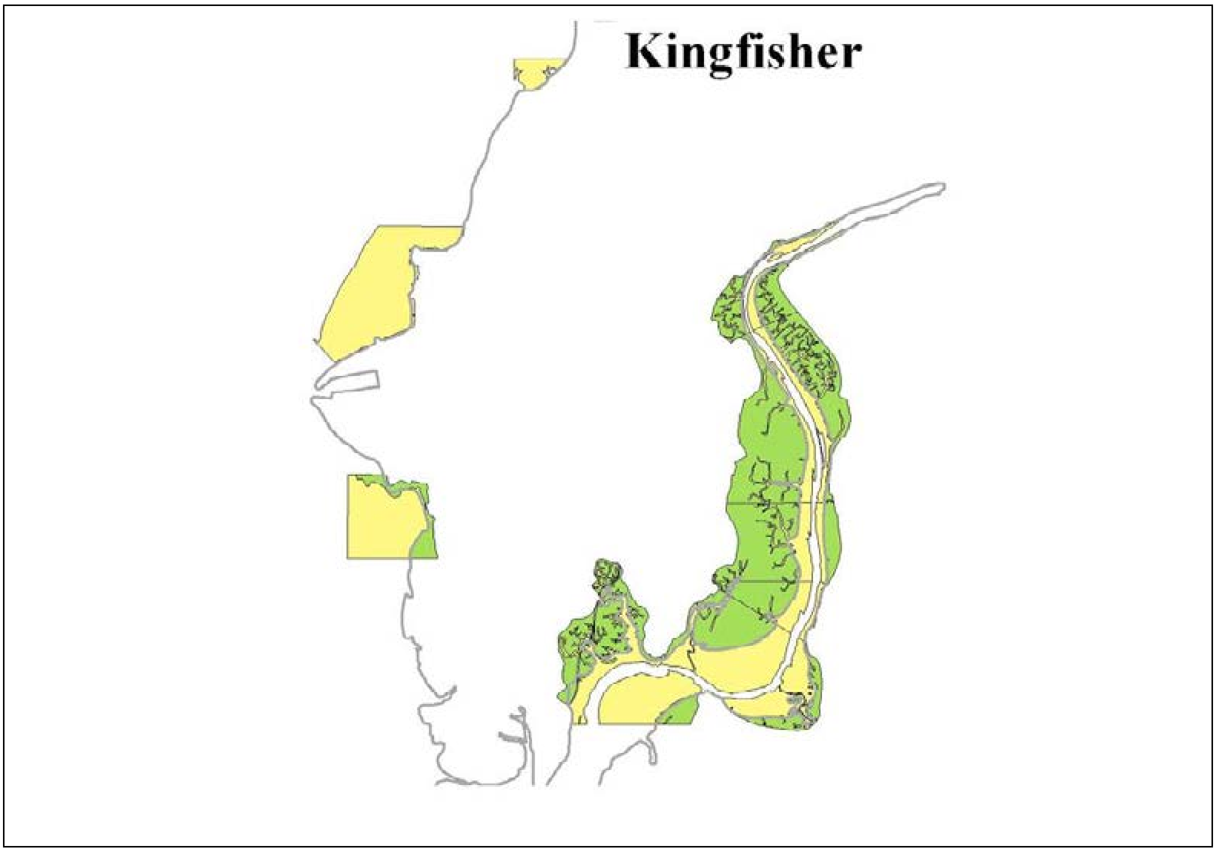
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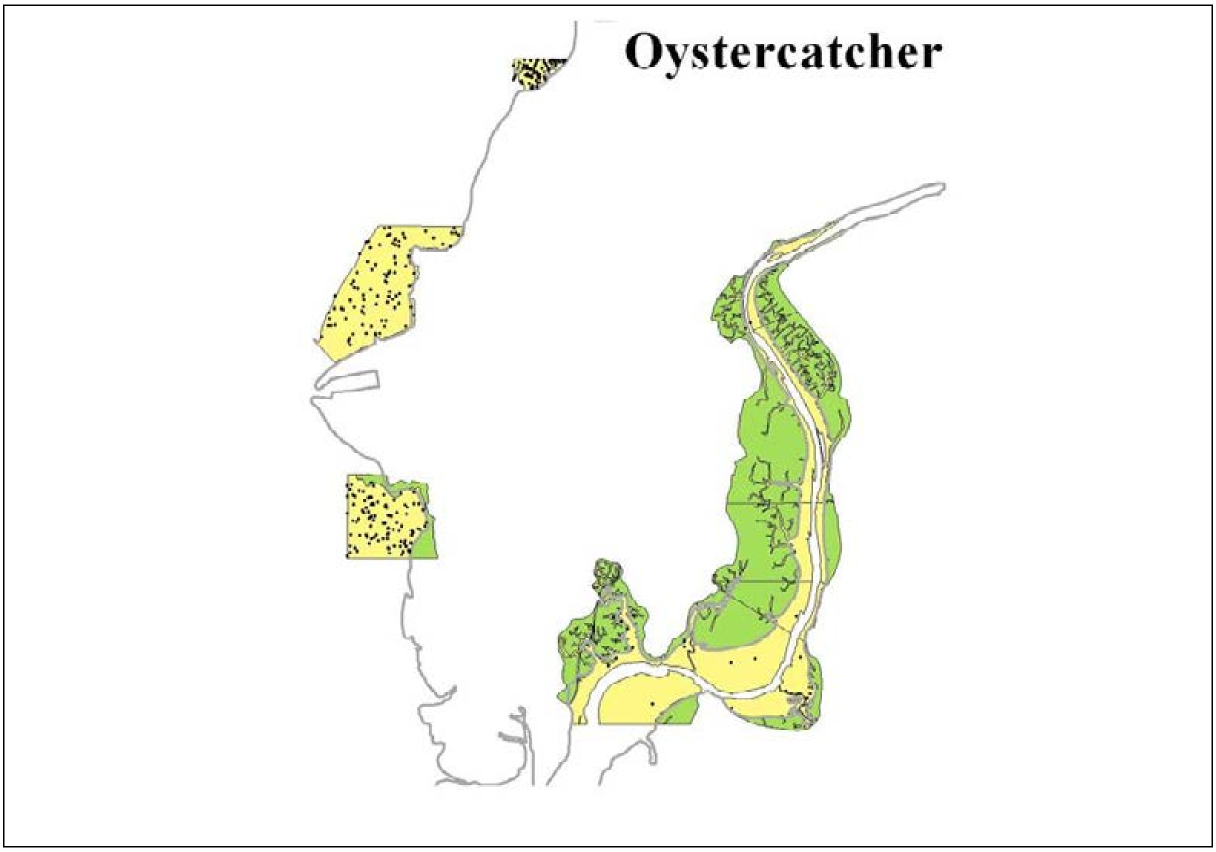
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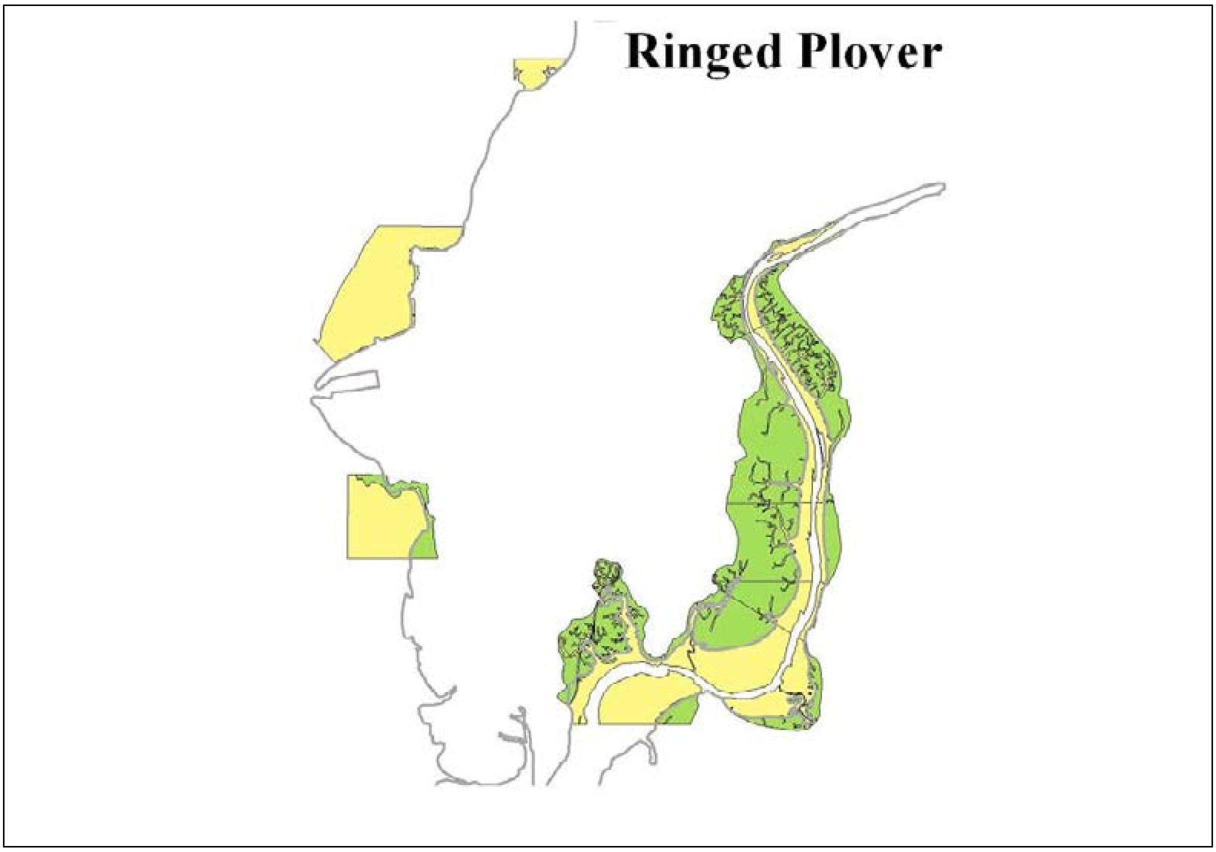
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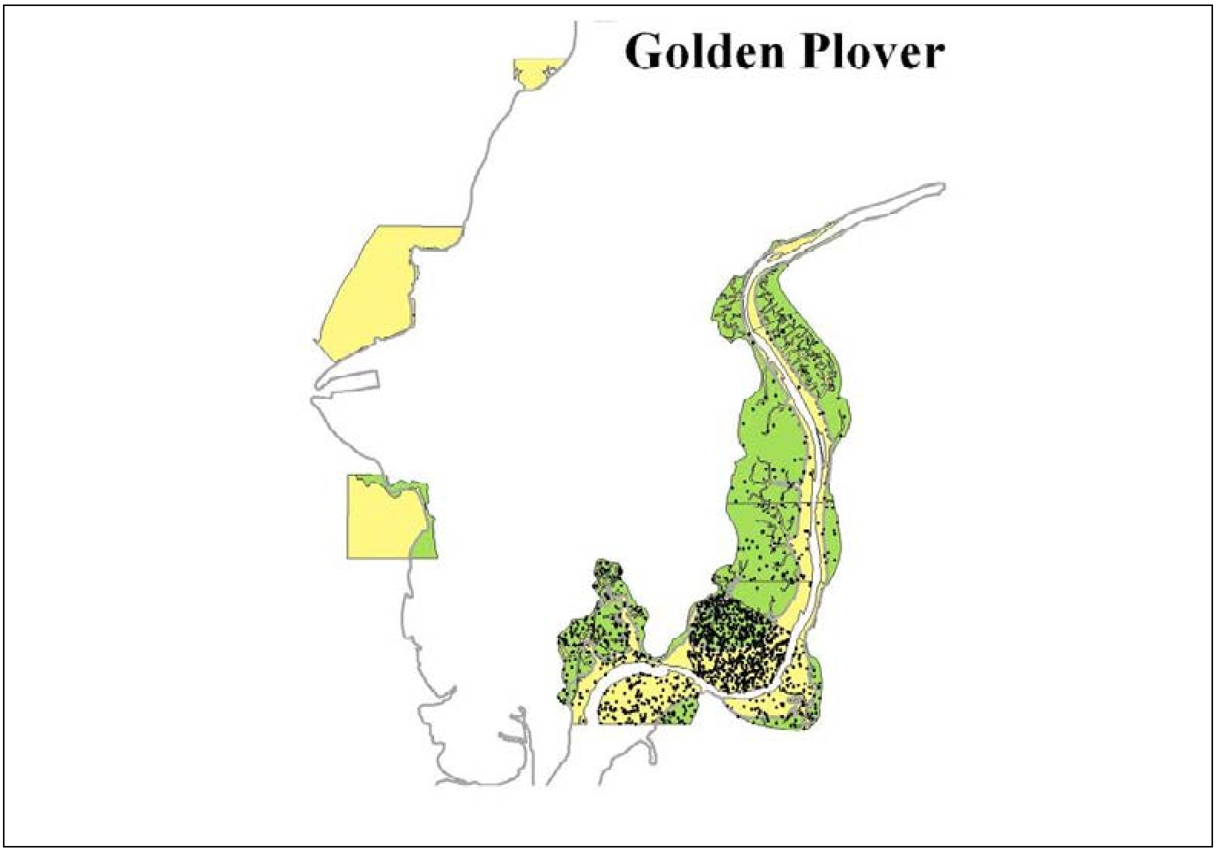
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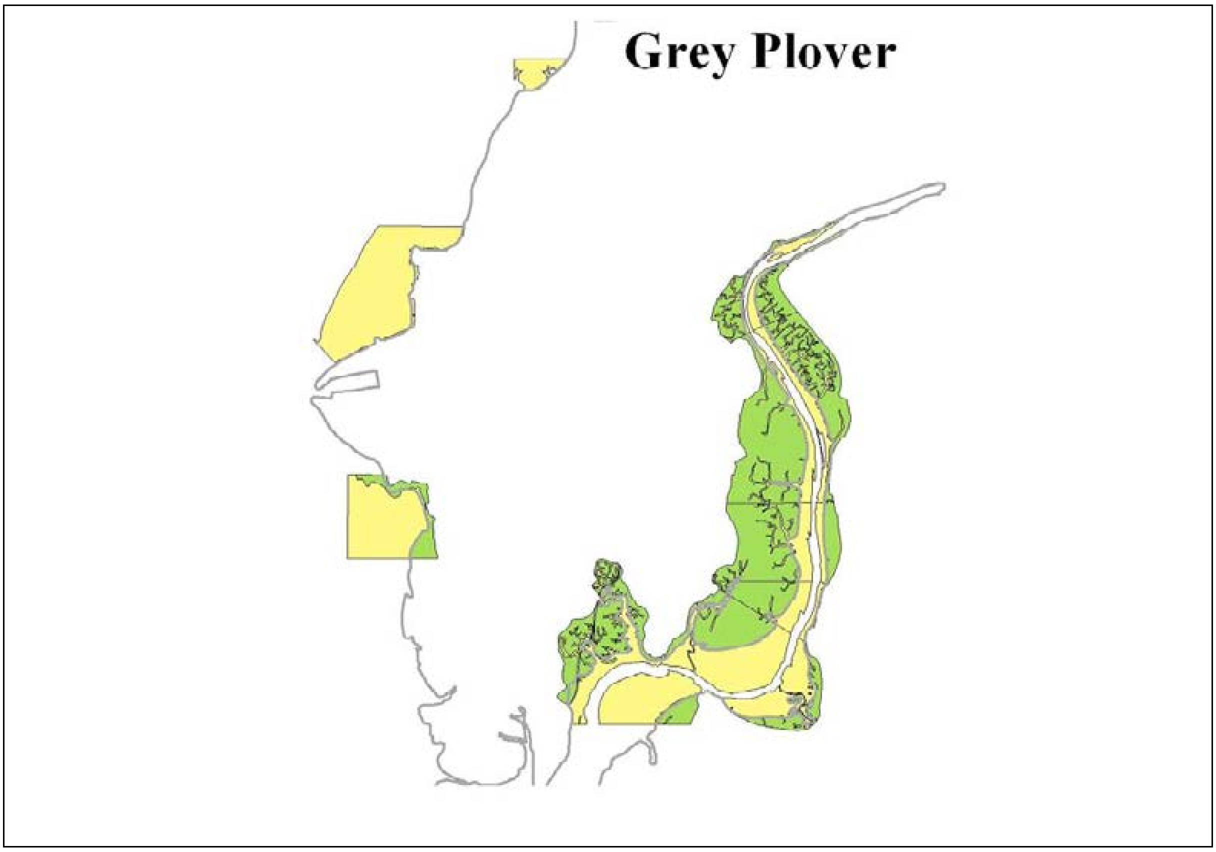
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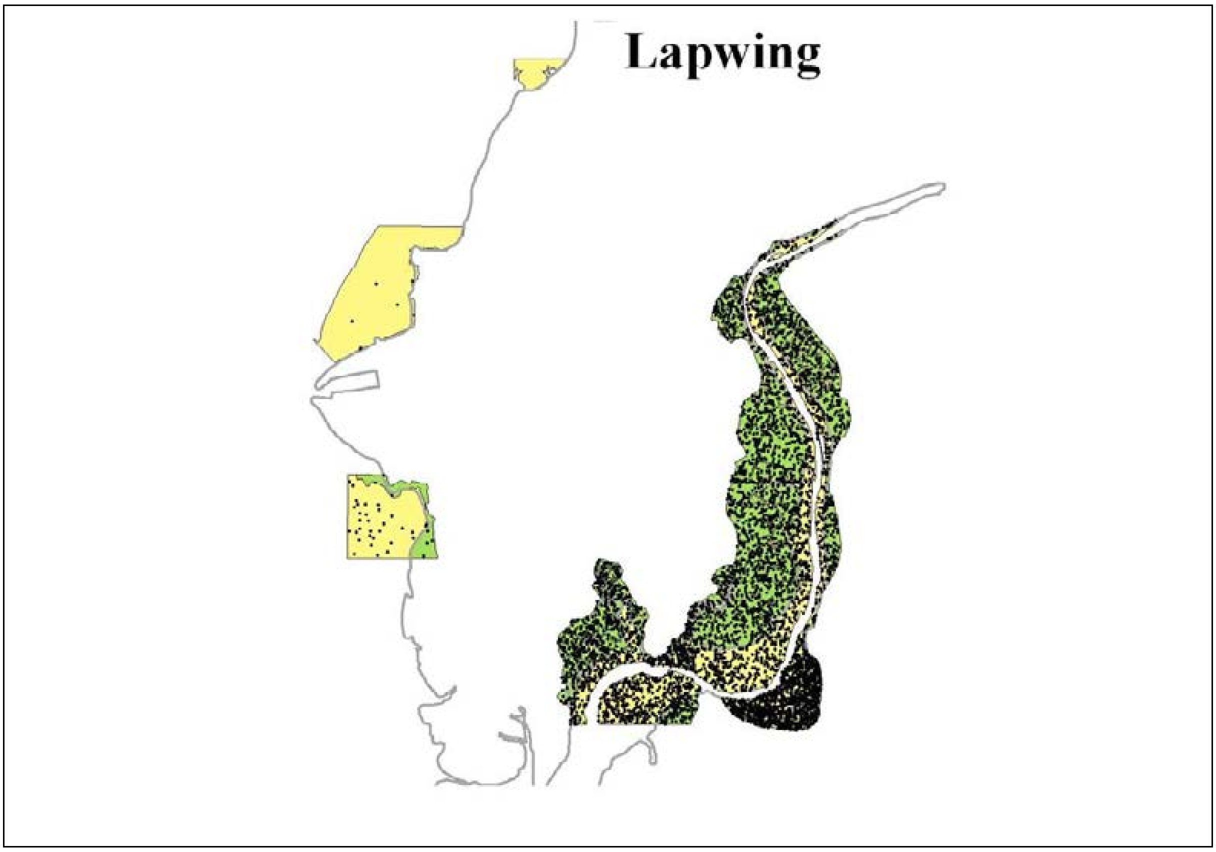
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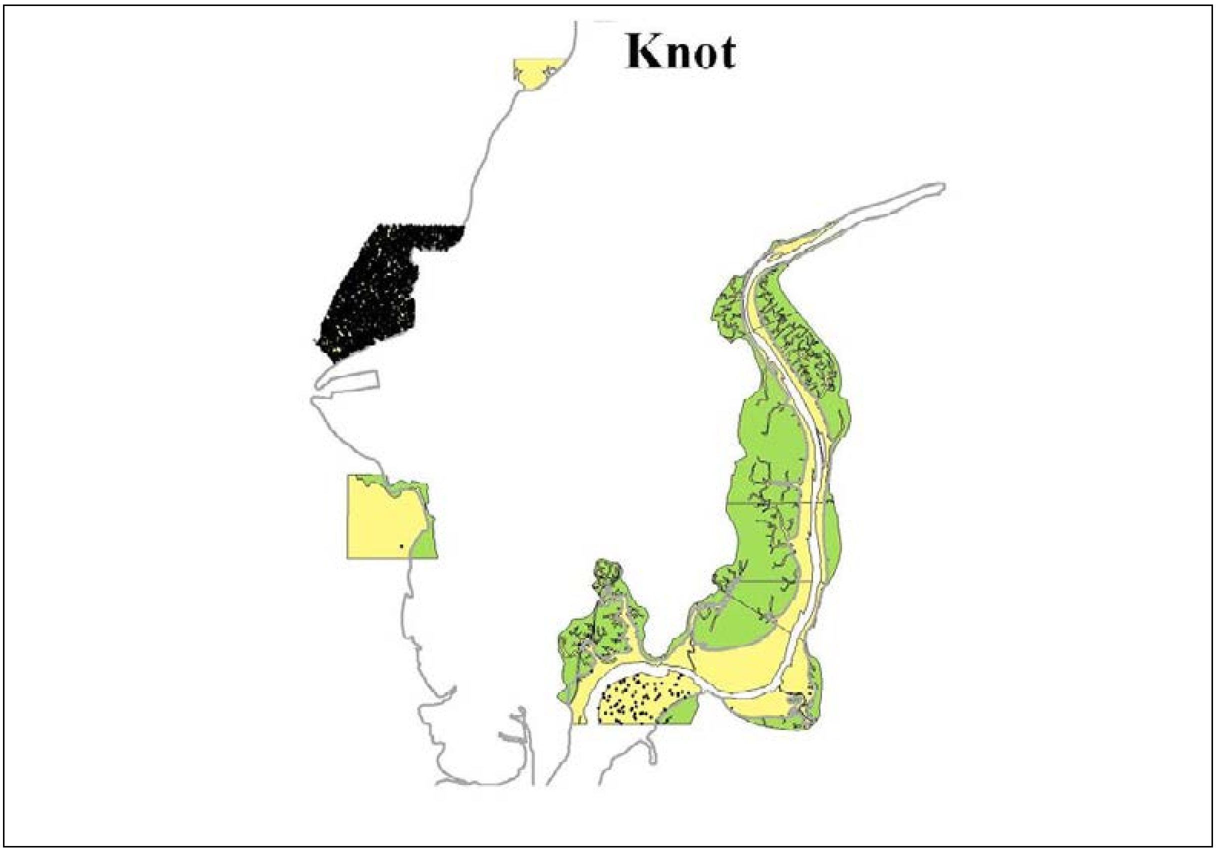
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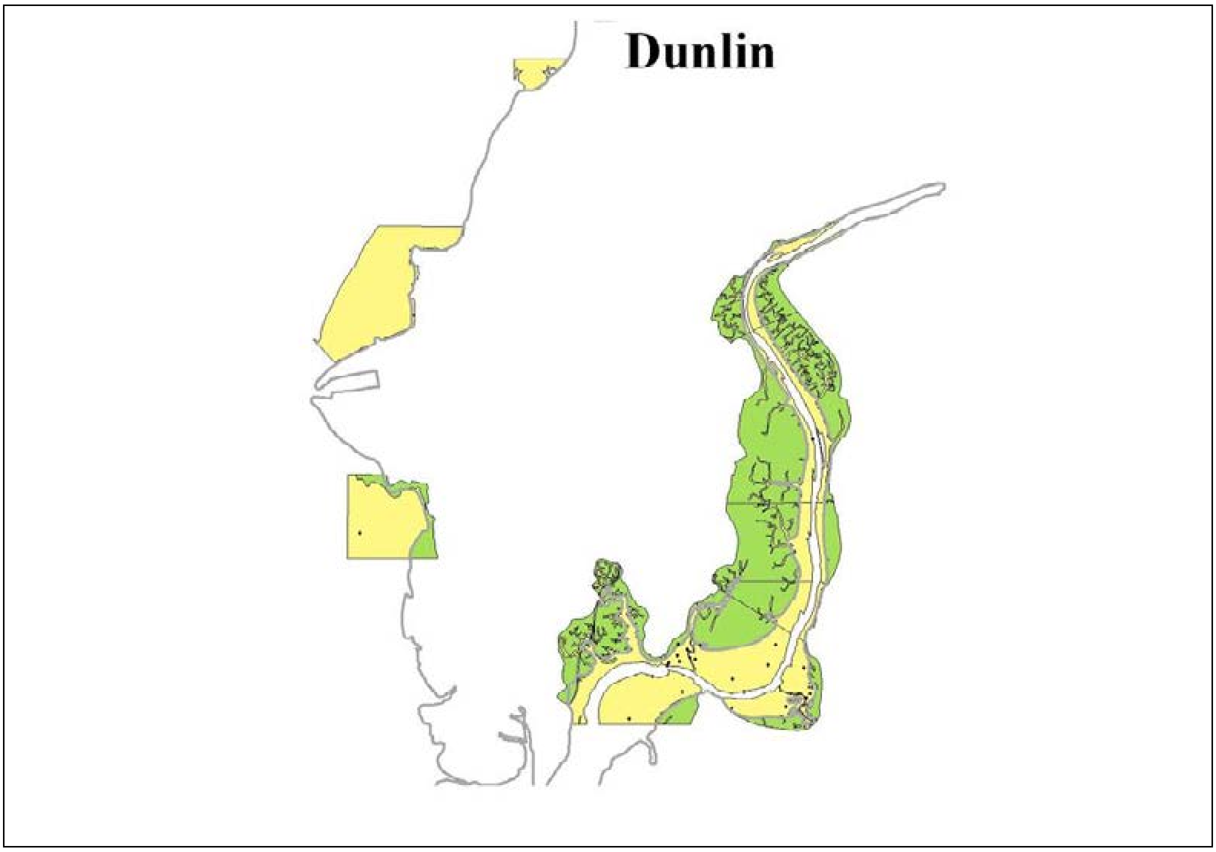
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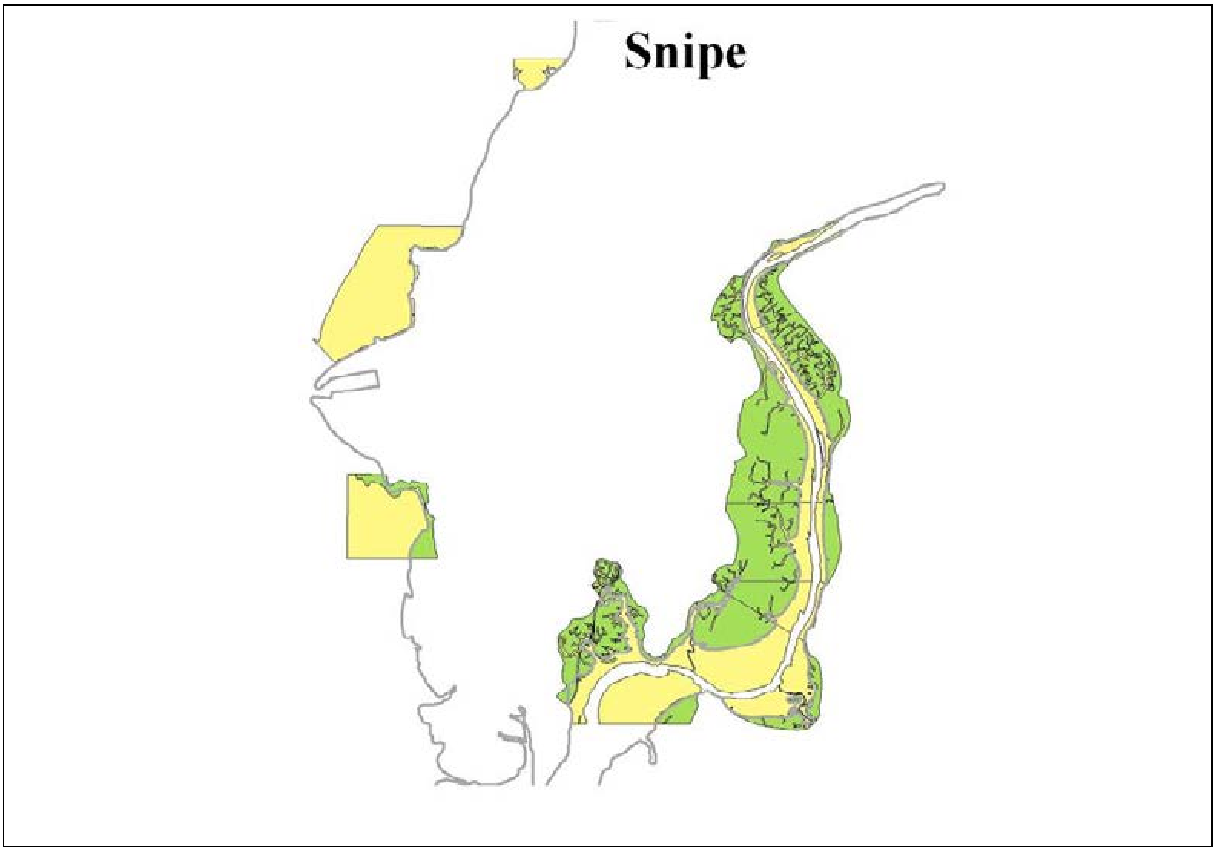
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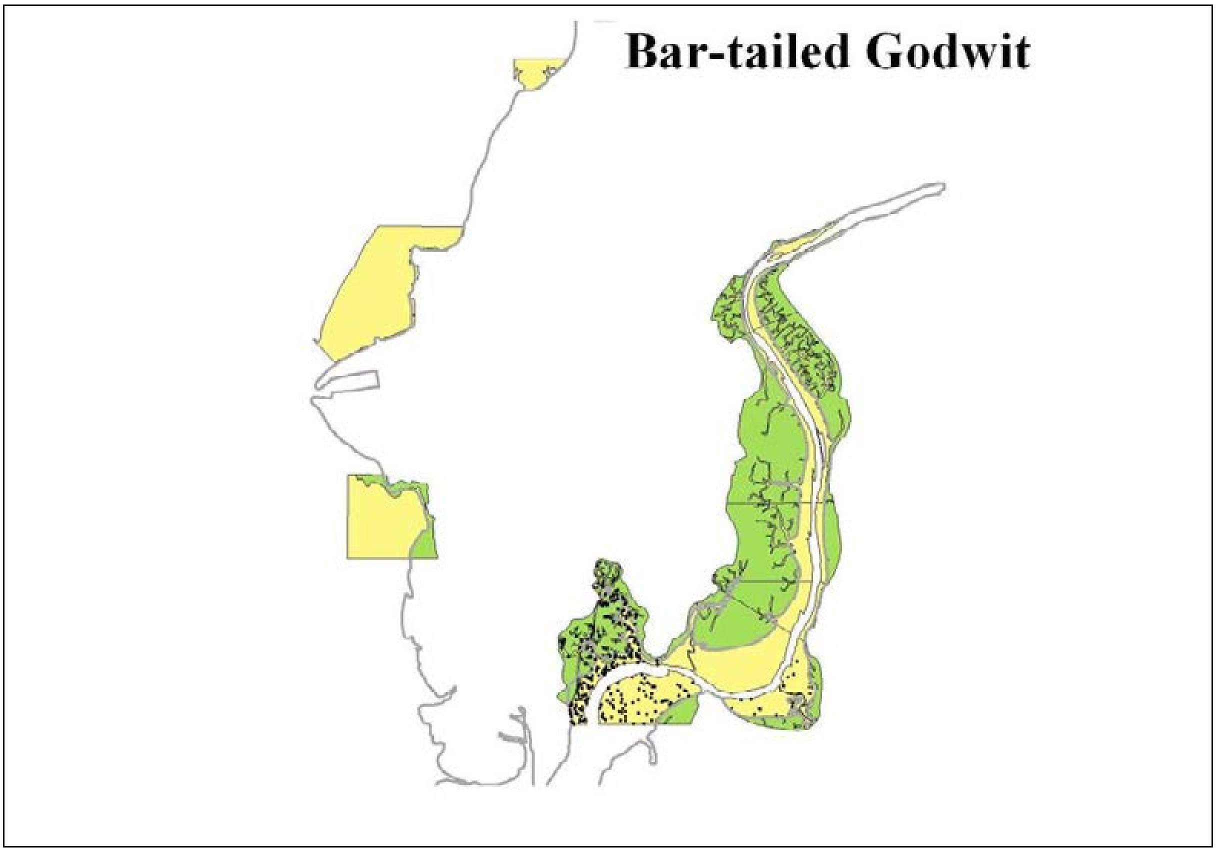
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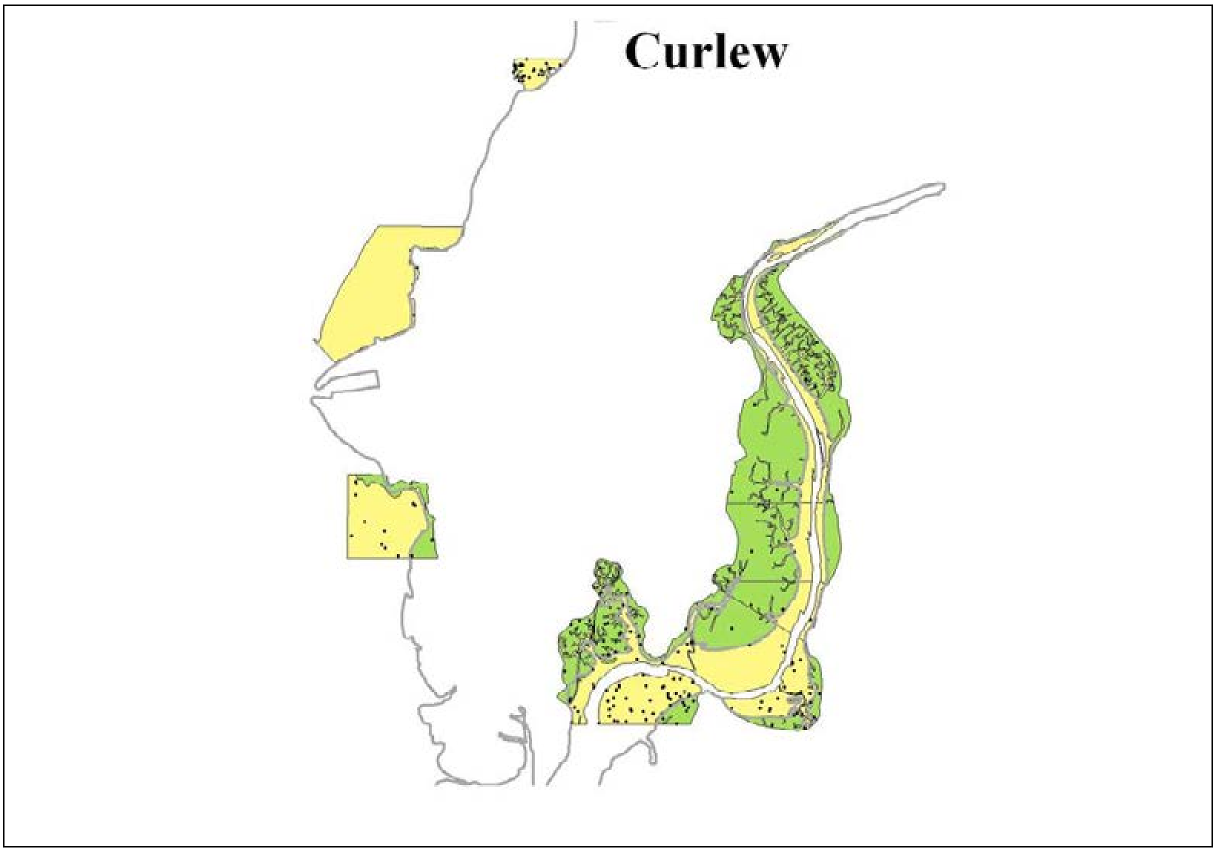
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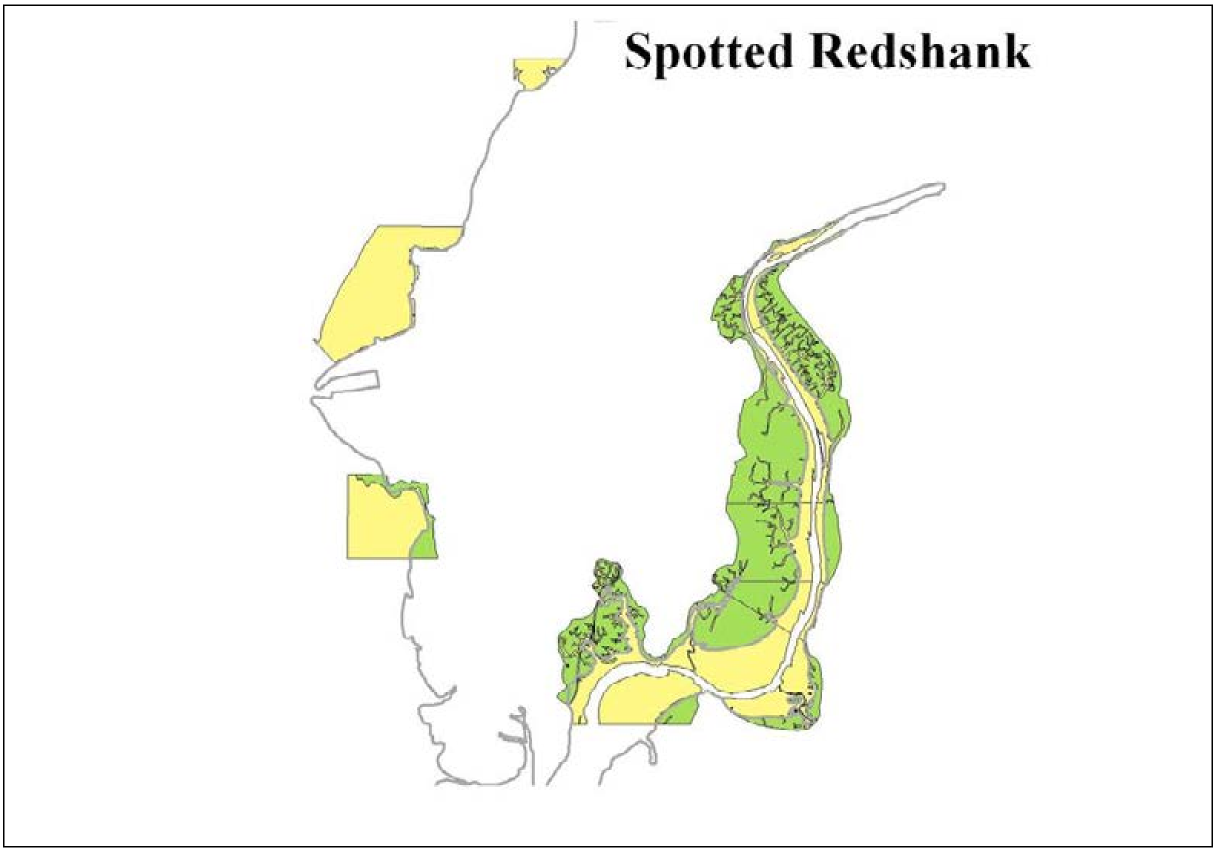
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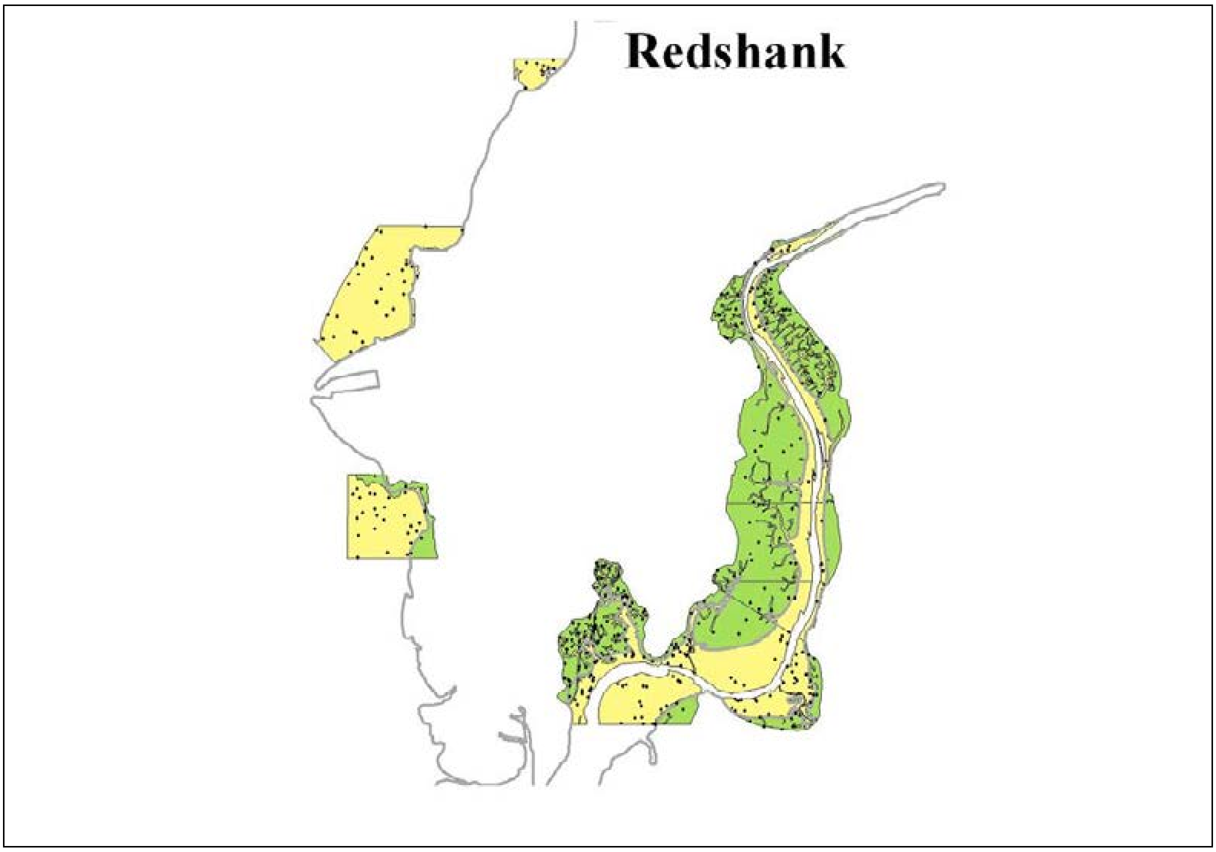
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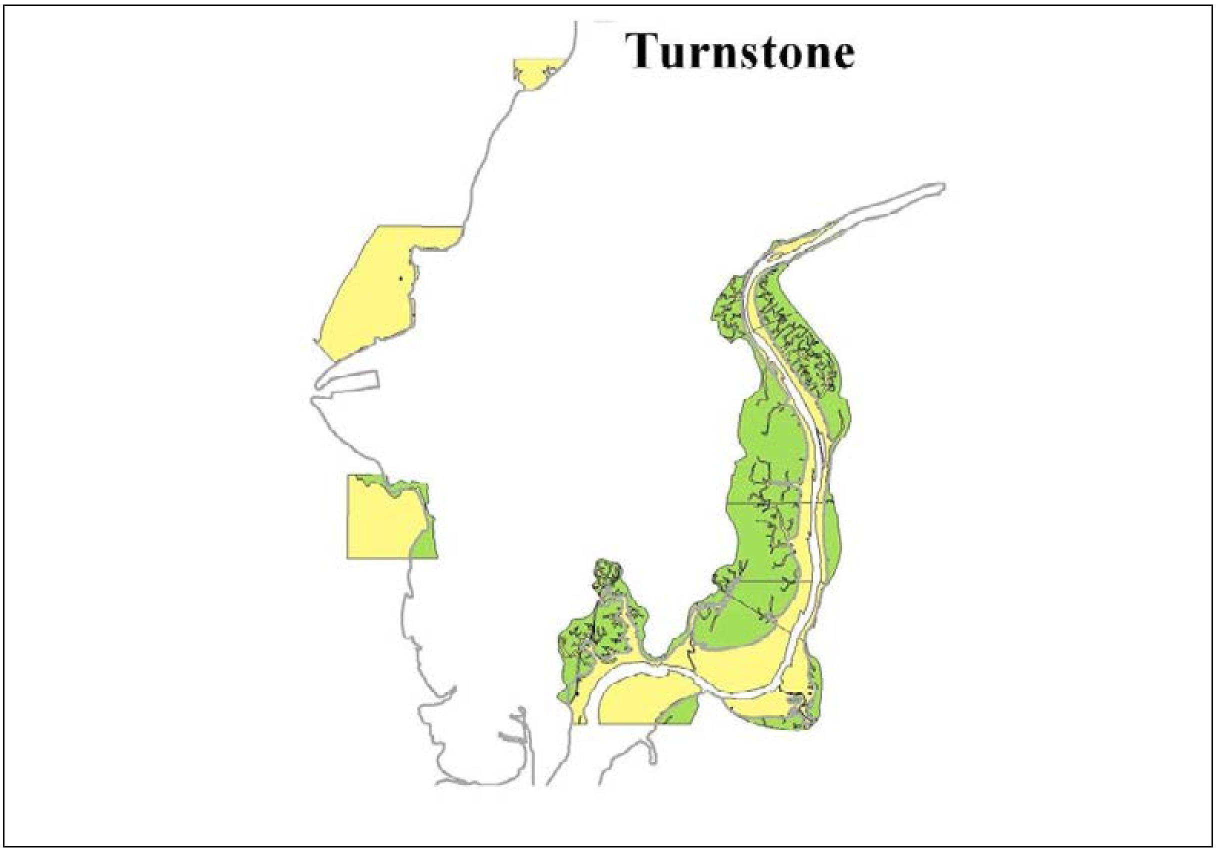
Turnstone

