Spatial Data Basics

Contents

Coordinate reference systems and projected reference systems

We use two reference systems, depending on the task:

- WGS84 coordinate reference system is *unprojected*; it references points on an ellipsoid surface. Paradoxically, we use this reference system for drawing maps because the functions we use for map-making understand this reference system and know how to project it to a planar surface. Coordinates in this reference system are measured in decimal degrees or degrees:minutes:seconds.
- The New Jersey State Planar *projected* reference system is locally tailored for the state of New Jersey for accurate spatial representations, measured in meters, and can be used for euclidean distance calculations that would otherwise be distorted if attempted on an ellipsoid reference system such as WGS84. However, mapping functions generally do not know how to interpret this reference system.

The ArcGIS blog has a nice explanation of geographic coordinate systems and projected coordinate systems: https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/gcs_vs_pcs/ if you'd like further reading.

These coordinate reference systems can be referred to by standardized codes. We'll define two constants referring to those codes here, and we'll refer to the coordinate references by these variable names later on.

```
WGS84 = 4326
NJ_PLANAR = 'ESRI:102311'
```

Example: New Jersey Bus Stops

We'll use New Jersey bus stop locations to explore some of the analyses you can perform with spatial data. Navigate to New Jersey Geographic Information Network and download the shapefile dataset by clikcing on the download icon in the right-hand panel and selecting the "Shapefile" option. This will download the data as a `zip` archive. Unpack the `zip` archive and make note of the directory path. As you work through these exercises on your own, you can either move the shapefile directory to your working directory and load with a relative file path, or load the data by specifying its full file path.

Load a shapefile from file

We will use the `st_read()` function from the library `sf` to load the shapefile. Other functions from the library `sf` will help us explore this dataset. We're also going to load the `tidyverse` library, which has additional useful methods for data exploration.

```
library(sf)
```

```
## Linking to GEOS 3.8.1, GDAL 3.2.1, PROJ 7.2.1; sf_use_s2() is TRUE
```

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --

## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.6     v dplyr   1.0.7
## v tidyr   1.1.4     v stringr 1.4.0
## v readr   2.1.1     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
bus <- st_read('data/Bus_Stops_of_NJ_Transit.shp')
```

```
## Reading layer 'Bus_Stops_of_NJ_Transit' from data source
##   '/Users/kpierce/data_trainings/PAP-TACC-2022/data/Bus_Stops_of_NJ_Transit.shp'
##   using driver 'ESRI Shapefile'
## Simple feature collection with 30499 features and 12 fields
## Geometry type: MULTIPOINT
## Dimension:     XY
## Bounding box:  xmin: -8406962 ymin: 4712207 xmax: -8230860 ymax: 5050000
## Projected CRS: WGS 84 / Pseudo-Mercator
```

Identify the coordinate reference system and geometry type

This dataset is loaded as a "simple feature collection", but you can treat it almost the same as a dataframe or `tbl_df`. This dataset does have two additional features that make it better suited for spatial data analysis than a regular dataframe:

Shapefiles contain metadata about the coordinate reference system (CRS) that are loaded with the raw data are loaded. You may have noticed some of this metadata printed when we loaded the data; we can als inspect the CRS with the `st_crs()` function:

```
st_crs(bus)
```

```
## Coordinate Reference System:
##   User input: WGS 84 / Pseudo-Mercator
##   wkt:
## PROJCRS["WGS 84 / Pseudo-Mercator",
##     BASEGEOGCRS["WGS 84",
##         DATUM["World Geodetic System 1984",
##             ELLIPSOID["WGS 84",6378137,298.257223563,
##                 LENGTHUNIT["metre",1]]],
##         PRIMEM["Greenwich",0,
##             ANGLEUNIT["degree",0.0174532925199433]],
##         ID["EPSG",4326]],
##     CONVERSION["Popular Visualisation Pseudo-Mercator",
##         METHOD["Popular Visualisation Pseudo Mercator",
##             ID["EPSG",1024]],
##         PARAMETER["Latitude of natural origin",0,
##             ANGLEUNIT["degree",0.0174532925199433],
##             ID["EPSG",8801]],
##         PARAMETER["Longitude of natural origin",0,
##             ANGLEUNIT["degree",0.0174532925199433],
##             ID["EPSG",8802]],
##         PARAMETER["False easting",0,
##             LENGTHUNIT["metre",1],
##             ID["EPSG",8806]],
##         PARAMETER["False northing",0,
##             LENGTHUNIT["metre",1],
##             ID["EPSG",8807]]],
##     CS[Cartesian,2],
##         AXIS["easting (X)",east,
##             ORDER[1],
##             LENGTHUNIT["metre",1]],
##         AXIS["northing (Y)",north,
##             ORDER[2],
##             LENGTHUNIT["metre",1]],
##     USAGE[
##         SCOPE["Web mapping and visualisation."],
##         AREA["World between 85.06°S and 85.06°N."],
##         BBOX[-85.06,-180,85.06,180]],
##     ID["EPSG",3857]]
```

Second, simple feature collections contain a special `geometry` column that contains `POINT`, `MULTIPOINT` and `POLYGON` data. If we look at the first element of the `bus` dataset `geometry` column, we see that this column contains `MULTIPOINT` data.

