BTO Research Report No.612

Production of Representative Cormorant Population Trends with Confidence Limits

Final report to the Food and Environment Research Agency (Fera) and the Department for Environment, Food and Rural Affairs (Defra)

Authors

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June 2012

The British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU
Registered Charity No. 216652

British Trust for Ornithology

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Published in June 2012 by the British Trust for Ornithology
The Nunnery, Thetford, Norfolk, IP24 2PU, UK

ISBN 978-1-908581-08-2

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1. BACKGROUND AND AIM

The Wetland Bird Survey (WeBS) produces indices and smoothed trends for over 70 species of waterbird overwintering in Great Britain and the four constituent countries of the UK, revised on an annual basis (Holt *et al.* 2011, Thaxter *et al.* 2010). Regional trends (based on administrative regions of the Environment Agency and the Scottish Environment Protection Agency) are also produced routinely. In addition, a Cormorant trend for England and Wales combined is generated to supply Fera / Defra. All these trends are generated using the Underhill Indexing Method (Underhill & Prŷs-Jones 1994).

With respect to the Cormorant index, there are two issues that give cause for concern. Firstly, the current index is based on all consistently counted (at least 50% of potential counts undertaken) WeBS sites in England and Wales both coastal and inland. It would be informative to produce a separate population trend from inland sites only. Secondly, and more importantly, because WeBS counts are based on sites of variable size and nature, hitherto no attempt has been made to attach confidence limits to these indices. While this has not been considered an issue previously for the general population trend monitoring for which WeBS indices are used, it does becomes an issue when one wishes to consider the significance of between winter changes to the index value with respect to control measures such as those currently in place for Cormorants.

Thus an action point arising from a meeting held between Defra, government agencies and NGOs on Cormorants (9 January 2009) was to consider the possibility of incorporating data from the WeBS Dispersed Waterbird Survey (Jackson *et al.* 2006) to inform the WeBS index for Cormorant to allow confidence limits to be fitted to the Cormorant trend. The analysis presented below arose from a later meeting (2 February 2009), and actioned as a result of discussion at a meeting informing Defra's current review of the culling of fish-eating birds (5 October 2011).

This analysis would add considerably to our understanding of trends in the Cormorant population of England and Wales, both at this national level and regionally

1.2 Objective

To construct a time series of estimates of the England & Wales (and regional) wintering Cormorant population, adjusted for the unrepresentative coverage of inland wetlands by WeBS, that will better inform the current Defra review of the culling of fish-eating birds and specifically the model used to assess the impact of culling on the national Cormorant population, which currently utilises the unadjusted WeBS index (Smith *et al.* 2008, see also Green 2008).

2. METHODS AND RESULTS

Inland trends - WeBS Core data were used to calculate maximum Cormorant count per winter (Dec-Feb inclusive) per site from 1987 to 2009 (NB year refers to the December of a given calendar year, so 2009 signifies winter 2009/10). For each site, categories of urban habitat cover and water cover (high, medium or low), habitat class (upland or lowland) and region (East and West Midlands were combined into midlands, and Yorkshire and North East was combined into northeast, due to low sample sizes) were assigned according to the principal 1-km squares of each WeBS site (therefore, for larger sites, it is assumed that the habitat categories of the principal 1-km is representative of the site as a whole). Only WeBS sites from England was Wales were included. Only inland sites were included by deleting sites clipped by a 1-km coastal buffer.

Estimates of year-to-year change in the Cormorant population were made using the modelling approach of Freeman and Newson (2008), hence forth F&N. A mixed effects Poisson model was run in R using glmmPQL, specifying site as a random effect, and analysing maximum count in relation to urban cover, water cover and habitat class as fixed effects and the matrix r1-r22 (for 23 years data) as the estimates of year-to-year change. Model output is shown in Table 1.

Data from the Dispersed Waterbird Survey (DWS; Jackson et al. 2006) were used to estimate inland population estimates from non-WeBS 1-km squares. Maximum Cormorant count per square for winter 2002/03 was calculated. Squares with <90% coverage were omitted. Region, habitat codes and coastal squares were treated as for the analysis of WeBS data. Squares that included a WeBS site (or part of a WeBS site) were omitted. The final sample was 339 squares. Cormorant count was modelling using a negative binomial model with PROC GENMOD in SAS. Model output s are shown in Table 2. Parameter estimates from this model in conjunction with habitat data for all inland England and Wales were used to predict Cormorant count in each 1-km square that didn't contain a WeBS site.