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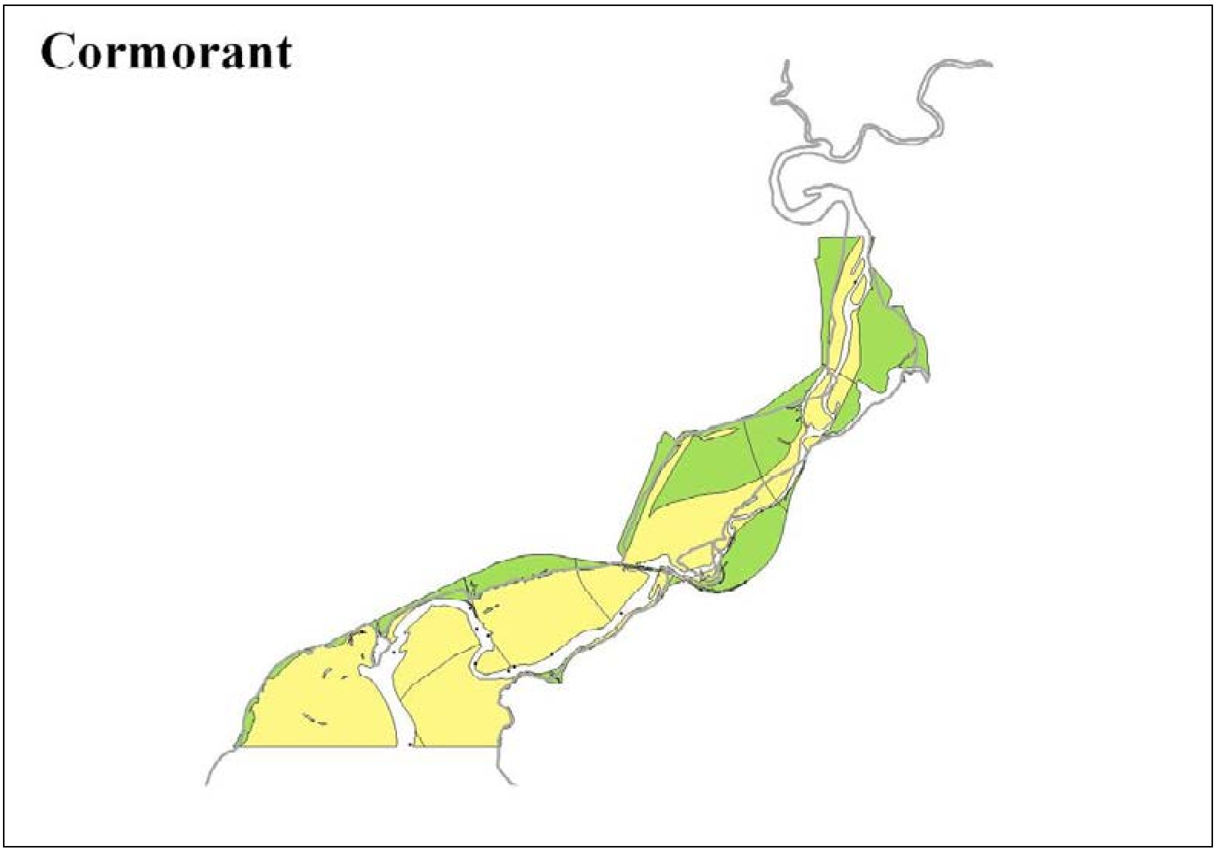

