

Spatial Data and Cartography (Part 2)

Lecture 17

Dr. Colin Rundel

Plotting

Example Data - NC SIDS

```
1 ( nc = read_sf(system.file("shape/nc.shp", package="sf"), quiet = TRUE) |>
2   select(-(AREA:CNTY_ID), -(FIPS:CRESS_ID)))
```

Simple feature collection with 100 features and 7 fields

Geometry type: MULTIPOLYGON

Dimension: XY

Bounding box: xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965

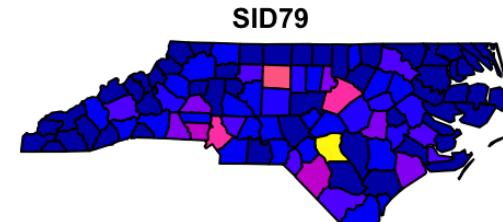
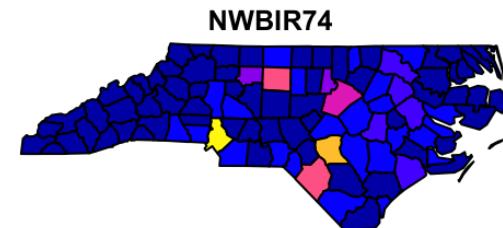
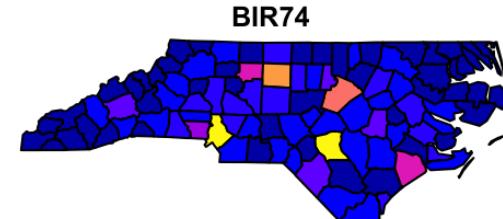
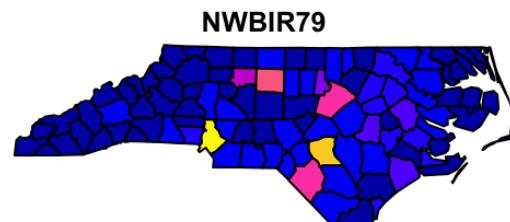
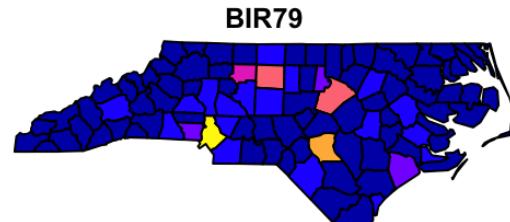
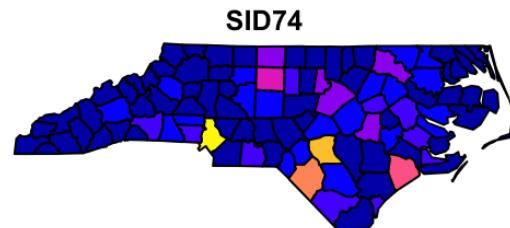
Geodetic CRS: NAD27

A tibble: 100 × 8

| | NAME | BIR74 | SID74 | NWBIR74 | BIR79 | SID79 | NWBIR79 |
|--|--------------|-------|-------|---------|-------|-------|---------|
| | <chr> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> |
| 1 | Ashe | 1091 | 1 | 10 | 1364 | 0 | 19 |
| 2 | Alleghany | 487 | 0 | 10 | 542 | 3 | 12 |
| 3 | Surry | 3188 | 5 | 208 | 3616 | 6 | 260 |
| 4 | Currituck | 508 | 1 | 123 | 830 | 2 | 145 |
| 5 | Northhampton | 1421 | 9 | 1066 | 1606 | 3 | 1197 |
| 6 | Hertford | 1452 | 7 | 954 | 1838 | 5 | 1237 |
| 7 | Camden | 286 | 0 | 115 | 350 | 2 | 139 |
| 8 | Gates | 420 | 0 | 254 | 594 | 2 | 371 |
| 9 | Warren | 968 | 4 | 748 | 1190 | 2 | 844 |
| 10 | Stokes | 1612 | 1 | 160 | 2038 | 5 | 176 |
| # i 90 more rows | | | | | | | |
| # i 1 more variable: geometry <MULTIPOLYGON [°]> | | | | | | | |

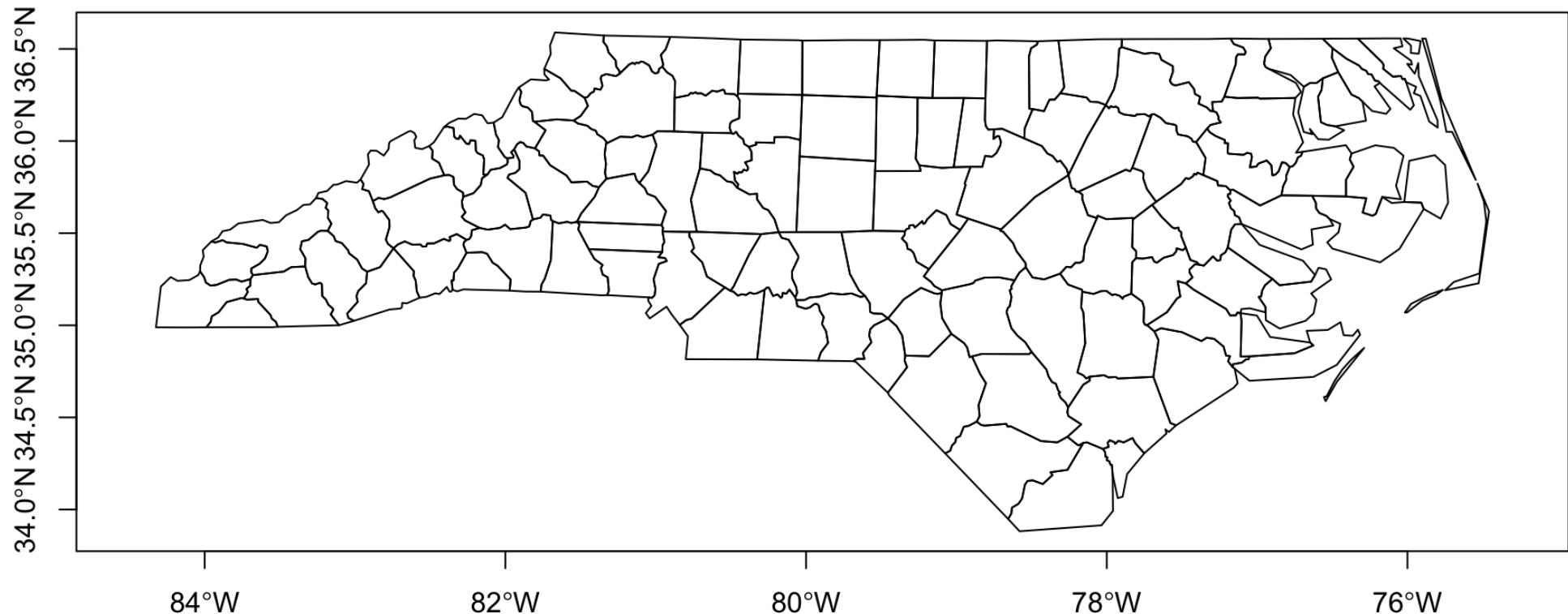
Base Plots

```
1 plot(nc)
```



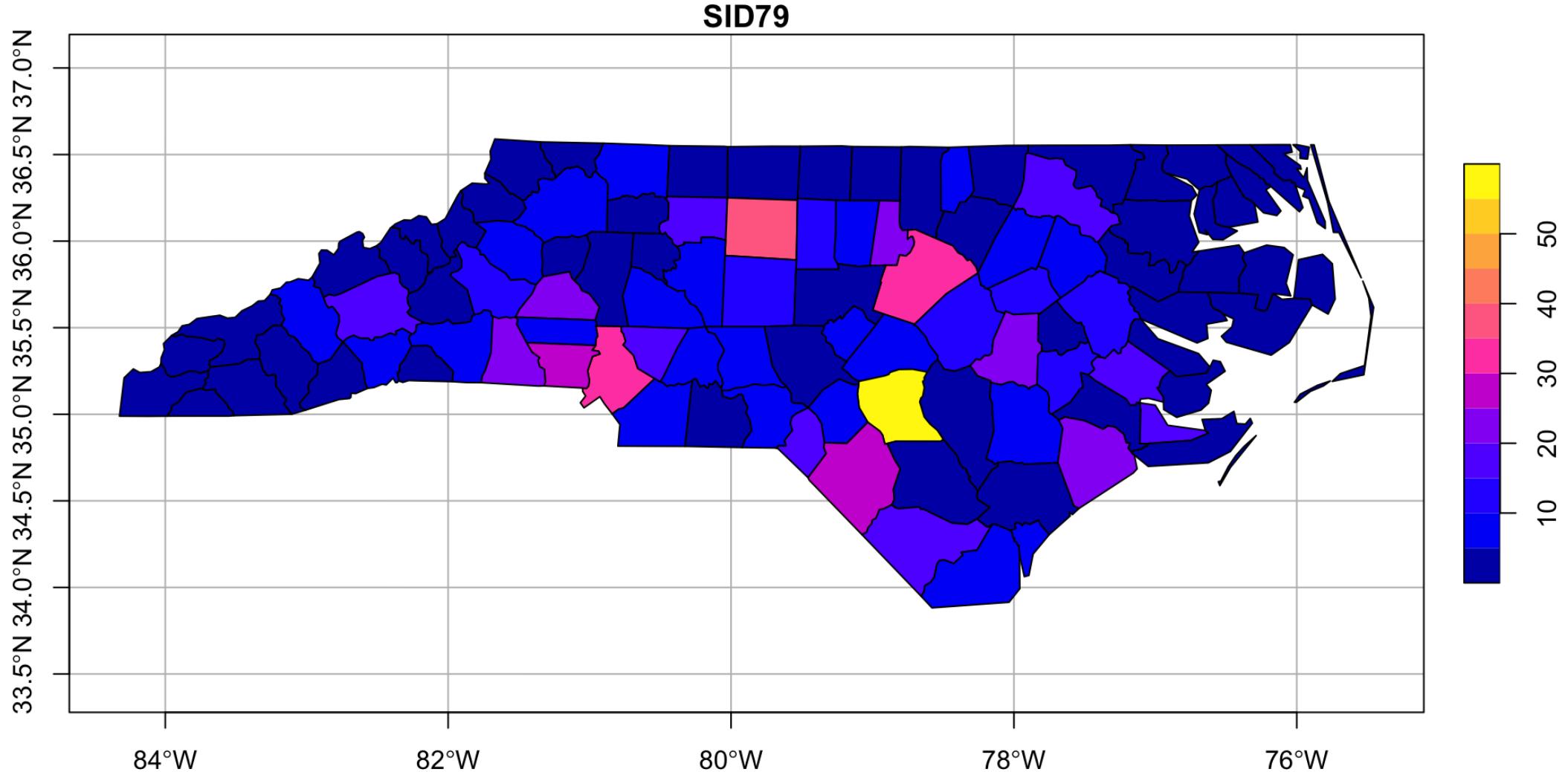
Geometry Plot

```
1 plot(st_geometry(nc), axes=TRUE)
```



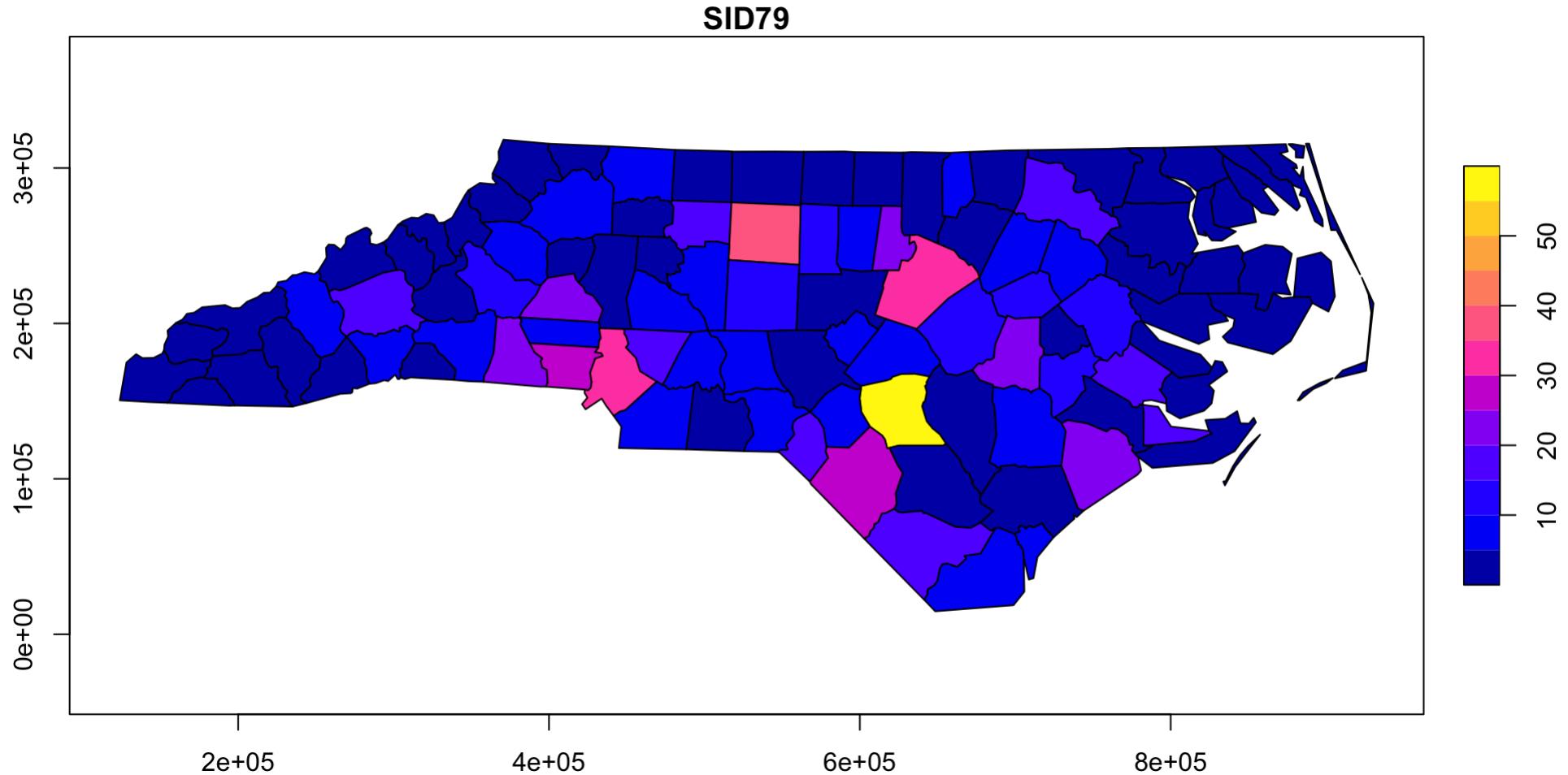
Graticules

```
1 plot(nc[, "SID79"], graticule=TRUE, axes=TRUE)
```



EPSG 3631

```
1 plot(st_transform(nc[, "SID79"], 3631), axes=TRUE)
```

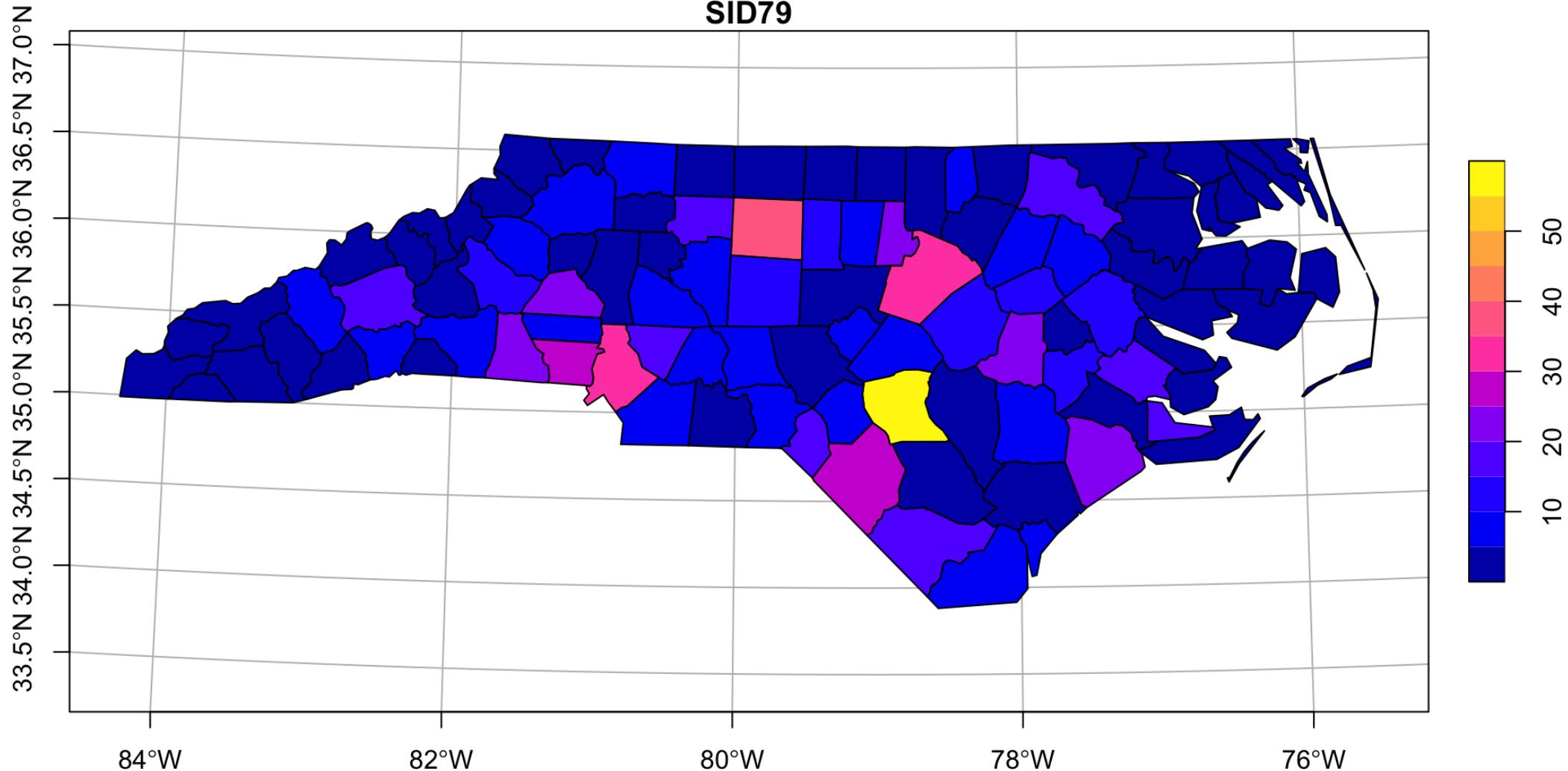


EPSG 3631 is a projected LCC coordinate system that is centered on North Carolina (uses meters as units).

