Biomathematics and Statistics Scotland

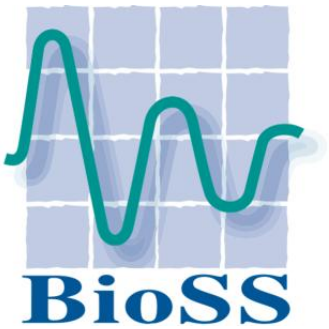
Additional Work Coquet Colony – Seabird Tracking Data (Under Agreement C10-0206-0387)

CONTRACT No: C10-0206-0387

Report submitted to:

Joint Nature Conservation Committee

December 2012



Authors:

Jackie M Potts, Mark J Brewer,

Elizabeth I Duff, David A Elston

CONTENTS PAGE

In addition to this report, there are ancillary files associated with this project:

(i) Spreadsheet files of grid predictions for the Coquet Colony

5.

1. Introduction

The Joint Nature Conservation Committee (JNCC) is working on the identification of important marine areas around the UK that are used by five species of tern during the breeding season. For the four larger tern species (Arctic, common, roseate and Sandwich terns), visual tracking data are available from boat surveys.

A Phase I project completed by BioSS earlier in 2012 used these data to learn about important associations between terns usage/preference and environmental covariates, and to predict usage/preference. During subsequent Phase II work it became apparent that for some environmental covariates there were some issues with outliers and skewed distributions. BioSS was therefore asked to use the methodology developed from the Phase I project to re-run the models for the Coquet colony after removing outliers and transforming variables where necessary.

2. Methods

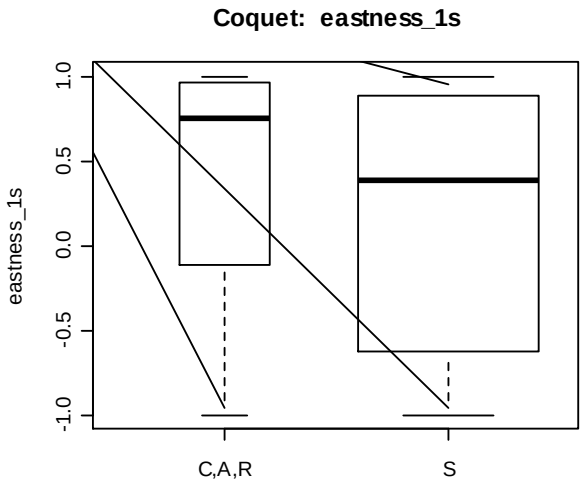
We followed the methodology described in the report for Phase I (Brewer et al., 2012a) with modifications described below.

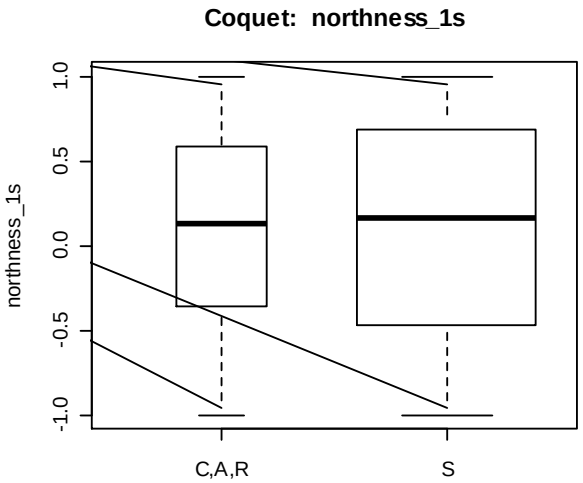
The boxplots in the Phase II report (Brewer et al., 2012b) show a negatively skewed distribution for sea surface temperature, with low values occurring near the shore. The extent to which these data are reliable is uncertain. Removal of values considered unreliable would have resulted in considerable loss of data, resulting in a possible bias of the predictive model when applied to grid cells close to shore; for this reason, sea surface temperature (SST) was excluded from the Phase II analysis. For the current work we fitted models both excluding data points with extreme values of SST (for April this is interpreted as less than 6°C, for May as less than 8°C, and for June as less than 9.3°C) and models that excluded the SST variables entirely.

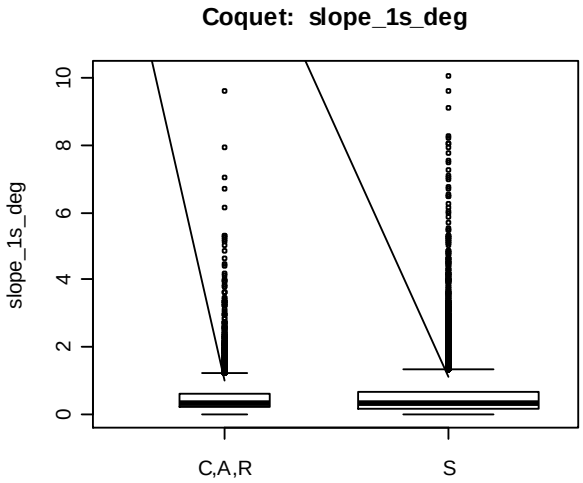
Chlorophyll concentrations and wave and current shear stresses had positively skewed distributions and were therefore log-transformed as in the Phase II report. The Phase II report did not include boxplots for eastness, northness, slope, sum_front_sd, or spring_front_sd, as the decision had been taken to remove them after consideration of biological realism. For consistency with the Phase I report, these are presented as part of this report. The boxplots show that slope has a skewed distribution and hence this was also log-transformed prior to analysis. Where necessary, a small constant was added to variables prior to log transformation to avoid taking logs of zero values.

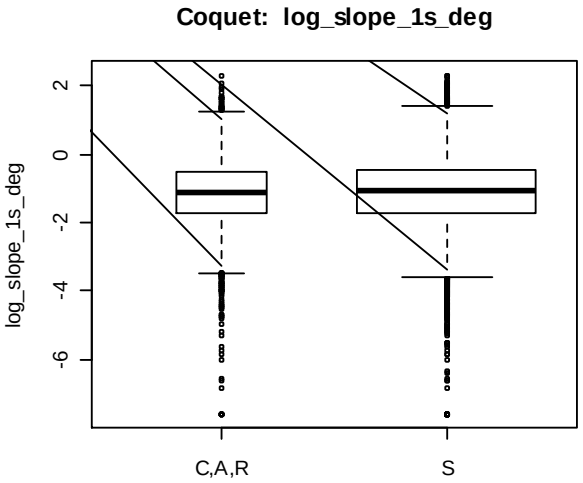
It was apparent that a model selected for roseate terns (including SST with outliers removed) by the stepwise AIC procedure did not in fact have minimum AIC, as the model selected using LRT had a lower AIC. This is to be expected, as the stepwise procedure is never guaranteed to find an optimal model; note that running an exhaustive search would be prohibitive given the size of the data set and the number of variables, and at least in a predictive sense the model is still likely to be a "good" model, if not the "best" (a concept whose legitimacy is doubtful in any case). Instead, some additional code has now been written which starts with a model having the distance to colony variable as sole explanatory variable; the original code for performing stepwise selection started with all the potential covariates in the model. Where the models selected by the two methods are the same, we can be reasonably confident that we have found a minimum AIC model. However, where they differ, the two models should be examined to see which one is better. Code was also added for calculating correlations between variables in the selected model and variance inflation factors (VIFs).

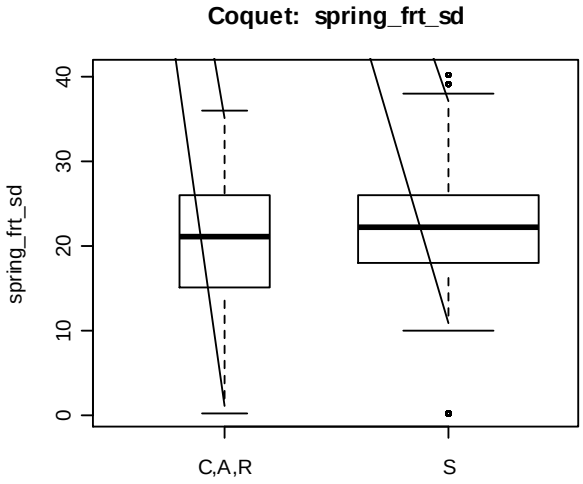
It was suggested by JNCC that grid cells within 500m of the colony should be removed. However, as there were four grid cells at distances of approximately 500m (489, 494, 507 and 512 metres, respectively), a cut-off of 500m would be rather arbitrary and all four cells were therefore removed.

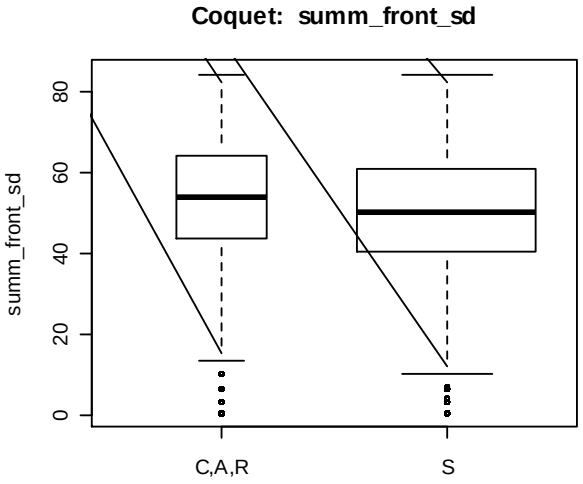

Coquet: eastness_1s
eastness_1s
1.0
0.5
0.0
-0.5
-1.0
C,A,R
S


Coquet: northness_1s
northness_1s
1.0
0.5
0.0
-0.5
-1.0
C,A,R
S


Coquet: slope_1s_deg
slope_1s_deg
10
8
6
4
2
0
C,A,R
S


Coquet: log_slope_1s_deg
log_slope_1s_deg
2
0
-2
-4
-6
C,A,R
S


Coquet: spring_frt_sd
spring_frt_sd
40
30
20
10
0
C,A,R
S


Coquet: summ_front_sd
summ_front_sd
80
60
40
20
0
C,A,R
S

3. Results

The results are presented in the Appendix.

For Arctic terns, models both with and without SST involve dist_col, chl_june and sum_front_sd, bathy_1sec. The models including SST have two additional variables: sst_may and ss_current. Fitted values from the two models are very similar, so we use the model without SST for prediction, as this allows us to make predictions for all grid points.

For common terns the SST variables are not selected in the LRT or GAM models. We therefore base predictions on a model that excludes SST and use the GAM model which has a nonlinear term in dist_col and linear terms in chl_june and bathy_1sec.

For roseate terns, the model excluding SST is more parsimonious, involving just three variables (dist_col, chl_june and sst_may) instead of seven, some of which have large VIFs.

For Sandwich terns SST variables were not selected in the AIC, BIC, LRT or GAM models; we did not therefore consider models involving SST any further. The GAM selection procedure selects a model involving dist_col, chl_may and bathy_1sec. There is a very high correlation (0.96) between ss_wave and bathy_1sec, resulting in VIFs of 7.1 and 9.5, respectively, but this should not be an issue if LRT or GAM models are used for prediction as ss_wave is not selected.