Predicted counts for each square from 2002/03 were used as a baseline to predict year-to-year change using estimates from the F&N model. For each grid square, an estimate was made by summing parameter estimates (urban + water + habitatclass + region + intercept + year), where year is the estimated rate of change r1 to r22. This was done by standardising estimates relative to 2002/03, i.e. the (untransformed) estimate for 2002/03 was subtracted from other estimates, meaning that for 2002/03 it was zero. For each square in each year, the predicted count was count DWS prediction * (exp(estimate)). The final output was therefore an estimate of Cormorant abundance for each inland 1-km square (not including WeBS sites) from 1988 to 2009. The annual estimate of total inland abundance was therefore these model-derived estimates added to the observed maximum counts for WeBS sites.

Confidence intervals were fitted to the above trends using bootstrapping. WeBS data were bootstrapped by randomly resampling (with replacement) from the dataset 119 times for each region in each year (i.e. a random data set was created, randomly sampling from a given region and up to the same sample size as that region/year). For each bootstrap, the F&N model was run to output parameter estimates for year-to-year change.

DWS data were bootstrapped by randomly resampling (with replacement) from the dataset for each region as above. A model was then run on each bootstrap sample to produce estimates (per region) for all non-WeBS inland 1-km squares in England and Wales, using the same approach as previously (i.e. a negative binomial model). For each run of the bootstrap, annual totals were extrapolated using the F&N parameter estimates for the equivalently numbered bootstrap of the WeBS data, as outlined previously.

A GAM was run on the total WeBS count per year for inland sites. The DWS estimates from bootstrapping was added to the GAM annual estimate to give total annual estimates of inland Cormorants for each bootstrap. This data set was ranked by year, and the upper and lower 95% confidence limits were identified. Estimates of annual Cormorant population size for non-coastal sites over all years (note the first year is 1988 as the first estimated rate of change is 1987/88 to 1988/89), including confidence intervals, are given in Fig. 1.

Coastal trends - The procedure for estimating inland trends for WeBS data was also run on coastal sites (i.e. those which were clipped by 1-km coastal buffer). For a national population estimate, this was combined with NEWS data. NEWS data was extracted for sections in England and Wales that were counted for Cormorants in the survey in 1997 and 2006. This did not include estuaries, which are covered under WeBS. Sections were included with at least one of the three habitats covered, thus it is assumed that non-covered habitats were unsuitable and therefore zero. Total per region and year were output. There was c. 10% of suitable coastline that was not surveyed in either year. This was corrected for in the population estimates by taking the mean Cormorant density per km of coastline for each region, and applying this mean to the uncounted coastline. These additional estimates were then added to the observed totals.

For annual totals, parameter estimates were used from F&N run on coastal WeBS data using only year-to-year change and region (DWS habitat codes were not available for most coastal squares). Sections were either surveyed only once, either in 1997 or 2006, or in both years. In order to construct a time series, annual estimates from F&N were derived for different groups: 1997 only, 2006 only, 1997 both and 2006 both (using the appropriate corresponding WeBS year as the reference year), also including estimates of 'missing' coastline. A mean of the annual estimates that were covered in both years was calculated and added to the annual estimates from 1997 and 2006. NEWS annual totals plus WeBS annual totals were then summed to produce the coastal population trend.

WeBS data for coastal sites were bootstrapped as above, and F&N parameters were output for each bootstrap. NEWS data was bootstrapped by selecting sections at random for a given year (1998 or 2007) and region so the total length of sections was approximately (usually within c. 1 km) the same as that covered in the actual survey. The counts from these random sections was summed to give a regional and year estimate for each bootstrap. These bootstrap estimates were then used in conjunction with parameter estimates from the coastal F&N models to extrapolate annual totals, as described for the observed NEWS data. NEWS estimates were added to an annual estimate for WeBS coastal sites derived from a GAM, and confidence intervals were calculated based on this sample of bootstraps. Trends with confidence intervals for separate coastal and inland sites are given in Fig. 2.