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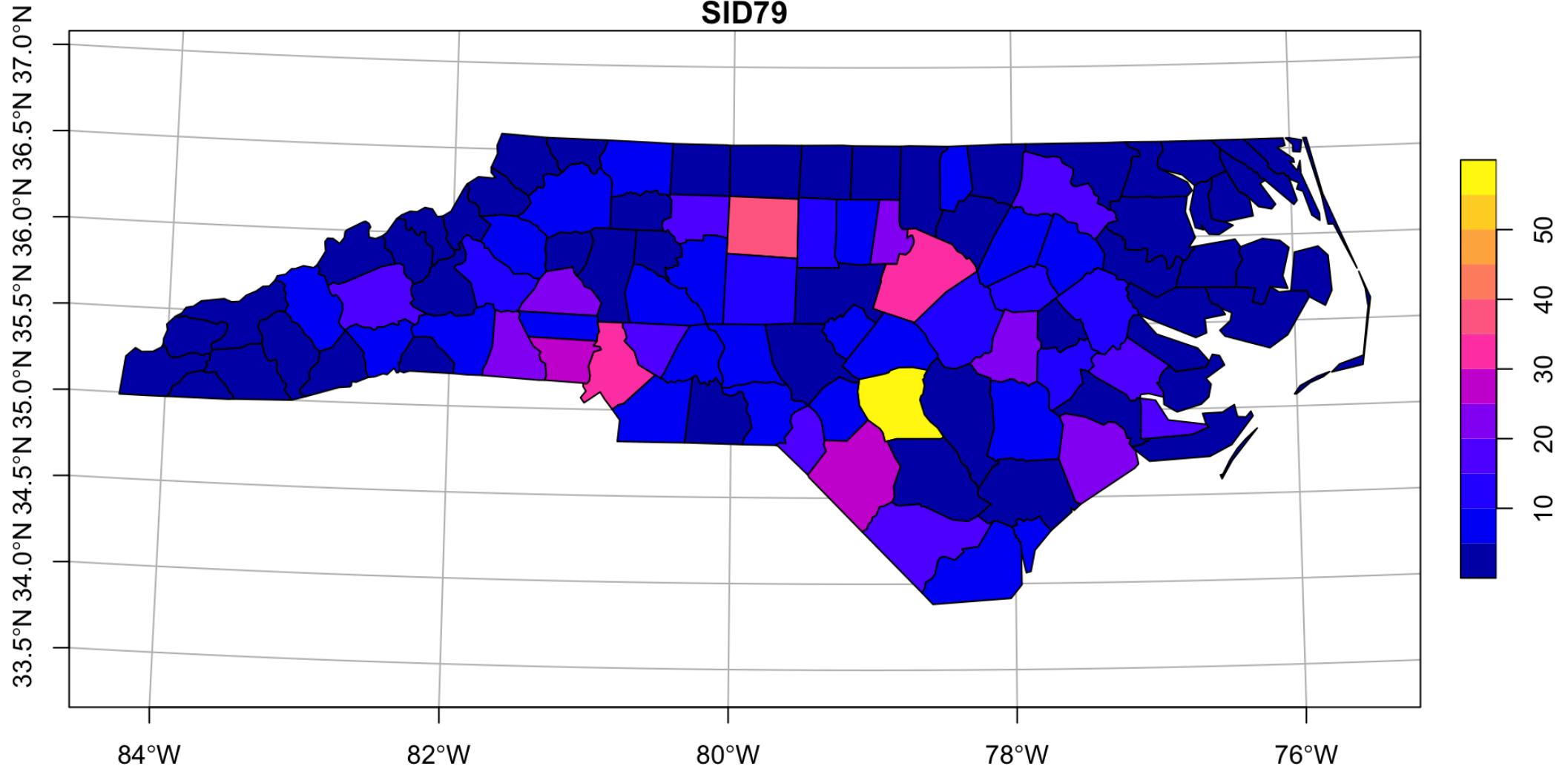
EPSG 3631 w/ Graticules

```
1 plot(st_transform(nc[, "SID79"], 3631), graticule=TRUE, axes=TRUE)
```



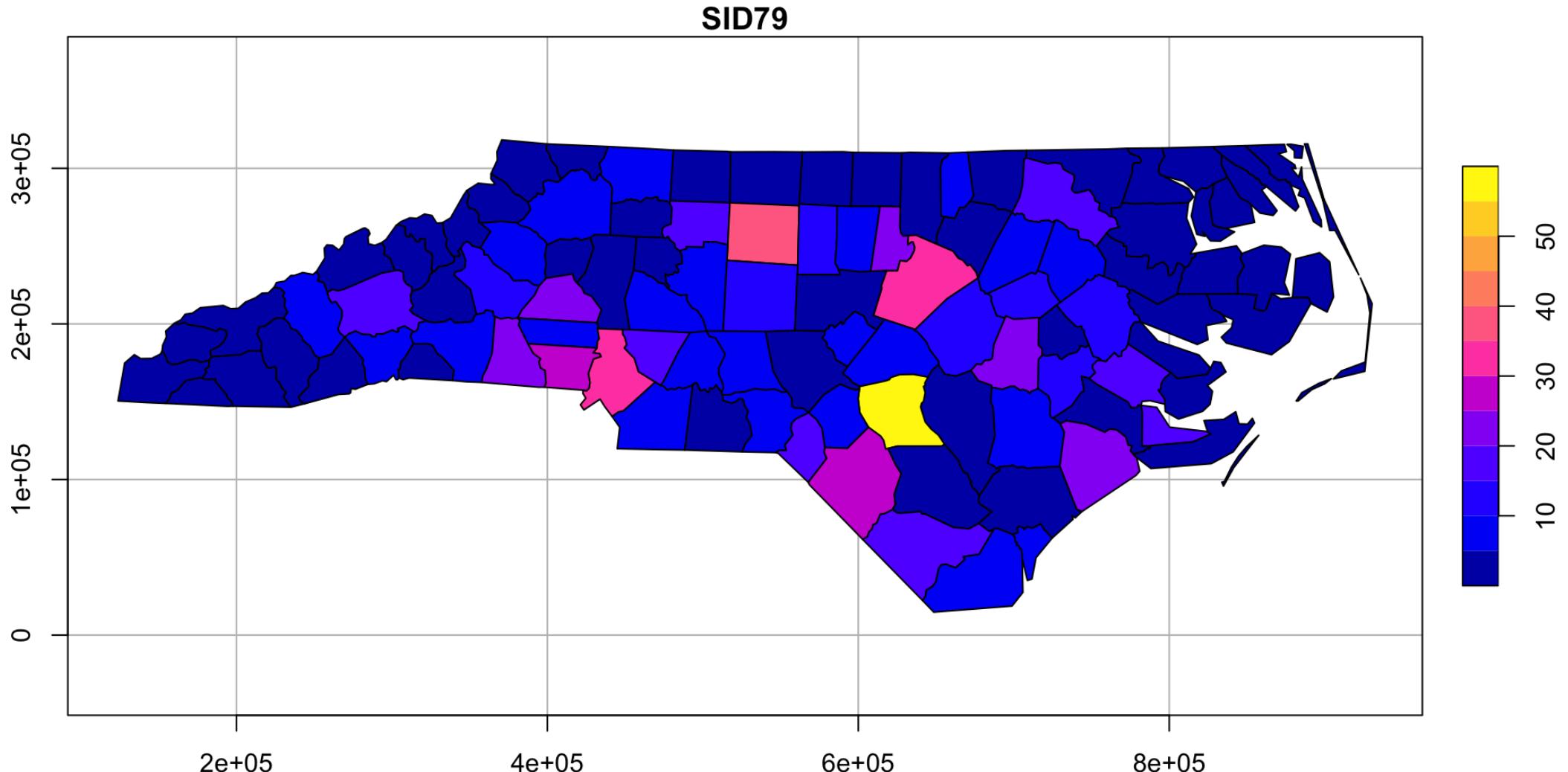
EPSG 3631 w/ Lat / long Graticules

```
1 plot(st_transform(nc[, "SID79"], 3631), graticule=st_crs(4326), axes=TRUE)
```



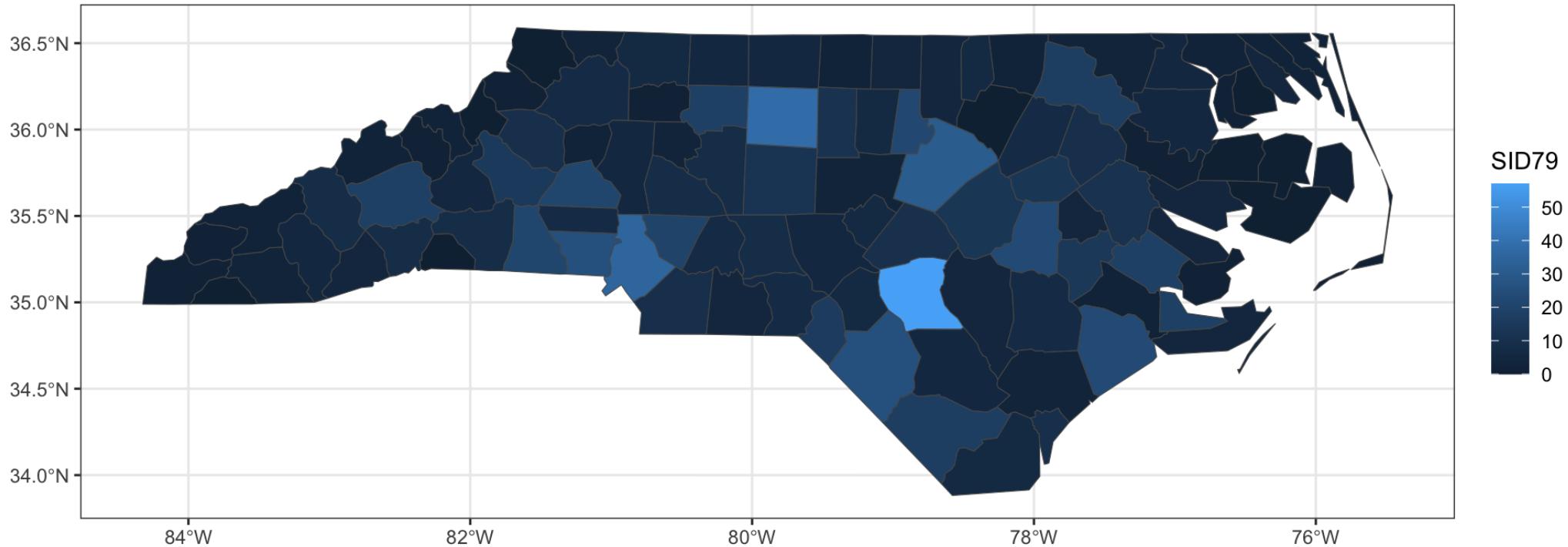
EPSG 3631 w/ 3631 Graticules

```
1 plot(st_transform(nc[, "SID79"], 3631), graticule=st_crs(3631), axes=TRUE)
```



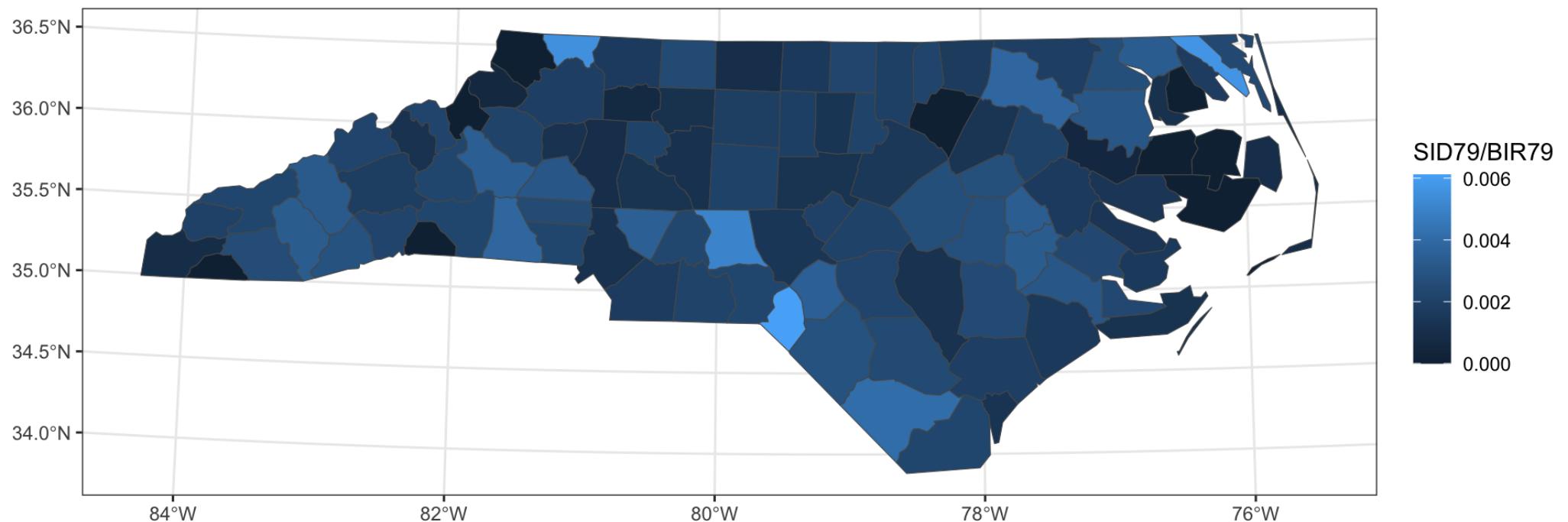
ggplot2

```
1 ggplot(nc) +  
2   geom_sf(aes(fill=SID79))
```



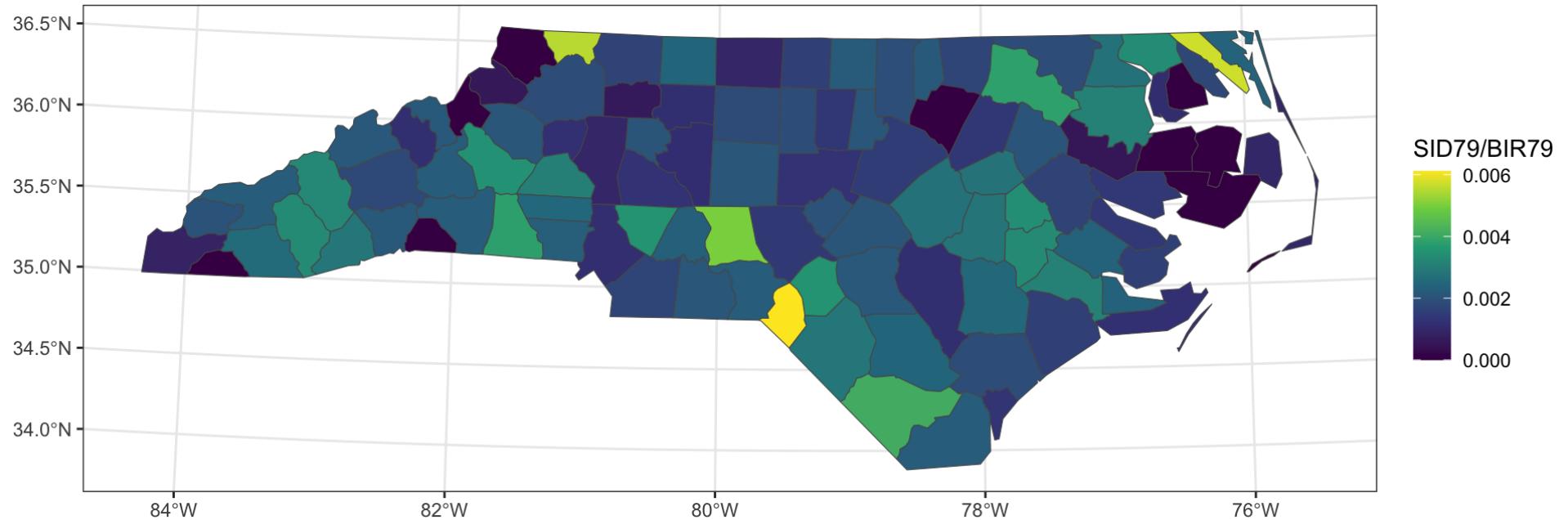
ggplot2 + projections

```
1 ggplot(st_transform(nc, 3631)) +  
2   geom_sf(aes(fill=SID79 / BIR79))
```



ggplot2 + viridis

```
1 ggplot(st_transform(nc, 3631)) +  
2   geom_sf(aes(fill=SID79 / BIR79)) +  
3   scale_fill_viridis_c()
```



Example Data - Meuse

```
1 data(meuse, meuse.riv, package="sp")
2 (meuse = st_as_sf(meuse, coords=c("x", "y"), crs=28992) |>
3   as_tibble() |> st_as_sf())
```

Simple feature collection with 155 features and 12 fields

Geometry type: POINT

Dimension: XY

Bounding box: xmin: 178605 ymin: 329714 xmax: 181390 ymax: 333611

Projected CRS: Amersfoort / RD New

A tibble: 155 × 13

| | cadmium | copper | lead | zinc | elev | dist | om | ffreq | | | | |
|---|---------|--------|-------|-------|-------|---------|-------|-------|--|--|--|--|
| | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <fct> | | | | |
| 1 | 11.7 | 85 | 299 | 1022 | 7.91 | 0.00136 | 13.6 | 1 | | | | |
| 2 | 8.6 | 81 | 277 | 1141 | 6.98 | 0.0122 | 14 | 1 | | | | |
| 3 | 6.5 | 68 | 199 | 640 | 7.8 | 0.103 | 13 | 1 | | | | |
| 4 | 2.6 | 81 | 116 | 257 | 7.66 | 0.190 | 8 | 1 | | | | |
| 5 | 2.8 | 48 | 117 | 269 | 7.48 | 0.277 | 8.7 | 1 | | | | |
| 6 | 3 | 61 | 137 | 281 | 7.79 | 0.364 | 7.8 | 1 | | | | |
| 7 | 3.2 | 31 | 132 | 346 | 8.22 | 0.190 | 9.2 | 1 | | | | |
| 8 | 2.8 | 29 | 150 | 406 | 8.49 | 0.0922 | 9.5 | 1 | | | | |
| 9 | 2.4 | 37 | 133 | 347 | 8.67 | 0.185 | 10.6 | 1 | | | | |
| 10 | 1.6 | 24 | 80 | 183 | 9.05 | 0.310 | 6.3 | 1 | | | | |
| # i 145 more rows | | | | | | | | | | | | |
| # i 5 more variables: soil <fct>, lime <fct>, | | | | | | | | | | | | |
| # landuse <fct>, dist.m <dbl>, geometry<POINT [n]t> | | | | | | | | | | | | |

```
1 ( meuse_riv = st_polygon(list(meuse.riv)) |>
2   st_sfc() |>
3   st_set_crs(28992) |>
4   st_as_sf()
5 )
```