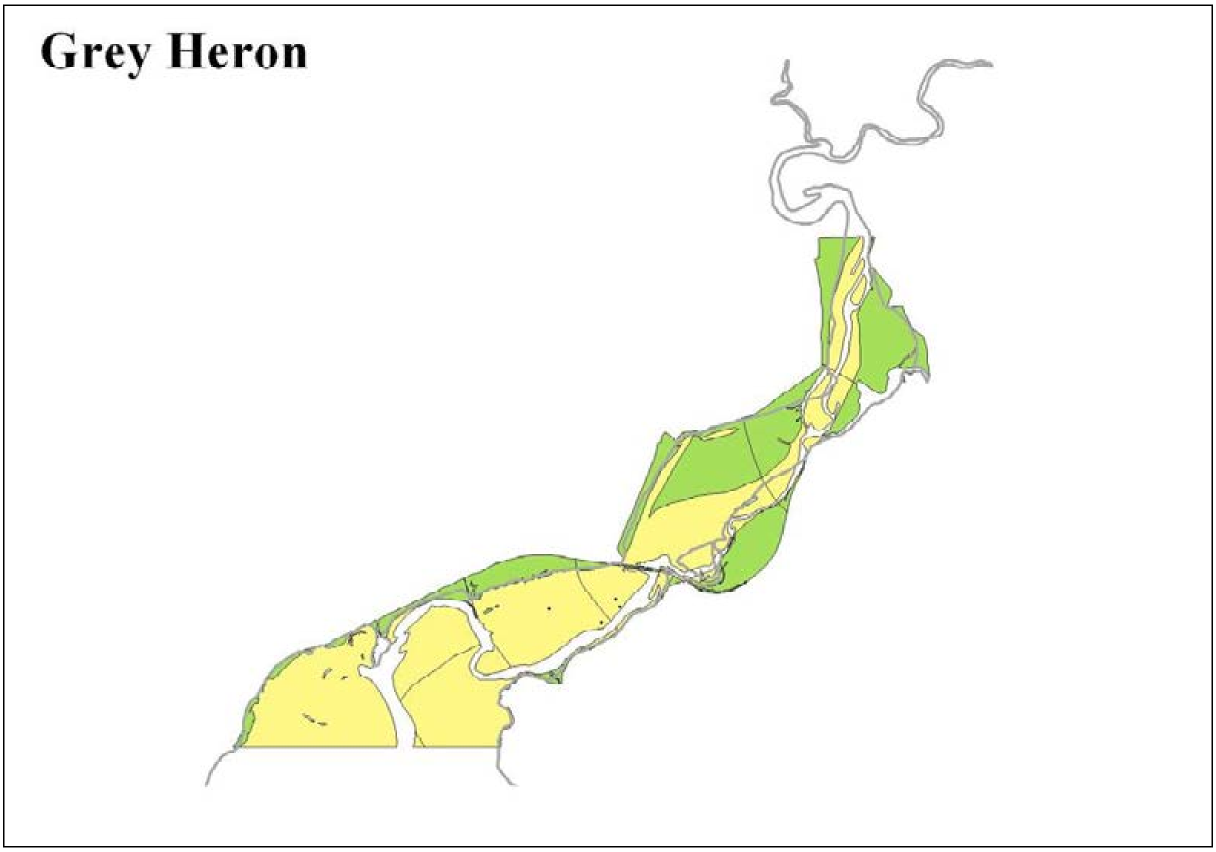

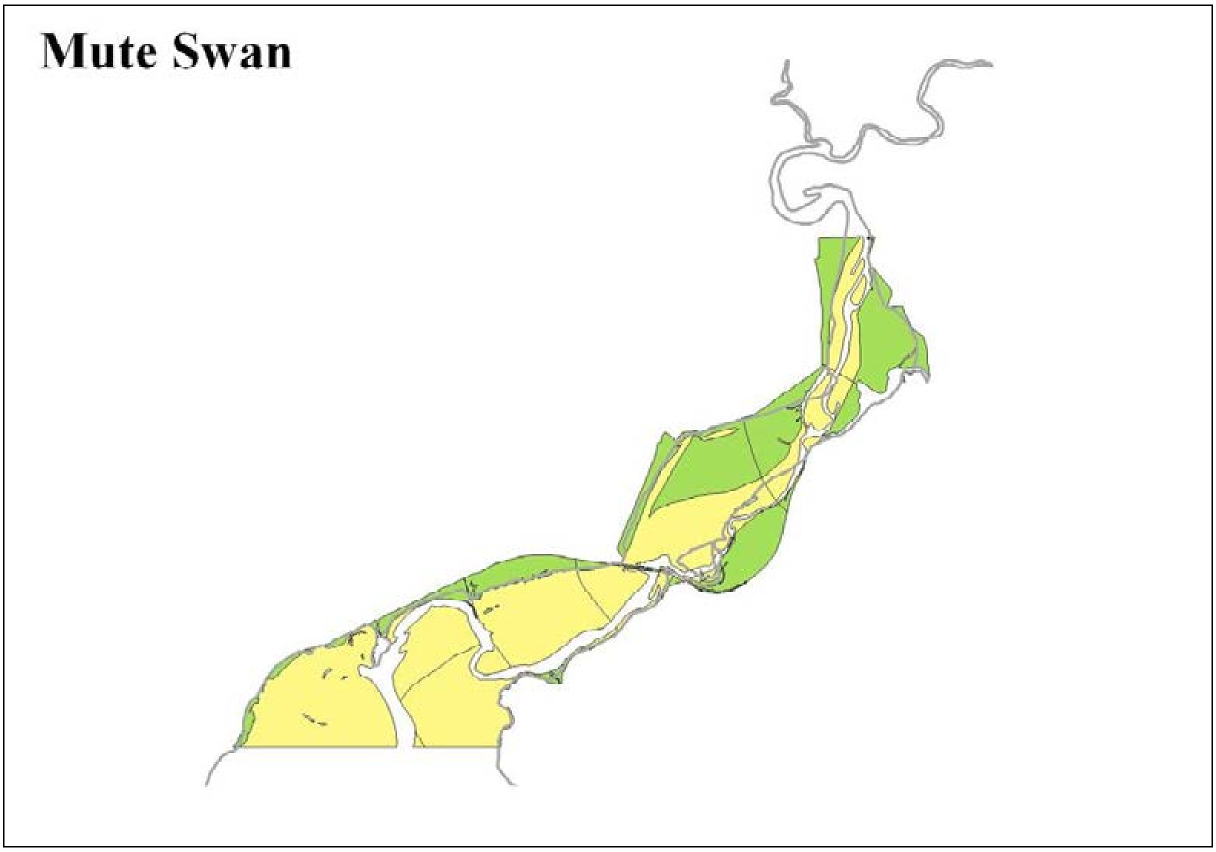
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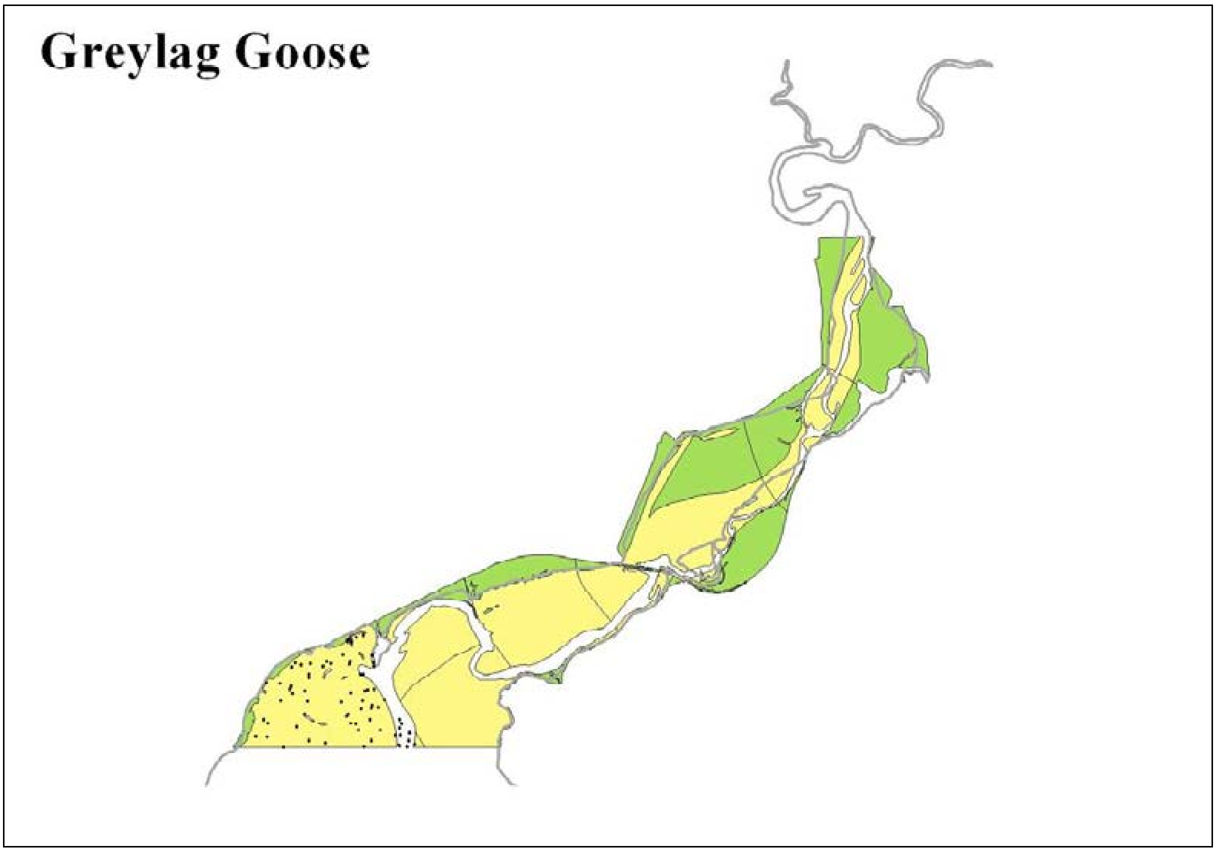
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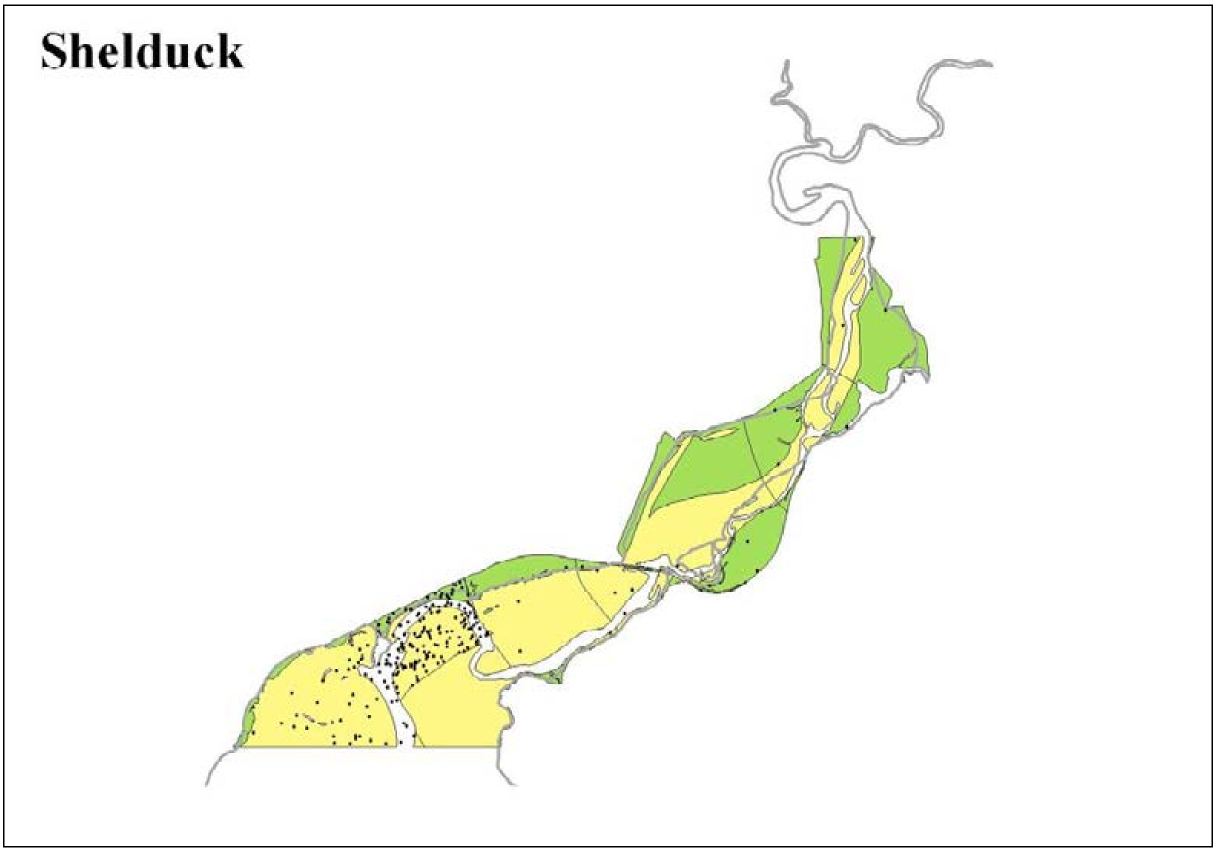
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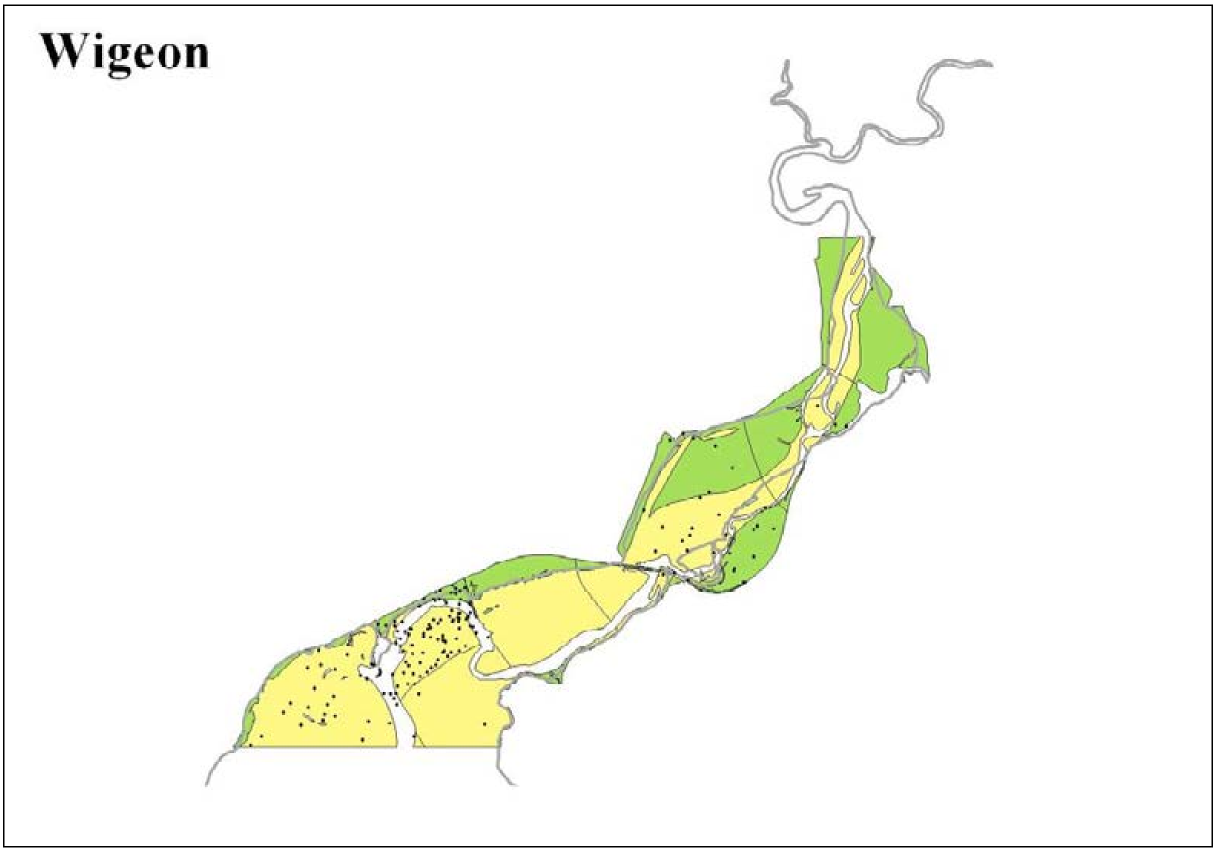
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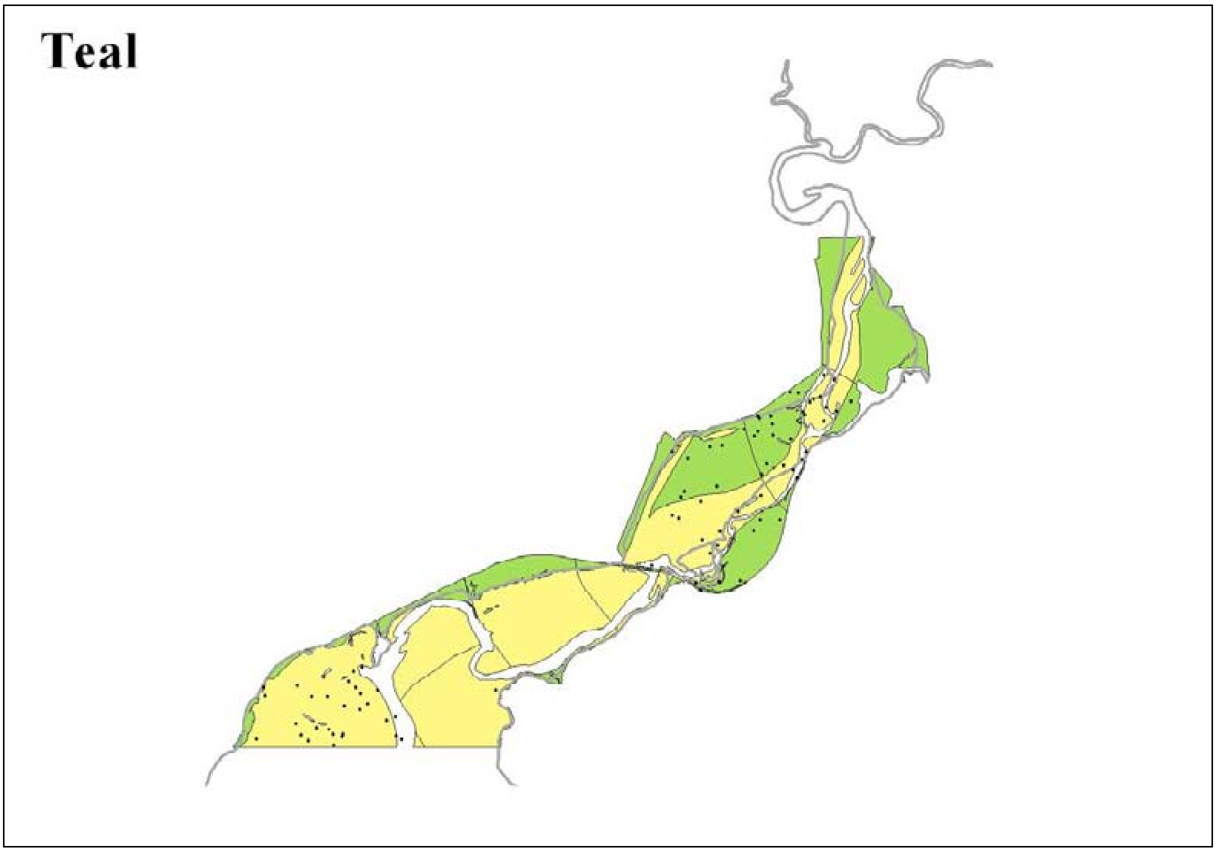