References

Brewer M.J., Potts J.M., Duff E.I. & Elston D.A. (2012a). To carry out tern modelling under the Framework Agreement C10-0206-0387. Report submitted to: Joint Nature Conservation Committee.

Brewer M.J., Potts J.M., Duff E.I. & Elston D.A. (2012b). Prediction of New Colonies – Seabird Tracking Data (Under Agreement C10-0206-0387). Report submitted to: Joint Nature Conservation Committee.

Appendix

Arctic terns – SST included with outliers removed

```
AIC Selected Model:


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + chl_june + sst_may +
    summ_front_sd + ss_current + bathy_1sec, family = "binomial",
    data = complete.data.to.analyse, weights = weights)


Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.96827  -0.03506  -0.01563  -0.00825   1.96597


Coefficients:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)   -16.18994    7.11271  -2.276  0.02283 *
dist_col       -0.22366    0.04388  -5.097 3.45e-07 ***
chl_june        1.77415    0.70781   2.507  0.01219 *
sst_may         1.33067    0.75854   1.754  0.07939 .
summ_front_sd  -0.02412    0.01366  -1.765  0.07750 .
ss_current      0.74834    0.42481   1.762  0.07814 .
bathy_1sec     -0.05801    0.02218  -2.616  0.00891 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


(Dispersion parameter for binomial family taken to be 1)
```

```
    Null deviance: 524.57  on 47322  degrees of freedom
Residual deviance: 401.17  on 47316  degrees of freedom
AIC: 57.086

Number of Fisher Scoring iterations: 8


BIC Selected Model:


Call:
glm(formula = SEARCH_FORAGE ~ dist_col, family = "binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.79847  -0.03649  -0.01705  -0.00697   1.92602

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.88128    0.18899  -4.663 3.11e-06 ***
dist_col    -0.21249    0.02855  -7.443 9.86e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 524.57  on 47322  degrees of freedom
Residual deviance: 414.38  on 47321  degrees of freedom
AIC: 49.348
```

```
Number of Fisher Scoring iterations: 8


LRT Selected Model:


Call:

glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,

    weights = weights)


Deviance Residuals:

     Min        1Q    Median        3Q       Max

-0.96827  -0.03506  -0.01563  -0.00825   1.96597


Coefficients:

               Estimate Std. Error z value Pr(>|z|)

(Intercept)   -16.18994    7.11271  -2.276  0.02283 *

dist_col       -0.22366    0.04388  -5.097 3.45e-07 ***

chl_june        1.77415    0.70781   2.507  0.01219 *

sst_may         1.33067    0.75854   1.754  0.07939 .

summ_front_sd  -0.02412    0.01366  -1.765  0.07750 .

ss_current      0.74834    0.42481   1.762  0.07814 .

bathy_1sec     -0.05801    0.02218  -2.616  0.00891 **

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


(Dispersion parameter for binomial family taken to be 1)


    Null deviance: 524.57  on 47322  degrees of freedom
```

```
Residual deviance: 401.17  on 47316  degrees of freedom
AIC: 57.086

Number of Fisher Scoring iterations: 8


Single term deletions


Model:
SEARCH_FORAGE ~ dist_col + chl_june + sst_may + summ_front_sd +
    ss_current + bathy_1sec
             Df Deviance     AIC    LRT  Pr(>Chi)
<none>            401.17  57.086
dist_col      1   450.62 104.536 49.450 2.034e-12 ***
chl_june      1   407.32  61.234  6.148  0.013156 *
sst_may       1   404.32  58.235  3.149  0.075975 .
summ_front_sd 1   404.47  58.387  3.301  0.069249 .
ss_current    1   404.30  58.214  3.128  0.076969 .
bathy_1sec    1   408.56  62.477  7.391  0.006556 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Now checking for interactions with Year.
Single term deletions


Model:
SEARCH_FORAGE ~ Year * (dist_col + chl_june + sst_may +
summ_front_sd +
    ss_current + bathy_1sec)
                  Df Deviance    AIC     LRT Pr(>Chi)
```

```
<none>                  390.56 84.201
Year:dist_col       2   393.09 82.731 2.53009   0.2822
Year:chl_june       2   390.78 80.419 0.21754   0.8969
Year:sst_may        2   391.32 80.955 0.75403   0.6859
Year:summ_front_sd  2   391.23 80.868 0.66693   0.7164
Year:ss_current     2   390.80 80.434 0.23329   0.8899
Year:bathy_1sec     2   391.30 80.941 0.73940   0.6909
No significant Year interactions.

Running GAM.

GAM Model selected (ML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(sst_may,
    k = 3) + s(summ_front_sd, k = 3) + s(ss_current, k = 3) +
    s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.0518     0.3258  -12.44   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                edf Ref.df Chi.sq  p-value
```

```
s(dist_col)        1      1 25.982 3.45e-07 ***
s(chl_june)        1      1  6.283  0.01219 *
s(sst_may)         1      1  3.077  0.07939 .
s(summ_front_sd)   1      1  3.117  0.07750 .
s(ss_current)      1      1  3.103  0.07814 .
s(bathy_1sec)      1      1  6.841  0.00891 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.232   Deviance explained = 23.5%
ML score = 200.59  Scale est. = 1         n = 47323

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(sst_may,
    k = 3) + s(summ_front_sd, k = 3) + s(ss_current, k = 3) +
    s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.9105     0.3054   -12.8   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
```

```
                   edf Ref.df Chi.sq  p-value
s(dist_col)      1.625  1.859 32.810 5.87e-08 ***
s(chl_june)      1.000  1.000  6.321   0.0119 *
s(sst_may)       1.000  1.000  2.701   0.1003
s(summ_front_sd) 1.000  1.000  2.033   0.1539
s(ss_current)    1.000  1.000  2.159   0.1417
s(bathy_1sec)    1.000  1.000  7.055   0.0079 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.235   Deviance explained = 24.1%
REML score = 204.51  Scale est. = 1         n = 47323
Running INLA.

Call:
c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose =
TRUE)")

Time used:
 Pre-processing    Running inla Post-processing           Total
       8.252414     1014.204581      441.823976     1464.280971

Fixed effects:
                      mean         sd   0.025quant     0.5quant
0.975quant
(Intercept)   -15.80343264 6.96513547 -29.71785598 -15.71790518 -
2.381378967
chl_june        1.84899787 0.72981499   0.41120145   1.85139713
3.273482817
```

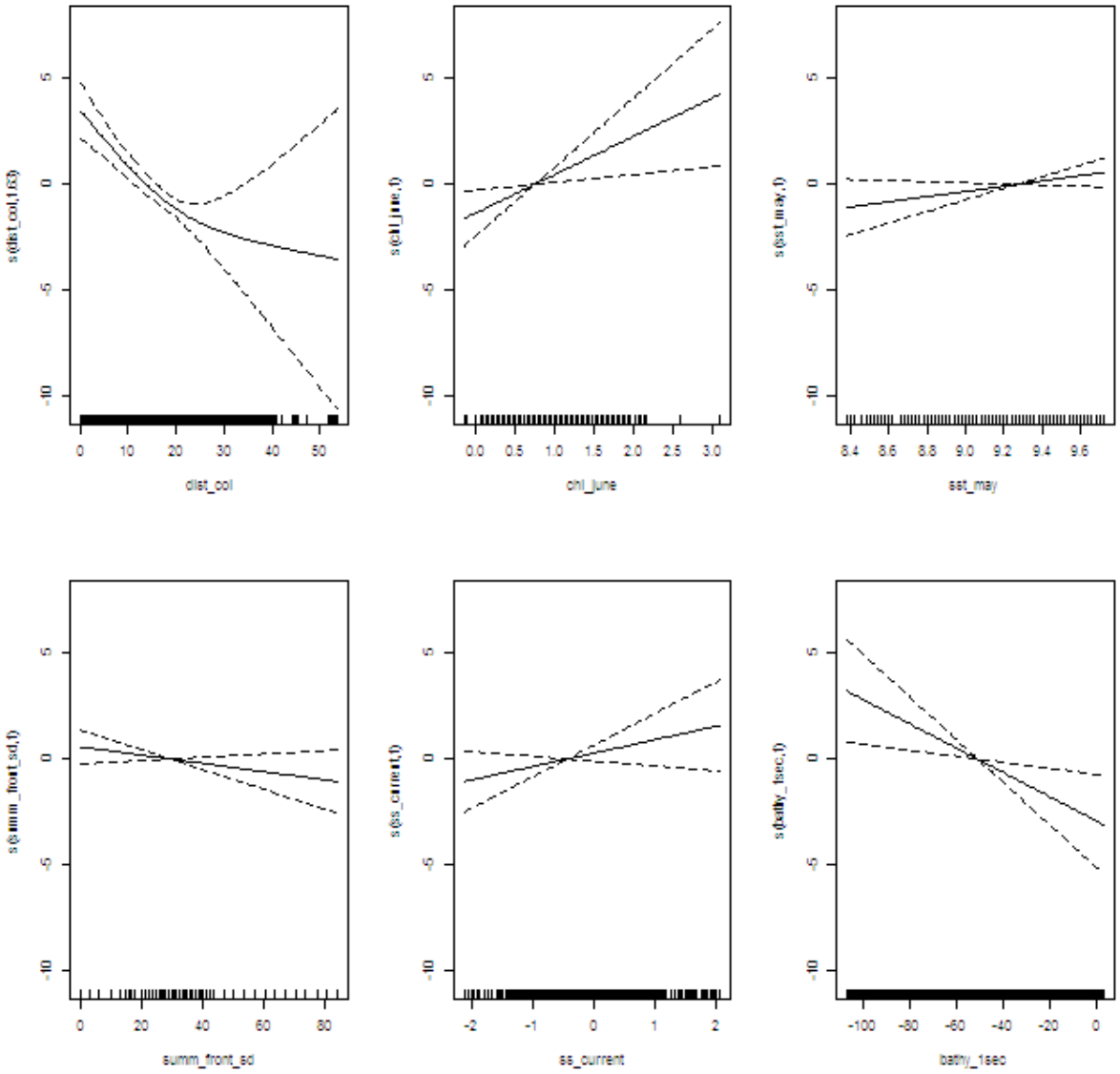
```
sst_may         1.28141835 0.74649658  -0.16186267   1.27373868
2.768318318

summ_front_sd  -0.01794380 0.01365707  -0.04562755  -0.01764065
0.008024216

ss_current      0.58411433 0.43613776  -0.26880017   0.58324510
1.442128817

bathy_1sec     -0.05970494 0.02132887  -0.10275585  -0.05929434 -
0.018983481

dist_col1     -10.55911704 2.32672743 -15.58000967 -10.39287378 -
6.445102056

dist_col2      -2.12409860 3.83919303 -10.68494460  -1.71775894
4.315279905

                      kld

(Intercept)   0.0068190888

chl_june      0.0000995303

sst_may       0.0063532090

summ_front_sd 0.0047399743

ss_current    0.0005071765

bathy_1sec    0.0056925455

dist_col1     0.0684144995

dist_col2     0.0092390962


Random effects:

Name    Model          Max KLD

UserFunction0   NoModelName

UserFunction1   NoModelName

mesh.points   SPDE model


Model hyperparameters:

                           mean    sd     0.025quant 0.5quant
0.975quant

T.0 for mesh.points-basisT  7.521  3.185  1.250      7.530   13.754
```