Simple feature collection with 1 feature and 0 fields

Geometry type: POLYGON

Dimension: XY

Bounding box: xmin: 178304 ymin: 325698.5 xmax: 182331.5 ymax: 337684.8

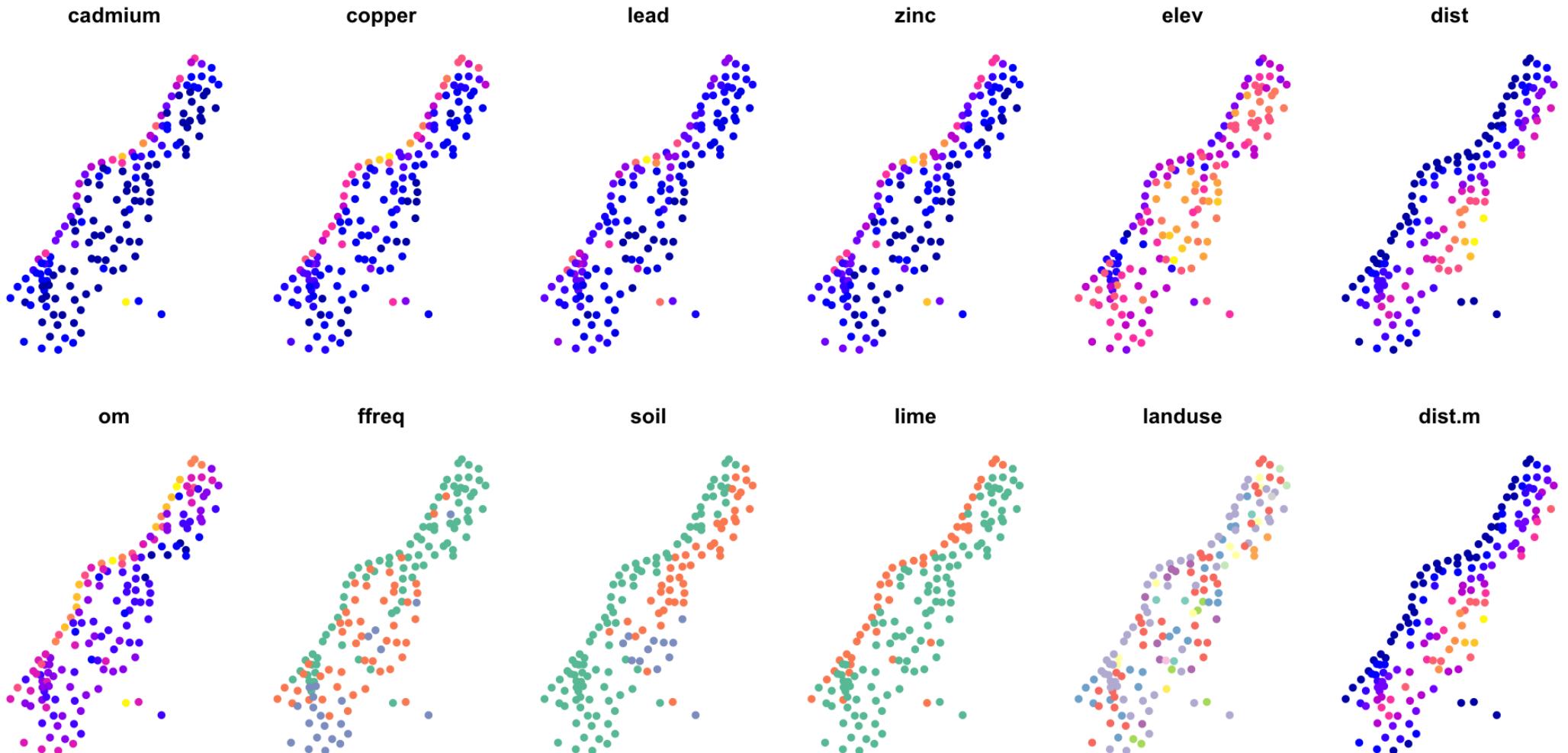
Projected CRS: Amersfoort / RD New

x

1 POLYGON ((182003.7 337678.6...

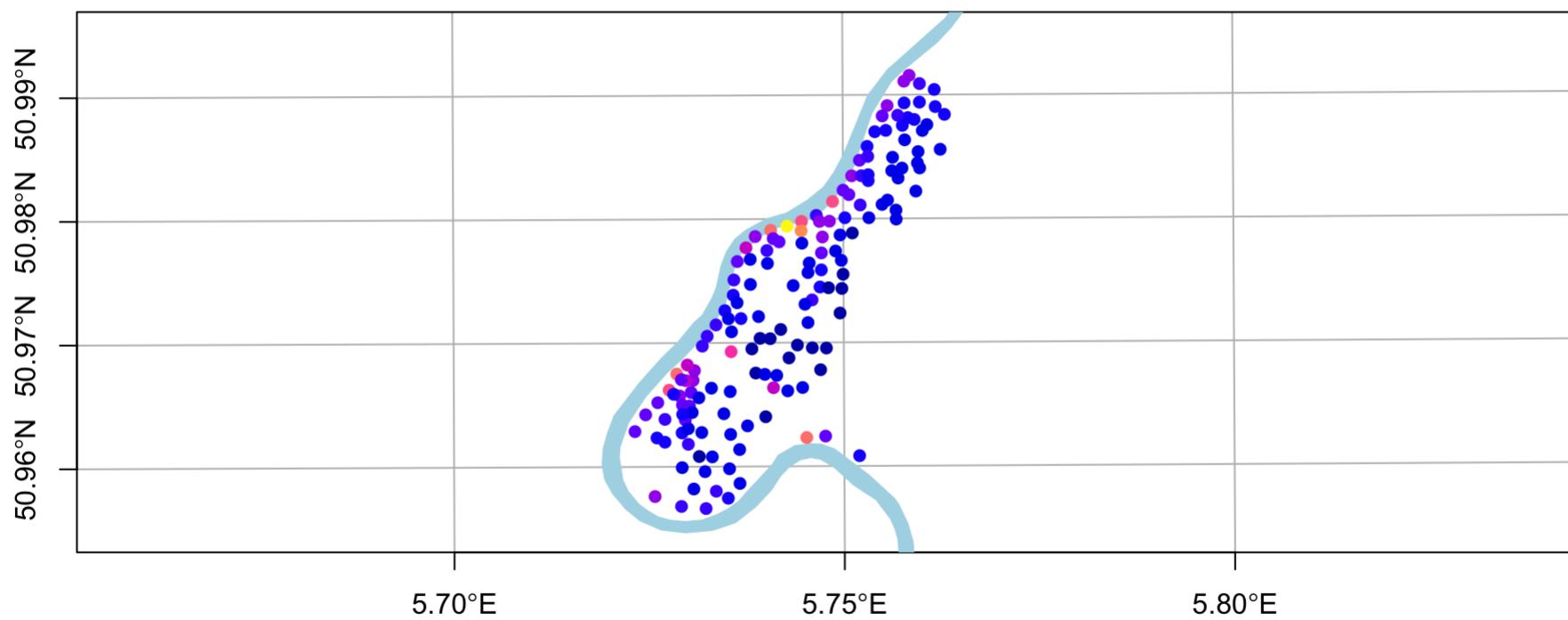
Meuse

```
1 plot(meuse, pch=16, max.plot=12)
```



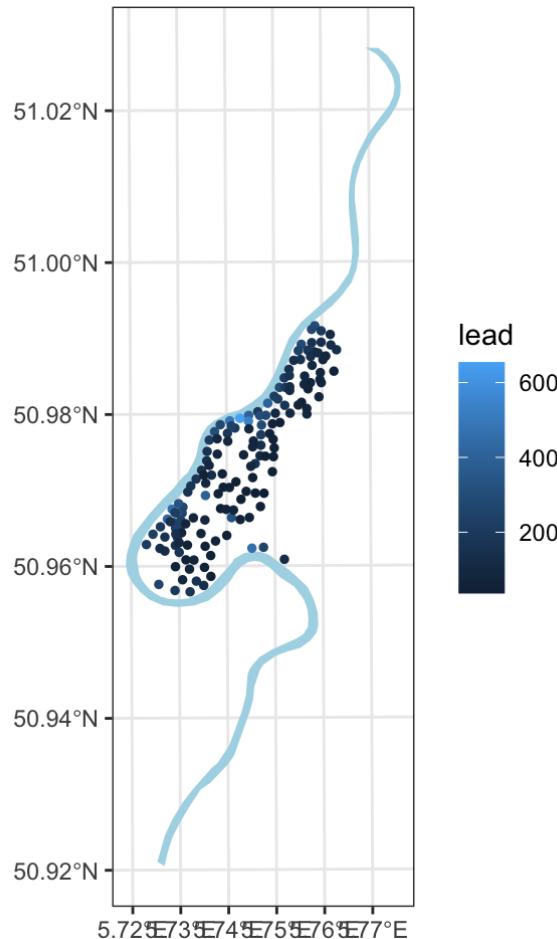
Layering plots

```
1 plot(  
2   meuse_riv, col=adjustcolor("lightblue", alpha.f=1), border = NA,  
3   axes=TRUE, graticule=st_crs(4326),  
4   ylim = c(329500, 334000)  
5 )  
6 plot(meuse[, "lead"], pch=16, add=TRUE)
```



ggplot2

```
1 ggplot() +  
2   geom_sf(data=meuse_riv, fill="lightblue", color=NA) +  
3   geom_sf(data=meuse, aes(color=lead), size=1)
```



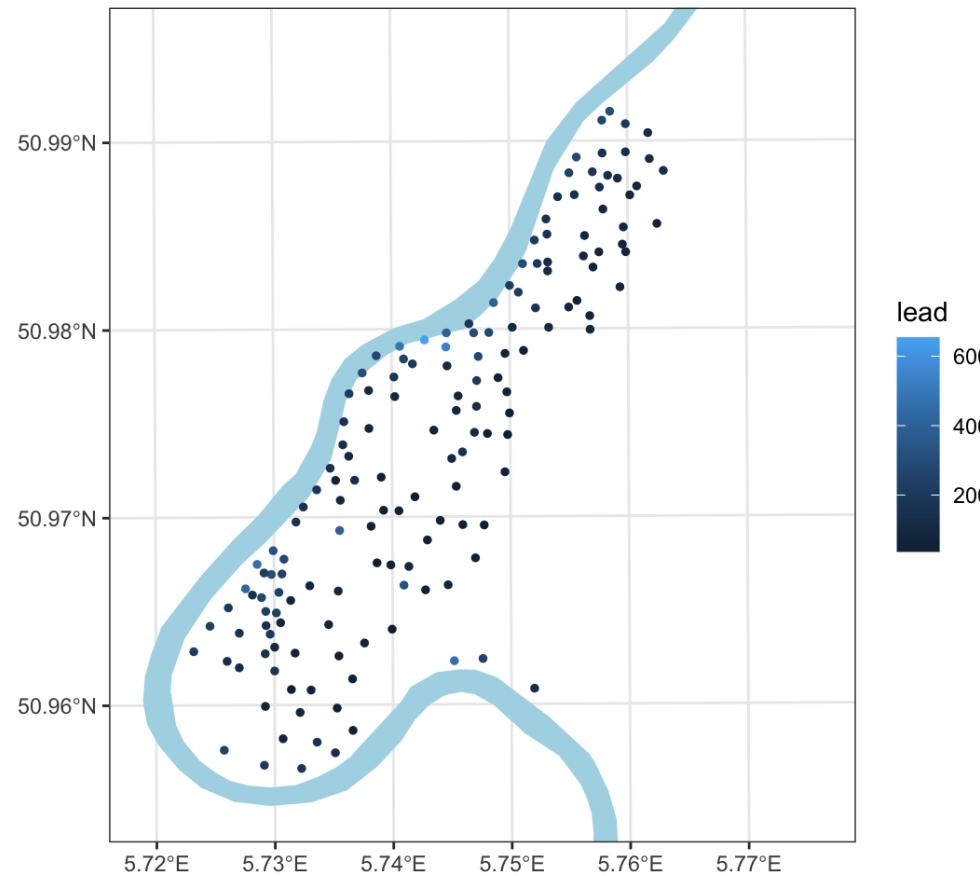
ggplot2 - axis limits

```
1 ggplot() +  
2   geom_sf(data=meuse_riv, fill="lightblue", color=NA) +  
3   geom_sf(data=meuse, aes(color=lead), size=1) +  
4   ylim(50.95, 50.99)
```



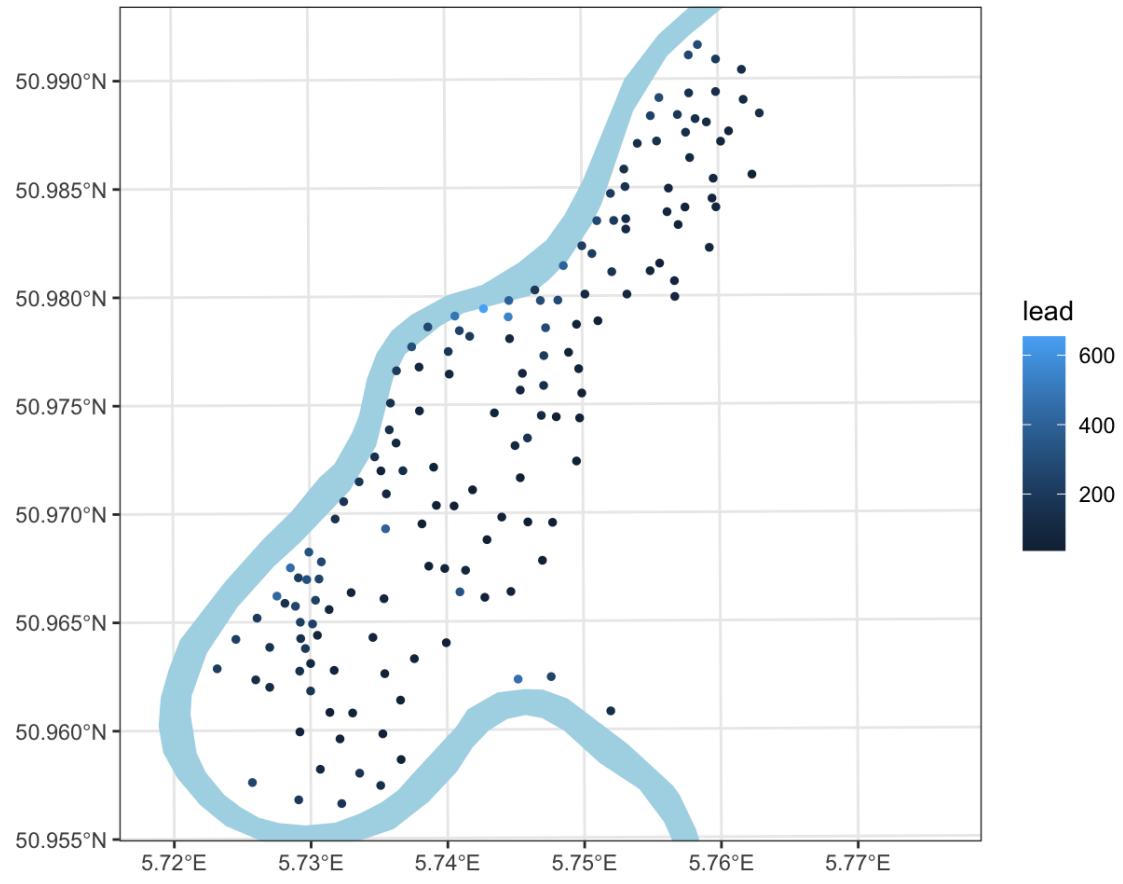
ggplot2 - axis limits

```
1 ggplot() +  
2   geom_sf(data=meuse_riv, fill="lightblue", color=NA) +  
3   geom_sf(data=meuse, aes(color=lead), size=1) +  
4   ylim(329500, 334000)
```



ggplot2 - bounding box

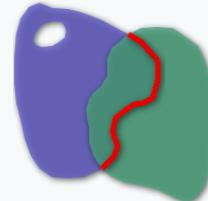
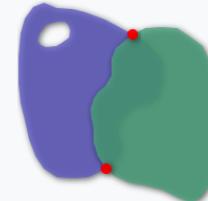
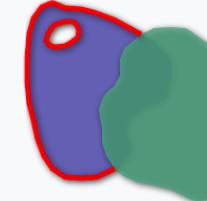
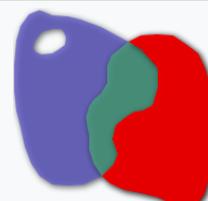
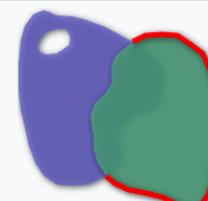
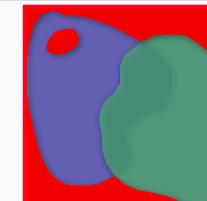
```
1 ggplot() +  
2   geom_sf(data=st_sf(meuse_riv), fill="lightblue", color=NA) +  
3   geom_sf(data=meuse, aes(color=lead), size=1) +  
4   ylim(st_bbox(meuse)[ "ymin" ], st_bbox(meuse)[ "ymax" ])
```



Geometry Predicates

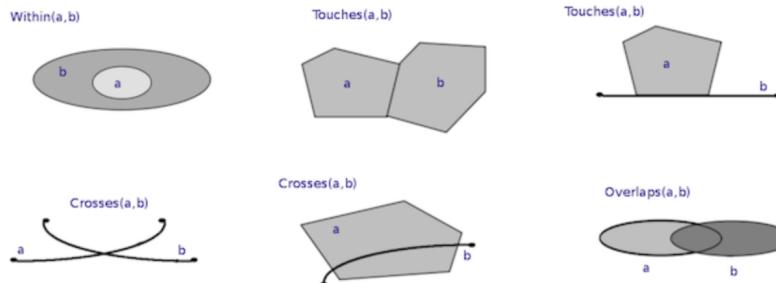
DE-9IM



| | Interior | Boundary | Exterior |
|-----------------|--|---|---|
| Interior |  |  |  |
| Boundary |  |  |  |
| Exterior |  |  |  |

$\dim[I(a) \cap I(b)] = 2$ $\dim[I(a) \cap B(b)] = 1$ $\dim[I(a) \cap E(b)] = 2$
 $\dim[B(a) \cap I(b)] = 1$ $\dim[B(a) \cap B(b)] = 0$ $\dim[B(a) \cap E(b)] = 1$
 $\dim[E(a) \cap I(b)] = 2$ $\dim[E(a) \cap B(b)] = 1$ $\dim[E(a) \cap E(b)] = 2$

Spatial predicates



st_within(a,b):

$$\begin{bmatrix} T & * & F \\ * & * & F \\ * & * & * \end{bmatrix}$$

st_touches(a,b):

$$\begin{bmatrix} F & T & * \\ * & * & * \\ * & * & * \end{bmatrix} \cup \begin{bmatrix} F & * & * \\ T & * & * \\ * & * & * \end{bmatrix} \cup \begin{bmatrix} F & * & * \\ * & T & * \\ * & * & * \end{bmatrix}$$

Sparse vs Full Results

```
1 st_intersects(ncc[20:30,], air) %>% str()
```

```
List of 11
$ : int(0)
$ : int 268
$ : int 717
$ : int(0)
$ : int(0)
$ : int(0)
$ : int(0)
- attr(*, "predicate")= chr "intersects"
- attr(*, "region.id")= chr [1:11] "1" "2" "3" "4" ...
- attr(*, "remove_self")= logi FALSE
- attr(*, "retain_unique")= logi FALSE
- attr(*, "ncol")= int 940
- attr(*, "class")= chr [1:2] "sgbp" "list"
```

```
1 st_intersects(ncc, air, sparse=FALSE) %>% str()
```