```
bus$geometry[1]
```

```
## Geometry set for 1 feature
## Geometry type: MULTIPOINT
## Dimension:     XY
## Bounding box:  xmin: -8262706 ymin: 4971264 xmax: -8262706 ymax: 4971264
## Projected CRS: WGS 84 / Pseudo-Mercator
```

```
## MULTIPOINT ((-8262706 4971264))
```

All values in the `geometry` column must be of the same type, so even though this first entry is a single point there are likely other bus stops in the data set that have multiple points. We'll work to understand the contents of the `geometry` column later in this example.

Change the coordinate reference system

At this point you may have noticed that the values in the `geometry` column don't look like regular latitude and longitude values. Indeed, the CRS for the bus stop data is indicated as "WGS 84 / Pseudo-Mercator". This is a planar projection of the data, but not the one we want. We can use the `st_transform()` function to do the geometric calculations to translate between coordinate reference systems.

We'll make a new data object in the WGS84 CRS:

```
bus_wgs84 <- st_transform(bus, crs=WGS84)
```

We'll also make a new data object in the NJ Planar projection:

```
bus_nj <- st_transform(bus, crs=NJ_PLANAR)
```

We can double check that our transformations changed the data by looking at the `head()` of our new datasets and inspecting the CRS metadata:

```
head(bus_wgs84)
```

```
## Simple feature collection with 6 features and 12 fields
## Geometry type: MULTIPOINT
## Dimension:     XY
## Bounding box:  xmin: -74.23071 ymin: 40.72092 xmax: -74.17066 ymax: 40.79424
## Geodetic CRS:  WGS 84
##     FID COUNTY DLAT_GIS DLONG_GIS LINE STOP_NUM STOP_TYPE STREET_DIR
## 1 30448  Essex 40.72093 -74.22520   37    17819        NS          N
## 2 30449  Essex 40.72093 -74.22520  107    17819        NS          N
## 3 30450  Essex 40.72115 -74.22518   90    17841        NS          S
## 4 30451  Essex 40.79417 -74.23053   97    19442        NS          N
## 5 30452  Essex 40.79419 -74.23067   97    19445        FS          S
## 6 30453  Essex 40.77684 -74.17063   99    18659        NS          E
##               DESCRIPTIO DIRECTION_      MUNICIPALI
## 1 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 2 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 3 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
```

```
## 4 HARRISON AVE AT ELM ST         In WEST ORANGE TWP
## 5 HARRISON AVE AT ELM ST         Ou WEST ORANGE TWP
## 6 HELLER PKWY AT LAKE ST         In          NEWARK
##                               GlobalID                       geometry
## 1 9dd47d93-3ac8-4167-85bd-20fefa063e33 MULTIPOINT ((-74.22516 40.7...
## 2 f3cde248-5286-4a0d-8710-94c38b3bafd8 MULTIPOINT ((-74.22516 40.7...
## 3 8fc8919f-8a25-4eec-aa65-f5c9d6d793dd MULTIPOINT ((-74.22523 40.7...
## 4 65a3bde8-d8f0-475d-9f49-ff86a81d387f MULTIPOINT ((-74.2305 40.79...
## 5 4a3fa65f-a13a-4f07-bfcd-977f7562c5c4 MULTIPOINT ((-74.23071 40.7...
## 6 70298ad9-9b33-419d-b883-1d2434264126 MULTIPOINT ((-74.17066 40.7...
```

