Code and data supplement to Grinde et al.

Collection of trend models applied to CONW

Connecticut Warbler population trends are partly dependent on the model and the underlying geographic stratifications.

To explore the among-model variation in our understanding of the species' population trends, we fit the data to two models, each at two different stratifications to estimate trends at different spatial-grains. The two models are a GAMYE and a first-difference model (). The two stratifications are: 1) coarse-grained stratification based on the intersection of political jurisdictions (states, provinces, territories) and Bird Conservation Regions, (BCRs) that we refer to in the code as the `"bbs_usgs"` (in the paper "BBS" stratification) and a finer-grained stratification based on a latitude by longitude 1-degree grid-cell that we refer to in the code as `"latlong"` (in the paper "1-degree cell" stratification)

Model fitting

We used the R package `bbsBayes2`.

```
library(bbsBayes2)
library(patchwork)
library(tidyverse)
library(sf)
library(ebirdst)
library(terra)
library(tidyterra)
source("functions/trend_colour_palette_apply.r")

models <- c("gamye","first_diff")
stratifications <- c("latlong","bbs_usgs")
species <- "Connecticut Warbler"
refit <- FALSE
```

```
if(refit){
for(mod in models){
  for(stratification in stratifications){
    min_n <- ifelse(stratification == "latlong",1,3)
    s <- stratify(by = stratification,
                  species = species)
    p <- prepare_data(s,
                      min_n_routes = min_n,
                      min_max_route_years = 2)
    ps <- prepare_spatial(p,strata_map = load_map(stratification))

    pm <- prepare_model(ps,
                  model = mod,
                  model_variant = "spatial")

    saveRDS(pm,paste0("data/",mod,"_",stratification,".rds"))

    m <- run_model(pm,
                   output_basename = paste0(mod,"_",stratification),
                   output_dir = "output",
                   iter_sampling = 3000)

    summ <- get_summary(m) %>%
      mutate(model = mod,
             stratification = stratification)
    saveRDS(summ,paste0("output/parameter_summary_",mod,"_",stratification,".rds"))

  }
}
}
```

We prepare the data setting the minimum number of routes to different values depending on the stratification used. For the coarse-grain stratification, we use the 3-route minimum cut-off to reflect the thresholds used by the CWS and USGS in their annual analyses. For the fine-grain stratification, we use a minimum of 1-route, to include the largest number of strata and to reflect the underlying design of the BBS. For all estimates, we also set a higher minimum for the number of non-zero observations on a given route to ensure that each included route and stratum has more reliable data for estimating change in abundance over time.

Then we estimate population trajectories and trends, comparing them across these two models and stratifications.

The similarities and differences in trends across the different models and stratifications reflect