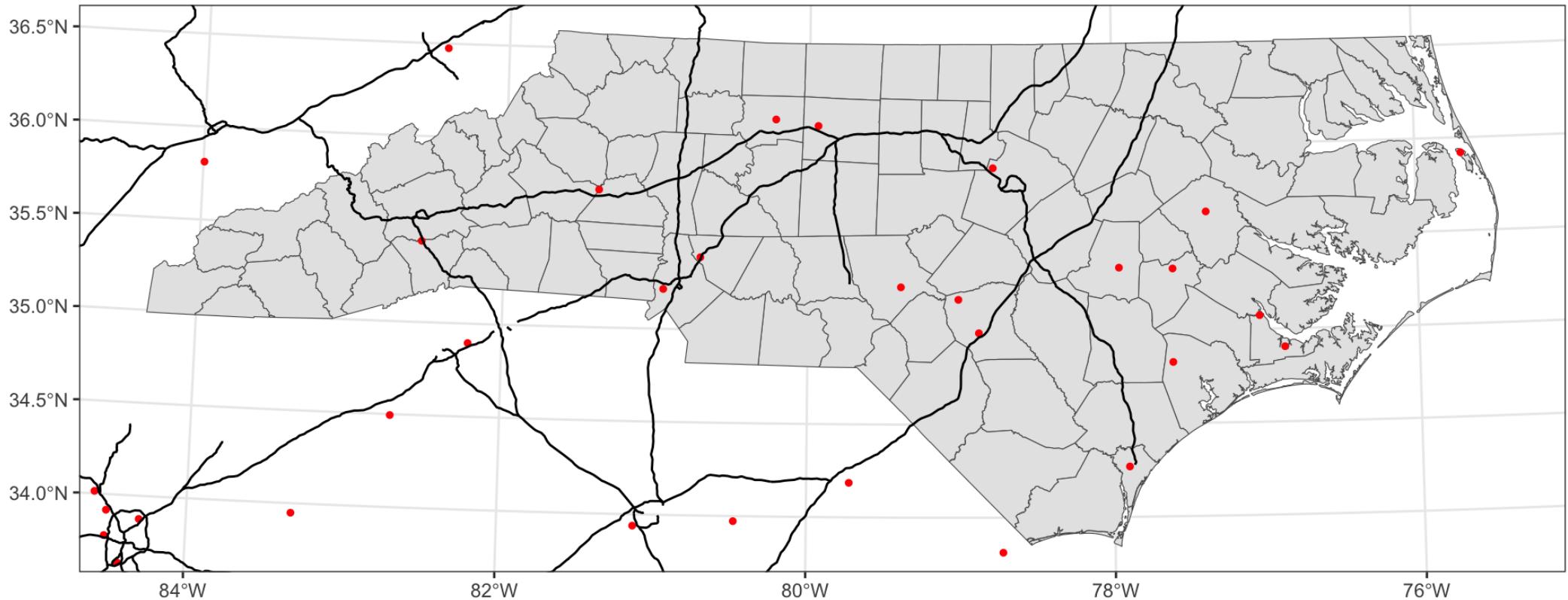
```
logi [1:100, 1:940] FALSE FALSE FALSE FALSE FALSE FALSE ...
```

Examples

- Which counties have an airport?
- Which counties are adjacent to Durham County?
- Which counties have more than 4 neighbors?

```
1 ncc = read_sf("data/gis/nc_counties/", quiet=TRUE) |> st_transform(3631)
2 air = read_sf("data/gis/airports/", quiet=TRUE) |> st_transform(3631)
3 hwy = read_sf("data/gis/us_interstates/", quiet=TRUE) |> st_transform(3631)
```

Data



Which counties have an airport?

```
1 ncc |>
2   select(COUNTY, geometry) |>
3   mutate(
4     airports = st_intersects(ncc, air) |> unclass(),
5     n = purrr::map_int(airports, length),
6     airport_names = purrr::map_chr(
7       airports,
8       ~ paste(air$AIRPT_NAME[.x], collapse=", "))
9     ) |>
10    filter(n > 0) |>
11    arrange(desc(n))
```

Simple feature collection with 16 features and 4 fields

Geometry type: MULTIPOLYGON

Dimension: XY

Bounding box: xmin: 257742.1 ymin: 20311.68 xmax: 930352.8 ymax: 280007

Projected CRS: NAD83(NSRS2007) / North Carolina

A tibble: 16 × 5

| | COUNTY | geometry | airports | n | airport_names |
|---|-------------------|---|----------|-------|-----------------|
| | <chr> | <MULTIPOLYGON [m]> | <list> | <int> | <chr> |
| 1 | Craven County | (((815892.7 133083, 815712 132990.1, 8... | <int> | 2 | Cherry Point... |
| 2 | Cumberland County | (((634732.8 168173.4, 634781.1 168150... | <int> | 2 | Pope Air For... |
| 3 | Forsyth County | (((480355.6 279558.3, 480622.3 279554... | <int> | 1 | Smith Reynol... |
| 4 | Guilford County | (((516951.1 278659.3, 517346.4 278644... | <int> | 1 | Piedmont Tri... |

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| | | | | |
|----|--------------------|--|---|-----------------|
| 5 | Dare County | ((925331.7 195868.4, 925150.9 195670... <int> | 1 | Dare County ... |
| 6 | Wake County | ((635486.1 258098.2, 635729.3 258098... <int> | 1 | Raleigh-Durh... |
| 7 | Pitt County | ((756611.7 231604, 757952.2 231061.2,... <int> | 1 | Pitt-Greenvi... |
| 8 | Catawba County | ((416107.9 232317.8, 416052.5 231678... <int> | 1 | Hickory Regi... |
| 9 | Buncombe County | ((304720 234673.2, 304825.7 234591.9,... <int> | 1 | Asheville Re... |
| 10 | Wayne County | ((700246.7 204130.8, 700364.9 204087... <int> | 1 | Seymour John... |
| 11 | Mecklenburg County | ((446654.6 196384.3, 446836 196381, 4... <int> | 1 | Charlotte/Do... |
| 12 | Moore County | ((577854 196164.2, 577890.8 195888.4,... <int> | 1 | Moore County... |
| 13 | Cabarrus County | ((453375.4 196276.2, 453511.2 196262... <int> | 1 | Concord Regi... |

Which counties neighbor Durham County?

```
1 ncc |>
2   select(COUNTY, geometry) |>
3   mutate(
4     touch_durham = st_touches(ncc, ncc) |> filter(COUNTY == "Durham County")) |> unclass(),
5     n_touches = map_int(touch_durham, length)
6   ) |>
7   filter(n_touches > 0)
```

Simple feature collection with 5 features and 3 fields

Geometry type: MULTIPOLYGON

Dimension: XY

Bounding box: xmin: 559195.8 ymin: 195938.7 xmax: 676918.6 ymax: 309925.7

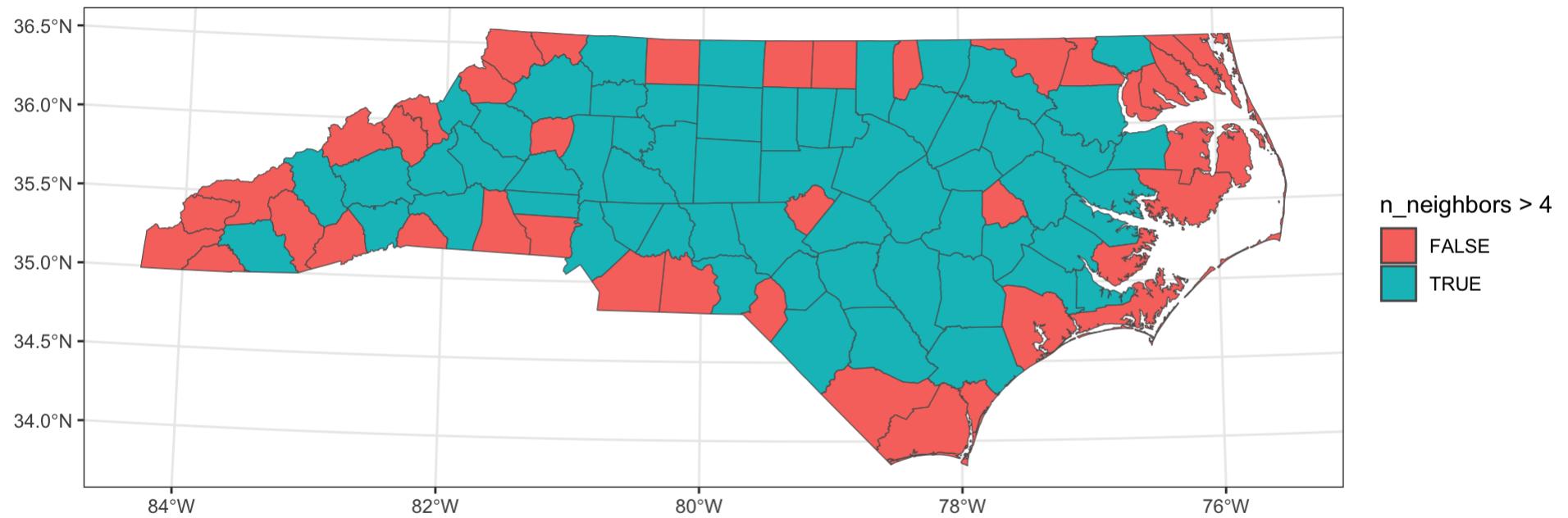
Projected CRS: NAD83(NSRS2007) / North Carolina

A tibble: 5 × 4

| | COUNTY | geometry | touch_durham | n_touches |
|---|------------------|---|--------------|-----------|
| * | <chr> | <MULTIPOLYGON [m]> | <list> | <int> |
| 1 | Person County | (((611470.1 309761.9, 611935.8 309762, 612123.9..., 611470.1 309761.9)) | <int [1]> | 1 |
| 2 | Granville County | (((658298.4 309773.1, 658351.6 309762.4, 658405..., 658298.4 309773.1)) | <int [1]> | 1 |
| 3 | Orange County | (((586623.3 276687.6, 587090.7 276675.3, 587378..., 586623.3 276687.6)) | <int [1]> | 1 |
| 4 | Wake County | (((635486.1 258098.2, 635729.3 258098.9, 635815..., 635486.1 258098.2)) | <int [1]> | 1 |
| 5 | Chatham County | (((589371.3 235671.1, 589560.8 235648.5, 589606..., 589371.3 235671.1)) | <int [1]> | 1 |

Which counties have more than 4 neighbors?

```
1 ncc |>
2   mutate(
3     neighbors = st_touches(ncc) |> unclass(),
4     n_neighbors = map_int(neighbors, length)
5   ) |>
6   ggplot(aes(fill = n_neighbors > 4)) +
7   geom_sf()
```



Geometry Manipulation

Casting

```
1 (nc_pts = st_cast(nc, "MULTIPOINT"))
```

Simple feature collection with 100 features and 7 fields

Geometry type: MULTIPOINT

Dimension: XY

Bounding box: xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965

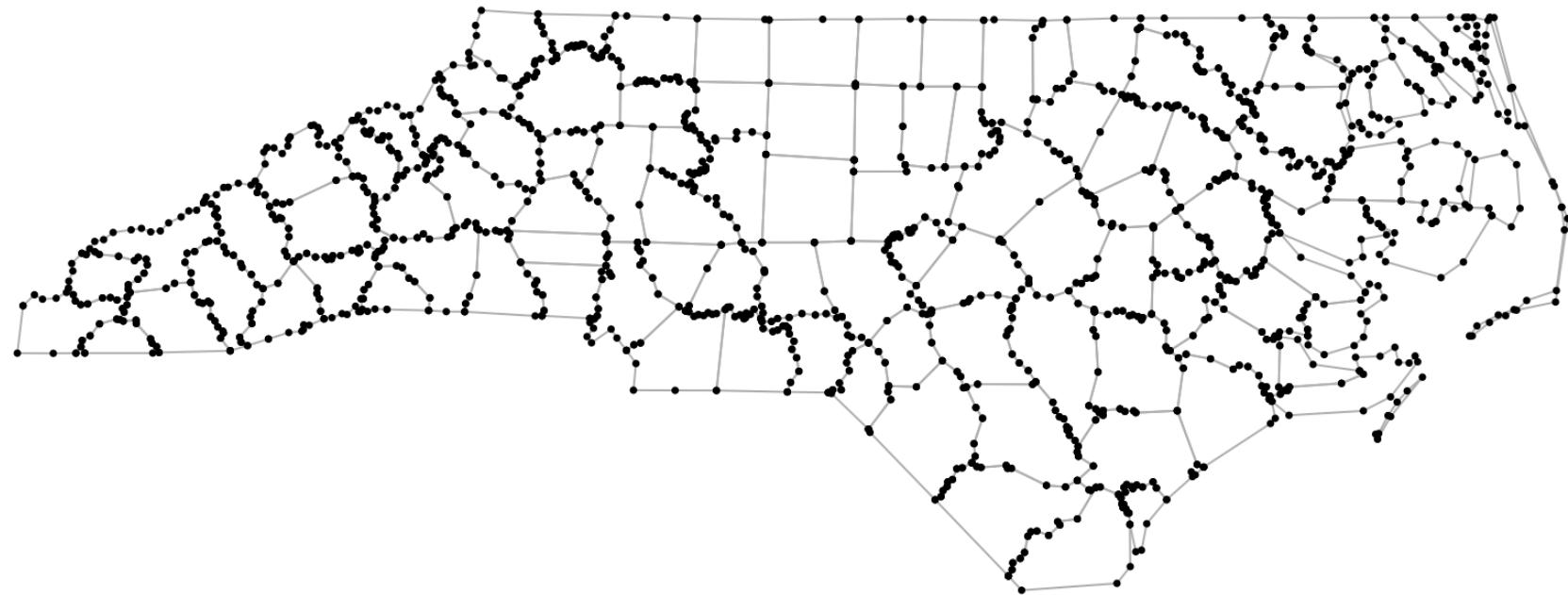
Geodetic CRS: NAD27

A tibble: 100 × 8

| | NAME | BIR74 | SID74 | NWBIR74 | BIR79 | SID79 | NWBIR79 | geometry |
|----|--------------|-------|-------|---------|-------|-------|---------|---------------------------------------|
| | <chr> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <MULTIPOINT [°]> |
| 1 | Ashe | 1091 | 1 | 10 | 1364 | 0 | 19 | ((-81.47276 36.23436), (-81.54084 ... |
| 2 | Alleghany | 487 | 0 | 10 | 542 | 3 | 12 | ((-81.23989 36.36536), (-81.24069 ... |
| 3 | Surry | 3188 | 5 | 208 | 3616 | 6 | 260 | ((-80.45634 36.24256), (-80.47639 ... |
| 4 | Currituck | 508 | 1 | 123 | 830 | 2 | 145 | ((-76.00897 36.3196), (-76.01735 3... |
| 5 | Northhampton | 1421 | 9 | 1066 | 1606 | 3 | 1197 | ((-77.21767 36.24098), (-77.23461 ... |
| 6 | Hertford | 1452 | 7 | 954 | 1838 | 5 | 1237 | ((-76.74506 36.23392), (-76.98069 ... |
| 7 | Camden | 286 | 0 | 115 | 350 | 2 | 139 | ((-76.00897 36.3196), (-75.95718 3... |
| 8 | Gates | 420 | 0 | 254 | 594 | 2 | 371 | ((-76.56251 36.34057), (-76.60424 ... |
| 9 | Warren | 968 | 4 | 748 | 1190 | 2 | 844 | ((-78.30876 36.26004), (-78.28293 ... |
| 10 | Stokes | 1612 | 1 | 160 | 2038 | 5 | 176 | ((-80.02567 36.25023), (-80.45301 ... |

i 90 more rows

```
1 plot(st_geometry(nc), border='grey')
2 plot(st_geometry(nc_pts), pch=16, cex=0.5, add=TRUE)
```

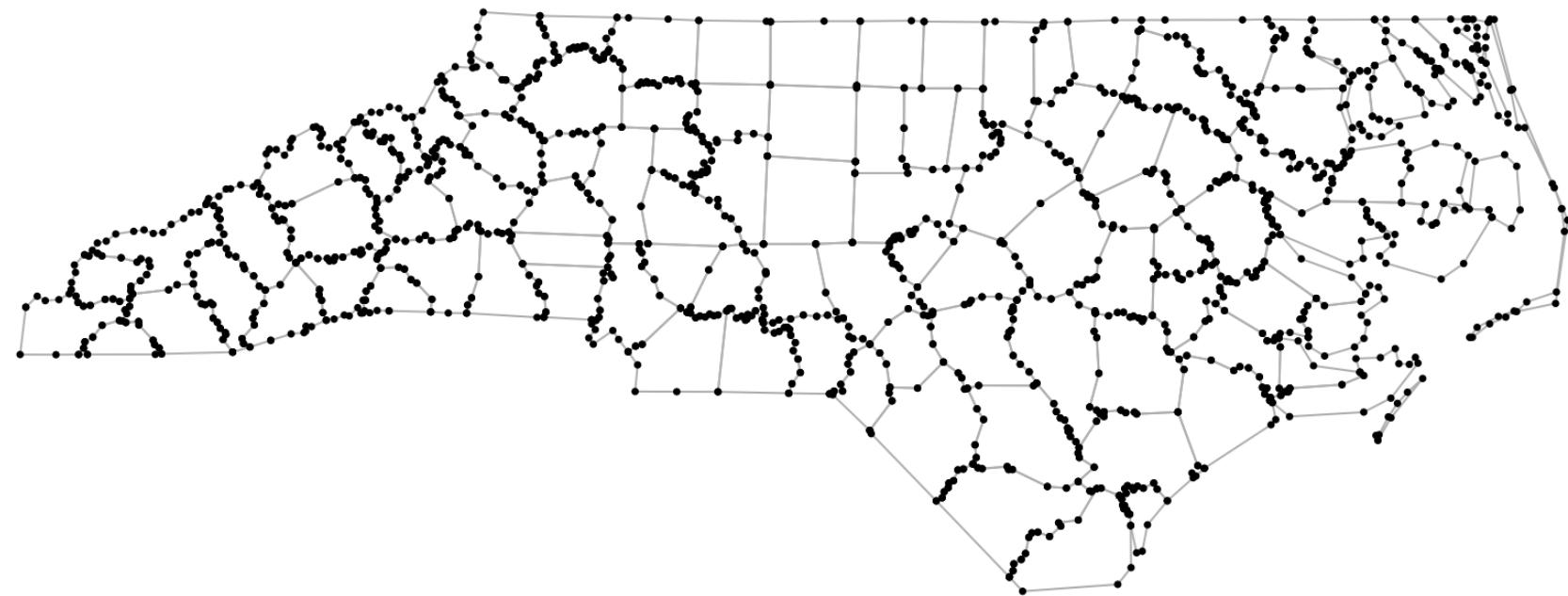


Casting - POINT

```
1 st_cast(nc, "POINT")
```

```
Simple feature collection with 2529 features and 7 fields
Geometry type: POINT
Dimension:      XY
Bounding box:   xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965
Geodetic CRS:   NAD27
# A tibble: 2,529 × 8
  NAME    BIR74  SID74  NWBIR74  BIR79  SID79  NWBIR79       geometry
  <chr> <dbl>  <dbl>    <dbl>  <dbl>  <dbl>    <dbl>    <POINT [°]>
1 Ashe     1091     1        10    1364     0        19 (-81.47276 36.23436)
2 Ashe     1091     1        10    1364     0        19 (-81.54084 36.27251)
3 Ashe     1091     1        10    1364     0        19 (-81.56198 36.27359)
4 Ashe     1091     1        10    1364     0        19 (-81.63306 36.34069)
5 Ashe     1091     1        10    1364     0        19 (-81.74107 36.39178)
6 Ashe     1091     1        10    1364     0        19 (-81.69828 36.47178)
7 Ashe     1091     1        10    1364     0        19 (-81.7028 36.51934)
8 Ashe     1091     1        10    1364     0        19 (-81.67 36.58965)
9 Ashe     1091     1        10    1364     0        19 (-81.3453 36.57286)
10 Ashe    1091     1        10    1364     0        19 (-81.34754 36.53791)
# i 2,519 more rows
```

```
1 plot(st_geometry(nc), border='grey')
2 plot(st_geometry(st_cast(nc, "POINT"))), pch=16, cex=0.5, add=TRUE)
```