Combined trends – Annual population estimates were simply the sum of coastal and inland estimates for each year. Confidence intervals were calculated as the 95% confidence limits of the sum of coastal and inland bootstrap estimates for each year. The estimates are shown in Fig. 3.
Estimates and upper and lower 95% confidence limits for inland, coastal and combined Cormorant populations in England and Wales are given in the Appendix.

Regional trends – The above procedures were repeated for England only. Inland, coastal and combined trends are shown in Fig. 4. Similar trends were also derived for eight regions of England and Wales, shown in Fig. 5. Estimates and upper and lower 95% confidence limits for inland, coastal and combined Cormorant populations in England are given in the Appendix.

Acknowledgements

This work was funded through the Food and Environment Research Agency (Fera) by the UK Department for Environment, Food and Rural Affairs (Defra). Our thanks go to Tim Andrews and Ashley Smith from Defra and Graham Smith from Fera for their help and comments, and to members of the fish-eating birds policy review group and to Stuart Newson and Alison Johnston (BTO) for their comments. Data on Cormorant numbers were obtained from the Wetland Bird Survey (WeBS), a joint scheme of the British Trust for Ornithology (BTO), Royal Society for the Protection of Birds (RSPB) and Joint Nature Conservation Committee (JNCC), in association with Wildfowl & Wetlands Trust (WWT), that aims to monitor non-breeding waterbirds in the UK.

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Table 1. Estimates and se of year-to-year change of maximum winter Cormorant count on inland WeBS sites derived from a F&N model, in relation to urban habitat category, water cover category ('high' is the reference category for both, with Parameter =0), habitat class ('Upland' reference category), and region (East Anglia reference category). Year-to-year change estimates are given by r1-r22, where r1 is the change from 1987 to 1988. Site was fitted as a random effect (sd = 2.50) and Poisson errors were specified. N = 16734 observations from 1415 sites.

Parameter	Level	Estimate	Se	P
Urban	Low	-0.010	0.004	0.007
	Medium	-0.011	0.003	0.000
Water	Low	0.010	0.002	0.000
	Medium	0.022	0.003	0.000
Habitat class	Lowland	0.025	0.006	0.000
Region	London	0.023	0.006	0.000
	Southeast	-0.003	0.004	0.444
	Southwest	0.023	0.005	0.000
	Northeast	0.025	0.005	0.000
	Northwest	-0.021	0.003	0.000
	Midlands	-0.001	0.004	0.708
	Wales	-0.019	0.008	0.021
Annual change	r1	0.135	0.018	0.000
	r2	0.247	0.016	0.000
	r3	0.057	0.015	0.000
	r4	-0.058	0.015	0.000
	r5	0.142	0.015	0.000
	r6	-0.082	0.015	0.000
	r7	0.086	0.015	0.000
	r8	0.133	0.014	0.000
	r9	-0.078	0.014	0.000
	r10	-0.153	0.015	0.000
	r11	0.080	0.015	0.000
	r12	-0.022	0.015	0.141
	r13	-0.045	0.015	0.003
	r14	0.156	0.027	0.000
	r15	0.003	0.027	0.914
	r16	0.006	0.014	0.668
	r17	-0.087	0.014	0.000
	r18	-0.030	0.015	0.045
	r19	-0.022	0.015	0.151
	r20	0.041	0.015	0.006
	r21	0.008	0.015	0.600
	r22	-0.099	0.015	0.000
Intercept		0.273	0.053	0.000

Table 2. Estimates and se of winter Cormorant count on inland 1-km squares on DWS sites in relation to urban habitat category, water cover category, habitat class and region, derived from a negative binomial model. n = 339 sites.

