Example script for VAST for spatio-temporal analysis of multispecies catch-rate data

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Contents

```
## package 'pander' successfully unpacked and MD5 sums checked
##
## The downloaded binary packages are in
##  C:\Users\James.Thorson\AppData\Local\Temp\RtmpEBxS5G\downloaded_packages
```

1 Overview

This tutorial will walk through a simple example of how to use `VAST` for estimating abundance indices, distribution shifts, and range expansion using (1) biomass/count samples for a single species, (2) biomass/count samples for multiple ages/sizes of a single species, or (3) biomass/count samples for multiple species.

2 Getting started

To install TMB on a windows machine, we need to first install Rtools. During the installation, please select the option to have Rtools included in your system path. On other operating systems, it is not necessary to install Rtools. We then install `VAST`.

```
devtools::install_github("james-thorson/VAST")
```

We also install `FishData`, which is used to download data for our example

```
devtools::install_github("james-thorson/FishData")
```

Next load libraries.

```
library(TMB)               # Can instead load library(TMBdebug)
```

```
## Warning: package 'TMB' was built under R version
## 3.3.2
```

```
library(VAST)
```

2.1 Further information

If you have further questions after reading this tutorial, please explore the GitHub repo mainpage, wiki, and glossary. Also please explore the R help files, e.g., e.g., `?Data_Fn` for explanation of data inputs, or `?Param_Fn` for explanation of parameters.

2.2 Related tools

Related tools for spatio-temporal fisheries analysis are currently housed at www.FishStats.org. These include SpatialDeltaGLMM, a single-species antecedent of VAST, and www.FishViz.org, a tool for visualizing single-species results using worldwide. `VAST` and `SpatialDeltaGLMM` both use continuous integration to confirm that they give identical estimates when applied to single-species data.

2.3 How to cite SpatialDeltaGLMM

`VAST` has involved many publications for developing individual features. If using `VAST`, please read and cite:

```r
citation("VAST")
```

```
##
## Please cite 2016 (ICES J. Mar. Sci. J.
## Cons.) if using the package; 2016 (Glob.
## Ecol. Biogeogr) if exploring factor
## decomposition of spatio-temporal variation;
## 2015 (ICES J. Mar. Sci. J. Cons.) if
## calculating an index of abundance; 2016
## (Methods Ecol. Evol.) if using the
## center-of-gravity metric; 2016 (Fish. Res.)
## if using the bias-correction feature; 2016
## (Proc R Soc B) if using the
## effective-area-occupied metric.
##
##   Thorson, J.T., and Barnett, L.A.K. In
##   press. Comparing estimates of abundance
##   trends and distribution shifts using
##   single- and multispecies models of fishes
##   and biogenic habitat. ICES J. Mar. Sci. J.
##   Cons
##
##   Thorson, J.T., Ianelli, J.N., Larsen, E.,
##   Ries, L., Scheuerell, M.D., Szuwalski, C.,
##   and Zipkin, E. 2016. Joint dynamic species
##   distribution models: a tool for community
##   ordination and spatiotemporal monitoring.
##   Glob. Ecol. Biogeogr. 25(9): 1144-1158.
##   doi:10.1111/geb.12464. url:
##   http://onlinelibrary.wiley.com/doi/10.1111/geb.12464/abstract
##
##   Thorson, J.T., Shelton, A.O., Ward, E.J.,
##   Skaug, H.J., 2015. Geostatistical
##   delta-generalized linear mixed models
##   improve precision for estimated abundance
##   indices for West Coast groundfishes. ICES
##   J. Mar. Sci. J. Cons. 72(5), 1297-1310.
##   doi:10.1093/icesjms/fsu243. URL:
##   http://icesjms.oxfordjournals.org/content/72/5/1297
##
##   Thorson, J.T., and Kristensen, K. 2016.
##   Implementing a generic method for bias
```

```
##   correction in statistical models using
##   random effects, with spatial and
##   population dynamics examples. Fish. Res.
##   175: 66-74.
##   doi:10.1016/j.fishres.2015.11.016. url:
##   http://www.sciencedirect.com/science/article/pii/S0165783615301399
##
##   Thorson, J.T., Pinsky, M.L., Ward, E.J.,
##   2016. Model-based inference for estimating
##   shifts in species distribution, area
##   occupied, and center of gravity. Methods
##   Ecol. Evol. 7(8), 990-1008.
##   doi:10.1111/2041-210X.12567.  URL:
##   http://onlinelibrary.wiley.com/doi/10.1111/2041-210X.12567/full
##
##   Thorson, J.T., Rindorf, A., Gao, J.,
##   Hanselman, D.H., and Winker, H. 2016.
##   Density-dependent changes in effective
##   area occupied for sea-bottom-associated
##   marine fishes. Proc R Soc B 283(1840):
##   20161853. doi:10.1098/rspb.2016.1853. URL:
##   http://rspb.royalsocietypublishing.org/content/283/1840/20161853.
```

and also browse the GitHub list of packages.

3 Settings

We use latest version for CPP code

```
Version = "VAST_v1_9_0"
```

3.1 Spatial settings

The following settings define the spatial resolution for the model, and whether to use a grid or mesh approximation

```
Method = c("Grid", "Mesh")[2]
grid_size_km = 50
n_x = c(50, 100, 250, 500, 1000, 2000)[1] # Number of stations
Kmeans_Config = list( "randomseed"=1, "nstart"=100, "iter.max"=1e3 )
```

3.2 Model settings

The following settings define whether to include spatial and spatio-temporal variation, the rank of this covariance among species, whether its autocorrelated, and whether there's overdispersion

```
FieldConfig = c(Omega1 = 3, Epsilon1 = 3, Omega2 = 3,
    Epsilon2 = 3)
RhoConfig = c(Beta1 = 0, Beta2 = 0, Epsilon1 = 0, Epsilon2 = 0)
OverdispersionConfig = c(Vessel = 0, VesselYear = 0)
ObsModel = c(2, 0)
```

We also decide on which post-hoc calculations to include in the output

```
Options = c(SD_site_density = 0, SD_site_logdensity = 0,
    Calculate_Range = 1, Calculate_evenness = 0, Calculate_effective_area = 1,
    Calculate_Cov_SE = 0, Calculate_Synchrony = 0,
    Calculate_Coherence = 0)
```

3.3 Stratification for results

We also define any potential stratification of results, and settings specific to any case-study data set

```
strata.limits <- data.frame(STRATA = "All_areas")
```

3.4 Derived objects

In this case, we'll use publicly available data for three groundfishes in the Eastern Bering Sea, so we set `Region` and `Species_set` accordingly. `Region` is used to define both the database for downloading data, as well as the region for extrapolation density, while `Species_set` is only used when downloading data.

```
Region = "Eastern_Bering_Sea"
Species_set = c("Atheresthes stomias","Gadus chalcogrammus","Hippoglossoides elassodon")
```

3.5 Save settings

We then set the location for saving files.

```
DateFile = paste0(getwd(),'/VAST_output/')
  dir.create(DateFile)
```

I also like to save all settings for later reference, although this is not necessary.

```
Record = list(Version = Version, Method = Method, grid_size_km = grid_size_km,
    n_x = n_x, FieldConfig = FieldConfig, RhoConfig = RhoConfig,
    OverdispersionConfig = OverdispersionConfig, ObsModel = ObsModel,
    Kmeans_Config = Kmeans_Config, Region = Region,
    Species_set = Species_set, strata.limits = strata.limits)
save(Record, file = file.path(DateFile, "Record.RData"))
capture.output(Record, file = paste0(DateFile, "Record.txt"))
```

4 Prepare the data

4.1 Data-frame for catch-rate data

We then download data for three species using `FishData`.

```
DF = FishData::download_catch_rates(survey = "Eastern_Bering_Sea",
    species_set = Species_set)
Data_Geostat = data.frame(spp = DF[, "Sci"], Year = DF[,
    "Year"], Catch_KG = DF[, "Wt"], AreaSwept_km2 = 0.01,
    Vessel = 0, Lat = DF[, "Lat"], Lon = DF[, "Long"])
```

The data is formatted as shown here, with head…

spp	Year	Catch_KG	AreaSwept_km2	Vessel	Lat	Lon
Atheresthes_stomias	1982	6.98	0.01	0	55	-167
Atheresthes_stomias	1982	4.37	0.01	0	55	-166
Atheresthes_stomias	1982	12.6	0.01	0	55	-166
Atheresthes_stomias	1982	4.28	0.01	0	55	-165
Atheresthes_stomias	1982	0	0.01	0	55	-165
Atheresthes_stomias	1982	10.3	0.01	0	55.3	-167

… and tail

Table 2: Table continues below

	spp	Year	Catch_KG	AreaSwept_km2	Vessel
38878	Hippoglossoides_elassodon	2016	1.15	0.01	0
38879	Hippoglossoides_elassodon	2016	0	0.01	0
38880	Hippoglossoides_elassodon	2016	0	0.01	0
38881	Hippoglossoides_elassodon	2016	0	0.01	0
38882	Hippoglossoides_elassodon	2016	0	0.01	0
38883	Hippoglossoides_elassodon	2016	28	0.01	0

	Lat	Lon
38878	61.7	-176
38879	62	-174
38880	62	-174
38881	62	-175
38882	62	-176
38883	54.7	-165

4.2 Extrapolation grid

We also generate the extrapolation grid appropriate for a given region. For new regions, we use `Region="Other"`.

```
Extrapolation_List = SpatialDeltaGLMM::Prepare_Extrapolation_Data_Fn(Region = Region,
    strata.limits = strata.limits)
```