```
head(bus_nj)
```

```
## Simple feature collection with 6 features and 12 fields
## Geometry type: MULTIPOINT
## Dimension:     XY
## Bounding box:  xmin: 172725.2 ymin: 209594.1 xmax: 177799.7 ymax: 217734.3
## Projected CRS: NAD_1983_HARN_StatePlane_New_Jersey_FIPS_2900
##     FID COUNTY DLAT_GIS DLONG_GIS LINE STOP_NUM STOP_TYPE STREET_DIR
## 1 30448  Essex 40.72093 -74.22520   37    17819        NS          N
## 2 30449  Essex 40.72093 -74.22520  107    17819        NS          N
## 3 30450  Essex 40.72115 -74.22518   90    17841        NS          S
## 4 30451  Essex 40.79417 -74.23053   97    19442        NS          N
## 5 30452  Essex 40.79419 -74.23067   97    19445        FS          S
## 6 30453  Essex 40.77684 -74.17063   99    18659        NS          E
##               DESCRIPTIO DIRECTION_      MUNICIPALI
## 1 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 2 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 3 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 4 HARRISON AVE AT ELM ST         In WEST ORANGE TWP
## 5 HARRISON AVE AT ELM ST         Ou WEST ORANGE TWP
## 6 HELLER PKWY AT LAKE ST         In          NEWARK
##                               GlobalID                       geometry
## 1 9dd47d93-3ac8-4167-85bd-20fefa063e33 MULTIPOINT ((173219.2 20959...
## 2 f3cde248-5286-4a0d-8710-94c38b3bafd8 MULTIPOINT ((173219.2 20959...
## 3 8fc8919f-8a25-4eec-aa65-f5c9d6d793dd MULTIPOINT ((173212.4 20962...
## 4 65a3bde8-d8f0-475d-9f49-ff86a81d387f MULTIPOINT ((172742.3 21772...
## 5 4a3fa65f-a13a-4f07-bfcd-977f7562c5c4 MULTIPOINT ((172725.2 21773...
## 6 70298ad9-9b33-419d-b883-1d2434264126 MULTIPOINT ((177799.7 21581...
```

Map the bus stops

Load the New Jersey state and county borders

We will load a basemap of the state of New Jersey and its county boundaries directly from the ArcGIS Open Data by downloading a `geojson` file from a URL. `geojson` files are specially formatted text files that can be interpreted by the `read_sf()` function.

```
nj <- read_sf(
  'https://opendata.arcgis.com/datasets/5f45e1ece6e14ef5866974a7b57d3b95_1.geojson'
  )
nj <- nj %>% st_transform(crs=WGS84)
```

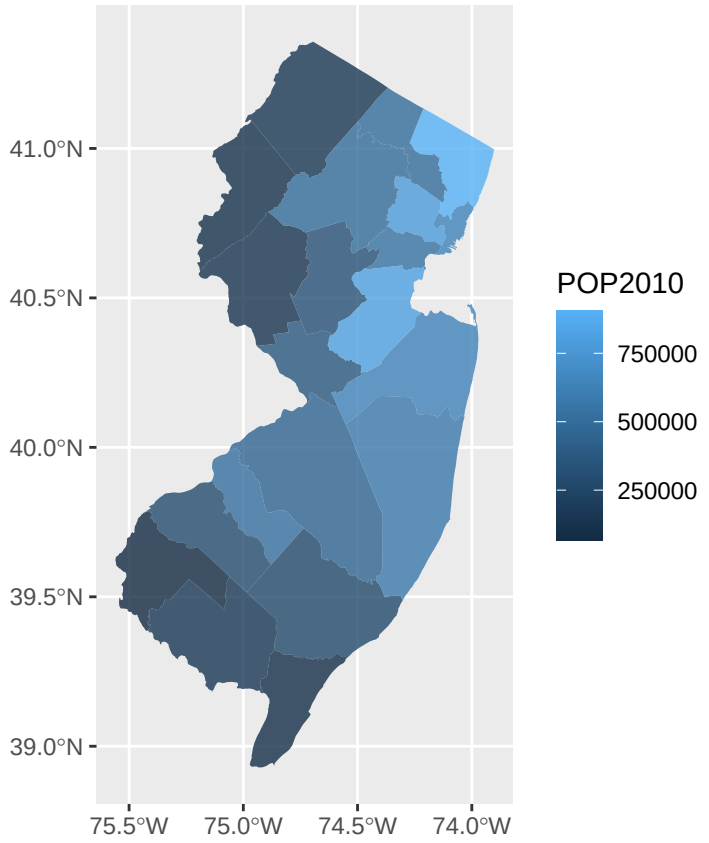
This dataset happens to include a number of measures for each county. We'll take one measure, `POP2010` (the population of each county from the 2010 decennial census) and make a choropleth map. We'll use the library `ggmap` to build our map. `ggmap` uses layers to construct images. Our first layer is a blank plotting space, which we create by calling the `ggplot()` function without any arguments. We then add the actual data we want to visualize in another layer with the `geom_sf` function, which understands how to generate the choropleth map.