Expected number of effective parameters(std dev): 7.993(0.001666)

Number of equivalent replicates : 5920.87

Marginal Likelihood: -233.79

	mean	sd	0.025quant	0.5quant	0.975quant	kld
(Intercept)	-15.8034	6.9651	-29.7179	-15.7179	-2.3814	0.0068
chl_june	1.8490	0.7298	0.4112	1.8514	3.2735	0.0001
sst_may	1.2814	0.7465	-0.1619	1.2737	2.7683	0.0064
summ_front_sd	-0.0179	0.0137	-0.0456	-0.0176	0.0080	0.0047
ss_current	0.5841	0.4361	-0.2688	0.5832	1.4421	0.0005
bathy_1sec	-0.0597	0.0213	-0.1028	-0.0593	-0.0190	0.0057
dist_col1	-10.5591	2.3267	-15.5800	-10.3929	-6.4451	0.0684
dist_col2	-2.1241	3.8392	-10.6849	-1.7178	4.3153	0.0092



Arctic terns – SST excluded

```
AIC Selected Model:


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + chl_june + summ_front_sd +
    bathy_1sec, family = "binomial", data = complete.data.to.analyse,
    weights = weights)


Deviance Residuals:
     Min        1Q    Median        3Q       Max
```

```
-0.91533  -0.03595  -0.01519  -0.00745   1.93331

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   -3.80859    1.29761  -2.935  0.00333 **
dist_col      -0.22048    0.03941  -5.595  2.2e-08 ***
chl_june       1.44940    0.68547   2.114  0.03447 *
summ_front_sd -0.02344    0.01349  -1.738  0.08212 .
bathy_1sec    -0.05269    0.02061  -2.556  0.01058 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 542.78  on 47731  degrees of freedom
Residual deviance: 420.58  on 47727  degrees of freedom
AIC: 50.803

Number of Fisher Scoring iterations: 8

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col, family = "binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.79352  -0.03705  -0.01715  -0.00702   1.93099
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.89725    0.18258  -4.914 8.91e-07 ***
dist_col    -0.21127    0.02803  -7.537 4.81e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 542.78  on 47731  degrees of freedom
Residual deviance: 429.21  on 47730  degrees of freedom
AIC: 46.903

Number of Fisher Scoring iterations: 8

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.91533  -0.03595  -0.01519  -0.00745   1.93331

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)   -3.80859    1.29761  -2.935  0.00333 **
dist_col      -0.22048    0.03941  -5.595  2.2e-08 ***
chl_june       1.44940    0.68547   2.114  0.03447 *
```

```
summ_front_sd -0.02344    0.01349  -1.738  0.08212 .
bathy_1sec    -0.05269    0.02061  -2.556  0.01058 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 542.78  on 47731  degrees of freedom
Residual deviance: 420.58  on 47727  degrees of freedom
AIC: 50.803

Number of Fisher Scoring iterations: 8

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + chl_june + summ_front_sd + bathy_1sec
              Df Deviance    AIC    LRT  Pr(>Chi)
<none>             420.58 50.803
dist_col       1   471.76 99.983 51.180 8.427e-13 ***
chl_june       1   424.94 53.168  4.365  0.036688 *
summ_front_sd  1   423.79 52.014  3.210  0.073170 .
bathy_1sec     1   427.43 55.656  6.853  0.008851 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Now checking for interactions with Year.
Single term deletions

Model:
```

```
SEARCH_FORAGE ~ Year * (dist_col + chl_june + summ_front_sd +
    bathy_1sec)
                  Df Deviance    AIC     LRT Pr(>Chi)
<none>                  410.93 70.784
Year:dist_col      2   414.05 69.900 3.11630   0.2105
Year:chl_june      2   411.18 67.029 0.24483   0.8848
Year:summ_front_sd 2   411.58 67.431 0.64715   0.7236
Year:bathy_1sec    2   411.61 67.464 0.68062   0.7116
No significant Year interactions.

Running GAM.

GAM Model selected (ML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(summ_front_sd,
    k = 3) + s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.1100     0.3328  -12.35   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(dist_col)       1      1 31.307 2.2e-08 ***
```

```
s(chl_june)        1      1  4.471  0.0345 *
s(summ_front_sd)   1      1  3.022  0.0821 .
s(bathy_1sec)      1      1  6.534  0.0106 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.202   Deviance explained = 22.5%
ML score = 210.29  Scale est. = 1         n = 47732

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(summ_front_sd,
    k = 3) + s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.9027     0.2984  -13.08   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                  edf Ref.df Chi.sq  p-value
s(dist_col)     1.744  1.934 29.469 3.57e-07 ***
s(chl_june)     1.000  1.000  4.856  0.02756 *
s(summ_front_sd) 1.000  1.000  1.748  0.18614
s(bathy_1sec)   1.000  1.000  6.835  0.00894 **
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.203   Deviance explained = 23.3%
REML score = 212.19  Scale est. = 1         n = 47732
Running INLA.

Call:
c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose = TRUE)")

Time used:
 Pre-processing    Running inla Post-processing           Total
       7.628414     1008.947372       79.825340     1096.401126

Fixed effects:
                    mean         sd   0.025quant    0.5quant  0.975quant
(Intercept)   -3.90900218 1.31281510  -6.49076802 -3.90633291 -1.34186621
chl_june       1.58965424 0.70842570   0.19273306  1.59243788  2.97108358
summ_front_sd -0.01658983 0.01340367  -0.04372188 -0.01630558  0.00893142
bathy_1sec    -0.05373979 0.01994945  -0.09356625 -0.05350362 -0.01527430
dist_col1     -9.68644917 1.96757797 -13.91786931 -9.55175439 -6.19284249
dist_col2     -0.86978841 3.37145595  -8.40630496 -0.50347308  4.76031320
                       kld
(Intercept)   4.286010e-04
chl_june      1.351205e-05
summ_front_sd 2.382156e-03
bathy_1sec    1.230062e-03
dist_col1     5.396084e-02
dist_col2     3.868163e-03
```

Random effects:

Name	Model	Max KLD
UserFunction0	NoModelName	
UserFunction1	NoModelName	
mesh.points	SPDE model	

Model hyperparameters:

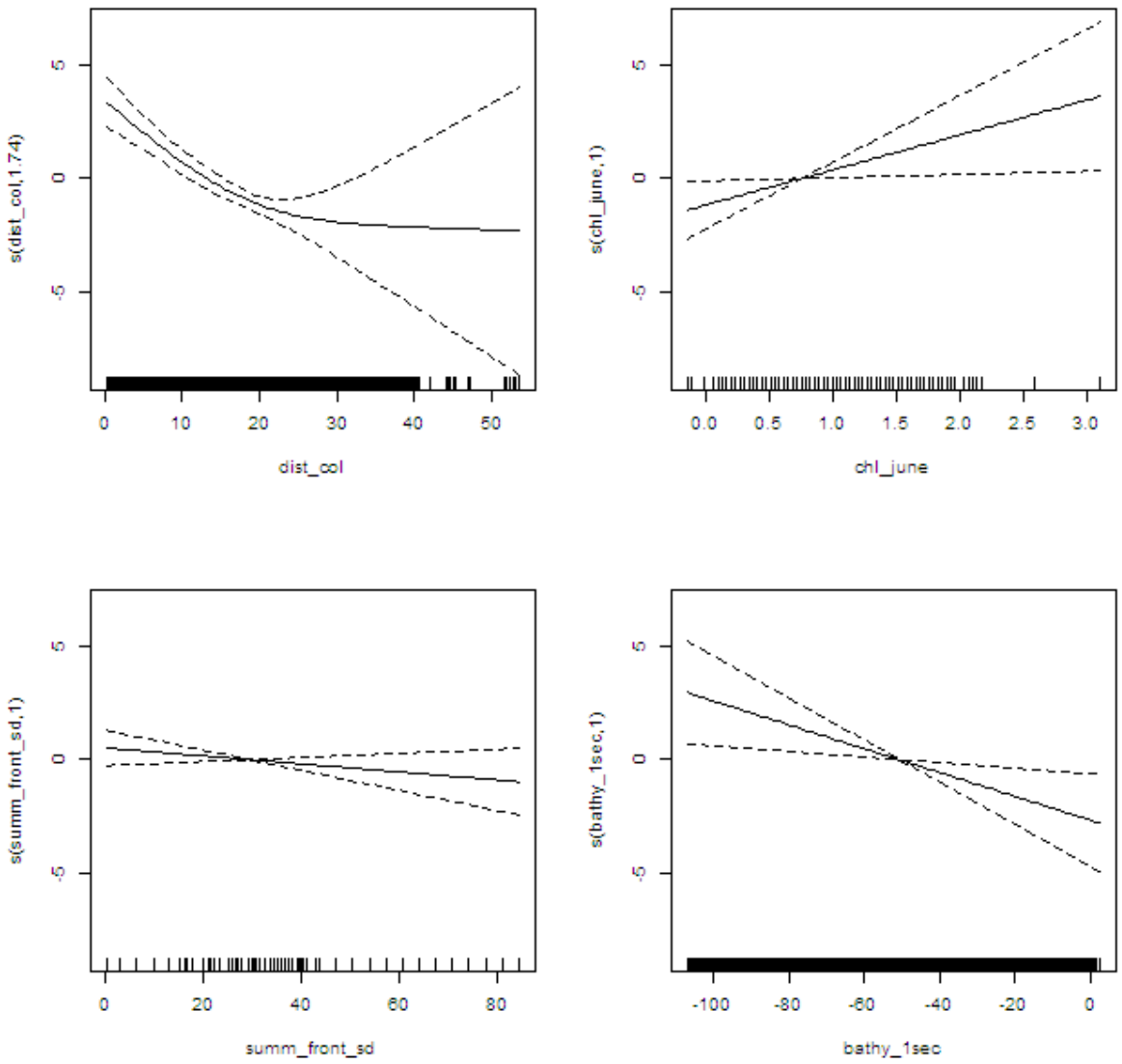
	mean	sd	0.025quant	0.5quant	0.975quant
T.0 for mesh.points-basisT	7.556	3.163	1.357	7.549	13.775

Expected number of effective parameters(std dev): 5.985(0.0002149)

Number of equivalent replicates : 7975.61

Marginal Likelihood: -234.66

	mean	sd	0.025quant	0.5quant	0.975quant	kld
(Intercept)	-3.9090	1.3128	-6.4908	-3.9063	-1.3419	0.0004
chl_june	1.5897	0.7084	0.1927	1.5924	2.9711	0.0000
summ_front_sd	-0.0166	0.0134	-0.0437	-0.0163	0.0089	0.0024
bathy_1sec	-0.0537	0.0199	-0.0936	-0.0535	-0.0153	0.0012
dist_col1	-9.6864	1.9676	-13.9179	-9.5518	-6.1928	0.0540
dist_col2	-0.8698	3.3715	-8.4063	-0.5035	4.7603	0.0039



Common terns – SST included with outliers removed

```
AIC Selected Model:


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + chl_june + sst_april +
    bathy_1sec + sst_june, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)
```