4.3 Derived objects for spatio-temporal estimation

And we finally generate the information used for conducting spatio-temporal parameter estimation, bundled in list `Spatial_List`

```
Spatial_List = SpatialDeltaGLMM::Spatial_Information_Fn(grid_size_km = grid_size_km,
    n_x = n_x, Method = Method, Lon = Data_Geostat[,
        "Lon"], Lat = Data_Geostat[, "Lat"], Extrapolation_List = Extrapolation_List,
    randomseed = Kmeans_Config[["randomseed"]], nstart = Kmeans_Config[["nstart"]],
    iter.max = Kmeans_Config[["iter.max"]], DirPath = DateFile,
```

```
    Save_Results = FALSE)
# Add knots to Data_Geostat
Data_Geostat = cbind(Data_Geostat, Spatial_List$loc_UTM,
    knot_i = Spatial_List$knot_i)
```

5 Build and run model

5.1 Build model

To estimate parameters, we first build a list of data-inputs used for parameter estimation. `Data_Fn` has some simple checks for buggy inputs, but also please read the help file `?Data_Fn`.

```
TmbData = Data_Fn(Version = Version, FieldConfig = FieldConfig,
    OverdispersionConfig = OverdispersionConfig, RhoConfig = RhoConfig,
    ObsModel = ObsModel, c_i = as.numeric(Data_Geostat[,
        "spp"]) - 1, b_i = Data_Geostat[, "Catch_KG"],
    a_i = Data_Geostat[, "AreaSwept_km2"], v_i = as.numeric(Data_Geostat[,
        "Vessel"]) - 1, s_i = Data_Geostat[, "knot_i"] -
        1, t_i = Data_Geostat[, "Year"], a_xl = Spatial_List$a_xl,
    MeshList = Spatial_List$MeshList, GridList = Spatial_List$GridList,
    Method = Spatial_List$Method, Options = Options)
```

We then build the TMB object.

```
TmbList = Build_TMB_Fn(TmbData = TmbData, RunDir = DateFile,
    Version = Version, RhoConfig = RhoConfig, loc_x = Spatial_List$loc_x)
Obj = TmbList[["Obj"]]
```

5.2 Estimate fixed effects and predict random effects

Next, we use a gradient-based nonlinear minimizer to identify maximum likelihood estimates for fixed-effects

```
Opt = TMBhelper::Optimize(obj = Obj, lower = TmbList[["Lower"]],
    upper = TmbList[["Upper"]], getsd = TRUE, savedir = DateFile,
    bias.correct = FALSE)
```

Finally, we bundle and save output

```
Report = Obj$report()
Save = list("Opt"=Opt, "Report"=Report, "ParHat"=Obj$env$parList(Opt$par), "TmbData"=TmbData)
save(Save, file=paste0(DateFile,"Save.RData"))
```

6 Diagnostic plots

We first apply a set of standard model diagnostics to confirm that the model is reasonable and deserves further attention. If any of these do not look reasonable, the model output should not be interpreted or used.

6.1 Plot data

It is always good practice to conduct exploratory analysis of data. Here, I visualize the spatial distribution of data. Spatio-temporal models involve the assumption that the probability of sampling a given location is statistically independent of the probability distribution for the response at that location. So if sampling "follows" changes in density, then the model is probably not appropriate!

```
SpatialDeltaGLMM::Plot_data_and_knots(Extrapolation_List = Extrapolation_List,
    Spatial_List = Spatial_List, Data_Geostat = Data_Geostat,
    PlotDir = DateFile)
```

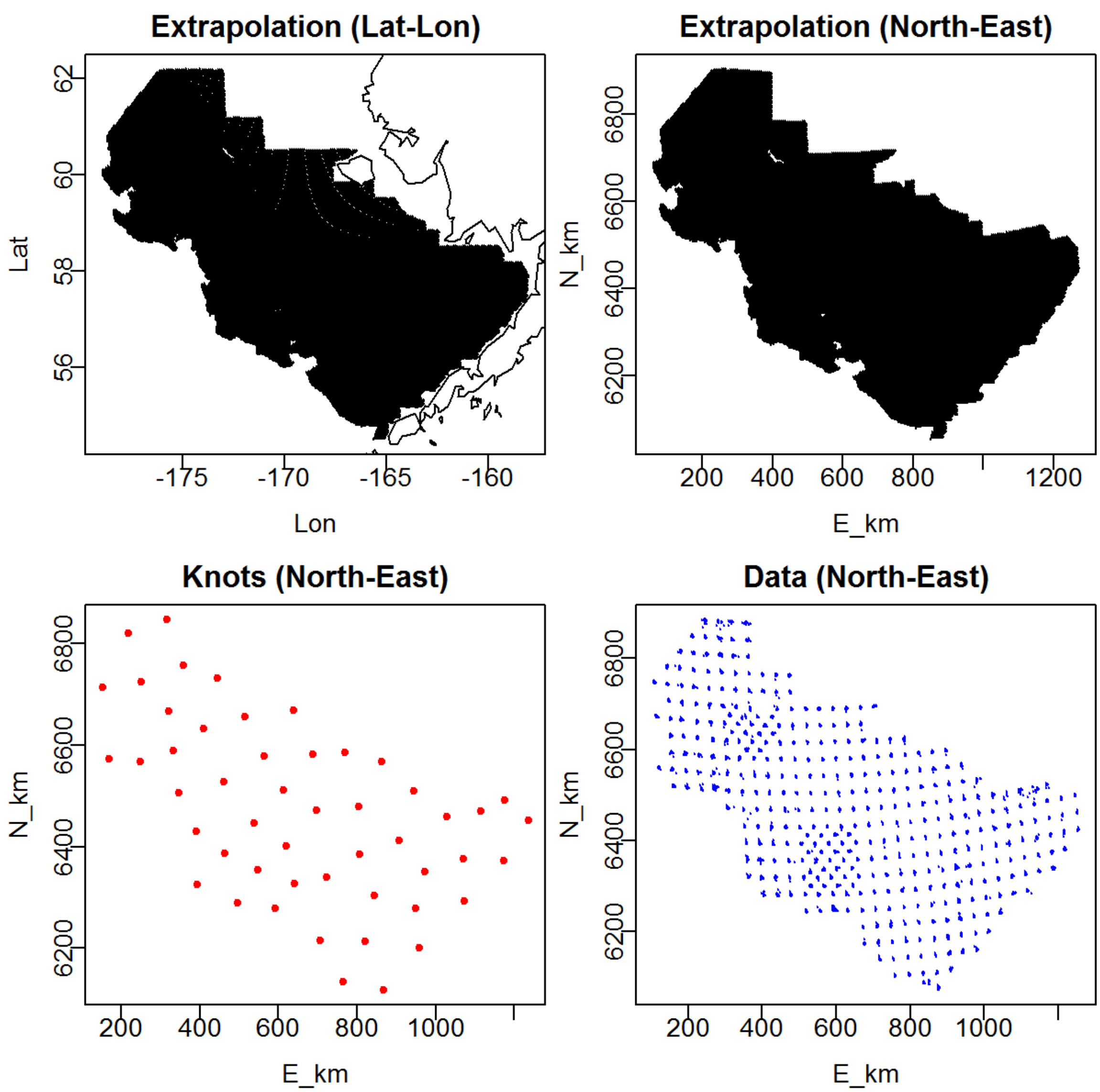

Figure 1: Spatial extent and location of knots

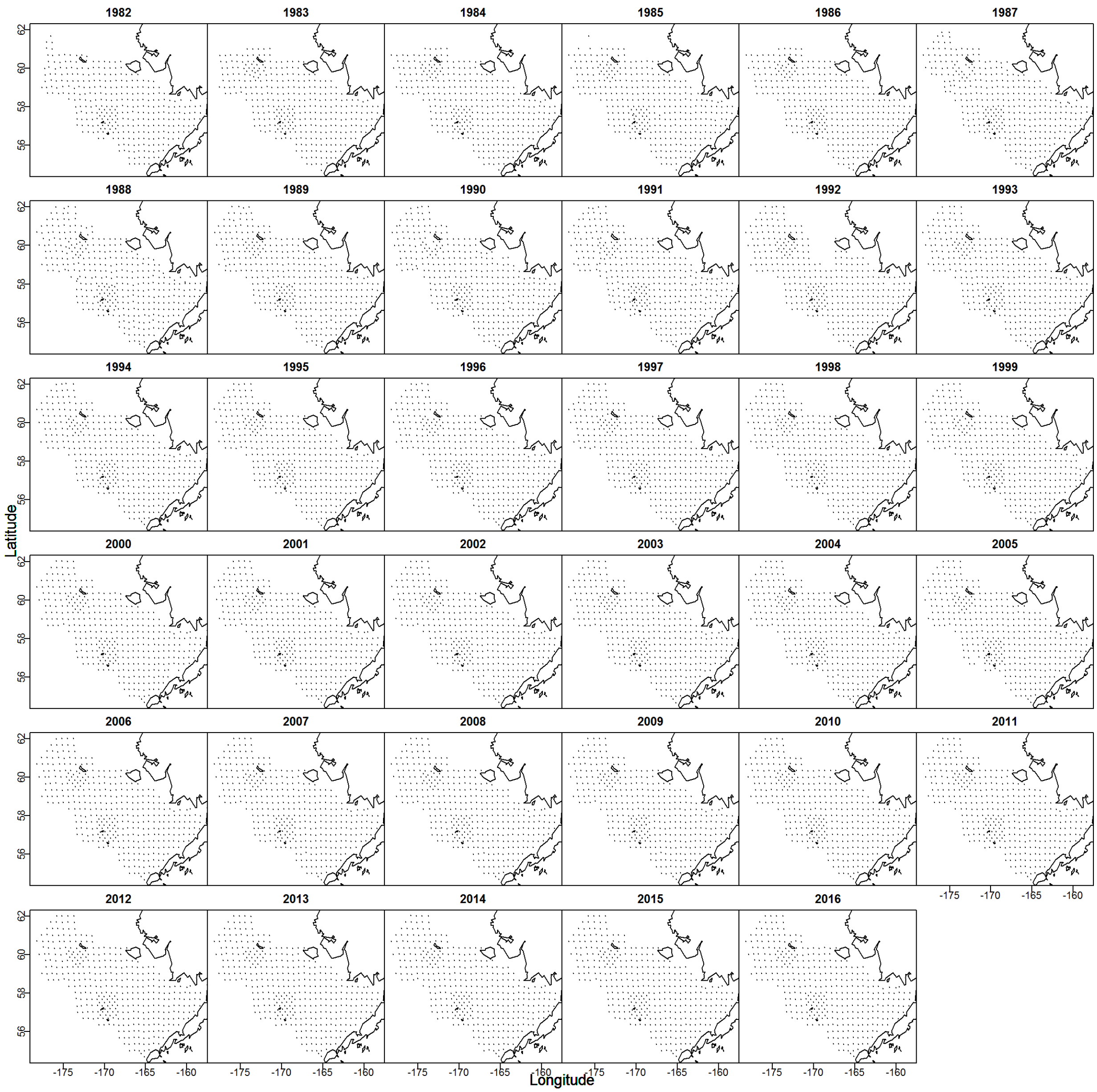

Figure 2: Spatial distribution of catch-rate data

6.2 Convergence

Here I print the diagnostics generated during parameter estimation, and I confirm that (1) no parameter is hitting an upper or lower bound and (2) the final gradient for each fixed-effect is close to zero. For explanation of parameters, please see `?Data_Fn`.

```
pander::pandoc.table( Opt$diagnostics[,c('Param','Lower','MLE','Upper','final_gradient')] )
```