Casting - LINESTRING

```
1 st_cast(nc, "MULTILINESTRING")
```

Simple feature collection with 100 features and 7 fields

Geometry type: MULTILINESTRING

Dimension: XY

Bounding box: xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965

Geodetic CRS: NAD27

A tibble: 100 × 8

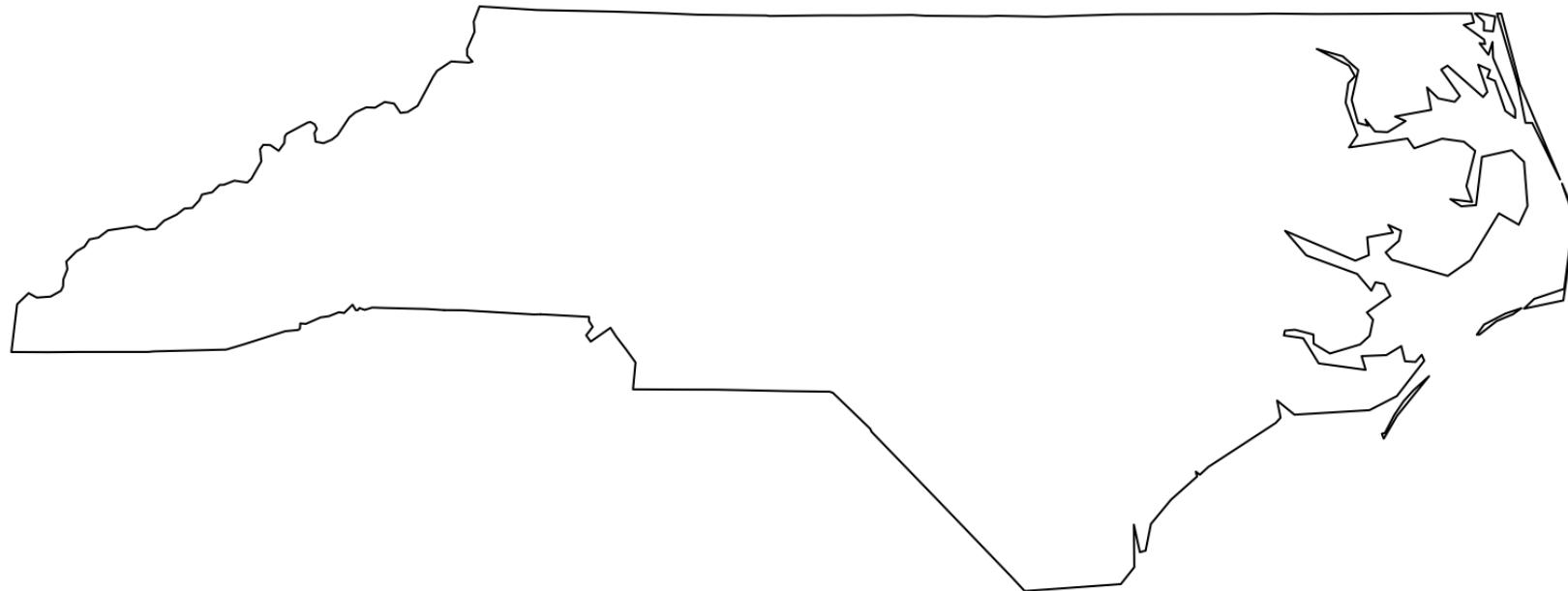
| | NAME | BIR74 | SID74 | NWBIR74 | BIR79 | SID79 | NWBIR79 | geometry |
|------------------|--------------|-------|-------|---------|-------|-------|---------|---------------------------------------|
| | <chr> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <dbl> | <MULTILINESTRING [°]> |
| 1 | Ashe | 1091 | 1 | 10 | 1364 | 0 | 19 | ((-81.47276 36.23436, -81.54084 36... |
| 2 | Alleghany | 487 | 0 | 10 | 542 | 3 | 12 | ((-81.23989 36.36536, -81.24069 36... |
| 3 | Surry | 3188 | 5 | 208 | 3616 | 6 | 260 | ((-80.45634 36.24256, -80.47639 36... |
| 4 | Currituck | 508 | 1 | 123 | 830 | 2 | 145 | ((-76.00897 36.3196, -76.01735 36... |
| 5 | Northhampton | 1421 | 9 | 1066 | 1606 | 3 | 1197 | ((-77.21767 36.24098, -77.23461 36... |
| 6 | Hertford | 1452 | 7 | 954 | 1838 | 5 | 1237 | ((-76.74506 36.23392, -76.98069 36... |
| 7 | Camden | 286 | 0 | 115 | 350 | 2 | 139 | ((-76.00897 36.3196, -75.95718 36... |
| 8 | Gates | 420 | 0 | 254 | 594 | 2 | 371 | ((-76.56251 36.34057, -76.60424 36... |
| 9 | Warren | 968 | 4 | 748 | 1190 | 2 | 844 | ((-78.30876 36.26004, -78.28293 36... |
| 10 | Stokes | 1612 | 1 | 160 | 2038 | 5 | 176 | ((-80.02567 36.25023, -80.45301 36... |
| # i 90 more rows | | | | | | | | |

```
1 st_cast(nc, "MULTILINESTRING") |> st_geometry() |> plot()
```



Grouping Features

```
1 nc_state = st_union(nc)
2 plot(nc_state)
```

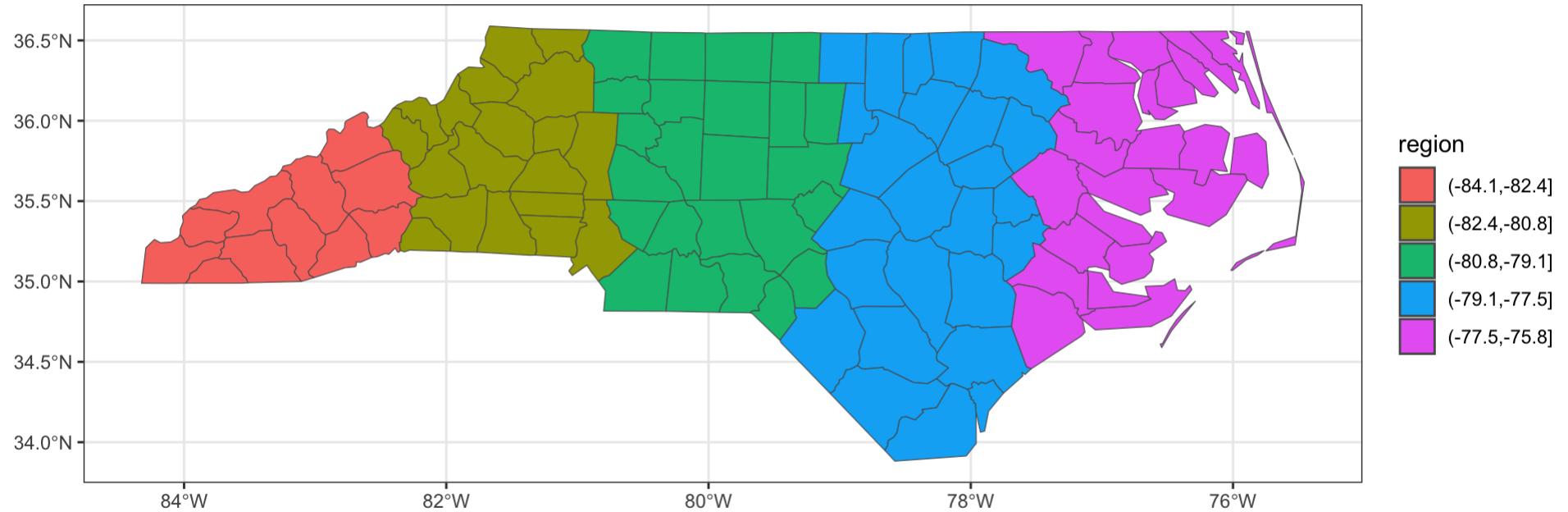


More Grouping

```
1 ( nc_cut = nc |>
  2   mutate(X = st_centroid(nc) |> st_coordinates() |> (\(x) x[,1]))() |>
  3   mutate(region = cut(X, breaks = 5)) )
```

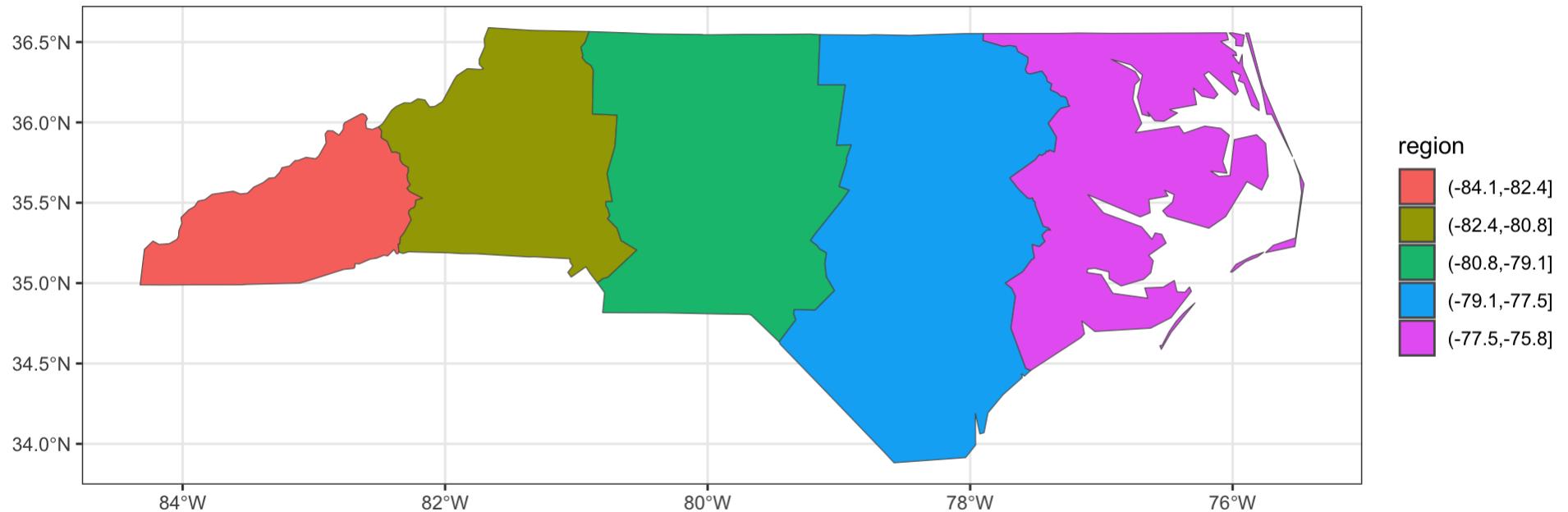
```
Simple feature collection with 100 features and 9 fields
Geometry type: MULTIPOLYGON
Dimension:      XY
Bounding box:   xmin: -84.32385 ymin: 33.88199 xmax: -75.45698 ymax: 36.58965
Geodetic CRS:   NAD27
# A tibble: 100 × 10
  NAME    BIR74  SID74  NWBIR74  BIR79  SID79  NWBIR79      geometry     x region
* <chr>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <dbl>  <MULTIPOLYGON [°]> <dbl> <fct>
  1 Ashe     1091     1      10    1364     0      19 (((-81.47276 36.23436, ...
  2 Allegha... 487      0      10     542     3      12 (((-81.23989 36.36536, ...
  3 Surry    3188      5     208    3616     6      260 (((-80.45634 36.24256, ...
  4 Curritu... 508      1     123     830     2      145 (((-76.00897 36.3196, ...
  5 Northam... 1421      9    1066    1606     3      1197 (((-77.21767 36.24098, ...
  6 Hertford 1452      7     954    1838     5      1237 (((-76.74506 36.23392, ...
  7 Camden    286      0     115     350     2      139 (((-76.00897 36.3196, ...
  8 Gates     420      0     254     594     2      371 (((-76.56251 36.34057, ...
  9 Warren    968      4     748    1190     2      844 (((-78.30876 36.26004, ...
 10 Stokes   1612      1     160    2038     5      176 (((-80.02567 36.25023, ...
# i 90 more rows
```

```
1 ggplot(nc_cut) +  
2   geom_sf(aes(fill=region))
```



Union via summarize

```
1 nc_cut |>
2   group_by(region) |>
3   summarize() |>
4   ggplot() +
5     geom_sf(aes(fill=region))
```



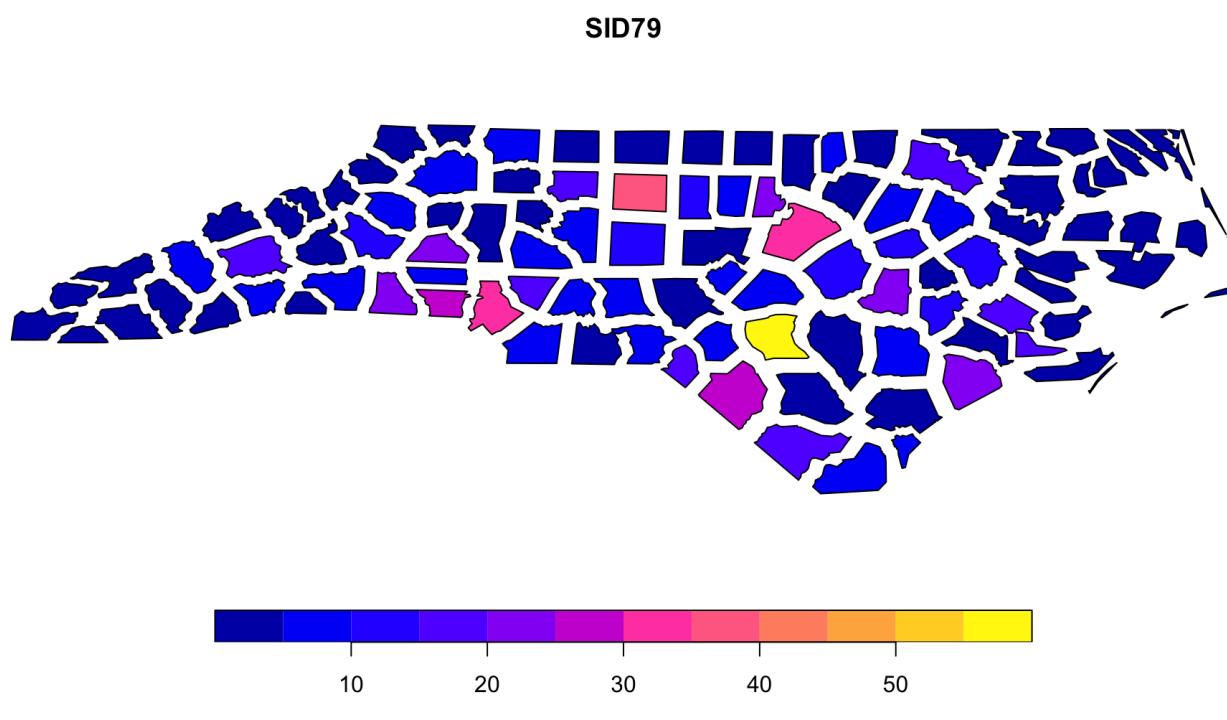
Affine Transformations

```
1 rotate = function(a) matrix(c(cos(a), sin(a), -sin(a), cos(a)), 2, 2)
2
3 ctrd = st_centroid(nc_state)
4 state_rotate = (nc_state) * rotate(-pi/4)
5 plot(state_rotate, axes=TRUE)
```



Scaling Size

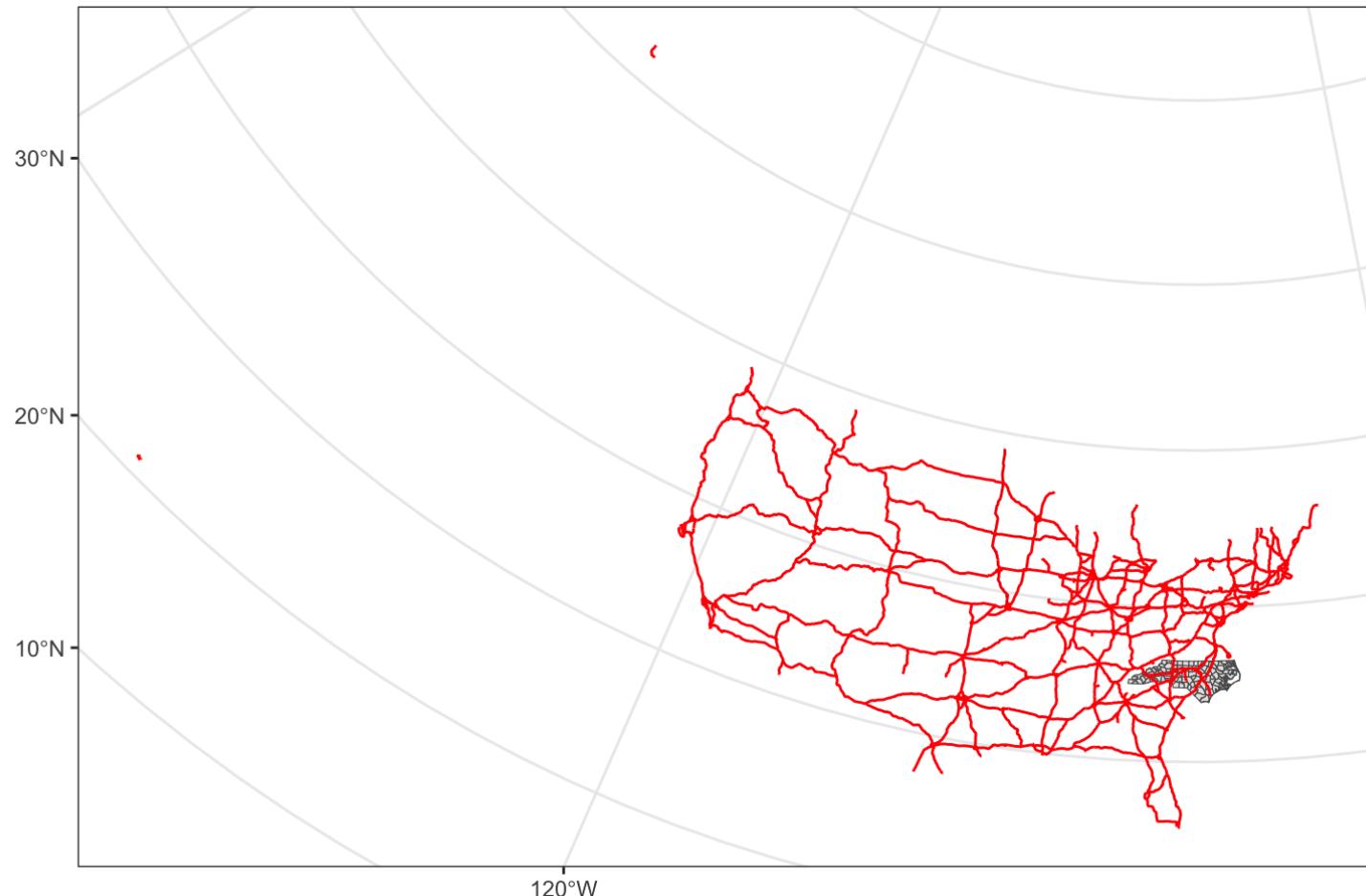
```
1 ctrd = st_centroid(st_geometry(nc))
2 area = st_area(nc) |> strip_attrs()
3
4 nc_rot = nc
5 st_geometry(nc_rot) = (st_geometry(nc) - ctrd) * 0.75 + ctrd
6
7 plot(nc_rot[, "SID79"])
```