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.82985  -0.04135  -0.01208  -0.00441   2.26769

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.54375   14.04657   0.110   0.9125
dist_col    -0.26060    0.05551  -4.695 2.67e-06 ***
chl_june     1.96148    0.90724   2.162   0.0306 *
sst_april    1.76848    1.18084   1.498   0.1342
bathy_1sec  -0.04720    0.02424  -1.947   0.0515 .
sst_june    -1.58961    1.01222  -1.570   0.1163
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 406.92  on 29483  degrees of freedom
Residual deviance: 305.90  on 29478  degrees of freedom
AIC: 26.276

Number of Fisher Scoring iterations: 8

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col, family = "binomial",
    data = complete.data.to.analyse, weights = weights)
```

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.75057  -0.04414  -0.01844  -0.00799   2.25600

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.95103    0.21796  -4.363 1.28e-05 ***
dist_col    -0.22265    0.03482  -6.395 1.61e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 406.92  on 29483  degrees of freedom
Residual deviance: 322.84  on 29482  degrees of freedom
AIC: 17.005

Number of Fisher Scoring iterations: 8

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.79572  -0.04154  -0.01434  -0.00651   2.26004
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -5.70345    1.54060  -3.702 0.000214 ***
dist_col    -0.23234    0.04846  -4.795 1.63e-06 ***
chl_june     2.62596    0.78605   3.341 0.000836 ***
bathy_1sec  -0.05203    0.02343  -2.221 0.026370 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 406.92  on 29483  degrees of freedom
Residual deviance: 310.54  on 29480  degrees of freedom
AIC: 20.981

Number of Fisher Scoring iterations: 8

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + chl_june + bathy_1sec
           Df Deviance    AIC    LRT  Pr(>Chi)
<none>          310.54 20.981
dist_col    1   347.84 56.278 37.296 1.015e-09 ***
chl_june    1   322.20 30.635 11.653 0.0006409 ***
bathy_1sec  1   315.88 24.320  5.338 0.0208620 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Now checking for interactions with Year.

Single term deletions


Model:

SEARCH_FORAGE ~ Year * (dist_col + chl_june + bathy_1sec)

                Df Deviance    AIC    LRT Pr(>Chi)

<none>               303.73 35.990

Year:dist_col    2   307.42 35.683 3.6924   0.1578

Year:chl_june    2   305.27 33.534 1.5437   0.4622

Year:bathy_1sec  2   304.32 32.589 0.5990   0.7412

No significant Year interactions.


Running GAM.


GAM Model selected (ML output):


Family: binomial

Link function: logit


Formula:

SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) +
s(bathy_1sec,

    k = 3)


Parametric coefficients:

            Estimate Std. Error z value Pr(>|z|)

(Intercept)  -4.3787     0.4312  -10.15   <2e-16 ***

---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
              edf Ref.df Chi.sq  p-value
s(dist_col)     1      1 22.987 1.63e-06 ***
s(chl_june)     1      1 11.160 0.000836 ***
s(bathy_1sec)   1      1  4.931 0.026373 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0893   Deviance explained = 23.7%
ML score = 155.27  Scale est. = 1         n = 29484

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) +
s(bathy_1sec,
    k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.8100     0.7859  -6.121 9.32e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(dist_col)   1.526  1.776 11.403 0.00251 **
s(chl_june)   1.000  1.000  9.662 0.00188 **
s(bathy_1sec) 1.000  1.000  4.140 0.04189 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.0909   Deviance explained = 23.9%
REML score = 156.74  Scale est. = 1         n = 29484
```

Common terns – SST excluded

```
AIC Selected Model (forwards):


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + chl_may + strat_temp,
    family = "binomial", data = complete.data.to.analyse, weights =
weights)


Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.81262  -0.04578  -0.01442  -0.00435   2.27538


Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.76896    2.25121   0.342  0.73267
dist_col    -0.14588    0.04925  -2.962  0.00306 **
chl_may      0.51844    0.27789   1.866  0.06209 .
strat_temp  -0.93045    0.62090  -1.499  0.13399
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 430.38  on 29956  degrees of freedom
Residual deviance: 329.69  on 29953  degrees of freedom
AIC: 20.545

Number of Fisher Scoring iterations: 8

AIC Selected Model(backwards):

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + chl_apr + summ_front_sd +
    strat_temp + sal_summ + sal_spring + ss_current + bathy_1sec,
    family = "binomial", data = complete.data.to.analyse, weights =
weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.85772  -0.04245  -0.01314  -0.00344   2.35404

Coefficients:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)   2280.56304 6876.91998   0.332  0.74017
dist_col        -0.17217    0.06194  -2.780  0.00544 **
chl_apr          1.52198    0.64787   2.349  0.01881 *
summ_front_sd   -0.03109    0.01534  -2.026  0.04273 *
```

```
strat_temp      -2.28255    0.85454  -2.671  0.00756 **
sal_summ       310.64817  292.10740   1.063  0.28757
sal_spring    -375.56977  170.74309  -2.200  0.02783 *
ss_current      -0.78831    0.40811  -1.932  0.05341 .
bathy_1sec      -0.06836    0.02577  -2.652  0.00799 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 430.38  on 29956  degrees of freedom
Residual deviance: 319.88  on 29948  degrees of freedom
AIC: 29.887

Number of Fisher Scoring iterations: 9

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col, family = "binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.75936  -0.04579  -0.01874  -0.00808   2.24320

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.92484    0.20783  -4.450 8.59e-06 ***
```

```
dist_col    -0.22190    0.03366  -6.592 4.33e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 430.38  on 29956  degrees of freedom
Residual deviance: 340.30  on 29955  degrees of freedom
AIC: 16.789

Number of Fisher Scoring iterations: 8

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.85772  -0.04245  -0.01314  -0.00344   2.35404

Coefficients:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)   2280.56304 6876.91998   0.332  0.74017
dist_col        -0.17217    0.06194  -2.780  0.00544 **
chl_apr          1.52198    0.64787   2.349  0.01881 *
summ_front_sd   -0.03109    0.01534  -2.026  0.04273 *
```

```
strat_temp      -2.28255    0.85454  -2.671  0.00756 **
sal_summ       310.64817  292.10740   1.063  0.28757
sal_spring    -375.56977  170.74309  -2.200  0.02783 *
ss_current      -0.78831    0.40811  -1.932  0.05341 .
bathy_1sec      -0.06836    0.02577  -2.652  0.00799 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 430.38  on 29956  degrees of freedom
Residual deviance: 319.88  on 29948  degrees of freedom
AIC: 29.887

Number of Fisher Scoring iterations: 9

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + chl_apr + summ_front_sd + strat_temp +
    sal_summ + sal_spring + ss_current + bathy_1sec
             Df Deviance    AIC     LRT Pr(>Chi)
<none>            319.88 29.887
dist_col      1   330.35 38.352 10.4649 0.001217 **
chl_apr       1   325.45 33.452  5.5644 0.018329 *
summ_front_sd 1   324.26 32.265  4.3773 0.036420 *
strat_temp    1   328.55 36.549  8.6620 0.003249 **
sal_summ      1   322.66 30.664  2.7764 0.095661 .
sal_spring    1   325.95 33.956  6.0682 0.013764 *
```

```
ss_current     1   323.72 31.725  3.8375 0.050120 .
bathy_1sec     1   327.48 35.488  7.6006 0.005835 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Now checking for interactions with Year.
Single term deletions

Model:
SEARCH_FORAGE ~ Year * (dist_col + chl_apr + summ_front_sd +
    strat_temp + sal_summ + sal_spring + ss_current + bathy_1sec)
                 Df Deviance    AIC    LRT Pr(>Chi)
<none>                304.00 63.070
Year:dist_col     2   305.45 60.520 1.4493   0.4845
Year:chl_apr      2   307.73 62.790 3.7194   0.1557
Year:summ_front_sd  2   305.77 60.834 1.7633   0.4141
Year:strat_temp   2   305.23 60.293 1.2224   0.5427
Year:sal_summ     2   304.06 59.128 0.0577   0.9716
Year:sal_spring   2   304.32 59.385 0.3142   0.8546
Year:ss_current   2   305.66 60.725 1.6548   0.4372
Year:bathy_1sec   2   307.56 62.623 3.5522   0.1693
No significant Year interactions.

Running GAM.

GAM Model selected (ML output):

Family: binomial
Link function: logit
```

```
Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(summ_front_sd, k = 3) +
    s(strat_temp, k = 3) + s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -4.7091     0.5915  -7.961 1.71e-15 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(dist_col)       1      1  6.438  0.0112 *
s(summ_front_sd)  1      1  2.947  0.0860 .
s(strat_temp)     1      1  4.944  0.0262 *
s(bathy_1sec)     1      1  3.040  0.0812 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.154   Deviance explained = 23.5%
ML score = 164.64  Scale est. = 1         n = 29957

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
```

```
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(summ_front_sd, k = 3) +
    s(strat_temp, k = 3) + s(bathy_1sec, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   -5.683      1.195  -4.756 1.98e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                  edf Ref.df Chi.sq p-value
s(dist_col)      1.698  1.909  3.931  0.1299
s(summ_front_sd) 1.000  1.000  3.306  0.0690 .
s(strat_temp)    1.000  1.000  3.027  0.0819 .
s(bathy_1sec)    1.000  1.000  1.977  0.1597
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =   0.16   Deviance explained =   24%
REML score = 165.06  Scale est. = 1         n = 29957
Running INLA.

Call:
c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose =
TRUE)")

Time used:
 Pre-processing    Running inla Post-processing           Total
```

```
       5.288409      366.195043       37.627266      409.110718


Fixed effects:

                      mean          sd   0.025quant     0.5quant
0.975quant

(Intercept)     2.88575072  2.54362974  -1.79018884   2.76958373
8.2069291341

summ_front_sd  -0.02846866  0.01523990  -0.05919033  -0.02818933
0.0006633967

strat_temp     -1.46885089  0.87216742  -3.29022247  -1.43056737
0.1382222306

bathy_1sec     -0.03038028  0.02172686  -0.07360470  -0.03017156
0.0116340869

dist_col1     -11.93446328  6.65679445 -26.73892393 -11.24937056 -
0.7195157446

dist_col2     -18.66787888 12.57327954 -46.54660279 -17.41457803
2.6157828993

                       kld

(Intercept)   4.410405e-04

summ_front_sd 6.402627e-04

strat_temp    2.082387e-05

bathy_1sec    9.155687e-04

dist_col1     1.193949e-03

dist_col2     2.080870e-03


Random effects:

Name    Model          Max KLD

UserFunction0   NoModelName

UserFunction1   NoModelName

mesh.points   SPDE model


Model hyperparameters:
```