Param	Lower	MLE	Upper	final_gradient
ln_H_input	-50	0.3356	50	-0.001267
ln_H_input	-50	-1.154	50	-0.0006145
beta1_ct	-50	-1.256	50	-0.0001182
beta1_ct	-50	3.846	50	5.423e-05
beta1_ct	-50	3.088	50	0.0001828
beta1_ct	-50	-0.8958	50	-8.598e-05
beta1_ct	-50	3.842	50	0.0004441
beta1_ct	-50	3.443	50	8.095e-05
beta1_ct	-50	-1.399	50	-2.043e-08
beta1_ct	-50	3.895	50	2.622e-05
beta1_ct	-50	2.833	50	-4.037e-05
beta1_ct	-50	-1.464	50	3.79e-05
beta1_ct	-50	4.539	50	0.0001092
beta1_ct	-50	2.843	50	-0.0001226
beta1_ct	-50	-1.277	50	1.814e-05
beta1_ct	-50	4.896	50	-0.0002892
beta1_ct	-50	2.456	50	-0.000236
beta1_ct	-50	0.2561	50	0.0001032
beta1_ct	-50	3.699	50	7.562e-05
beta1_ct	-50	2.442	50	-0.0002076
beta1_ct	-50	-0.5268	50	2.645e-05
beta1_ct	-50	4.553	50	-1.216e-05
beta1_ct	-50	2.077	50	-1.399e-05
beta1_ct	-50	0.3131	50	6.032e-05
beta1_ct	-50	3.693	50	0.0001181
beta1_ct	-50	2.588	50	-2.843e-05
beta1_ct	-50	-0.7505	50	1.128e-06
beta1_ct	-50	3.889	50	-3.487e-05
beta1_ct	-50	2.846	50	-0.0001723
beta1_ct	-50	-1.036	50	0.0001713
beta1_ct	-50	5.499	50	-8.195e-05
beta1_ct	-50	2.746	50	-0.00015
beta1_ct	-50	-2.36	50	-0.0002017
beta1_ct	-50	4.066	50	9.551e-05
beta1_ct	-50	3.018	50	0.000319
beta1_ct	-50	0.05969	50	4.77e-05
beta1_ct	-50	4.744	50	8.379e-05
beta1_ct	-50	3.203	50	-0.0001064
beta1_ct	-50	-1.514	50	4.061e-06
beta1_ct	-50	5.165	50	0.0001705
beta1_ct	-50	2.976	50	-0.000277
beta1_ct	-50	-2.512	50	-4.839e-05
beta1_ct	-50	4.391	50	8.561e-05
beta1_ct	-50	2.424	50	-3.394e-05

Param	Lower	MLE	Upper	final_gradient
beta1_ct	-50	-0.5557	50	-1.267e-05
beta1_ct	-50	4.644	50	0.0002281
beta1_ct	-50	3.08	50	4.527e-06
beta1_ct	-50	-1.831	50	-2.517e-05
beta1_ct	-50	4.308	50	4.163e-05
beta1_ct	-50	3.285	50	0.0002154
beta1_ct	-50	-0.6579	50	-9.061e-05
beta1_ct	-50	4.575	50	-0.0001272
beta1_ct	-50	4.611	50	0.0004308
beta1_ct	-50	-3.12	50	4.149e-05
beta1_ct	-50	5.697	50	-0.0001216
beta1_ct	-50	1.88	50	-0.0004073
beta1_ct	-50	-1.363	50	2.578e-05
beta1_ct	-50	4.67	50	-0.0001364
beta1_ct	-50	2.711	50	-0.0001696
beta1_ct	-50	-0.3361	50	6.295e-05
beta1_ct	-50	5.225	50	0.0001459
beta1_ct	-50	3.14	50	-0.0001695
beta1_ct	-50	0.1003	50	-8.69e-06
beta1_ct	-50	4.328	50	9.474e-07
beta1_ct	-50	2.857	50	2.964e-05
beta1_ct	-50	2.384	50	2.392e-05
beta1_ct	-50	4.118	50	0.0003323
beta1_ct	-50	2.889	50	9.428e-05
beta1_ct	-50	1.846	50	6.768e-05
beta1_ct	-50	4.999	50	-0.000288
beta1_ct	-50	2.758	50	-0.0001496
beta1_ct	-50	3.082	50	8.714e-05
beta1_ct	-50	4.291	50	-0.0004088
beta1_ct	-50	3.162	50	-6.209e-05
beta1_ct	-50	-0.005148	50	1.71e-06
beta1_ct	-50	4.128	50	5.592e-05
beta1_ct	-50	2.135	50	-7.521e-05
beta1_ct	-50	-0.5616	50	2.117e-05
beta1_ct	-50	3.75	50	-0.0001301
beta1_ct	-50	2.33	50	-9.314e-05
beta1_ct	-50	-0.4674	50	-7.177e-05
beta1_ct	-50	2.549	50	-0.0005197
beta1_ct	-50	2.098	50	0.0003196
beta1_ct	-50	-1.43	50	-0.0003181
beta1_ct	-50	3.045	50	-0.0004958
beta1_ct	-50	1.443	50	0.001236
beta1_ct	-50	-0.8587	50	3.755e-05
beta1_ct	-50	2.642	50	0.0001241
beta1_ct	-50	2.098	50	6.283e-05
beta1_ct	-50	1.079	50	3.073e-05
beta1_ct	-50	4.283	50	-9.143e-05
beta1_ct	-50	2.316	50	-4.919e-05
beta1_ct	-50	-1.732	50	-2.135e-05
beta1_ct	-50	4.237	50	0.0002698
beta1_ct	-50	1.725	50	-7.038e-06
beta1_ct	-50	-1.051	50	-1.405e-05

Param	Lower	MLE	Upper	final_gradient
beta1_ct	-50	4.699	50	0.0001277
beta1_ct	-50	2.165	50	6.936e-06
beta1_ct	-50	1.023	50	7.024e-05
beta1_ct	-50	5.749	50	-6.342e-05
beta1_ct	-50	2.391	50	-0.0001765
beta1_ct	-50	0.7601	50	5.515e-05
beta1_ct	-50	6.855	50	-8.129e-05
beta1_ct	-50	2.351	50	-0.0002185
beta1_ct	-50	3.608	50	-5.313e-05
beta1_ct	-50	5.685	50	-6.57e-05
beta1_ct	-50	3.241	50	9.837e-06
L_omega1_z	-50	3.405	50	0.0002239
L_omega1_z	-50	0.268	50	7.82e-05
L_omega1_z	-50	2.16	50	-0.000172
L_omega1_z	-50	2.358	50	-0.0004346
L_omega1_z	-50	0.9883	50	0.0002571
L_omega1_z	-50	-1.268	50	0.0005442
L_epsilon1_z	-50	0.9849	50	0.0002511
L_epsilon1_z	-50	-0.08927	50	-0.0005582
L_epsilon1_z	-50	-0.6912	50	0.0006211
L_epsilon1_z	-50	0.291	50	0.00272
L_epsilon1_z	-50	-0.2594	50	0.0002011
L_epsilon1_z	-50	0.6556	50	0.003132
logkappa1	-5.978	-4.669	-3.114	-9.609e-05
beta2_ct	-50	3.375	50	0.0007278
beta2_ct	-50	7.688	50	-0.0003077
beta2_ct	-50	5.564	50	0.0002468
beta2_ct	-50	3.951	50	-0.001064
beta2_ct	-50	8.968	50	-0.0003524
beta2_ct	-50	5.757	50	0.001932
beta2_ct	-50	4.082	50	-0.001215
beta2_ct	-50	8.212	50	0.0008825
beta2_ct	-50	5.511	50	-0.0009895
beta2_ct	-50	4.359	50	-0.0007853
beta2_ct	-50	8.498	50	0.0006329
beta2_ct	-50	5.538	50	-0.0004918
beta2_ct	-50	4.103	50	-0.0002336
beta2_ct	-50	8.221	50	-0.0006742
beta2_ct	-50	5.642	50	0.001382
beta2_ct	-50	5.086	50	-0.0001042
beta2_ct	-50	8.617	50	0.000293
beta2_ct	-50	5.993	50	-0.0004235
beta2_ct	-50	4.755	50	0.001301
beta2_ct	-50	8.528	50	-0.0002326
beta2_ct	-50	6.14	50	-0.0006563
beta2_ct	-50	5.004	50	-0.0001411
beta2_ct	-50	8.426	50	2.756e-07
beta2_ct	-50	6.062	50	-4.466e-05
beta2_ct	-50	4.951	50	-0.001488
beta2_ct	-50	8.334	50	-0.0005123
beta2_ct	-50	6.232	50	0.001674
beta2_ct	-50	4.496	50	0.001918