Parameter	Level	Estimate	se	P
Urban	H	0.606	1.324	0.647
	L	0.649	0.965	0.501
	M	0.000	0.000	.
Water	H	-0.011	1.305	0.993
	L	-3.740	0.856	<.0001
	M	0.000	0.000	.
Habitat class	L	25.834	0.000	.
	U	0.000	0.000	.
Region	East Anglia	1.925	1.162	0.098
	London	-21.692	153129	1.000
	Midlands	-0.461	1.742	0.791
	Northeast	1.252	1.653	0.449
	Northwest	2.776	1.766	0.116
	Southeast	2.195	1.175	0.062
	Southwest	1.360	1.413	0.336
	Wales	0.000	0.000	.
Intercept		-27.630	1.229	<.0001

Figure 1. Annual estimates of inland winter Cormorant populations in England and Wales, based on combined WeBS and DWS data. Dashed lines represent upper and lower 95% confidence limits.

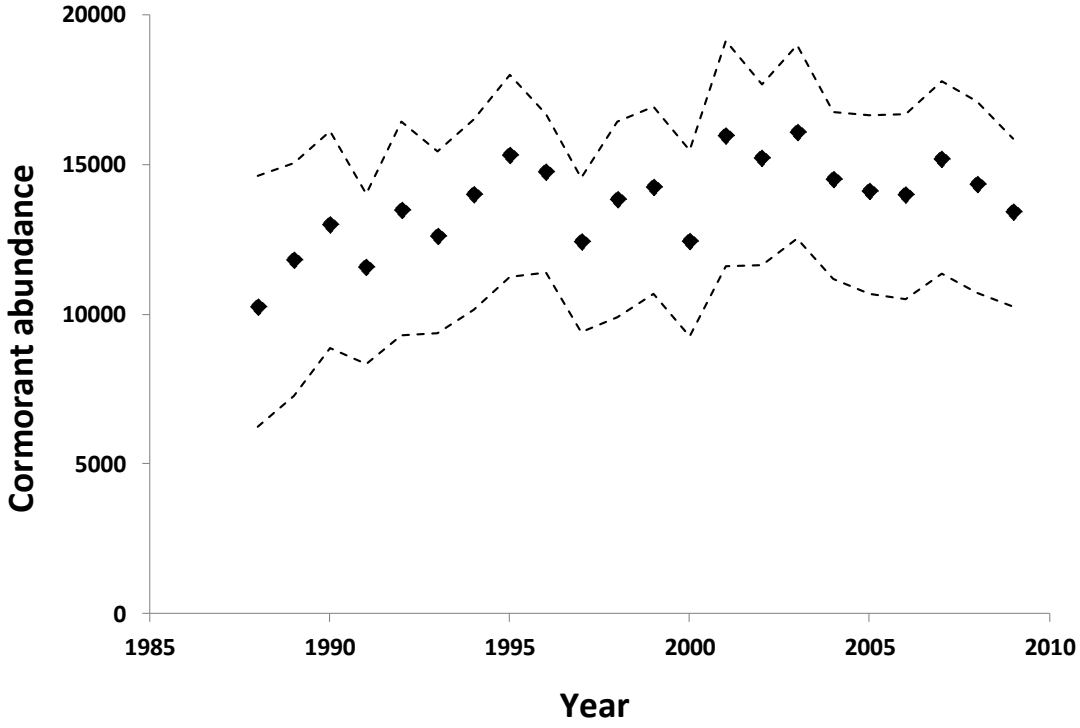


Figure 2. Annual estimates of coastal winter Cormorant populations in England and Wales, based on combined WeBS and NEWS data. Dashed lines represent upper and lower 95% confidence limits.