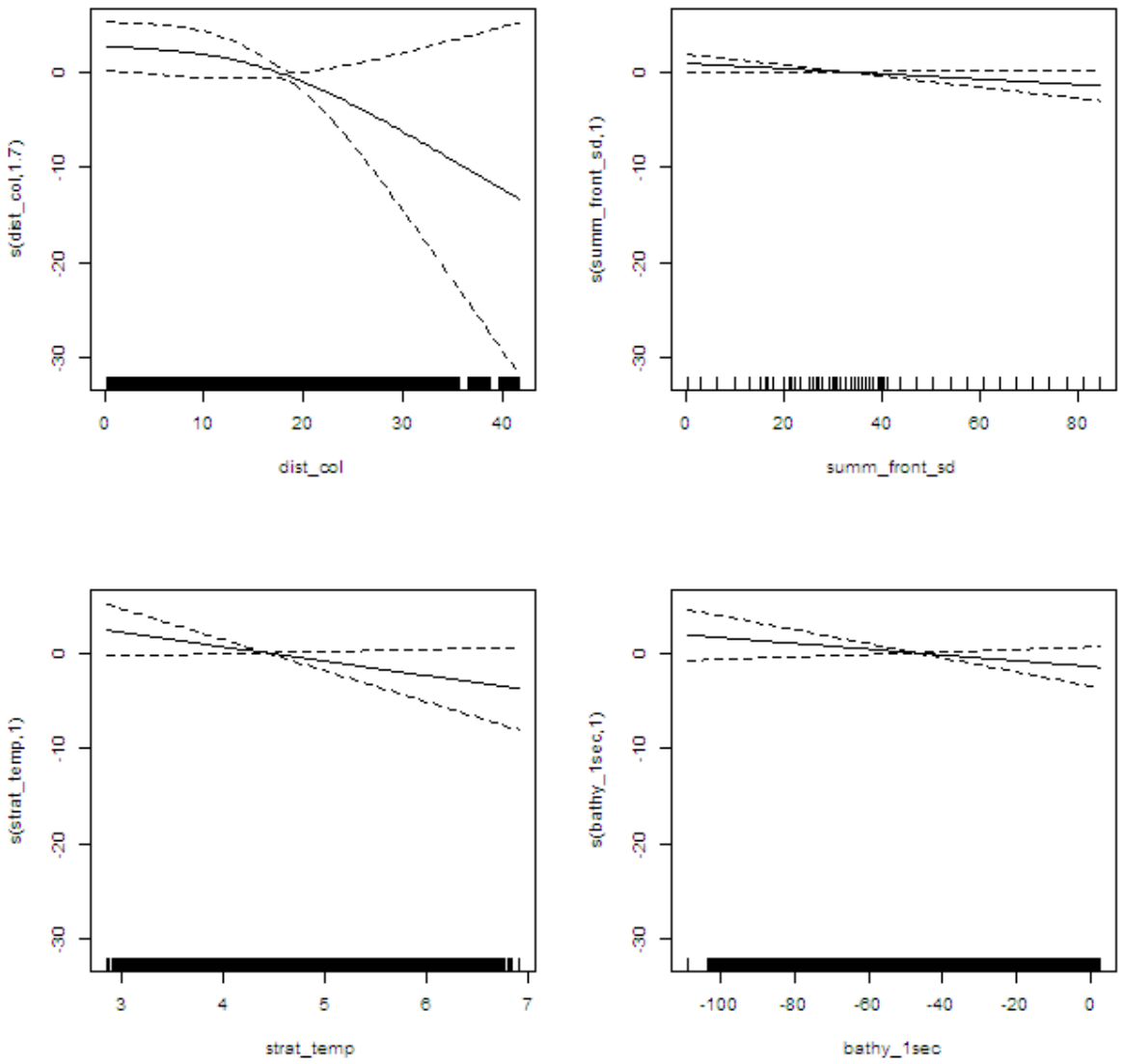
	mean	sd	0.025quant	0.5quant	0.975quant
T.0 for mesh.points-basisT	7.351	3.160	1.148	7.353	13.562

Expected number of effective parameters(std dev): 5.799(0.0001968)

Number of equivalent replicates : 5165.93

Marginal Likelihood: -188.06

	mean	sd	0.025quant	0.5quant	0.975quant	kld
(Intercept)	2.8858	2.5436	-1.7902	2.7696	8.2069	0.0004
summ_front_sd	-0.0285	0.0152	-0.0592	-0.0282	0.0007	0.0006
strat_temp	-1.4689	0.8722	-3.2902	-1.4306	0.1382	0.0000
bathy_1sec	-0.0304	0.0217	-0.0736	-0.0302	0.0116	0.0009
dist_col1	-11.9345	6.6568	-26.7389	-11.2494	-0.7195	0.0012
dist_col2	-18.6679	12.5733	-46.5466	-17.4146	2.6158	0.0021



Roseate terns – SST included with outliers removed

```
AIC Selected Model (forwards):


Call:

glm(formula = SEARCH_FORAGE ~ dist_col + sst_may + chl_june,

    family = "binomial", data = complete.data.to.analyse, weights =
weights)


Deviance Residuals:
```

```
     Min        1Q    Median        3Q       Max
-1.26451  -0.01579  -0.00840  -0.00354   1.13378

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -61.4293    16.2506  -3.780 0.000157 ***
dist_col     -0.1389     0.0762  -1.823 0.068265 .
sst_may       6.0750     1.7496   3.472 0.000516 ***
chl_june      2.3922     0.9148   2.615 0.008922 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 152.037  on 23776  degrees of freedom
Residual deviance:  86.027  on 23773  degrees of freedom
AIC: 16.473

Number of Fisher Scoring iterations: 8

AIC Selected Model (backwards):

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_may +
    chl_june + sst_april + sst_may + sal_summ + sal_spring +
    ss_wave, family = "binomial", data = complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
```

```
     Min        1Q    Median        3Q       Max
-1.19098  -0.01262  -0.00396  -0.00090   1.31249

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept) -1189.3904 26136.1760  -0.046 0.963703
dist_col       -0.1561     0.1091  -1.432 0.152248
dist_shore     -0.9450     0.4381  -2.157 0.031021 *
chl_may        -2.1428     1.0046  -2.133 0.032928 *
chl_june        3.4515     1.8494   1.866 0.061996 .
sst_april       3.3277     2.3368   1.424 0.154433
sst_may        10.1408     2.9705   3.414 0.000641 ***
sal_summ      779.8877  1130.8640   0.690 0.490421
sal_spring   -749.1439   510.2635  -1.468 0.142063
ss_wave        -1.8782     1.0351  -1.815 0.069600 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 152.037  on 23776  degrees of freedom
Residual deviance:  76.022  on 23767  degrees of freedom
AIC: 27.365

Number of Fisher Scoring iterations: 10

BIC Selected Model:

Call:
```

```
glm(formula = SEARCH_FORAGE ~ chl_june + sst_may, family =
"binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.05757  -0.01643  -0.00858  -0.00473   1.30217

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -66.3809    16.2546  -4.084 4.43e-05 ***
chl_june      3.6421     0.6319   5.764 8.23e-09 ***
sst_may       6.3127     1.7134   3.684 0.000229 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 152.037  on 23776  degrees of freedom
Residual deviance:  89.986  on 23774  degrees of freedom
AIC: 15.403

Number of Fisher Scoring iterations: 8

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
```

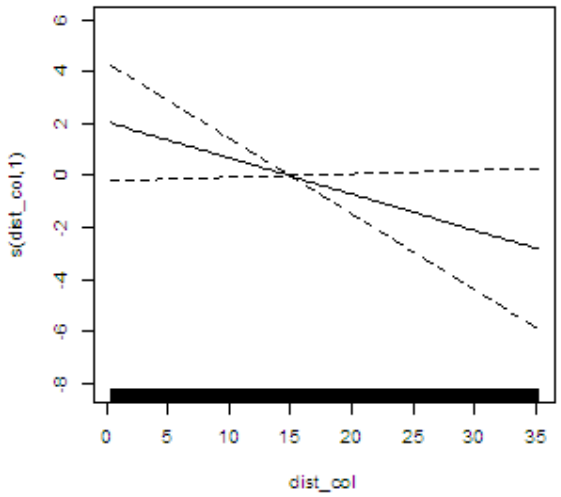
```
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.26451  -0.01579  -0.00840  -0.00354   1.13378

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -61.4293    16.2506  -3.780 0.000157 ***
dist_col     -0.1389     0.0762  -1.823 0.068265 .
chl_june      2.3922     0.9148   2.615 0.008922 **
sst_may       6.0750     1.7496   3.472 0.000516 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 152.037  on 23776  degrees of freedom
Residual deviance:  86.027  on 23773  degrees of freedom
AIC: 16.473

Number of Fisher Scoring iterations: 8

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + chl_june + sst_may
         Df Deviance    AIC     LRT Pr(>Chi)
<none>        86.027 16.473
```

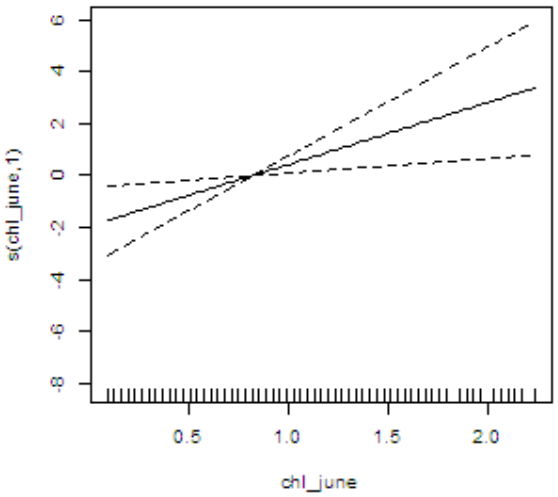
```
dist_col  1   89.986 18.432  3.9594 0.046610 *
chl_june  1   92.933 21.379  6.9063 0.008589 **
sst_may   1  102.194 30.639 16.1667  5.8e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Now checking for interactions with Year.
Single term deletions

Model:
SEARCH_FORAGE ~ Year * (dist_col + chl_june + sst_may)
             Df Deviance    AIC     LRT Pr(>Chi)
<none>            77.284 31.878
Year:dist_col  2   77.348 27.943 0.06452   0.9683
Year:chl_june  2   78.093 28.688 0.80975   0.6671
Year:sst_may   2   78.838 29.433 1.55476   0.4596
No significant Year interactions.

Running GAM.

GAM Model selected (ML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(sst_may,
    k = 3)
```