Highway Example

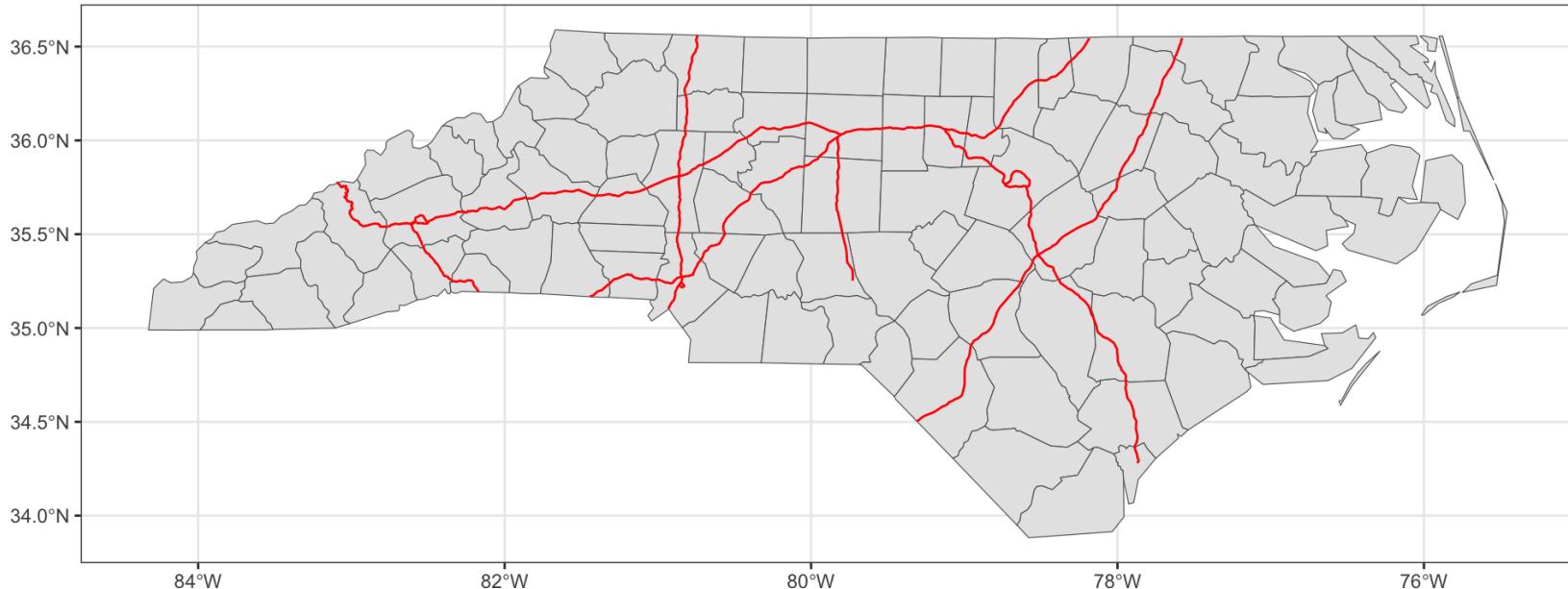
Highways

```
1 ggplot() +  
2   geom_sf(data=ncc) +  
3   geom_sf(data=hwy, col='red')
```



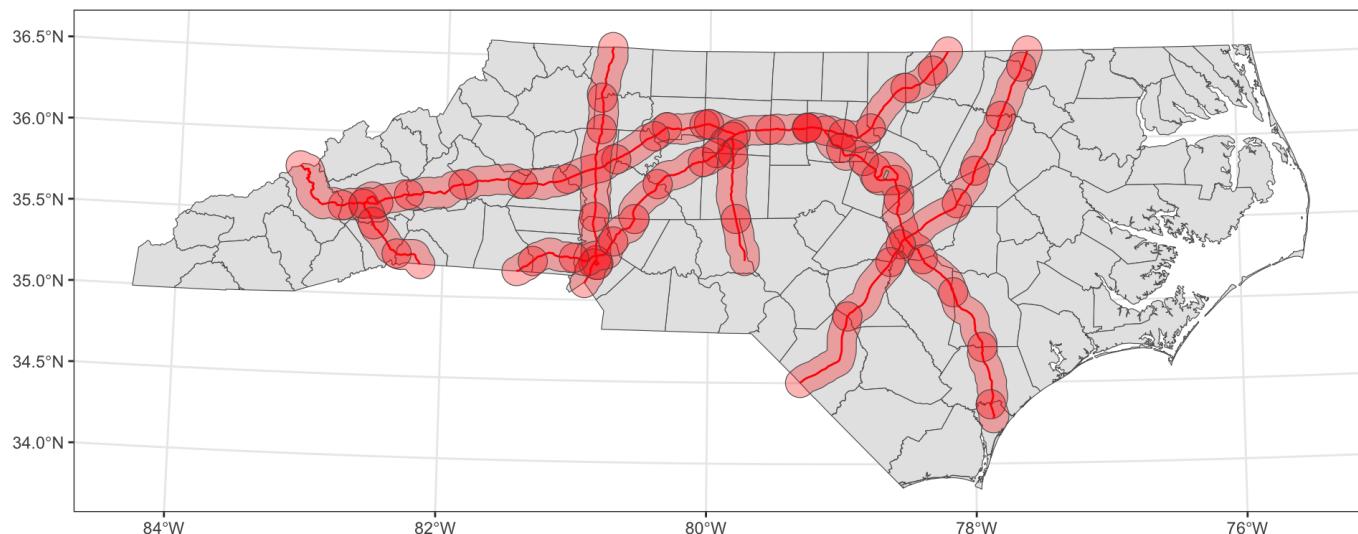
NC Interstate Highways

```
1 hwy_nc = st_intersection(hwy, ncc)
2
3 ggplot() +
4   geom_sf(data=ncc) +
5   geom_sf(data=hwy_nc, col='red')
```



Counties near the interstate (Buffering)

```
1 hwy_nc_buffer = hwy_nc |>  
2   st_buffer(10000)  
3  
4 ggplot() +  
5   geom_sf(data=ncc) +  
6   geom_sf(data=hwy_nc, color='red') +  
7   geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```



Counties near the interstate (Buffering + Union)

```
1 hwy_nc_buffer = hwy_nc |>  
2   st_buffer(10000) |>  
3   st_union() |>  
4   st_sf()
```

```
1 ggplot() +  
2   geom_sf(data=ncc) +  
3   geom_sf(data=hwy_nc, color='red') +  
4   geom_sf(data=hwy_nc_buffer, fill='red', alp
```

Example

How many counties in North Carolina are within 5, 10, 20, or 50 km of an interstate highway?

```
1 hwy_nc |>
2   st_buffer(10000) |>
3   st_union() |>
4   st_intersects(ncc, y = _) |>
5   map_lgl(~ length(.x) >= 1) |>
6   sum()
```

```
[1] 55
```

Gerrymandering Example

NC House Districts - 112th Congress

```
1 nc_house = read_sf("data/nc_districts112.gpkg", quiet = TRUE) |>
2   select(ID, DISTRICT) |>
3   mutate(DISTRICT = as_factor(DISTRICT))
4 )
```

Simple feature collection with 13 features and 2 fields

Geometry type: MULTIPOLYGON

Dimension: XY

Bounding box: xmin: -84.32187 ymin: 33.84452 xmax: -75.45998 ymax: 36.58812

Geodetic CRS: WGS 84

A tibble: 13 × 3

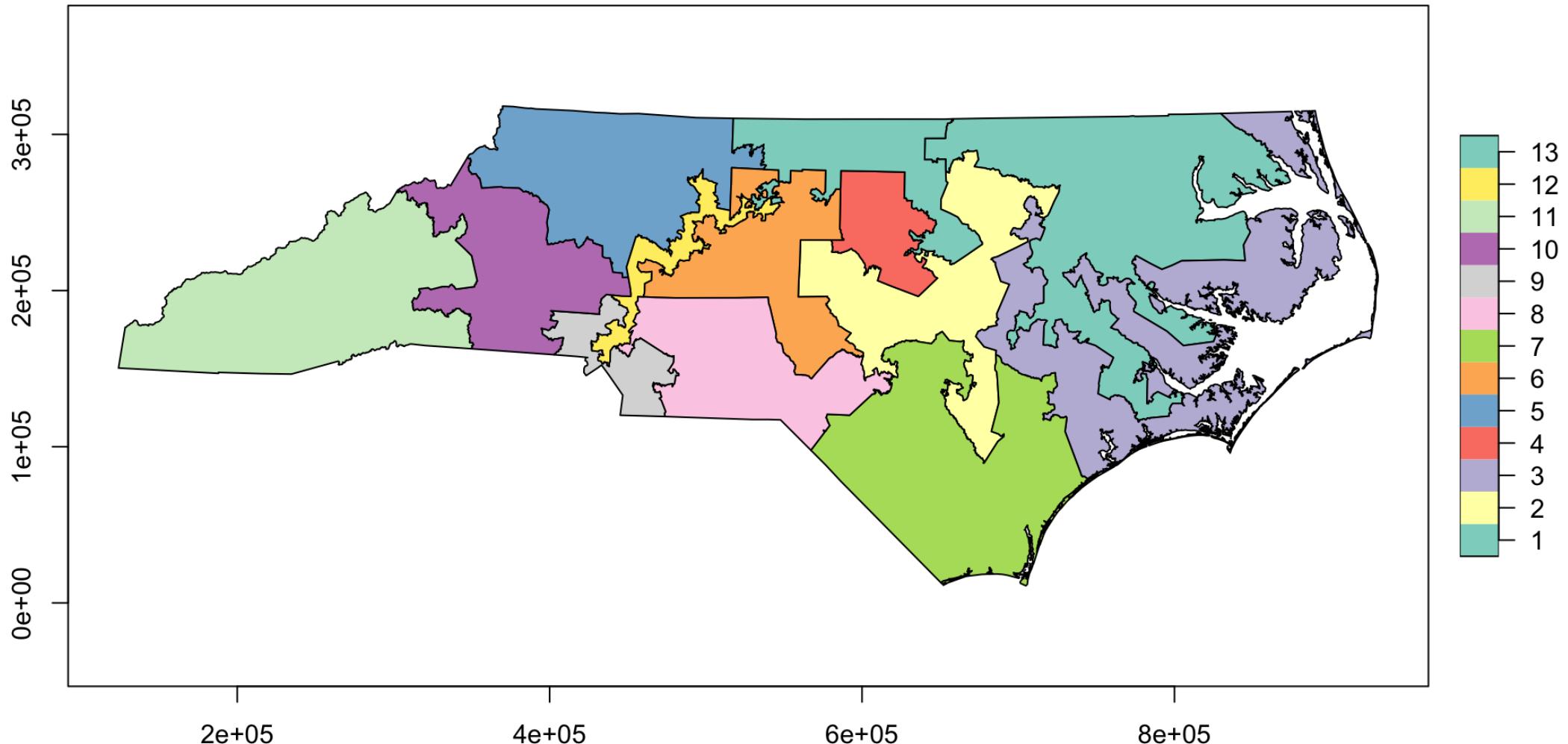
| | ID | DISTRICT | geom |
|---|--------------|----------|--|
| * | <chr> | <fct> | <MULTIPOLYGON [°]> |
| 1 | 037108112001 | 1 | (((-77.32845 35.35031, -77.35398 35.32799, -77.33... |
| 2 | 037108112002 | 2 | (((-78.89928 35.12619, -78.89763 35.12859, -78.89... |
| 3 | 037108112003 | 3 | (((-75.68266 35.23291, -75.68113 35.23237, -75.68... |
| 4 | 037108112004 | 4 | (((-78.77926 35.78568, -78.77947 35.77568, -78.79... |
| 5 | 037108112005 | 5 | (((-79.8968 36.38075, -79.89213 36.37108, -79.892... |
| 6 | 037108112006 | 6 | (((-80.4201 35.68953, -80.41483 35.68918, -80.411... |
| 7 | 037108112007 | 7 | (((-77.59169 34.40907, -77.58699 34.40611, -77.58... |
| 8 | 037108112008 | 8 | (((-78.93373 34.95909, -78.94074 34.95789, -78.94... |

9 037108112009 9

(((-80.93058 35.18181, -80.9244 35.16754, -80.921...

```
1 nc_house = st_transform(nc_house, 3631)
2 plot(nc_house[, "DISTRICT"], axes=TRUE)
```

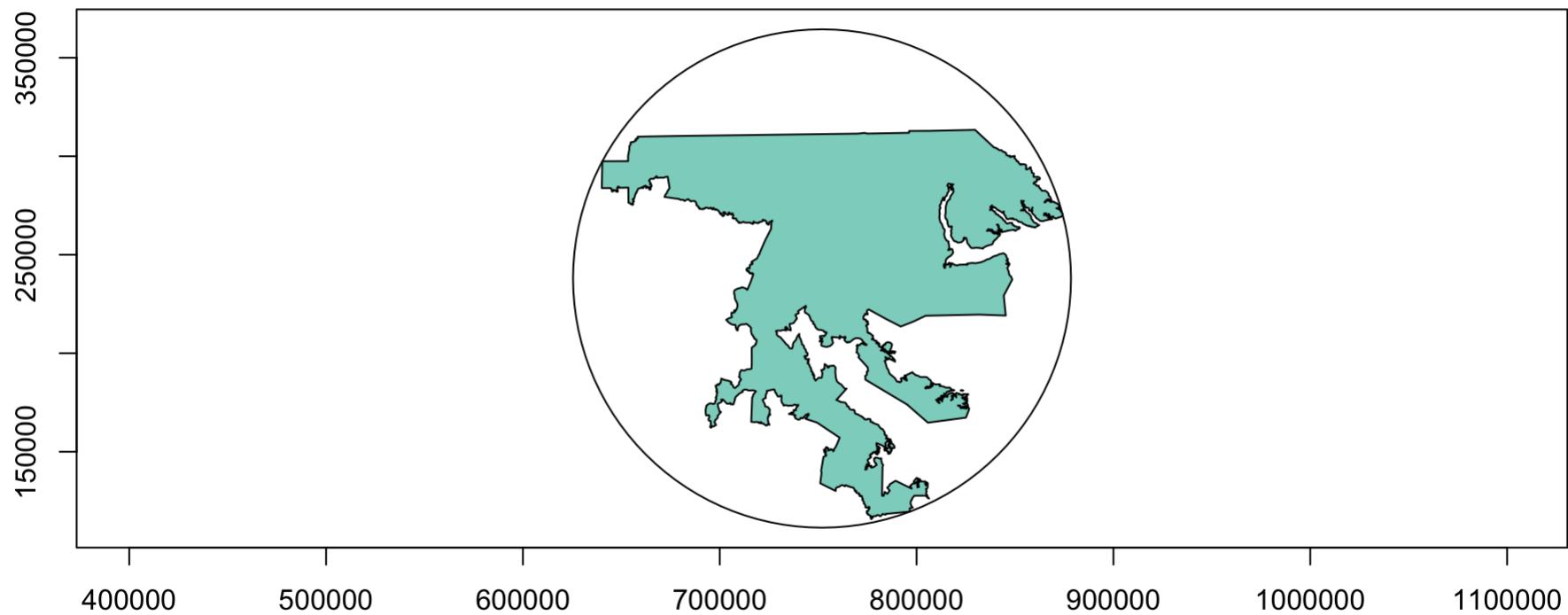
DISTRICT



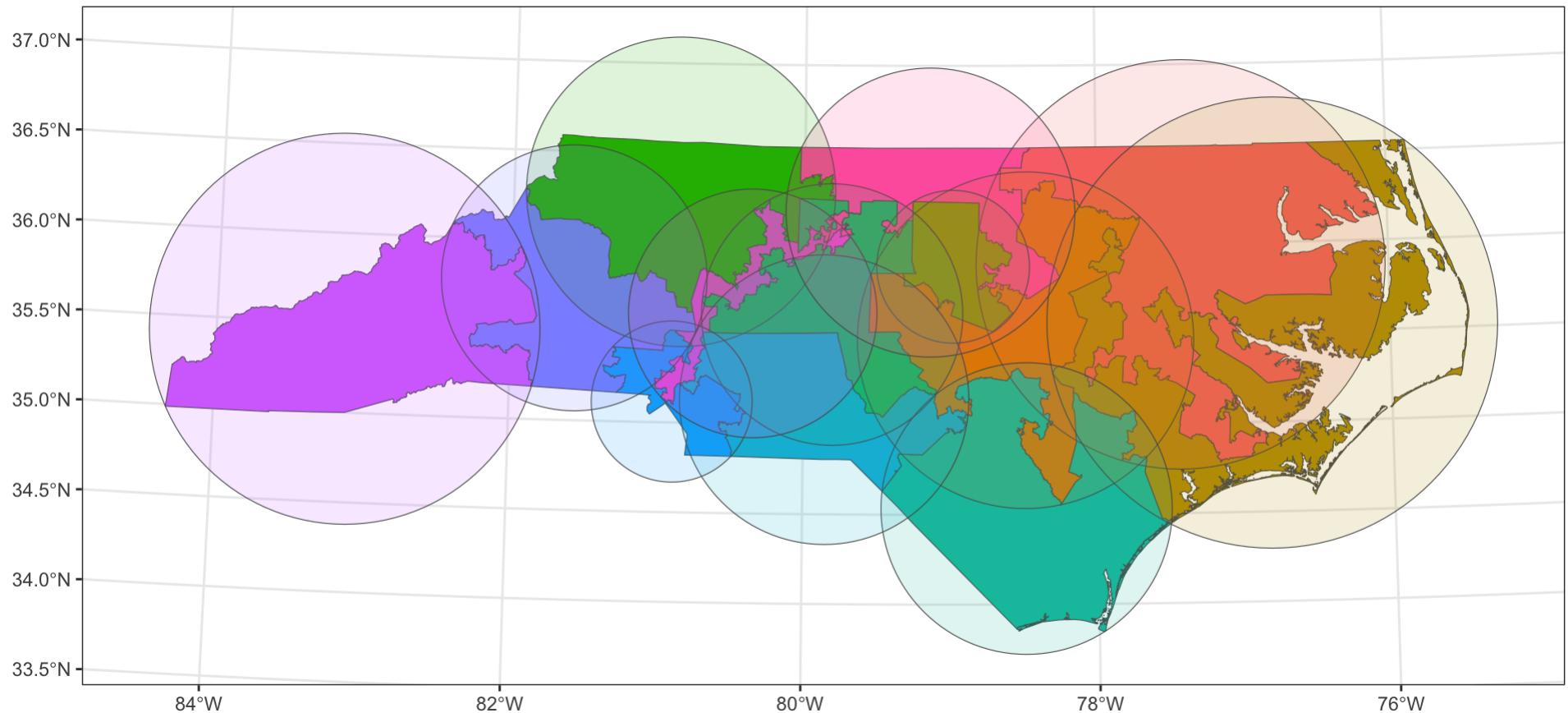
Measuring Compactness - Reock Score

The Reock score is a measure of compactness that is calculated as the ratio of the area of a shape to the area of its minimum bounding circle.