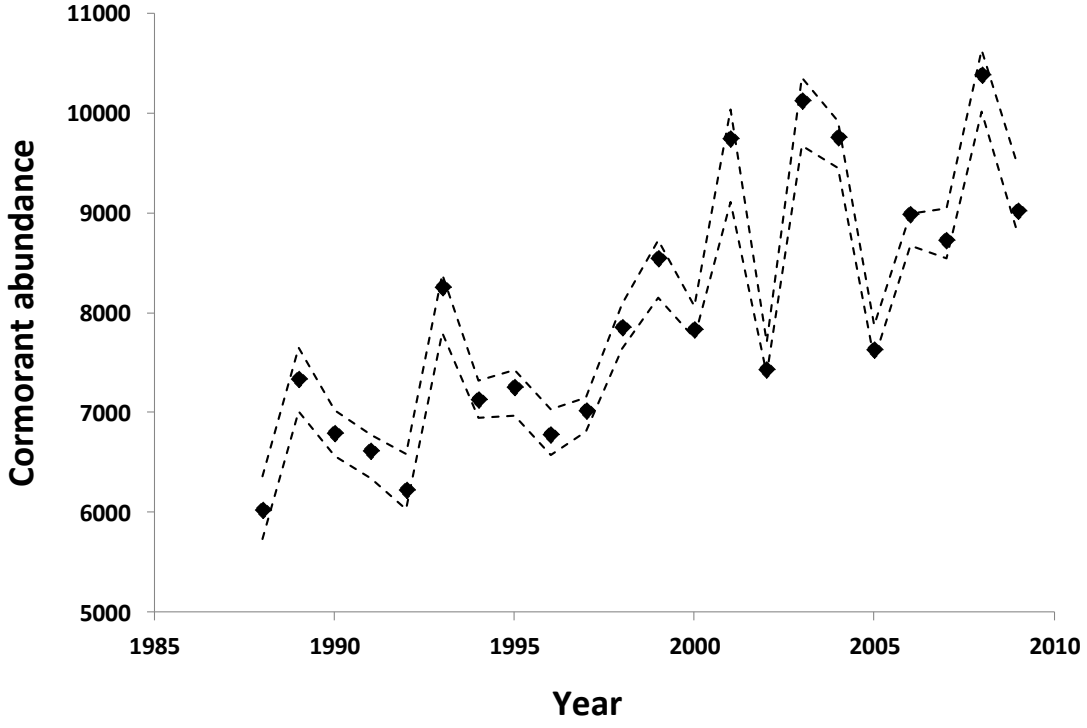


Figure 3. Annual estimates of winter Cormorant populations in England and Wales, based on combined WeBS, DWS and NEWS data. Dashed lines represent upper and lower 95% confidence limits.

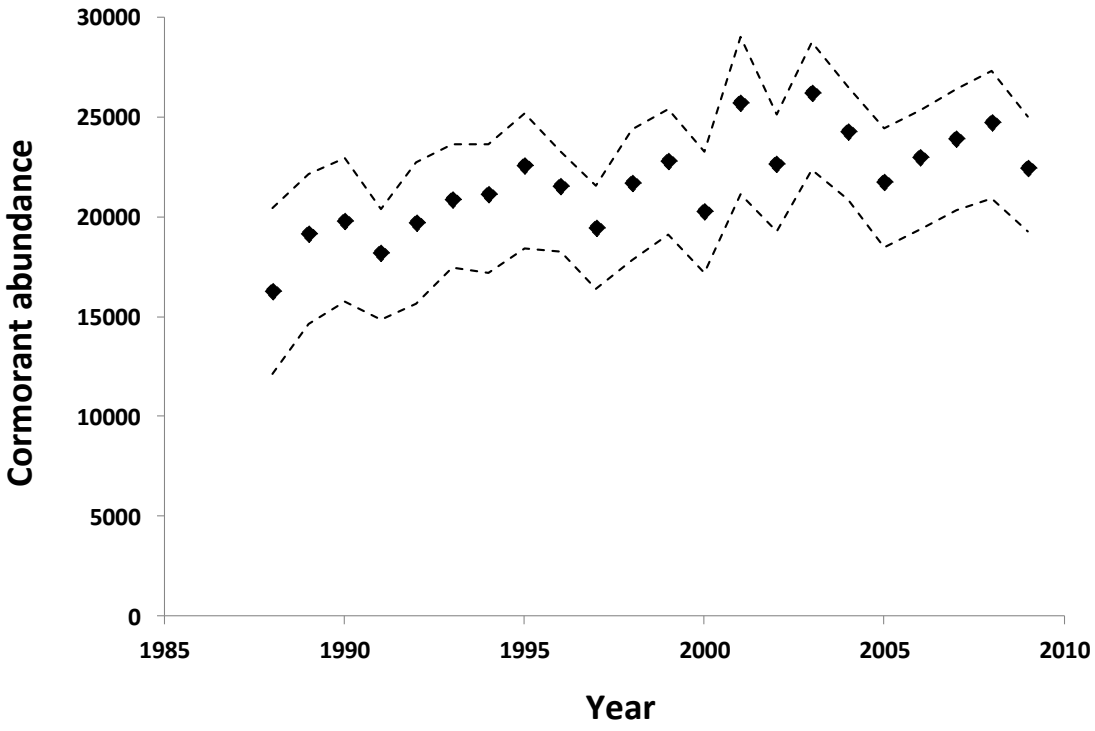


Figure 4. Annual estimates of winter Cormorant population in England, for inland sites (a), coastal sites (b) and all sites (c). Dashed lines are upper and lower 95% confidence limits.