conclusions and inferences about the species' status that may depend on the assumptions of each approach to modeling the trends or stratifying the data.

```
fits <- vector(mode = "list",4)
names(fits) <- paste0(rep(models,each = 2),"_",rep(stratifications,2))
summ_out <- NULL
indices_out <- NULL
trends_out <- NULL


for(mod in models){
  for(stratification in stratifications){

    tmp <- readRDS(paste0("output/",mod,"_",stratification,".rds"))

    # summ <- get_summary(tmp) %>%
    #   mutate(model = mod,
    #          stratification = stratification)

      summ <- readRDS(paste0("output/parameter_summary_",mod,"_",stratification,".rds"))
  summ_out <- bind_rows(summ_out,summ)
    fits[[paste0(mod,"_",stratification)]] <- tmp




## group latlong strata into original BBS strata
if(stratification == "latlong"){

    bbs_usgs <- load_map("bbs_usgs")%>%
      select(-area_sq_km) %>%
      rename(bbs_strata = strata_name,
             Country = country)


    strata_join <- load_map(stratification) %>%
    filter(strata_name %in% tmp$meta_strata$strata_name) %>%
    sf::st_join(.,bbs_usgs,
                largest = TRUE,
                left = TRUE) %>% # intersection
    sf::st_drop_geometry() %>%
    mutate(bbs_strata = ifelse(is.na(bbs_strata),"other",bbs_strata))
```

```
    # generate trajectories for original BBS strata
inds_tmp <- generate_indices(tmp,alternate_n = "n",
                                  regions = c("Country","bbs_strata"),
                                  regions_index = strata_join,
                                  hpdi = TRUE,
                                  start_year = 1970)
  saveRDS(inds_tmp,paste0("output/inds_comp_",mod,"_",stratification,".rds"))

  indices_tmp <- inds_tmp$indices %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "full")
  indices_out <- bind_rows(indices_out,
                           indices_tmp)

  tt_long <- generate_trends(inds_tmp,
                             min_year = 1970,
                             prob_decrease = c(0,30,50))
  tt_short <- generate_trends(inds_tmp,
                             min_year = 2012,
                             prob_decrease = c(0,30,50))
      tt_pre_90 <- generate_trends(inds_tmp,
                             min_year = 1970,
                             max_year = 1990,
                             prob_decrease = c(0,30,50))
        tt_post_90 <- generate_trends(inds_tmp,
                             min_year = 1990,
                             prob_decrease = c(0,30,50))
  tt_t <- tt_long$trends %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "full")
  trends_out <- bind_rows(trends_out,tt_t)

  tt_t <- tt_short$trends %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "full")
```

```
  trends_out <- bind_rows(trends_out,tt_t)

      tt_t <- tt_pre_90$trends %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "full")
  trends_out <- bind_rows(trends_out,tt_t)
      tt_t <- tt_post_90$trends %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "full")
  trends_out <- bind_rows(trends_out,tt_t)

# trajs <- plot_indices(inds_comp,
#                       add_observed_means = TRUE,
#                       add_number_routes = TRUE)
#

if(mod == "gamye"){
   inds_tmp <- generate_indices(tmp,alternate_n = "n_smooth",
                                regions = c("Country","bbs_strata"),
                                regions_index = strata_join,
                                hpdi = TRUE,
                                start_year = 1970)
  saveRDS(indices_tmp,paste0("output/inds_comp_smooth_",mod,"_",stratification,".rds"))

  indices_tmp <- inds_tmp$indices %>%
    mutate(model = mod,
           stratification = stratification,
           summary_type = "composite",
           type = "smooth")
  indices_out <- bind_rows(indices_out,
                       indices_tmp)

  tt_long <- generate_trends(inds_tmp,
                             min_year = 1970,
                             prob_decrease = c(0,30,50))
  tt_short <- generate_trends(inds_tmp,
                             min_year = 2012,
```

```
                                prob_decrease = c(0,30,50))
            tt_pre_90 <- generate_trends(inds_tmp,
                                min_year = 1970,
                                max_year = 1990,
                                prob_decrease = c(0,30,50))
            tt_post_90 <- generate_trends(inds_tmp,
                                min_year = 1990,
                                prob_decrease = c(0,30,50))
    tt_t <- tt_long$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "composite",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

    tt_t <- tt_short$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "composite",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

        tt_t <- tt_pre_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "composite",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

        tt_t <- tt_post_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "composite",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

  }

inds_tmp <- generate_indices(tmp,
                          hpdi = TRUE,
                                    start_year = 1970,
```

```
                        regions = c("continent","stratum"))

indices_tmp <- inds_tmp$indices %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "full")
    indices_out <- bind_rows(indices_out,
                          indices_tmp)

    tt_long <- generate_trends(inds_tmp,
                               min_year = 1970,
                               prob_decrease = c(0,30,50))
    tt_short <- generate_trends(inds_tmp,
                               min_year = 2012,
                               prob_decrease = c(0,30,50))
                tt_pre_90 <- generate_trends(inds_tmp,
                               min_year = 1970,
                               max_year = 1990,
                               prob_decrease = c(0,30,50))
            tt_post_90 <- generate_trends(inds_tmp,
                               min_year = 1990,
                               prob_decrease = c(0,30,50))

    tt_t <- tt_long$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "full")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_short$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "full")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_pre_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "full")
```

```
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_post_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "full")
    trends_out <- bind_rows(trends_out,tt_t)

    saveRDS(inds_tmp,paste0("output/indices_",mod,"_",stratification,".rds"))

if(mod == "gamye"){
inds_tmp <- generate_indices(tmp,alternate_n = "n_smooth",
                         hpdi = TRUE,
                                   start_year = 1970,
                         regions = c("continent","stratum"))
saveRDS(inds_tmp,paste0("output/indices_smooth_",mod,"_",stratification,".rds"))

indices_tmp <- inds_tmp$indices %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "smooth")
    indices_out <- bind_rows(indices_out,
                          indices_tmp)

    tt_long <- generate_trends(inds_tmp,
                               min_year = 1970,
                               prob_decrease = c(0,30,50))
    tt_short <- generate_trends(inds_tmp,
                               min_year = 2012,
                               prob_decrease = c(0,30,50))
                    tt_pre_90 <- generate_trends(inds_tmp,
                               min_year = 1970,
                               max_year = 1990,
                               prob_decrease = c(0,30,50))
            tt_post_90 <- generate_trends(inds_tmp,
                               min_year = 1990,
                               prob_decrease = c(0,30,50))

    tt_t <- tt_long$trends %>%
      mutate(model = mod,
```

```
            stratification = stratification,
            summary_type = "simple",
            type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

    tt_t <- tt_short$trends %>%
      mutate(model = mod,
            stratification = stratification,
            summary_type = "simple",
            type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_pre_90$trends %>%
      mutate(model = mod,
            stratification = stratification,
            summary_type = "simple",
            type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_post_90$trends %>%
      mutate(model = mod,
            stratification = stratification,
            summary_type = "simple",
            type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)


}


}else{
  inds_tmp <- generate_indices(tmp,
                          hpdi = TRUE,
                                    start_year = 1970,
                          regions = c("continent","country","stratum"))
  indices_tmp <- inds_tmp$indices %>%
      mutate(model = mod,
            stratification = stratification,
            summary_type = "simple",
            type = "full")
    indices_out <- bind_rows(indices_out,
                           indices_tmp)
```

```
tt_long <- generate_trends(inds_tmp,
                           min_year = 1970,
                           prob_decrease = c(0,30,50))
tt_short <- generate_trends(inds_tmp,
                           min_year = 2012,
                           prob_decrease = c(0,30,50))

                    tt_pre_90 <- generate_trends(inds_tmp,
                           min_year = 1970,
                           max_year = 1990,
                           prob_decrease = c(0,30,50))
        tt_post_90 <- generate_trends(inds_tmp,
                           min_year = 1990,
                           prob_decrease = c(0,30,50))


tt_t <- tt_long$trends %>%
  mutate(model = mod,
         stratification = stratification,
         summary_type = "simple",
         type = "full")
trends_out <- bind_rows(trends_out,tt_t)

tt_t <- tt_short$trends %>%
  mutate(model = mod,
         stratification = stratification,
         summary_type = "simple",
         type = "full")
trends_out <- bind_rows(trends_out,tt_t)
    tt_t <- tt_pre_90$trends %>%
  mutate(model = mod,
         stratification = stratification,
         summary_type = "simple",
         type = "full")
trends_out <- bind_rows(trends_out,tt_t)
    tt_t <- tt_post_90$trends %>%
  mutate(model = mod,
         stratification = stratification,
         summary_type = "simple",
         type = "full")
trends_out <- bind_rows(trends_out,tt_t)
```

```
    saveRDS(inds_tmp,paste0("output/indices_",mod,"_",stratification,".rds"))

if(mod == "gamye"){
inds_tmp <- generate_indices(tmp,alternate_n = "n_smooth",
                         hpdi = TRUE,
                                    start_year = 1970,
                         regions = c("continent","country","stratum"))

indices_tmp <- inds_tmp$indices %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "smooth")
    indices_out <- bind_rows(indices_out,
                          indices_tmp)

    tt_long <- generate_trends(inds_tmp,
                               min_year = 1970,
                               prob_decrease = c(0,30,50))
    tt_short <- generate_trends(inds_tmp,
                               min_year = 2012,
                               prob_decrease = c(0,30,50))
            tt_pre_90 <- generate_trends(inds_tmp,
                               min_year = 1970,
                               max_year = 1990,
                               prob_decrease = c(0,30,50))
            tt_post_90 <- generate_trends(inds_tmp,
                               min_year = 1990,
                               prob_decrease = c(0,30,50))

    tt_t <- tt_long$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)

    tt_t <- tt_short$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
```