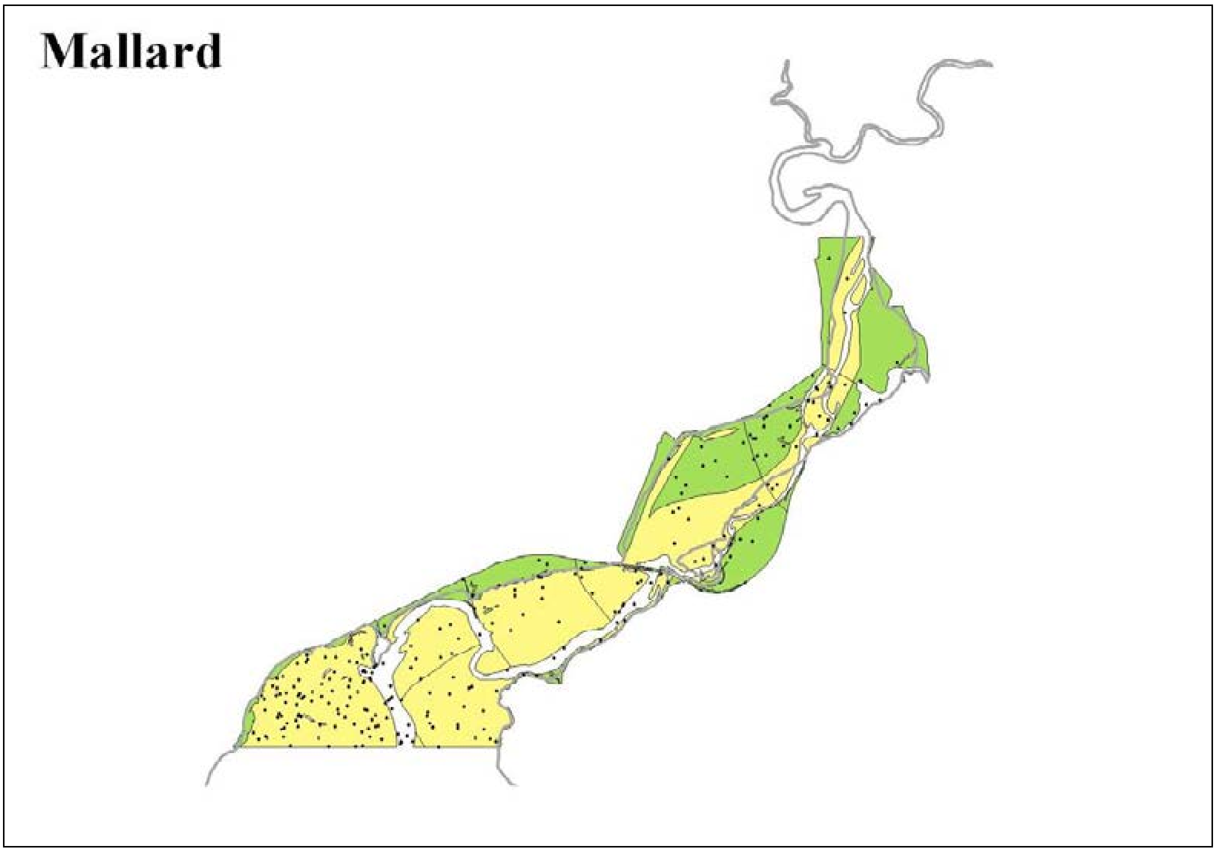

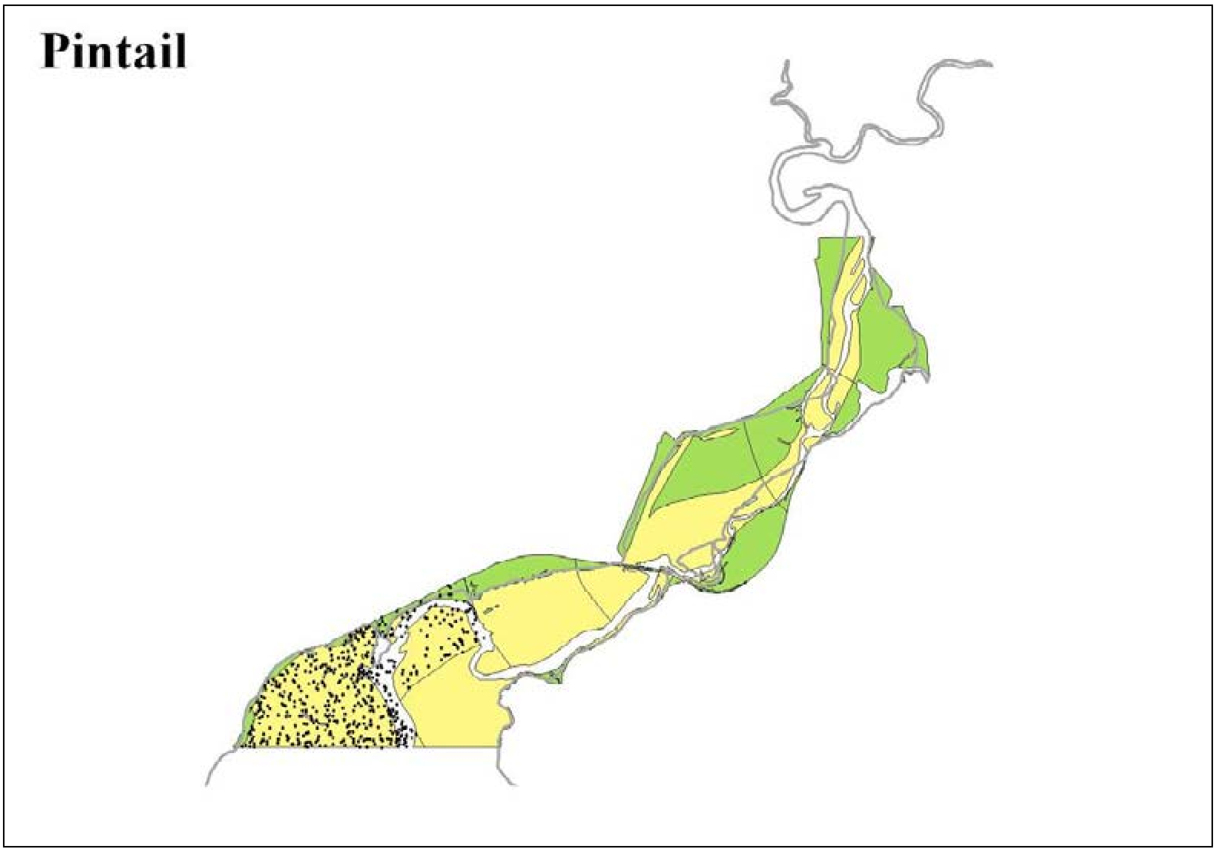
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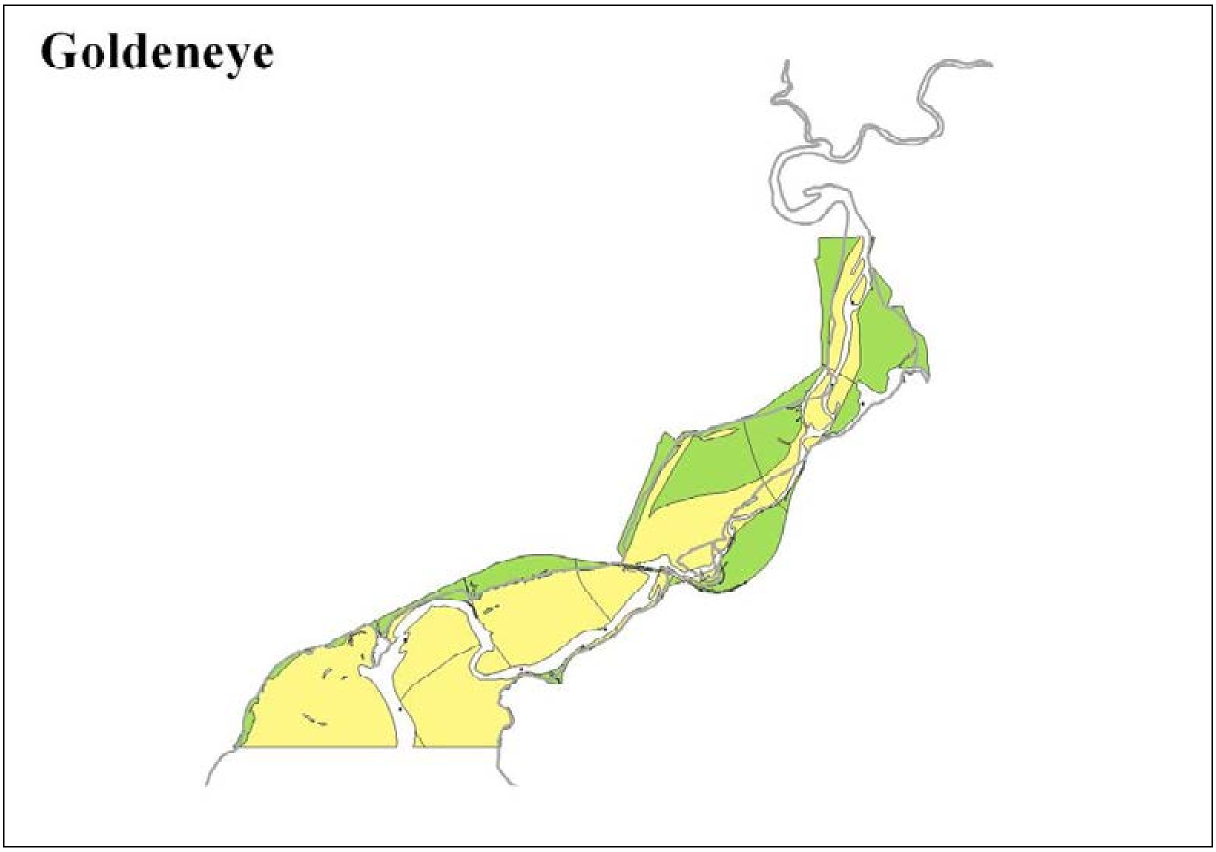
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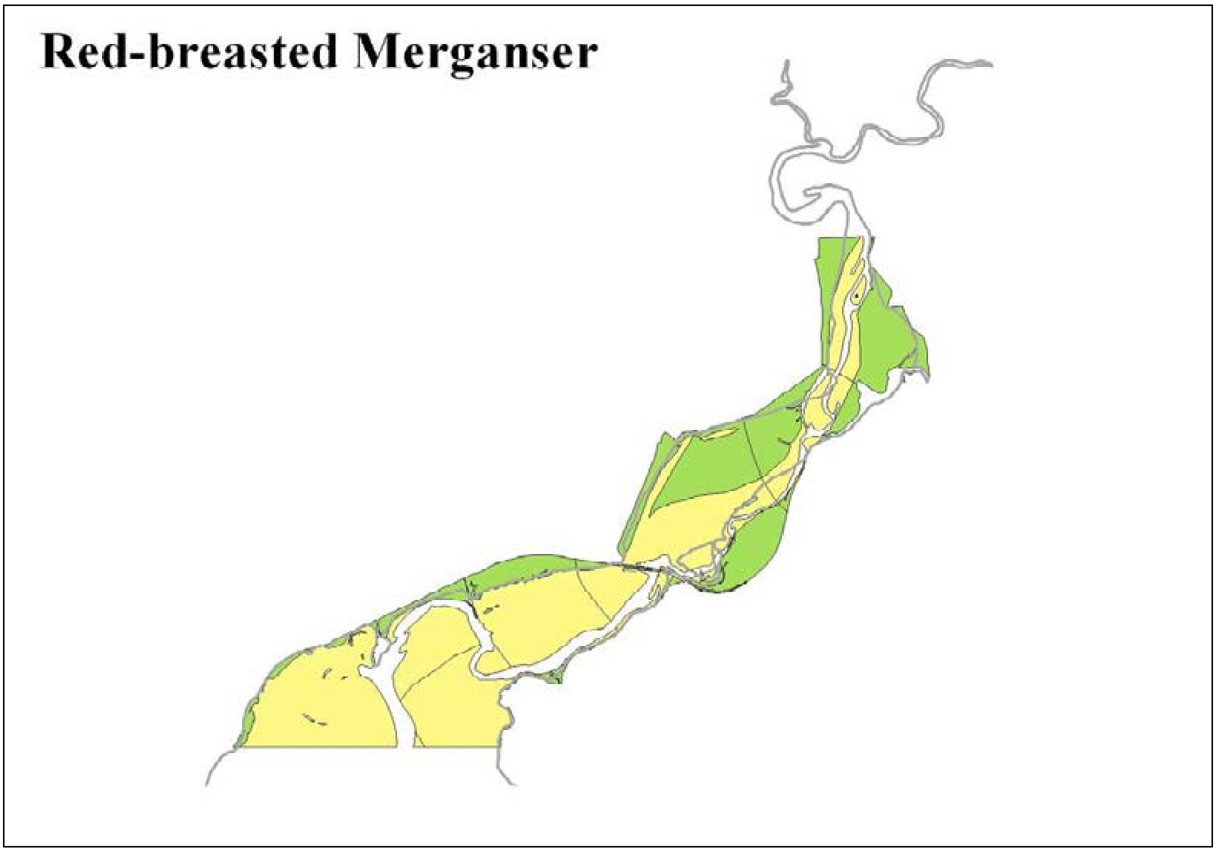
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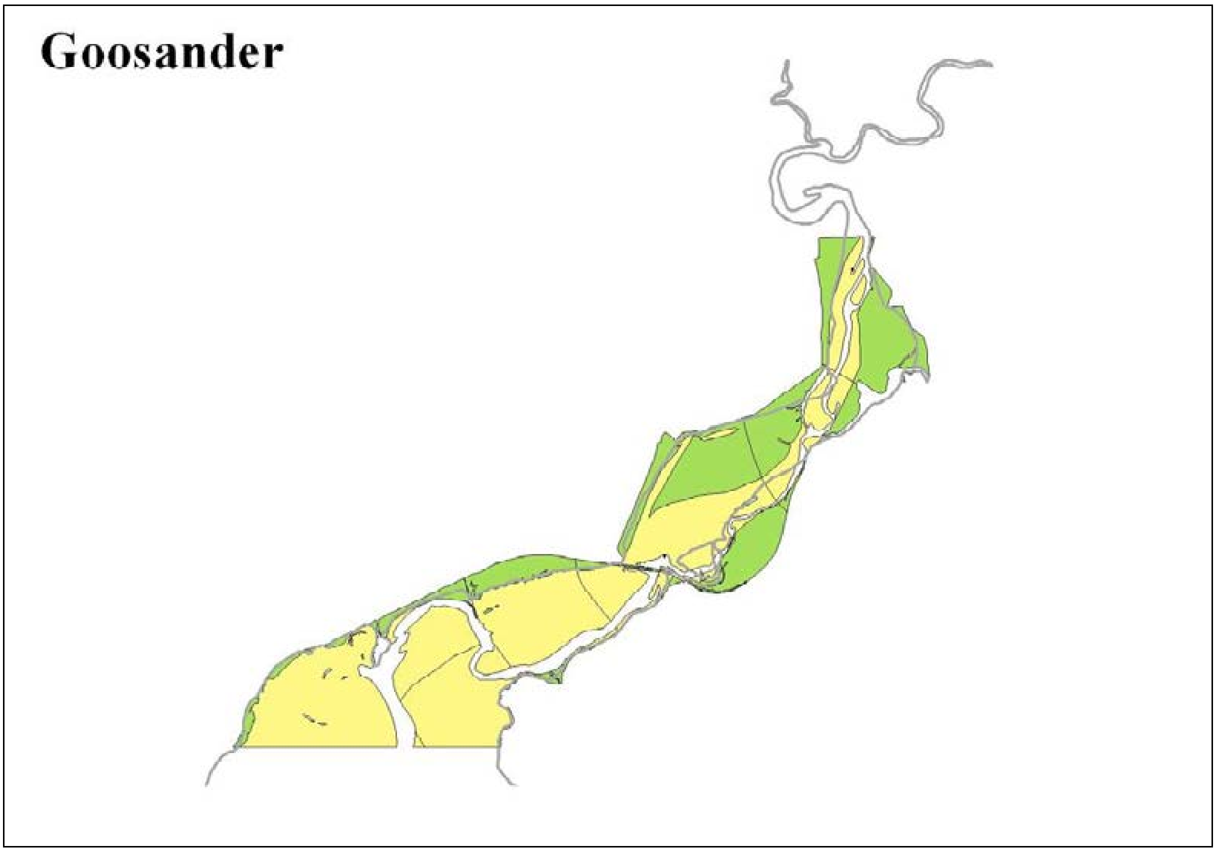
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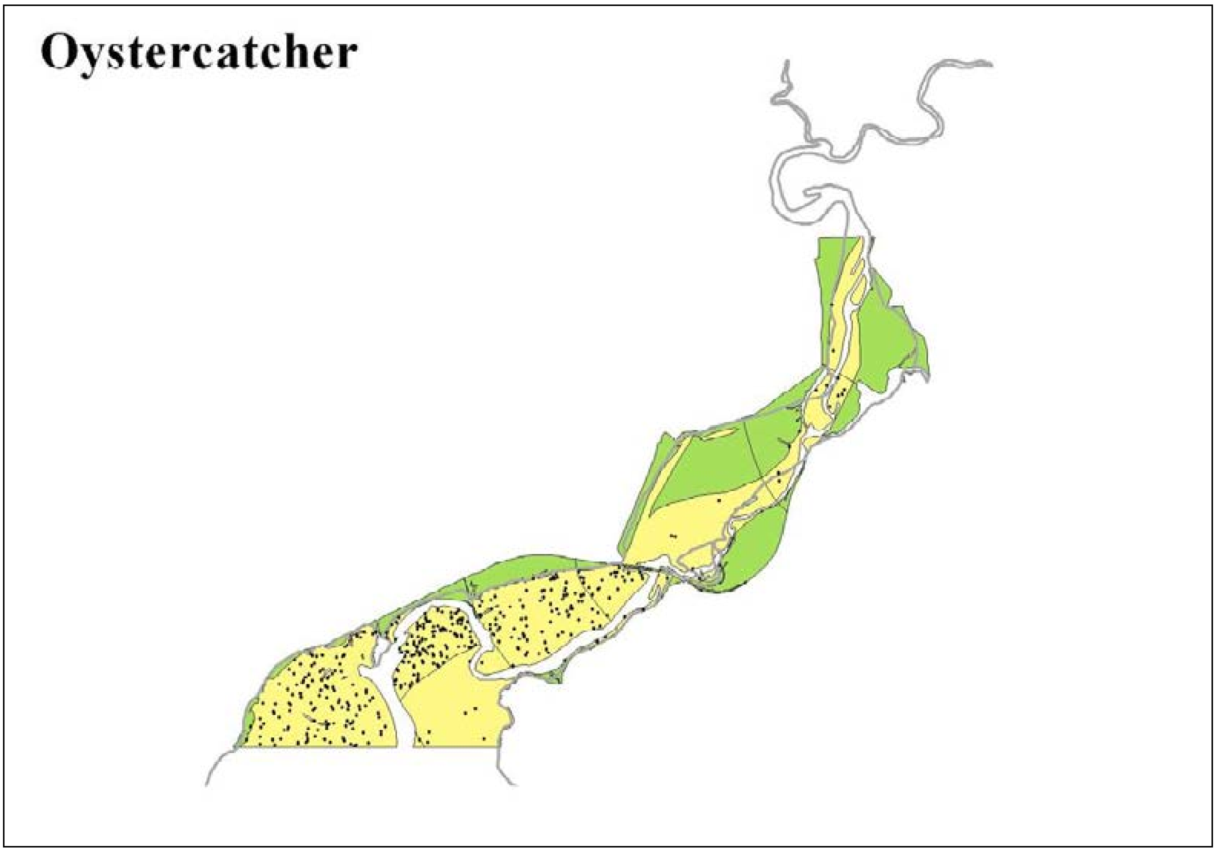
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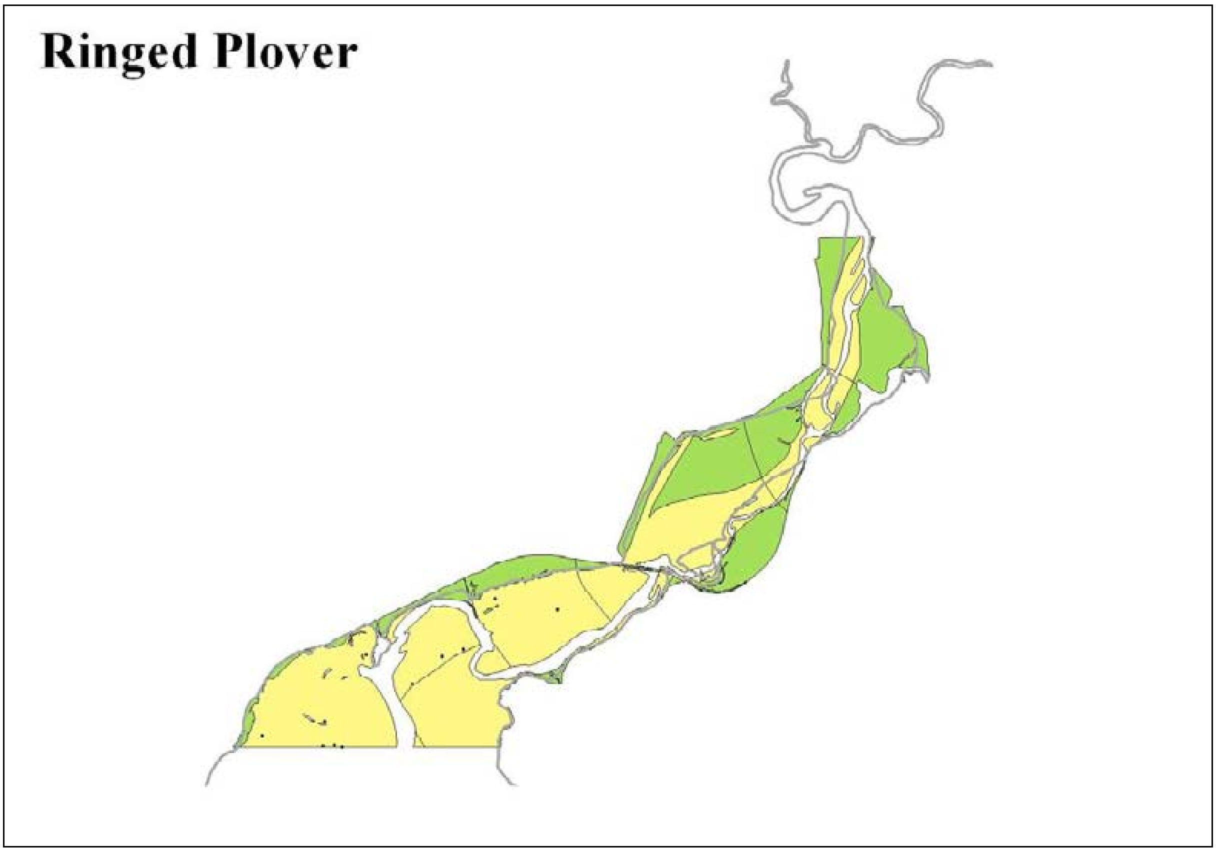
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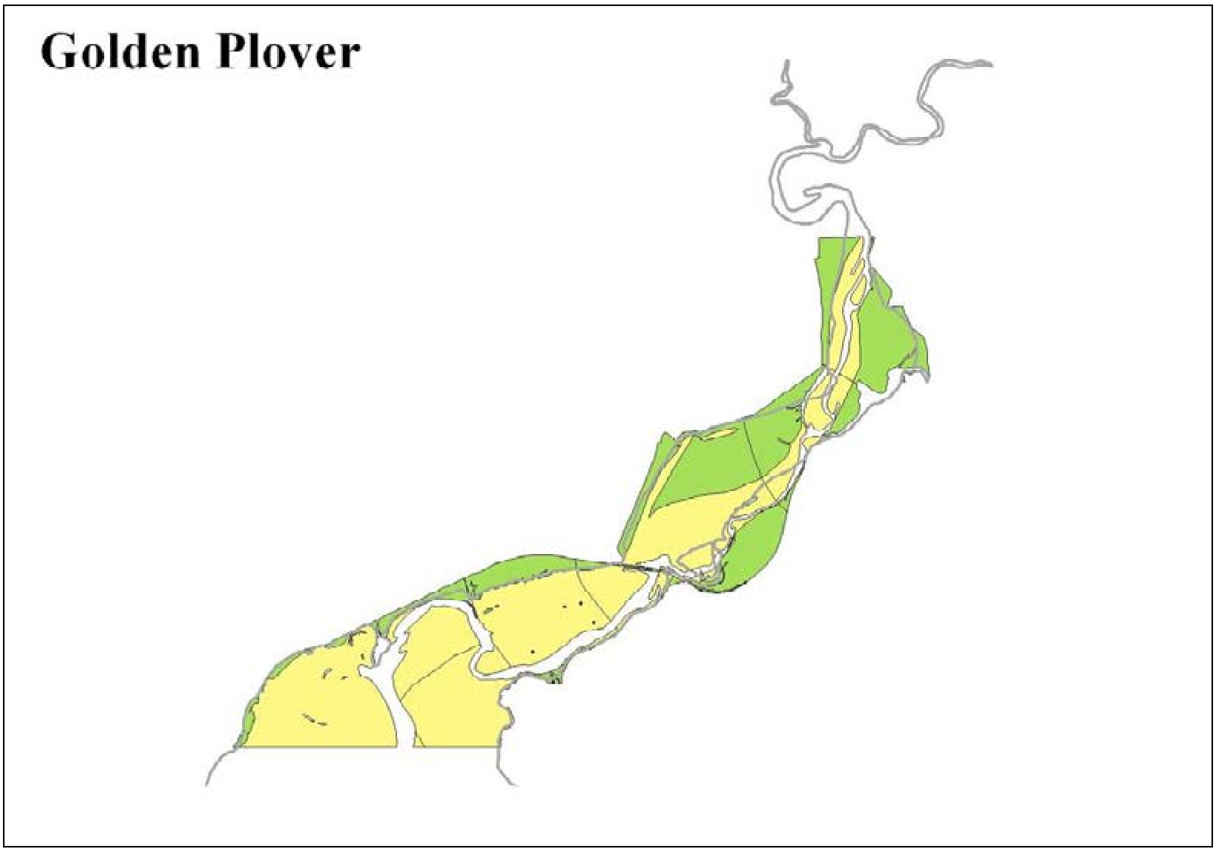
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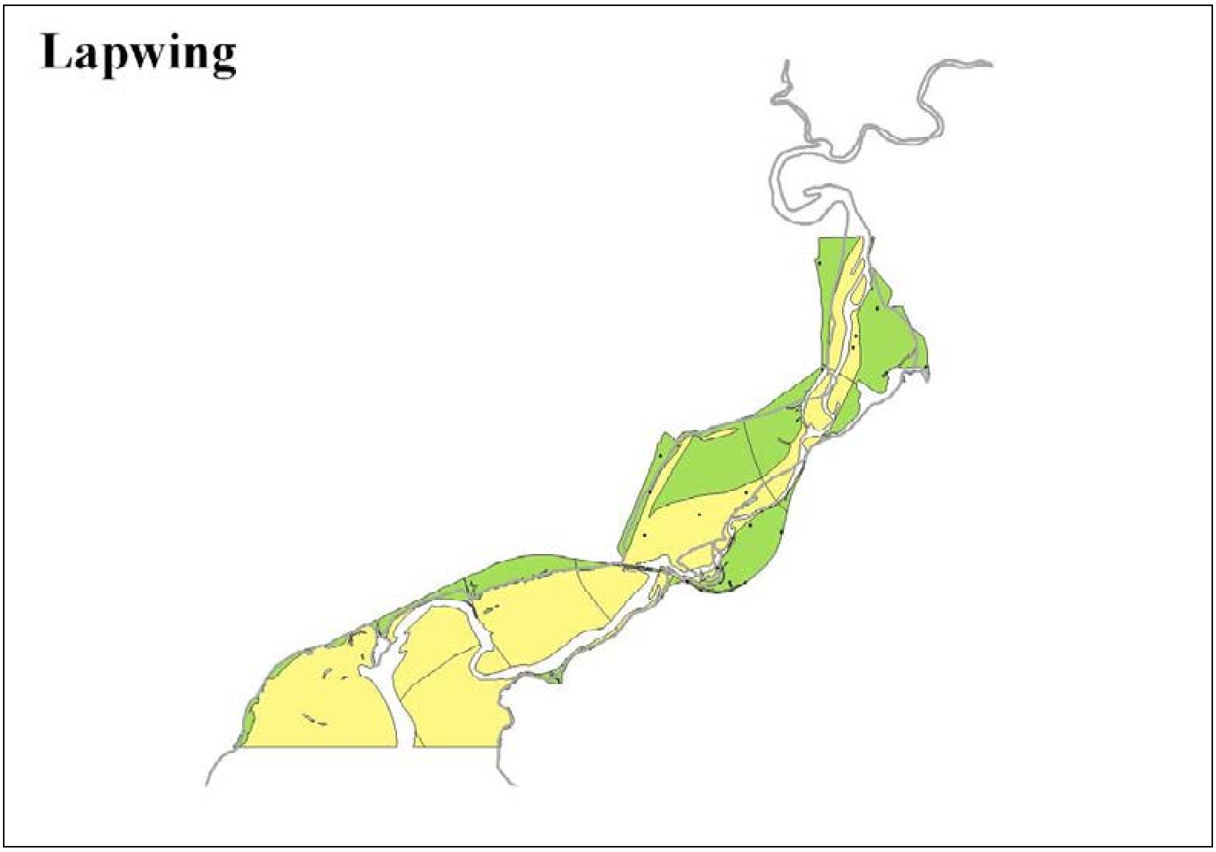
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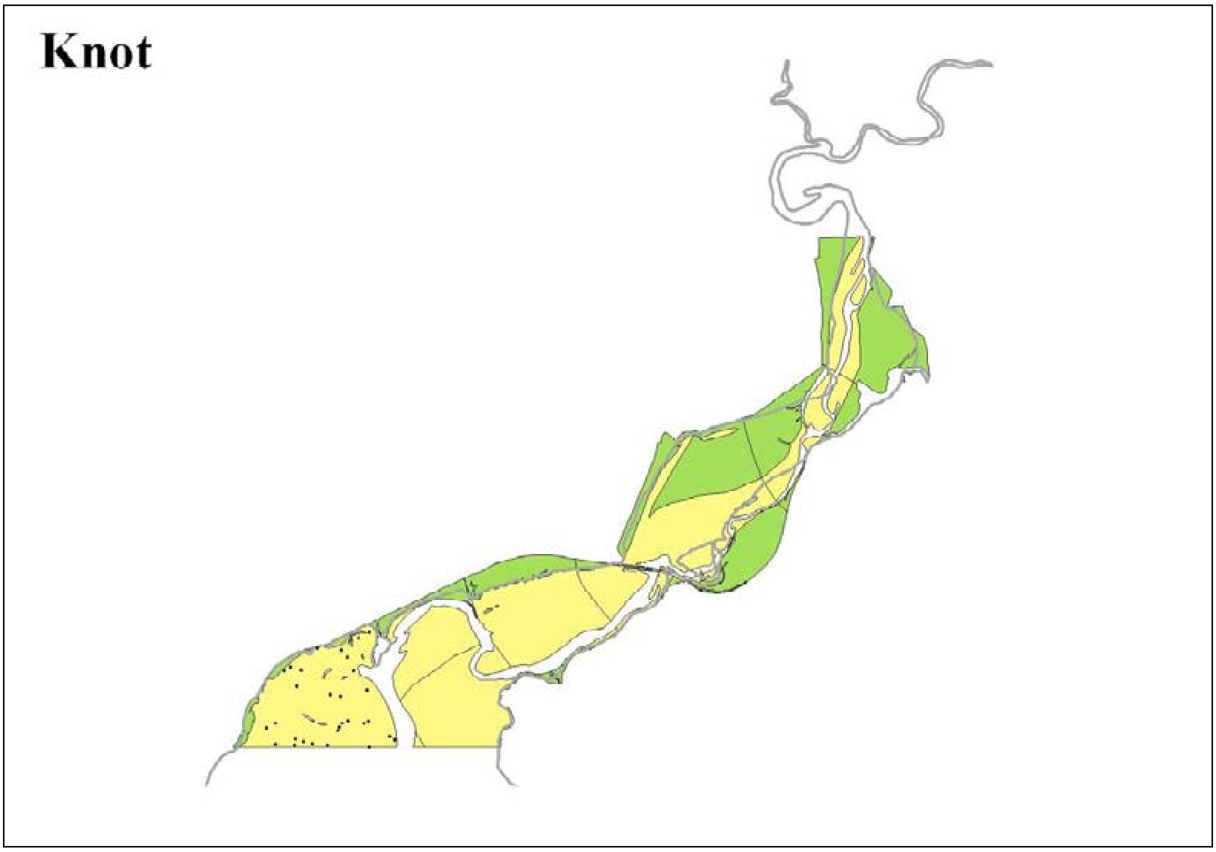
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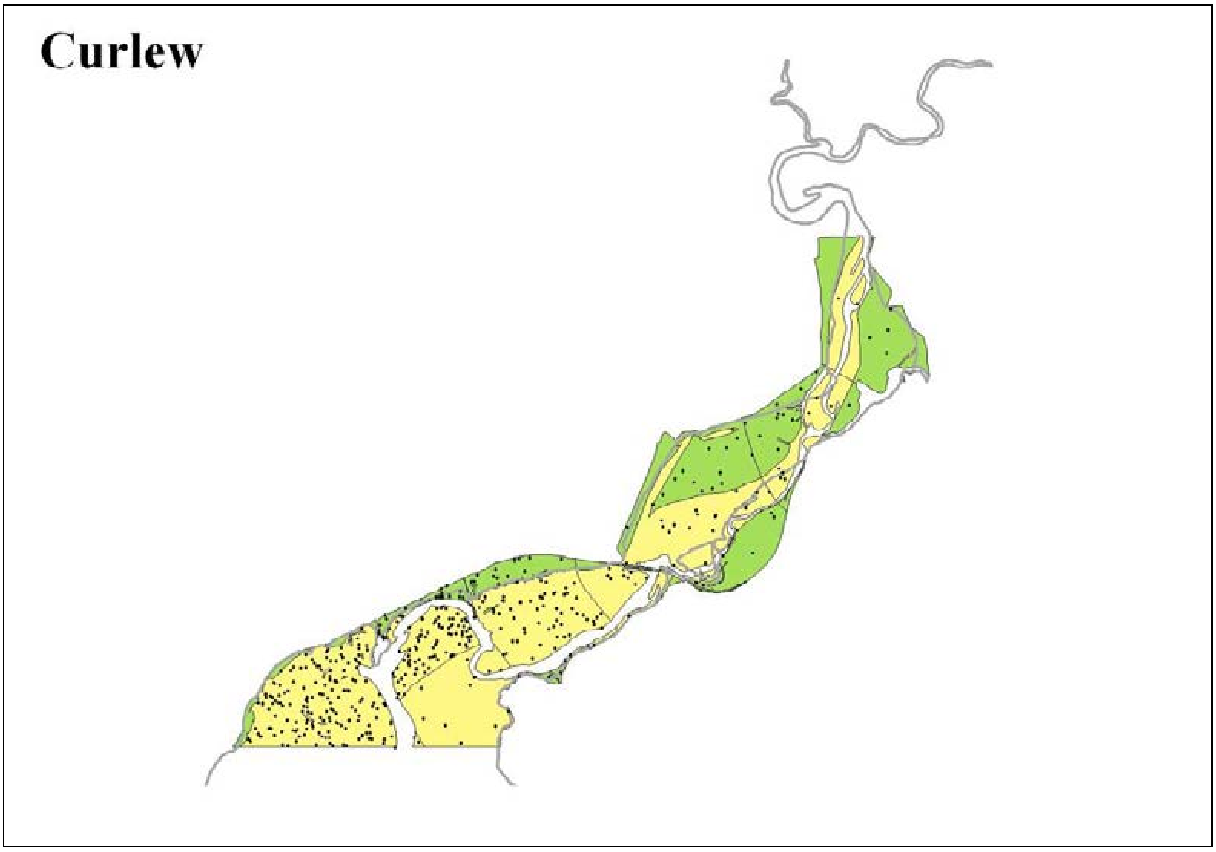
Dunlin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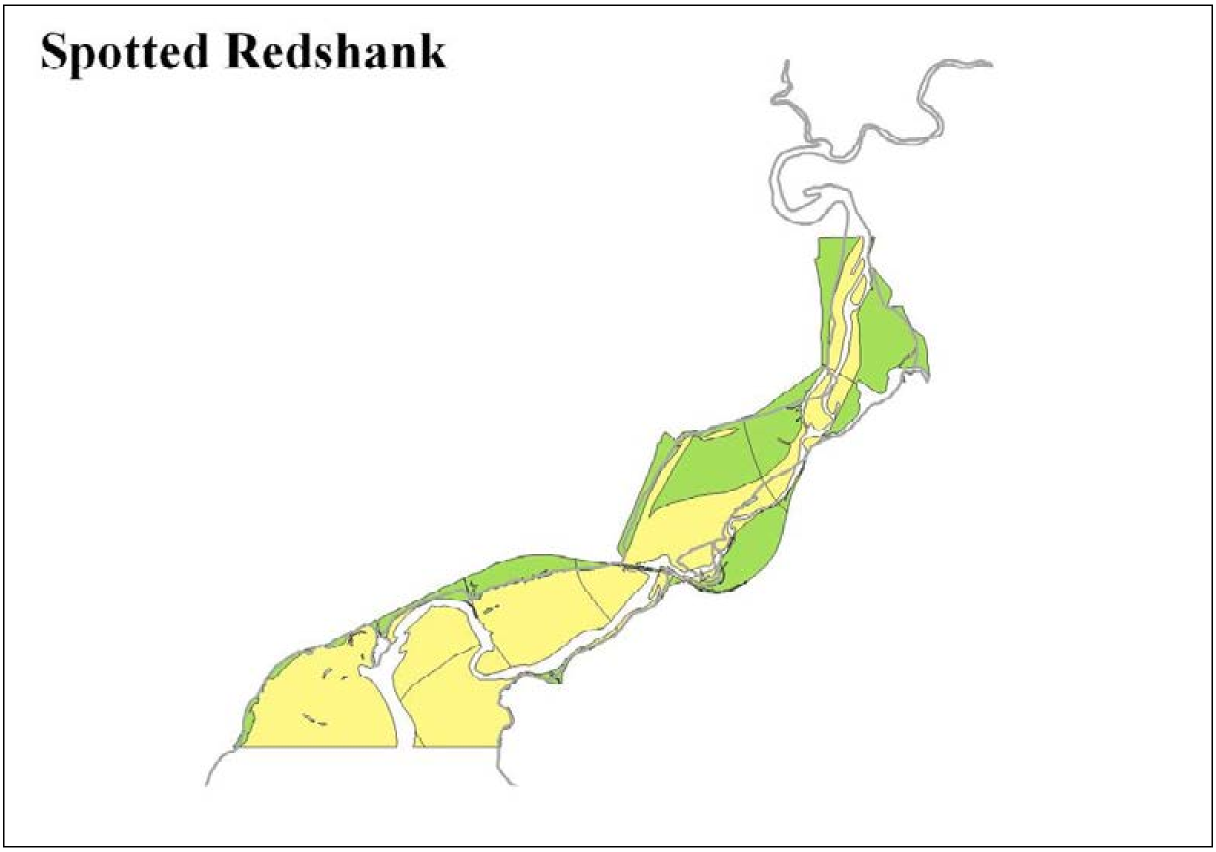
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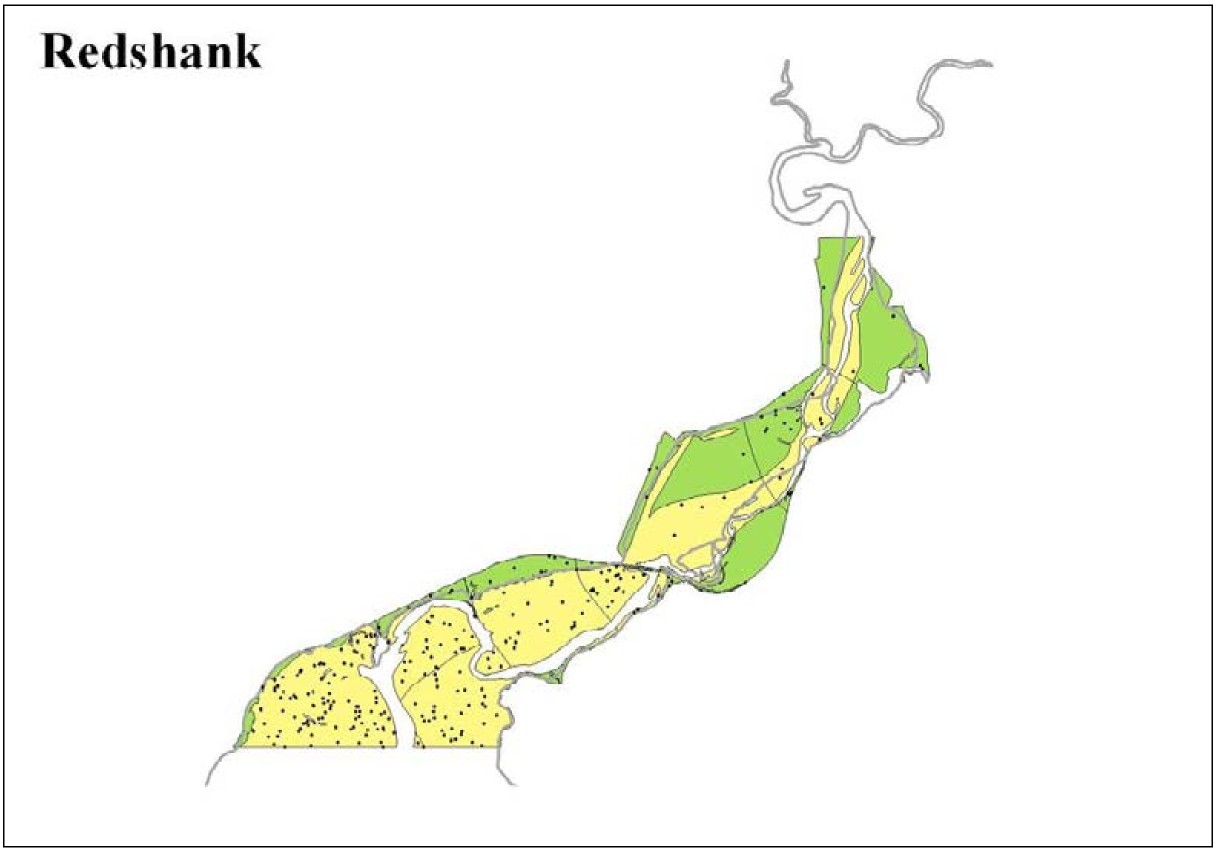