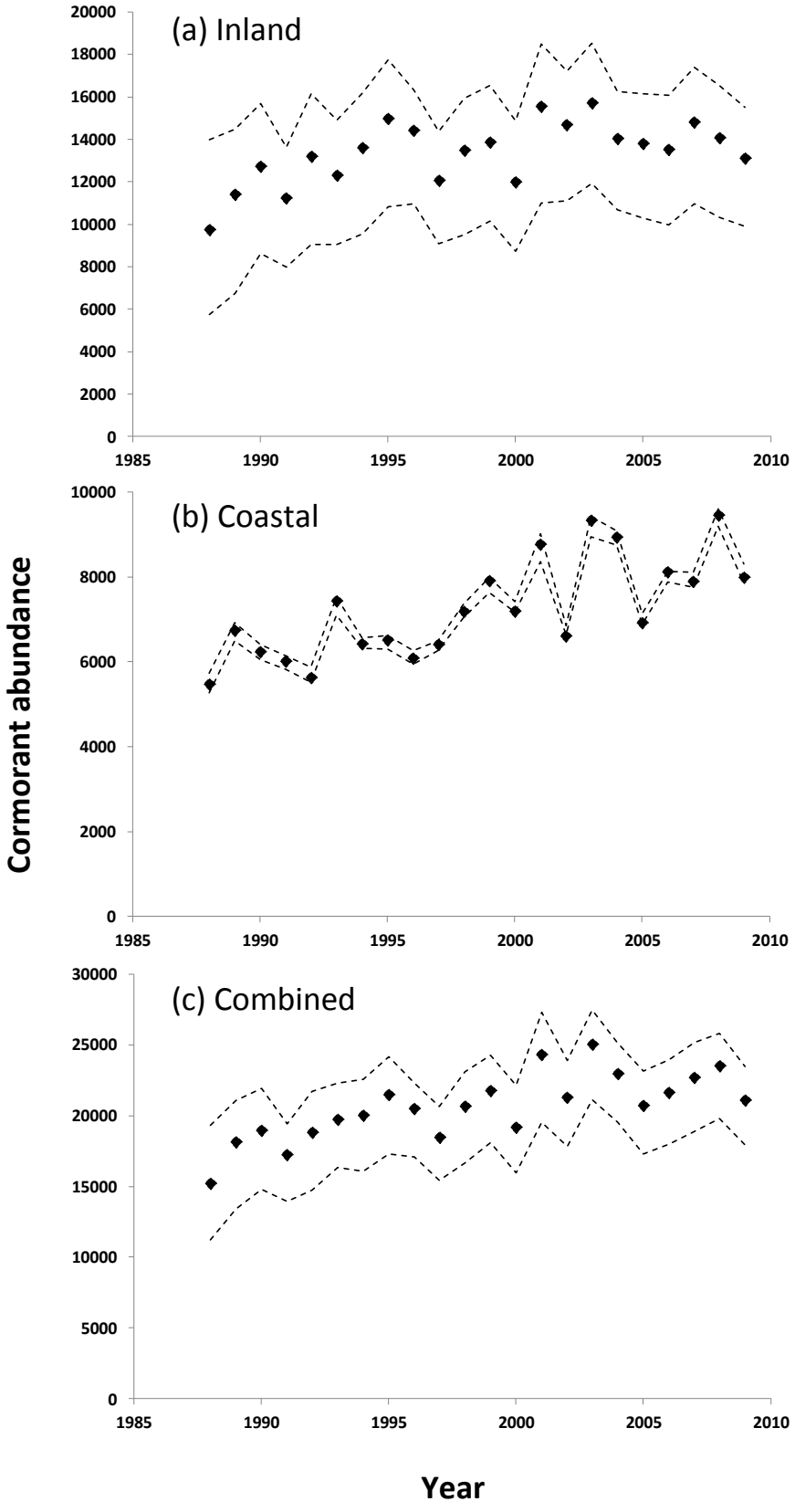