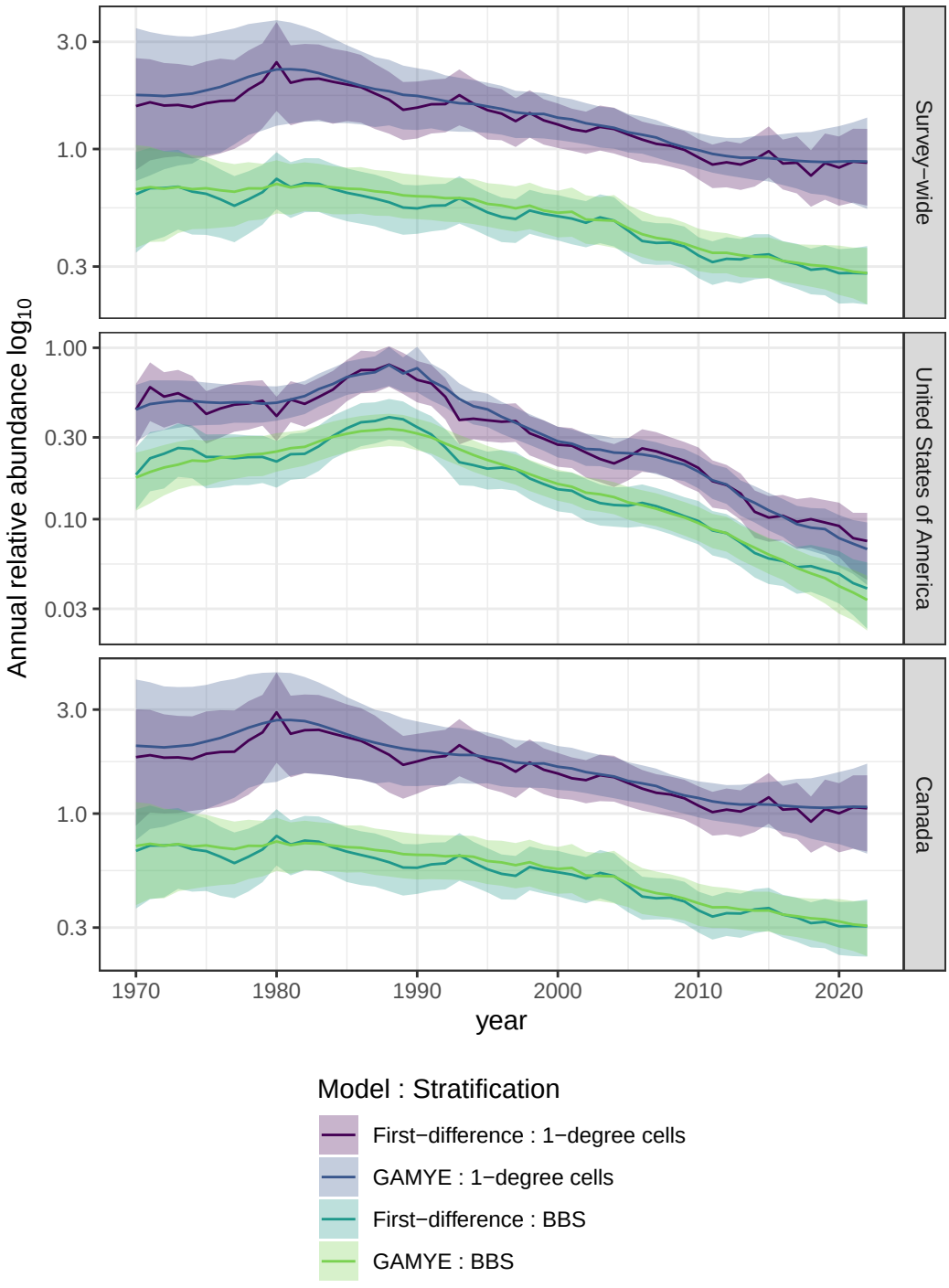
```
            type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_pre_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)
        tt_t <- tt_post_90$trends %>%
      mutate(model = mod,
             stratification = stratification,
             summary_type = "simple",
             type = "smooth")
    trends_out <- bind_rows(trends_out,tt_t)


saveRDS(inds_tmp,paste0("output/indices_smooth_",mod,"_",stratification,".rds"))

}

}



  }
  }

saveRDS(trends_out,"output/trends_out.rds")
saveRDS(summ_out,"output/summ_out.rds")
saveRDS(indices_out,"output/indices_out.rds")
```

Survey-wide and national trajectories

The broad-scale status assessments are generally similar across the different models and stratifications, but there is some variation particularly for recent trends in the Canadian portion of the species' range.

```
trends_out <- readRDS("output/trends_out.rds")
summ_out <- readRDS("output/summ_out.rds")
indices_out <- readRDS("output/indices_out.rds")
```

```r
model_names <- data.frame(model = c("first_diff","gamye"),
                          Model = c("First-difference","GAMYE"))
stratification_names <- data.frame(stratification = c("bbs_usgs","latlong"),
                                   Stratification = c("BBS","1-degree cells"))
broad_trajectories <- indices_out %>%
  filter(region_type %in% c("continent","country","Country"),
         type == "full") %>%
  mutate(Region = ifelse(region == "continent","Survey-wide",region),
         Region = factor(Region,levels = c("Survey-wide",
                                           "United States of America",
                                           "Canada"))) %>%
  inner_join(.,model_names,by = "model") %>%
  inner_join(.,stratification_names,by = "stratification")

trajs <- ggplot(data = broad_trajectories,
                aes(x = year,y = index))+
  geom_ribbon(aes(ymin = index_q_0.05,ymax = index_q_0.95,
                  fill = interaction(Model,Stratification, sep = " : ")), alpha = 0.3)+
  geom_line(aes(colour = interaction(Model,Stratification, sep = " : ")))+
  scale_colour_viridis_d(aesthetics = c("fill","colour"),
                         end = 0.8)+
  scale_y_continuous(trans = "log10")+
  facet_grid(rows = vars(Region),
             scales = "free")+
  guides(fill = guide_legend(title = "Model : Stratification"),
         colour = guide_legend(title = "Model : Stratification"))+
  ylab(expression(Annual~relative~abundance~log[10]))+
  theme_bw()+
  theme(legend.position = "bottom",
        legend.direction = "vertical")

print(trajs)
```