```
library(ggmap)
```

```
## Google's Terms of Service: https://cloud.google.com/maps-platform/terms/.
```

```
## Please cite ggmap if you use it! See citation("ggmap") for details.
```

```
nj_map <- ggplot() +
  geom_sf(data=nj, aes(fill=POP2010), inherit.aes = FALSE, color = NA, alpha = 0.8)
nj_map
```



Load street data basemap

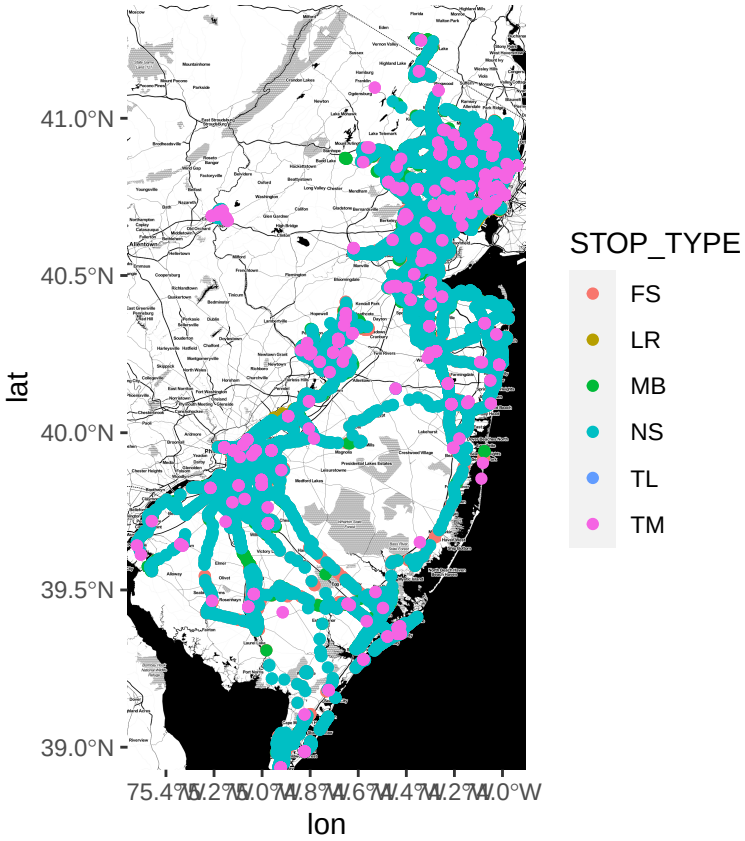
We can bring in street-level data to make a background for our map. We first use the shapefile of New Jersey to determine a bounding box, and then use the `get_stamenmap()` function to download a stylized street map background from Open Street Maps.

```
nj_bbox <- unname(st_bbox(nj))
nj_base_map <- get_stamenmap(bbox=nj_bbox, maptype="toner", force=TRUE)
```

Map bus stops on streetmap

Next we'll build a map of bus stops in with the same layer-based approach we used for the choropleth map example above. This time we will make our first layer with the basemap by calling the `ggmap()` function instead of `ggplot`, and passing our base map variable as an argument. Our next layer will be the bus stop data, and for this example we will color points by the bus stop type (one of the columns in the dataset). The argument `inherit.aes = FALSE` instructs to the function to ignore default plot aesthetics in favor of the aesthetic instructions we have provided.

```
nj_bus_map <- ggmap(nj_base_map) +
  geom_sf(data=bus_wgs84, aes(color=STOP_TYPE), inherit.aes = FALSE)
nj_bus_map
```



Aggregate bus stops into a grid

Rather than viewing the individual points where bus stops are located, we can aggregate bus stops spatially. By counting the number of stops in different areas, we may see patterns about service level coverage that are hard to pick out when viewing stop locations individually.

We will first create a grid that covers the state of New Jersey, then we will identify the bus stops that fall inside each grid cell.

Create a five-mile "fishnet" grid

We will need the following elements to build our fishnet grid: 1. The coverage area, in our case the entire state of New Jersey 2. The width of each square in the grid, specified in meters

We will use the `NJ_PLANAR` projection because we want a flat grid. This projection measures spatial distances in meters, and so we specify our fishnet width in meters. We would like to overlay a five-mile grid on the state of New Jersey, so we convert five miles into meters using the constant of 1,609 meters per mile.