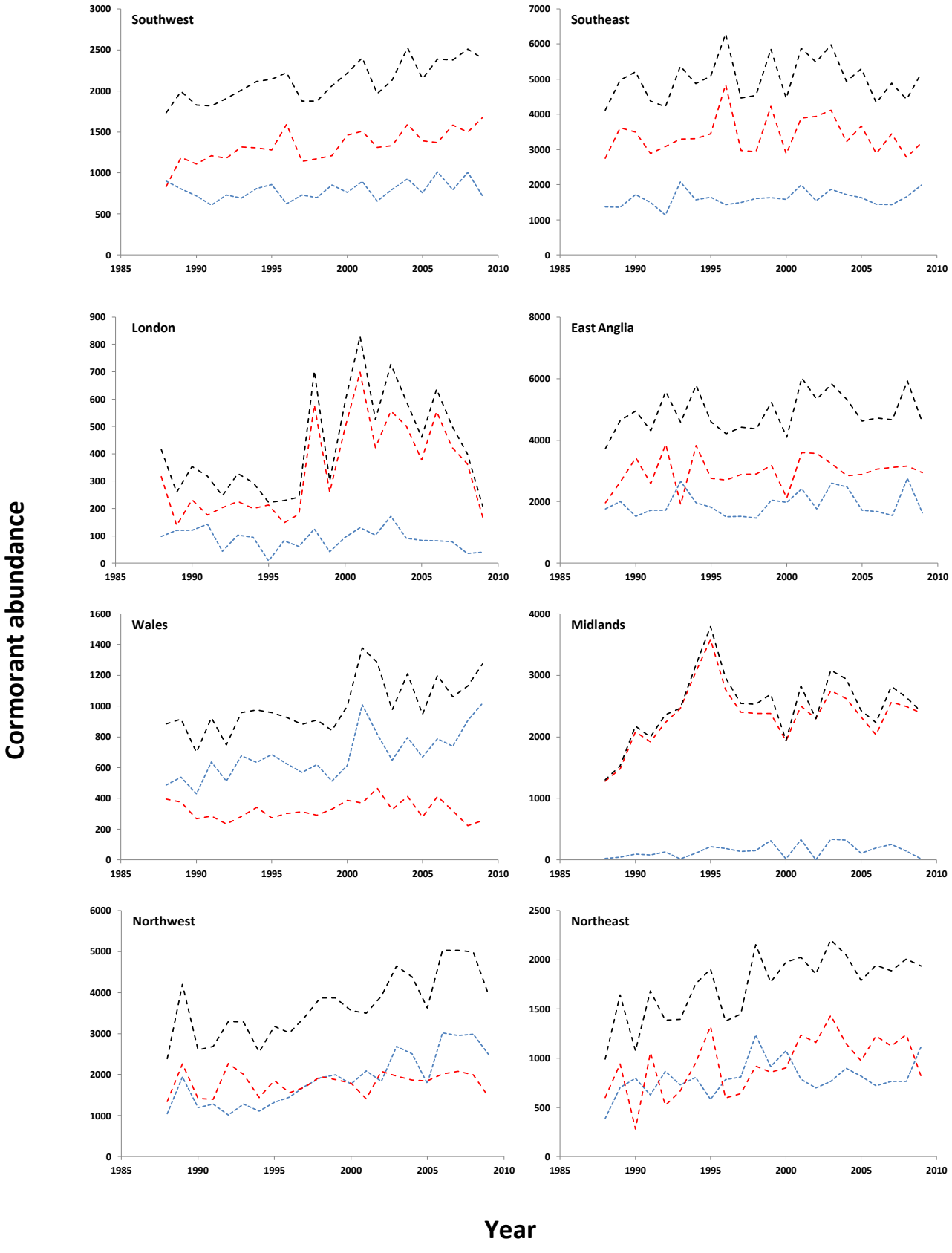