Param	Lower	MLE	Upper	final_gradient
beta2__ct	-50	8.387	50	-0.0001637
beta2__ct	-50	6.195	50	-0.0015
beta2__ct	-50	4.685	50	0.0007802
beta2__ct	-50	8.173	50	-0.000403
beta2__ct	-50	6.177	50	5.331e-05
beta2__ct	-50	5.38	50	-0.0003652
beta2__ct	-50	8.537	50	0.0001664
beta2__ct	-50	6.325	50	-0.0001943
beta2__ct	-50	5.522	50	0.00308
beta2__ct	-50	8.303	50	-3.717e-05
beta2__ct	-50	6.319	50	-0.002186
beta2__ct	-50	5.185	50	-0.001084
beta2__ct	-50	7.958	50	0.0002668
beta2__ct	-50	6.053	50	-9.117e-05
beta2__ct	-50	5.618	50	9.304e-08
beta2__ct	-50	8.008	50	0.0002618
beta2__ct	-50	6.273	50	-0.0004764
beta2__ct	-50	5.094	50	-0.001737
beta2__ct	-50	8.13	50	0.0008938
beta2__ct	-50	6.4	50	-0.0006078
beta2__ct	-50	5.083	50	0.0006726
beta2__ct	-50	7.862	50	-0.0004019
beta2__ct	-50	6.376	50	0.0006567
beta2__ct	-50	4.219	50	0.0002347
beta2__ct	-50	7.763	50	-0.0002536
beta2__ct	-50	5.521	50	0.00017
beta2__ct	-50	4.898	50	0.001613
beta2__ct	-50	8.403	50	-0.0002626
beta2__ct	-50	5.9	50	-0.0005983
beta2__ct	-50	5.045	50	-0.0003563
beta2__ct	-50	8.479	50	-1.804e-05
beta2__ct	-50	6.044	50	0.0001973
beta2__ct	-50	4.722	50	-0.0006167
beta2__ct	-50	8.307	50	-4.621e-05
beta2__ct	-50	6.16	50	0.0005025
beta2__ct	-50	5.621	50	0.0004523
beta2__ct	-50	8.844	50	-0.0004985
beta2__ct	-50	6.061	50	0.00118
beta2__ct	-50	5.755	50	0.0001285
beta2__ct	-50	8.348	50	-1.837e-05
beta2__ct	-50	6.33	50	-1.006e-05
beta2__ct	-50	6.126	50	-0.0006118
beta2__ct	-50	8.205	50	0.001097
beta2__ct	-50	6.328	50	-0.001476
beta2__ct	-50	5.382	50	-0.001461
beta2__ct	-50	7.537	50	-0.0002694
beta2__ct	-50	6.052	50	0.001275
beta2__ct	-50	5.03	50	0.0002724
beta2__ct	-50	7.382	50	0.0001642
beta2__ct	-50	5.984	50	-0.0005616
beta2__ct	-50	5.28	50	-0.0004942
beta2__ct	-50	7.04	50	2.847e-05

Param	Lower	MLE	Upper	final_gradient
beta2_ct	-50	5.734	50	-0.0001639
beta2_ct	-50	4.73	50	0.001031
beta2_ct	-50	6.569	50	-0.0004785
beta2_ct	-50	5.223	50	-0.0003785
beta2_ct	-50	5.576	50	-0.0003197
beta2_ct	-50	7.547	50	-0.0001472
beta2_ct	-50	5.529	50	0.0005754
beta2_ct	-50	5.459	50	-0.0001016
beta2_ct	-50	7.672	50	-0.0002105
beta2_ct	-50	5.711	50	0.000692
beta2_ct	-50	5.127	50	-0.0006416
beta2_ct	-50	7.666	50	-0.0001212
beta2_ct	-50	5.537	50	0.0003799
beta2_ct	-50	5.178	50	-0.0008361
beta2_ct	-50	7.772	50	-0.0001726
beta2_ct	-50	5.654	50	0.0008496
beta2_ct	-50	5.737	50	0.0002883
beta2_ct	-50	8.766	50	0.000326
beta2_ct	-50	5.852	50	-0.000311
beta2_ct	-50	5.583	50	5.977e-05
beta2_ct	-50	8.959	50	0.0001358
beta2_ct	-50	5.887	50	0.0001831
beta2_ct	-50	6.344	50	0.0002586
beta2_ct	-50	8.877	50	0.0004653
beta2_ct	-50	6.1	50	0.0002887
L_omega2_z	-50	1.445	50	0.0005743
L_omega2_z	-50	0.7518	50	-0.0006592
L_omega2_z	-50	0.7635	50	-0.001712
L_omega2_z	-50	0.8668	50	-0.0005367
L_omega2_z	-50	0.06516	50	-0.0002567
L_omega2_z	-50	-0.6737	50	0.0001701
L_epsilon2_z	-50	-0.5415	50	0.01363
L_epsilon2_z	-50	-0.2826	50	-0.002142
L_epsilon2_z	-50	-0.9256	50	-0.002783
L_epsilon2_z	-50	-0.248	50	-0.001182
L_epsilon2_z	-50	-0.1679	50	0.002491
L_epsilon2_z	-50	-0.6256	50	-0.005238
logkappa2	-5.978	-4.298	-3.114	-0.0005733
logSigmaM	-50	-0.01823	10	-0.003529
logSigmaM	-50	0.2275	10	0.003819
logSigmaM	-50	0.04248	10	0.007789

6.3 Diagnostics for encounter-probability component

Next, we check whether observed encounter frequencies for either low or high probability samples are within the 95% predictive interval for predicted encounter probability

```
Enc_prob = SpatialDeltaGLMM::Check_encounter_prob(Report = Report,
    Data_Geostat = Data_Geostat, DirName = DateFile)
```

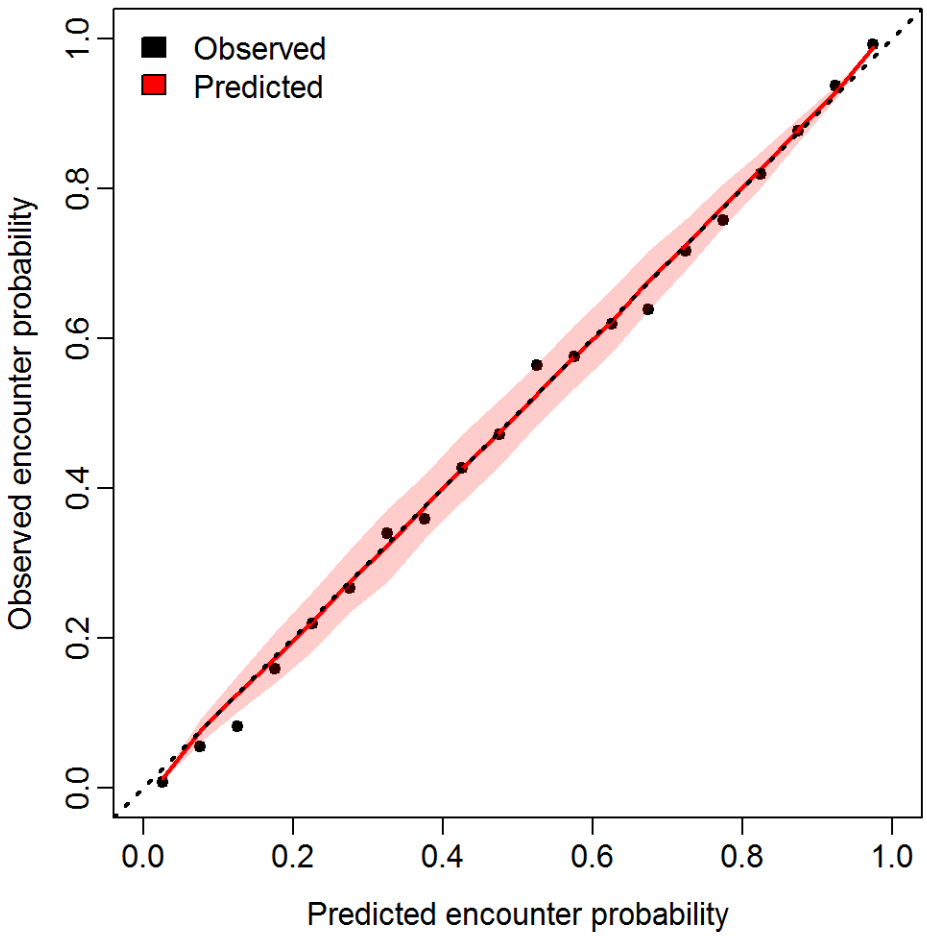

Figure 3: Expectated probability and observed frequency of encounter for “encounter probability” component

6.4 Diagnostics for positive-catch-rate component

I haven't yet added the Q-Q plotting options from `SpatialDeltaGLMM` so that is missing for now.

6.5 Model selection

To select among models, we recommend using the Akaike Information Criterion, AIC, via `Opt$AIC=` ".