```
nj_flat <- st_transform(nj, crs=NJ_PLANAR)
fishnet_width <- 1609 * 5
```

Next we need to adjust our New Jersey shapefile so it contains only the state border, and not the internal county borders. The `st_union()` function accomplishes this. We also use the `st_make_valid()` function to correct any loops or places where the border appears to cross itself.

```
nj_border <- st_make_valid(st_union(nj_flat))
```

Now that we have our coverage area and our fishnet grid size determined, we are ready to use the `st_make_grid()` function to generate our grid. After we make the grid, we will assign each cell a unique identifier (a "net_id"). We will remove grid cells that fall outside the state border, and reshape the list of grid objects into a dataframe that is easier to work with.

```
net <- st_make_grid(
  x=nj_border, cellsize=fishnet_width, what='polygons', square=TRUE, crs=NJ_PLANAR
  )
net_agg <- st_as_sf(net) %>% tibble::rowid_to_column(., "net_id")
net_intersect <- st_intersects(nj_border, net_agg)
fishnet <- net_agg[unique(unlist(net_intersect)),]
```

Point-in-polygon join

With our fishnet created, we're ready to join our bus stop data. We use the `st_join()` function to identify the bus stops in each fishnet cell. This join preserves only the bus stop geometry, but we're really interested in the grid square shapes. So we drop the geometry column – we will add it back later with another join.

```
bus_net <- st_join(bus_nj, fishnet, join=st_within) %>%
    st_drop_geometry()
head(bus_net)
```

```
##     FID COUNTY DLAT_GIS DLONG_GIS LINE STOP_NUM STOP_TYPE STREET_DIR
## 1 30448  Essex 40.72093 -74.22520   37    17819        NS          N
## 2 30449  Essex 40.72093 -74.22520  107    17819        NS          N
## 3 30450  Essex 40.72115 -74.22518   90    17841        NS          S
## 4 30451  Essex 40.79417 -74.23053   97    19442        NS          N
## 5 30452  Essex 40.79419 -74.23067   97    19445        FS          S
## 6 30453  Essex 40.77684 -74.17063   99    18659        NS          E
##               DESCRIPTIO DIRECTION_      MUNICIPALI
## 1 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 2 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 3 GROVE ST AT HERPERS ST         Ou   IRVINGTON TWP
## 4 HARRISON AVE AT ELM ST         In WEST ORANGE TWP
```

```
## 5 HARRISON AVE AT ELM ST         Ou WEST ORANGE TWP
## 6 HELLER PKWY AT LAKE ST         In          NEWARK
##                                GlobalID net_id
## 1 9dd47d93-3ac8-4167-85bd-20fefa063e33    447
## 2 f3cde248-5286-4a0d-8710-94c38b3bafd8    447
## 3 8fc8919f-8a25-4eec-aa65-f5c9d6d793dd    447
## 4 65a3bde8-d8f0-475d-9f49-ff86a81d387f    465
## 5 4a3fa65f-a13a-4f07-bfcd-977f7562c5c4    465
## 6 70298ad9-9b33-419d-b883-1d2434264126    465
```

Now that we have bus stops associated with `net_id` values, we can count the number of bus stops in each cell by grouping rows by the `net_id` value. To make our analysis a bit more interesting, we will keep the `STOP_TYPE` data by using that as a grouping variable as well. This allows us to look at bus stop counts by stop type to see how service type varies spatially. The `summarise(count=n())` operation is what performs this count aggergation by counting the rows in each group.

```
bus_net_summary <- bus_net %>%
  group_by(net_id, STOP_TYPE) %>%
  summarise(count=n())
```