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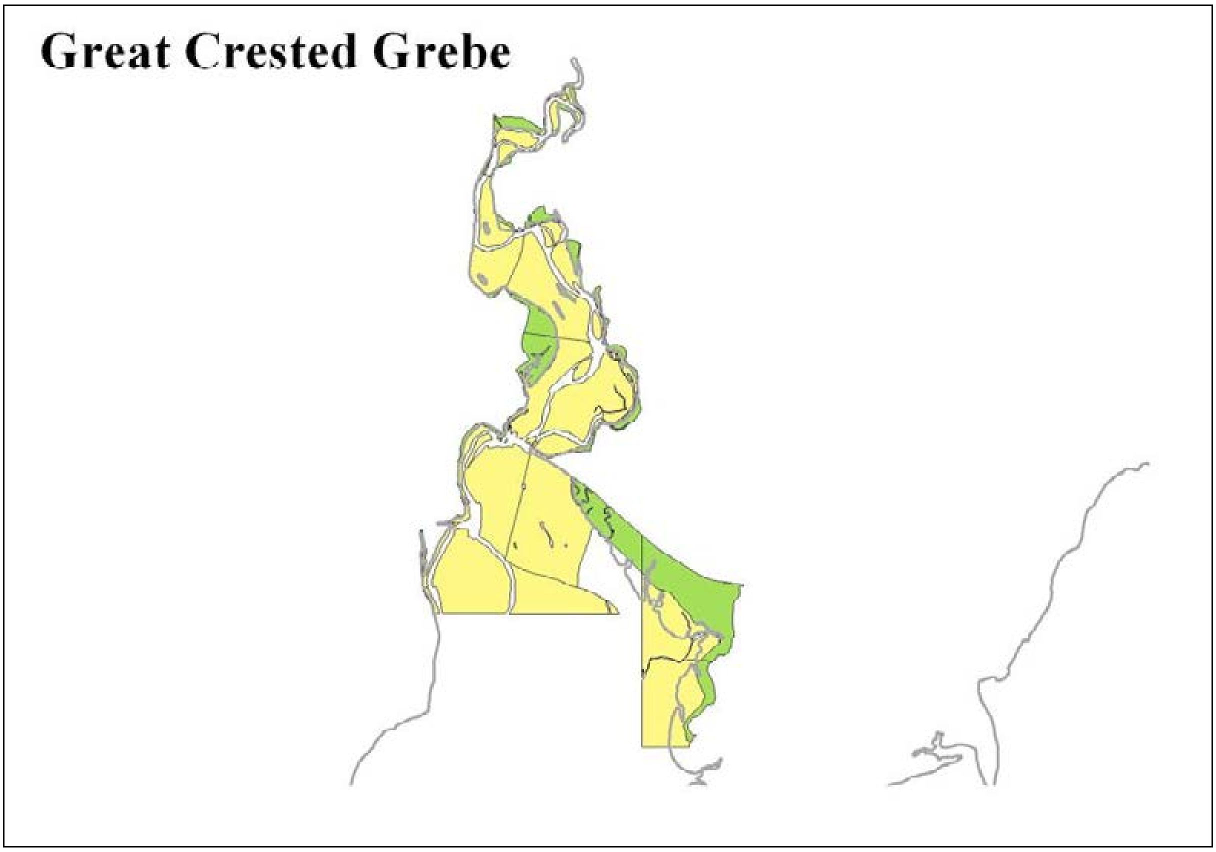

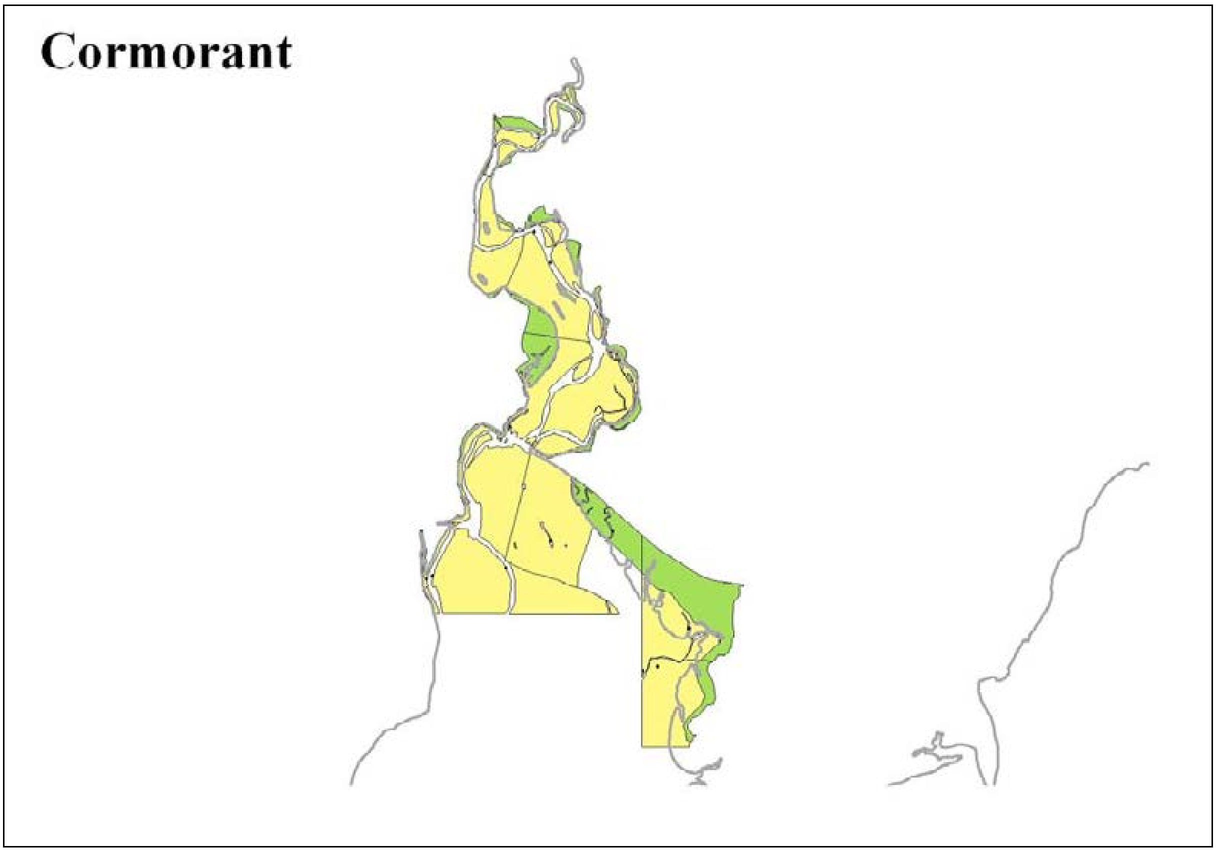
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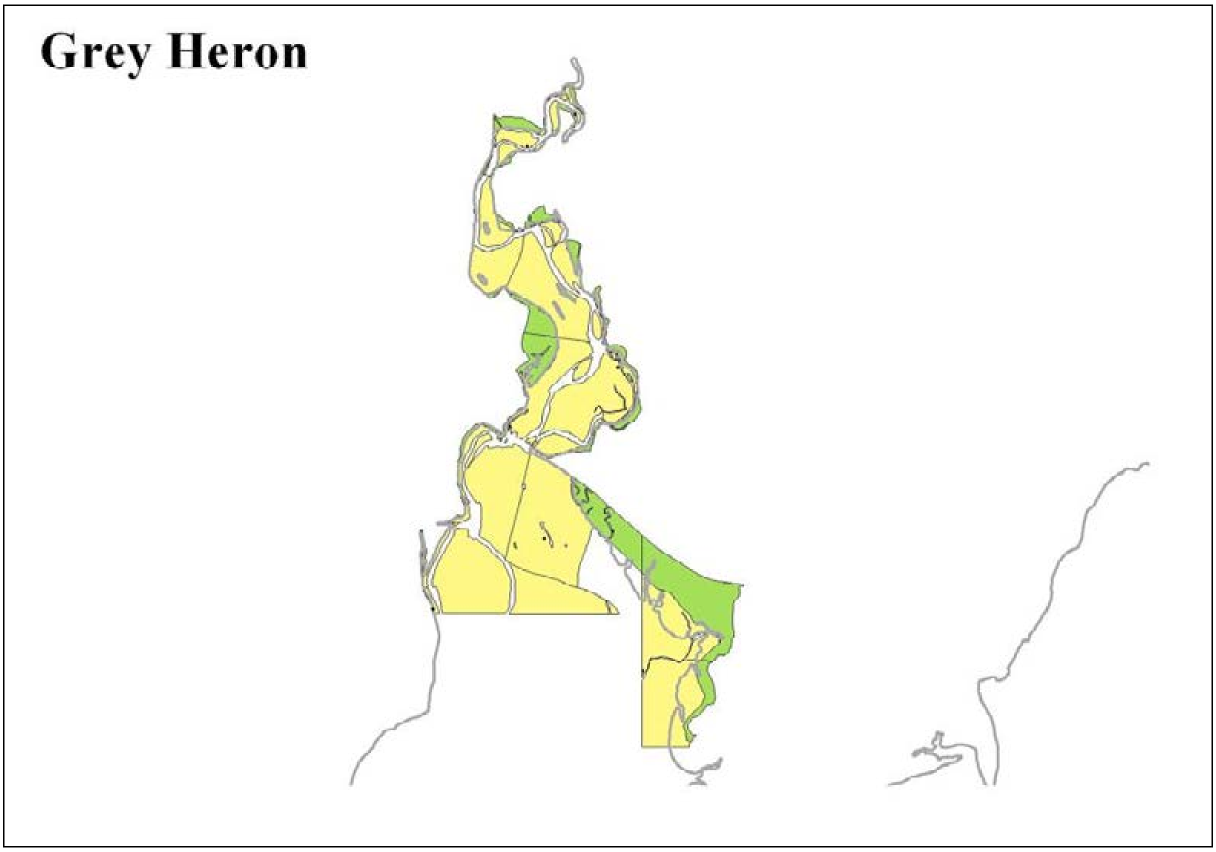
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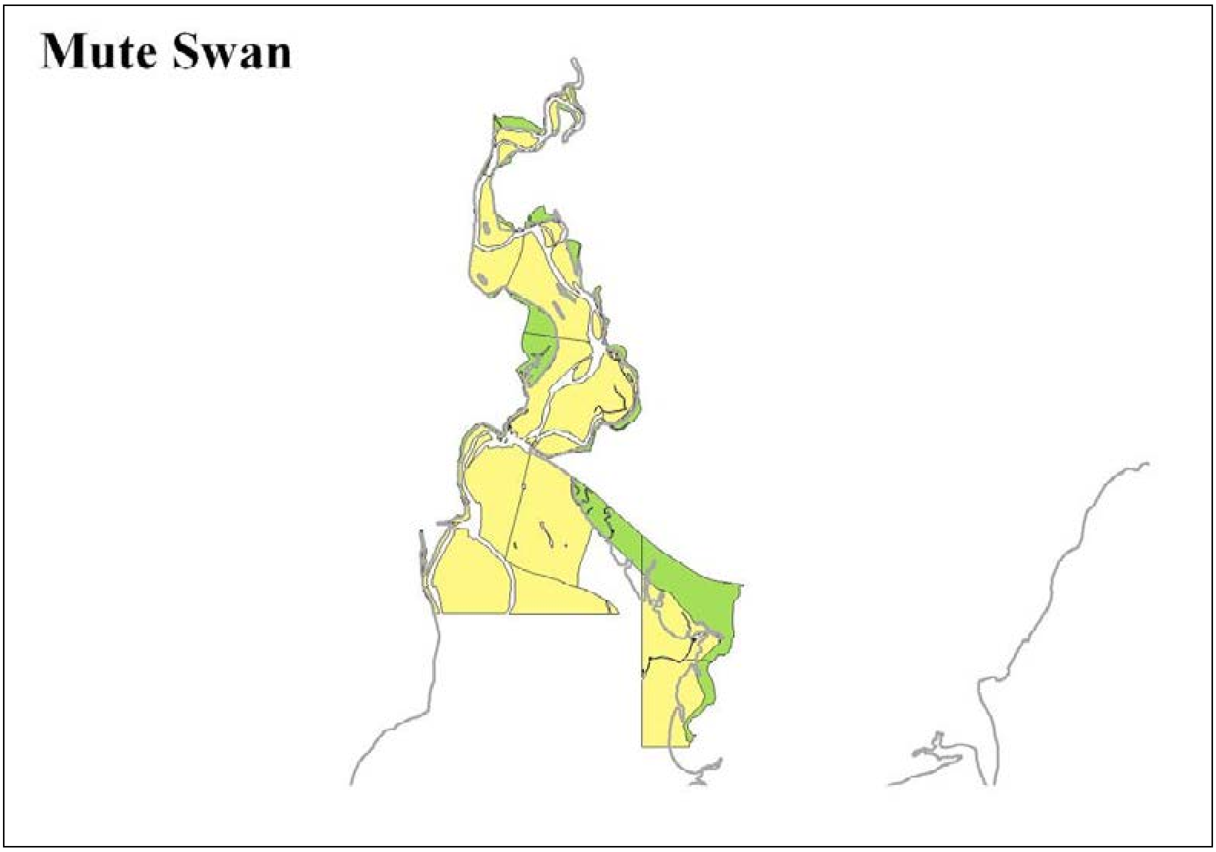
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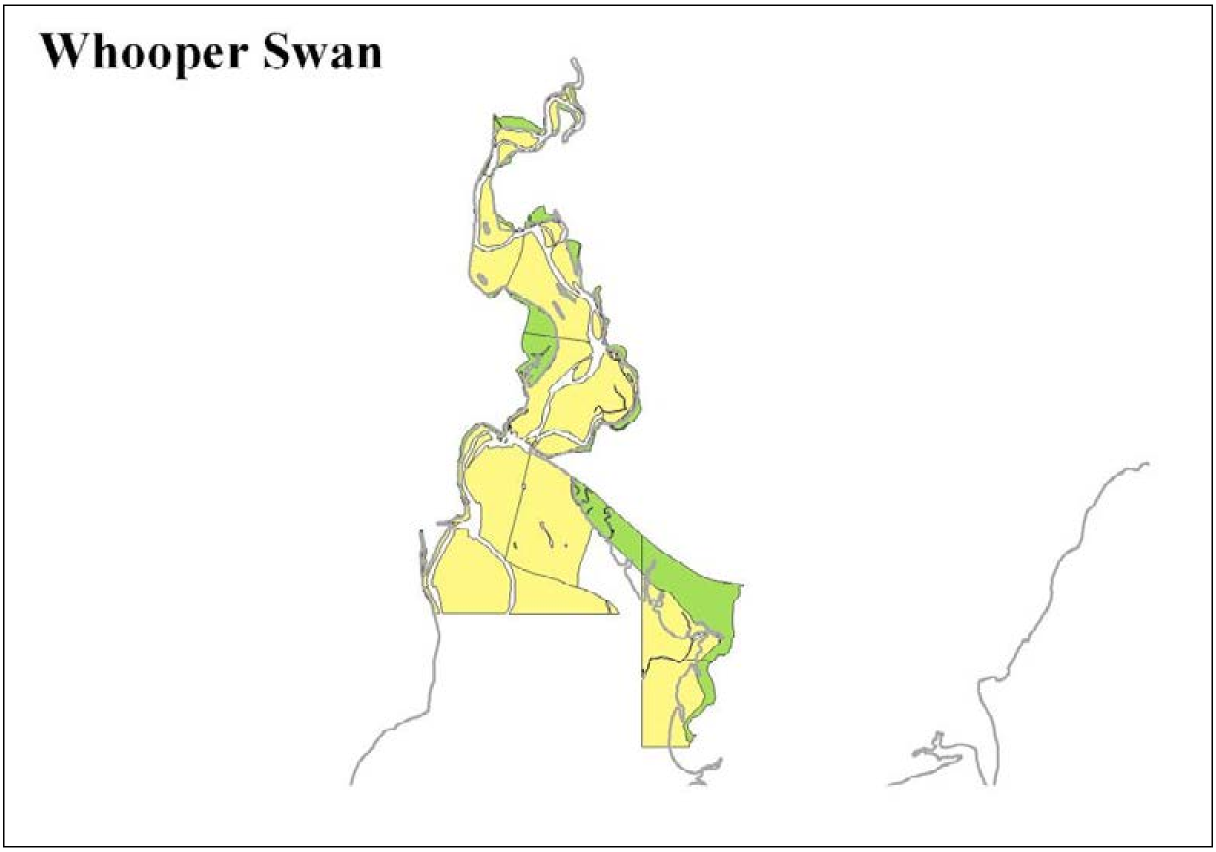
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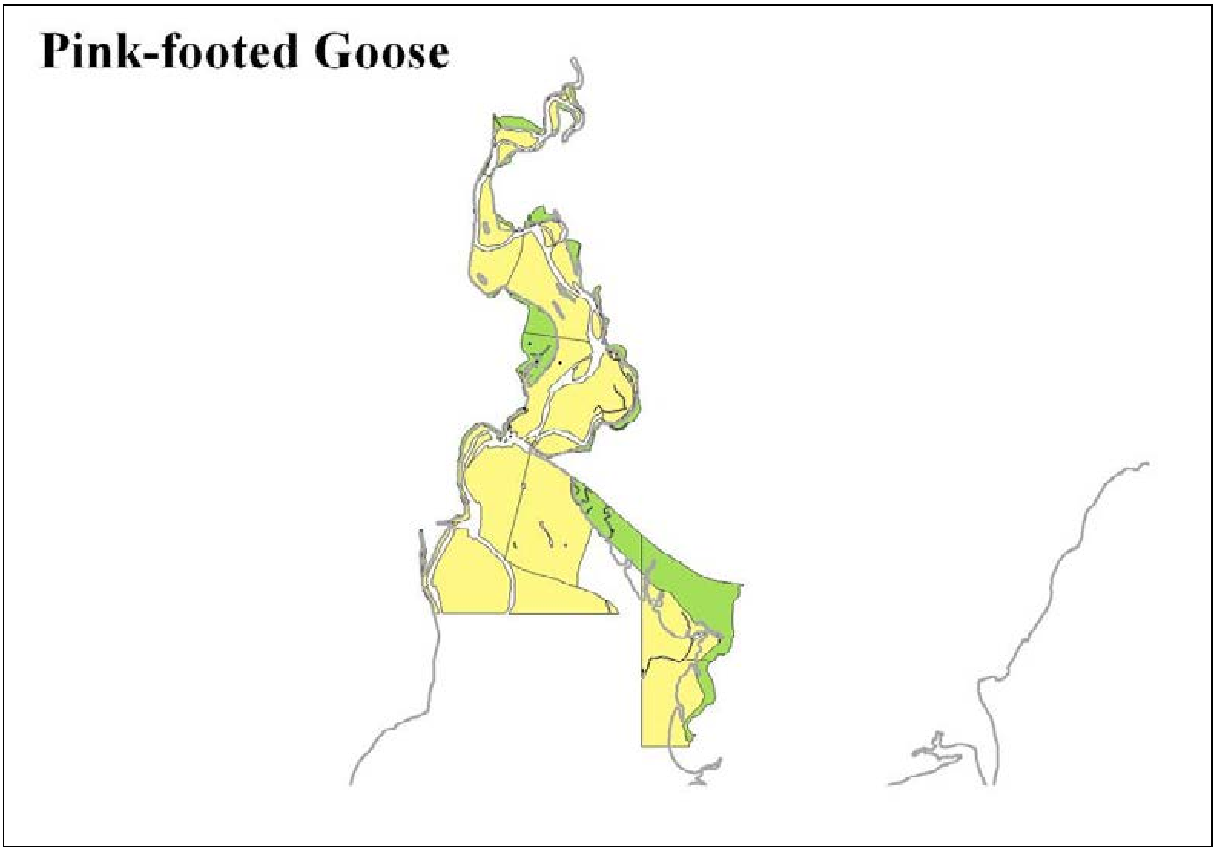
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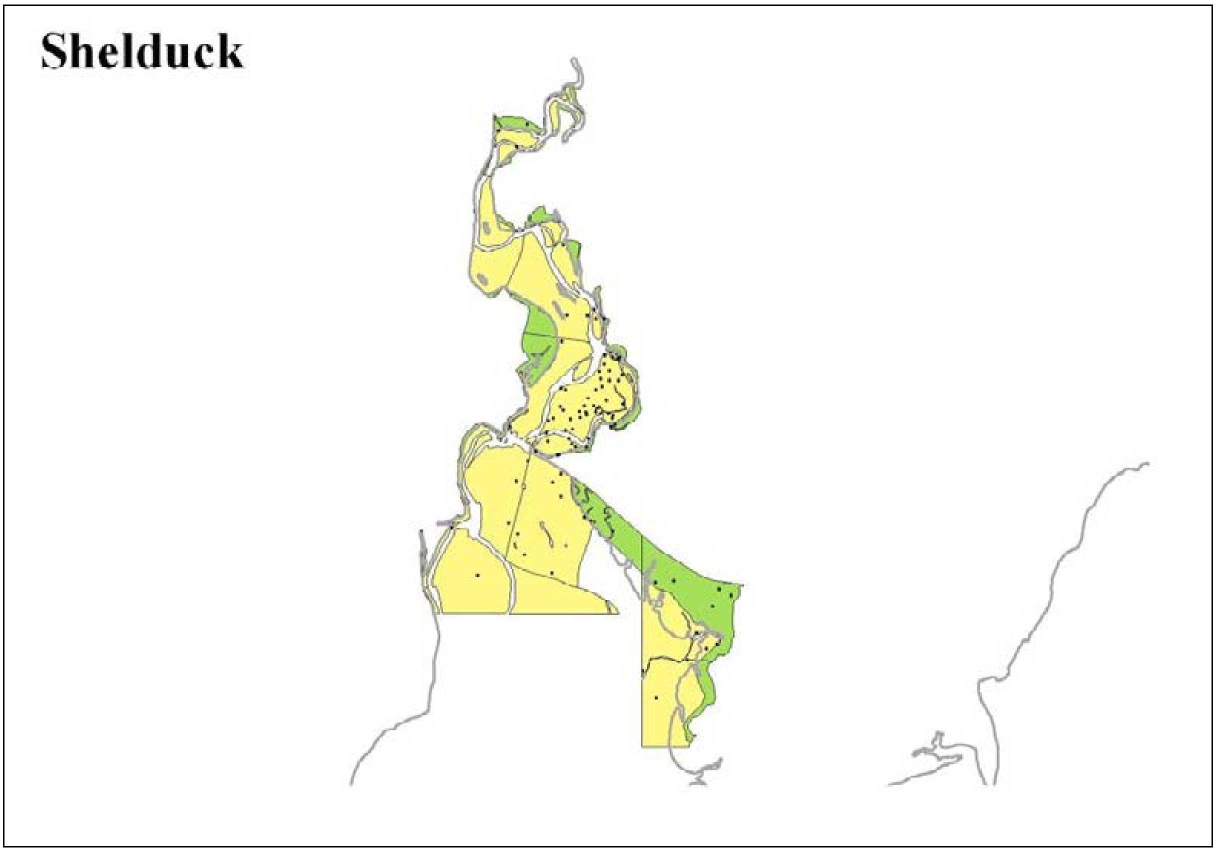
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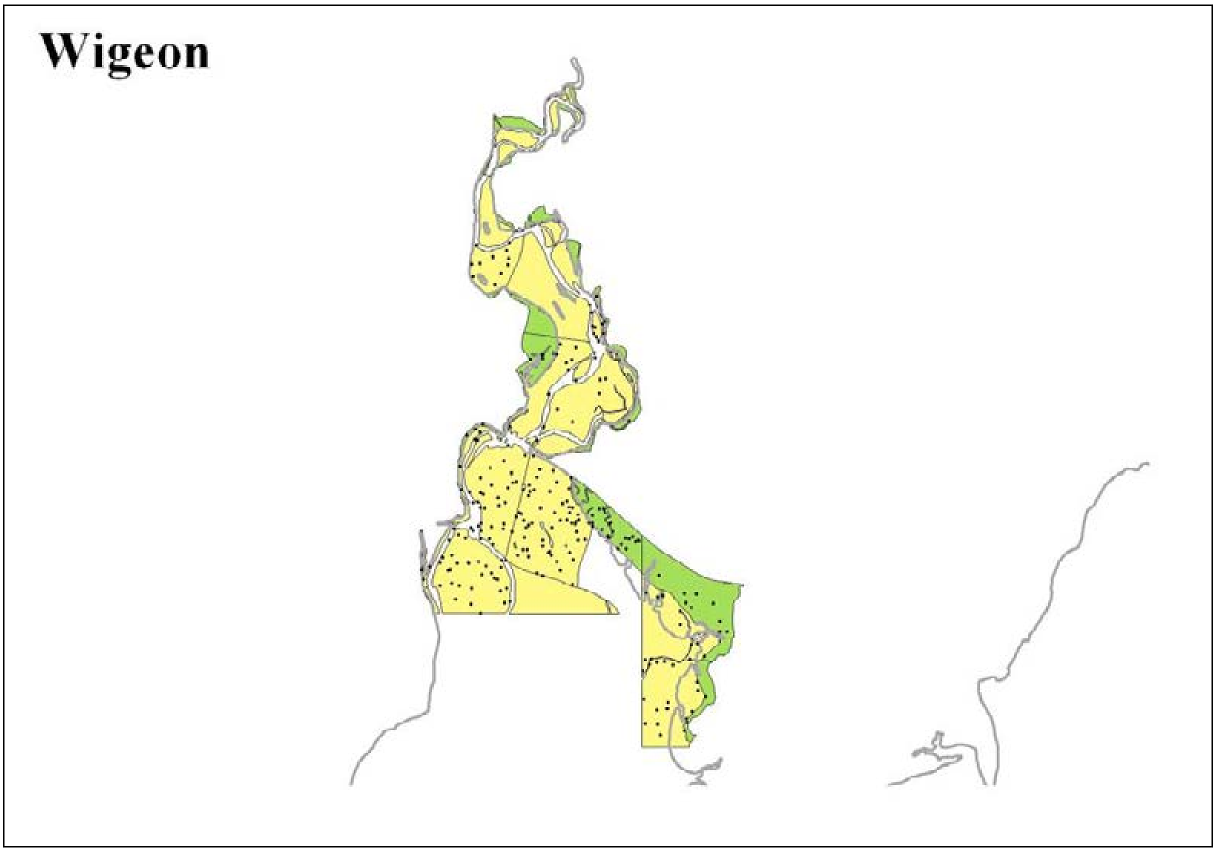
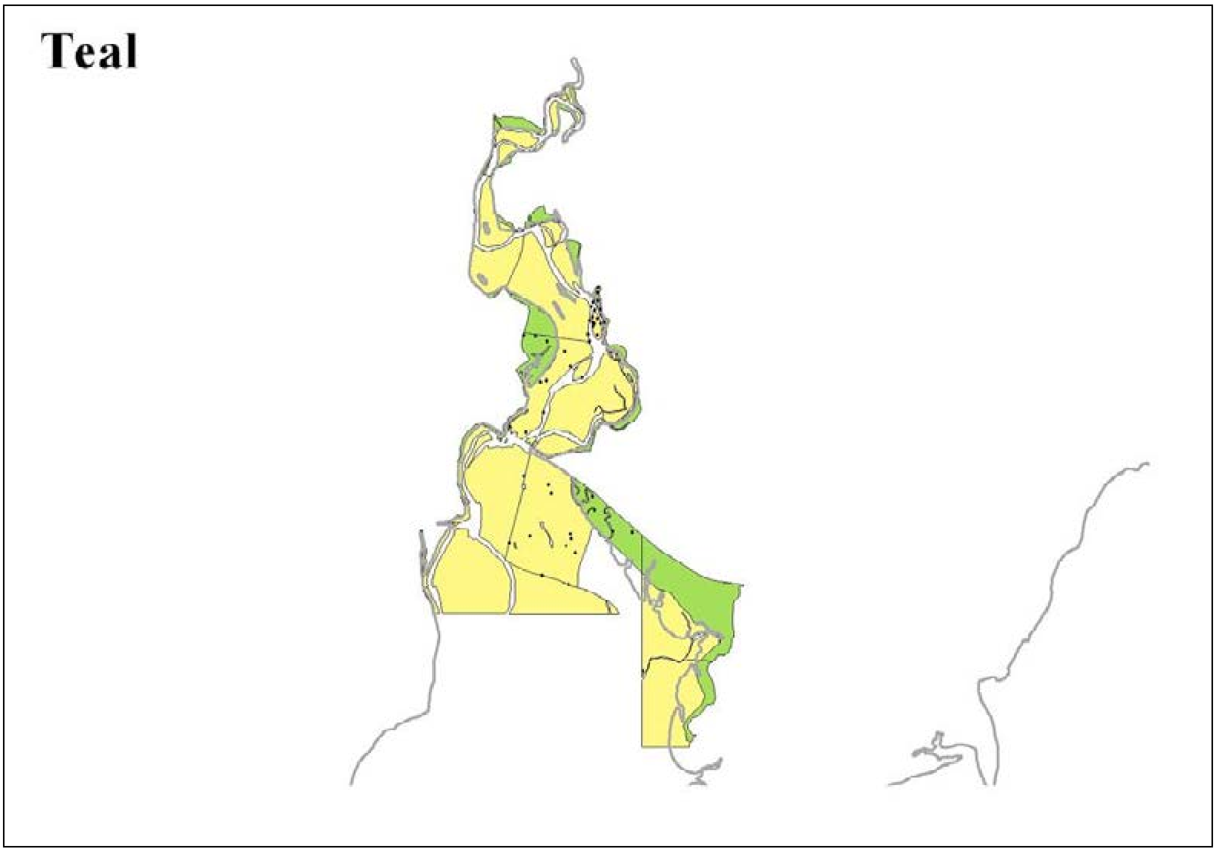