7 Model output

Last but not least, we generate useful plots by first determining which years to plot (`Years2Include`), and labels for each plotted year (`Year_Set`)

```
Year_Set = seq(min(Data_Geostat[,'Year']),max(Data_Geostat[,'Year']))
Years2Include = which( Year_Set %in% sort(unique(Data_Geostat[,'Year'])))
```

We then run a set of pre-defined plots for visualizing results

7.1 Direction of "geometric anisotropy"

We can visualize which direction has faster or slower decorrelation (termed "geometric anisotropy")

```
SpatialDeltaGLMM::PlotAniso_Fn(FileName = paste0(DateFile,
    "Aniso.png"), Report = Report, TmbData = TmbData)
```

7.2 Plot spatial and spatio-temporal covariance

We can visualize the spatial and spatio-temporal covariance among species in encounter probability and positive catch rates (depending upon what is turned on via `FieldConfig`):

```
Cov_List = Summarize_Covariance(Report = Report, ParHat = Obj$env$parList(),
    Data = TmbData, SD = Opt$SD, plot_cor = FALSE,
    category_names = levels(Data_Geostat[, "spp"]),
    plotdir = DateFile, plotTF = FieldConfig, mgp = c(2,
        0.5, 0), tck = -0.02, oma = c(0, 5, 2, 2))
```

7.3 Density surface for each year

We can visualize many types of output from the model. Here I only show predicted density, but other options are obtained via other integers passed to `plot_set` as described in `?PlotResultsOnMap_Fn`

```
# Get region-specific settings for plots
MapDetails_List = SpatialDeltaGLMM::MapDetails_Fn(Region = Region,
    NN_Extrap = Spatial_List$PolygonList$NN_Extrap,
    Extrapolation_List = Extrapolation_List)
# Plot maps representing density or other variables
```

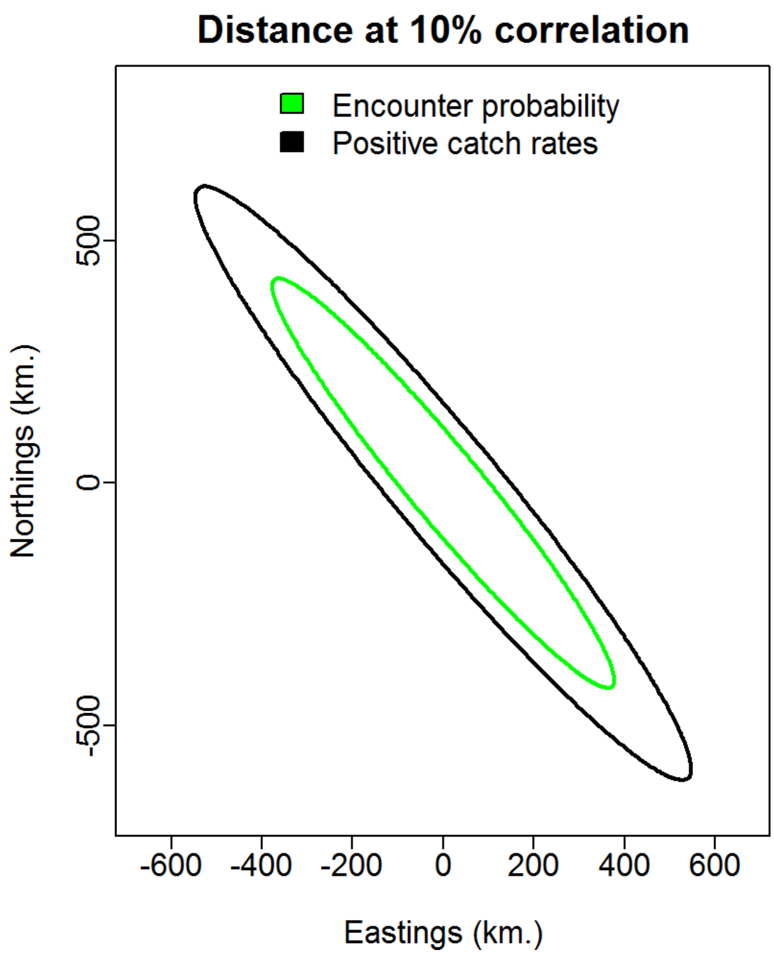

Figure 4: Decorrelation distance for different directions

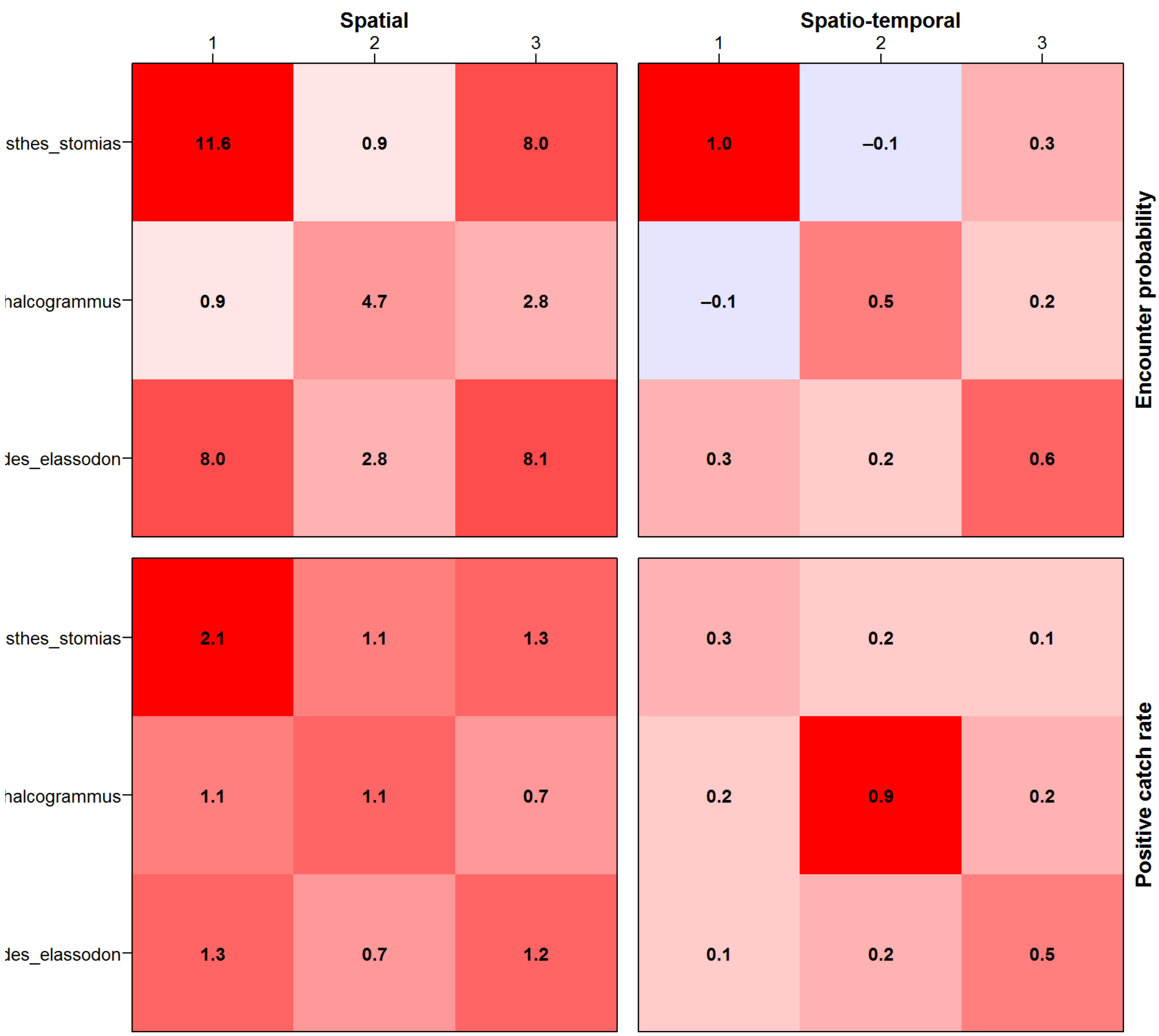

Figure 5: Spatial and spatio-temporal covariance

```
SpatialDeltaGLMM::PlotResultsOnMap_Fn(plot_set = c(3),
    MappingDetails = MapDetails_List[["MappingDetails"]],
    Report = Report, Sdreport = Opt$SD, PlotDF = MapDetails_List[["PlotDF"]],
    MapSizeRatio = MapDetails_List[["MapSizeRatio"]],
    Xlim = MapDetails_List[["Xlim"]], Ylim = MapDetails_List[["Ylim"]],
    FileName = DateFile, Year_Set = Year_Set, Years2Include = Years2Include,
    Rotate = MapDetails_List[["Rotate"]], Cex = MapDetails_List[["Cex"]],
    Legend = MapDetails_List[["Legend"]], zone = MapDetails_List[["Zone"]],
    mar = c(0, 0, 2, 0), oma = c(3.5, 3.5, 0, 0), cex = 1.8,
    category_names = levels(Data_Geostat[, "spp"]))
```