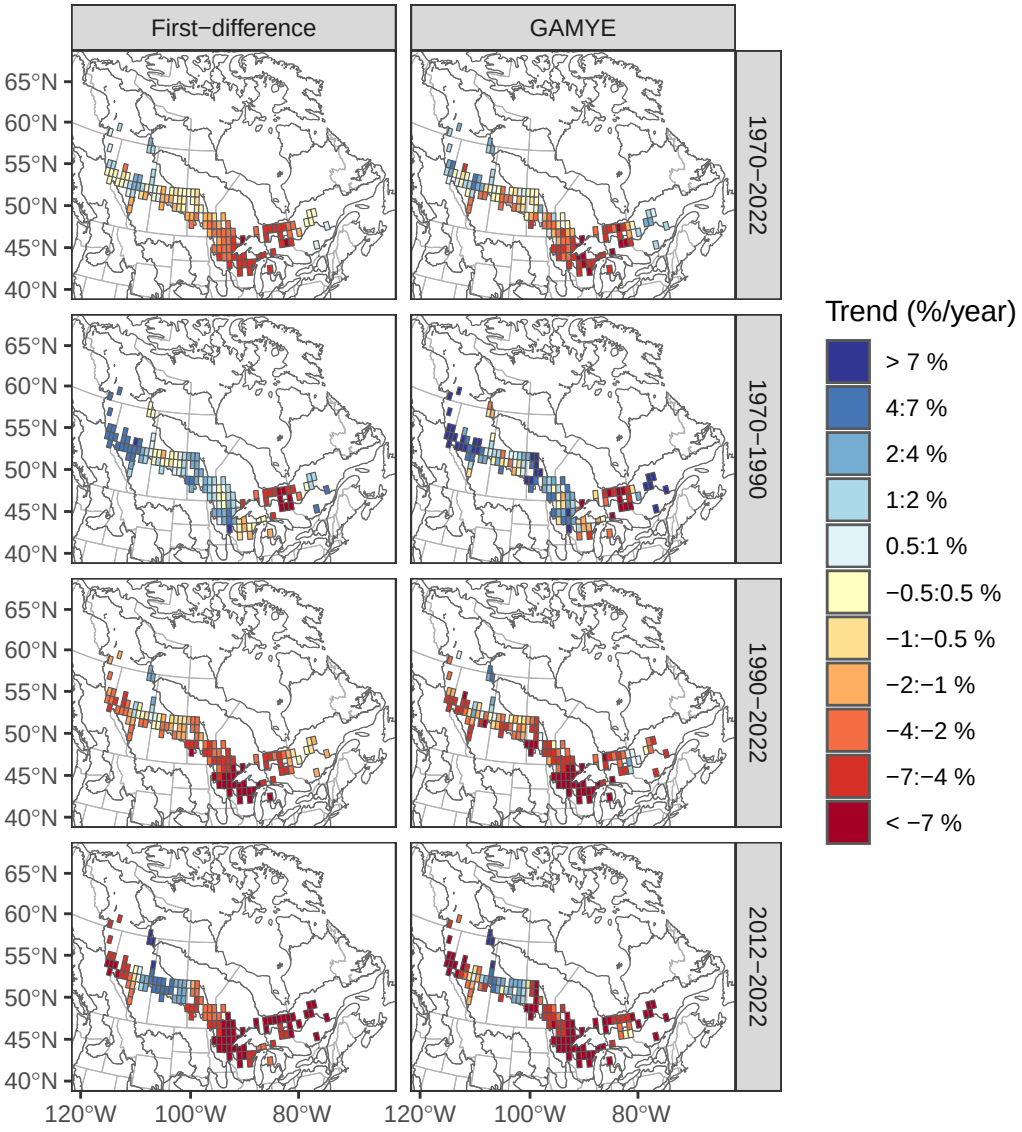

Survey−wide
United States of America
Canada
Annual relative abundance log10
3.0
1.0
0.3
1.00
0.30
0.10
0.03
1970
1980
1990
2000
2010
2020
year
Model : Stratification
First−difference : 1−degree cells
GAMYE : 1−degree cells
First−difference : BBS
GAMYE : BBS

```
pdf
  2
```

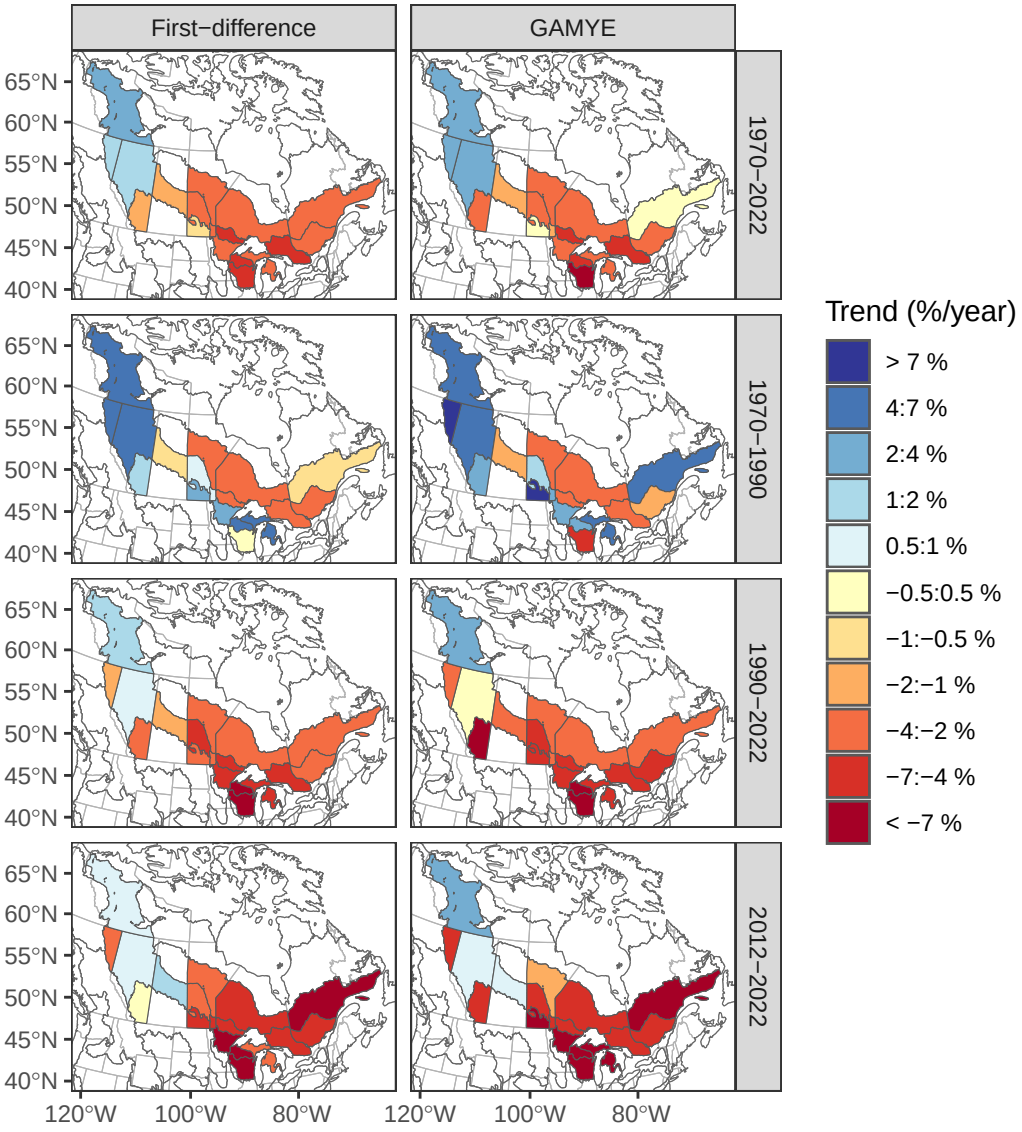
Mapping the spatial pattern in trends.

```
strata_trends <- trends_out %>%
  filter(region_type == "stratum",
         (model == "gamye" & type == "smooth")|
         (model == "first_diff" & type == "full")) %>%
  mutate(strata_name = region,
         trend_se = width_of_95_percent_credible_interval/(1.96*2),
         span = paste(start_year,end_year,sep = "-"),
         nyears = end_year-start_year,
         span = factor(span,levels = c("1970-2022","1970-1990",
                                       "1990-2022","2012-2022"),
                       ordered = TRUE)) %>%
  inner_join(.,model_names,by = "model") %>%
  inner_join(.,stratification_names,by = "stratification")

tcols <- trend_colour_breaks(strata_trends)
pal <- tcols$pal
strata_trends <- strata_trends %>%
  mutate(trends_map = tcols[["trends_plot_cats"]])

latlong_map <- load_map("latlong") %>%
  inner_join(.,strata_trends,
             by = "strata_name")


bbs_map <- load_map("bbs_usgs") %>%
  inner_join(.,strata_trends,
             by = "strata_name")

bbox <- sf::st_bbox(bbs_map)
xlm <- bbox[c("xmin","xmax")]
ylm <- bbox[c("ymin","ymax")]

base_map1 <- load_map("prov_state")
base_map2 <- load_map("bcr")

latlong_trend <- ggplot()+
  geom_sf(data = base_map1,
          fill = NA,
          colour = grey(0.7))+
```

```
  geom_sf(data = base_map2,
          fill = NA,
          colour = grey(0.4))+
  geom_sf(data = latlong_map,
          aes(fill = trends_map))+
  coord_sf(xlim = xlm,ylim = ylm)+
  scale_fill_manual(values = pal)+
  guides(fill = guide_legend(reverse = TRUE,
                             title = "Trend (%/year)"))+
  theme_bw()+
  theme(panel.grid.major = element_blank(),
        panel.grid.minor = element_blank())+
  facet_grid(cols = vars(Model),
             rows = vars(span))

print(latlong_trend)
```