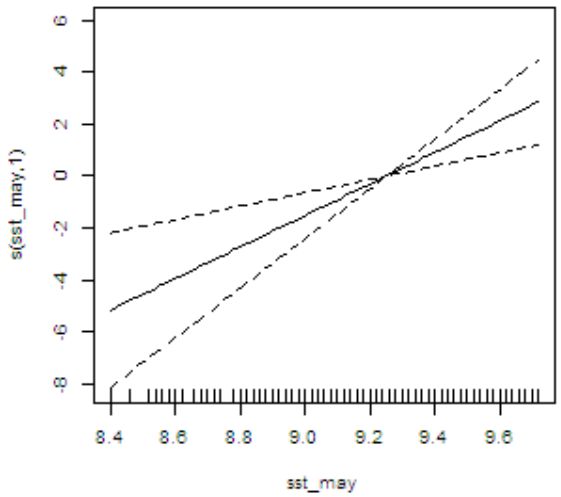
```
Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -5.3353     0.7244  -7.366 1.76e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
            edf Ref.df Chi.sq  p-value
s(dist_col)   1      1  3.324 0.068290 .
s(chl_june)   1      1  6.838 0.008926 **
s(sst_may)    1      1 12.056 0.000516 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.547   Deviance explained = 43.4%
ML score = 43.014  Scale est. = 1         n = 23777

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_june, k = 3) + s(sst_may,
    k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -5.3353     0.7244  -7.366 1.76e-13 ***
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Approximate significance of smooth terms:
            edf Ref.df Chi.sq  p-value
s(dist_col)   1      1  3.324 0.068293 .
s(chl_june)   1      1  6.837 0.008932 **
s(sst_may)    1      1 12.055 0.000517 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


R-sq.(adj) =  0.547   Deviance explained = 43.4%
REML score = 42.804  Scale est. = 1         n = 23777
Running INLA.


Call:
c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose =
TRUE)")


Time used:
 Pre-processing    Running inla Post-processing           Total
       4.009207      214.328776       28.969251      247.307234


Fixed effects:
                   mean          sd  0.025quant   0.5quant
0.975quant
(Intercept) -58.3199202 15.24188825 -90.2301034 -57.615178 -
30.30411312
dist_col     -0.1490866  0.07567855  -0.3085743  -0.145206  -
0.01101368
```

```
chl_june      2.5220610  0.90212343   0.7957233   2.506268
4.33722865

sst_may       5.7345578  1.64441725   2.6936579   5.665215
9.15841756

                     kld

(Intercept) 0.0006666827

dist_col    0.0090943008

chl_june    0.0078334218

sst_may     0.0005512711


Random effects:

Name    Model          Max KLD

UserFunction0   NoModelName

UserFunction1   NoModelName

mesh.points   SPDE model


Model hyperparameters:

                            mean    sd     0.025quant 0.5quant
0.975quant

T.0 for mesh.points-basisT  7.659  3.029  1.867      7.597   13.737


Expected number of effective parameters(std dev): 3.934(0.00264)

Number of equivalent replicates : 6043.23


Marginal Likelihood:  -57.63

                mean      sd 0.025quant 0.5quant 0.975quant    kld

(Intercept) -58.3199 15.2419   -90.2301 -57.6152   -30.3041 0.0007

dist_col     -0.1491  0.0757    -0.3086  -0.1452    -0.0110 0.0091

chl_june      2.5221  0.9021     0.7957   2.5063     4.3372 0.0078

sst_may       5.7346  1.6444     2.6937   5.6652     9.1584 0.0006
```







Roseate terns – SST excluded

```
AIC Selected Model (forwards):


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + spring_frt_sd + chl_apr +
    summ_front_sd + ss_current + dist_shore + spring_front, family =
"binomial",
    data = complete.data.to.analyse, weights = weights)
```

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.88454  -0.01414  -0.00228  -0.00007   1.46200

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)   -1.76959    1.69987  -1.041  0.29787
dist_col      -0.22721    0.08313  -2.733  0.00627 **
spring_frt_sd -0.24877    0.07882  -3.156  0.00160 **
chl_apr        1.47884    0.81862   1.807  0.07084 .
summ_front_sd  0.07729    0.03733   2.071  0.03839 *
ss_current    -1.17329    0.60579  -1.937  0.05277 .
dist_shore    -0.74037    0.35381  -2.093  0.03639 *
spring_front   0.16653    0.08128   2.049  0.04048 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 207.04  on 24099  degrees of freedom
Residual deviance: 104.28  on 24092  degrees of freedom
AIC: 27.317

Number of Fisher Scoring iterations: 10

AIC Selected Model(backwards):

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_apr +
```

```
    chl_may + chl_june + summ_front_sd + spring_front +
spring_frt_sd +

    ss_current, family = "binomial", data =
complete.data.to.analyse,

    weights = weights)


Deviance Residuals:

     Min        1Q    Median        3Q       Max

-0.98022  -0.01264  -0.00213  -0.00013   1.32210


Coefficients:

              Estimate Std. Error z value Pr(>|z|)

(Intercept)   -5.03524    3.04441  -1.654   0.0981 .

dist_col      -0.21226    0.08740  -2.429   0.0152 *

dist_shore    -0.62434    0.35334  -1.767   0.0772 .

chl_apr        2.33921    0.98792   2.368   0.0179 *

chl_may       -1.16329    0.69506  -1.674   0.0942 .

chl_june       2.45022    1.61685   1.515   0.1297

summ_front_sd  0.08477    0.03863   2.194   0.0282 *

spring_front   0.16968    0.08544   1.986   0.0470 *

spring_frt_sd -0.20549    0.08453  -2.431   0.0151 *

ss_current    -1.41175    0.65603  -2.152   0.0314 *

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


(Dispersion parameter for binomial family taken to be 1)


    Null deviance: 207.04  on 24099  degrees of freedom

Residual deviance: 100.55  on 24090  degrees of freedom
```

```
AIC: 30.464

Number of Fisher Scoring iterations: 10

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + spring_frt_sd, family =
"binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.05505  -0.01404  -0.00571  -0.00208   1.32104

Coefficients:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)   -0.01991    0.33981  -0.059  0.95328
dist_col      -0.16688    0.05840  -2.858  0.00427 **
spring_frt_sd -0.17563    0.04014  -4.376 1.21e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 207.04  on 24099  degrees of freedom
Residual deviance: 123.49  on 24097  degrees of freedom
AIC: 19.175
```

```
Number of Fisher Scoring iterations: 8


LRT Selected Model:


Call:

glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,

    weights = weights)


Deviance Residuals:

     Min        1Q    Median        3Q       Max

-0.88454  -0.01414  -0.00228  -0.00007   1.46200


Coefficients:

             Estimate Std. Error z value Pr(>|z|)

(Intercept)   -1.76959    1.69987  -1.041  0.29787

dist_col      -0.22721    0.08313  -2.733  0.00627 **

dist_shore    -0.74037    0.35381  -2.093  0.03639 *

chl_apr        1.47884    0.81862   1.807  0.07084 .

summ_front_sd  0.07729    0.03733   2.071  0.03839 *

spring_front   0.16653    0.08128   2.049  0.04048 *

spring_frt_sd -0.24877    0.07882  -3.156  0.00160 **

ss_current    -1.17329    0.60579  -1.937  0.05277 .

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


(Dispersion parameter for binomial family taken to be 1)


    Null deviance: 207.04  on 24099  degrees of freedom
```

```
Residual deviance: 104.28  on 24092  degrees of freedom
AIC: 27.317

Number of Fisher Scoring iterations: 10


Single term deletions


Model:
SEARCH_FORAGE ~ dist_col + dist_shore + chl_apr + summ_front_sd +
    spring_front + spring_frt_sd + ss_current
              Df Deviance    AIC     LRT  Pr(>Chi)
<none>             104.28 27.317
dist_col       1   119.83 40.868 15.5510 8.031e-05 ***
dist_shore     1   109.55 30.583  5.2658 0.0217480 *
chl_apr        1   107.64 28.676  3.3589 0.0668421 .
summ_front_sd  1   108.90 29.938  4.6204 0.0315946 *
spring_front   1   108.36 29.392  4.0741 0.0435460 *
spring_frt_sd  1   116.28 37.321 12.0038 0.0005309 ***
ss_current     1   108.60 29.635  4.3176 0.0377206 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Now checking for interactions with Year.
Single term deletions


Model:
SEARCH_FORAGE ~ Year * (dist_col + dist_shore + chl_apr +
summ_front_sd +
    spring_front + spring_frt_sd + ss_current)
```

```
                   Df Deviance    AIC    LRT Pr(>Chi)
<none>                  90.621 57.791
Year:dist_col       2   91.556 54.725 0.9349   0.6266
Year:dist_shore     2   92.143 55.312 1.5217   0.4673
Year:chl_apr        2   94.291 57.461 3.6701   0.1596
Year:summ_front_sd  2   91.370 54.539 0.7487   0.6877
Year:spring_front   2   90.625 53.795 0.0041   0.9980
Year:spring_frt_sd  2   90.663 53.832 0.0417   0.9794
Year:ss_current     2   91.068 54.237 0.4469   0.7997
No significant Year interactions.


Running GAM.


GAM Model selected (ML output):


Family: binomial
Link function: logit


Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(dist_shore, k = 3) +
s(chl_apr,
    k = 3) + s(summ_front_sd, k = 3) + s(spring_front, k = 3) +
    s(spring_frt_sd, k = 3) + s(ss_current, k = 3)


Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   -8.973      2.066  -4.342 1.41e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(dist_col)       1      1  7.470 0.00627 **
s(dist_shore)     1      1  4.377 0.03642 *
s(chl_apr)        1      1  3.263 0.07085 .
s(summ_front_sd)  1      1  4.286 0.03842 *
s(spring_front)   1      1  4.197 0.04050 *
s(spring_frt_sd)  1      1  9.960 0.00160 **
s(ss_current)     1      1  3.751 0.05278 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =   0.67   Deviance explained = 49.6%
ML score =  52.14  Scale est. = 1         n = 24100

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(dist_shore, k = 3) +
s(chl_apr,
    k = 3) + s(summ_front_sd, k = 3) + s(spring_front, k = 3) +
    s(spring_frt_sd, k = 3) + s(ss_current, k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
```

```
(Intercept)   -9.837      2.253  -4.367 1.26e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                   edf Ref.df Chi.sq p-value
s(dist_col)      1.000  1.000  7.633 0.00573 **
s(dist_shore)    1.000  1.000  5.105 0.02386 *
s(chl_apr)       1.000  1.000  4.588 0.03222 *
s(summ_front_sd) 1.000  1.000  3.995 0.04563 *
s(spring_front)  1.000  1.000  4.724 0.02974 *
s(spring_frt_sd) 1.000  1.000  8.515 0.00352 **
s(ss_current)    1.714  1.918  4.260 0.11081
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.686   Deviance explained = 50.8%
REML score = 49.085  Scale est. = 1         n = 24100
Running INLA.