```
1 circs = nc_house |>
2   lwgeom::st_minimum_bounding_circle()
3
4 plot(circs |> filter(DISTRICT == 1) |> st_geometry(), axes=TRUE)
5 plot(nc_house |> select(DISTRICT) |> filter(DISTRICT == 1), add=TRUE)
```

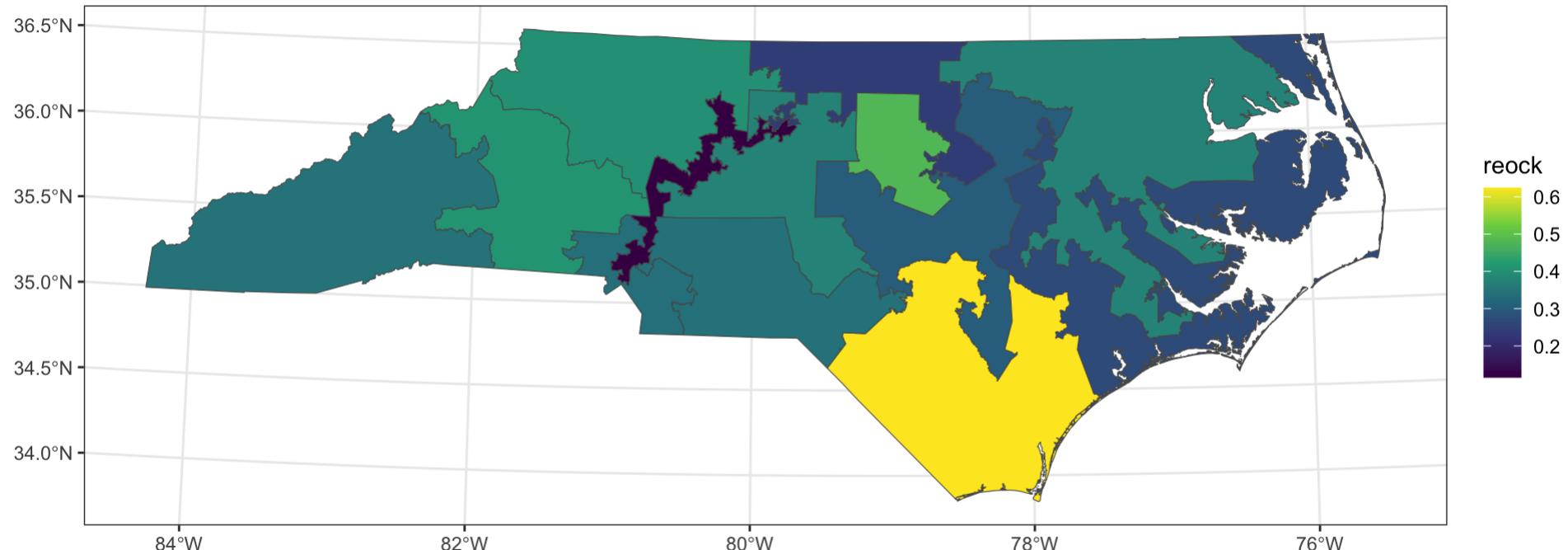


```
1 ggplot(mapping = aes(fill=DISTRICT)) +  
2   geom_sf(data=nc_house) +  
3   geom_sf(data=circs, alpha=0.15) +  
4   guides(color="none", fill="none")
```



Calculating Reock

```
1 nc_house |>  
2   mutate(reock = (st_area(nc_house) / st_area(circs)) |> as.numeric()) |>  
3   ggplot(aes(fill = reock)) +  
4     geom_sf() +  
5     scale_fill_viridis_c()
```



```

1 nc_house |>
2   mutate(reock = st_area(nc_house) / st_area(circs)) |>
3   arrange(reock) |>
4   print(n=13)

```

Simple feature collection with 13 features and 3 fields

Geometry type: MULTIPOLYGON

Dimension: XY

Bounding box: xmin: 123998.5 ymin: 10979.77 xmax: 930346 ymax: 318095.3

Projected CRS: NAD83(NSRS2007) / North Carolina

A tibble: 13 × 4

| | ID | DISTRICT | geom | reock |
|----|--------------|----------|---|-------|
| | <chr> | <fct> | <MULTIPOLYGON [m]> | [1] |
| 1 | 037108112012 | 12 | ((473814.9 211717.3, 472007.4 209951.4, 47... | 0.116 |
| 2 | 037108112013 | 13 | ((528146.8 292339.5, 528222.3 292562.4, 52... | 0.237 |
| 3 | 037108112003 | 3 | ((911479.9 169543.9, 911621.3 169488.3, 91... | 0.266 |
| 4 | 037108112002 | 2 | ((618780.6 152664.8, 618930.2 152932.2, 61... | 0.303 |
| 5 | 037108112009 | 9 | ((433786.4 160540.2, 434318.7 158946.9, 43... | 0.339 |
| 6 | 037108112008 | 8 | ((615653.2 134126.5, 615013 133993.3, 6147... | 0.342 |
| 7 | 037108112011 | 11 | ((154791.1 191470.8, 154769.4 192168.1, 15... | 0.344 |
| 8 | 037108112006 | 6 | ((481076.7 216074.5, 481553 216028, 481879... | 0.378 |
| 9 | 037108112001 | 1 | ((761514.7 178801.2, 759235.4 176286.8, 76... | 0.378 |
| 10 | 037108112005 | 5 | ((529128.7 292213.3, 529538 291136.4, 5294... | 0.399 |
| 11 | 037108112010 | 10 | ((424301.6 185435.1, 400728.7 187075, 4018... | 0.411 |
| 12 | 037108112004 | 4 | ((629556.3 225844, 629539.1 224734.4, 6281... | 0.480 |
| 13 | 037108112007 | 7 | ((739073.9 74030.77, 739510.2 73709.48, 73... | 0.624 |

Raster Data (stars)

Example data - Meuse

```
1 ( meuse_rast = stars::read_stars(  
2     system.file("external/test.grd", package="raster")  
3   ) |>  
4     st_transform(st_crs(meuse_riv))  
5   )
```

stars object with 2 dimensions and 1 attribute

attribute(s):

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. | NA's |
|----------|----------|----------|----------|---------|----------|----------|------|
| test.grd | 138.7071 | 293.9575 | 371.9001 | 425.606 | 501.0102 | 1736.058 | 6022 |

dimension(s):

| | from | to | refsys | values | x/y |
|---|------|-----|------------------------------|-------------------|-----|
| x | 1 | 80 | Amersfoort / RD New [80x115] | 178451,...,181611 | [x] |
| y | 1 | 115 | Amersfoort / RD New [80x115] | 329530,...,334090 | [y] |

curvilinear grid

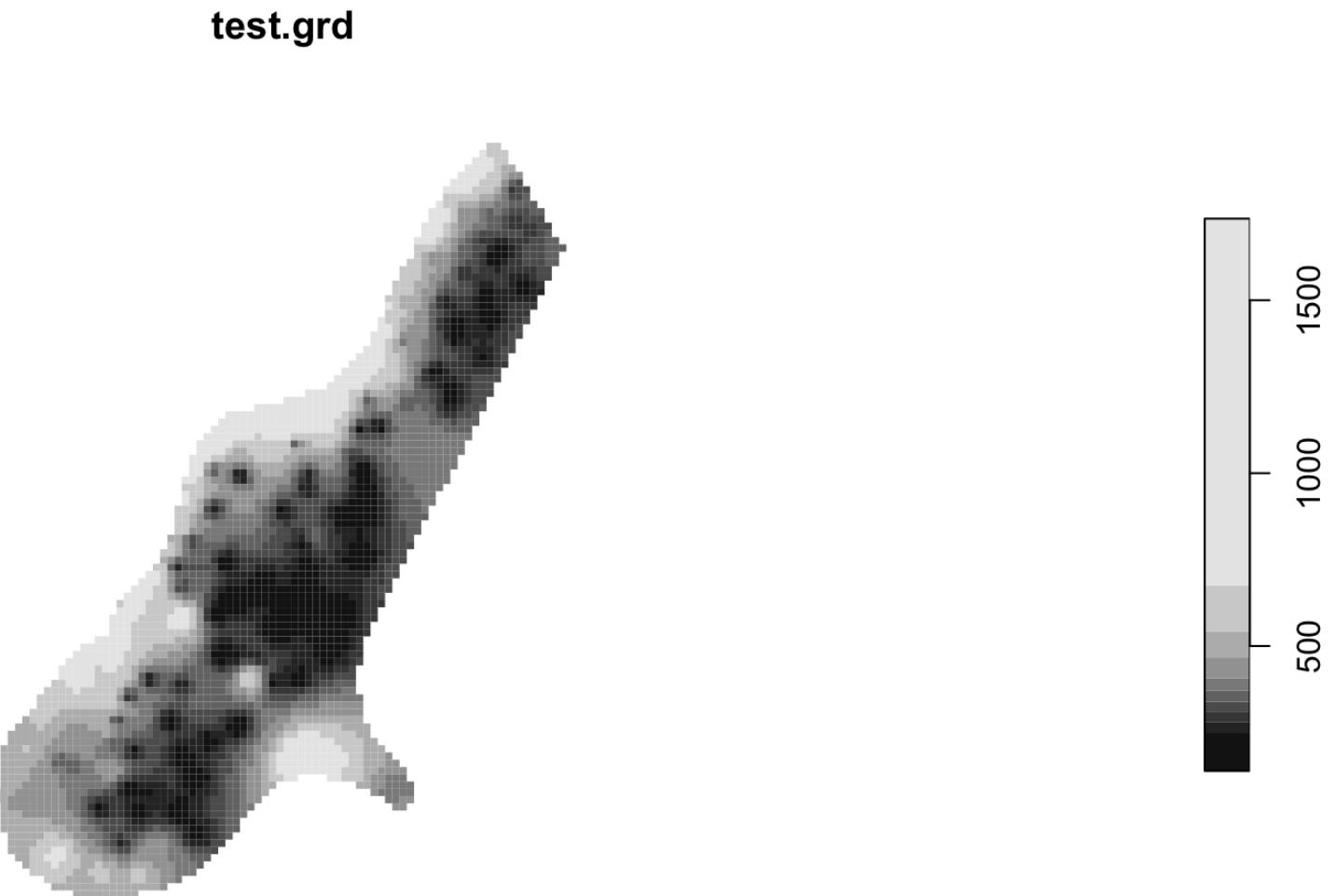
stars class

```
1 str(meuse_rast)
```

```
List of 1
$ test.grd: num [1:80, 1:115] NA ...
- attr(*, "dimensions")=List of 2
..$ x:List of 7
.. ..$ from : num 1
.. ..$ to : num 80
.. ..$ offset: num NA
.. ..$ delta : num NA
.. ..$ refsys:List of 2
.. .. ..$ input: chr "EPSG:28992"
.. .. ..$ wkt : chr "PROJCRS[\\"Amersfoort / RD New\\",\n      BASEGEOGCRS[\\"Amersfoort\\",\nDATUM[\\"Amersfoort\\",\n          E" | __truncated__
.. .. ...- attr(*, "class")= chr "crs"
.. ..$ point : logi NA
.. ..$ values: num [1:80, 1:115] 178451 178491 178531 178571 178611 ...
.. ..- attr(*, "class")= chr "dimension"
..$ y:List of 7
.. ..$ from : num 1
.. ..$ to : num 115
.. ..$ offset: num NA
.. ..$ delta : num NA
  ^-----^
```

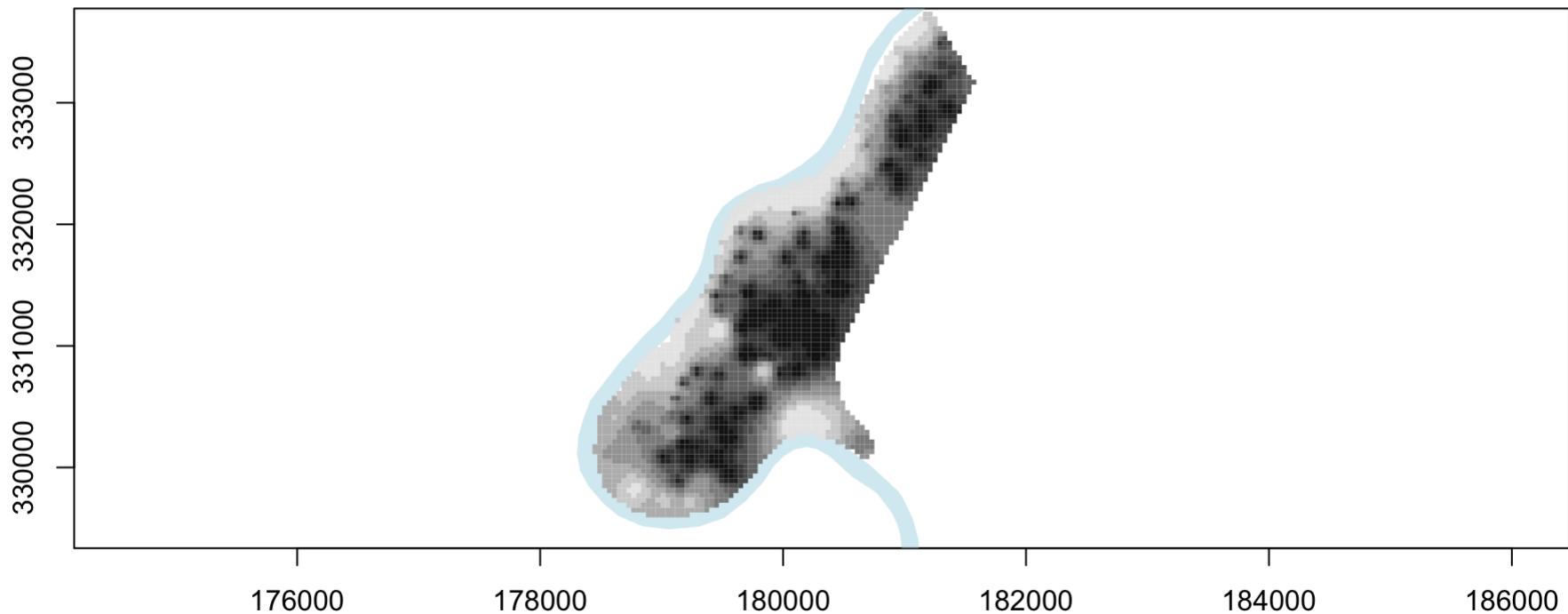
Plotting

```
1 plot(meuse_rast)
```



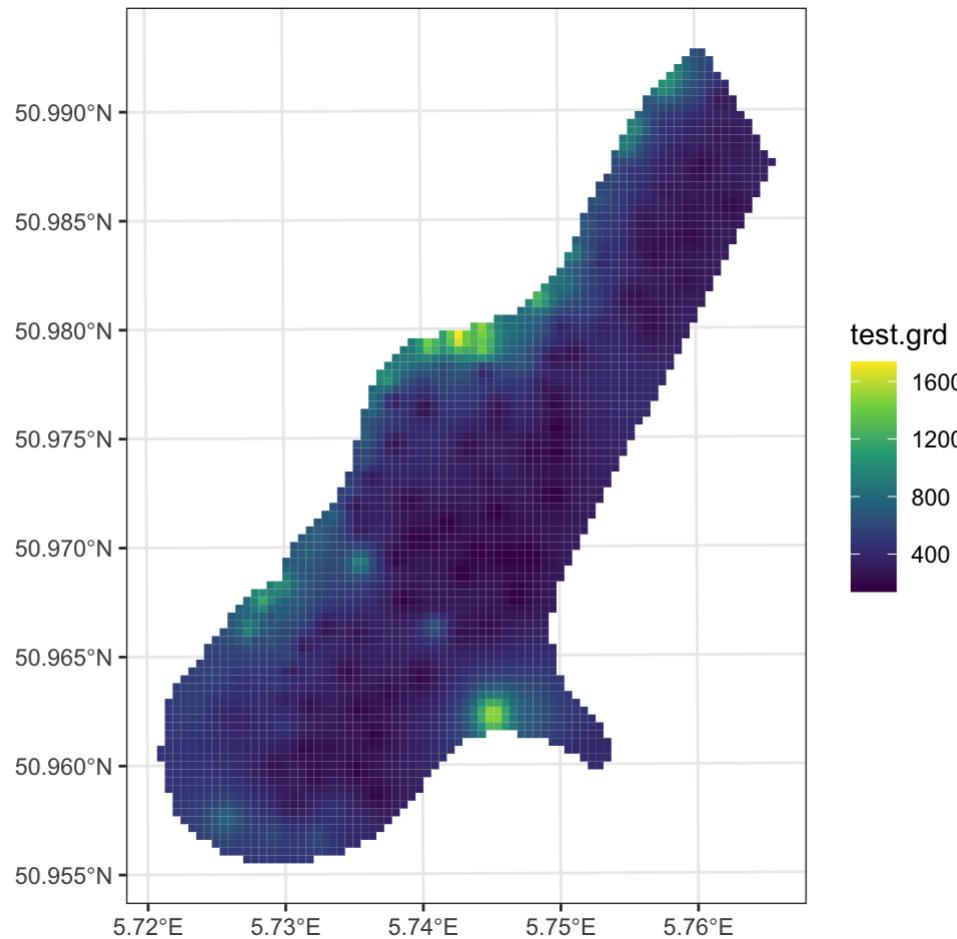
```
1 plot(  
2   meuse_riv,  
3   col=adjustcolor("lightblue",alpha.f = 0.5), border=NA,  
4   ylim = c(329500, 333611), axes=TRUE  
5 )  
6 plot(meuse_rast, add=TRUE)
```

test.grd

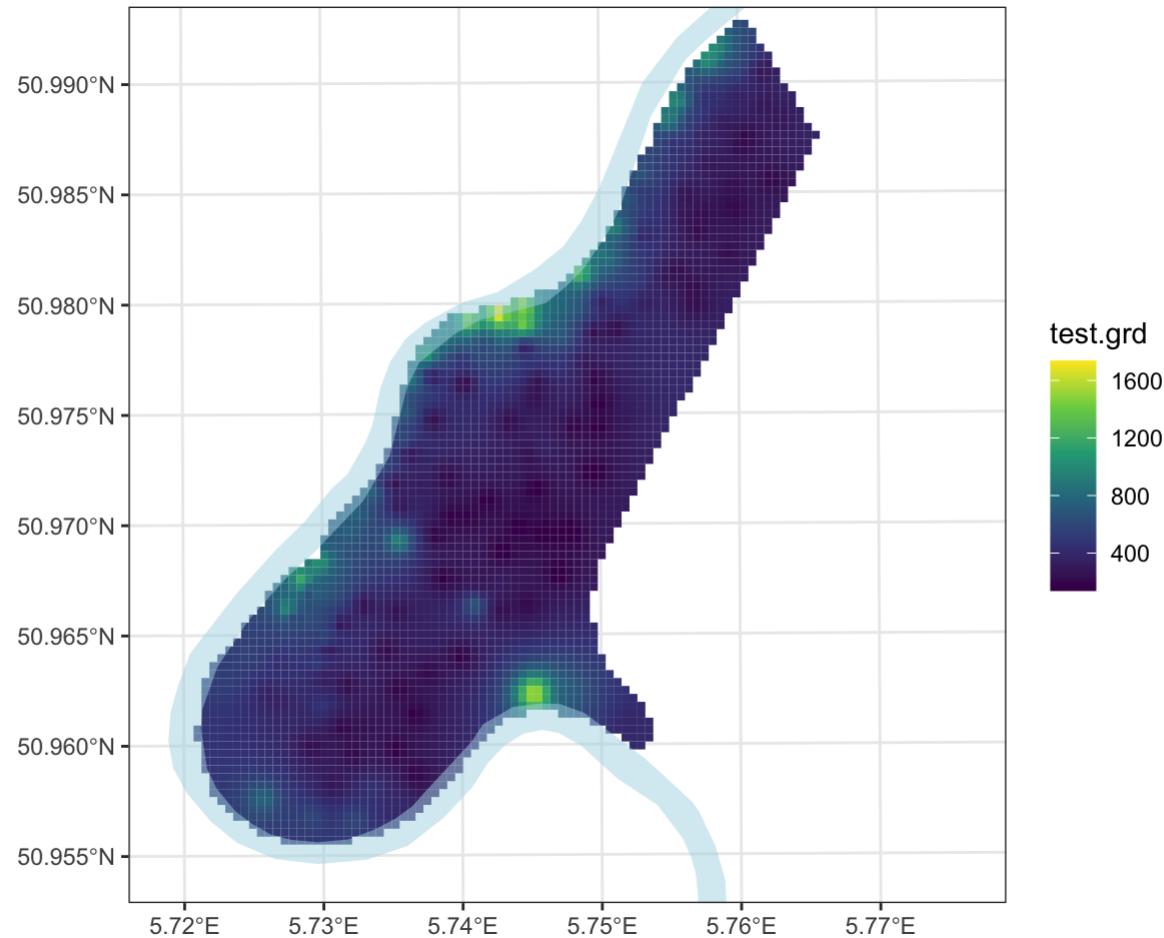


ggplot