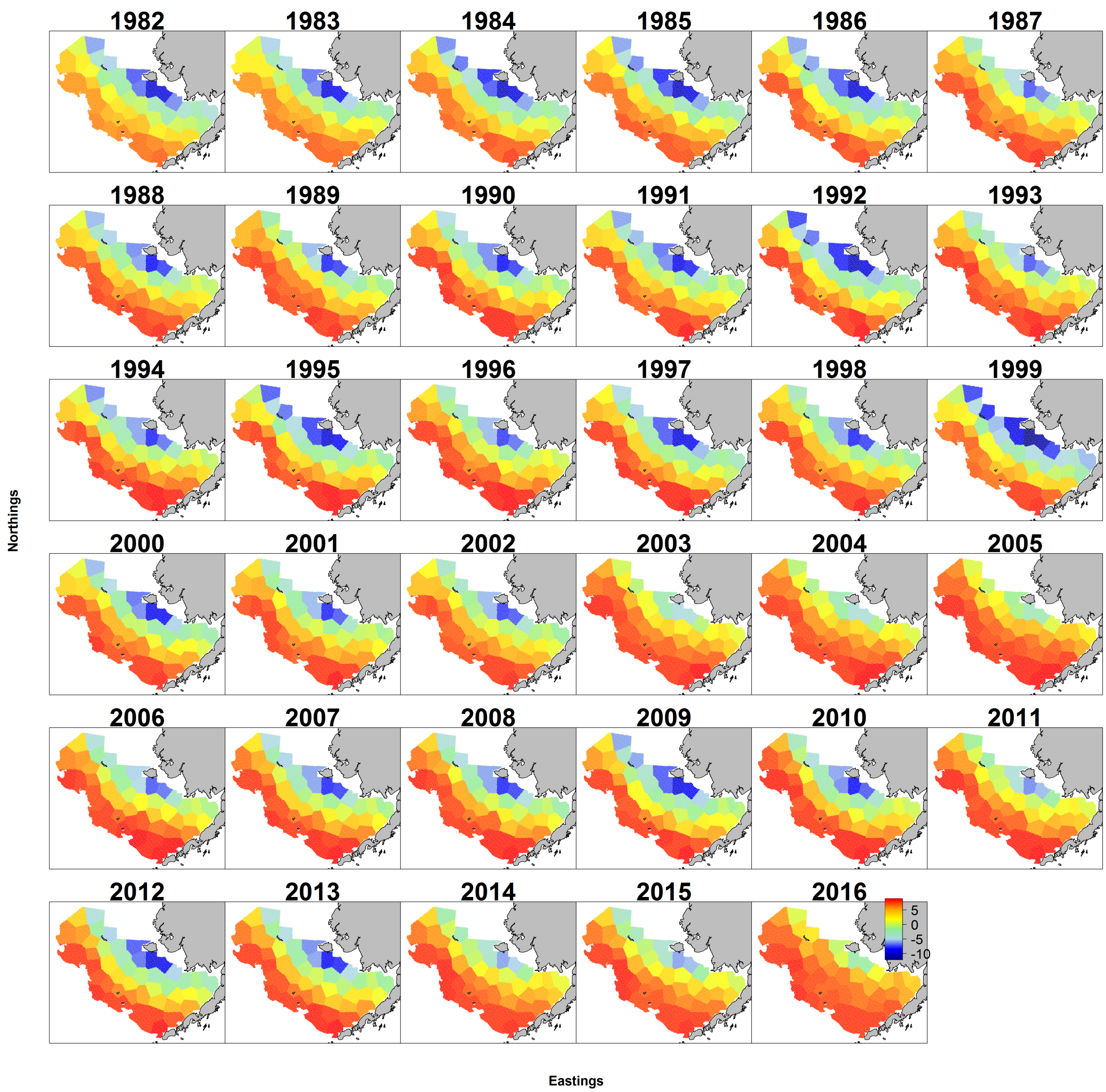

Figure 6: Density maps for each year for arrowtooth flounder

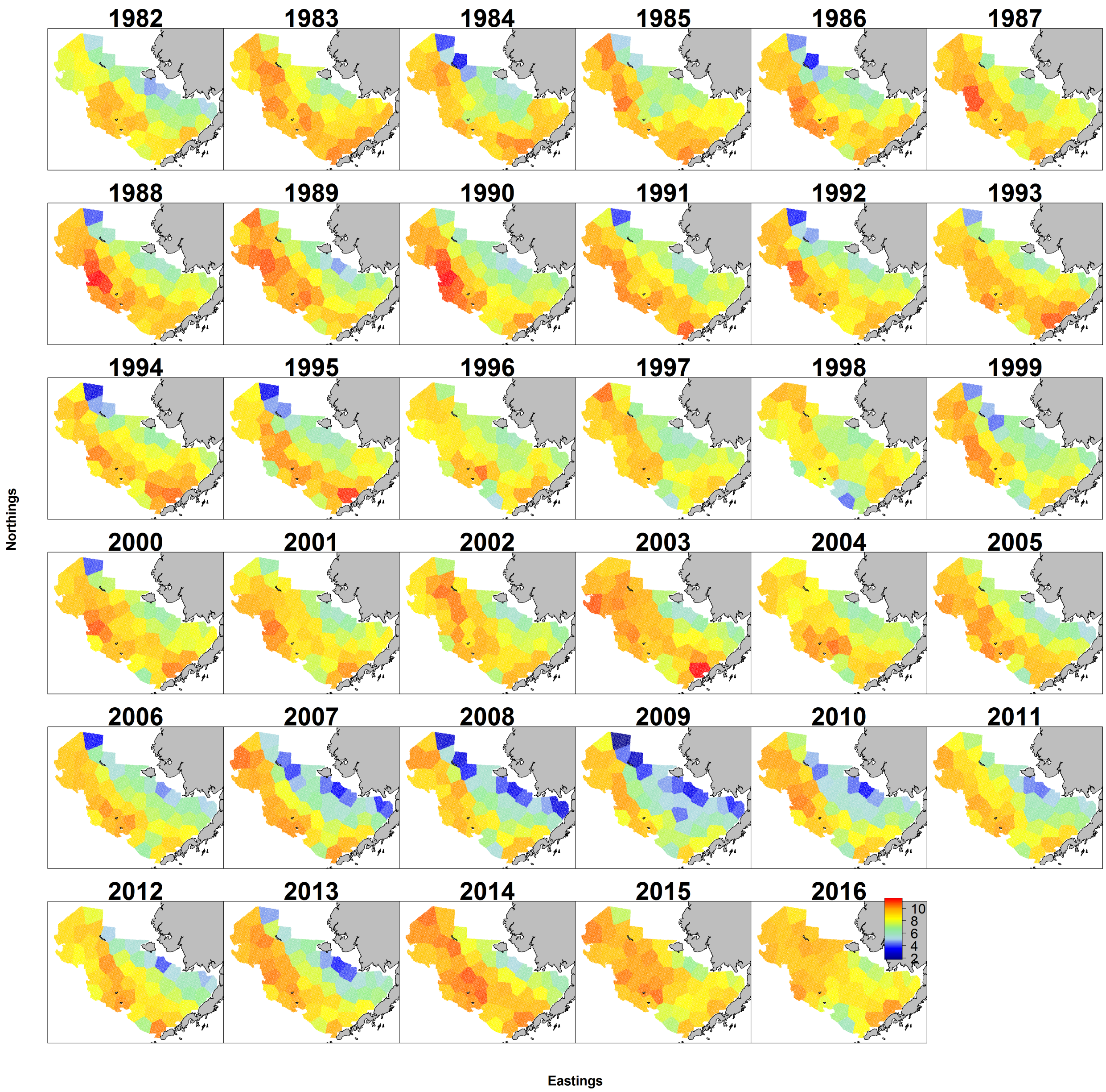

Figure 7: Density maps for each year for Alaska pollock

7.4 Index of abundance

The index of abundance is generally most useful for stock assessment models.

```
Index = SpatialDeltaGLMM::PlotIndex_Fn(DirName = DateFile,
    TmbData = TmbData, Sdreport = Opt[["SD"]], Year_Set = Year_Set,
    Years2Include = Years2Include, strata_names = strata.limits[,
        1], use_biascorr = TRUE, category_names = levels(Data_Geostat[,
        "spp"]))
pander::pandoc.table(Index$Table[, c("Category", "Year",
    "Estimate_metric_tons", "SD_mt")])
```

Category	Year	Estimate_metric_tons	SD_mt
Atheresthes_stomias	1982	64250	6689
Atheresthes_stomias	1983	97125	9268
Atheresthes_stomias	1984	144536	14117
Atheresthes_stomias	1985	159191	15511
Atheresthes_stomias	1986	192115	18334
Atheresthes_stomias	1987	282950	25800
Atheresthes_stomias	1988	286339	26542
Atheresthes_stomias	1989	329649	28784
Atheresthes_stomias	1990	371866	34531
Atheresthes_stomias	1991	263361	26139
Atheresthes_stomias	1992	291365	30620
Atheresthes_stomias	1993	413321	36091
Atheresthes_stomias	1994	456740	44292
Atheresthes_stomias	1995	391249	40099
Atheresthes_stomias	1996	486618	44812
Atheresthes_stomias	1997	387234	36274
Atheresthes_stomias	1998	306540	27454
Atheresthes_stomias	1999	185833	19306
Atheresthes_stomias	2000	277585	25497
Atheresthes_stomias	2001	342030	30674
Atheresthes_stomias	2002	276769	24311
Atheresthes_stomias	2003	497710	40161
Atheresthes_stomias	2004	514975	42567
Atheresthes_stomias	2005	693424	55143
Atheresthes_stomias	2006	559045	48919
Atheresthes_stomias	2007	446585	40009
Atheresthes_stomias	2008	477890	42434
Atheresthes_stomias	2009	362744	33808
Atheresthes_stomias	2010	520134	46941
Atheresthes_stomias	2011	498272	42279
Atheresthes_stomias	2012	365701	33920
Atheresthes_stomias	2013	380564	34985
Atheresthes_stomias	2014	469431	39297
Atheresthes_stomias	2015	414551	34492
Atheresthes_stomias	2016	521987	39352
Gadus_chalcogrammus	1982	2443408	211826
Gadus_chalcogrammus	1983	5862956	518710
Gadus_chalcogrammus	1984	4055674	354979
Gadus_chalcogrammus	1985	4608481	449565
Gadus_chalcogrammus	1986	4432944	401038