Call:
c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose =
TRUE)")

Time used:
 Pre-processing    Running inla Post-processing           Total
       4.274408      260.598457      134.519037      399.391902
```

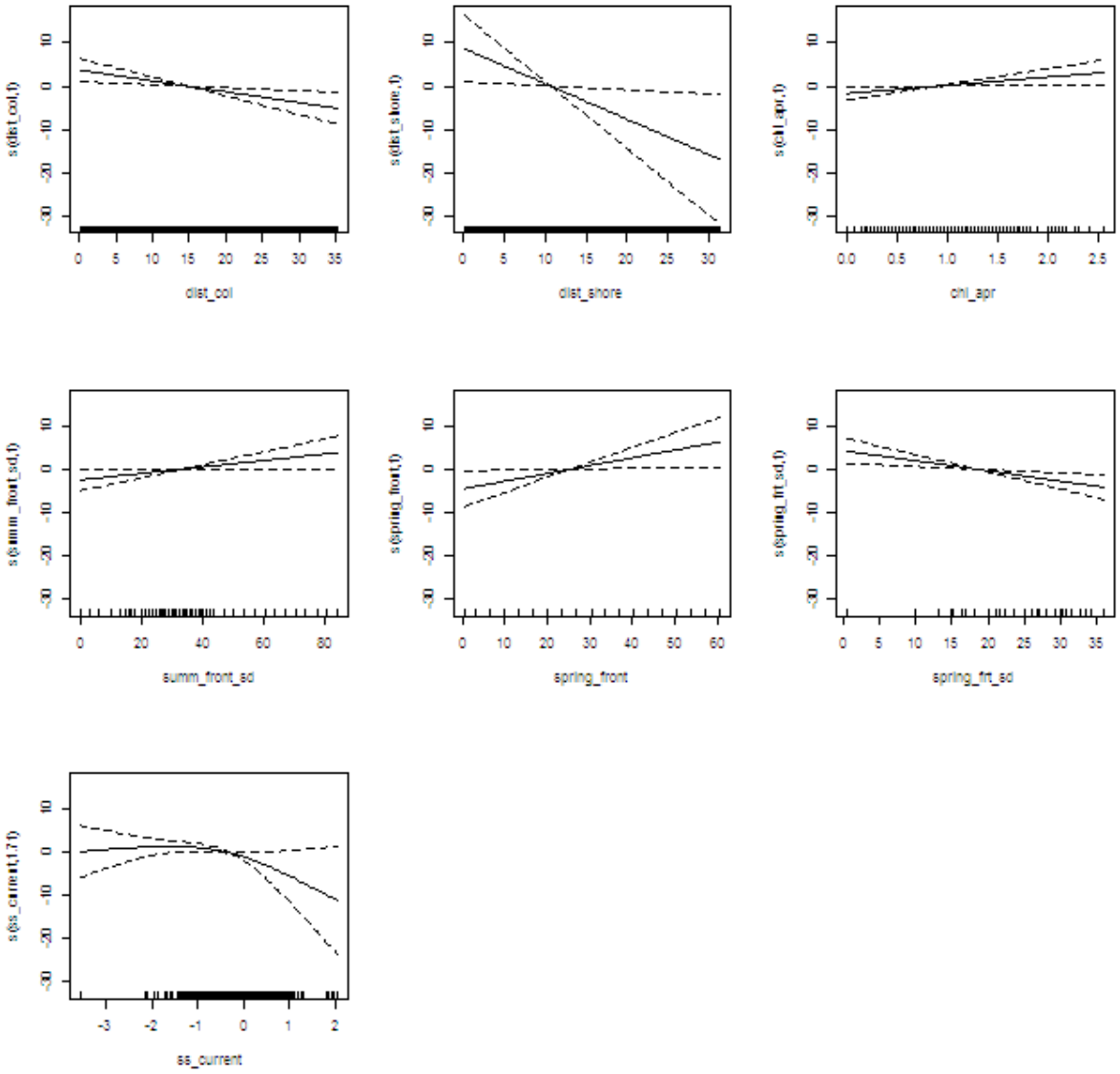
Fixed effects:

	mean	sd	0.025quant	0.5quant	0.975quant
(Intercept)	-3.89146324	4.93212613	-14.58219272	-3.51669287	4.77858073
dist_col	-0.27480379	0.09203716	-0.47515565	-0.26738643	-0.11388958
dist_shore	-0.94319517	0.36927706	-1.71605636	-0.92631322	-0.26419945
chl_apr	2.14580048	0.90349962	0.42444768	2.12735928	3.97178222
summ_front_sd	0.08307844	0.03775422	0.01231117	0.08185252	0.16070465
spring_front	0.19264712	0.08358823	0.03141790	0.19163898	0.35954604
spring_frt_sd	-0.24121878	0.08033603	-0.40997595	-0.23731110	-0.09410133
ss_current1	-0.53076514	6.66212229	-12.27682067	-1.02692769	13.88251817
ss_current2	-14.81097398	6.49787405	-28.64374683	-14.41859618	-3.10700804

	kld
(Intercept)	1.286369e-03
dist_col	2.146974e-02
dist_shore	3.360716e-02
chl_apr	2.002575e-02
summ_front_sd	1.647998e-02
spring_front	6.244368e-03
spring_frt_sd	4.518262e-03
ss_current1	7.561957e-07
ss_current2	4.181191e-02

Random effects:

```
Name    Model          Max KLD
UserFunction0   NoModelName
UserFunction1   NoModelName
mesh.points   SPDE model

Model hyperparameters:
                            mean    sd     0.025quant 0.5quant
0.975quant
T.0 for mesh.points-basisT  7.321  3.159  1.145      7.313   13.556

Expected number of effective parameters(std dev): 8.913(0.0002458)
Number of equivalent replicates : 2703.78

Marginal Likelihood:  -88.70
                   mean     sd 0.025quant 0.5quant 0.975quant    kld
(Intercept)    -3.8915 4.9321   -14.5822  -3.5167     4.7786 0.0013
dist_col       -0.2748 0.0920    -0.4752  -0.2674    -0.1139 0.0215
dist_shore     -0.9432 0.3693    -1.7161  -0.9263    -0.2642 0.0336
chl_apr         2.1458 0.9035     0.4244   2.1274     3.9718 0.0200
summ_front_sd   0.0831 0.0378     0.0123   0.0819     0.1607 0.0165
spring_front    0.1926 0.0836     0.0314   0.1916     0.3595 0.0062
spring_frt_sd  -0.2412 0.0803    -0.4100  -0.2373    -0.0941 0.0045
ss_current1    -0.5308 6.6621   -12.2768  -1.0269    13.8825 0.0000
ss_current2   -14.8110 6.4979   -28.6437 -14.4186    -3.1070 0.0418
```



Sandwich terns – SST included with outliers removed

```
AIC Selected Model (forwards):


Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_apr +
    chl_june, family = "binomial", data = complete.data.to.analyse,
    weights = weights)


Deviance Residuals:
```

```
     Min        1Q    Median        3Q       Max
-1.11619  -0.01143  -0.00112  -0.00009   2.14536

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.13942    1.45755  -0.096  0.92380
dist_col    -0.07377    0.02565  -2.877  0.00402 **
dist_shore  -0.34391    0.14097  -2.440  0.01470 *
chl_apr     -1.46258    0.68294  -2.142  0.03223 *
chl_june     1.20165    0.56285   2.135  0.03277 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 373.27  on 55201  degrees of freedom
Residual deviance: 237.28  on 55197  degrees of freedom
AIC: 50.169

Number of Fisher Scoring iterations: 10

AIC Selected Model (backwards):

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_apr +
    chl_june + summ_front_sd + ss_wave, family = "binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
```

```
     Min        1Q    Median        3Q       Max
-0.96057  -0.00981  -0.00135  -0.00010   2.02261

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)    1.67114    1.74933   0.955   0.3394
dist_col      -0.06693    0.02711  -2.468   0.0136 *
dist_shore    -0.36899    0.17130  -2.154   0.0312 *
chl_apr       -1.58321    0.72402  -2.187   0.0288 *
chl_june       1.30794    0.58894   2.221   0.0264 *
summ_front_sd -0.03224    0.02332  -1.382   0.1669
ss_wave       -0.60335    0.38387  -1.572   0.1160
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 373.27  on 55201  degrees of freedom
Residual deviance: 233.55  on 55195  degrees of freedom
AIC: 52.258

Number of Fisher Scoring iterations: 11

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore, family =
"binomial",
    data = complete.data.to.analyse, weights = weights)
```

```
Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.94821  -0.01150  -0.00123  -0.00010   2.15189

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.23169    0.30767  -0.753  0.45141
dist_col    -0.07501    0.02330  -3.220  0.00128 **
dist_shore  -0.35555    0.08826  -4.029 5.61e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 373.27  on 55201  degrees of freedom
Residual deviance: 245.78  on 55199  degrees of freedom
AIC: 48.431

Number of Fisher Scoring iterations: 10

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
```

```
     Min        1Q    Median        3Q       Max
-1.11619  -0.01143  -0.00112  -0.00009   2.14536

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.13942    1.45755  -0.096  0.92380
dist_col    -0.07377    0.02565  -2.877  0.00402 **
dist_shore  -0.34391    0.14097  -2.440  0.01470 *
chl_apr     -1.46258    0.68294  -2.142  0.03223 *
chl_june     1.20165    0.56285   2.135  0.03277 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 373.27  on 55201  degrees of freedom
Residual deviance: 237.28  on 55197  degrees of freedom
AIC: 50.169

Number of Fisher Scoring iterations: 10

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + dist_shore + chl_apr + chl_june
           Df Deviance    AIC     LRT  Pr(>Chi)
<none>          237.28 50.169
dist_col    1   250.48 61.370 13.2012 0.0002798 ***
dist_shore  1   245.09 55.981  7.8119 0.0051904 **
```

```
chl_apr     1   242.09 52.976  4.8068 0.0283469 *
chl_june    1   241.83 52.722  4.5525 0.0328715 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Now checking for interactions with Year.
Single term deletions

Model:
SEARCH_FORAGE ~ Year * (dist_col + dist_shore + chl_apr + chl_june)
               Df Deviance    AIC    LRT Pr(>Chi)
<none>              223.89 67.969
Year:dist_col   2   225.15 65.231 1.2622   0.5320
Year:dist_shore 2   230.90 70.982 7.0132   0.0300 *
Year:chl_apr    2   223.96 64.040 0.0715   0.9649
Year:chl_june   2   225.26 65.340 1.3712   0.5038
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Year effects not consistent - run one year at a time.

Running GAM.

GAM Model selected (ML output):

Family: binomial
Link function: logit

Formula:
```

```
SEARCH_FORAGE ~ s(chl_apr, k = 3) + s(chl_june, k = 3) +
s(strat_temp,
    k = 3)


Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   -7.766      1.168  -6.651 2.92e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Approximate significance of smooth terms:
              edf Ref.df Chi.sq  p-value
s(chl_apr)      1      1  3.759  0.05254 .
s(chl_june)     1      1  6.793  0.00915 **
s(strat_temp)   1      1 16.309 5.38e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


R-sq.(adj) =  0.261   Deviance explained = 35.7%
ML score = 119.96  Scale est. = 1         n = 55202


GAM Model selected (REML output):


Family: binomial
Link function: logit


Formula:
SEARCH_FORAGE ~ s(chl_apr, k = 3) + s(chl_june, k = 3) +
s(strat_temp,
```

```
    k = 3)


Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)   -7.766      1.168   -6.65 2.93e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Approximate significance of smooth terms:
              edf Ref.df Chi.sq  p-value
s(chl_apr)      1      1  3.756  0.05262 .
s(chl_june)     1      1  6.788  0.00918 **
s(strat_temp)   1      1 16.306 5.39e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


R-sq.(adj) =  0.261   Deviance explained = 35.7%
REML score = 121.18  Scale est. = 1         n = 55202
```

Sandwich terns – SST excluded

AIC Selected Model (forwards):

```
Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_may,
    family = "binomial", data = complete.data.to.analyse, weights =
weights)


Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.05311  -0.00859  -0.00059  -0.00003   2.22445
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.67811    0.66862  -1.014 0.310491
dist_col    -0.08874    0.02378  -3.731 0.000191 ***
dist_shore  -0.40978    0.09831  -4.168 3.07e-05 ***
chl_may      0.36957    0.25108   1.472 0.141045
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 447.26  on 55926  degrees of freedom
Residual deviance: 272.26  on 55923  degrees of freedom
AIC: 58.191