```
1 ggplot() +  
2   stars::geom_stars(data=meuse_rast) +  
3   scale_fill_viridis_c()
```



```
1 ggplot() +  
2   stars::geom_stars(data=meuse_rast) +  
3   geom_sf(data=meuse_riv, fill="lightblue", color=NA, alpha=0.5) +  
4   scale_fill_viridis_c() +  
5   ylim(329500, 333611)
```

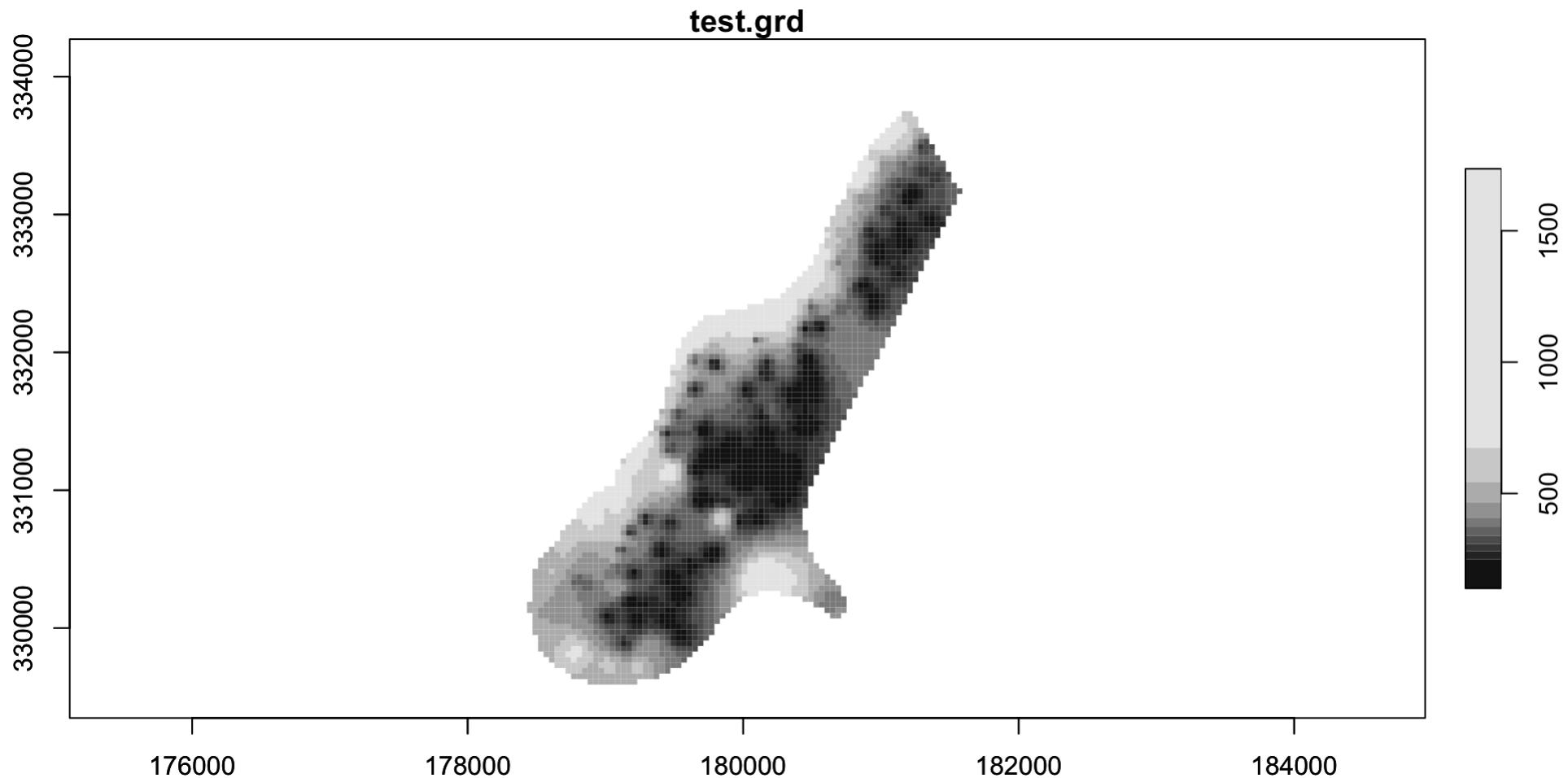


Rasters and Projections

EPSG 3631

Lat / Long

```
1 plot(meuse_rast, axes=TRUE)
```



```
1 meuse_rast
```

stars object with 2 dimensions and 1 attribute

attribute(s):

| | Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. | NA's |
|----------|----------|----------|----------|---------|----------|----------|------|
| test.grd | 138.7071 | 293.9575 | 371.9001 | 425.606 | 501.0102 | 1736.058 | 6022 |

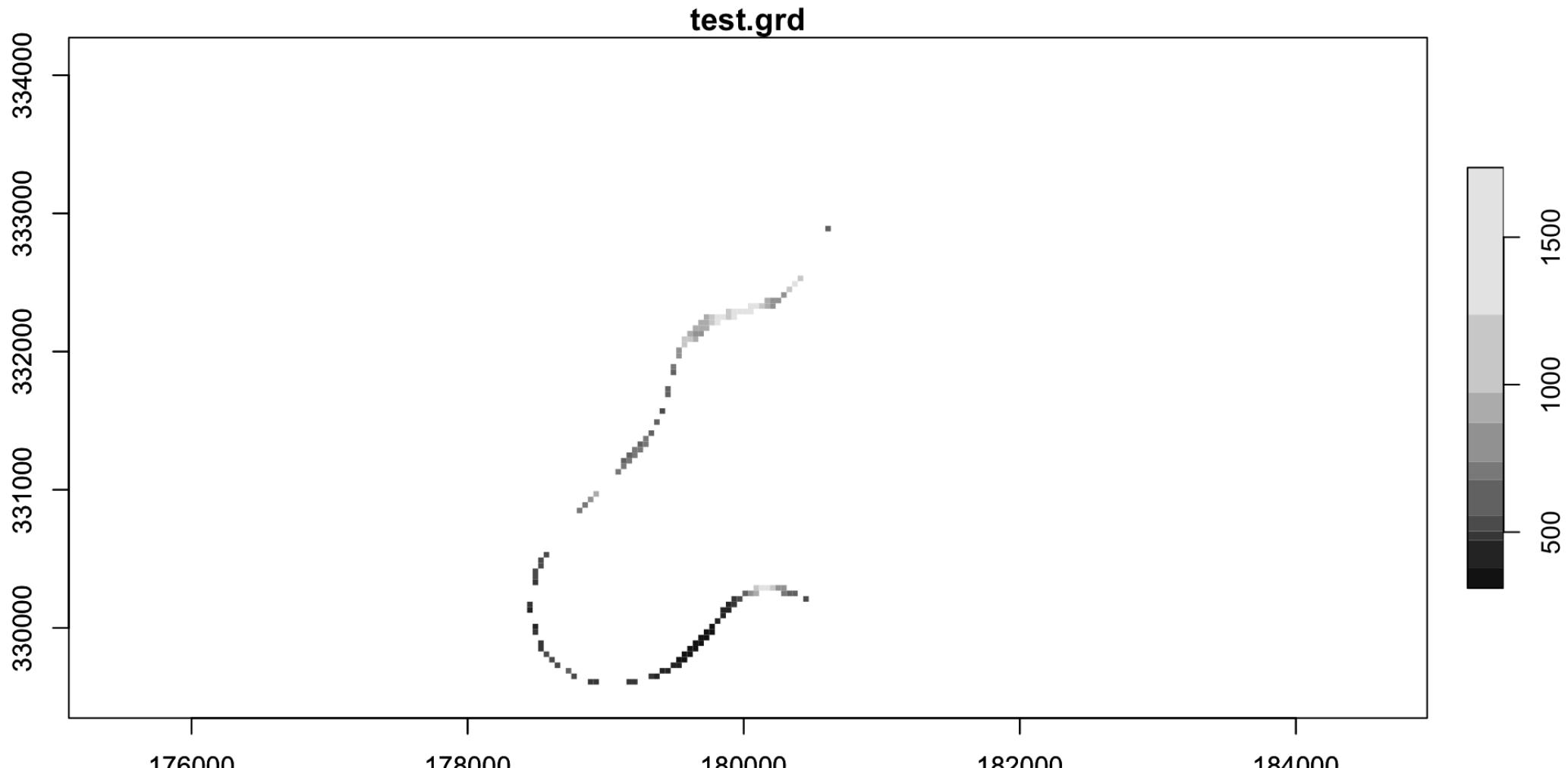
dimension(s):

| | from | to | refsys | values | x/y |
|---|------|-----|------------------------------|---------------------|-----|
| x | 1 | 80 | Amersfoort / RD New [80x115] | 178451, ..., 181611 | [x] |
| y | 1 | 115 | Amersfoort / RD New [80x115] | 329530, ..., 334090 | [y] |

curvilinear grid

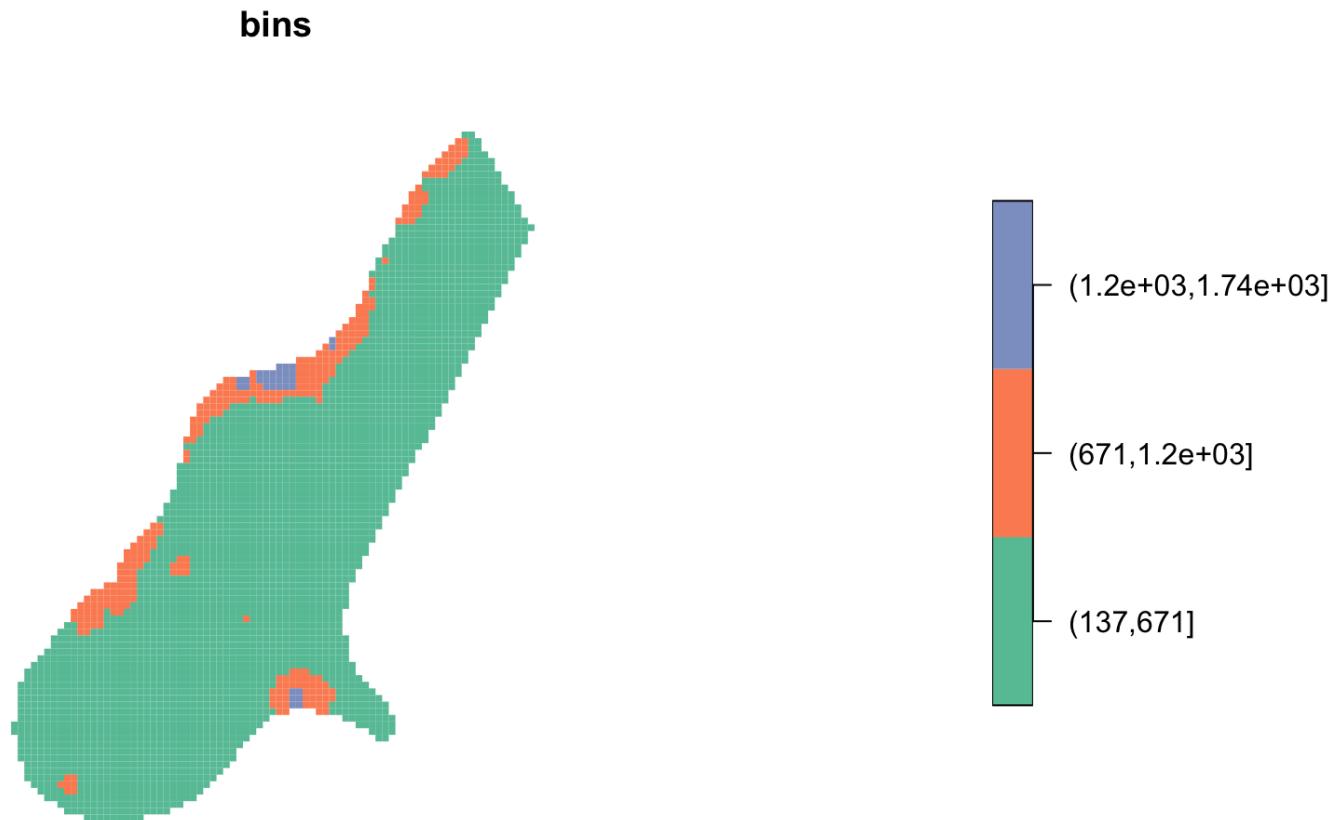
Cropping

```
1 meuse_rast_riv = meuse_rast[ meuse_riv ]
2 plot(meuse_rast_riv, axes=TRUE)
```



Segmentation

```
1 meuse_rast |>  
2   mutate(bins = cut(test.grd, 3) ) |>  
3   select(bins) |>  
4   plot()
```

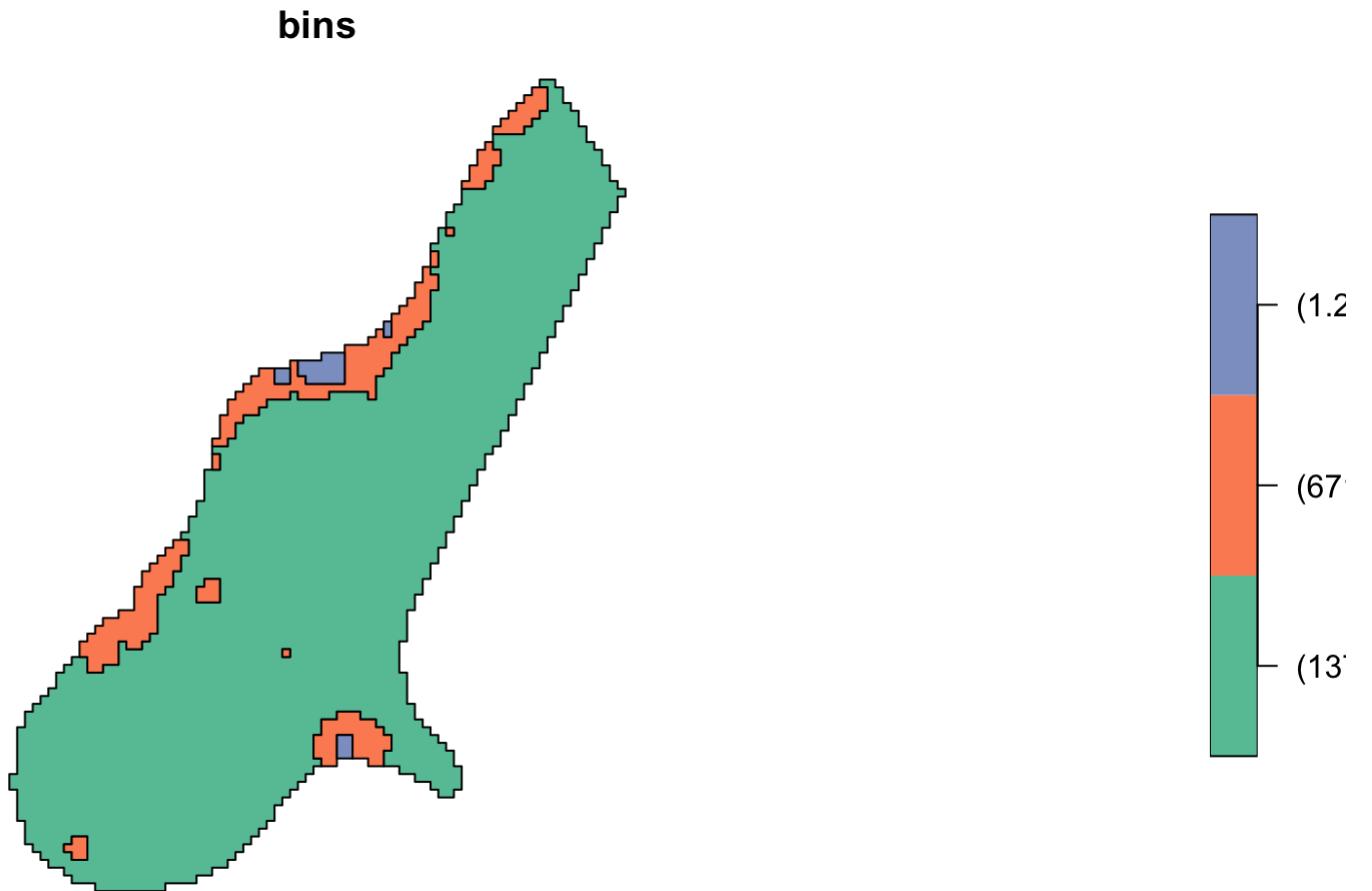


Polygonization

```
1 meuse_rast_poly = meuse_rast |>
2   mutate(bins = cut(test.grd, 3) ) |>
3   select(bins) |>
4   st_as_sf()
5 plot(meuse_rast_poly)
```



```
1 meuse_rast_poly |>  
2   group_by(bins) |>  
3   summarize() |>  
4   plot()
```



```
1 meuse_rast_poly |>  
2   group_by(bins) |>  
3   summarize() |>  
4   mutate(area = st_area(geometry))
```

Simple feature collection with 3 features and 2 fields

Geometry type: GEOMETRY

Dimension: XY

Bounding box: xmin: 178431 ymin: 329589.8 xmax: 181590.9 ymax: 333749.8

Projected CRS: Amersfoort / RD New

A tibble: 3 × 3

| bins | | geometry | area |
|------|--------------------|---|--------|
| * | <fct> | <GEOMETRY [m]> | [m^2] |
| 1 | (137,671] | POLYGON ((178551 329829.8, 178511 329829.8, 17... | 4.56e6 |
| 2 | (671,1.2e+03] | MULTIPOLYGON (((178711 329829.8, 178751 329829... | 4.74e5 |
| 3 | (1.2e+03,1.74e+03] | MULTIPOLYGON (((179790.9 332189.8, 179790.9 33... | 5.12e4 |