Category	Year	Estimate_metric_tons	SD_mt
Gadus_chalcogrammus	1987	4903689	455187
Gadus_chalcogrammus	1988	6549119	643655
Gadus_chalcogrammus	1989	5908851	517503
Gadus_chalcogrammus	1990	6551132	729069
Gadus_chalcogrammus	1991	4693389	420687
Gadus_chalcogrammus	1992	4243904	393317
Gadus_chalcogrammus	1993	5053489	412703
Gadus_chalcogrammus	1994	4564134	387784
Gadus_chalcogrammus	1995	4372436	393454
Gadus_chalcogrammus	1996	2800743	220332
Gadus_chalcogrammus	1997	3351579	292780
Gadus_chalcogrammus	1998	2449501	204356
Gadus_chalcogrammus	1999	3419438	334998
Gadus_chalcogrammus	2000	4638374	400684
Gadus_chalcogrammus	2001	4018529	353179
Gadus_chalcogrammus	2002	4421403	347734
Gadus_chalcogrammus	2003	7416789	663530
Gadus_chalcogrammus	2004	3691154	301271
Gadus_chalcogrammus	2005	4418703	372835
Gadus_chalcogrammus	2006	2903144	260096
Gadus_chalcogrammus	2007	3956889	405952
Gadus_chalcogrammus	2008	2759963	286115
Gadus_chalcogrammus	2009	2003801	226412
Gadus_chalcogrammus	2010	3351568	336491
Gadus_chalcogrammus	2011	2933201	265810
Gadus_chalcogrammus	2012	3271419	273255
Gadus_chalcogrammus	2013	4259455	384217
Gadus_chalcogrammus	2014	7317196	570098
Gadus_chalcogrammus	2015	6333121	485373
Gadus_chalcogrammus	2016	4589921	339788
Hippoglossoides_elassodon	1982	190158	15384
Hippoglossoides_elassodon	1983	243393	18185
Hippoglossoides_elassodon	1984	253018	20489
Hippoglossoides_elassodon	1985	246100	19248
Hippoglossoides_elassodon	1986	322161	25284
Hippoglossoides_elassodon	1987	370795	29876
Hippoglossoides_elassodon	1988	504259	39500
Hippoglossoides_elassodon	1989	470715	36459
Hippoglossoides_elassodon	1990	549522	43221
Hippoglossoides_elassodon	1991	515733	41335
Hippoglossoides_elassodon	1992	567638	44681
Hippoglossoides_elassodon	1993	578248	45517
Hippoglossoides_elassodon	1994	649203	51090
Hippoglossoides_elassodon	1995	553243	44921
Hippoglossoides_elassodon	1996	575392	45093
Hippoglossoides_elassodon	1997	711442	57595
Hippoglossoides_elassodon	1998	646766	53507
Hippoglossoides_elassodon	1999	354328	28829
Hippoglossoides_elassodon	2000	364290	27771
Hippoglossoides_elassodon	2001	466217	36078
Hippoglossoides_elassodon	2002	503612	38315
Hippoglossoides_elassodon	2003	469804	35325

Category	Year	Estimate_metric_tons	SD_mt
Hippoglossoides_elassodon	2004	573280	42320
Hippoglossoides_elassodon	2005	612223	45584
Hippoglossoides_elassodon	2006	572859	42731
Hippoglossoides_elassodon	2007	548477	42900
Hippoglossoides_elassodon	2008	488285	37764
Hippoglossoides_elassodon	2009	359244	30357
Hippoglossoides_elassodon	2010	407602	32437
Hippoglossoides_elassodon	2011	510629	43116
Hippoglossoides_elassodon	2012	346193	28211
Hippoglossoides_elassodon	2013	414889	36025
Hippoglossoides_elassodon	2014	469584	36041
Hippoglossoides_elassodon	2015	369205	27642
Hippoglossoides_elassodon	2016	427498	30173

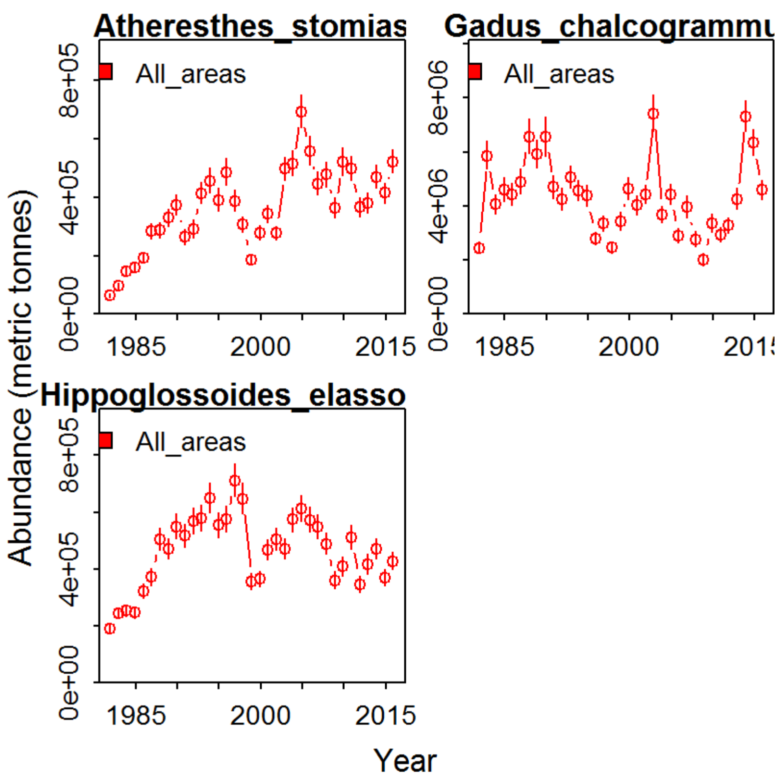

Figure 8: Index of abundance plus/minus 1 standard error

7.5 Center of gravity and range expansion/contraction

We can detect shifts in distribution or range expansion/contraction.

```
SpatialDeltaGLMM::Plot_range_shifts(Report = Report,
    TmbData = TmbData, Sdreport = Opt[["SD"]], Znames = colnames(TmbData$Z_xm),
    PlotDir = DateFile, category_names = levels(Data_Geostat[,
        "spp"]), Year_Set = Year_Set)
```

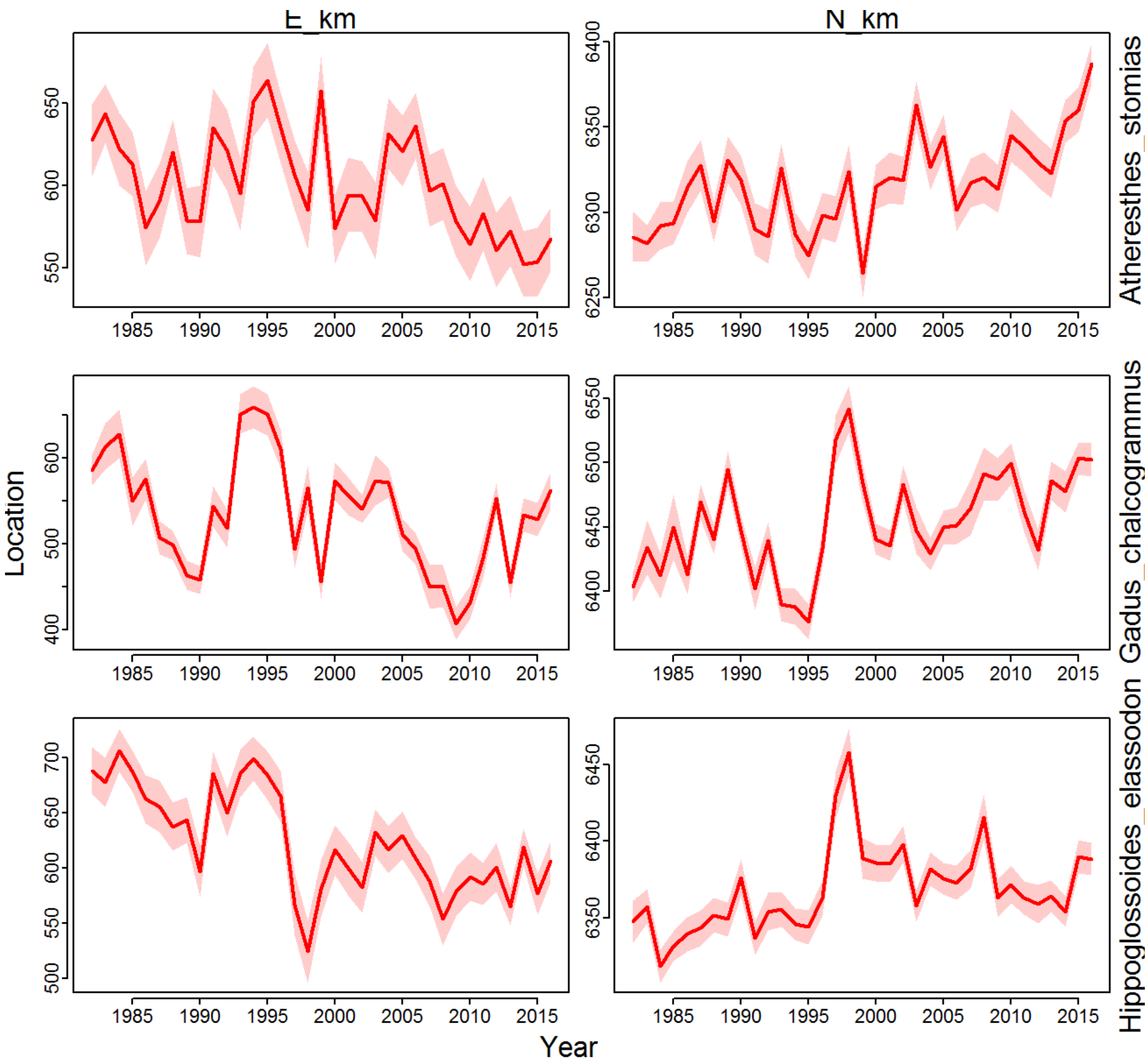

Figure 9: Center of gravity (COG) indicating shifts in distribution plus/minus 1 standard error