Wigeon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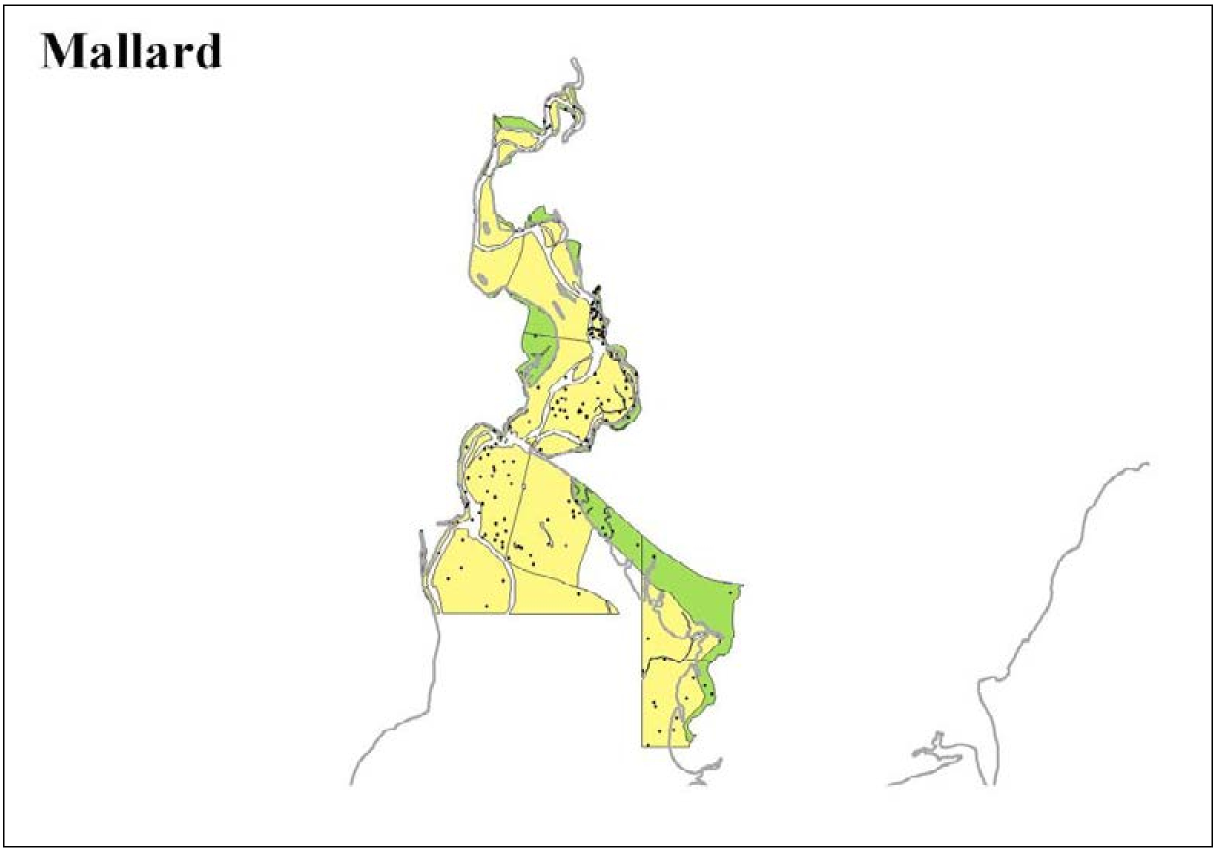
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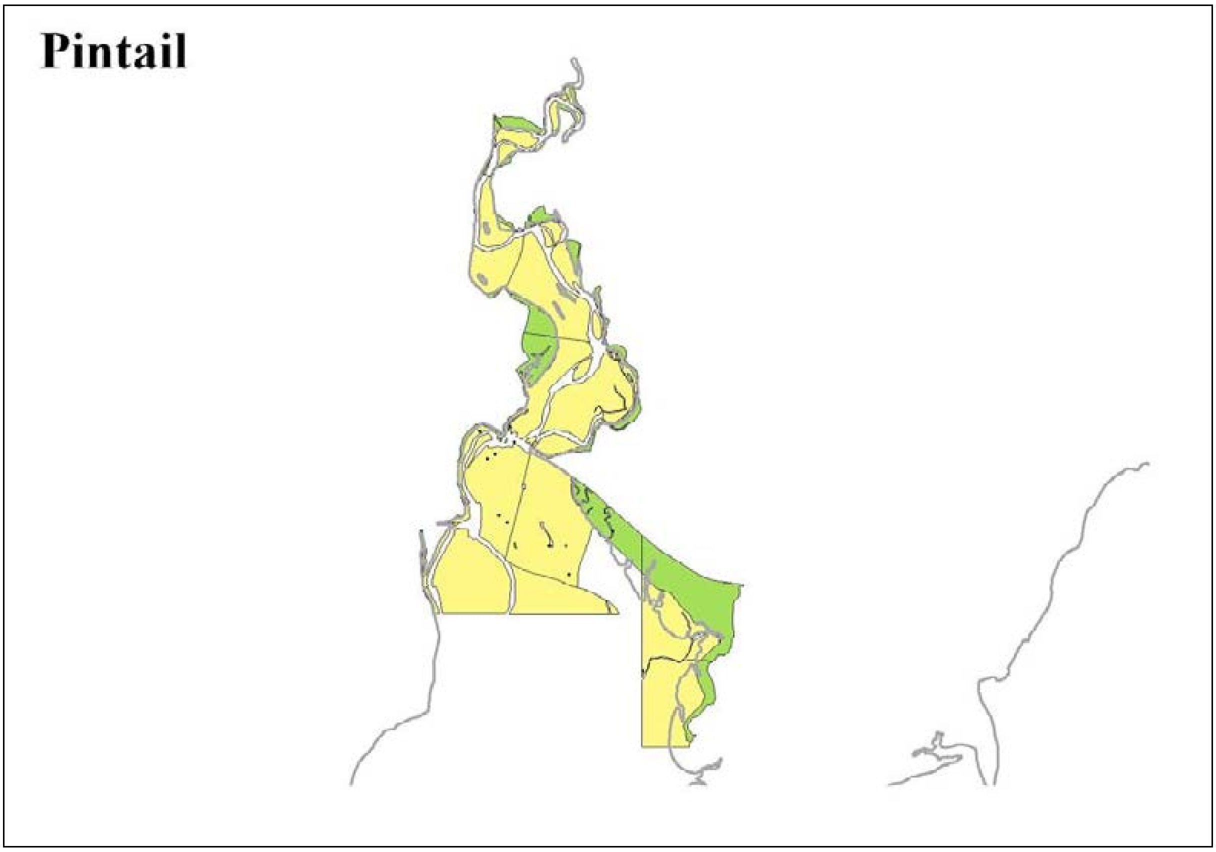
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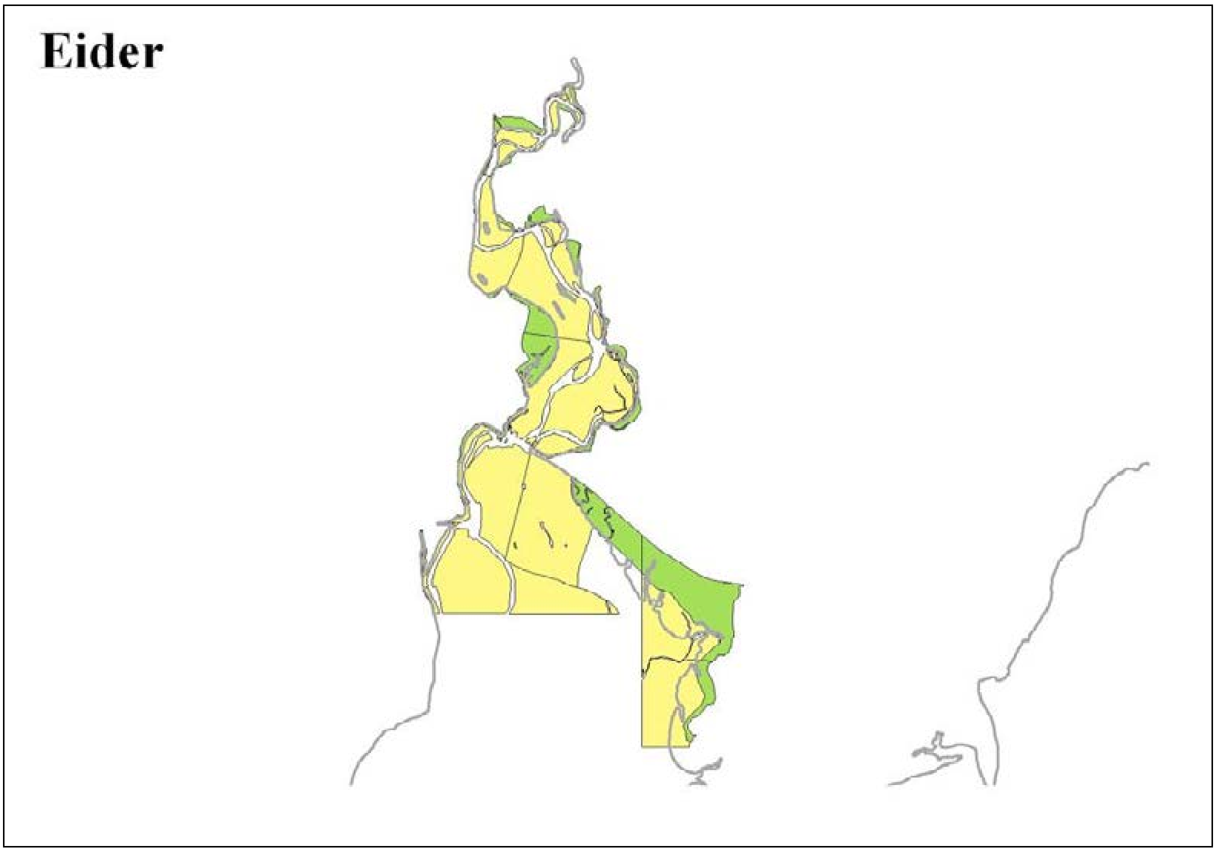
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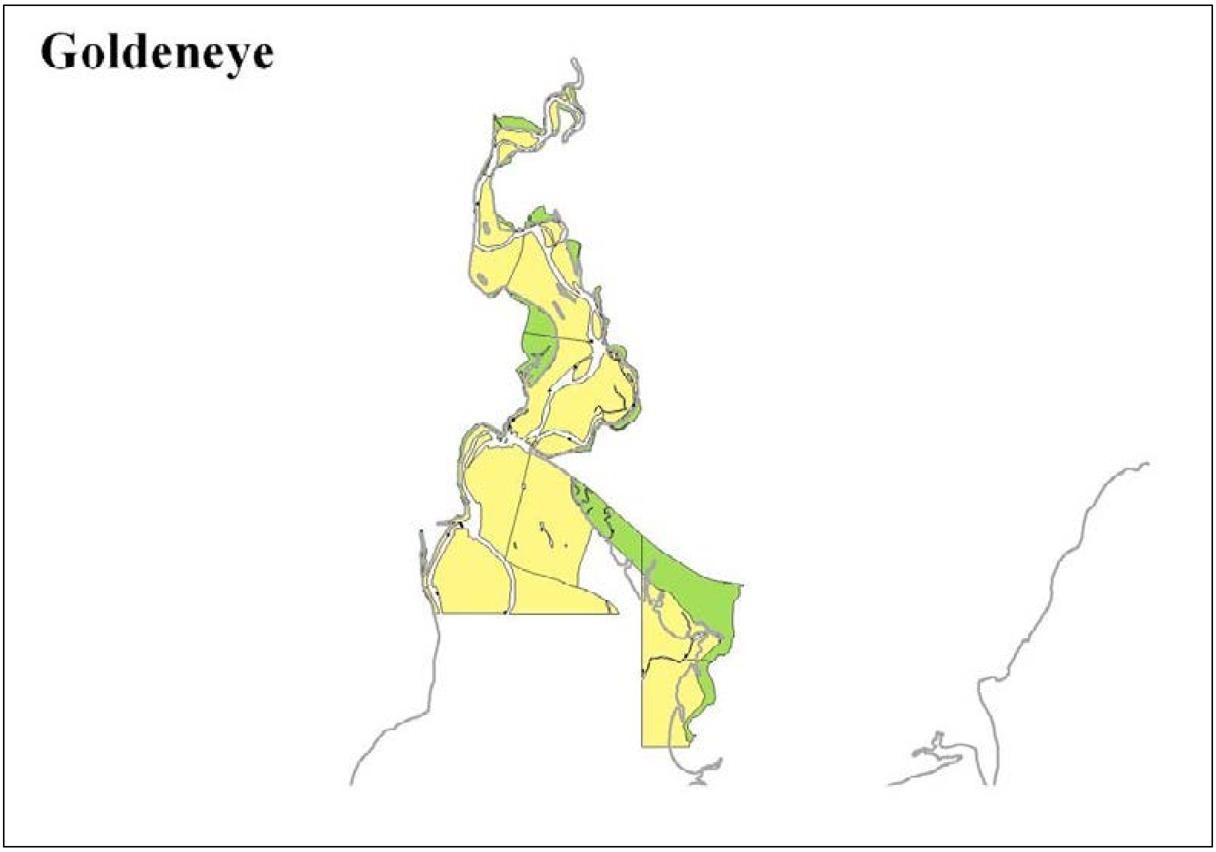
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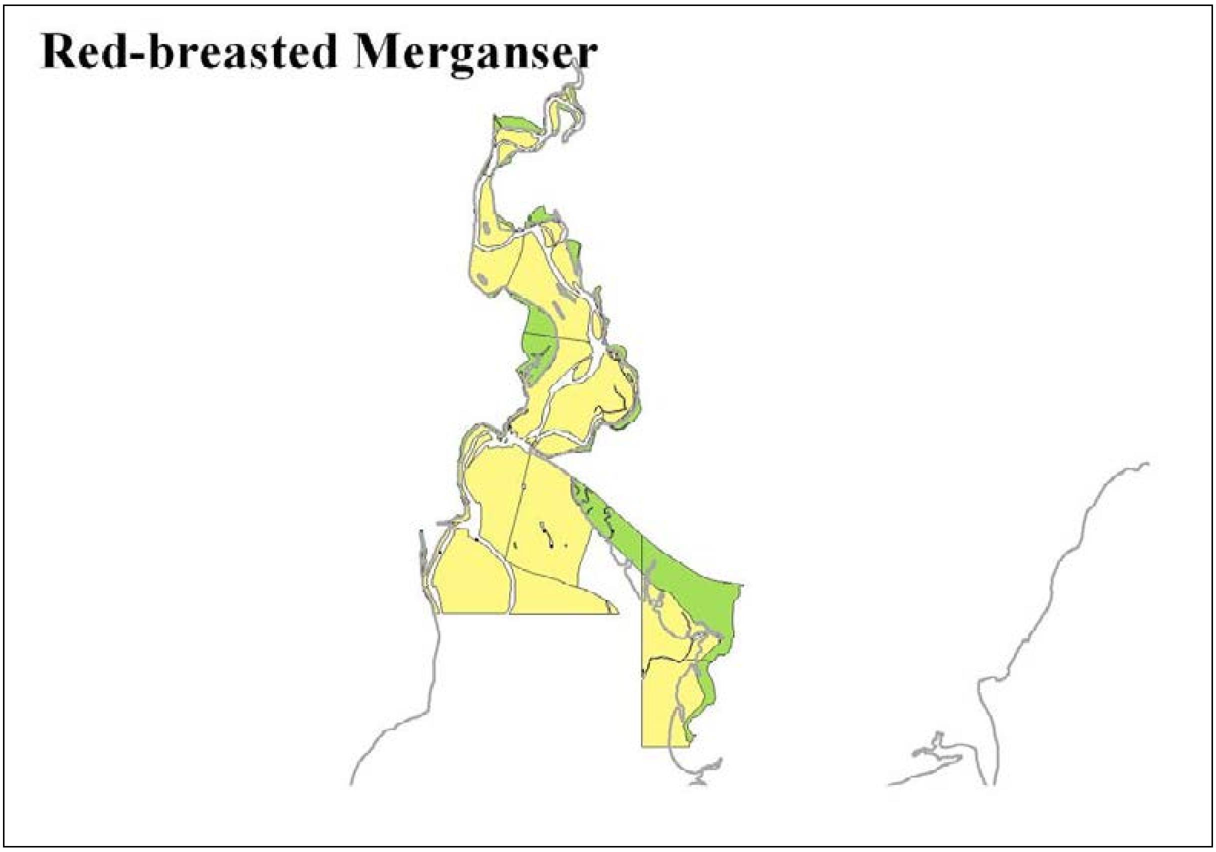
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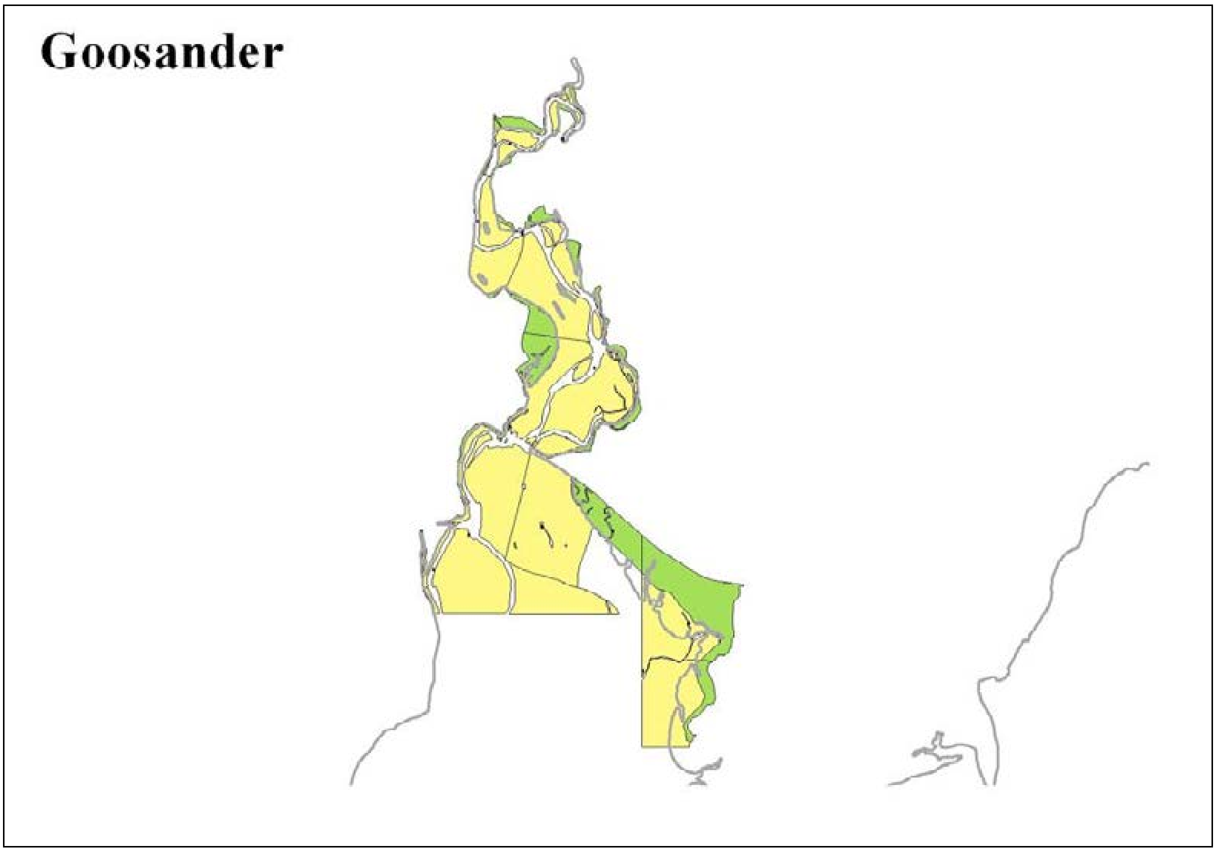
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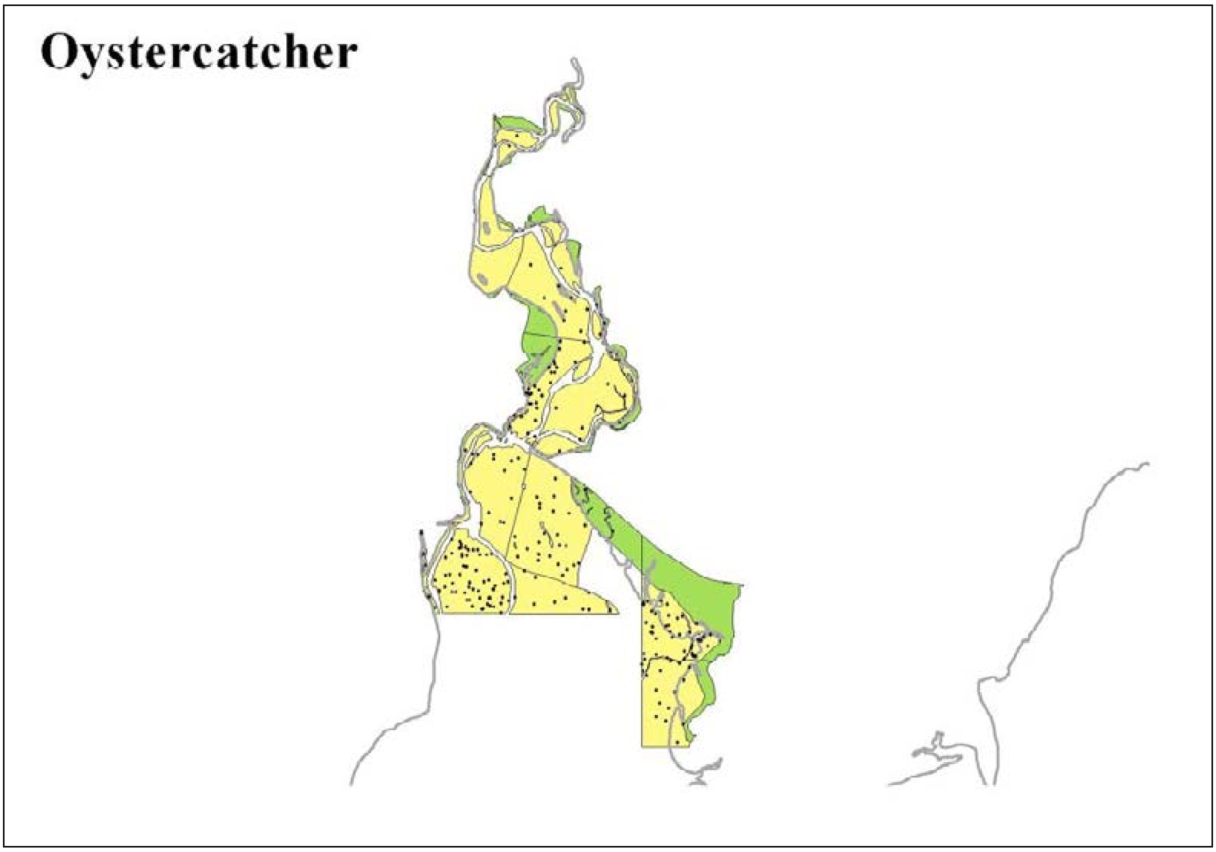
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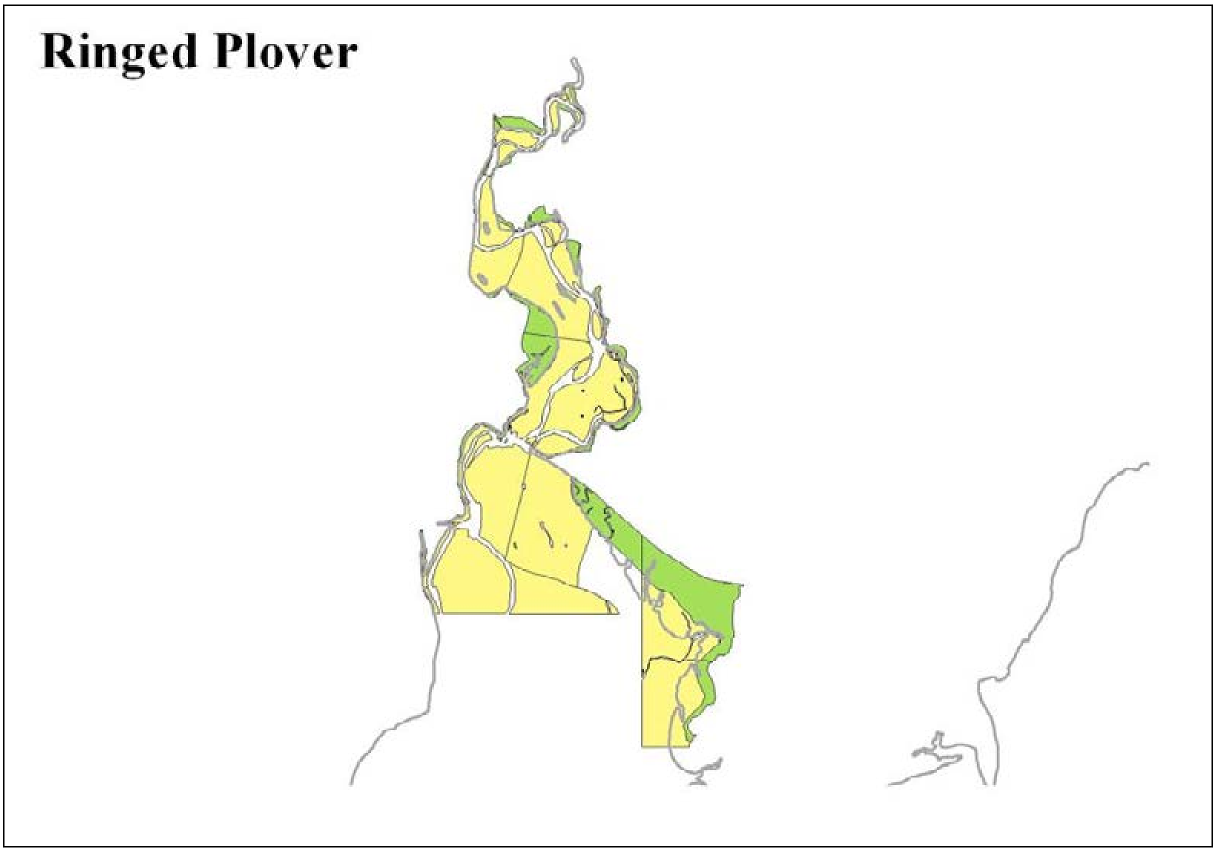
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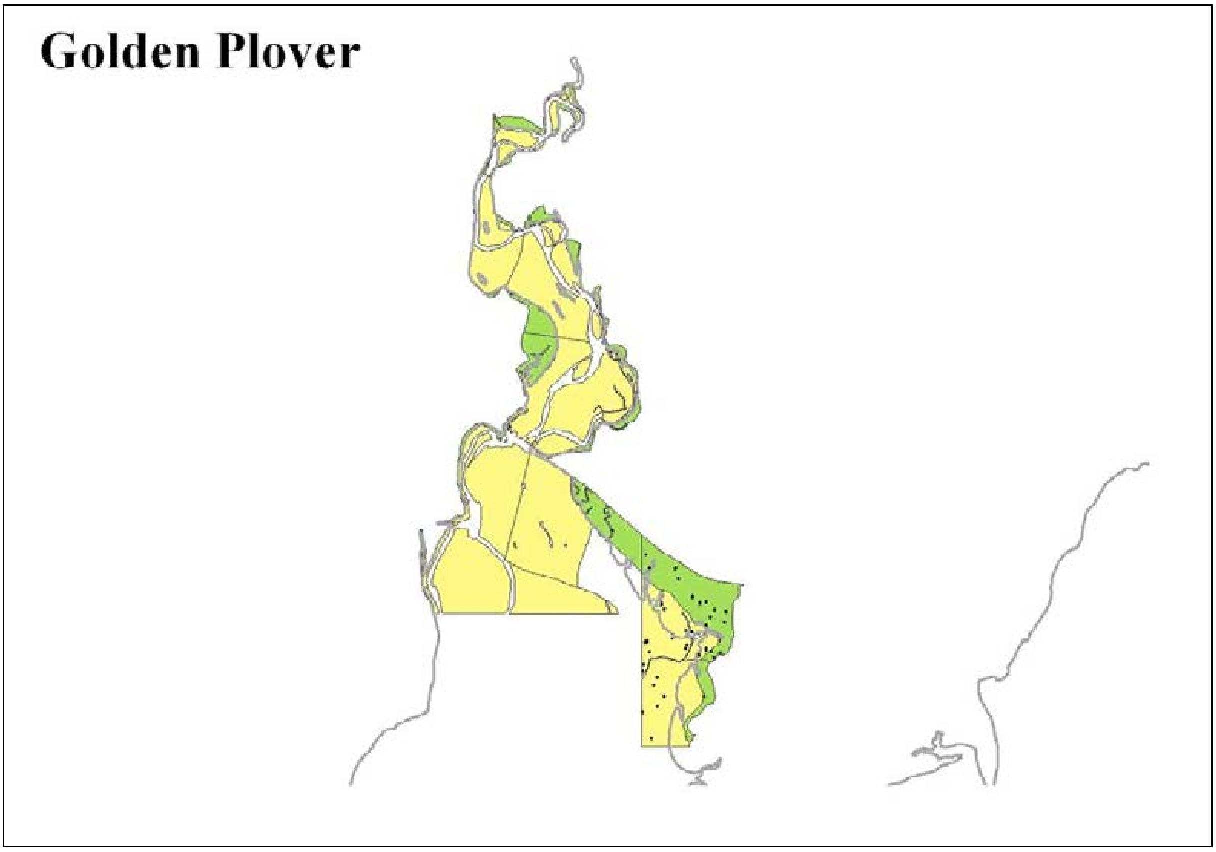
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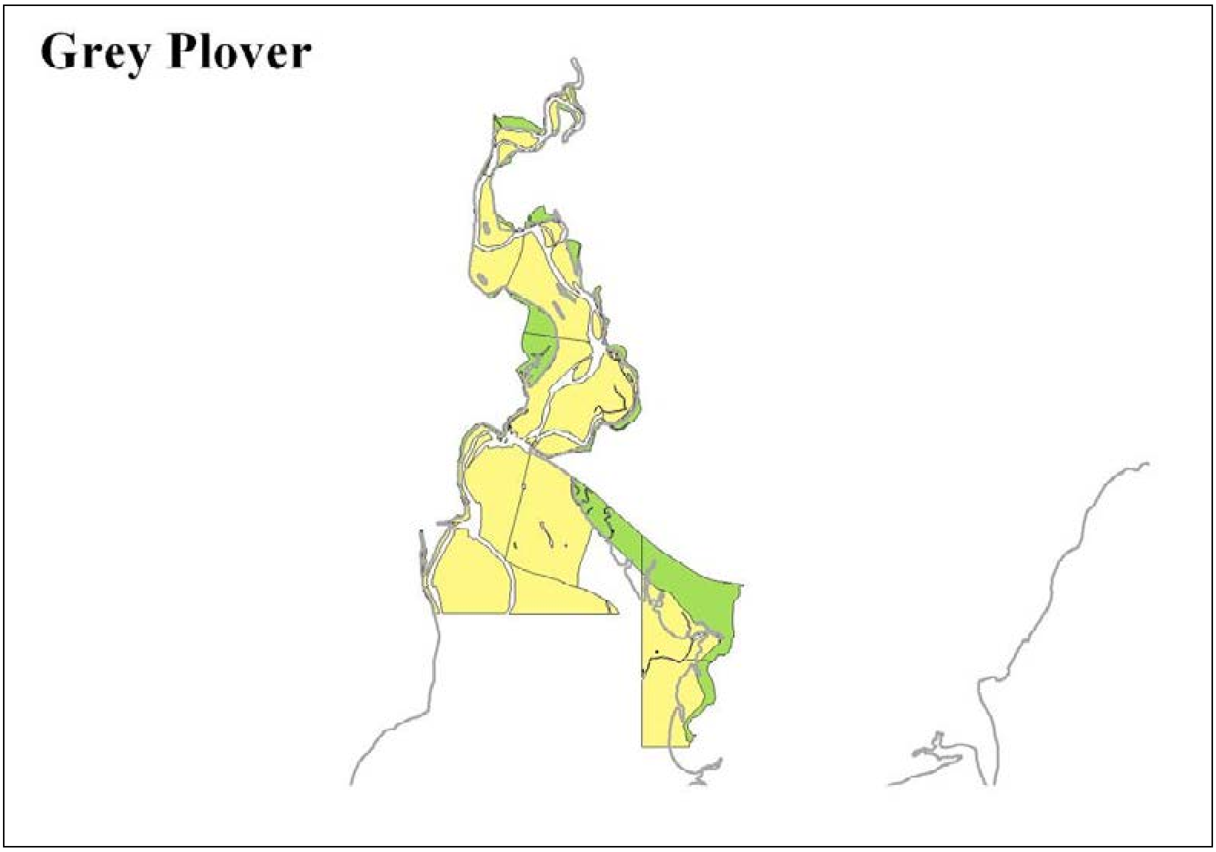
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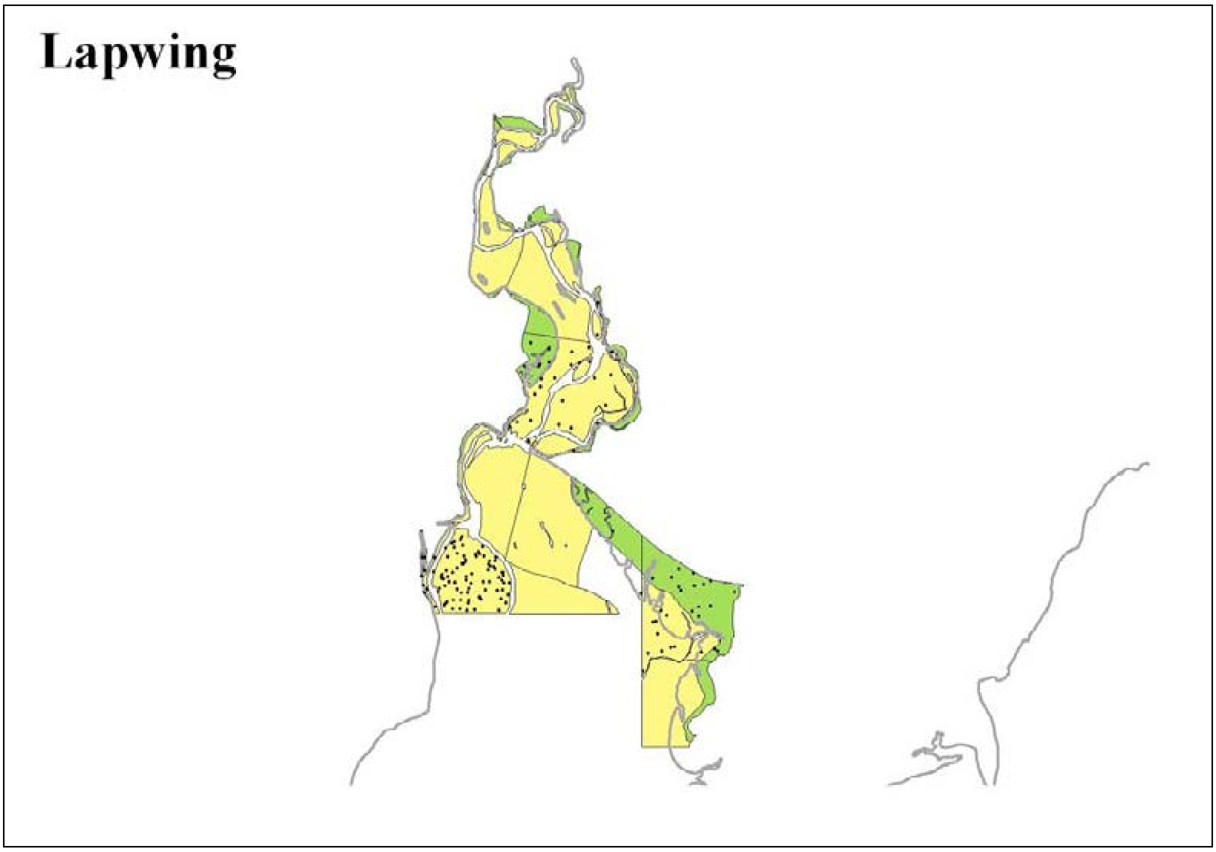
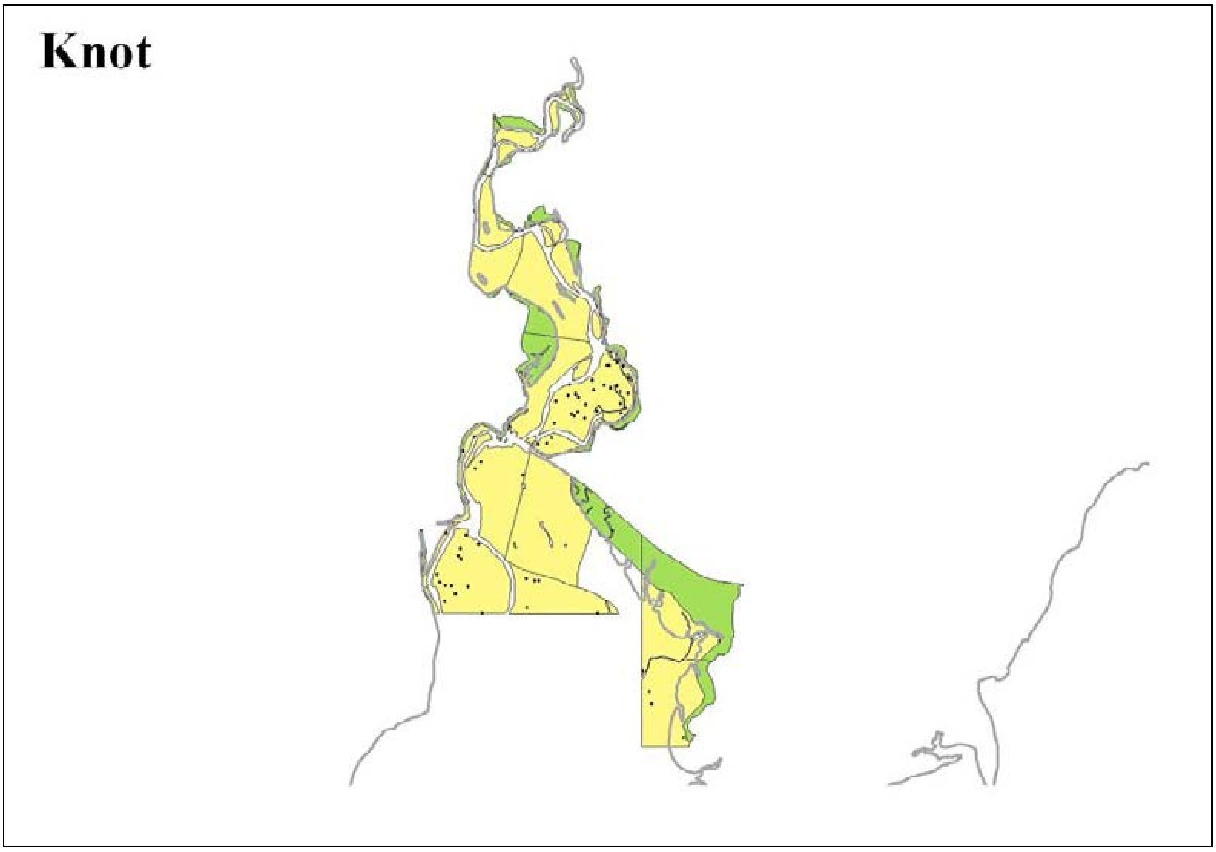