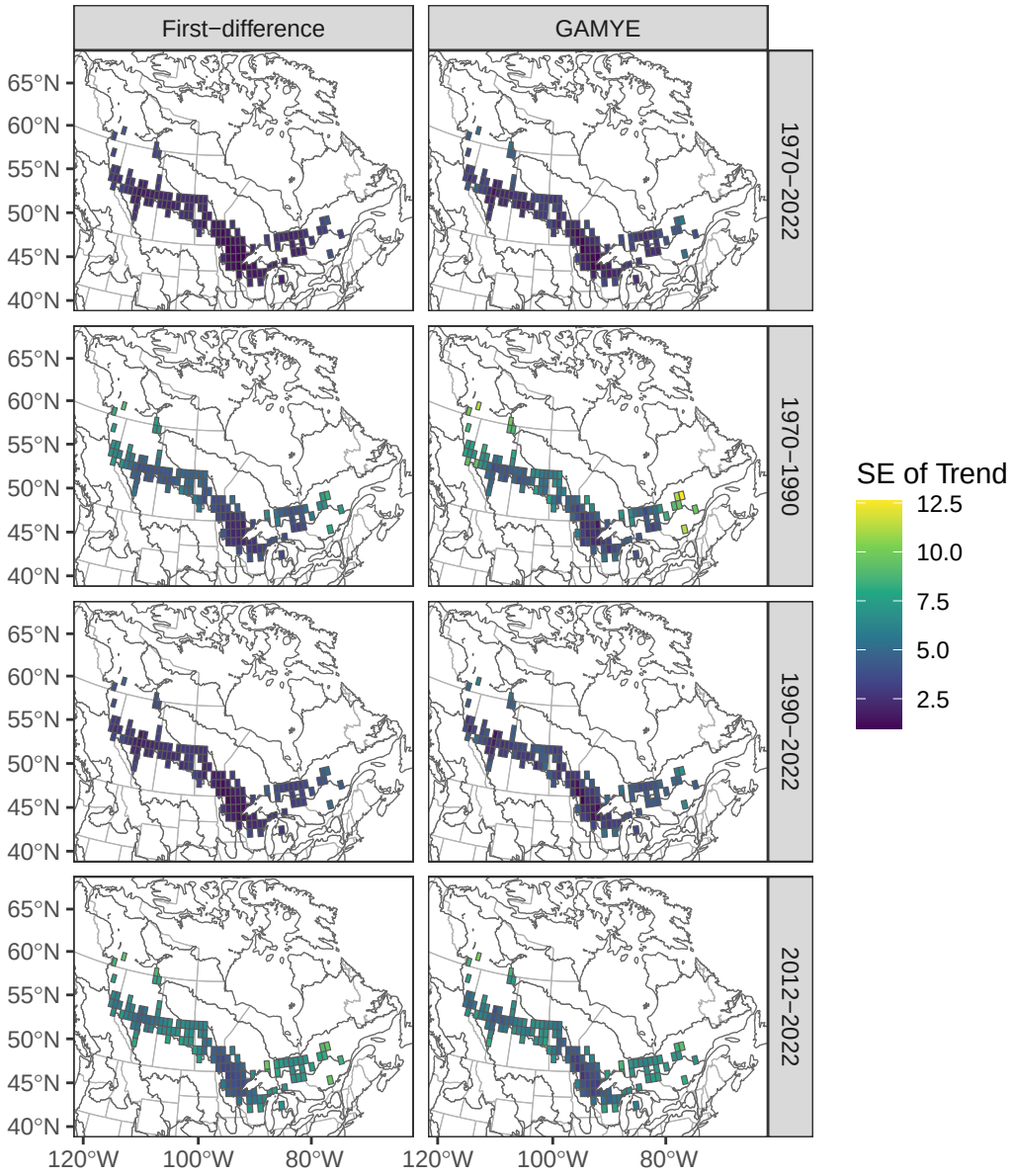

First−difference
GAMYE
1970−2022
1970−1990
1990−2022
2012−2022
65°N
60°N
55°N
50°N
45°N
40°N
120°W
100°W
80°W
Trend (%/year)
> 7 %
4:7 %
2:4 %
1:2 %
0.5:1 %
−0.5:0.5 %
−1:−0.5 %
−2:−1 %
−4:−2 %
−7:−4 %
< −7 %

```r
bbs_trend <- ggplot()+
  geom_sf(data = base_map1,
          fill = NA,
          colour = grey(0.7))+
  geom_sf(data = base_map2,
          fill = NA,
          colour = grey(0.4))+
  geom_sf(data = bbs_map,
          aes(fill = trends_map))+
  coord_sf(xlim = xlm,ylim = ylm)+
  scale_fill_manual(values = pal)+
  guides(fill = guide_legend(reverse = TRUE,
                             title = "Trend (%/year)"))+
  theme_bw()+
    theme(panel.grid.major = element_blank(),
        panel.grid.minor = element_blank())+
  facet_grid(cols = vars(Model),
             rows = vars(span))

print(bbs_trend)
```