Figure 5. Annual estimates of winter Cormorant populations in separate regions, for inland sites (dashed red line), coastal sites (dotted blue line) and all sites (black solid line).



Appendix. Annual estimates and confidence intervals for the winter Cormorant population in England and Wales, and England only. Estimates and upper and lower 95% confidence limits are given for the inland population the coastal population and the total population.

(a) England and Wales

Year	Inland			Coastal			Combined		
	Estimate	**LCL**	**UCL**	**Estimate**	**LCL**	**UCL**	**Estimate**	**LCL**	**UCL**
1988	10262	6234	14624	6028	5731	6358	16290	12145	20420
1989	11828	7271	15041	7339	7015	7650	19168	14620	22150
1990	13008	8875	16107	6797	6568	7023	19806	15771	22935
1991	11590	8328	14026	6620	6342	6777	18210	14849	20376
1992	13491	9291	16440	6229	6032	6586	19720	15638	22699
1993	12622	9356	15415	8259	7796	8386	20881	17465	23611
1994	14015	10152	16514	7134	6947	7321	21149	17188	23613
1995	15326	11242	17973	7259	6968	7424	22585	18399	25188
1996	14768	11370	16664	6784	6577	7028	21552	18236	23279
1997	12439	9399	14558	7023	6805	7145	19462	16385	21563
1998	13850	9883	16435	7858	7636	8082	21708	17817	24365
1999	14260	10677	16934	8549	8147	8729	22809	19111	25392
2000	12453	9259	15452	7836	7747	8059	20289	17204	23251
2001	15976	11584	19116	9748	9105	10035	25724	21117	29031
2002	15231	11623	17664	7435	7381	7699	22666	19249	25145
2003	16092	12515	18990	10128	9678	10350	26220	22358	28737
2004	14522	11158	16730	9761	9453	9916	24283	20886	26526
2005	14126	10683	16649	7634	7536	7874	21759	18441	24408
2006	14006	10494	16674	8990	8673	8991	22996	19388	25354
2007	15197	11354	17766	8730	8540	9040	23927	20304	26417
2008	14356	10726	17092	10387	10009	10633	24743	20925	27313
2009	13434	10250	15863	9024	8787	9468	22458	19236	25002

(b) England only

Year	Inland			Coastal			Combined		
	Estimate	**LCL**	**UCL**	**Estimate**	**LCL**	**UCL**	**Estimate**	**LCL**	**UCL**
1988	9754	5725	13981	5476	5268	5720	15230	11212	19332
1989	11417	6746	14470	6744	6491	6919	18161	13409	21062
1990	12737	8600	15671	6239	6057	6405	18977	14778	21909
1991	11244	7962	13611	6017	5816	6138	17261	13943	19428
1992	13207	9036	16148	5631	5524	5870	18838	14739	21738
1993	12315	9035	14908	7437	7095	7515	19752	16310	22277
1994	13615	9551	16176	6426	6311	6568	20041	16052	22572
1995	14986	10822	17755	6517	6297	6617	21503	17268	24178
1996	14430	10973	16316	6089	5945	6258	20519	17106	22283
1997	12075	9071	14358	6411	6260	6498	18486	15446	20664
1998	13494	9505	15914	7189	7044	7364	20683	16665	23106
1999	13874	10138	16527	7913	7628	7988	21787	18079	24270
2000	12001	8718	14852	7195	7161	7407	19196	15968	22125
2001	15562	11003	18493	8771	8353	9016	24333	19522	27303
2002	14696	11107	17190	6611	6626	6841	21307	17851	23911
2003	15726	11927	18513	9335	8949	9423	25061	21139	27481
2004	14046	10669	16237	8939	8752	9075	22985	19551	25118
2005	13811	10278	16128	6923	6884	7129	20734	17302	23127
2006	13530	9978	16070	8121	7873	8128	21652	17980	23968
2007	14820	10947	17382	7895	7751	8105	22715	18886	25193
2008	14082	10338	16531	9457	9187	9599	23539	19781	25824
2009	13120	9879	15491	7994	7855	8310	21114	17908	23443