Number of Fisher Scoring iterations: 10

AIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore + chl_may +
    ss_wave + bathy_1sec, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.16017  -0.00901  -0.00109  -0.00013   2.09111
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.92164    1.99426   0.964   0.3353
dist_col    -0.07300    0.02543  -2.870   0.0041 **
dist_shore  -0.23885    0.17394  -1.373   0.1697
chl_may      0.42894    0.25193   1.703   0.0886 .
ss_wave     -0.72665    0.52229  -1.391   0.1641
bathy_1sec   0.07223    0.03917   1.844   0.0652 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 447.26  on 55926  degrees of freedom
Residual deviance: 268.72  on 55921  degrees of freedom
AIC: 61.428

Number of Fisher Scoring iterations: 11

BIC Selected Model:

Call:
glm(formula = SEARCH_FORAGE ~ dist_col + dist_shore, family =
"binomial",
    data = complete.data.to.analyse, weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
```

```
-0.93590  -0.00920  -0.00064  -0.00003   2.15522

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.19595    0.29277   0.669 0.503311
dist_col    -0.08246    0.02221  -3.712 0.000206 ***
dist_shore  -0.44069    0.09469  -4.654 3.26e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 447.26  on 55926  degrees of freedom
Residual deviance: 274.44  on 55924  degrees of freedom
AIC: 57.509

Number of Fisher Scoring iterations: 10

LRT Selected Model:

Call:
glm(formula = formula.glm, family = "binomial", data =
complete.data.to.analyse,
    weights = weights)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.93590  -0.00920  -0.00064  -0.00003   2.15522
```

```
Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.19595    0.29277   0.669 0.503311
dist_col    -0.08246    0.02221  -3.712 0.000206 ***
dist_shore  -0.44069    0.09469  -4.654 3.26e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 447.26  on 55926  degrees of freedom
Residual deviance: 274.44  on 55924  degrees of freedom
AIC: 57.509

Number of Fisher Scoring iterations: 10

Single term deletions

Model:
SEARCH_FORAGE ~ dist_col + dist_shore
           Df Deviance    AIC    LRT  Pr(>Chi)
<none>          274.44 57.509
dist_col    1   297.06 78.134 22.624 1.970e-06 ***
dist_shore  1   315.30 96.372 40.863 1.633e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Now checking for interactions with Year.
Single term deletions
```

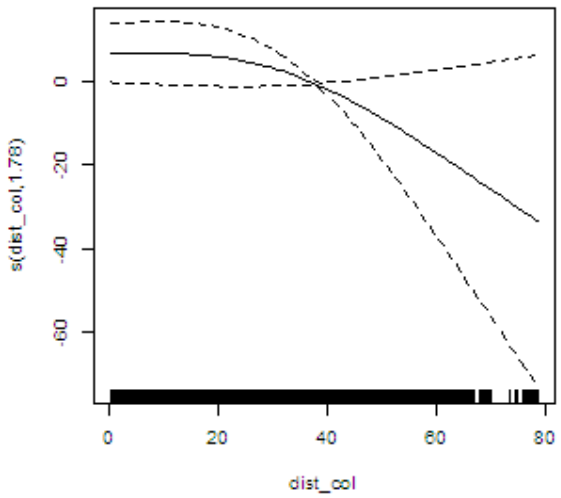
```
Model:
SEARCH_FORAGE ~ Year * (dist_col + dist_shore)
                Df Deviance    AIC     LRT  Pr(>Chi)
<none>               256.69 62.876
Year:dist_col    2   257.58 59.772  0.8961 0.6388641
Year:dist_shore  2   271.50 73.684 14.8083 0.0006087 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Year effects not consistent - run one year at a time.


Running GAM.


GAM Model selected (ML output):


Family: binomial
Link function: logit


Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_may, k = 3) +
s(bathy_1sec,
    k = 3)


Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -6.4775     0.6966  -9.298   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

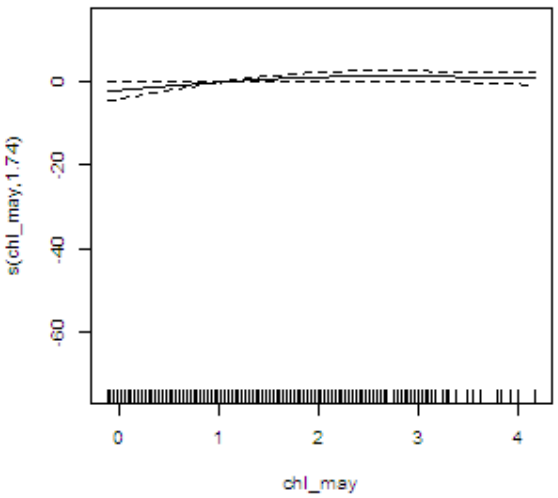
```
Approximate significance of smooth terms:
              edf Ref.df Chi.sq  p-value
s(dist_col)     1      1 12.382 0.000434 ***
s(chl_may)      1      1  4.289 0.038356 *
s(bathy_1sec)   1      1 22.594    2e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.397   Deviance explained =   39%
ML score = 136.38  Scale est. = 1         n = 55927

GAM Model selected (REML output):

Family: binomial
Link function: logit

Formula:
SEARCH_FORAGE ~ s(dist_col, k = 3) + s(chl_may, k = 3) +
s(bathy_1sec,
    k = 3)

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -12.177      3.776  -3.225  0.00126 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
               edf Ref.df Chi.sq  p-value
```

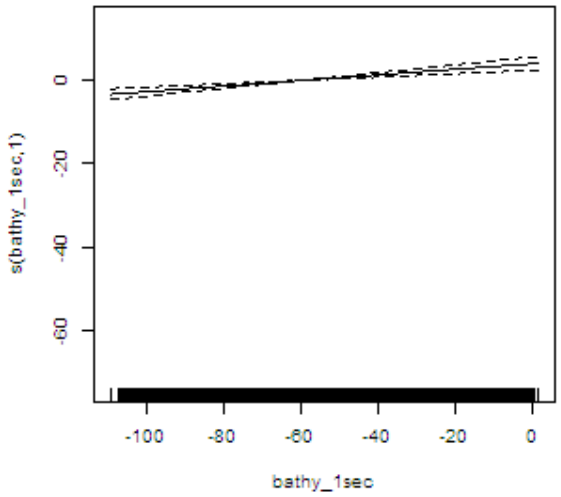
```
s(dist_col)   1.782  1.952   6.33   0.0402 *

s(chl_may)    1.739  1.932   3.94   0.1318

s(bathy_1sec) 1.000  1.000  25.50 4.42e-07 ***

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


R-sq.(adj) =  0.392   Deviance explained = 40.6%

REML score = 136.39  Scale est. = 1         n = 55927

Running INLA.


Call:

c("inla(formula = formula.inla, family = \"binomial\", data =
complete.data.to.analyse, ",  "    weights = weights, verbose =
TRUE)")


Time used:

 Pre-processing    Running inla Post-processing           Total

       9.500417     1320.886321      185.343926     1515.730664


Fixed effects:

                    mean          sd   0.025quant     0.5quant
0.975quant

(Intercept)  -5.43840679  2.64987462 -10.94920787  -5.32945102 -
0.5341445

bathy_1sec    0.06747274  0.01330845   0.04227278   0.06714279
0.0945406

dist_col1   -17.79413016  8.66266498 -36.63624746 -17.10742092 -
2.6315940

dist_col2   -28.58541689 16.41798545 -63.89194512 -27.45796809
0.5826683

chl_may1     10.03138044  4.89989045   0.98684934   9.81857212
20.2492269
```

```
chl_may2      2.32065696  1.10282970   0.23980301   2.29046736
4.5725689

                     kld
(Intercept) 0.0030535172
bathy_1sec  0.0041734944
dist_col1   0.0025193175
dist_col2   0.0039443896
chl_may1    0.0026498437
chl_may2    0.0007893911


Random effects:
Name    Model          Max KLD
UserFunction0   NoModelName
UserFunction1   NoModelName
mesh.points   SPDE model


Model hyperparameters:
                            mean    sd     0.025quant 0.5quant
0.975quant
T.0 for mesh.points-basisT  8.013  3.160  1.763      8.033   14.162


Expected number of effective parameters(std dev): 5.628(0.0004809)
Number of equivalent replicates : 9937.15


Marginal Likelihood:  -152.14
                mean      sd 0.025quant 0.5quant 0.975quant    kld
(Intercept)  -5.4384  2.6499   -10.9492  -5.3295    -0.5341 0.0031
bathy_1sec    0.0675  0.0133     0.0423   0.0671     0.0945 0.0042
dist_col1   -17.7941  8.6627   -36.6362 -17.1074    -2.6316 0.0025
```

```
dist_col2   -28.5854 16.4180   -63.8919 -27.4580     0.5827 0.0039
chl_may1     10.0314  4.8999     0.9868   9.8186    20.2492 0.0026
chl_may2      2.3207  1.1028     0.2398   2.2905     4.5726 0.0008
```







Variance Inflation Factors

Arctic tern, AIC selected model, including SST

```
     dist_col      chl_june       sst_may summ_front_sd    ss_current
     2.590696      4.579082      1.540922      2.526619      1.558960
   bathy_1sec
     7.486712
```

Arctic tern, AIC selected model, excluding SST

dist_col	chl_june	summ_front_sd	bathy_1sec
1.965858	**4.317997**	**2.526375**	**6.674326**

Common tern, AIC selected model, including SST

dist_col	chl_june	sst_april	bathy_1sec	sst_june
1.720706	4.623803	1.449510	4.555302	2.950160

Common tern, AIC selected model, excluding SST

dist_col	chl_apr	summ_front_sd	strat_temp	sal_summ
2.692582	2.557135	2.551321	4.646595	2.946827

sal_spring	ss_current	bathy_1sec
5.469419	1.602503	6.241017

Roseate tern, LRT selected model, including SST

dist_col	chl_june	sst_may
1.517489	1.539523	1.017911

Roseate tern, AIC selected model, excluding SST

dist_col	dist_shore	chl_apr	chl_may	chl_june
1.588470	5.518533	2.414380	2.174784	3.230091

summ_front_sd	spring_front	spring_frt_sd	ss_current
5.786227	8.709124	5.425485	1.703359

Sandwich tern, AIC selected model, including SST

dist_col	dist_shore	chl_apr	chl_june	summ_front_sd	ss_wave
1.124730	3.652339	1.817593	2.020926	2.729867	2.996139

Sandwich tern, AIC selected model, excluding SST

dist_col	dist_shore	chl_may	ss_wave	bathy_1sec
1.150402	3.750730	1.112642	7.076829	9.538748

	dist_col	dist_shore	chl_may	ss_wave	bathy_1sec
dist_col	1.0000000	0.7006419	-0.5509828	-0.5065455	-0.5723878
dist_shore	0.7006419	1.0000000	-0.7563967	-0.7518555	-0.8016200
chl_may	-0.5509828	-0.7563967	1.0000000	0.7533570	0.7775044

ss_wave	-0.5065455	-0.7518555	0.7533570	1.0000000	0.9612668
bathy_1sec	-0.5723878	-0.8016200	0.7775044	0.9612668	1.0000000