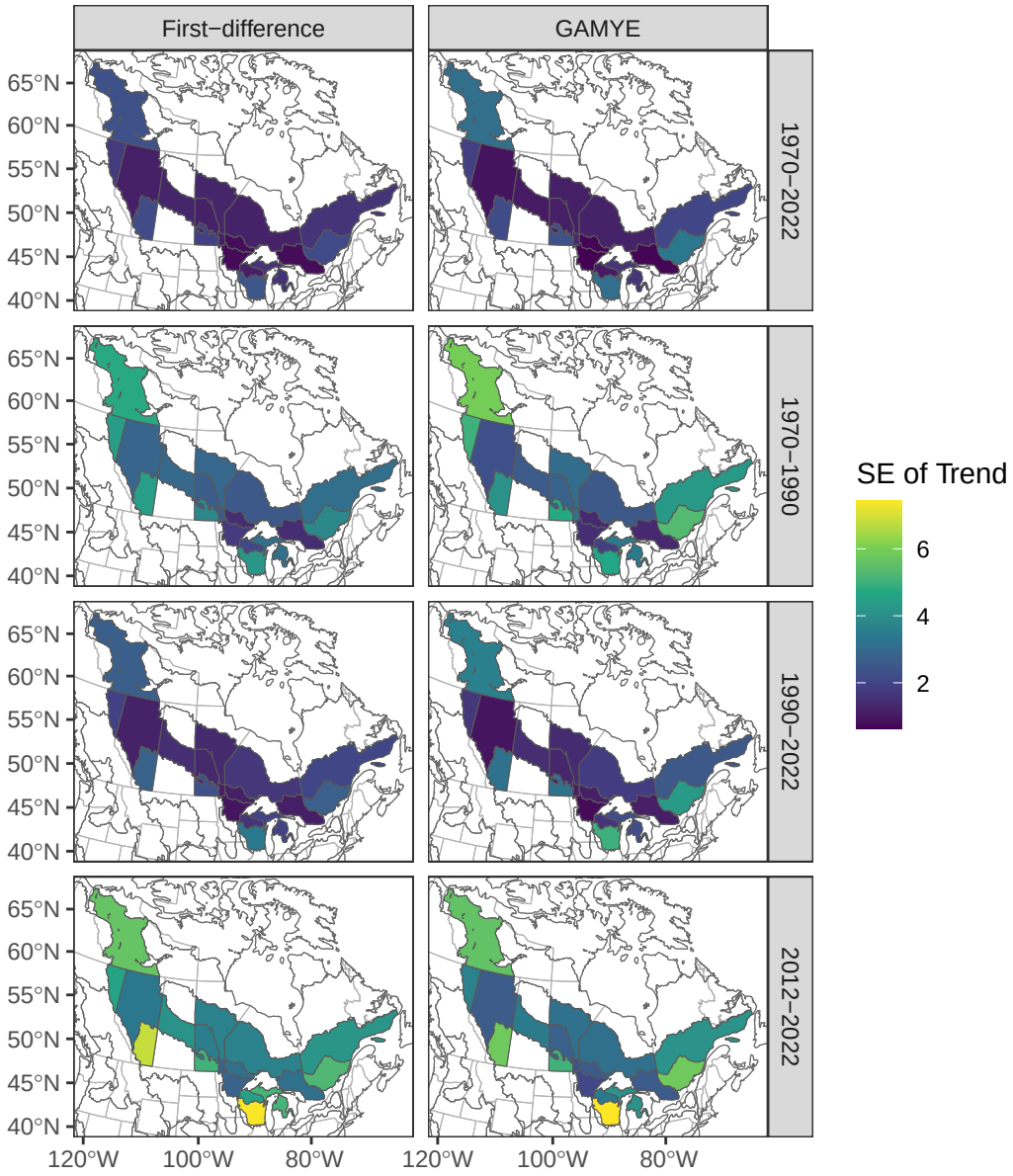


The precision of the trends varies by model, region, and stratification.

```r
latlong_trend_se <- ggplot()+
  geom_sf(data = base_map1,
          fill = NA,
          colour = grey(0.7))+
  geom_sf(data = base_map2,
          fill = NA,
          colour = grey(0.4))+
  geom_sf(data = latlong_map,
          aes(fill = trend_se))+
  coord_sf(xlim = xlm,ylim = ylm)+
  scale_fill_viridis_c()+
  guides(fill = guide_colorbar(title = "SE of Trend"))+
  theme_bw()+
    theme(panel.grid.major = element_blank(),
        panel.grid.minor = element_blank())+
  facet_grid(cols = vars(Model),
             rows = vars(span))

latlong_trend_se
```


First−difference
GAMYE
1970–2022
1970–1990
1990–2022
2012–2022
65°N
60°N
55°N
50°N
45°N
40°N
120°W
100°W
80°W
SE of Trend
12.5
10.0
7.5
5.0
2.5

```r
bbs_trend_se <- ggplot()+
  geom_sf(data = base_map1,
          fill = NA,
          colour = grey(0.7))+
  geom_sf(data = base_map2,
          fill = NA,
          colour = grey(0.4))+
  geom_sf(data = bbs_map,
          aes(fill = trend_se))+
  coord_sf(xlim = xlm,ylim = ylm)+
  scale_fill_viridis_c()+
  guides(fill = guide_colorbar(title = "SE of Trend"))+
  theme_bw()+
    theme(panel.grid.major = element_blank(),
        panel.grid.minor = element_blank())+
  facet_grid(cols = vars(Model),
             rows = vars(span))

bbs_trend_se
```



We can assess the spatial coverage of the BBS by overlaying the 1-degree grid cells on the

eBird breeding season proportion of the population map.

```
species <- "Connecticut Warbler"

ebirdst::ebirdst_download_status(species)
abd_seasonal_percent <- load_raster(species = species,
                                    product = "proportion-population",
                                  period = "seasonal", #metric = "mean",
                                  resolution = "27km") #3km high resolution
abd_breeding_percent <- clamp(abd_seasonal_percent$breeding*100,
                              lower = 0.0001, values = FALSE)

prov_state <- load_map("prov_state")
bcr <- load_map("bcr")

ebird_breed <- ggplot()+
    geom_sf(data = base_map1,
          fill = NA,
          colour = "white")+
  geom_spatraster(data = abd_breeding_percent,
                  maxcell = 1e6)+
  geom_sf(data = prov_state,
          fill = NA,
          colour = grey(0.8))+
    geom_sf(data = bcr,
          fill = NA,
          colour = grey(0.6))+
    geom_sf(data = latlong_map,
          fill = NA,
          colour = viridisLite::mako(1, begin = 0.3),#grey(0.7),
          linewidth = 0.15)+
  coord_sf(xlim = xlm,ylim = ylm)+
  scale_fill_viridis_c(na.value = "white", direction = -1, end = 0.98)+
  guides(fill = guide_colourbar(reverse = FALSE,
                                title = "Percent of\nbreeding\npopulation"))+
  theme_bw()
```