Lapwing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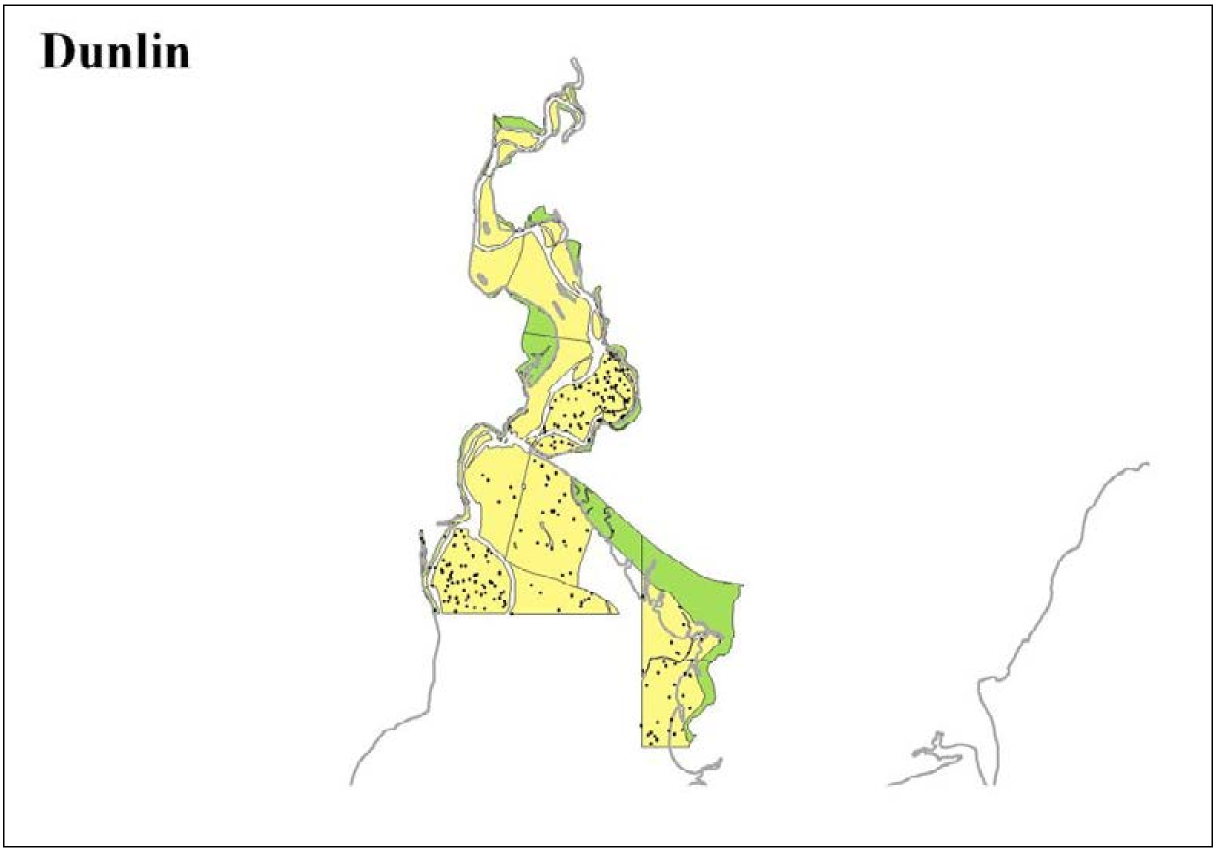
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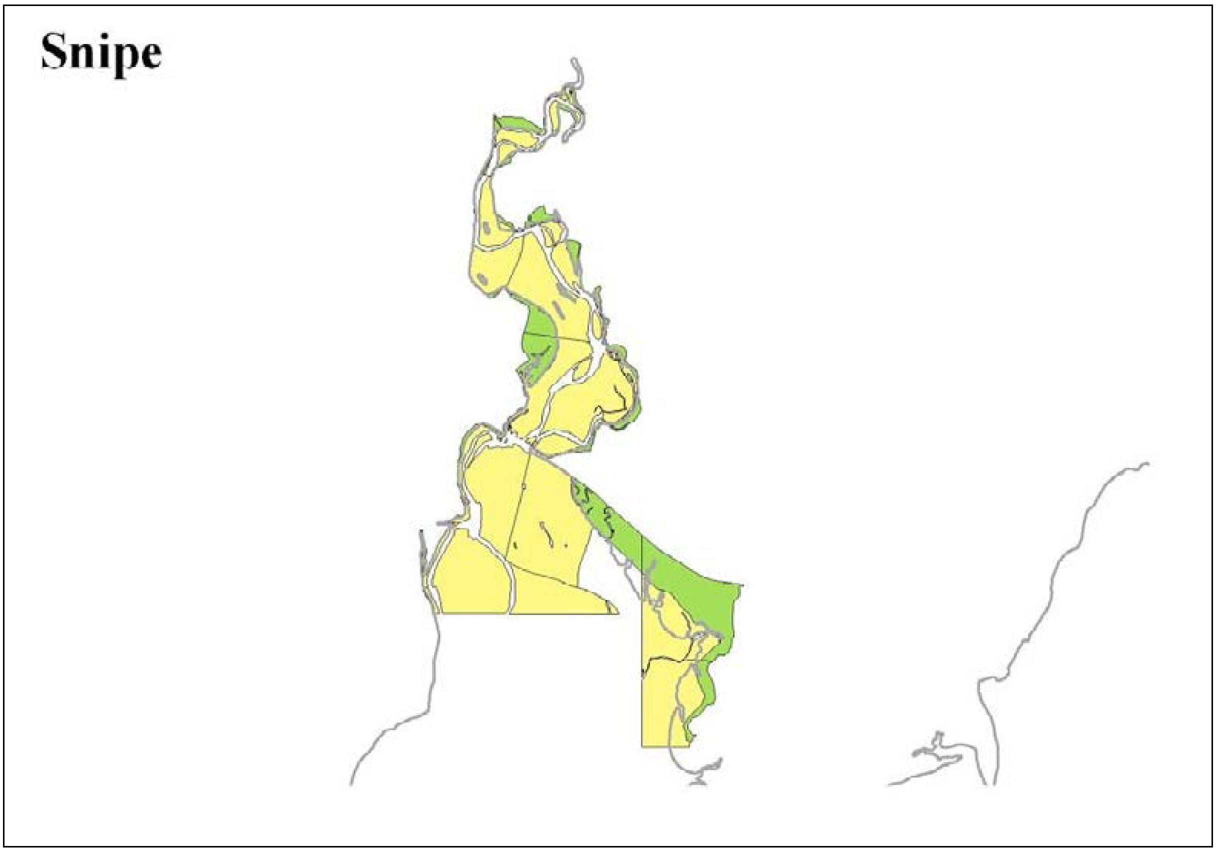
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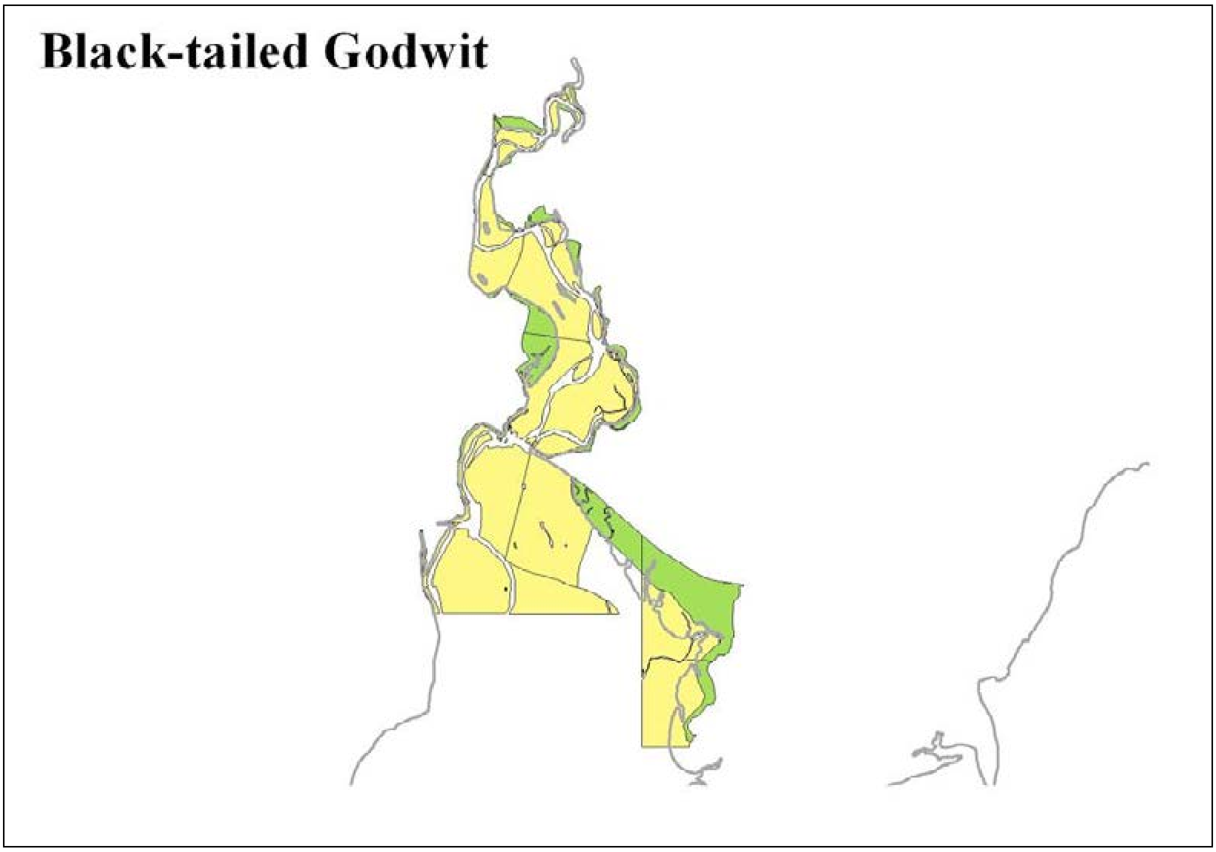
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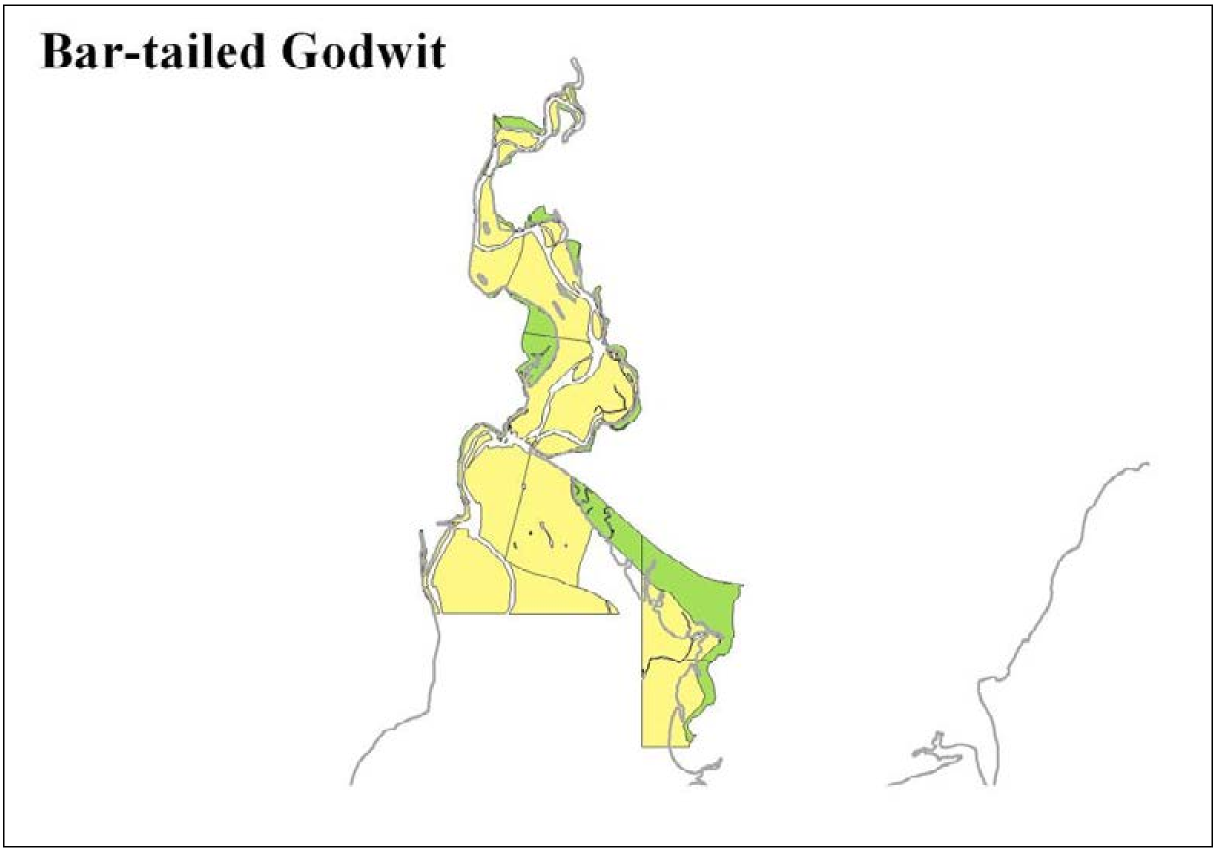
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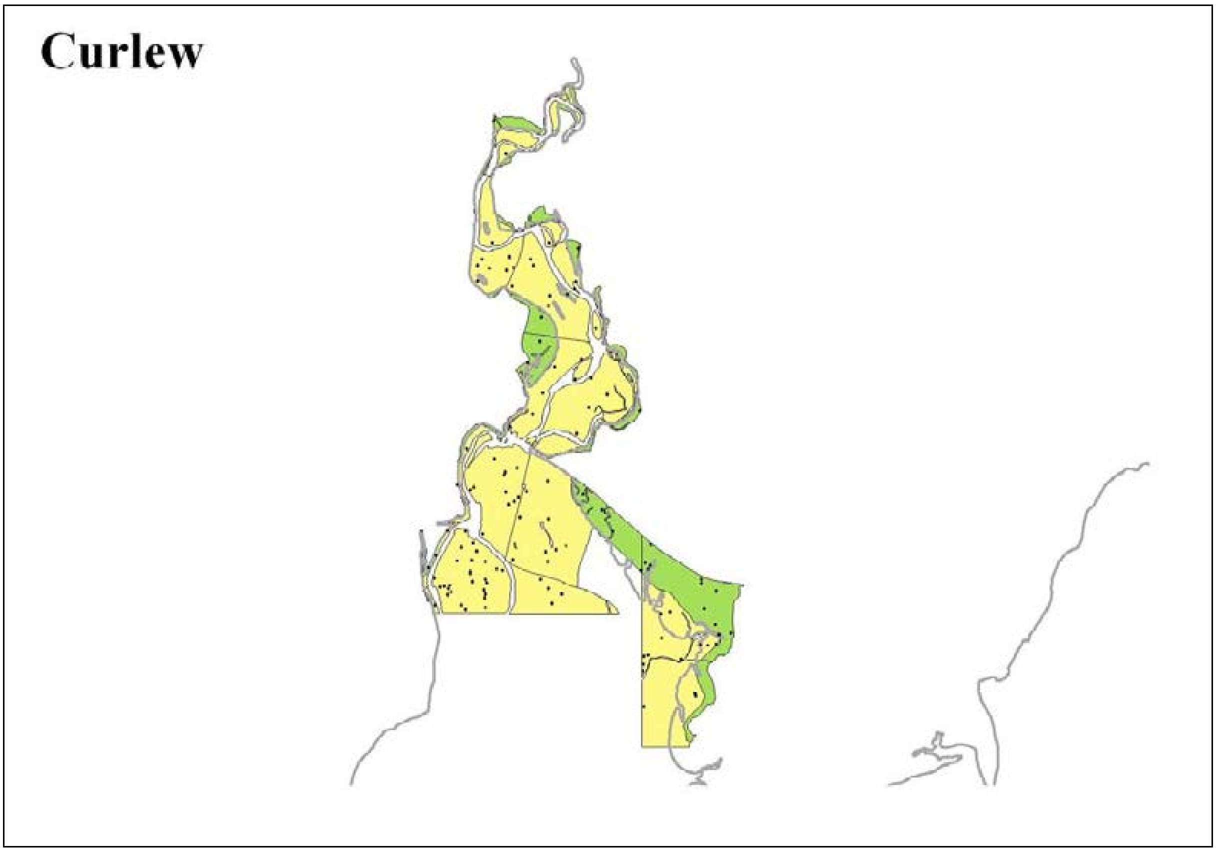
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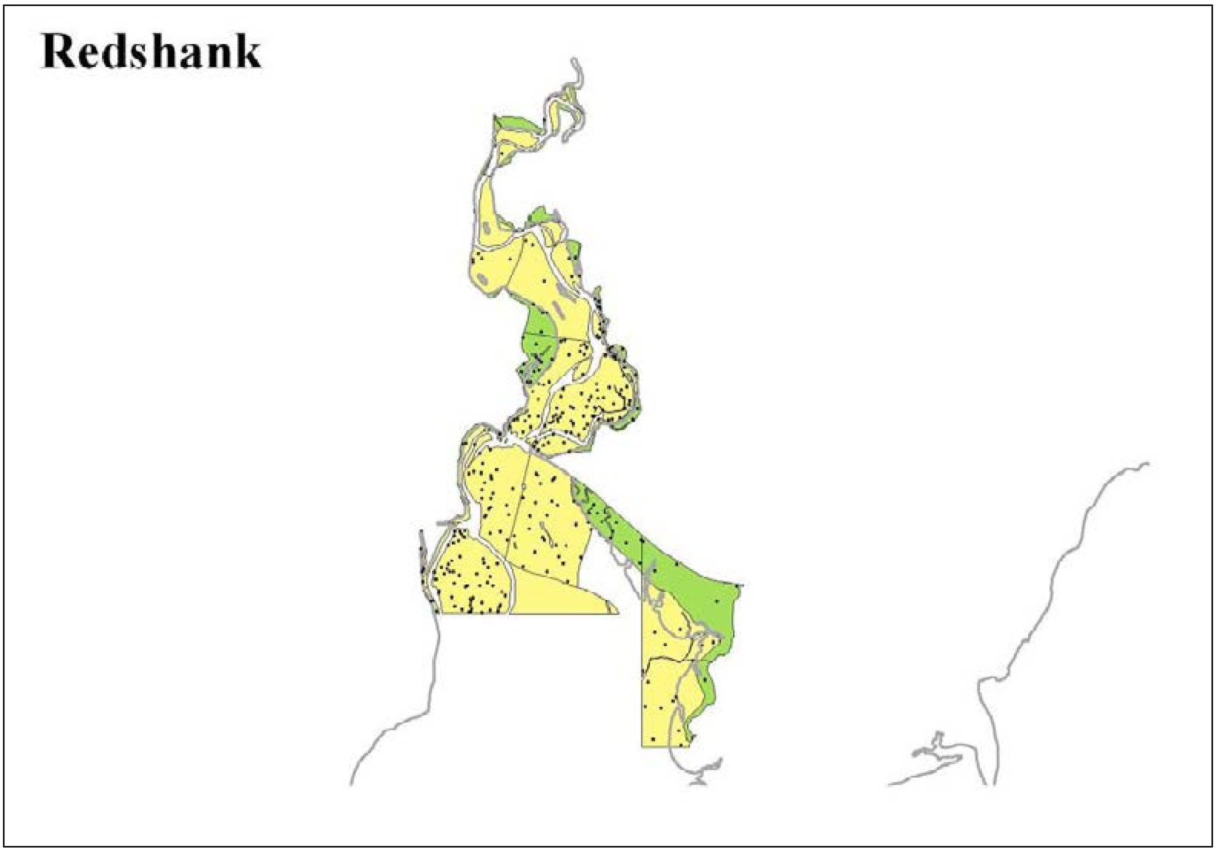
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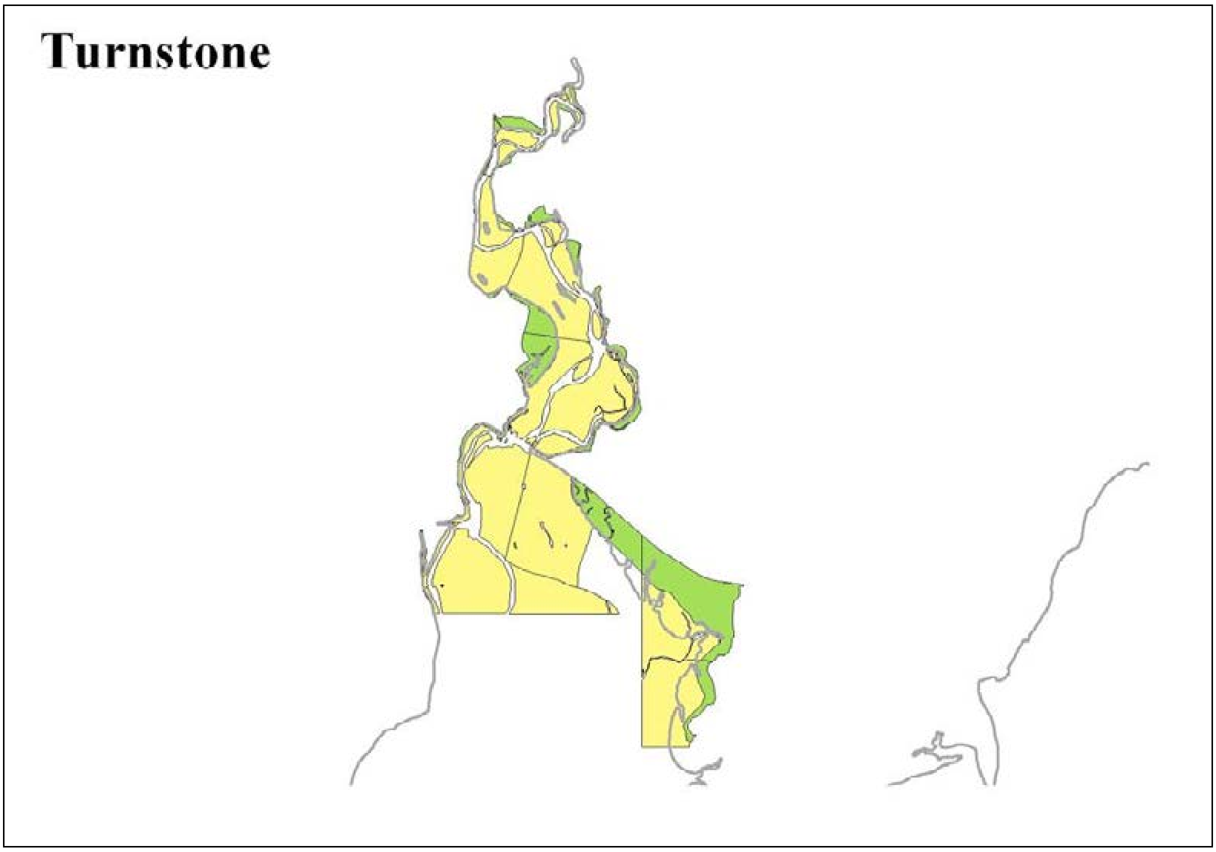
Turnstone