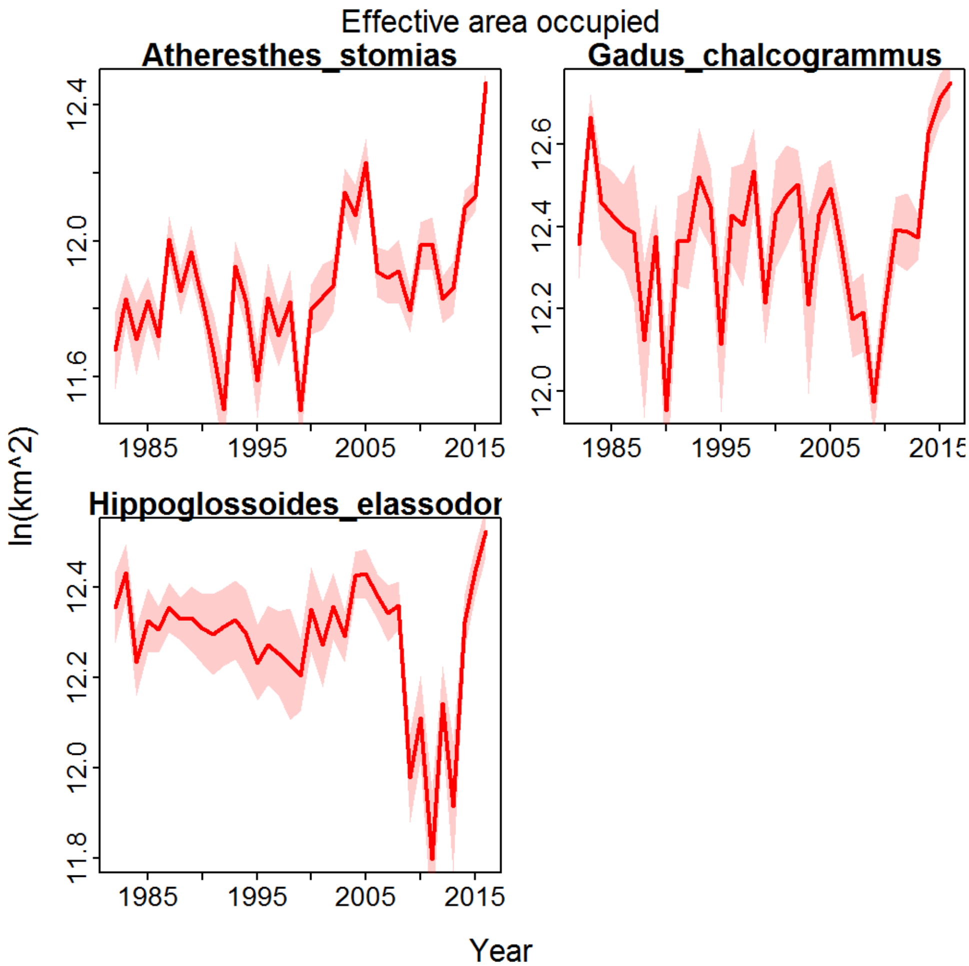

Figure 10: Effective area occupied indicating range expansion/contraction plus/minus 1 standard error

7.6 Plot overdispersion

We can also plot and inspect overdispersion (e.g., vessel effects, or tow-level fisher targetting), although this example doesn't include any.

```
Plot_Overdispersion(filename1 = paste0(DateDir, "Overdispersion"),
    filename2 = paste0(DateDir, "Overdispersion--panel"),
    Data = TmbData, ParHat = ParHat, Report = Report,
    ControlList1 = list(Width = 5, Height = 10, Res = 200,
        Units = "in"), ControlList2 = list(Width = TmbData$n_c,
        Height = TmbData$n_c, Res = 200, Units = "in"))
```

```
## No overdispersion for presence/absence component so not generating output...
```

```
## No overdispersion for positive catch rates component so not generating output...
```

7.7 Plot factors

Finally, we can inspect the factor-decomposition for community-level patterns. This generates many plots, only some of which are included in this tutorial document.

```
Plot_factors(Report = Report, ParHat = Obj$env$parList(),
    Data = TmbData, SD = Opt$SD, mapdetails_list = MapDetails_List,
    Year_Set = Year_Set, category_names = levels(DF[,
        "Sci"]), plotdir = DateFile)
```

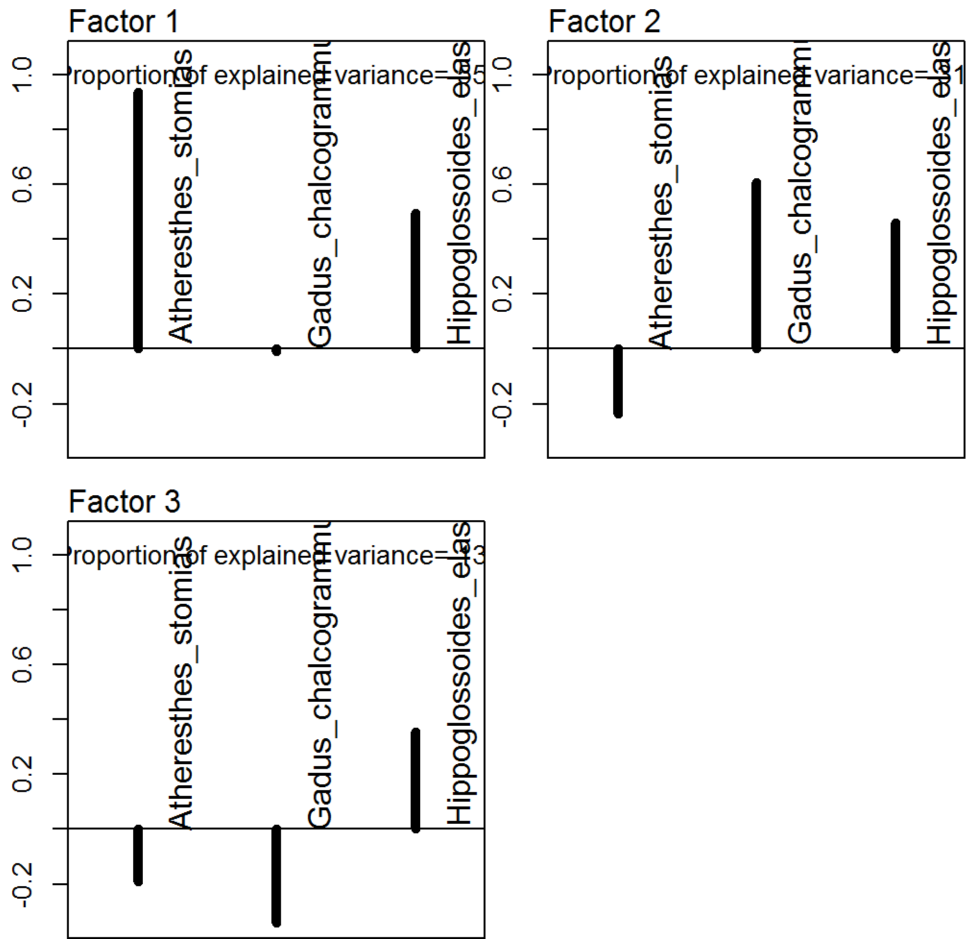

Figure 11: Factor loadings for spatio-temporal variation in encounter probability

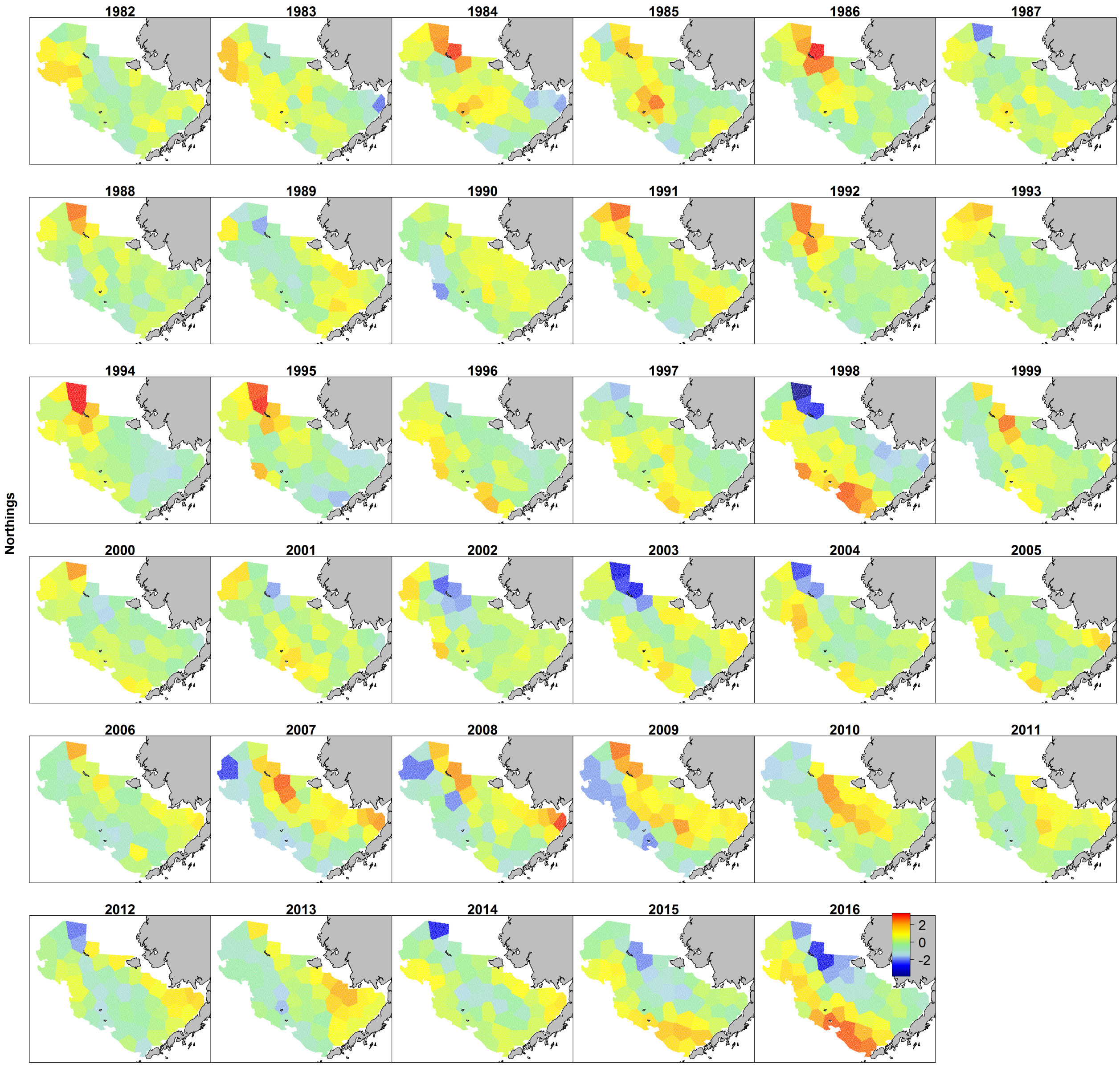

Figure 12: Factor maps for dominant (first) factor for spatio-temporal variation in positive catch rates