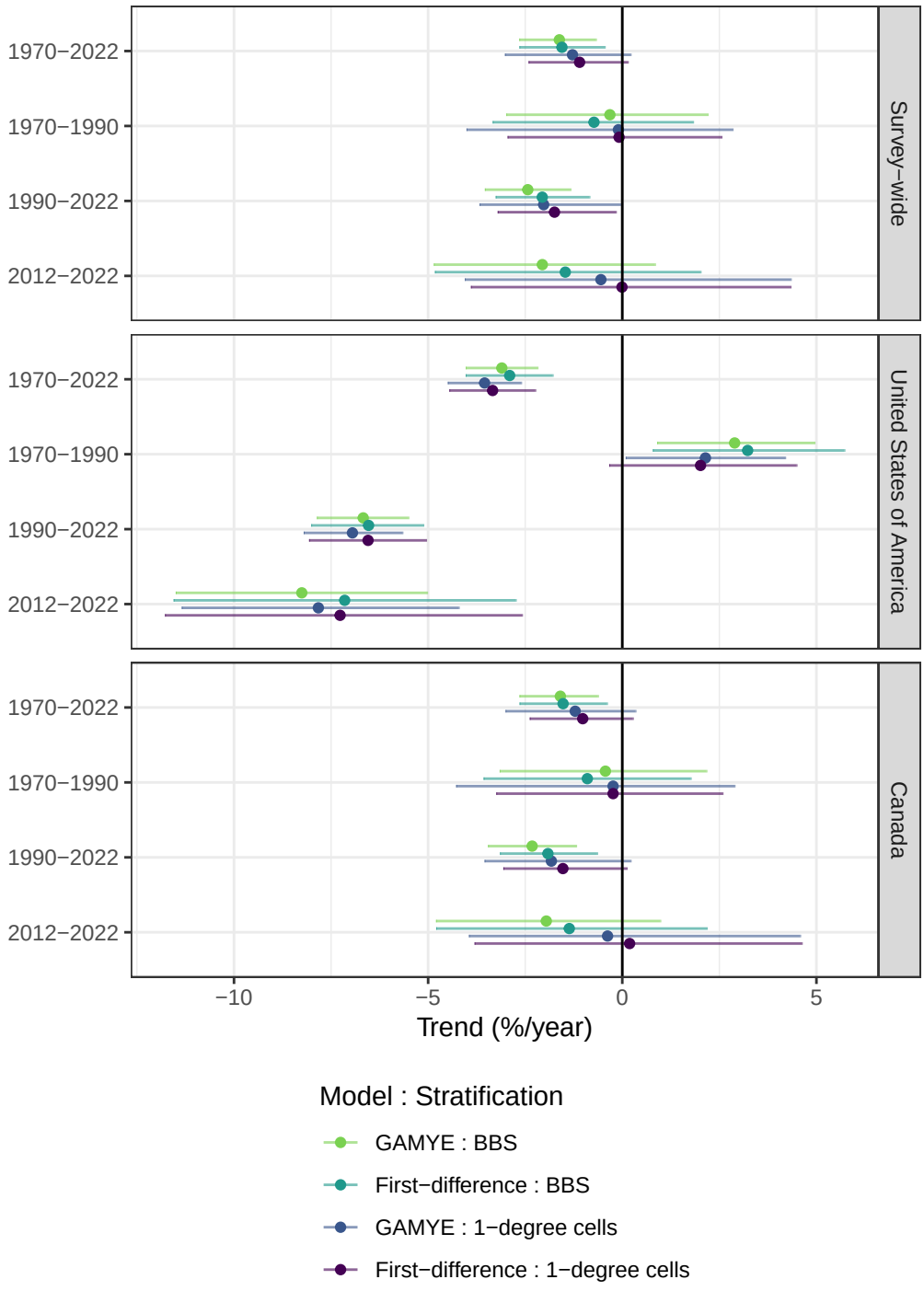
```
pdf("figures/eBird_breeding_distribution.pdf",
    width = 6,
    height = 4.5)
print(ebird_breed)
```

```
dev.off()


pdf("figures/trend_maps_latlong.pdf",
    width = 6,
    height = 10)
latlong_trend
dev.off()

pdf("figures/trend_se_maps_latlong.pdf",
    width = 6,
    height = 10)
latlong_trend_se
dev.off()



pdf("figures/trend_maps_bbs.pdf",
    width = 6,
    height = 10)
bbs_trend
dev.off()

pdf("figures/trend_se_maps_bbs.pdf",
    width = 6,
    height = 10)
bbs_trend_se
dev.off()
```