Appendix 3 Photographic images of Knot flock in Half Moon Bay, December 2005.

Figure 3.1 Flock of Knot from the shore (John Marchant).

Figure 3.2 Same flock of Knot in flight (John Marchant).

Figure 3.3 Detail of Knot flock to illustrate density of birds (John Marchant).

Appendix 4 Aerial imagery (Royal Air Force Ornithological Society).

4.1 Royal Air Force Ornithological Society (RAFOS)

RAFOS is an organisation for people connected with the RAF with an interest in ornithology, and lists around 250 members. The group makes valuable contributions to a number of schemes and surveys, including The Wetland Bird Survey (WeBS). The expertise and enthusiasm of the group has provided WeBS with some unique datasets, notably on bird numbers in remote parts of Scotland that would otherwise remain unvisited. Therefore there exist strong links between RAFOS and WeBS. The goodwill between the two organisations was further extended by the offer to investigate image capture of bird distribution using RAF technology. Resulting knowledge would not only benefit WeBS but also the RAF themselves, as such data could be used in bird-strike models and risk analysis. Thus, attempts were made to pioneer such a method, and BTO staff visited RAF Marham to discuss results. The outcomes and implications of this collaboration are considered in this Appendix.

4.2 Survey methods

During November 2005, the Tactical Imagery Wing based at RAF Marham, Norfolk, undertook a series of sorties over The Wash, designed to obtain imagery of the area and to take a snapshot view of the bird distribution therein. Sorties were flown on one date when the tidal state was low. Images were captured using a camera mounted on the undercarriage of the aircraft, and were displayed on acetate film using a light-box. Eighteen final images were supplied in digital (.tif) format for computerised analysis. Spatial position of habitat in images was inferred from recognisable landmarks as co-ordinates were not stamped onto slides, nor was a scale provided.

4.3 Images

An example of the images obtained is displayed below (Figures 4.3.1, 4.3.2), with a map included for spatial reference (Figure 4.3.3). Although at the resolution displayed detection of likely bird groups is difficult, it is possible to zoom in to a finer level without losing clarity. Even at this level, however, it is extremely difficult to be certain that apparent flocks of birds are indeed so (Figure 4.3.2). It is also evident that most pixels thought to be birds are white. This may be an effect of the exposure of the film, or it may be that only large species with light plumage are detectable (*e.g.* gulls, swans, geese, Shelduck). The images do give an excellent impression of habitat, with creeks, saltmarsh, water and other habitat types clearly visible. It is therefore possible to focus attention on areas likely to support large flocks of feeding birds, but detecting birds and discriminating them from habitat features, film blemishes and so on is as yet problematic.

1.4 Conclusions

It is clear that aerial imagery of the type supplied by RAFOS offers a potentially revolutionary method for accurately mapping distributions of birds at low tide. Images have the potential to reveal locations of birds uncountable from the land without the drawbacks of counter error and disturbance associated with standard aerial survey.

However, detailed analysis of the images obtained by RAFOS has not been undertaken, due to the great difficulty of discriminating birds from other features found on this exploratory analysis. However, at the current resolution it may be possible to investigate further areas of importance for birds at low tide. If it is accepted that an unknown proportion of birds is undetected, it should probably be feasible to undertake an automated counting assessment of all pixels thought to be birds. This process could be repeated at different levels of filtering, adjusted to confidence in determination (albeit totally subjective). Such an approach would at least help identify major bird concentrations. However, it is impossible to know which species were being represented; this would need to be retrospectively inferred from habitat type and prior knowledge of distribution.

The first step in this process would be to assign each image file to a 'real world' location. This should be possible using Geographical Information Systems (GIS). This would allow actual spatial locations to be determined, ensuring that bird flocks are plotted in the correct locations. It would also allow an overall picture of coverage achieved by the RAF sorties. Subsequently, image analysis could be undertaken within the same package in order to obtain some quantitative measure of bird abundance or density. It would be worthwhile liasing with site managers of the reserves over which aerial images were taken, in order to learn how known distributions correspond to anything derived from aerial images. The distributions could also be compared to those recorded between 1985 and 1987 (Goss-Custard & Yates 1992; Yates *et al*. 1993), although inevitably some differences will exit between distributions measured twenty years apart.

Should RAFOS be amenable to the idea of developing this method further, one essential approach from a WeBS viewpoint would be to undertake ground-truthing surveys simultaneously with, or as close as possible to, the RAF sorties. This would allow ground-based observers to record, at a limited number of locations, the distributions and numbers of birds that could then be compared to aerial images of the same areas. Alternatively, images taken at slightly higher resolution would be necessary to allow confident determination of bird flocks; to identify which species are present would require even finer resolution.

In conclusion, it is hoped that RAFOS and WeBS can continue to co-operate with surveys of this type, so that bird distributions can be determined to feed into bird-strike models for aircraft and into conservation monitoring protocol. Although at current resolution the data are of somewhat limited value, it is nonetheless encouraging that some probable congregations of birds can be identified; the challenge now is to discover whether birds present at the time of this survey can all be detected, or whether future attempts will reveal further aggregations of birds not detectable using the technology supplied at present.

Figure 4.3.1 Aerial image of The Wash coast at Snettisham obtained by RAF Tactical Imagery Wing. Box shows approximate area of detail in Figure 4.3.2.

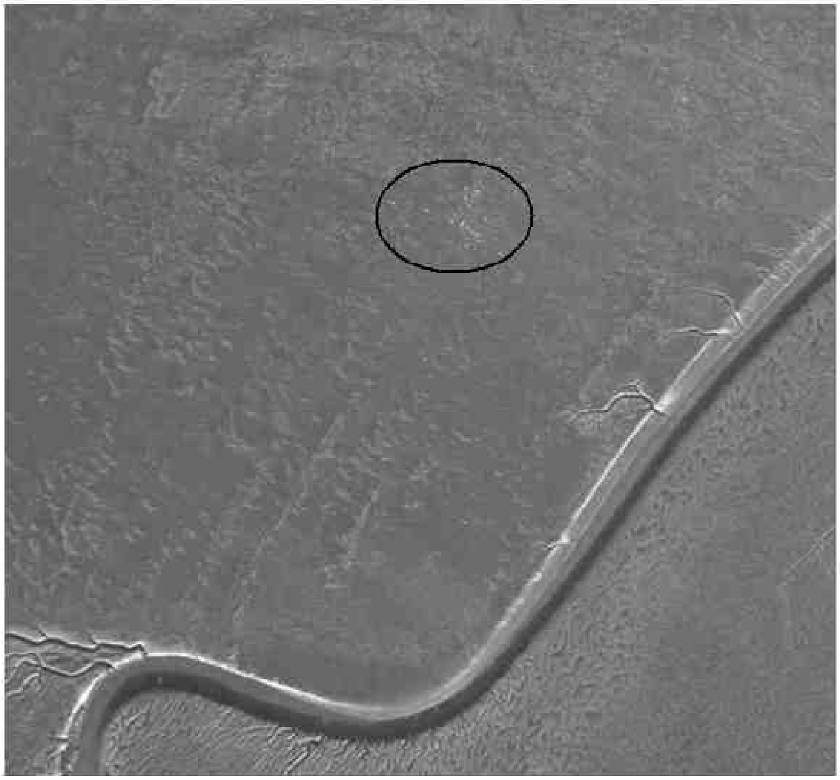

Figure 4.3.2 Detailed aerial image of The Wash coast obtained by RAF Tactical Imagery Wing. Oval shows possible bird flock.

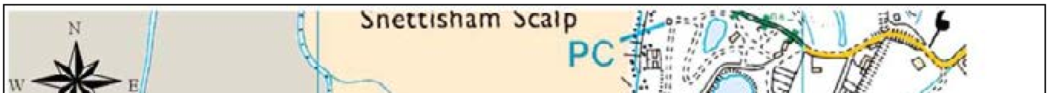

Figure 4.3.3 Approximate area of image in Figure 4.3.1.

Copyright Information

References

Goss-Custard, J.D. & Yates, M.G. 1992. Towards predicting the effect of salt-marsh reclamation on feeding bird numbers on the Wash. *Journal of Applied Ecology*, **29**, 330-340.

Yates, M.G., Goss-Custard, J.D., McGrorty, S., Lakhani, K.H., Durell, S.E.A. le V. dit, Clarke, R.T., Rispin, W.E., Moy, I., Yates, T., Plant, R.A. & Frost, A.E. 1993. Sediment characteristics, invertebrate densities and shorebird densities on the inner banks of the Wash. *Journal of Applied Ecology*, **30**, 599-614.