```
## `summarise()` has grouped output by 'net_id'. You can override using the
## `.groups` argument.
```

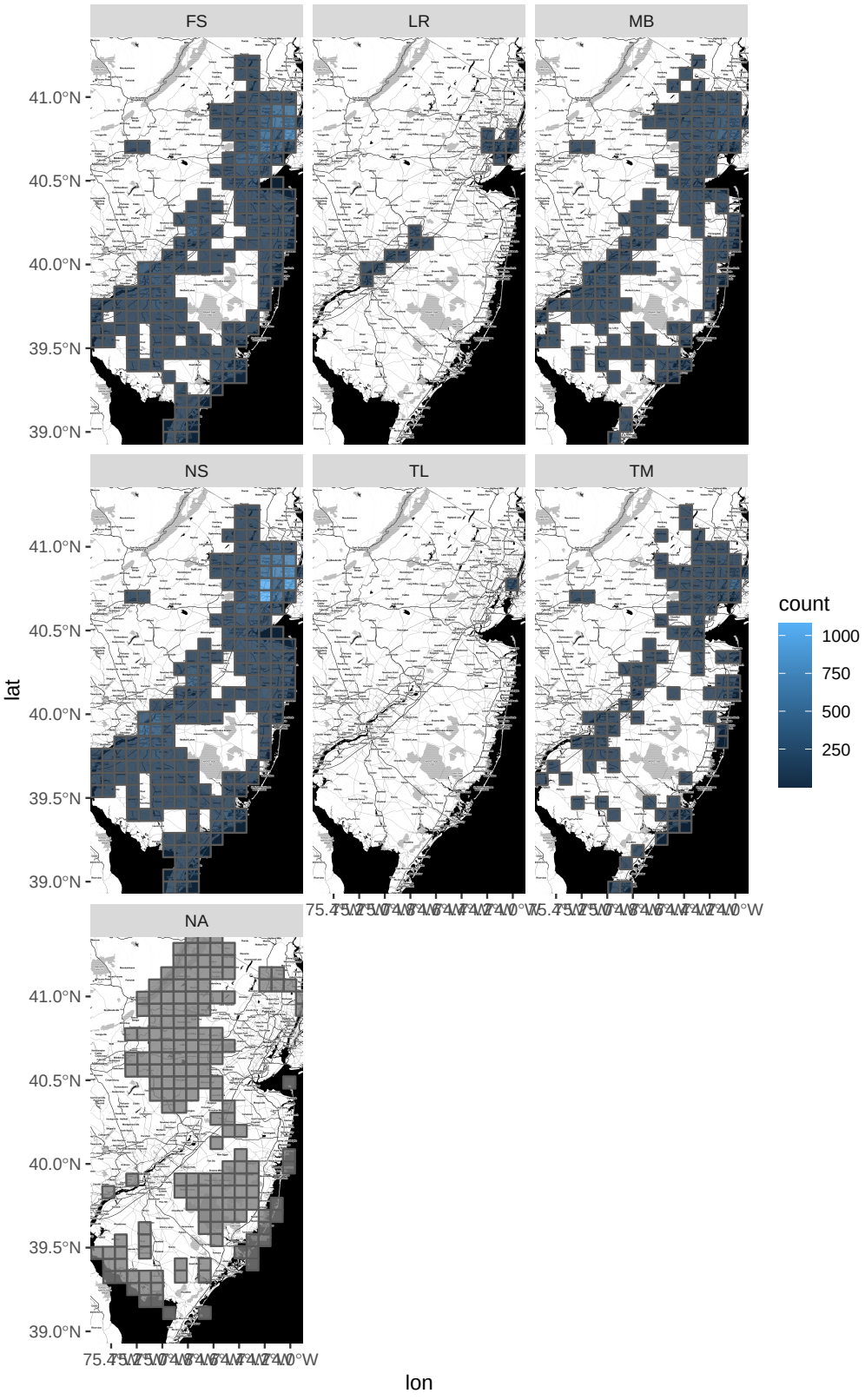
Earlier we dropped the `geometry` column, but now we're ready to add it back. We specifically want to add the fishnet `geometry` (not the bus stop point locations), so we'll join our `bus_net_summary` data to our original `fishnet` on the column `net_id`. We have to wrap that join in the `st_as_sf()` function to ensure the resulting dataframe is an `sf` object; we also specify that we would like to use the CRS already present in the `fishnet` data.

```
bus_net_final <- st_as_sf(
  left_join(
    fishnet,
    bus_net_summary,
    by='net_id'
    ),
  crs=st_crs(fishnet))
```

Map gridded bus stop counts by type

Now we're ready to map our data. We will use the `nj_base_map` as the first layer of our map, and we'll use the fishnet grids as the second layer. The `facet_wrap()` function allows us to easily make separate panels to display each bus stop type individually. We'll spread our facets over two rows for easier viewing:

```
bus_type_map <- ggmap(nj_base_map) +
  geom_sf(
    data=st_transform(bus_net_final, crs=WGS84),
    aes(fill=count),
    inherit.aes = FALSE, alpha=0.8
    ) +
  facet_wrap(facets='STOP_TYPE', nrow=3)
bus_type_map
```


FS
LR
MB
NS
TL
TM
NA
41.0°N
40.5°N
40.0°N
39.5°N
39.0°N
lat
lon
count
1000
750
500
250