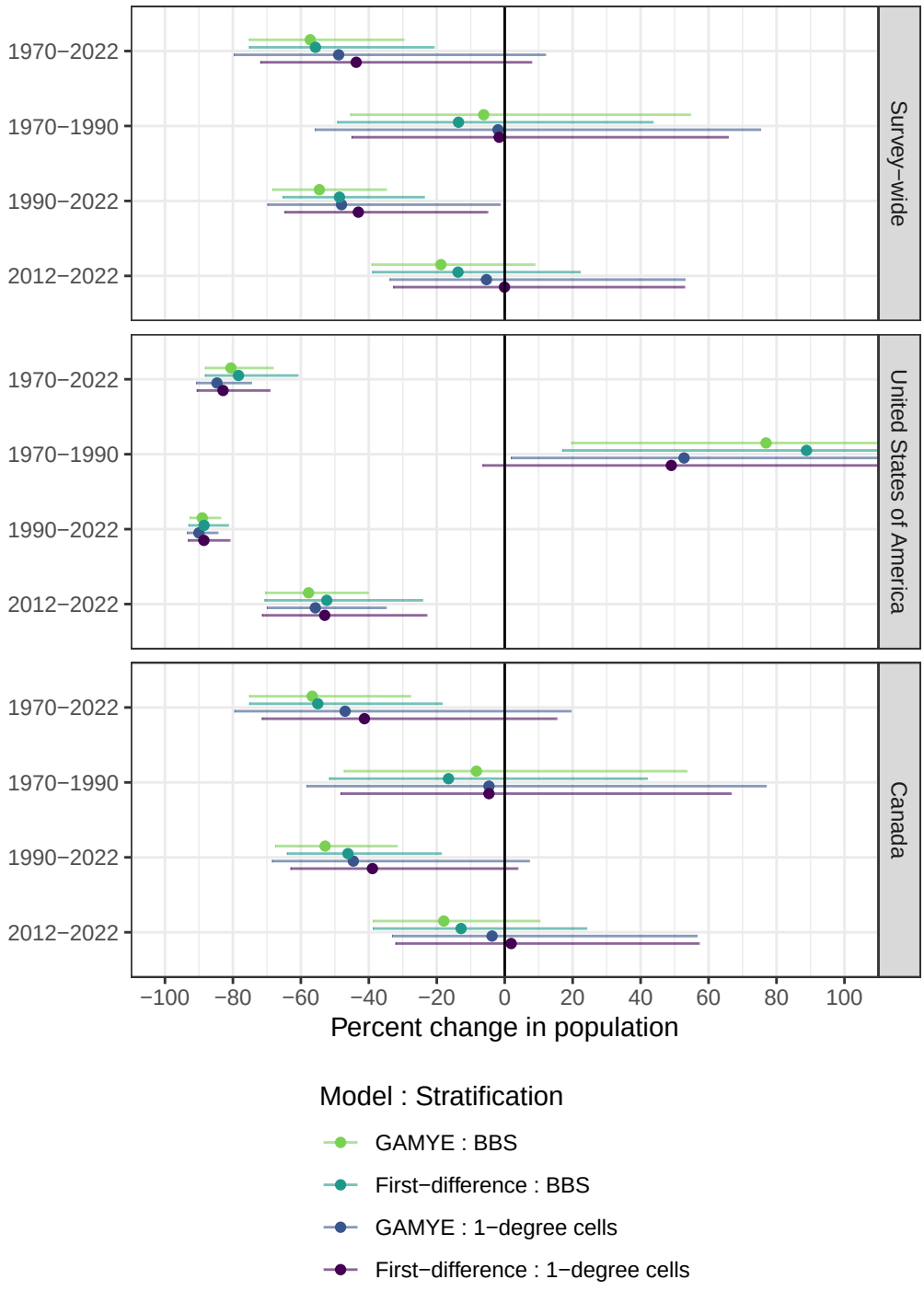
Plotting the trend estimates.

```
highlevel_trends <- trends_out %>%
  filter(region_type %in% c("continent","country","Country"),
         (model == "gamye" & type == "smooth")|
         (model == "first_diff" & type == "full")) %>%
  mutate(Region = ifelse(region == "continent","Survey-wide",region),
         Region = factor(Region,levels = c("Survey-wide",
                                           "United States of America",
                                           "Canada"))) %>%
  inner_join(.,model_names,by = "model") %>%
  inner_join(.,stratification_names,by = "stratification")%>%
```

```
  mutate(trend_se = width_of_95_percent_credible_interval/(1.96*2),
         span = paste(start_year,end_year,sep = "-"),
         nyears = end_year-start_year,
         span = factor(span,levels = rev(c("1970-2022","1970-1990",
                                           "1990-2022","2012-2022")),
                       ordered = TRUE))



trend_plot <- ggplot(data = highlevel_trends,
                     aes(x = span,y = trend,
                         group = interaction(Model,Stratification, sep = " : ")))+
  geom_errorbar(aes(ymin = trend_q_0.05,ymax = trend_q_0.95,
                    colour = interaction(Model,Stratification, sep = " : ")), alpha = 0.6,
                width = 0,
                position = position_dodge(width = 0.4))+
  geom_point(aes(colour = interaction(Model,Stratification, sep = " : ")),
                position = position_dodge(width = 0.4))+
  geom_hline(yintercept = 0)+
  scale_colour_viridis_d(aesthetics = c("fill","colour"),
                         end = 0.8)+
  facet_grid(rows = vars(Region),
             scales = "fixed")+
  guides(colour = guide_legend(title = "Model : Stratification",
                               reverse = TRUE))+
  ylab("Trend (%/year)")+
  xlab("")+
  theme_bw()+
  theme(legend.position = "bottom",
        legend.direction = "vertical")+
  coord_flip()



trend_plot
```


1970–2022
1970–1990
1990–2022
2012–2022
Survey–wide
United States of America
Canada
−10
−5
0
5
Trend (%/year)
Model : Stratification
GAMYE : BBS
First−difference : BBS
GAMYE : 1−degree cells
First−difference : 1−degree cells

```r
change_plot <- ggplot(data = highlevel_trends,
                      aes(x = span,y = percent_change,
                          group = interaction(Model,Stratification, sep = " : ")))+
  geom_errorbar(aes(ymin = percent_change_q_0.05,ymax = percent_change_q_0.95,
                    colour = interaction(Model,Stratification, sep = " : ")), alpha = 0.6,
                width = 0,
                position = position_dodge(width = 0.4))+
  geom_point(aes(colour = interaction(Model,Stratification, sep = " : ")),
                position = position_dodge(width = 0.4))+
  geom_hline(yintercept = 0)+
  scale_colour_viridis_d(aesthetics = c("fill","colour"),
                         end = 0.8)+
  #coord_cartesian()+
  scale_y_continuous(breaks = c(-100,-80,-60,-40,-20,0,20,40,60,80,100))+
  facet_grid(rows = vars(Region),
             scales = "fixed")+
  guides(colour = guide_legend(title = "Model : Stratification",
                               reverse = TRUE))+
  ylab("Percent change in population")+
  xlab("")+
  theme_bw()+
  theme(legend.position = "bottom",
        legend.direction = "vertical")+
  coord_flip(ylim = c(-100,100))



change_plot
```


1970–2022
1970–1990
1990–2022
2012–2022
Survey–wide
United States of America
Canada
−100
−80
−60
−40
−20
0
20
40
60
80
100
Percent change in population
Model : Stratification
GAMYE : BBS
First−difference : BBS
GAMYE : 1−degree cells
First−difference : 1−degree cells

```
pdf("figures/trends_high_level.pdf",
    width = 6,
    height = 10)
trend_plot
dev.off()

write_csv(highlevel_trends,"High_level_trends.cv")

pdf("figures/change_high_level.pdf",
    width = 6,
    height = 10)
change_plot
dev.off()
```

```
prob_decl_30_50 <- highlevel_trends %>%
  filter(start_year == 2012) %>%
  group_by(region, stratification) %>%
  summarise(min_prob_30 = min(prob_decrease_30_percent),
            max_prob_30 = max(prob_decrease_30_percent),
            min_prob_50 = min(prob_decrease_50_percent),
            max_prob_50 = max(prob_decrease_50_percent),
            min_p_change = min(percent_change),
            max_p_change = max(percent_change))
```